

# Future Building Gas Sensing Applications

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**Abstract** It is often thought that technology drives innovation – a process that creates great values from ideas. But historically, it is a great vision that drives innovation and seeks for technologies as enablers. Take computer as a technology. “There is no reason for any individual to have a computer in their home,” said Mr. Ken Nelson, the then president of Digital Equipment Corporation or DEC in 1977 (Nova Online. “Traveling Through Time – Part 2”. Public Broadcasting Service. <http://www.pbs.org/wgbh/nova/time/through2.html>). Although immensely successful in minicomputer business, DEC failed to imagine what Home PC can do, and hence, unfortunately, saw one of the most dramatic demise of a technology company. It was lack of vision and imagination and not technology that led to such demise. Currently, Apple’s success in mobile industry is driven by Steven Jobs’ vision of delivering consumer infotainment by bundling technologies with flair and sleek products.

Therefore, it is important to paint a vision of what gas sensing can do in the future (Hagleitner et al., *Nature* 414:293–296, 2001; Moos et al., *Sensors* 9:4323–4365, 2009). What are the possibilities? How it can touch and benefit environment and human lives? Below is an attempt to paint vision through common-life examples. The goal here is to inspire and motivate us to think or dream big as how sensing can change our daily life experience. The dream should not be bounded by what can be achieved or not. That shall ultimately be governed by the real-life constraints such as costs, available technology, etc. But such lofty sensing vision should set a roadmap by defining requirements and seeking solutions for future.

This chapter presents a vision of solutions, particularly with gas sensing, that are achievable today with various matured and emerging technologies. The landscape

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of sensing solutions is changing fast as more and more technologies are becoming commercially available at even faster rate. Hence, once again, it is our vision that should set the pace of what we can expect tomorrow. So, let us keep imagining.

**Keywords** Application, Building, Built-environment, Carbon footprint, Environment, Future, Gas sensing, Innovation, MEMS, Microsystems, Sustainability

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## 1 Vision of Sustainable Built Environment

It was early in the morning, Adam wake up but not at the sound of alarm clock buzzer but by a voice that comes from his cell phone alerting him that his newly born baby's room has unusually high level of total volatile organic compounds (TVOC). Adam jumps from his bed and rushes toward that room. He takes a deep sigh of relief as he noted that his little daughter is sleeping well. He then checks on a new web-enabled sensor that not only measures TVOC, CO<sub>2</sub>, CO, T, and relative humidity (RH) in that room but also transmits such data to his smart phone should there be any level of any gas that requires human attention. Adam checked the TVOC level and found that reading is somewhat high but nothing to be alarmed about. He then, using his smart phone, downloaded TVOC reading over last week and actually noticed that the TVOC level is slowly creeping up. Smart sensor on the wall really did its job by noticing gradual change in the TVOC value and sending an alarm message to the Smart Phone. This was great – Adam said to himself. He recalled that recently he painted this room with so-called Non-VOC type, but it seems that the paint is not completely free of volatile organic compounds (VOC). He decided to wait for few more days for the paint to dry before he puts his baby girl back into the room.

While Adam was on the train, he checked his Smart Phone which has a built-in sensor arrays for a variety of information besides the outside temperature and humidity such as any indication of any toxic substance or flu virus. He sat down and dialed a sensor address at an apartment where his 82-year-old mother lives by

herself. He found there is no indication of alarm and all the readings from the sensor suites are normal.

Adam works in a hospital as a physician. As he enters through the hospital door, he gets a summary report of control and containment in the hospital with respect to any pathogens, biological, chemical, and radiological agents, and any disease that may be injurious to public health. The Smart Phone notifies Adam that the indoor environment quality or IEQ in the vicinity of Adam's office is good. There is no sign of any exposure of any gases or substance that may be injurious to Adam's health. It verified that the virus-monitoring system within the building is active and there is no report of any breakout of any virus within the building.

As Adam heads toward the lunch room, his Smart Phone continuously gets an update from the entire kitchen and food management systems notifying him about the freshness [1] of "Today's Catch" of Red Snapper but warns him about not to think about the frozen custard since the freezer temperature is not cold enough. The Smart Phone assures that he can drink from the faucet and does not need to buy any fancy expensive bottle water.

During the day break as Adam wants to use the toilet and he is close to it, he gets an alert that essentially asks to use another toilet because the smell inside is not acceptable due to malfunctioning of bathroom ventilation system.

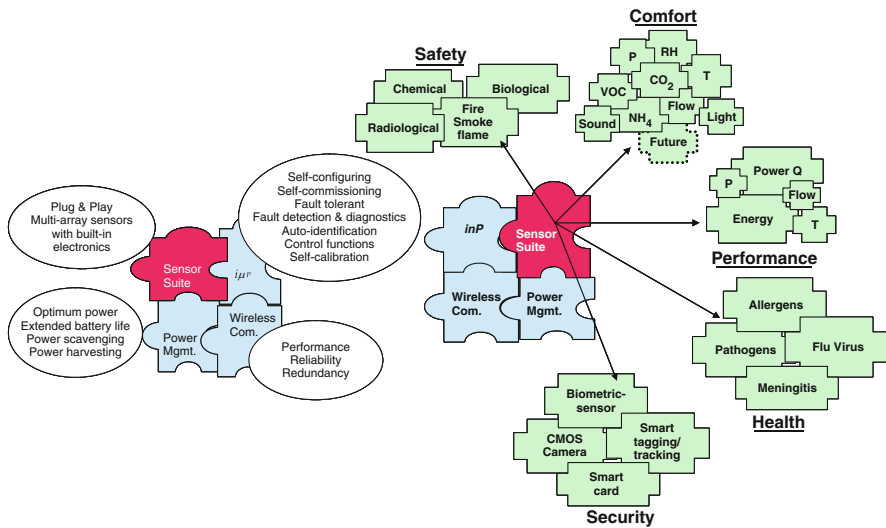
What is described above may sound like a science fiction, but the description is a realistic projection of a home or building automation system of the future that is more integrated within our life to protect us and provide us a comfortable environment by using granular level, pervasive, and ubiquitous sensing.

