Implementation of integrated wireless sensors technology in renovation of social housing buildings. A Danish case study.

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ABSTRACT

Social housing units built in the 1960s and 1970s make up one-fifth of all housing units in Denmark. Their renovation is an important step towards meeting the goals of the national energy road map. Sensors based on wireless technology could be considered a feasible solution to increase occupant's awareness towards their indoor climate and their energy consumption. In the present experimental study, a framework implementing wireless sensors to monitor energy and indoor climate before and after renovation has been applied in two apartments of a Danish social housing site. In the first phase of the study, the accuracy of some commercially available wireless systems was investigated. This was followed by installation in the field, where occupant behavior (e.g. window opening status) was also monitored. Heating energy data monitored before and after renovation indicated savings of up to 34%.

KEYWORDS

Social housing, buildings renovation, data collection, integrated wireless sensors.

INTRODUCTION

Measurement and verification are effective ways of documenting energy savings achieved as a result of buildings renovation, while most of current renovation assessment are based on numerical simulations (Ma et al., 2012). On the other hand and in Denmark, one of the current barriers of energy renovation decision making is the lack of sufficient information about energy consumption and accordingly cost and possible savings (Bjørneboe et al.2018). Wireless sensor technology offers new potential for monitoring energy consumption and indoor environmental parameters such as temperature, relative humidity and CO2 with less invasive nature to occupants comparing to wired systems (Stojkoska et al., 2014). The idea of using wireless sensors in the built environment is not new, but applications are limited despite the recognized potential of this technology and more research in the domain is needed to lift the barriers (Noye et al. 2018). While, it can be implemented in either new or renovated buildings with means for internal and external communication (Loboccaro et al., 2017), but particularly applying the technology at building renovation projects can help to comprehend the performance of existing systems and to evaluate the improvements after the completion of the renovation (Noye et al. 2018). Another advantage is that it communicates with end-user through user-friendly app´s where direct interaction is a priority. On the other hand, very few studies has focused on accuracy checking of these wireless sensors. Petersen et al. (2018) have investigated two commercial indoor climate monitoring systems (IC-METERS and NETATMO) through an experimental campaign. Results showed that the accuracy of latter system to measure the CO2 concentrations was highly dependent on the air temperature. For the study reported in this paper, two particular systems (IC-METERS and WIRELESS- TAGS) have been investigated for use in a project for social housing in Aalborg, Denmark to monitor performance before and after renovation. These two WSN systems have been applied in previous projects in Denmark and have shown good reliability to monitor the indoor climate and occupant behavior, (Henriksen and Olsen, 2018) and (Azouz,. 2017). The monitored parameters included heating consumption, electricity use measured by SMAPPEE´s, air temperature, relative humidity, CO2, occupancy with PIR sensors, and window opening. The measuring campaign in the field started with a lab test of the sensors to determine their accuracy and determine the sensibility of CO2 measurements to temperature variations.

METHODOLOGY

The experimental based study is subdivided into two main steps, the first is calibrating the IC meters and wireless tags, checking how to save and retrieve the collected data on lab level. Followed by the field site installation phase, which included two groups of apartments, renovated and non-renovated cases.

Calibration of the wireless sensors

IC meters and wire-less tags systems were investigated in climatic chambers of the Technical University of Denmark. The IC METER (version 4.3) communicates through a GSM based module and has accuracy of the CO2 measurements of ± 30 ppm or ± 3%.The WIRELESS TAGS are square tags with dimension 4.0 x 4.0 x 0.2 cm, which can be distributed over indoor zones and connected to a data router that is connected to the internet via a LAN cable. These tags are capable of measuring air temperature and RH with accuracy of ± 0.4 °C and ± 2 % respectively, in addition to being able to track the motion of windows and doors. Both systems have shown good reliability in many projects (Henriksen and Olsen, 2018) and (Azouz,. 2017).
The climate chamber has a volume of 22 m^3 and it is well insulated preventing outside factors to influence the temperature stability inside the chamber, see Figure 1a. The CO_2 concentration was measured by a Photoacoustic Gas Monitor “INNOVA 1412i” (LumaSense Technologies Inc., Figure 1b) with a detection limit of ± 1.5 ppm for CO_2. Two gas flow meters were used to control the dosing of CO_2, see Figure 1c.

Testing in the field

The measurements were carried out in two non-renovated and renovated apartments, which were selected in a social housing site (Figures 2a and 2b). Thermal characteristics of the building envelope were different for the two types of apartments. The measured heat transfer coefficients for the external walls of the renovated and non-renovated apartments were 0.12 and 1.4 W/m^2K, respectively, and 0.85 and 2.6 W/m^2K for the windows. The heat transfer coefficients were measured by a wireless heat flow meter (GREENTEG) with accuracy of ±3% for a continuous 3 days in compliance with ISO 9869.

