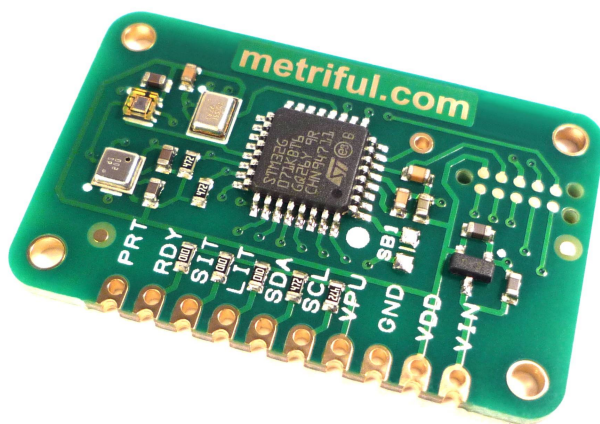


Indoor environment monitor with I2C compatible interface



DESCRIPTION

The Metriful MS430 is a low power, high accuracy, smart sensor cluster for indoor environment monitoring. It is operated via a simple I2C-compatible interface and measures eighteen variables including air quality, light and sound levels. The MS430 also offers an active interrupt feature to reduce burden on the host system.

In this document:

- How to set up your hardware system
- Explanations of the environment data measured
- Application ideas

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1. FURTHER INFORMATION

To achieve the fastest development time, use this guide together with the following resources which can be found at www.github.com/metriful/sensor

- Device datasheet – this describes the electrical characteristics and pin connections of the MS430 circuit board, and covers the low-level details of the communications interface.
- Readme, demo code, examples and instructions to help you get started immediately.

2. HANDLING PRECAUTIONS

The MS430 can be damaged by static electricity discharges. Minimize this risk by observing the following precautions:

- Handle the board by the edges
- Avoid touching any metal part of the device or circuit it connects to
- Store in the provided antistatic bag when not connected in a circuit
- Keep away from metal objects which could cause shorted connections

3. DEMONSTRATION SYSTEMS

The MS430 must be used together with a host system, which transmits or displays the measured environment data. The minimum required features of the host are:

- I2C compatible two wire interface
- At least one digital input (three digital inputs if light and sound interrupts are used)
- System voltage of 3.3 V or 5 V

These requirements are met by a large number of microcontrollers, development boards and embedded computers. The Github repository contains specific wiring details, setup instructions and example software for using the MS430 with the following host systems:

With network access:

- Raspberry Pi 0/2/3/4
- Raspberry Pi Pico W
- Arduino Nano 33 IoT
- Arduino MKR WiFi 1010
- ESP8266
- ESP32

Without network access:

- Arduino Uno
- Arduino Nano
- Raspberry Pi Pico

To run one of the demonstration systems, follow these steps:

1. Wire up your hardware according to the GitHub Readme
2. Download the software examples from www.github.com/metriful/sensor
3. Follow the GitHub Readme section for your host system for first-time software setup
4. Choose a software example
5. Load the software to your host system and run it

The examples are a convenient starting point for developing new applications.

4. HARDWARE SETUP

Connect the MS430 to a host with wires only: no extra electronic components are needed. You should initially wire all connections without a power source connected. Double-check the wiring is correct before applying power.

Table 1 describes the function of each terminal in the 10-pin header on the MS430 board. The GitHub Readme explains how to connect these to the different host systems.

Table 1 - MS430 connector pin description.

Connector label	Description
VIN	Power input if no 3.3 V supply is available. Leave unconnected if VDD is used.
VDD	Power input for 3.3 V supply. Leave unconnected if VIN is used.
GND	0 V ground
VPU	Pull-up voltage input. Apply the host system voltage.
SCL	Two-wire interface (I2C compatible) clock input
SDA	Two-wire interface (I2C compatible) data input/output
LIT	Light interrupt signal output (optional)
SIT	Sound interrupt signal output (optional)
RDY	READY signal output
PRT	PPD42 particle sensor signal input (optional)

Optional pins SIT, LIT and PRT may be left unconnected – this will disable the functions offered by these but still allows the other functions of the MS430 to operate. Further detail on electrical characteristics and pin functions is given in the device datasheet, available at www.github.com/metriful/sensor.

