

## **A Sense Diary System for Intelligent Buildings**

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### **SUMMARY**

This paper presents a novel device called a Sense Diary for intelligent buildings. To introduce the new device and its applied system, a brief review of sensor-based systems applied in buildings has been conducted, which is based on current literature and products. The aim of this review is to understand current research and development situation of sensor-based systems that have been developed for all kinds of buildings and their systems across the world, and to further identify specific research tasks for an UK government EPSRC funded project focusing on innovative solutions of building façade systems. For acquiring the knowledge of sensor-based systems for buildings, some target information sources have been subjectively chosen. According to the literature and products review, several key research tasks of a Sense Diary System have been identified and discussed. It is concluded that the proposed Sense Diary and its applied system have advantages by providing daily real-time feedback to the facilities managers on environmental conditions thus improving control and health of occupants.

### **INTRODUCTION**

This paper introduces a novel sensor-based subjective opinion feedback system called a Sense Diary for intelligent buildings. The initiative of this research was led by Clements-Croome in 1990 [1] and is being deployed through an IDCOP (Innovation in Design, Construction & Operation of Buildings for People) research project <<http://www.idcop.soton.ac.uk/>>, which is funded by the Engineering and Physical Sciences Research Council (EPSRC) in UK.

The EPSRC [2] has been conducting a research programme called Sustainable Urban Environment (SUE) since 2001. The key drivers of the SUE programme are to improve the quality of life of UK citizens, to support the sustainable development and to meet the needs of users of the built environment. The IDCOP is one of 12 research projects involved in current SUE programme, and it aims to develop innovative solutions with respect to the maintenance and refurbishment of existing buildings, specifically to find new ways to improve the performance of building envelopes over the whole building lifecycle [3]. There are two research themes:

- To develop sustainable façade technologies and enhanced methods for building refurbishment, and
- To reduce the consumption of non-renewable resources in a way that is economically viable and socially acceptable.

The research into a sensor-based system is linked to two IDCOP work packages, including embedded sensor systems and system personalisation. The research into a Sense Diary System has been deployed to achieve the following research targets, including

- a prototype of embedded sensors system with focus on occupants' well-being,
- a Sense Diary and its applied system that can be used at either work or residential places to register various degrees of either satisfaction or dissatisfaction by occupants in regard to commonly design environmental factors of buildings,
- to evaluate physical conditions of buildings while a Sense Diary system is used,
- to describe the well-being state of the occupants while they are using a Sense Diary, and
- to power a real-time facilities management process.

According to this deployment, a 4-stage plan has been made, which comprises of

- *A review of sensor-based systems for buildings,*
- *A new prototype of Sense Diary,*
- *The development of the Sense Diary and its applied system,* and
- *An experimental case study.*

This paper focuses on a brief review of current status of sensor-based systems applied in buildings across the world, and a concise introduction of the proposed Sense Diary system to be used for intelligent control of buildings. The review is based on current literature and products relevant to sensors and their applications in buildings and their systems. The aim of this review is to understand current research and development situation of sensor-based systems that have been developed for all kinds of buildings and their systems across the world, so as to further identify specific research tasks for the IDCOP project with focuses on innovative solutions of building envelop systems. For acquiring knowledge of sensor-based systems for buildings, both academic and professional information sources have been subjectively chosen, including *ScienceDirect Navigator* and *IEEE Computer Society Digital Library (IEEE Xplore)* for literature review and *ThomasNet* and *Google* for products review. According to the literature and products review, several key research tasks of the Sense Diary system are identified and discussed. It is concluded that the proposed Sense Diary and its applied system has the advantage in improving well-being and saving energy in buildings.

## METHODOLOGY

Figure 1 illustrates a research framework for the review of literature and products and then the development of Sense Diary and its applied system. The research into a Sense Diary system for intelligent buildings has been divided into two stages in terms of related theoretical and methodological contexts:

- *The review stage:* Comprehensive information will be collected from three sources, including academic information sources (such as the *ScienceDirect Navigator*, the *IEEE Digital Library*, i.e., the *IEEE Xplore* and the *Elsevier EI Compendex*), professional information sources (such as the *ThomasNet*, the *Questex Media Group Sensors* and the *GlobalSpec Search Engine*), and general information sources (such as the *Google*).
- *The development stage:* System analysis and development method will be used to build up the Sense Diary system architecture and to program for a demo system.

With regard to each connection between a preceding stage and a following stage, which is based on a schedule for deploying each research task, a research and development strategy is being set up, which focuses on the products literature review, and the guidance for developing the Sense Diary system.

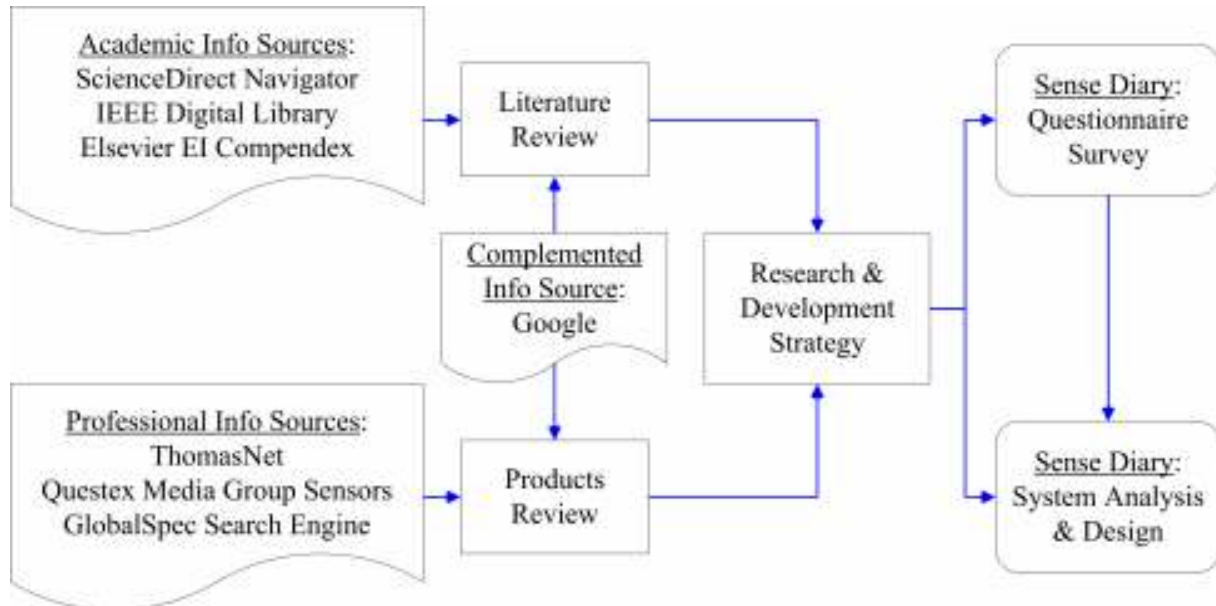


Figure 1: A framework for the research processes.

There are plenty of information sources around the world; however, to select a source of information for literature and products review, two criteria are adopted, depending on whether it is an *original source* of relevant information or whether it is an *authoritative source* of relevant information. Based on these criteria, several online databases have been selected from academic, professional or general information sources (see Figure 1).

## LITERATURE REVIEW

Two main kinds of academic literature have been targeted and pursued, including periodicals and books. The reason for this selection is that periodicals can normally provide the most recent information about the review target; while books can give comprehensive information about relevant issues.

According to recent literatures such as the book edited by Gassmann and Meixner [4], the main areas of *sensor-based systems for buildings* cover the following five streams of research and development:

- *energy and heating ventilation & air conditioning* (HVAC) such as self-commissioned heating control system using Artificial Neural Networks (ANN), air-conditioning control, air quality measurement and management, sensor-based management of energy and thermal comfort, sensors in HVAC systems for metering and energy cost allocation, and pressure sensors in the HVAC systems, etc.;
- *information and transportation* such as wireless and M-Bus enabled metering devices, field-bus systems, wireless in-building networks, sensor systems in modern high-rise elevators, and sensing chair and floor using distributed contact sensors, etc.;
- *safety and security* such as life safety and security systems, biometric authentication for access control, smart cameras for intelligent buildings, and load sensing for improved site safety, etc.;
- *maintenance and facilities management* such as maintenance management in industrial installations, and worldwide facility management, etc. and

- *system technologies* such as sensor systems in intelligent buildings, and system technologies for private homes, etc.

The review has shown that modern sensor-based systems based on structured Wireless Sensor Network (WSN) have been applied in facilities management for the energy supply system, the HVAC system, and the safety and security system in buildings. In this regard, the proposed research into a Sense Diary system, which aims to set up an occupancy feedback system to be used at work or residential places to register various degrees of satisfaction/dissatisfaction with commonly design environmental factors, is within the main areas in the research and development of sensor-based systems for buildings, and the unique feature of the proposed Sense Diary system indicates that it is a novel device for aiding facilities management with regard to improving the energy efficiency of buildings and the well-being of occupants.

Davidsson and Boman [5] present a multi-agent system for controlling intelligent buildings. In a de-regulated market the distribution utilities will compete with benefit for the customer in addition to the delivery of energy. They describe a system consisting of a collection of software agents that monitor and control an office building. It uses the existing power lines for the communication between the agents and the electrical devices of the building, such as sensors and actuators for lights, heating, and ventilation. The objectives are both energy saving and increasing customer satisfaction through value added services. Results of qualitative simulations and quantitative analysis based on thermodynamically modelling of an office building and its staff using four different approaches for controlling the building indicates that significant energy savings, up to 40 per cent, can be achieved by using the agent-based approach. The evaluation also shows that customer satisfaction can be increased in most situations. In fact, this approach makes it possible to control the trade-off between energy saving and customer satisfaction (and actually increase both in comparison with current approaches).

## **PRODUCTS REVIEW**

The literature review shows that the research and development of a Sense Diary system for buildings is a creative and innovative practice. However, this practice need to be deployed based on current level of relevant technologies. In this regard, a products review has been conducted, which aims to find out some relevant industrial systems that can be used for reference as follow.

### **Wireless Sensor Network**

A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations [6,7]. The development of WSN was originally motivated by military applications such as battlefield surveillance; however, the WSN is now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, and traffic control [6,8]. The WSN can bring a broad range of diverse applications from house to commercial buildings, from simple system to complex system. The advantage of WSN set up based on wireless network other than traditional wired network can just fulfil the requirements of occupants who want much interior space from the building services systems.

To review current applications of WSN in the built environment, two commercial systems have been identified as good applications. One example is for commercial buildings and the other one is for residential buildings. For the WSN applied in commercial buildings as well as households, the example is GAMMA Building Management System from Siemens [9]; meanwhile, for the WSN applied in residential buildings, the example is the CyberEye system from Sungji [10].

### Commercial Initiatives

As the proposed Sense Diary is to be integrated with a local WSN either within a residential building or within an office building, another part of products review goes to control devices; and six set of commercial systems have been reviewed, including

- The Secom building services control station [11], which is a *Building Services Panel* that tenants can use to control the turning on and turning off lighting and air conditioning according to pre-defined time zones.
- The Ambi-Rad SmartCom Control Unit [12], which is designed for warm air heater units and radiant systems and has been designed to consolidate the function of all previous control panels into one unit.
- The Echelon NES system [13,14], which is a state-of-the-art, future-proof smart metering system that brings new features and benefits to every aspect of ones utility's operations - from metering and customer services to distribution operations and value-added business.
- The TAC Satchwell MicroNet [15], which is a modular building management system that is easy to specify, operate, and tailor. It is suitable for small to medium scale operations and is sold through a locally accredited partner network.
- The Microsoft Home [16,17], which simulates a domestic environment including a front door, entry/foyer, kitchen, family room, dining room, entertainment room and bedroom. The Microsoft's technology-laden home of the future aims to feature smart appliances connected by Web services and controlled by tablet PCs or cell phones.
- The Siemens Smart House [18], which is a range of options that enhance the functionality of any home and are easy to use. Once some basic *Standard Fit*, including pre-wired cables for lighting, heating, blinds, surround sound, audio, video, data, voice and living lighting, is installed, then home owners can really make their homes 'Smart' and evolve it as they may change the way of living, and it is also believed that the choice is endless. There are three options below for home owners to choose and match in regard to the level of functionality they require, and the three Siemens Smart Homes options are:
  - The *Silver SMART Home Technology* package includes all the preliminary systems detailed in the *Standard Fit* package,
  - The *Gold SMART Home Technology* package includes *Standard Fit* preliminary cabling, plus all the features in the Silver package.
  - The *Platinum SMART Home Technology* package includes *Standard Fit* preliminary cabling, plus all the features listed in both the Silver package plus Gold package upgrades.

As the proposed Sense Diary system aims to develop a new control panel for intelligent buildings control in regard to real-time occupants' opinions, products review has mostly gone to devices and relevant technical platforms that all current systems adopted. Mobile phone and PDA are currently popular intermediaries applied in buildings management systems [17-19]; in addition, touch screen devices are also popularly used in some buildings [19]. For example, mobile phones are used as a controller in Siemens Smart Home [18], and PDA is also used in buildings control [20]. All these information indicates that the intermediary of the

proposed Sense Diary system needs to be chosen from these devices or to be embedded into all kinds of these devices.

## **RESEARCH AND DEVELOPMENT**

### **Strategy**

The trend of research and development has been identified through literature and product review, including

- Multi-functional devices and systems based on WSN,
- Such devices need to be based on international standards,
- Such devices need to be with integrative functions,
- Easy to use and to be reliable and energy-efficient.

Although there are some relevant devices using desktop, laptop, PDA and touch screen, the proposed Sense Diary system is new and the idea has a very practical purpose but will contribute to sustainability.

### **A Sense Diary System**

The research into “Embedded Sensor Technology and Occupant Behaviour” aims to help building professionals to further understand building occupancy or use patterns during a period of occupancy time. This study will explore relevant issues related to the Sense Diary System, which is expected to aid managing energy use and monitoring building performance besides assessing occupants’ well-being requirements in regard to real-time performance of building services systems and building façade system. In particular, this study aims to identify the occupancy behaviour patterns associated with building use so as to find out a possible relationship among these variables, their carriers and energy use. As a result, a Sense Diary as a prototype intelligent sensor-based device to monitor these variables is introduced, and is to be developed and tested in collaboration with industrial leaders such as Siemens and Echelon, who promote interaction between UK science, engineering and industry.

To facilitate the research going further, the definitions of Sense Diary and its applied system are proposed first based on the idea proposed in the 1980s by Clements-Croome [1,21]. The Sense Diary is a user feedback panel which can be used by building occupants for inputting their opinions about well-being requirements based on indoor environmental status indication and their psychological feelings. The Sense Diary in the format of software can be programmed into different devices such as PDA, laptop, desktop PC and even mobile phone and TV. The Sense Diary within the environment of Ethernet and/or wireless network of the building can exchange data with wired network server and/or wireless network server; various sensor data parameters such as temperature, air quality, light and sound, etc. can be received by the Sense Diary, and Sense Diary can transmit occupants’ feedbacks to remote control centre for building services system management or facilities management. The architecture of the Sense Diary System is illustrated in Figure 2.

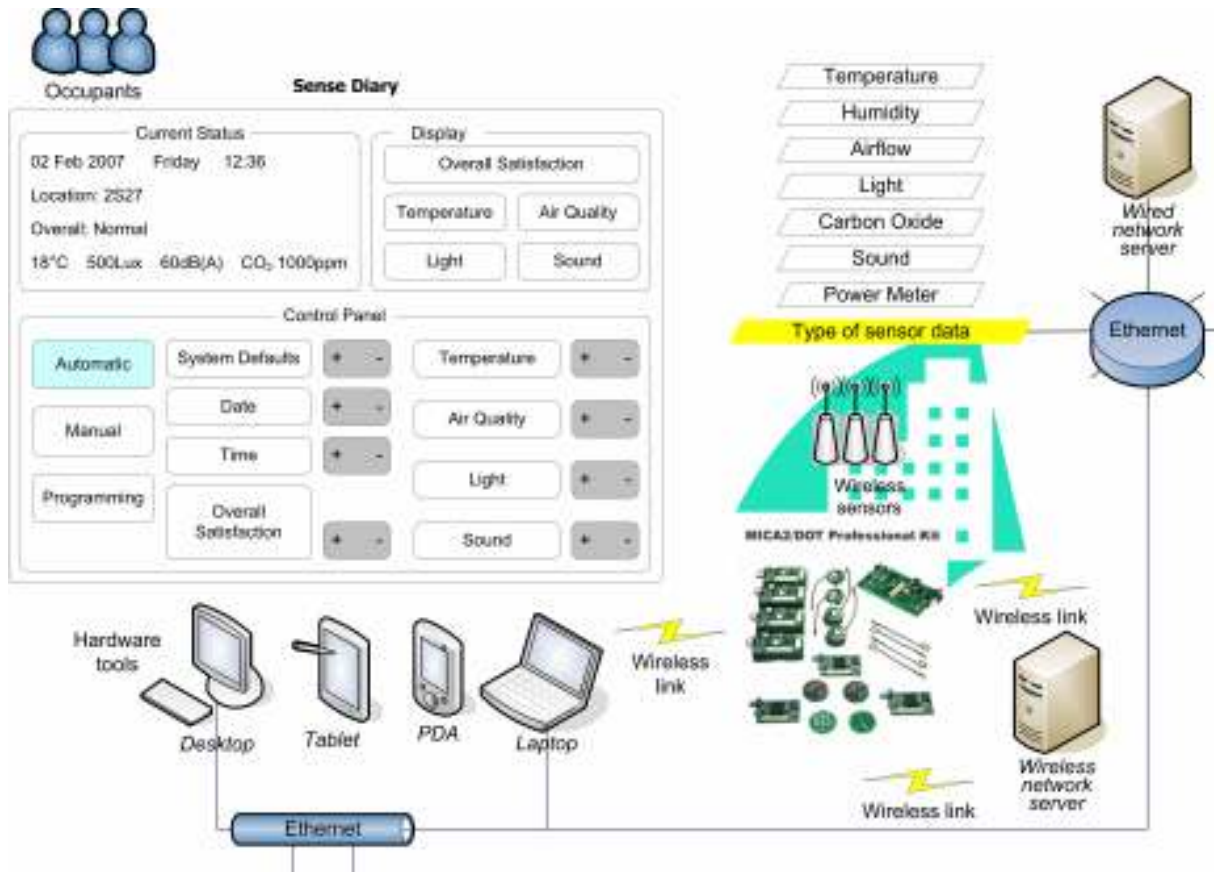


Figure 2: The Sense Diary System [1,21].

## DISCUSSION

This paper introduces on-going research into Sense Diary System for intelligent real-time feedback and control to buildings, which can improve energy-saving and well-being. A system diagram about the proposed device has been described, which is based on a comprehensive review of current information from both academic and professional sources. Further research will focus on the collection and analysis of experts' opinions in terms of the design of the proposed device and its integration into diverse buildings management systems; furthermore, a demonstration system is expected to be developed at the end of this research.

