



## Recent Developments in Indoor Environmental Quality Mobile Units

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### ABSTRACT

This paper explores the existing literature on Indoor Environmental Quality (IEQ) tools and applications, including the real-time monitoring system to achieve an optimal IEQ. The accurate, easy-to-use, and inexpensive equipment is a major obstacle to IEQ performance evaluation. With the rapid development of wireless monitoring equipment in recent years, measuring various building parameters has become a less labor-intensive process. While sensors and logging device manufacturers have made products that are increasingly accurate and easy-to-use, making new devices for measuring IEQ is still largely in the hands of researchers. IEQ measurement requires a combination of devices and individual sensors to capture the state of IEQ in a space. This paper presents a review of the recent development on IEQ evaluation methods and tools, proposes a new approach of Smart IEQ online monitoring mobile unit on small, low-cost, and desk-based monitors with sensors for thermal comfort (air and radiant temperatures, air speed, and humidity), acoustics (SPL), lighting (Lux), and air quality (CO<sub>2</sub>, CO, TVOC, Formaldehyde, and PM<sub>10</sub>). The measurements are relayed wirelessly to a server within the building that transmits data through the wireless network which can in real-time be presented to an online IEQ dashboard in a control room or to a mobile phone by an application program.

### 1. Introduction

Indoor Environmental Quality (IEQ) is one of the main criteria to evaluate the performance of buildings, as well as Green Building Benchmark Systems, for example, Leadership in Energy and Environmental Design (LEED) in the USA, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan, and Thailand's Rating of Energy and Environmental Sustainability (TREES). IEQ measurement can help to discover and correct problems. Such measurements are implemented in a standardized fashion, the IEQ models have to transform the measurements into scores that can be used in the ratings or standards. The measuring protocols of IEQ must follow the ASHRAE/CIBSE/USGBC Performance Measurement Protocols (PMP) for Commercial Buildings [1] and the Performance Measurement Protocols Best Practices Guide [2].

The European Standard EN15251 (2007) provides guidance on IEQ measurement, standards, and input values to use in energy simulations. The accurate, easy-to-use, and inexpensive measurement equipment is one of the major limitations in IEQ performance evaluation [3]. In recent years, the rapid development of wireless monitoring equipment has made the products cheaper. Measuring various building parameters has become less labor-intensive process due to the use of electronic devices. However, there are still a number of obstructions that still make a difficult process for measurement. While sensor and logging device manufacturers have made products that are increasingly accurate and easy-to-use (for example, wireless), making new devices with multiple sensors for measuring IEQ is still largely in the hands of IEQ researchers. IEQ measurement requires a combination of devices and individual sensors to capture the state of IEQ in a space.

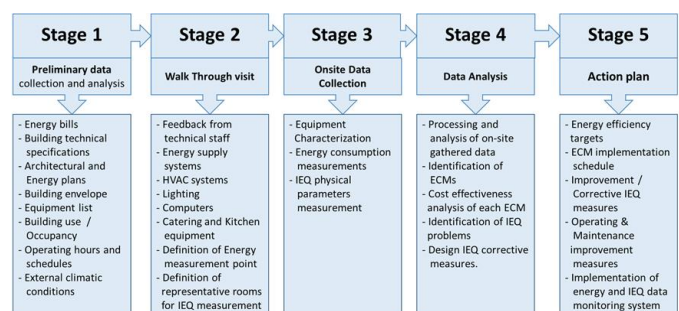
The aim of this paper is to present: (1) An overview of IEQ evaluation methods and tools; (2) historical development of IEQ tools, problems, and limitations; and (3) a proposed new IEQ mobile unit.

### 2. Overview of IEQ evaluation methods and tools:

IEQ can be simply described as the indoor conditions of the building. Not only from the good design from architecture and engineering before construction, it includes functional aspects of spaces, such as whether the layout provides easy access, and whether there is sufficient space for

occupants. IEQ involves acceptable levels of indoor air quality (IAQ), thermal comfort, acoustic quality, and visual or lighting quality. Poor IEQ can lead to negative effects of any buildings, such as the cost of absences and low productivity in an office. This often exceeds the cost of energy use associated with maintaining acceptable indoor environmental standards. On the other hand, good IEQ can improve overall working performance by minimizing the effects of building-related illnesses and absences, or the so-called the sick building syndrome. Improving a building's energy and environmental performance have become flagships towards sustainability.

Figure 1 presents different steps of improving a building's energy and environmental performance. First, data of the energy and indoor environment quality conditions are collected and managed to be preliminary data on the facility by auditors. Then the building inspection and installation of the monitoring equipment takes place to identify and evaluate potential improvement measures. Finally, the action plan could be elaborated to establish targets for reduction of energy use and improving IEQ.



**Figure 1. Stages of Improving a Building's Energy and Environmental Performance.**

The measurement of IEQ parameters is a process to collect the data from the site, which can identify IEQ problems. This leads to the analysis of improving IEQ and energy performance. The standardized documents for IEQ measurement and performance have been written in the USA. These are the ASHRAE/CIBSE/USGBC Performance Measurement Protocols

(PMP) for Commercial Buildings [4] and the Performance Measurement Protocols Best Practices Guide [5], which adds to the scope of the European Standard EN15251 (2007).