5. PARTICLE SENSORS

The MS430 provides an input connection (labeled PRT) and data analysis algorithm for an optional air particulate matter sensor (not included with the board). Two sensors are supported: the Shinyei PPD42 and the Nova SDS011, both of which can be purchased from many suppliers worldwide.

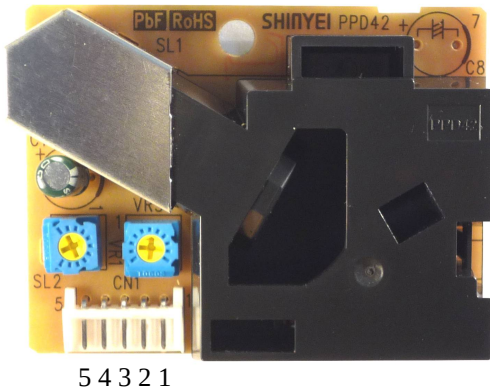


Figure 1 - PPD42 particle sensor with connector pin numbering shown



Figure 2 - SDS011 particle sensor

PPD42 (Not recommended for new use; included for backwards compatibility only)

The PPD42 uses a resistor heater and optical system to detect airborne particles of approximately $1\mu\text{m}$ diameter and larger.

Figure 1 shows the PPD42 and its 5-pin connector. Note that the connector is numbered 1 to 5 from **right to left**. Pin 1 (0 V ground) and pin 3 (5 V) provide power to the sensor, which must always be 5 V irrespective of the host system voltage. Pin 4 (signal output) connects to PRT on the MS430 board. PPD42 pins 2 and 5 are left unconnected.

For correct operation, mount the PPD42 vertically (connector pins pointing downwards) and cover the large central hole with opaque tape.

The PPD42 is sensitive to small power supply fluctuations and interference. For best results, power it with a dedicated, regulated 5 V supply. Using a 5 V output from the host system may cause increased signal noise, especially when the host is powered from a computer USB port.

SDS011

The SDS011, shown in Figure 2, uses a powered fan and laser system to detect particles of $0.3 - 10\mu\text{m}$ in size. It has a labeled 7 pin connector; connect pins GND and 5V to the power supply and connect the MS430 PRT pin to either of the outputs labeled “25um” (for particles $0.3 - 10\mu\text{m}$) or “1um” (for particles $0.3 - 2.5\mu\text{m}$). The “25um” output is recommended due to its larger detection rate.

6. PARTICLE SENSOR POWER CONTROL

Any particle sensor used with the MS430 is normally continuously powered by an external 5 V supply. Some users may wish to periodically disable the particle sensor to reduce sound noise, reduce power, or increase the sensor lifetime. This section briefly describes one way this can be done.

The code example **particle_sensor_toggle** shows how the host can output a digital signal synchronized to the MS430 data cycle. This signal can be used to gate power to the particle sensor using an external circuit, such as shown in Figure 3 (for hosts using 3.3 V) or Figure 4 (for hosts using 5 V). Input “Host” is the digital signal and output “PS_5V” is connected to the particle sensor 5 V power input.

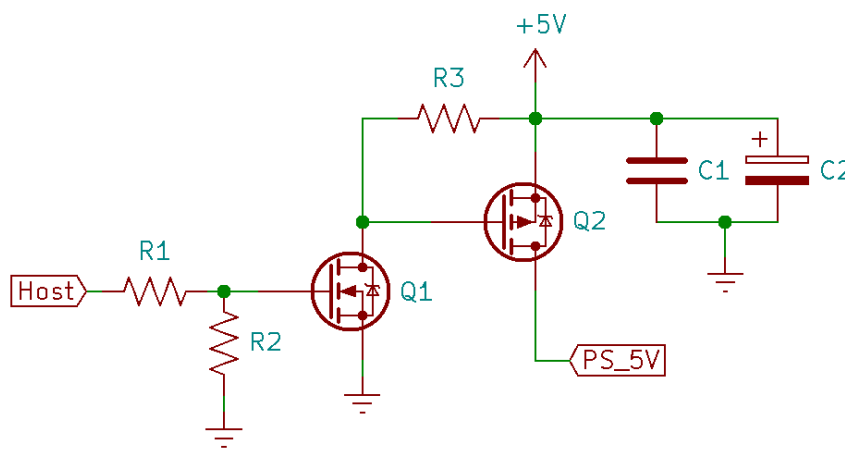


Figure 3 - Particle sensor power control circuit for 3.3 V hosts

The recommended component values are:

- R1, R4: 1 k Ω
- R2, R3, R5: 100 k Ω
- Q1: N-channel MOSFET, $V_{GS(th)} < 3.3$ V (“logic level”) e.g. 2N7000
- Q2, Q3: P-channel MOSFET, $R_{DS(on)} < 1$ Ω , $V_{GS(th)} < 3.3$ V (“logic level”) e.g. SPP15P10PL H
- C1, C3: (optional, use if interference occurs) 100 nF
- C2, C4: (optional, use if interference occurs) ≥ 100 μ F

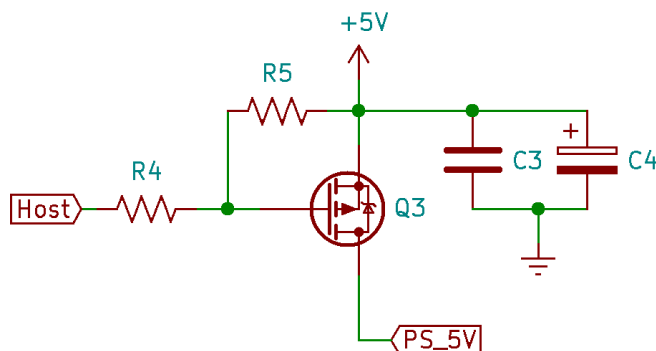


Figure 4 - Particle sensor power control circuit for 5 V hosts

7. INDOOR ENVIRONMENT DATA EXPLAINED

Each of the following sections describes the environment data quantities measured by the MS430. Table 12 (page 19) gives the numerical range and resolution of each measured variable.

SOUND

Sound travels as pressure fluctuations in the air, in the form of waves of measurable frequency and amplitude. Noise is often defined as unwanted or unpleasant sound.

Exposure to noise at home, at work, or during sleep has been associated with many adverse health and emotional outcomes. These include distraction, annoyance, cardiovascular disease, tinnitus and hearing loss. The World Health Organization states that traffic noise alone is harmful to the health of almost every third person in Europe, and that one in five Europeans is regularly exposed to sound levels at night that could significantly damage health.

The MS430 uses a high-performance digital microphone to detect frequencies between 50 Hz and 8000 Hz, covering the dominant range of human hearing.

Sound Pressure Level (A-weighted)

The Sound Pressure Level (SPL) is a popular measurement system for noise. Sound amplitudes measured by a microphone are averaged over all frequencies to produce a single SPL number, expressed on a logarithmic scale in decibel units. SPL measurements are best for ongoing constant noise, while peak amplitude measurements are best for brief, sudden sounds.

When calculating SPL, some frequencies can be emphasized relative to others – this is known as the *weighting*. The most common method is “A-weighting”, an internationally recognized standard which accounts for the variation in how the human ear hears different sound frequencies. For example, people’s perception of loudness tends to peak at around 3 kHz and drops at low and high frequencies. Noise around 3 kHz is therefore given a greater weighting when calculating the SPL – this weighting is shown in Figure 5.

The A-weighted Sound Pressure Level is a useful and very commonly used measure of environment noise and sound “loudness”. Table 2 and Table 3 give some example sound sources and typical SPL values. Note that the sound level (perceived or measured) generally depends on:

- What is creating the sound
- Distance from the source to the meter or ear
- Direction, angle or alignment
- Other factors such as nearby objects, air conditions, etc.

Table 2 - Typical A-weighted Sound Pressure Level values. All values are approximate and will vary depending on exact source type and positioning.

Sound source or description	Distance from source / m	A-weighted Sound Pressure Level / dBA	Typical sound amplitude / mPa
Quiet breathing	1	25	0.50
Quiet room in house	Ambient	30	0.9
Conversation	1	40 - 60	3 - 30
Hair dryer	1	70	90
Inside a car at 70 mph	Ambient	75	200
Expressway traffic	25	80	300
Lawnmower	1	90	900
Jackhammer	1	100	3,000
Night club with music	Ambient	110	9,000
Jet engine at takeoff	100	120	30,000

Table 3 - A-weighted Sound Pressure Level approximate guidelines from the World Health Organization and US government agencies NIOSH and OSHA.