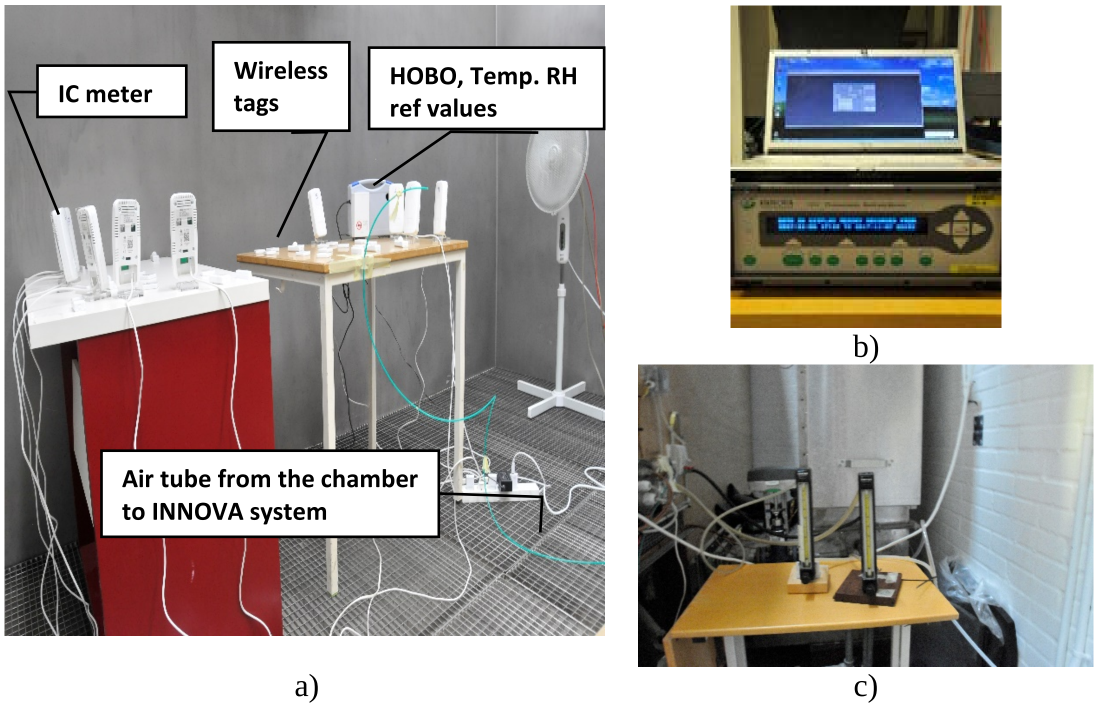


Figure 1. Calibration of the sensors. a) Climatic chamber, b) Photoacoustic Gas Monitor, c) CO_2 flow meters

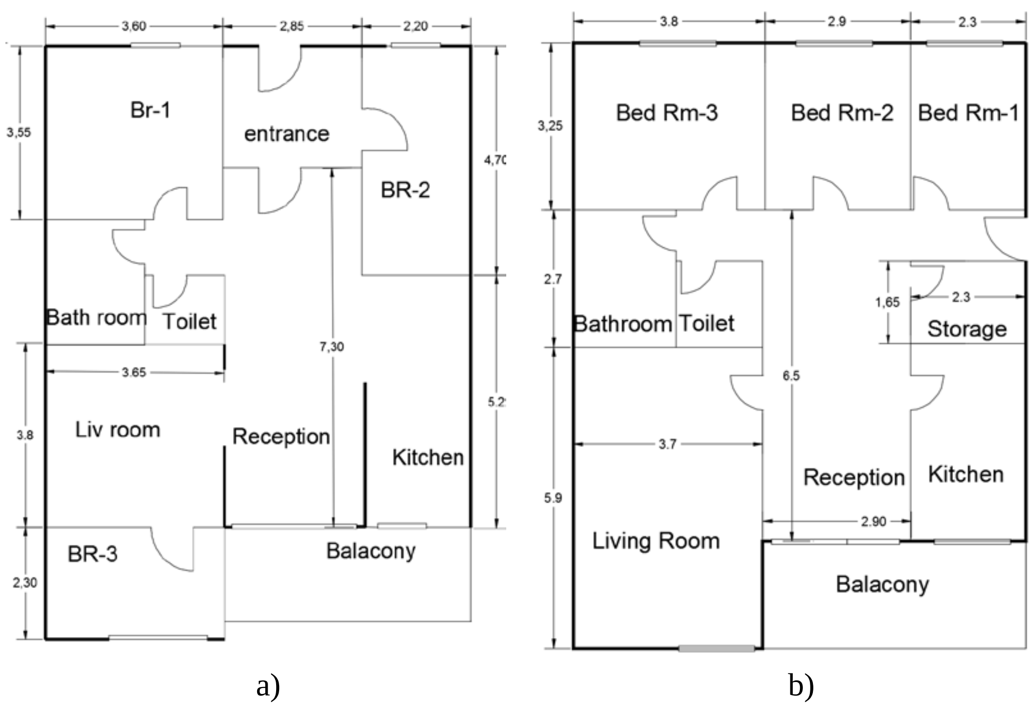


Figure 2. