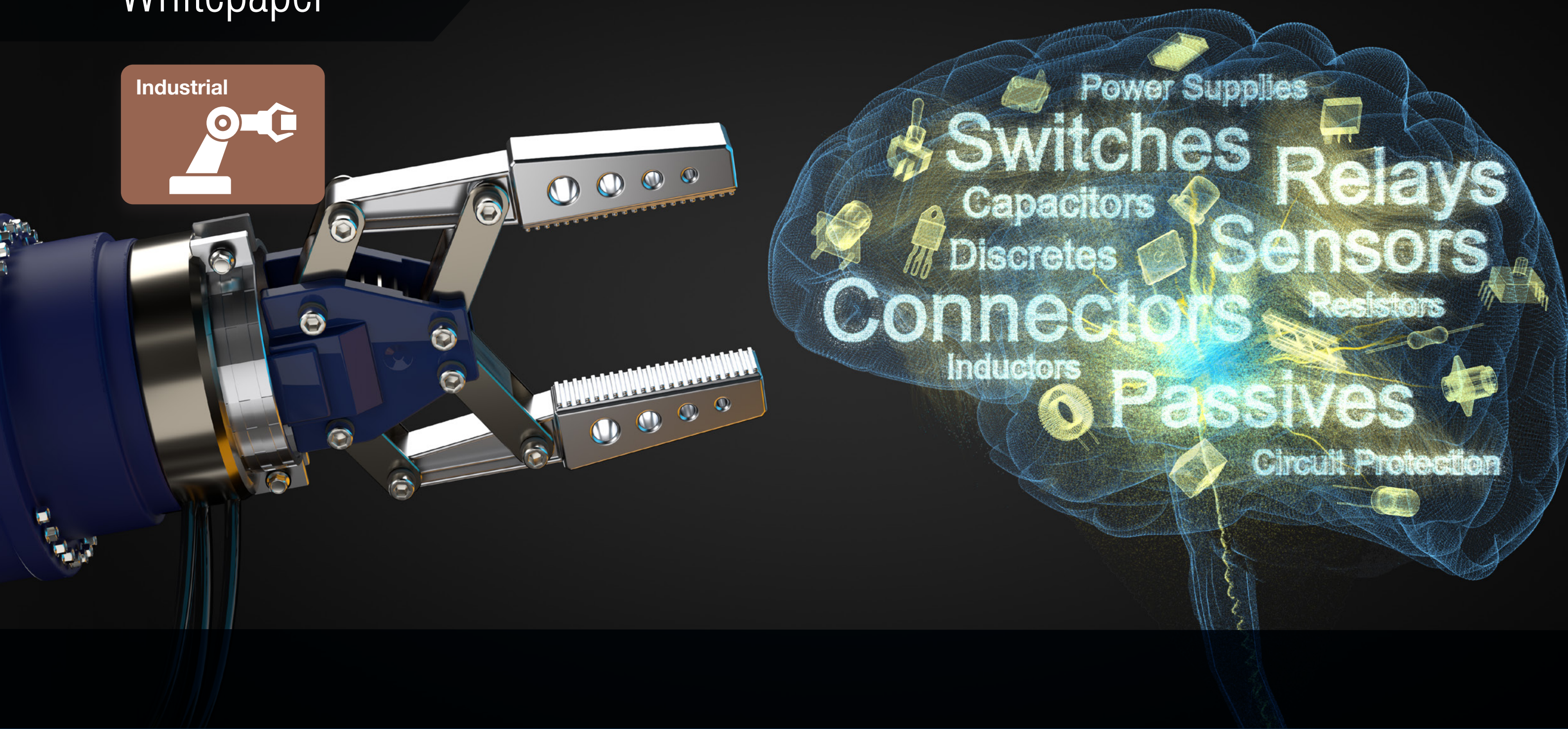
Whitepaper



Something in the air – getting a sense of indoor air quality

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Executive Summary

People are spending most of their time indoors, and they want their buildings to be comfortable, functional, efficient and safe. Technology is enabling transformational change in managing building performance, heralding the emergence of intelligent buildings and smart homes. Added motivation to the building automation revolution comes from the move towards sustainability and healthy living.

There is a growing awareness that in our modern world, indoor air quality (IAQ) has not been monitored effectively. The number and concentration of airborne pollutants is increasing, and recent research is highlighting air pollution as the major culprit to a host of health issues, as well as affecting concentration in the workplace.

Monitoring IAQ is emerging as the next ‘must-have’ in modern Building Management Systems as well as the smart home. If information technology is the heart of the BMS, then data, and data from sensors in particular, is the life blood. This White Paper considers how the latest IAQ sensors can help BMS developers achieve their goal of ensuring healthier buildings, improving the comfort, efficiency and safety of its occupants.

The indoor picture: smart buildings

On average, throughout Europe and North America, people spend 60 to 90% of their lives indoors, and 60% of that time in the home[1+2]. Clearly, users and owners want buildings to be comfortable, functional, efficient and safe. New technology is enhancing all these aspects, driving the markets for intelligent buildings and smart homes.

The once humble HVAC system has become considerably more sophisticated, and is increasingly required to be integrated with other building-wide, controllable functions that are managed centrally, such as renewable energy sources, smart meters, LED lighting, access control and safety mechanisms. The list is long and growing.

A decade ago, the widespread deployment of wireless sensor networks and the advent of IP made a huge impact on this sector. These same technologies have enabled the introduction of low cost sensor-based home automation systems. With cost savings the initial, and still the prime driver, building automation systems have been developing in sophistication over several decades. Centralized monitoring and control of this complex indoor environment has led to the evolution of the building management systems (BMS) market.

Figure 1: Smart Building, Internet of things concept management

The big picture: BMS and iBMS

Today, the BMS market is once again undergoing transformational change. Technologies such as IoT, artificial intelligence, advanced analytics and the cloud ('big data') are increasing the advance towards ever more intelligent and integrated systems. The intelligent BMS (iBMS) market is born!

Just a decade ago, BMS was mostly about energy management, with the HVAC sector at its core. At the heart of the modern, most advanced BMS is an integrated IT network managing, monitoring and controlling all these features. Increasingly, it needs to balance complex and sometimes conflicting demands. Taking in data not only from sensors and their associated systems, but also from external sources (such as the smart grid and smart city) and advanced analytical software, the iBMS is taking on facilities management roles.

Sustainability is becoming a strategic imperative for many building stakeholders, and today's technology can further contribute to cost savings over time. Users (employees, tenants, visitors) are beginning to seek 'green' credentials and shareholders see it as an asset in bottom-line valuation. However, occupant satisfaction is regarded as the second most important driver, as customers and employees will make decisions on where they work and spend their time and money[3].

IAQ: The missing link

One aspect that has, until recently, received less attention than it should have, is indoor air quality (IAQ). Partly, the lack of focus may have been due to the strong emphasis on cost savings, and it has not been so easy to measure the tangible benefits of investing in monitoring IAQ. International efforts to improve outdoor air quality are underway, though it is still a major issue, particularly in cities and industrial areas. Meanwhile, the results of various IAQ research programmes throughout Europe and the US are showing that in both modern and older buildings, poor IAQ is a concern. It not only impacts human health but can also adversely affect people's concentration, and thus productivity[4].

As a result, governments and the building industry are turning towards finding ways of identifying poor IAQ, primarily by detecting the presence of Particulate Matter (PM), Volatile Organic Compounds (VOCs) and gases including nitrogen oxides and carbon monoxide. Buildings are now expected to perform better to detect poor IAQ as well as mitigating its short-term and long-term effects.

Figure 2: Common indoor air pollutants and their sources.

Form of indoor pollutants		
Gases:	**Particulate Matter:**	**VOCs – volatile organic compounds:**
CO from heating and cooking appliances CO, N2O, NO, O3 such as, CO^2 from people and greenhouse gases (diesel combustion etc)	Liquid or solid particulates and ultrafine particles, dusts and fibres. PMs are regarded as the most dangerous form of pollution from aerosols, wood burning stoves and vehicle emissions. Some VOCs can also be classified as PMs. Categorised by size: PM_1, $PM_{2.5}$ and PM_{10}	Both natural and synthetic chemicals. Formaldehyde, for example, is found in construction materials, cleaning products and some electrical goods. VOCs are released when cooking food at high temperatures. VOCs indoors are considerably higher than in ambient air.

Sources of indoor pollutants
Pollutants generated by activities such as cooking, heating, smoking, burning candles/incense and cleaning (paints and varnishes, cleaning products, air fresheners)
Pollutants emanating from building materials, furniture, furnishings (especially carpets), pets
Pollutants entering from outside, greenhouse gases, vehicle emissions, industry etc
Natural radon gas that enters buildings from the ground
Mould and fungus produced by excessively humid conditions and dust mites can increase the adverse effects of pollution

IAQ research, regulations and guidelines

National and European bodies have, of course, been working on improving IAQ for decades. Since 1999, the European Collaborative Action (ECA) group has been managing a multidisciplinary collaboration of European scientists working on IAQ issues[5]. Further work this decade, led by the EU's DG Joint Research Centre, has been working on developing a framework of harmonized criteria, protocols and monitoring techniques for indoor air pollutants.

Some countries and international organizations have undertaken their own research and there are several independent sources of recommendations outlining length of exposure and concentrations harmful to health. The World Health Organisation, the German Research Foundation, the German Environment Agency (UBA) and the US Environmental Protection Agency (EPA), have all been active in comparing guidelines for workplace exposure to poor IAQ. Research is necessarily ongoing as the number of man-made chemicals continues to grow. Determining the effect of interaction between, and combined effects of, the myriad pollutants is also problematic.

In the UK, the impact of outdoor air pollution on IAQ has been studied since the mid 1990s. More recently, NICE has been working on guidelines addressing IAQ. Meanwhile, recommended exposure limits and codes of practice have also been established by organizations including HSE and BSI, and are written into building regulations.

In France, the government created the IAQ Observatory (OQAI) in 2001, and ANSES has been working since 2004 to develop IAQ guidelines, based on health criteria. The guidelines are regularly updated, taking into account work and recommendations from other organizations, such as the WHO. Monitoring programmes are being rolled out, starting with schools[2].

Germany started to address the IAQ issue in 1992 and has established an Indoor Air Hygiene Commission. Like France, Germany has its own guideline values (not legally binding) for about a dozen pollutants found in indoor air. Procedures for measurement and analysis of indoor air are laid down through its standards organization, VDI[6].

Challenges and exacerbating factors

Current trends to improve energy efficiency in buildings, particularly in terms of thermal performance, such as sealing buildings, can effectively exacerbate poor air quality, by trapping pollutants inside. Modern construction materials generate more VOCs, although some efforts are now in place to address specific cases. Furnishings and electrical equipment as well as cleaning products can generate airborne PMs and VOCs. Meanwhile, outdoor air pollution, including greenhouse gases, can negate or reduce the effectiveness of ventilation schemes.

The increased prevalence of VOCs in commercial buildings and homes is stimulating demand for more specific information on IAQ. Detecting all possible VOCs at any one time is near impossible. The European Commission Scientific Committee on Health and Environmental Risks (SCHER) suggests there may be more than 900 chemicals, particles and biological materials with potential health effects[7].

Already, at the consumer level, there is a growing number of portable, even wearable devices designed to give an instant reading of IAQ. Depending on the model, monitors are available to check for a range of pollutants including particulate matter (PM), volatile organic compounds (VOCs) and gases including CO_2 and CO, as well as humidity and mould. Many can be connected via WiFi to other devices, such as a smart home controller or mobile phone.

The prevalence of this type of gadget is beginning to put further pressure on building managers to ensure their BMSs are keeping track of IAQ[8]. Indeed, many governments have already introduced specific policies and guidelines for IAQ monitoring and control for educational establishments, not only in response to children's health concerns, but also to improve concentration. Portable IAQ devices will also put pressure on public transport providers to monitor and control IAQ either through air conditioning and/or HVAC systems.

Application requirements

The first step towards maintaining IAQ is to sample and monitor the air in strategic locations around the home or building. If IT is the heart of the building automation system, then data, and data from sensors in particular, is the life blood. Accurate and reliable sensors are critical, and performance has been improving in recent years. Drift can be an issue, requiring regular calibration, though some manufacturers are now offering lifetime guarantees. In other cases service intervals would be determined by the quality of the sensors used.

There is a wide choice of sensors available to detect a range of gases and chemicals, using a variety of techniques, in a number of formats and offering variable performance/price points. Selection will depend on the specific targets to be detected, sensitivity/accuracy, and connectivity/integration options.

Sensor devices should be 'IoT-ready', that is they can be retrofitted into an existing system or integrated into a custom design. Many BMSs, and iBMSs especially, are designed to be expandable and reconfigurable. Multiple sensor platforms are becoming a popular, cost-effective choice for smart buildings and the smart home, saving design time, cost and simplifying integration.

In smart buildings, controlling IAQ is, of course, closely linked with ventilation. Where BMSs are in operation, or even where there is a relatively modern HVAC installation, some sort of automatic ventilation system is generally in place.

IAQ monitoring via ventilation control

Where systems are fitted with a demand control ventilation system that measures CO_2 levels in a building, ventilation rates can be adjusted on a continuous basis, with reference to outside CO_2 levels and manual ventilation. CO_2 is not technically a pollutant, but becomes unhealthy and potentially dangerous when levels are high. Building code standards and guidelines generally set ventilation rates for typical locations and occupation levels, taking into account pollution generating activities, and pollution sources such as carpets, furnishings, and electrical equipment.

Efficient ventilation will normally help to dissipate other airborne pollutants. According to leading CO_2 sensor manufacturer, Amphenol[9], CO_2 sensing can be used as an air quality monitoring method. The theory is that maintaining carefully regulated CO_2 levels through ventilation, particularly when monitored and controlled on a zone basis, will simultaneously prevent the build-up of other gases and contaminants. Fortunately, ventilation control using CO_2 can usually be retrofitted into existing HVAC systems or BMSs, providing there is a direct digital building control system.

Checking IAQ for VOCs and PMs

The upcoming method of monitoring IAQ is via the measurement of VOCs. The resulting data can be used to trigger automatic ventilation systems in a building zone or the smart home, or to simply inform the occupant. However, note that VOC sensing should not replace CO_2 monitoring to determine ventilation rate, but it can be a useful enhancement to ensure good IAQ.

With the wide variety of VOCs that could be present, some of which might have health risks at very low concentrations, the choice of sensor can be problematic. Traditional IAQ sensor technologies for standards and reference use are highly accurate but expensive. The key detection methods for sensors in commercial applications include MOS-based chemi-resistors, and optical or non-dispersive infrared (NDIR).

MOS sensors are low cost and low power, and are typically used to detect VOCs in gaseous pollutants. They can be affected by changes in temperature and humidity. Sensitivity and specificity can also be limited. Most can detect a number of the most common pollutants but only measure total VOC (TVOC), with no information on respective concentrations. Some devices necessarily make a compromise on accuracy to obtain sufficiently low-power operation and small size for wearable or portable applications.

Airborne PM sensors are classified using size (mass concentration) of the particles, generally delineated as PM_1, $PM_{2.5}$ and PM_{10} (particles less than 1, 2.5 and 10µm in aerodynamic diameter respectively). Most sensors for commercial and domestic applications will detect $PM_{2.5}$ and PM_{10} particles.

Sensor product examples

Amphenol's Telaire T6713 is an NDIR based CO_2 sensor aimed at building automation applications such as demand control ventilation, and where it needs to be integrated with other energy saving functions. It incorporates the company's patented ABC logic self calibrated algorithm, providing stability better than 2% over its 15 year typical lifetime. The measurement range is 0 to 5000ppm and accuracy is quoted at 400 to 5000ppm +/-3% of reading. Digital output options are I^2C and UART. It operates from a 4.5 to 5V supply, and module size is 30 x 15.6 x 8.6mm).

The T67x3 sensor series incorporates a 'measure on demand' feature that eases the power consumption overhead usually associated with constant sensing. With this feature, the host application can request the sensor to take a reading as required by the application rather than at a pre-determined frequency. The ABC Logic will trigger a measurement every six hours, and the sensor will not respond to a request received within 15 seconds of a prior reading.

The Telaire T6703 is a low cost version with reduced sensitivity for residential and consumer applications.

Figure 3: Telaire T6713 Series CO_2 Module from Amphenol

For PM detection, the Telaire SM-PWM-01C Smart Dust Sensor uses optical sensing via an IR LED and photosensor. The photosensor detects the reflected IR LED light by dust particles in the air. It can distinguish between the smallest particles found in smoke and combustion emissions (1 to 2μm) from large house dust particles (3 to 10μm) by the pulse pattern of the signal output. The device is suitable for use in IAQ monitoring systems as well as air cleaners, air purifiers, and air conditioners.

Designed to monitor a range of VOCs and equivalent CO_2 in confined spaces, the SGS-Sensortech MiCS-VZ-89TE is based on MOS sensor technology. The monitoring range is quoted as 0 to 1000ppb isobutylene equivalent TVOCs and 400 to 2000ppm equivalent CO_2. Requiring no calibration, the module is low power, with a dual signal output allowing it to be used to control ventilation on demand to ensure good IAQ while saving energy.

Honeywell's HPM Series particle sensor uses laser-based light scattering to detect and count particles in concentrations up to 1mg/m^3. Laser technology typically delivers better accuracy over a longer period of time than LED-based devices. This series is designed to measure air quality in homes and commercial buildings, operating in HVAC systems, as well as in consumer products such as air purifiers.

The latest model in the range is a compact version which analyzes particulate size and concentration with a faster response time, better than 6s. This enables operators to respond to alerts in real time, and to take remedial action, as required. The sensor can detect particulates from 0.3 to 5μm in size, and calculates output readings as per industry norms and formats.

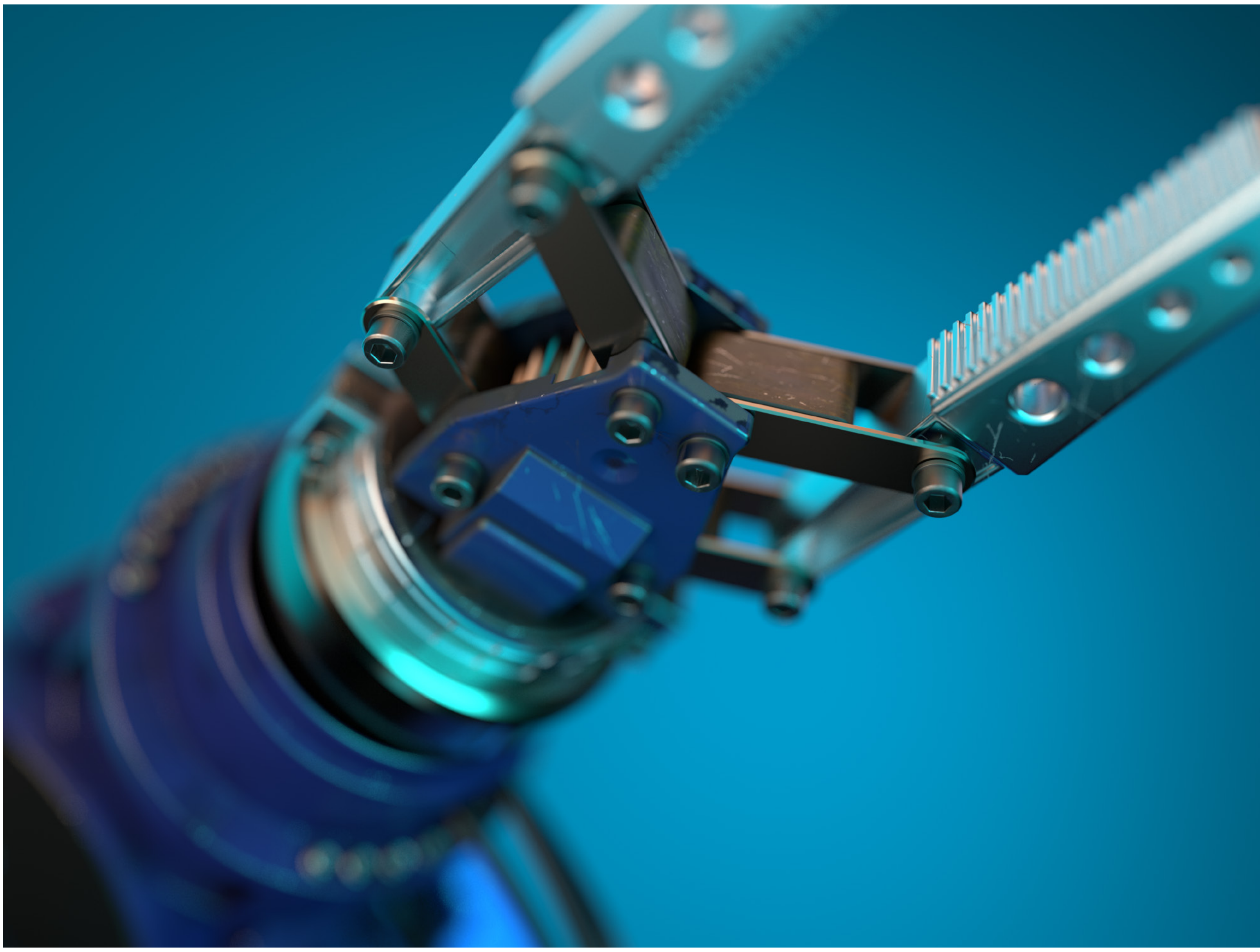
Models are available for heavy duty HVAC systems as well as for consumer and hand-held monitors. Units are designed to be robust, with proven EMC performance, operating for 20000 hours continuously and reliably with +/-15% accuracy. With UART protocol for PM_1, $PM_{2.5}$, PM_4 and PM_{10} outputs, the unit can be easily integrated into other automated systems.

Figure 4: HPM Compact particle sensor from Honeywell

The AmbiMate MS4 sensor module range from **TE Connectivity** delivers an application specific set of sensors on a ready to install PCB assembly, for easy integration into a host product. Pre-engineered sensors in a space-saving footprint are combined with the popular I^2C communication protocol to enable fast product prototyping, evaluation and design integration. Applications include IAQ monitoring, building automation including zonal environmental controls, home automation and energy management. In addition to basic sensor modules covering motion, light, temperature and humidity, additional modules include sensors for detecting VOCs and equivalent CO_2. The gas sensor measures TVOC in the range from 0 to 1187ppb and CO_2 from 400 to 8192ppm.

Conclusion

The monitoring of indoor air quality is gaining in momentum as people become more aware of the growing presence of pollutants from various sources and the health risks that they pose. Sensors for monitoring CO_2 and detecting VOCs and PMs have seen some considerable advances in recent years. Low-cost, maintenance-free devices are now available with good sensitivity. Developers should look for sensors or multi-sensor platforms that can be easily integrated into standard equipment such as ventilation systems and air conditioners, to become an integral part of a BMS or smart home installation. Further research into IAQ is likely to determine new requirements for sensors, but the certainty is that IAQ monitoring is the next 'must-have' for any building where people live or work.



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