Sound source or description	A-weighted Sound Pressure Level at ear / dBA
Continuous noise limit for unimpaired sleep	30
Distraction from tasks	40
Noise induced annoyance/stress	45 – 55
Long-term exposure causing adverse cardiovascular effects	65 – 70
Recommended maximum for long-term exposure (24 hours)	70
Recommended maximum for 8 hour exposure	85
Recommended maximum for 15 minute exposure	100

WARNING: these values are not safety advice and should not be treated as such. The sensor product is not suitable for safety or health-critical measurements.

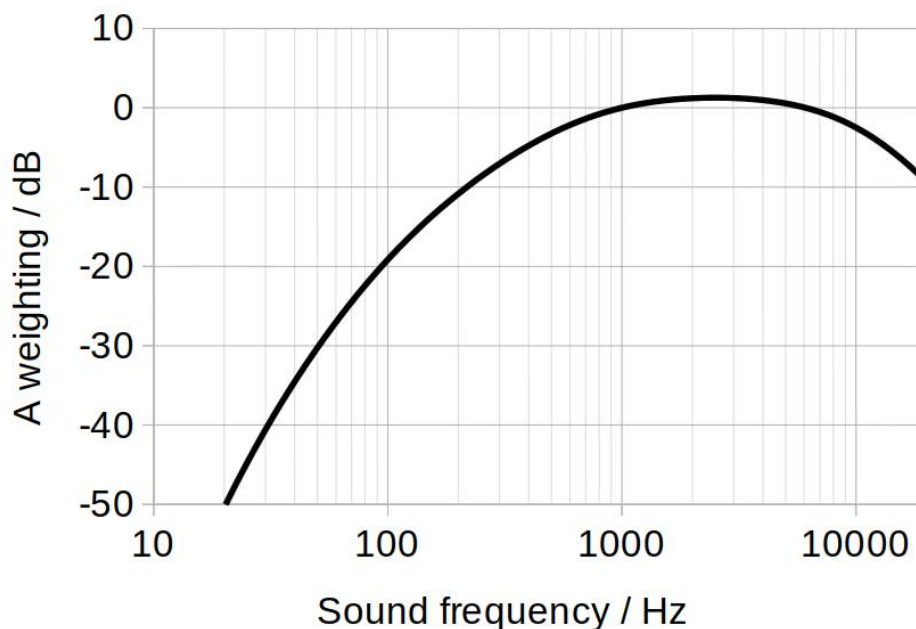


Figure 5 - The standard A-weighting curve.

Frequency band Sound Pressure Level

The MS430 also provides the unweighted SPL for several ranges of sound frequency (known as frequency bands). This reveals what pitches are present in the sound, for example the treble and bass notes in music. The band frequency ranges are listed in Table 4.

Table 4 - Frequency bands for unweighted Sound Pressure Level measurement.

Band	Midpoint frequency / Hz	Lower frequency / Hz	Upper frequency / Hz
1	125	88	177
2	250	177	354
3	500	354	707
4	1000	707	1414
5	2000	1414	2828
6	4000	2828	5657

Peak sound amplitude

The peak sound amplitude is a measurement of the largest pressure fluctuation to occur since the last time the value was read. The MS430 continually monitors the sound amplitude and internally updates this peak value (rather than making a one-off measurement). This means that sudden, impulsive noises are not missed. The peak value automatically resets after being read.

The sound interrupt system (explained further in the device datasheet) uses the peak amplitude value as a trigger for a digital output signal. This can be used to respond rapidly to changes in sound level, without the need for software processing.

Ideas for further investigation of sound

- Road/aircraft traffic noise – what levels are reached and which times of the day are worst?
- Use of sound interrupts for control of appliances e.g. turn on light with specific sequence of hand claps.
- Is your home music system set at an appropriate volume?
- Are areas for work or study maintained at a low enough sound level?
- Test the effectiveness of sound-proofing methods for reducing noise in the home from external sources.
- Use the frequency band SPL values to display a frequency spectrum for live visualization of music.

LIGHT

Light comprises photons of different wavelengths which are perceived as colors by the human eye and brain, while perceived brightness depends on the quantity of photons.

We need different minimum levels of light for vision during various indoor activities such as movement, reading/writing and detailed manual work. At the other extreme, too much light at night can adversely affect sleep quality.

Illuminance

Illuminance is a measure of the total brightness of light illuminating a surface, as would be perceived by a person. The illuminance calculation emphasizes some wavelengths more than others to represent differences in the brightness perception of human vision. Our vision responds to light between about 400 nm and 700 nm, with strongest response around 550 nm (green light). This is represented by the illuminance response curve shown in Figure 6.

Table 5 lists some examples of natural illuminance levels, while Table 6 lists recommended values for various indoor areas and activities.

The MS430 light interrupt system (see datasheet for further details) uses the measured illuminance value as a trigger for a digital output signal. This can be used to respond rapidly to changes in light level, without the need for software processing.

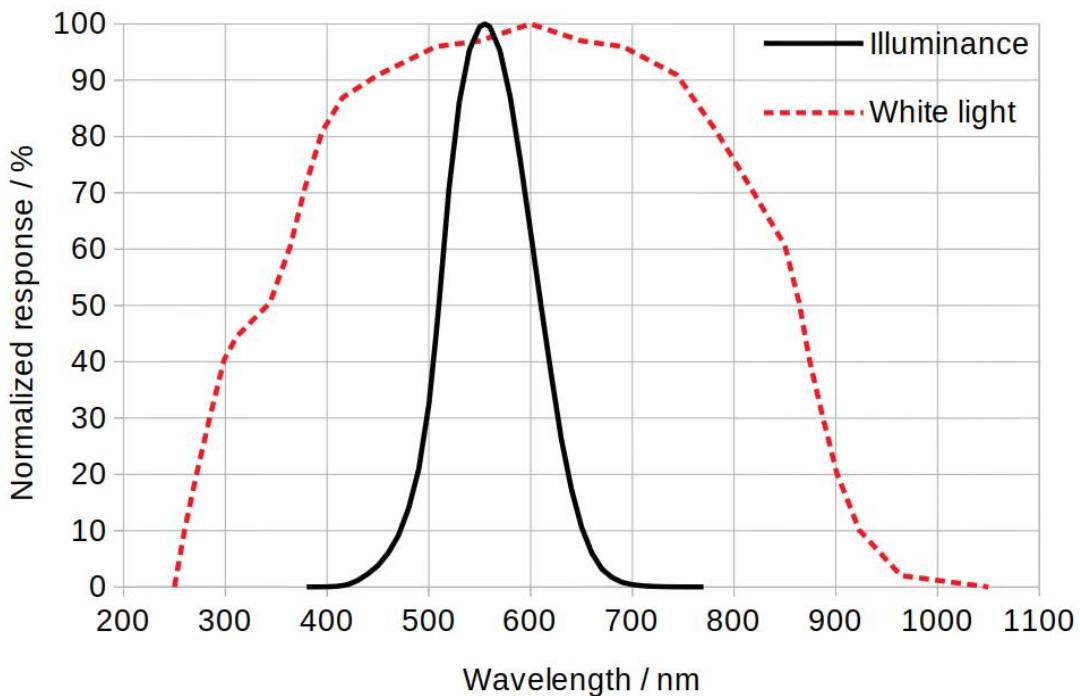


Figure 6 - Spectral response for illuminance and white light measurements.

White light level

A white light measurement (uncalibrated units) is also available from the MS430. This has a broader wavelength response over the range of about 250 to 1000 nm (shown in Figure 6 compared to the illuminance response). Although not provided in standardized units, this variable can be used to detect proportional increases/decreases in light level.

Ideas for further investigation of light

- Check that work areas, stairwells, etc. have light levels suitable for the work or activities being done there. Does this rely on sunlight, or is artificial light sufficient?
- Use the light interrupt system to control room lights in response to low/high ambient light levels.
- At what times of day/night does a bedroom become dark enough for good sleep? Does additional light-proofing help?