The PMP prescribes three levels of measurement details: basic, intermediate, and advanced levels. For the basic PMP protocol, the instrumental measurements include spot measurement, with a hand-held temperature, humidity, air speed, illuminance (Lux), and sound level. The intermediate PMP protocol requires time series (data logger) observations of air and mean radiant temperatures, relative humidity, occupied zone air speed, carbon dioxide (CO<sub>2</sub>) level, and vertical plus horizontal surface light-level measurements. The acoustic measurement includes sound pressure, level with parallel octave band filters and a noise source for calculation of background noise and reverberation time. The advanced PMP protocol requires air and radiant temperatures, humidity, air speed, CO<sub>2</sub>,

particulate matter (PM) 2.5, and total volatile organic compounds (TVOCs) sensors to be logged continuously for a defined period, while the requisite lighting measurements include a high dynamic range (HDR) camera and software. Advanced PMP requires a sound pressure level meter equipped with a parallel one-third octave band filters and loudspeakers for evaluations of speech privacy, speech communication, and sound and vibration isolation [4, 6].

For collection of IEQ data from field studies, there are two types of data collection systems: the first drop and collection (off line), and the second wireless monitoring (online monitoring). IEQ measurement requires a combination of devices and individual sensors to capture the state of IEQ in a space, which have many designs from IEQ studies. This paper studies the previous instrument of IEQ monitoring systems that is described in the following sessions. The paper contributes to the area of IEQ research by proposing an innovative smart IEQ online monitoring mobile unit.

### 3. Previous instrument of the IEQ monitoring system

The measurements of the IEQ parameters have a variety of solutions depending on the requirements of IEQ data from researchers. The mobile cart is a simplified drop and collection (off line) instruments, which consist of various sensors or transducers. It is usually connected with data logger in the cart. The cart is wheeled around inside the building and the data of IEQ from all sensors will be sampled by the data logger. Figure 2–5 shows some examples of various carts from the literature.

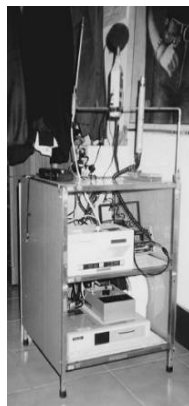


Figure 2. IEQ cart [7]



Figure 3. UFAD commissioning cart [8]



Figure 4. Comprehensive IEQ monitoring cart [4]

Figure 2 shows a simple mobile IEQ cart that has been used in a field test of the ASHRAE/CIBSE/USGBC PMP [7]. It was developed by the Department of Architecture, National Cheng-Kung University, Taiwan. Figure 3 illustrates a mobile IEQ cart with telescopic mast of temperature sensors. It was designed to specially commission underfloor air distribution systems [8], and developed by Lawrence Berkeley National Labs and the Center for the Built Environment in USA. Figure 4 shows a mobile IEQ cart same test similarly to Figure 2, but it has a camera for HDR luminance [6]. This cart was developed by Texas A&M University in USA.

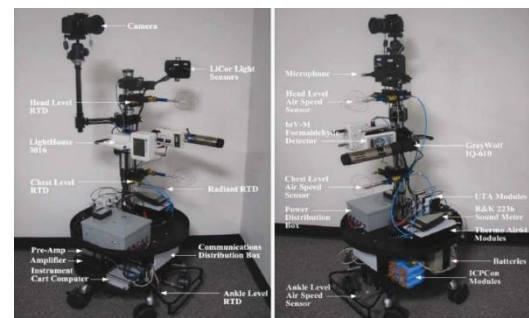


Figure 5. NICE instrumented cart - most sophisticated mobile IEQ cart to date includes most transducers required by the ASHRAE/USGBC/CIBSE PMP Advanced Level protocol [8] which is developed by National Research Council Canada

The design of all these mobile cart examples (Figure 2–5) has been installed in the laboratory. The instruments or sensors collect the individual IEQ parameters of interest, and then hard-wire them into a data logger for sampling IEQ data. The mobile cart is wheeled through the space within the targeted building and collects data from the site. The data logger collects the data by periodically trigger and sweeping all of all sensors, time-stamp their data, and stores the data in the memory for data analysis.

The mobile cart is primarily useful for its ability to move multiple sensors around a space. In addition, it has the ability to have multiple wired sensors log to one location, and to keep sensors steady for the measurement period. Consequently, the size of the IEQ mobile cart is quite big, and still needs some practical advantages to have multiple sensors on one cart. The bulkiness of the cart makes it difficult to move around spaces, and travel with a human operator to steer them along their random workspace while the occupant is present. It is hard to transport or move the equipment. With the development of wireless sensors and logging devices, manufacturers have made products that are increasingly accurate and easy-to-use. This leads to the development of novel wireless monitoring for IEQ online monitoring systems. Figure 6 and 7 show some examples of various IEQ online monitoring devices from the literature.



Figure 6. Desktop occupant polling and IEQ monitoring station. [10]



Figure 7. SAMBA IEQ device [11]

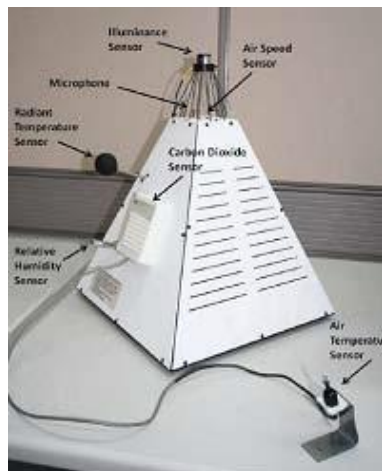


Figure 8. Pyramid desktop device [9]

Figure 6 shows a desktop occupant polling and IEQ monitoring station with illuminance and temperature sensors [10]. Figure 7 is a center desk-based IEQ monitors (SAMBA) with sensors for thermal comfort (air and radiant temperatures, air speed, and humidity), acoustics (SPL), lighting (Lux), and air quality (CO<sub>2</sub>, CO, TVOC, Formaldehyde, and PM<sub>10</sub>) [11]. Figure 8 presents a pyramid desktop device for monitor sound level, CO<sub>2</sub>, illuminance, air temperature, radiant temperature, air speed, and relative humidity [9]. The design of these devices (Figure 6-8) has simply been as a desk base device which has multiple small sensors complete with data logger and communication in one small unit. Data are communicated online by a wireless network to a server which is real time, and data are presented to an online IEQ dashboard in a control room or a mobile phone by an application program.

The previous IEQ monitoring devices have some limitations. Thus, this paper proposed an innovative design of a small, flexibility low-cost, autonomous of IEQ monitoring device. It could be placed permanently at multiple sampling points across the occupied zone of a building and on multiple levels of a multi-story building. Permanent placement of such devices could collect real time IEQ data that could collect a representative picture of IEQ performance.

#### 4. Proposed smart IEQ online monitoring mobile unit

The basic idea of a proposed smart IEQ online monitoring mobile unit is to design an online IEQ monitoring system, which is small, low-cost, plug-play, easy-to-use, and allows longitudinal measurements through time that is all occupied hours for weeks, months, seasons or even years. The device could collect the right data, which can represent a picture of the building's IEQ performance. This device can connect to IEQ data anytime and anywhere. The proposed scheme of a novel smart IEP monitoring unit is presented in Figure 9.

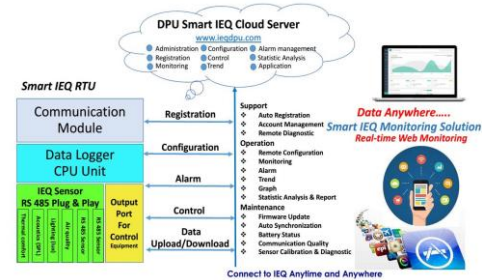


Figure 9. Proposed smart IEQ online monitoring system

A novel smart IEQ monitoring unit consists of three parts. The first part is a Remote Terminal Unit (RTU), which is a device to measure and selectable IEQ parameters or data. The functions of RTU are data collection, communication, logging, alarming, control, and analysis applications. The RTU has four components, namely (1) IEQ sensors, (2) Output port for control equipment, (3) Data logger and CPU unit, and (4) Communication module. The IEQ sensors are designed as plug and play multiple sensors using the RS485 standard communication. The output port is for controlling equipment, which can be used to control the energy performance of a building. Data logger and CPU unit is the brain of the RTU that has a memory to keep the IEQ data and control input-output ports. Communication module is a component for communicating data from RTU to cloud sever through various communication systems, such as GSM, GPRS, and Wi-Fi.

The second part is a smart cloud server, which is a logical server that is built, hosted, and delivered through a cloud computing platform over the internet. Users can access the IEQ smart monitoring system by a website. Analysts can support the function as auto registration, account management, remote diagnostic operation function as remote configuration, monitoring, alarm, statistical analysis and report maintenance function as firmware update, auto synchronization, battery status, communication quality, and sensor calibration, and diagnostic. The third part is a web monitoring system, which shows the system status and online monitoring in real time by remote computer or by an application program in a mobile phone.

#### 5. Conclusions

The smart IEQ online monitoring mobile unit is an innovative tool for improving of a building's energy and environmental performance. This paper presents a flexible sensor solution developed to monitor IEQ and energy multiple parameters of buildings and is based on web access to the database containing the information collected by a wireless network. The IEQ mobile unit is designed to serve as a low-cost, plug and play, easy to use and scalable platform to acquire detailed IEQ performance data.

The IEQ mobile unit can support web-based monitoring solution, collecting, displaying, registering, and processing the information generated by a wireless network of RTU which installed as a network in the target building. The collected real time information enables a detailed analysis of the performance and management of buildings to meet high energy and environment performance. However, this paper is only an open source proposal and an attempt to develop, achieve and implement a smart IEQ monitoring device in the nearly future.

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