## **2 The Role of Sensing Applications in Next Generation Building**

The above vision can be only realized if sensing, particularly gases, become central to the future building and home automation systems. Sensing is fundamental in sustaining our life. With the advent of digital control systems in late 1970s, the sensing applications have seen exponential growth both in terms of its scope and utilization. Today, the basic sensing element is now coupled with a microprocessor that can process the sensed signal right within the sensor itself. The sensor communicates digital signal over building automation system's communication network. With the availability of inexpensive microprocessor and advancement in sensing element and sensor manufacturing technologies using latest complementary metal-oxide semiconductor (CMOS) and other integrated circuit (IC) processes, the overall sensor cost has come down significantly. The sensors are also integrating wireless communication chip and as a result offering more versatility and affordability by reducing the overall installed cost. Today's Micro-Electro Mechanical Systems technology (MEMS) allows to create an array of sensors (4–5) all into a single chip combined with the microprocessor, wireless communication, and power that can be harvested or scavenged from ambient sources, such as light, sound, or vibration, and thus not requiring plug-power that conventionally comes

from fossil fuel source [2]. The power source can even come from a micro-fuel cell providing energy for years. Similar trend of converging functionalities into a single chip even to a smaller scale is evolving using nanotechnology. The technology platform [3] that can combine different functionalities using MEMS or Nano is known as Microsystems or Nanosystems, respectively. The fundamental technical advantages of such a system are better accuracy, precision, robustness, repeatability, and a smaller footprint of a sensor that is often a huge advantage to use sensors in an inconspicuous way. But what drives the advent of Microsystems or Nanosystems are compelling business reasons – a single chip that can sense multiple variables means lower manufacturing cost and combining wireless communication and self-powering means eliminating the need of field wiring altogether that can lower installed cost by as much as 70–80%. The rush is on to make the tiny microsensor or nanosensor to be almost self-sustaining with added features such as self-configuring, self-commissioning, self-healing, etc.

So, today's building automation systems (BAS) can measure, monitor, and communicate sensed values more easily and cost-effectively within a building. Using powerful computers and mass storage devices, the BAS can effectively process sensed values in creating rich and useful applications and knowledge. The building industry, which traditionally is very conservative, is slow to adapt, and first-cost conscious, finally having a major reawakening driven by the potential future that can be realized with the use of various types of gas sensors. Within buildings and outside, personal mobile device can sense, track, and monitor level of healthiness as captured in Fig. 1 depicted by different elements of sensing applications within the “Health” box or safety level as indicated by elements within



**Fig. 1** Microsystems platform for sensing applications

the “Safety” box. Using same building blocks of Microsystems, various types of sensing applications can be packaged as shown in Fig. 1 [4].

While the future sensing applications are only limited by human imagination, the current scope is dictated by the legacy of the past. Although the drivers for rapid applications growth are plentiful, buildings are still lethargic and slowly overcoming the inertia of embracing new sensing technologies. However, this will change as soon as the industry reaches a threshold where demand for new applications exceeds past expectations. Following is an attempt to discuss such solutions and applications in today’s buildings and beyond and more interestingly, what to expect in the future – only possible because of current and future sensor technologies.

Today, the most common sensing application in a building is dominated by space temperature control. Occasionally, relative humidity is added as a comfort variable. In a temperature centric building control system, a three-tier BAS is used. At the lowest or local level, the goal of sensing application is to maintain space temperature either by varying the flow rate of cooling or heating medium while keeping the temperature of that medium fixed or by varying the temperature of that medium while keeping the flow rate fixed.

In the future, sensing applications in a sustainable building will dramatically change. For the local comfort, additional variables will be added such as indoor air quality, often measured by CO<sub>2</sub> and TVOC. The result will be a complex mix and use of multiple variables that need to be sensed and controlled, and such application requires a new technology platform, for example, a Microsystems or a Nanosystem. Most dramatic change will emerge as a result of building’s ability to sense the presence of individual occupant at a specific location and tailor a comfort, security, and safety solution that is suited for that particular individual via Smart Phone applications, for example. This will require execution of advanced algorithms such as adaptive learning by observing past behavior of an individual occupant. Imagine that in case of an actual fire breakout, the BAS activates floor lighting, just like in an aircraft, and guides people in the surrounding areas to the nearest fire exit. Imagine a simple building water cooler that has embedded Microsystems chips that measure, process, and communicate water flow rates, water temperature, and even water quality to a BAS for further system level processing. The results can detect problems with water quality or flow or even not having right temperature. Fixes can be made to provide fresh and good quality water throughout the building.

Building, in addition to its traditional role of providing comfort, shall be able to offer more granular knowledge-based solutions that are related to healthy environment, security, and life safety. The various embodiments of how the future building sensing solutions will look like are shown in Fig. 2 [5].

Using Microsystems as a technology platform [6], buildings will be able to offer three categories of solutions such as for healthcare, building environment that includes operation, and overall sustainable environment.

Based on vision and above examples, it is clear that in a future building and home, more advanced applications will be needed that can be categorized as

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