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Wireless Building Monitoring and Control System

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***Abstract*—**The building sector is the largest energy consumer and CO_2 emitter in the European Union (EU) and therefore the active reduction of energy consumption and elimination of energy wastage are among the main goals in it. Healthy housing and energy efficiency are affected by many factors which set challenges to monitoring, control and research of indoor air quality (IAQ) and energy consumption, especially in old buildings. These challenges include measurement and equipment costs, for example. Additionally, the measurement results are difficult to interpret and their usage in the ventilation control is also limited when taking into account the energy efficiency of housing at the same time. The main goal of this study is to develop a cost-effective building monitoring and control system especially for old buildings. The starting point or keyword of the development process is a wireless system; otherwise the installation costs become too high. As the main result, this paper describes an idea of a wireless building monitoring and control system. The first prototype of the system has been installed in 10 residential buildings and in 10 school buildings located in the City of Kuopio, Finland.

***Keywords*—**Energy efficiency, Indoor air quality, Monitoring system, Building automation

I. Introduction

THE worldwide energy demand is rising constantly and at the same time motivation to save energy is also increasing among home or building owners. Considering increasing energy costs and reduced energy consumption, which also has economic benefits, the national and international environmental goals and laws have to be fulfilled. On the other hand, realizing an energy-efficient building operation is closely related to the employment of building automation systems, which are considered as an almost mandatory condition for the sustainable e.g. low-energy or low-emission home or building [1].

Buildings represent significant contributors to the energy use and consequent greenhouse gas emissions. With the threat of climate change and increased uncertainty for future energy prices, energy efficiency is in the forefront of the political debate [2].

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Energy standards for building provide control over the excessive usage of energy in buildings, promoting energy efficiency and mitigating detrimental environmental impacts by high energy consumption. Energy standards and strategies for building are important, because they are needed for ensuring the energy efficient design and sustained operations of buildings. Other benefits are creating the demand for energy efficient products and promoting cost effective solutions for energy conservation [3].

European Community level projects are promoting energy efficiency that could save about 20 % of the present consumption in a cost effective manner. For example, efficient strategies for operating district heating systems demand a realistic modeling of the heat consumption [4]. Building automation technology is rapidly developing towards more reliable communication systems, devices that control electronic equipments. This equipment, if controlled, leads to efficient energy management [5]. The development of automation technology for buildings has led to the development of wireless sensor networks, which do not need wired connections for communication or energy supply. This has made them attractive for many embedded systems applications, including environmental and habitat monitoring. For wireless networks, energy efficiency is a requirement of devices and concern for the hardware and communications protocols and device applications [6].

In past years there has been increasing concern about the health effects of indoor air quality [7]. Reasons for concern are not exaggerated when approximately 90 % of our time is spent indoors [8]. Especially children are sensitive to the possible health effects of poor indoor air, and there are studies relating poor indoor air quality to health effects such as asthma and allergic reactions [9]. There are many factors affecting indoor air quality, like the amount of people, ventilation, as well as maintenance and cleaning [9].

In general, indoor environment can be regarded as an environment where it is difficult to assess occupants’ exposure to indoor air pollutants because of the spatial and temporal variations in the substance spectrum. Today there is data available for a large number of substances and it is possible to make recommendations regarding good indoor air quality, based on statistically derived reference values and toxicologically based guideline values [8].

There are also many recent, prestige scientific publications on energy efficiency and indoor air quality. For instance, in Nature journal, there are discussions on low-energy buildings and their relation to carbon emissions [10] as well as on the use of biological indicators for indoor air quality [11]. In the Science Magazine, there are discussions on using and extending smart grids for energy efficiency [12], sustainability [13], and relation of healthiness to environment [14].

Nowadays, there are many commercial monitoring systems on the market and a large amount of research work has been done, for example [15], [16] and [17]. This paper describes a basic idea of wireless building monitoring and control system developed as a part of the Finnish AsKo-project. The rest of the paper is organized as follows. Section 2 presents monitoring and control system including overview, sensors, data transfer unit, user interface and its application fields. Related and future work is discussed in section 3 and 4. Final, section 5 concludes the paper.

Major new features and improvements are:

- First prototype of data transfer unit has been replaced with a commercial product
- Optical reader for reading the consumption of district heat and electricity
- Possibility to control building automation systems
- New sensors are connected to the system e.g. sensors for measuring volatile organic compounds (VOC) and a differential pressure transmitter
- Data transfer from sensors to the data transfer unit is possible to carry out wirelessly or wired
- Data transfer unit networking and management over

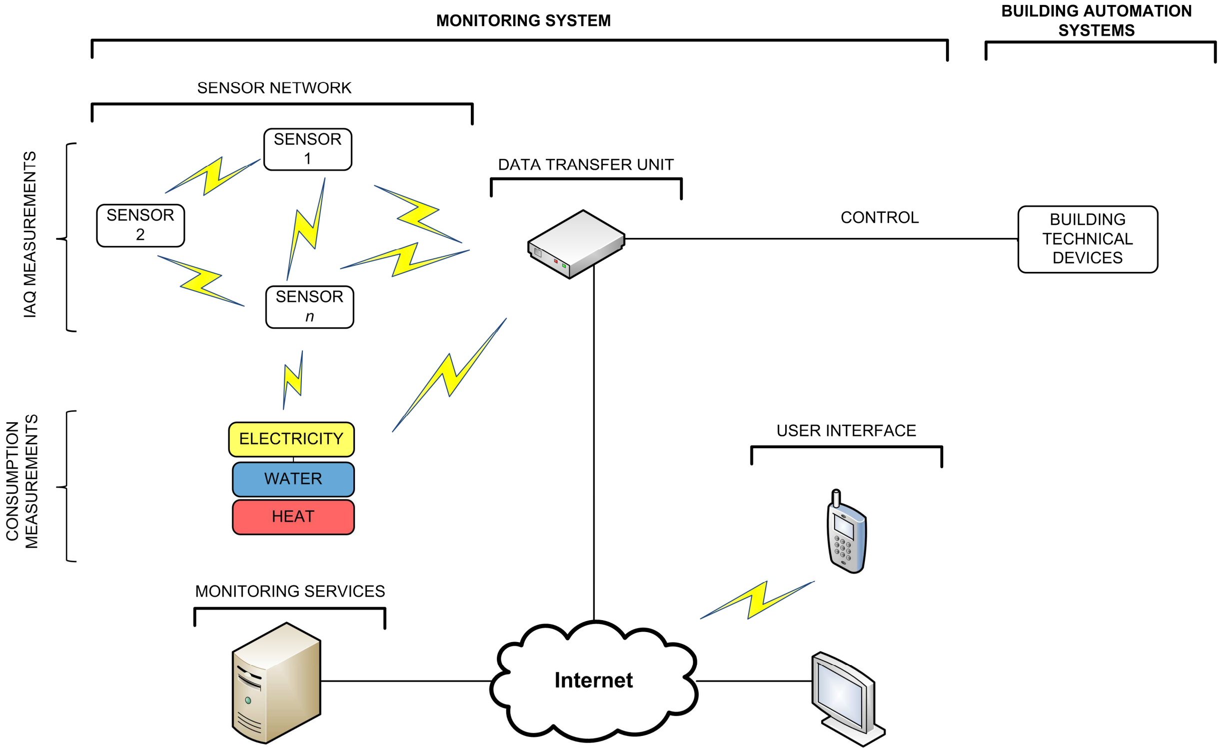

Fig. 1 Overview of the monitoring and control system

A. Overview

In 2009, we started to develop our energy consumption and indoor air quality monitoring system to research effects of energy efficient construction on indoor air quality. More detailed information of this previous system can be found in [18]. In this paper, we present a wireless building monitoring and control system (Figure 1), which is the next development version of earlier energy consumption and indoor air quality monitoring system presented in the Kuopio Housing Fair 2010. New version is based mostly on commercial products (Table 1) and we have developed an adapter card for connecting sensors to ZigBee radio transceiver.