Table 5 - Examples of naturally occurring illuminance levels.

Condition	Illuminance / lux
Full daylight	10,000
Overcast day	1,000
Very dark day	100
Twilight	10
Deep twilight	1
Full moon at night	0.1
Quarter moon at night	0.01
Starlight at night	0.001

Table 6 - Recommended illuminance levels¹ for activities and indoor areas (workplace and home). All values are approximate.

Location / activity	Illuminance / lux
Detailed or precise drawing / manual work	750 – 2000
Frequent reading / writing	500 – 1000
General office work, kitchen	300 – 750
Occasional reading / writing	200 – 300
Corridor, lobby, auditorium, dining area	150 – 200
Stairwell	100 – 200
Other home areas	50 – 150
Night-time maximum in bedroom	5 – 10
Night-time maximum, at pillow	0.5

AIR

The MS430 directly measures four variables which depend on properties of the air: temperature, air pressure, humidity and the resistance of a specialized gas sensor.

Temperature

Temperature is an essential measurement for indoor environment monitoring and is a standard feature of heating, air conditioning and home automation systems. The MS430 obtains accurate temperature measurements in degrees Celsius. Temperature is especially useful when combined with humidity measurements to determine the comfort level of the environment.

Pressure

Air pressure is caused by the weight of the gases in the atmosphere and decreases with altitude. At a fixed location, the pressure changes due to weather and atmospheric processes. Reduced pressures are often associated with clouds and rain, whereas pressure increases are associated with dry weather and mostly clear skies. The MS430 measures absolute atmospheric pressure, which also allows measurement of relative changes in altitude.

¹ Sources: the US government agencies GSA, NOAA, DoE, and the UK CIBSE guide for hospital lighting.

Humidity

Humidity is measured by the MS430 as percentage relative humidity, the most common form of humidity measurement. This quantifies the amount of water vapor in the air as a percentage of the maximum that could exist at the current temperature and pressure. This is a useful definition because it reveals whether water will condense onto objects exposed to air, and also correlates with people's level of discomfort.

In hot environments, high levels of humidity prevent sweat evaporation from skin, adversely affecting the body's cooling mechanism. This is uncomfortable and can be dangerous for the elderly or those with health problems. High humidity at low temperatures is also uncomfortable because heat is conducted away from the skin, making us feel cooler.

At the other extreme, very low humidity levels can be uncomfortable due to the drying effect on the skin and respiratory system.

The World Health Organization recommends² that indoor relative humidity be maintained in the range 30 – 50 %.

Moisture condensation onto surfaces due to high humidity risks the following problems:

- Mold and rot
- Dust mite growth
- Corrosion or degradation of materials
- Windshield fogging inside vehicles

Condensation of the water vapor in the air occurs when the air is cooled lower than the *dew point*, a special temperature which depends on the air humidity and temperature. This can happen when the air is in contact with an object at a temperature lower than the dew point e.g. a cool window, wall or mirror. Table 7 shows dew point values for common household air temperatures and humidities. For example: in a house with air at 25 °C and 50 % humidity, condensation could occur on a surface below 14 °C.

² World Health Organization, *Indoor air quality: biological contaminants*, 1988

Table 7 - Dew point temperatures (± 1 °C) for common household air temperatures and relative humidities³.

Dew point temperature / °C		Air relative humidity / %					
		30	40	50	60	70	80
Air temperature / °C	15	-3	1	4	7	10	12
	20	2	6	9	12	14	17
	25	6	11	14	17	19	21
	30	11	15	18	21	24	26
	35	15	19	23	26	29	31

Gas (volatile organic compound) sensor resistance

Volatile organic compounds (VOCs) are a class of air impurities that can evaporate at normal indoor temperatures and pressures. This means that VOCs originating in liquid and solid materials can enter the air in everyday conditions. Concentrations of VOCs are generally higher in indoor air than outdoor air due to reduced air volume and flow.

The effects of VOCs on health vary depending on VOC type, concentration and length of exposure. Minor adverse health effects of VOCs can include: eye, nose and throat irritation, headaches, fatigue, nausea and skin problems. Higher concentrations and/or long-term exposure are suspected of causing cancer, as well as damage to the liver, kidney, or central nervous system.