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REFERENCES

1. Clements-Croome, D.J. (1990) Invisible architecture, *Building Serv. Eng. Res. Technol.*, CIBSE, 11(1), 27-31.
2. EPSRC (2006) Sustainable Urban Environment. Engineering and Physical Sciences Research Council (EPSRC), UK.  
<<http://www.epsrc.ac.uk/ResearchFunding/Programmes/InfrastructureAndEnvironment/Initiatives/SUE/default.htm>> (20/09/2006).
3. IDCOP (2005) IDCOP Programme. University of Southampton, UK.  
<<http://www.idcop.soton.ac.uk/>> (20/09/2006).
4. Gassmann, O., and Meixner, H. (2001) *Sensors in intelligent buildings*. Wiley-VCH, Weinheim, Germany. ISBN: 3527295577.
5. Davidsson, P., Boman, M. (2000) A Multi-Agent System for Controlling Intelligent Buildings. *Proceedings of the 4<sup>th</sup> International Conference on Multi-Agent Systems (ICMAS'00)*. p. 0377.  
<DOI Bookmark: <http://doi.ieeecomputersociety.org/10.1109/ICMAS.2000.858483>>.
6. Römer, K., Mattern, F. (2004) The Design Space of Wireless Sensor Networks. *IEEE Wireless Communications*, 11(6): 54-61.
7. Haenselmann, T. (2006) *Sensornetworks*. GFDL Wireless Sensor Network textbook.
8. Hadim, S., Mohamed, N. (2006) Middleware Challenges and Approaches for Wireless Sensor Networks. *IEEE Distributed Systems Online*, 7(3). art. no. 0603-o3001.
9. Siemens (2006a) GAMMA Building Management System. Siemens, AG.  
<[https://www.automation.siemens.com/et/gamma/index\\_76.htm](https://www.automation.siemens.com/et/gamma/index_76.htm)> (29/09/2006).
10. Sungjin (2006) Security System (CYBEREYE). Sungjin International Co., Korea.  
<<http://www.howard.co.kr/electronics/cybereye/cybereye.htm>> (29/09/2006).
11. Secom (2006) Building Management Systems. Secom International, Inc., USA.  
<<http://www.secomintl.com/bldmgmtsys.html>> (29/09/2006).
12. Ambirad (2006) SmartCom Control Panels. Ambirad Limited, UK.  
<<http://support.ambirad.co.uk/article.aspx?id=10581>> (20/09/2006).
13. Echelon (2006a) NES: The Power behind Smart Metering. Echelon Corporation, USA.  
<<http://www.echelon.com/metering/>> (20/09/2006).
14. Echelon (2006b) The NES System Components. Echelon Corporation, USA.  
<<http://www.echelon.com/metering/components.htm>> (20/09/2006).
15. TAC (2006) Product Overview. TAC. <<http://www.tac.com/>> (29/09/2006).
16. Lai, E. (2006) Microsoft: Future homes to use smart appliances, interactive wallpaper. Computerworld Inc.  
<[http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=9003752&source=NLT\\_ES&nid=42](http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=9003752&source=NLT_ES&nid=42)> (29/09/2006).
17. Microsoft (2006) Microsoft Home Showcases New Prototypes of Technology for Daily Living. Microsoft Corporation. <<http://www.microsoft.com/presspass/press/2006/sep06/09-28NewPrototypesPR.msp>> (29/09/2006).
18. Siemens (2006b) Smart Home Innovation from Siemens. Siemens, AG.  
<<http://www.automation.siemens.co.uk/main/business%20groups/et/smart%20homes/>> (29/09/2006).
19. Jung (2006) Viviendas inteligentes con el sistema (Intelligent houses with the system). Jung Electro Iberica S.A., Spain. <<http://www.jungiberica.es/index.asp>> (20/09/2006).
20. T-Com (2006) T-Com House: W-LAN-based PDA. <<http://www.t-com-haus.de/>> (20/07/2006).
21. Clements-Croome, D.J. (2004) *Intelligent Buildings: Design, Management and Operation*. Thomas Telford, London, UK.