Wireless IAQ Profile Monitor by PPM Technology

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I. Introduction

The latest Wireless Indoor Air Quality (IAQ) Profile Monitor unit from PPM Technology, allows for a complete and accurate representation of indoor air quality in a building, in accordance with the buildings management standards concerning conditions such as sick building syndrome.

Wireless PPM IAQ monitor™

II. Benefits

IAQ profile is a visual presentation of indoor air quality. A good IAQ profile describes precisely changes in concentration levels of selected air quality parameters in an indoor environment over a period of time

Using state of the art gas sensors, automatic sampling, data logging, digital technology and IT, IAQ profiling can be accurate, efficient and therefore cost effective.

The new Product will contribute to the aims of sustainable development with relation to impact on the environment in a number of ways.

Having a product giving real time monitoring will give immediate warning of over exposure to toxic or harmful gases. Areas could be immediately evacuated giving minimal over exposure to workers/ members of the public and if the system is connected to air conditioning or ventilation systems, these could be triggered immediately to disperse the gases and bring in fresh air supply to the affected areas.

- As a result the health of the workers / members of the public are safeguarded thus giving less immediate impact on the emergency services and in the longer period less impact on the health service.
- The affected areas will not be contaminated for as long, thus minimizing product or manufacturing down time thus improving productivity.

A more effective air-conditioning or ventilating system would also have positive impact on the environment. It would take care of human comfort, energy conservation, cost effectiveness and health of the occupants inside the building. In order to ensure the preset targets of air quality are met but not over or under provided, signals from real time monitoring to control the air conditioning and ventilation systems could be used.

- Controlling some IAQ parameters would improve the comfort and work efficiency of the occupants as well as their immediate and long term health.
- A good IAQ profile and monitoring system would avoid wastage of energy and resources due to better control of the air conditioning system.

This system will therefore have dual environmental benefit, firstly by immediate warning of over exposure to harmful toxic gases to the public and secondly to avoid wastage of energy and resources due to better control of the air conditioning system.

Multiple units can be networked together allowing for precise changes in concentration levels for given IAQ parameters to be recorded in various locations over time.

III. BACKGROUND

A. Sick Building Syndrome (SBS)

Often neglected by building service professionals up until the last century, many had never even considered a buildings carbon emission or carbon footprint. It was only recently that members of the public and professionals alike began to seriously consider the implications of IAQ which directly affects our health and quality of life and the greater environment.

Sick Building Syndrome is concerned with a range of symptoms that can effect a worker in a particular building. SBS typically occurs in large open-plan offices with automated heating, ventilation and air conditioning systems. Sick Building Syndrome can effect people in a particular part of building or even the entire building itself. Common symptoms include:

- Fatigue
- Headaches
- Shortness of breath
- Loss of concentration
- Eye & throat irritation
- Itchy or dry skin
- Nausea

Sick Building Syndrome cannot be diagnosed precisely, and can effect people in different ways. It is not to be confused with specific building related illnesses however. Illnesses such as legionnaires disease or exposure to dangerous chemicals. SBS symptoms will usually resolve themselves as soon as the person leaves the room or building.
Common factors that can lead to Sick Building Syndrome:

- Poor Ventilation
- Airborne Pollutants

  (Dust, Carpet Fibres, Fungal Spores)
- Chemical Pollutants

  (Light industrial chemical substances, cleaning substances)
- Ozone
- High concentrations of VOC's, Carbon Monoxide and Formaldehyde
- Pollution from external sources (e.g. fumes)

B. Solution

Typical IAQ certification calls for taking four single point measurements of pollutant levels in an area over an eight hour period once a year. This monitoring method is unreliable, as the pollutant levels in a typical commercial premise is subject to hourly, daily and indeed seasonal fluctuations. Moreover, building service professionals and designers alike have regarded the current system as being insufficiently forward thinking considering today's environmental challenges. At the time of legislation, manual monitoring was the only option available to most professionals. However, advances in technology have made it possible for continuous monitoring to be achieved.

Gradually, building designers are realizing the importance of IAQ in the workplace and are taking this into account when designing modern buildings and air conditioning systems. It remains vitally important for regulators to continue to recognize the significance of safeguarding the health of workers, and the wider impact of the overall building on the environment. This requires a scientific approach to the systematic monitoring and management of IAQ. The PPM IAQ monitor™ is one such solution.

IV. THE IAQ PROFILE MONITOR™

A. System Specification

The IAQ Profile monitor™ unit is built around the high performance PIC16F877 8-bit microcontroller. This low power, 40 pin CMOS Flash microcontroller features:

- High performance RISC CPU
- Up to 8K x 14 words of FLASH program memory
- Up to 368 x 8 bytes of data memory (RAM)
- Up to 256 x 8 bytes of EEPROM data memory
- In circuit serial programming (ICSP) via two pins

Along side our microcontroller lays the Zigbee wireless module which is responsible for the transmission of sensor data to the receiving Zigbee USB module installed on a local PC or laptop.

Sitting on top of our microcontroller base board is the sensor communication board. This is responsible for converting sensor data into a digital format and forwarding this information to the base board. This top board setup is determined by the particular sensors installed in the unit itself.

Finally, we have the sensor bar, which as the name suggests contains the vital IAQ parameter sensors for the unit. Each IAQ Monitor™ can be configured with up to 8 parameter sensors varying from Carbon Monoxide, TVOC's, to Carbon Dioxide.

A wider variety of sensors are available depending on the particular environment.

The unit also contains a built in fan in order to help maintain air flow over the sensors at the front of the unit and to keep the unit cool.

A. System Architecture

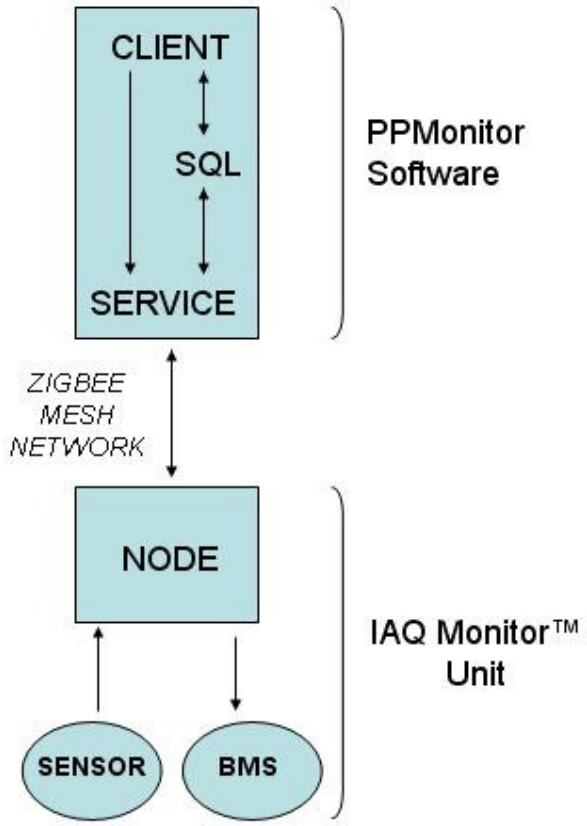


Fig. 1. IAQ monitor™ system architecture

From figure 1 we see that the system architecture comprises of the IAQ monitor™ units and the PPMonitor software installed on the controller PC or laptop.

Each of the wireless units is based around a set of IAQ parameter sensors that average the readings and collates the data at the node. This data is then sent every minute via the node integrated Zigbee module. This information is encrypted using the 128bit Advanced Encryption Standard (AES).

This data is received via the PC Zigbee module regarded as the data sink. At the PC the service collects the sensor reading information and deposits it into an SQL database. The PPMonitor client program can use the information in the database to present the data graphically, create sensor reports and use the data to trigger alarm events. Alternative 3rd party software can also be developed to use the PPM SQL database. During initial setup the client can talk to the service and implement a network scan. Units found can be added to the PPMonitor list of devices found in the SQL database. Any additional units that transmit after the network scan can also be added by the PPMonitor client. A list of blocked units is kept so that the client is not interrupted by unsolicited requests from unauthorised units.

Building Management System (BMS) events can be triggered by an optional three relays incorporated in each IAQ monitor™ unit. Dedicated alarm only units can also be provided. The BMS can activate air conditioning systems, turn on heating and as a last resort trigger building alarms.

V. WIRELESS SYSTEM

A. Utilisation of a wireless mesh system

The reason for a wireless IAQ sensor network arises from their ability for detailed sensor monitoring in inaccessible locations where a wired infrastructure is not viable or possible. A wireless network is also cheaper to install.

The PPM IAQ monitor™ system utilizes the reliable Zigbee Pro wireless mesh system. This is a cost effective, easy to install and simple to use networking solution for a wide variety of building layouts. The mesh is able to configure the optimal signal route automatically and is also self healing. This ability to self heal means that the network will still operate correctly even if a node were to break down, as information can be routed through an alternative node.

The new ZigBee Pro system utilizes a routing algorithm that uses a request/respond protocol in order to eliminate suboptimal routing. As a result, a typical ZigBee mesh network can be expanded indefinitely.

The size of the network can easily be extended by simply adding additional IAQ monitor™ units to the mesh, as each individual unit is also a router for its neighbour. This ability to further expand the network allows for a greater level of monitoring across the whole building or complex, and hence a more detailed representation of indoor air quality in general. A typical office setup is shown in Figure 2.

For areas that require no IAQ monitoring, dedicated repeater nodes can be used to maintain network coverage throughout the building. In areas where signals are weak, power amplified modules can be used to further extend the network thanks to

their more powerful antennae. This also reduces the need for repeater nodes and hence simplifies the overall network.

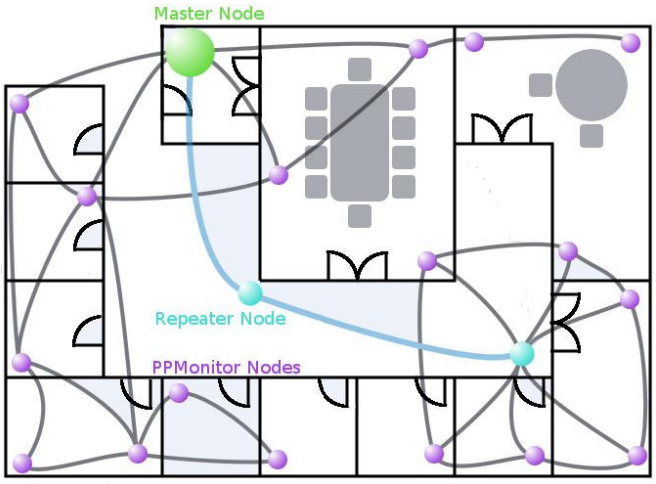


Fig. 2. A mesh network in a building or office

B. ZigBee Pro Mesh Networking System

Data integrity and security are a key benefit of the new ZigBee Pro network. By utilising the IEEE 802.15.4 MAC sub layer security model, the ZigBee system ensures trusted access control, data encryption and overall frame integrity.

- Low power 2.4GHz ISM Band Transceivers
- Various antennae options for required network coverage
- 250kbit/s over the air data rate
- 16 channels (802.15.4 Channel 11 to 26)
- +3dBm Output power (+5dB Boost mode)
- High sensitivity of -98dBm typical at 1% packet error rate
- 128k flash, 5kbytes of SRAM

By using the Zigbee Pro system over the standard Zigbee system, we are able to utilise many to one routing and also source routing. These techniques help to minimize traffic in our network, particularly when centralised nodes are being used, by providing a single route of discovery for all devices, thus reducing the route table size and route discovery broadcasts. This will free up more bandwidth for data as a result.

The ZigBee pro system also supports larger networks, which will allow for further expansion of the IAQ monitor™ units around a building or complex.

The ZigBee protocol stack is shown in Figure 3 which shows the structure of the system from the physical RF communication layer up to the application layer which is our PPMonitor software.

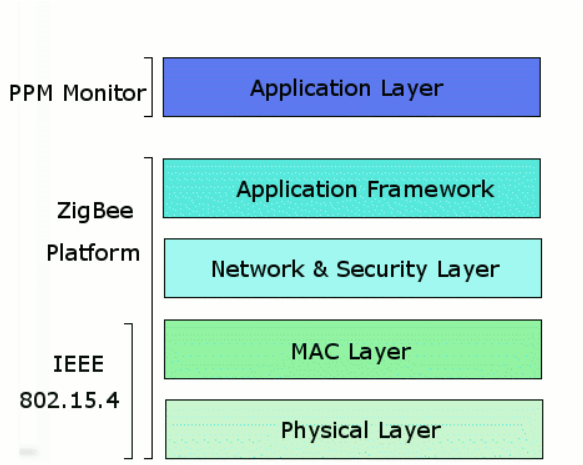


Fig. 3. ZigBee Protocol Stack

Using a ZigBee network over a Bluetooth one has several advantages. The main benefit being the relatively small stack (28 Kbytes) compared to Bluetooth (250 Kbytes), resulting in smaller costs and lower power consumption overall.

As discussed earlier, ZigBee Pro technology allows for a larger network to be implemented, while Bluetooth networks are limited to 8 devices for a typical network.

Concerns regarding the use the 2.4Ghz spectrum utilized by both Bluetooth, wifi with respect to the potential interference problems, are quickly dismissed as our IAQ monitor™ units use the Zigbee Pro system which when powered up analyzes the spectrum around it and can then re-align to a quieter part of the spectrum if needed to prevent any chance of interference. This feature works continuously to ensure that there are no interference problems.

Our ZigBee network can be broken down into two main device types:

Coordinator - The network coordinator for our mesh network maintains the overall network knowledge. As a result it requires the most memory and computing power. The coordinator is therefore setup on a laptop or PC where the PPMonitor software is installed.

Full Function Device - Or FFD is setup on the individual wireless units and supports all IEEE 802.15.4 functions. The FFD also has the ability to be utilised in network edge devices.

There is also a third device type as supported by the Zigbee standard which is the 'Reduced Function Device' or RFD. This device carries limited functionality and so is commonly used in network edge devices.

C. *Monitor Grouping*

As well as the ability for each IAQ monitor™ to route sensor information from one neighbour to another as part of the mesh network, the software is also capable of monitor grouping. The purpose of monitor grouping is so that only one unit needs to be connected to the BMS. Other units in the masters group can trigger alarms on the master unit thus initiating a BMS event. If a monitor unit has no alarms the option to trigger alarms is disabled. However if this unit is in a group with a master then the alarm options are enabled. For units that are in a group with a master then the alarm options refers to the relays on the master unit. Only units with relays can be assigned as group master units. A typical group example is shown in figure 4.

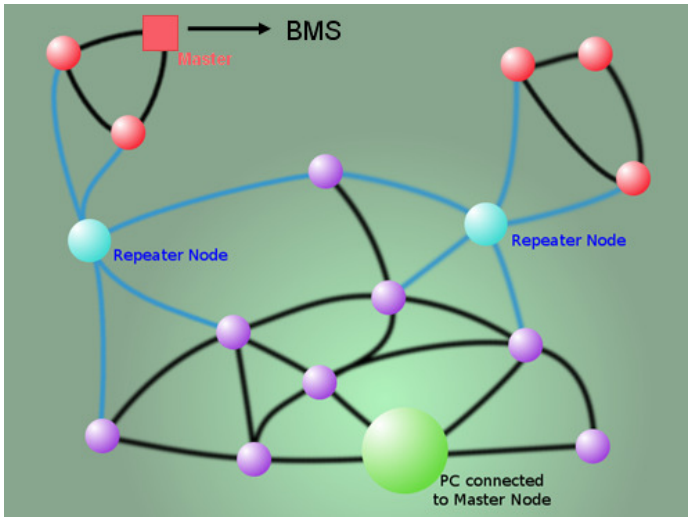


Fig. 4. Grouped nodes appear in red

D. *IAQ Wireless operation*

The IAQ monitor™ unit has been designed to be easy to setup and operate. A manager PC simply connects to the mesh network using a Telegesis ZigBee USB module, allowing for transmitting and receiving of information to a particular wireless unit on the network. The manager PC can then view, run and control the real time monitoring and data logging of air quality within the building at the click of a button.

The software utilizes windows authentication to determine user privileges for PPMonitor. The program has two sets of privileges as default; guest and administrator. Only members of the PPMAdministrators group have access to all areas of the program. For less trusted users the PPMGuests group is available which has only limited access to the program. Monitoring information can be viewed graphically through the PPMonitor software, see figure 5 and 6.

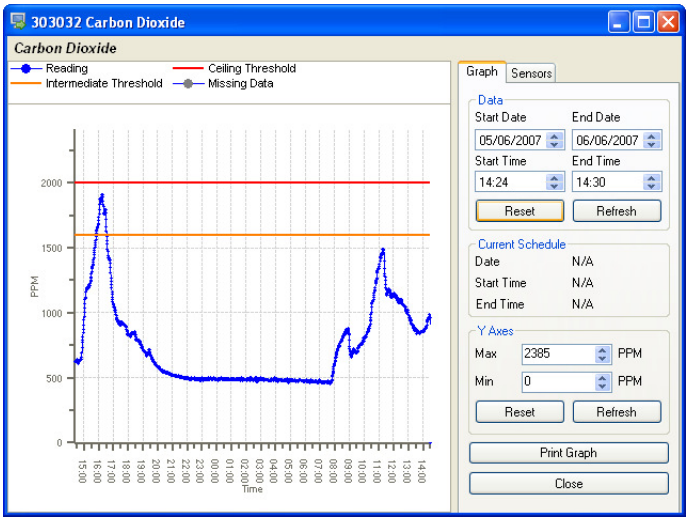


Fig. 5. PPMonitor Software

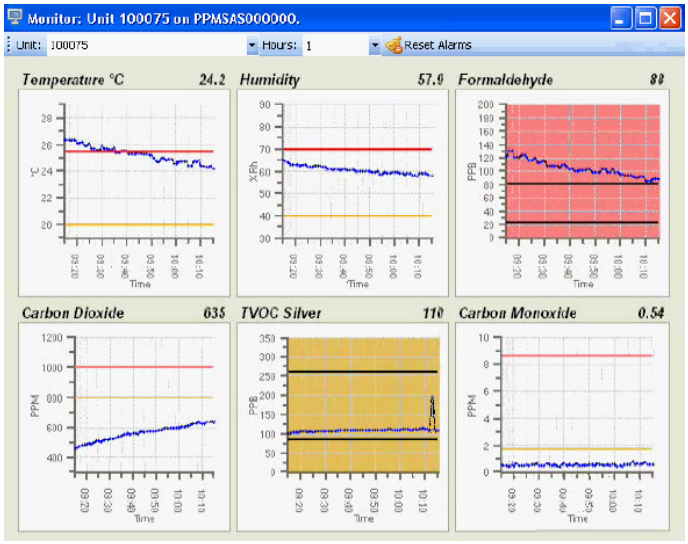


Fig. 6. IAQ monitor™ unit with 6 parameter sensors

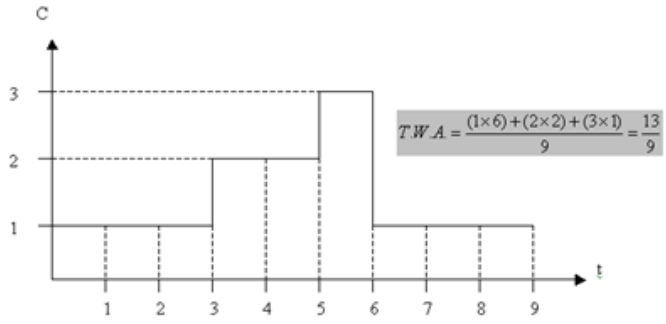
The software provides detailed statistical data, as well as the ability to produce reports, run schedules and configure individual alarms for particular sensors. There are various alarms types that can be triggered by the software. The two main alarms are ceiling and intermediate. The intermediate alarm can be used to give a warning that the gas concentration level has reached a non critical but concerning level. This can trigger the air conditioning before the gas concentration reaches a critical level. The ceiling alarm can give a more severe warning when the gas concentration reaches a critical level. Intermediate alarm can also be used to give a less than warning, say if we measure temperature or oxygen it can give a warning if the level is too low.

Other advanced industrial hygiene functions are also automatically calculated and could trigger alarm conditions. Two of which are Time Waited Average (TWA) and Short Term Exposure Limit (STEL). These levels are commonly legislated by governments and until recently there was no way of finding if these levels were breached.

$$TWA = \frac{\sum_{i=0}^{n} (C_i \times t_i)}{\sum_{i=0}^{n} t_i}$$

Where
C = Concentration
t = Duration at level 'C'
n = Session length

TWA Equation



TWA Calculation

STEL is typically the average concentration for the last 15 minutes.

Ethernet Access Points EAP can be used to expand the wireless network over different floors in a building. The EAP is a “gateway” allowing access to ETRX2 mesh networking modules via an industry standard Ethernet IP Network. Multiple EAPs can be deployed so a wireless network could be established on floor 5 and floor 10 without the use of repeater nodes. From figure 7 we see that the EPA utilizes the buildings own Ethernet backbone to expand the wireless network.

For operation from further afield, it is possible to set up a client program on a remote and connect to the service and database over a network. This could be used to connect to the data from anywhere in the world.

This allows for effective and economical building management.

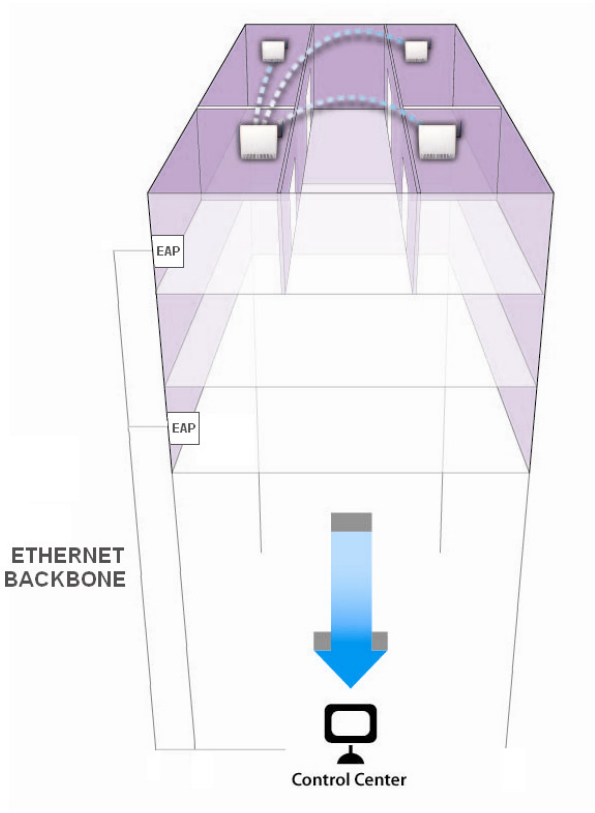
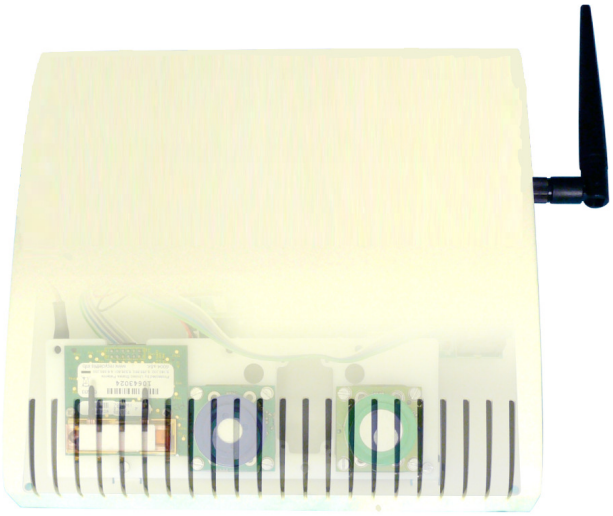


Fig. 7. EPA setup

VI. SENSOR CONFIGURATION



Each IAQ monitor™ unit can be configured with up to 8 different IAQ parameter sensors depending on the user's requirements. These typically include:

A. *Formaldehyde*

Range	0-10ppm as standard, extended range available on request.
Resolution	0.01ppm
Repeatability	2%
Accuracy	94% of all instruments readings meet the NIOSH criteria for an acceptable method at test concentrations of 0.3ppm of formaldehyde.
Response time	60s

B. *Temperature & Humidity*

Range	– 40 to +128°C, 0-100%RH
Accuracy	±0.3°C ±1.8% RH
Resolution	0.03% RH, 0.01°C
Repeatability	±0.1°C, ±0.1%
Response time	<3s

C. *Nitrogen Dioxide (N02)*

Method	Electrochemical
Range	0 to 10ppm
Resolution	0.01
Response time (t_{90})	<60s from 0-10ppm NO_2

D. *Carbon Monoxide (C0)*

Method	Electrochemical
Range	0 to 100ppm
Resolution	0.1ppm
Response time (t_{90})	30s from 0-400ppm CO

E. *Carbon Dioxide (C02)*

Range	0-5000ppm
Resolution	1ppm

F. *Total Volatile Organic Compounds (TV0C's)*

Range	ca. 0-20ppm
Resolution	0.01ppm
Response time	60s
Expected lifetime	
Output	Serial output

G. *Ozone (03)*

Range	ca. 0-1ppm
Resolution	< 0.02ppm
Response time	< 15 s
Expected lifetime	>18 months
Output	4 to 20 mA

A number of different sensing technologies are used within the IAQ monitor™. These include electrochemical – typical formaldehyde(HCHO), Carbon Monoxide(CO) and Ozone(O3), Non-Dispersive Infrared NDIR for Carbon Dioxide(CO2), Photo ionization Detector PID for TVOC and a single unit temperature and humidity sensors based on capacitive semiconductor principle using patented digital CMOSens® technology.

Other sensors options are available including non IAQ related configurations such as noise, vibration and air flow. The system can be modified to gather information from any 4-20mA current input, 0-5 Volt input or Serial input.

The sensors within the IAQ profile monitor™ sample the air mainly by augmented diffusion, whereby air flow over the sensors is not forced by a pump. A low volume fan is instead used to help maintain airflow. The augmented diffusion method is preferred by PPM for many reasons. Firstly, it gives a more accurate representation of the surrounding air quality since the pollutant is allowed sufficient time to diffuse evenly into the air. This coupled with an environment of an air conditioned room that already has 5 air changes (fresh air) or 30 air changes (internal air) per hour is more than sufficient for the sensors to give excellent representation of the air quality within a specified area.

A pump would inevitably speed things up, but may exaggerate conditions causing errors, which in turn would give misleading results.

Using augmented diffusion also helps to prolong the lifetime of the electrochemical sensors used in the instrument, as these types of sensors depend upon an aqueous electrolyte in order

to operate efficiently. By forcing air over such sensors, the gas stream could remove the electrolyte and cause them to dry out, resulting in a reduced lifetime for the sensor.

VII. PERFORMANCE RESULTS

We recently performed a trial setup of the IAQ monitor™ system over in Hong Kong in order to test out the units against a typical hot and humid Hong Kong summer.

In our test, all IAQ data was taken at regular 1 minute intervals using 4 IAQ monitor™ units for four consecutive days. These units were placed in various locations around the building for a wider analysis of data.

The information gathered was automatically stored on a PC connected to the wireless mesh system using the PPMonitor software.

The results were as follows:

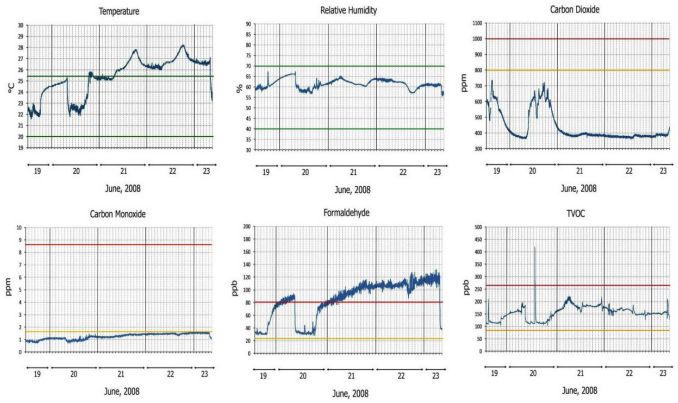


Fig.8 IAQ monitor™ unit 1

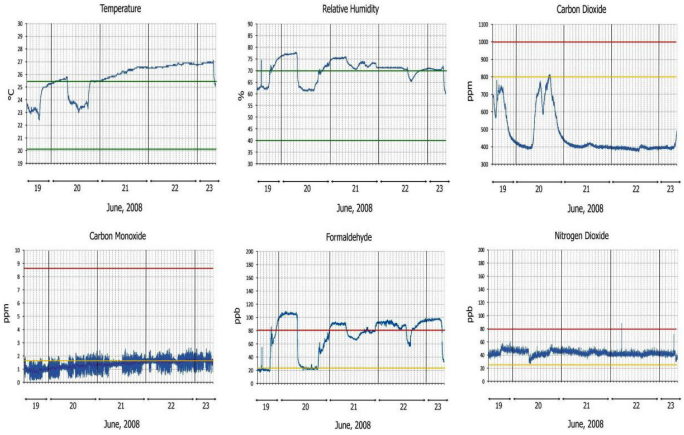


Fig.9 IAQ monitor™ unit 2

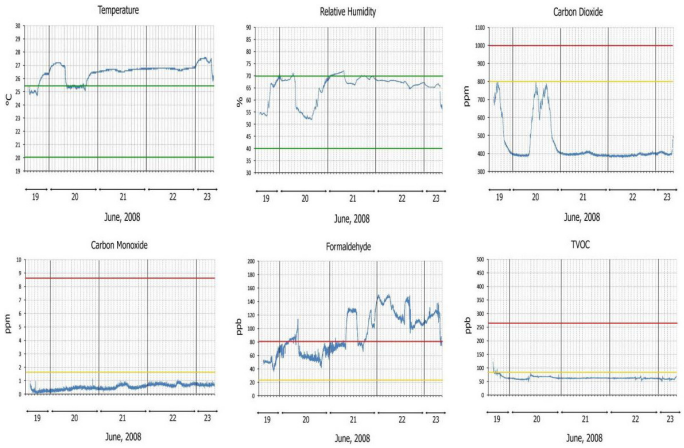


Fig.10 IAQ monitor™ unit 3

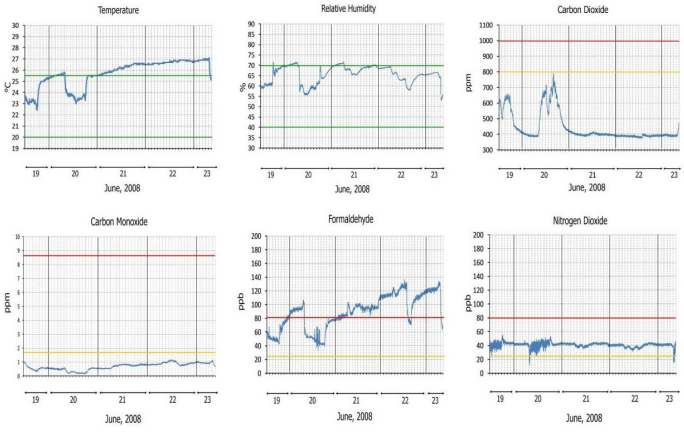


Fig.11 IAQ monitor™ unit 4

A. *DISCUSSION OF RESULTS*

Having completed the trial setup for the period of 4 days, here is what we found:

Temperature & Humidity – Both comfort factors of an air conditioned space. The office is maintained at a temperature of 23°C ± 1, with a relative humidity of 60 ± 5% during office hours. We found however that both levels elevate quickly to near outdoor levels during the end of the working day, and stay more or less at this level throughout the weekend. As a result the building may be susceptible to the potential hazard of mould and insect infections during the Honk Kong summer.

Carbon Dioxide – This is a good indicator of how adequate the current ventilation system is within the building. Looking at the data from the 4 IAQ Monitor™ units, we see that this particular office is well ventilated during office hours and over the weekend. An over ventilated air conditioned building however is not very energy efficient. Money can be saved as well as reduced greenhouse gas emissions, if the building service engineer has the correct data relating to the day to day operation of the air conditioning system, so that improvements to the design and management of the ventilation system can be made.

Formaldehyde & TVOC's – Both of which are generated inside the office premises. Looking at the data from the graphs, we see that both parameters are well within the levels for a good IAQ system. Formaldehyde levels however, sometimes peak towards the end of the working day and stay at this level during the night and indeed over the weekend. This can be potentially hazardous to any employee working late in the evening or coming in over the weekend.

Carbon Monoxide & N02 – Low levels of these parameters typically come from outside the building through fresh air intakes. Looking at the graphs however, show that both parameters are well within the levels of a good IAQ system.

B. *CONCLUSION*

Although this test run was conducted on a single office floor in a building, the IAQ profiles produced from it demonstrate that much can be done to the building management in order to save energy and hence reduce the CO2 emissions of the building.

The power required to air condition a 50 storey office building such as the one in which our test was undertaken, can easily exceed 10 million KWH per annum. This translates to the burning of over 1000 tons of coal and oil, and the emissions of over 3 million Kg of CO2.

Equipping a building with an IAQ monitoring system such as the PPM IAQ monitor™, can provide the building service professionals with the data they need for the effective management of air quality within the building, and help achieve a 10 to 20% saving in emissions which will ultimately save the company money.

SUMMARY

The PPM IAQ monitor™ system provides a dual environmental benefit. Real-time functions enable immediate warnings of the presence of harmful gases in the air thus protecting employees and the public. Analysis of recorded data over time allows for more efficient management of resources and energy.

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