Sources of VOCs include paint, furniture, garbage, plastics, cleaning products, perfumes, clothes, cooking and people (breath and odors). VOCs present in breath include isoprene, ethanol and acetone. Breath can become a dominant source of VOCs, especially in poorly ventilated rooms containing many people.

The MS430 detects VOCs using a highly responsive metal-oxide gas sensor. The gas sensor resistance is modified by VOC adsorption (and subsequent chemical oxidation/reduction) on its surface. Greater VOC concentrations result in a lower sensor resistance, while cleaner air gives a higher resistance.

Ideas for further investigation of air measurements

- Look for correlations of air pressure changes with local weather.
- Check that home heating/cooling systems maintain the correct temperature.
- Use the dew point table, temperature and humidity data to warn when condensation can occur.
- What is the effect on humidity of actions such as: improving home ventilation, drying clothes indoors, using air extraction during cooking and showering?

³ Source: the US National Oceanic and Atmospheric Administration (NOAA).

AIR QUALITY

The MS430 uses the directly measured air parameters (temperature, humidity and gas sensor resistance) as inputs to an intelligent monitoring algorithm. This produces three derived data values to indicate the quality of the air: Air Quality Index, Estimated CO₂ concentration, and Equivalent breath VOC concentration.

Air Quality Index

The US Environmental Protection Agency (EPA) has identified poor indoor air quality as one of the five major public health risks. The MS430 produces an Air Quality Index (AQI), with values between 0 and 500, to give a qualitative assessment of the air in the surrounding environment.

The AQI value is calculated using the gas sensor output, while also accounting for temperature and humidity changes. Lower values indicate better air quality and higher values indicate worse air quality: Table 8 shows approximate interpretations for the full range.

Table 8 - Interpretation of Air Quality Index values.

Air Quality Index	Interpretation
0 – 50	Good
51 – 100	Acceptable
101 – 150	Substandard
151 – 200	Poor
201 – 300	Bad
301 – 500	Very Bad

The AQI algorithm undergoes a process of automatic self-calibration to ensure that users experience consistent performance. A value of 25 corresponds to typical “good” air, and 250 to typical “polluted” air.

The MS430 provides an accuracy parameter to show the state of the self-calibration process, starting with a value of 0 indicating uncalibrated, and reaching 3 indicating highest accuracy – these values are shown in Table 9 and may take several minutes of operation to achieve, especially for a new sensor. During the code 0 period, values for AQI, equivalent breath VOC, and estimated CO₂ concentration are invalid. If the accuracy is slow to change, provide a variation of air quality e.g. by breathing heavily on the sensor or exposing to a solvent such as marker pen vapor.

Equivalent breath VOC concentration

This measurement makes the assumption that the detected VOCs are due to a typical characteristic mixture in exhaled human breath. This is reasonable in environments where breath is the dominant source of VOCs (e.g. in crowded rooms). The output value is the inferred concentration of this characteristic breath VOC mixture. The typical maximum VOC concentration in human breath is of order 10 ppm (parts per million).

Table 9 - Interpretation of the air quality accuracy code.

Accuracy code	Interpretation
0	Not valid: calibration incomplete
1	Low accuracy: calibration ongoing
2	Medium accuracy: calibration ongoing
3	High accuracy

Estimated carbon dioxide (CO₂) concentration

This measurement also makes the assumption that the detected VOCs are due to the typical characteristic mixture in exhaled human breath. This is reasonable in environments where breath is the dominant source of VOCs (e.g. in crowded rooms). A correlation between exhaled breath VOC concentration and exhaled CO₂ gas is then used to estimate the CO₂ concentration. Note that the MS430 does not detect CO₂ directly.

The global average atmospheric CO₂ concentration is approximately 400 ppm. US federal agency NIOSH considers that indoor CO₂ concentrations exceeding 1,000 ppm indicate inadequate ventilation. Increased CO₂ levels can cause drowsiness, headaches and reduced cognitive performance.

Ideas for further investigation of air quality

- Alert a room's occupants to worsening air quality so that they can take action (open window/door, leave the room, turn on air conditioning) rather than waiting until the air quality is noticeably bad.
- How fast or effective in improving air quality are various actions e.g. opening a window, using an air conditioner, removing garbage, using air extraction when cooking?