TABLE I
MAIN COMPONENTS OF MONITORING AND CONTROL SYSTEM

Monitoring system	Model	Parameter/Specification	Unit
Indoor sensors			
	EE80 [19]	Temperature, relative humidity, carbon dioxide	°C, %, ppm
	F2000TSM-CO-C101 [20]	Carbon monoxide	ppm
	Dwyer MS-221 [21]	Differential pressure	Pa
	TSM-VOC-L100 [22]	Volatile organic compounds	ppm
	Multical® 601 [23]	Water, heat and electricity consumption	l, kWh, kWh
	BSC1111 [24]	Heat and electricity consumption	kWh, kWh
	OS-550 [25]	Occupancy sensor	Form C (Nc/No)
Outdoor sensors			
	WXT520 [26]	Temperature, relative humidity, barometric pressure, wind speed, wind direction, rainfall	°C, %, Pa, m/s, °, mm
	EE21-FT3A26/T02 [27]	Temperature, relative humidity	°C, %
Data transfer unit			
	ConnectPort X4 [28]	Data collection and transfer	
	TL-ANT2408CL [29]	Antenna	
Monitoring services			
	Several servers	Data-analysis, modelling, user interface	

B. Sensors

The measuring equipment consists of sensors, which are wirelessly connected to a data transfer unit. Wireless data transfer is carried out using ZigBee technology. ZigBee is a wireless technology developed as an open global standard to address the unique needs of low-cost, low-power wireless M2M networks. The ZigBee standard operates on the IEEE 802.15.4 physical radio specification and in unlicensed bands including 2.4 GHz, 900 MHz and 868 MHz.

We have developed two radio adapter cards; for voltage output sensors and pulse output sensors. In case of voltage output (Figure 2); radio adapter card is able to connect four A/D converters (10 bit) of ZigBee radio transceiver to sensor voltage outputs.

Fig. 2 Commercial sensor (E+E Elektronik, EE80) has been modified to wireless using radio adapter card and ZigBee radio transceiver (Digi International Inc., XBee PRO S2B)

Usually, voltage range is from 0V to 10V, and maximum four sensors can be connected to one ZigBee radio transceiver (Digi International Inc., XBee PRO S2B). In case of pulse output sensors; radio adapter card includes micro controller, which calculates the sum of pulses, and it is connected to the serial port of ZigBee radio. A single radio adapter card is able to read pulses from three different channels.

C. Data Transfer Unit

We have used ConnectPort X4 (Digi International Inc.) for data collection, transfer and controlling. For control purposes, indoor and outdoor measurements can be used for example to modify the control curve for heating regulators. Its customs-made software was developed at Research Group of Environmental Informatics, University of Eastern Finland.

The data transfer unit can be connected to the Internet either wirelessly via a 3G-connection or by Ethernet. The server collects the measurements from the data transfer unit and saves them to a database. The end users can view the measurements using a web application, which is described in the next chapter.

D. User Interface

The client contains six different sections for normal users and special tools for administrators (Figure 3). The generally available sections are: a front page, a consumption page, an air quality page, a weather page, a living diary page, and a report page. A user can have rights to all of these pages or some subset of them.

When accessing the client, a username and a password need to be given. An alternative way to log in is to pass an encrypted token in the URL, which contains an identification key and a timestamp. This is beneficial for the third party software, which has a link to the Silverlight client. In these cases, the user has already logged in to the other software and there is no need to ask for credentials for a second time.

The front page of the Silverlight client has meters, which show the consumption of water, heat, and electricity for the most recent week and month (Figure 3). Each building has a set of consumption profiles associated with it, which give the expected consumption for normal circumstances. The readings of the front page meters are obtained by comparing the measured consumption to predictions given by the profiles. The consumption profiles are calculated from historical water, electricity, and heating consumption measurements of the building or from consumption data of similar buildings. The profiles are constructed by fitting weighted multiples of sine and cosine curves to historical consumption time series data. If outdoor temperature measurements are available, it is also possible to calculate temperature correction coefficients for the consumption variables. These coefficients can be used to remove the influence of outside temperature from the time series. For example, if a house is electrically heated, electricity consumption is highly dependent on outside temperature. To have a reliable comparison between current consumption and the profile, it is necessary to apply a temperature correction.

The client has a page, where it is also possible to query for more detailed consumption time series data. To inspect data from a desired time period, the user of the client selects one or multiple sensors and the length of the shown time window. Then it is possible to browse back and forth in time or directly choose an ending date for the time window from a calendar. Indoor air quality information is accessible through its own section (Figure 4). The user can select a time window in a similar way as with the consumption data. Various time window sizes are available: a month, a week, a day, and a tiny window. The user can specify the size of the tiny window to a range of desired hours within a day. When data is retrieved from the server, it is averaged or summed to a suitable resolution for the time window. This makes interpreting and visualizing the results easier.

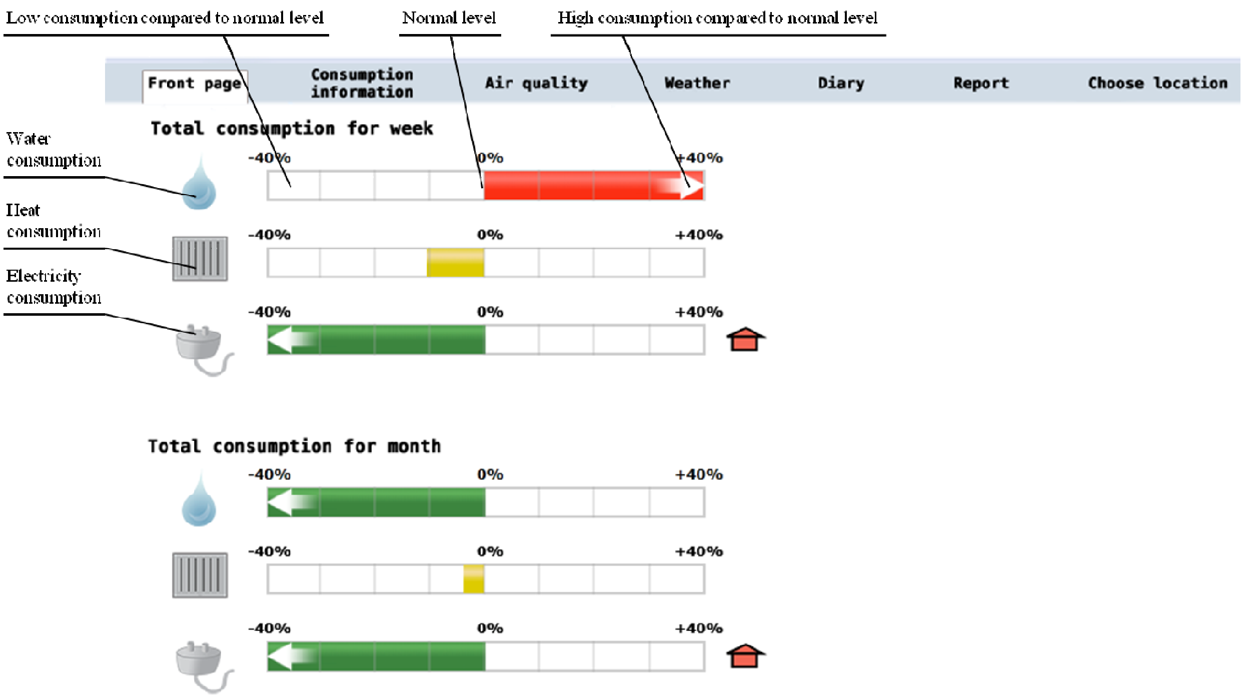

Fig. 3 Overview of consumption meters. The consumption profiles are calculated from historical data of water, electricity and heat consumption measurements of the building. Normal levels of consumptions are described as 0%

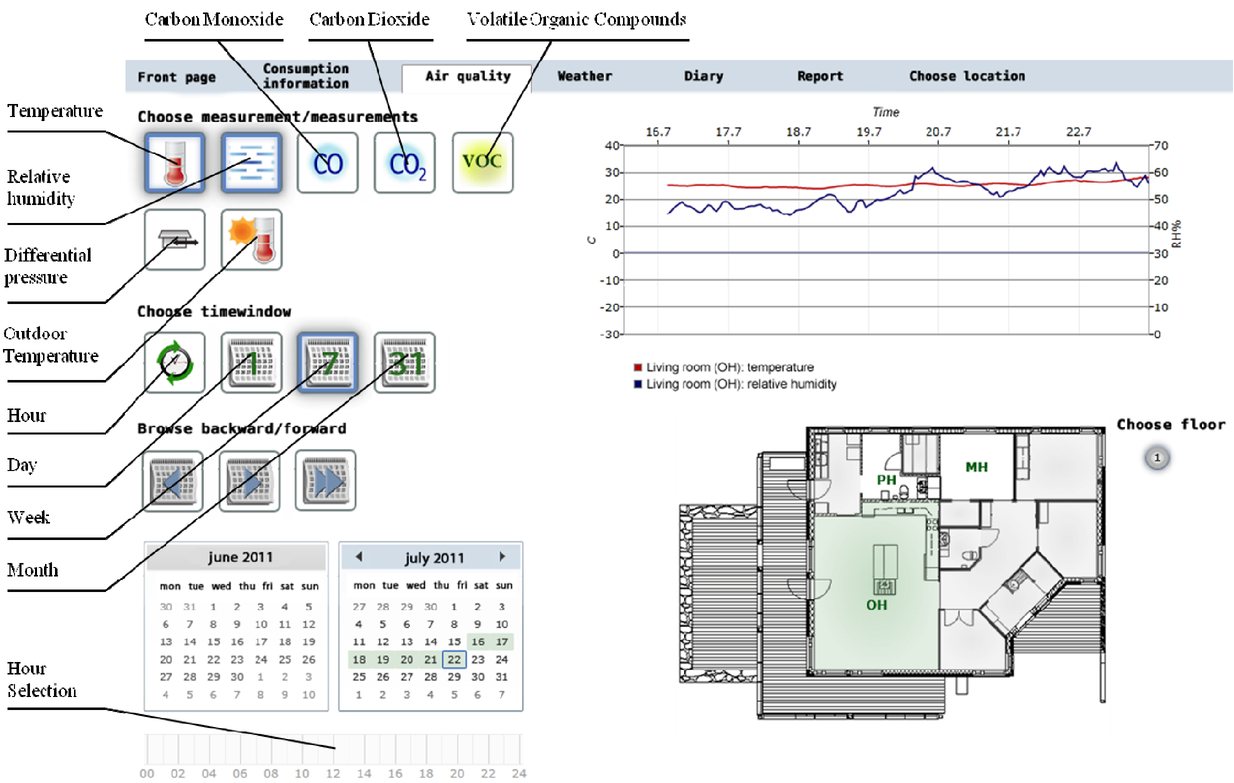

Fig. 4 Overview of indoor air quality page. End user can select sensors under consideration and a time window (a tiny window, a day, a week or a month)

For most types of indoor measurements, it is also necessary to select one or more rooms from a floorplan. Figure 4 has a screenshot of the air quality section. In the picture, living room temperature and humidity sensors have been selected and a monthly time windows are used.

E. Application Fields

This kind of monitoring system can be utilized in many different ways. As described in this paper, it can be used building monitoring and control. In addition, other application fields are for example detection of chemical emissions in the air, control access, identification and short-term measurements in buildings.

III. Related Work

In 2009, the AsTEKa- project has made it possible for the Research Group of Environmental Informatics to develop the energy consumption and indoor air quality monitoring system. The developed monitoring system enabled the research related to energy efficiency and indoor air quality. With our new research and development projects, we have been able to expand the Living Lab -environment, which was founded in the AsTEKa-project. Research related to the subject matter has been funded, among others, by Tekes (Finnish Funding Agency for Technology and Innovation) and the Ministry of the Environment. Expansion of the research environment has given new opportunities to produce innovations related to the subject matter.

IV. Future Work

Next, we will research how machine learning and computational methods can be integrated into home automation systems. The ultimate goal is to develop self-learning home automation systems. In addition, collected data must be analyzed to research effects of energy efficient construction on indoor air quality

V. Conclusion

This paper presented unique approach to utilize commercial products for monitoring building energy consumption and indoor air quality. The presented wireless monitoring and control system is the next development version of the earlier energy consumption and indoor air quality monitoring system presented in the Kuopio Housing Fair 2010 and developing work is still in progress. It is significant, that the system enables to use measurements for example to modify the control curve for heating regulators.

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