PARTICULATES

Airborne particles, sometimes referred to as *particulate matter*, include dust, smoke, pollen, and liquid vapor. Of special interest are those with diameters less than 10 µm, which are easily inhaled and so have the most impact on health. Particle pollution has been linked to problems including respiratory illness (e.g. asthma and bronchitis), cardiovascular disease and lung cancer.

Authorities do not yet provide reference levels for indoor air particulates. Guidelines/standards for **outdoor** air issued by the European Union, US EPA, and World Health Organization are shown in Table 10 for PM10 and Table 11 for PM2.5. Rules differ on the precise averaging and number of times that limits may be exceeded. Note that PM2.5 means the sum of all particles smaller than 2.5 µm and PM10 means the sum of all particles smaller than 10 µm.

Table 10 - Guideline concentration limits for outdoor PM10 pollution

µg/m ³	24 hour average	1 year average
EU	50	40
US EPA	150	-
WHO	50	20

Table 11 - Guideline concentration limits for outdoor PM2.5 pollution

µg/m ³	24 hour average	1 year average
EU	-	25
US EPA	35	12
WHO	25	10

The MS430 provides an input connection and data analysis algorithm compatible with Shinyei PPD42 and Nova SDS011 particle sensors. Both sensors use optical scattering to detect particles of around 1 µm diameter. Two related output quantities are produced by the MS430: particle sensor duty cycle and estimated particle concentration.

Particle sensor duty cycle

Both sensors output a digital signal which is active when particles are detected within the sensor. The signal activation time varies depending on the size or quantity of the detected particles. The “duty cycle” is the overall fraction of time during which this detection signal is active. Greater duty cycles indicate larger particulate concentrations.

Estimated particle concentration

The manufacturer’s nominal conversion method is used to obtain the particle concentration value from the duty cycle value. Because this is not a calibrated system, the value obtained should be treated as an estimate only. The PPD42 concentration units are particles per liter (ppL) and the SDS011 units are micrograms per cubic meter (µg/m³).

Ideas for further investigation of particulates

- What events or activities are associated with spikes in particle concentration?
- Can particle concentration be reduced through steps such as: air extraction during cooking, removal of dust, and removing indoor smoke sources?

Table 12 - Measurement range, resolution and accuracy for all data variables.

Data category	Data variable	Measurement unit (symbol)	Range minimum	Range maximum	Resolution	Measurement accuracy
Sound	A-weighted sound pressure level	decibel (dBA)	26.0	120.0	0.1	±1.0 dBA
	Frequency band sound pressure level	decibel (dB)	21.0	120.0	0.1	±1.0 dB
	Peak sound amplitude	millipascal (mPa)	0.00	28000.00	0.01	*
Light	Illuminance	lux (lx)	0.00	3774.00	0.01	±10%
	White light level	-	0	65535	1	*
Air	Temperature	degree Celsius (°C)	-40.0	85.0	0.1	±0.5 to ±1.0 °C
	Pressure	pascal (Pa)	30000	110000	1	±60 Pa
	Humidity	Percentage relative humidity (% RH)	0.0	100.0	0.1	±3% RH
	Gas sensor resistance	ohm (Ω)	0	4.29×10 ⁹	1	±1.5%
Air Quality	Air quality index	-	0.0	500.0	0.1	*
	Estimated CO ₂ concentration	Parts per million (ppm)	0.0	65535.0	0.1	*
	Equivalent breath VOC concentration	Parts per million (ppm)	0.00	1000.00	0.01	*
	Accuracy	-	0	3	1	*
Air particulate matter	Particle sensor duty cycle	Percentage (%)	0.00	100.00	0.01	±0.05%
	Particle concentration (PPD42)	Particles per liter (ppL)	0.00	28000.00	1.00	*
	Particle concentration (SDS011)	micrograms per cubic meter (µg/m ³)	0.00	999.90	0.01	The greater of ±15% and ±10 µg/m ³

*These measurements are either: relative/qualitative values, use a non-standard measurement scale, or are uncalibrated. The values are useful for direct comparisons or further research.

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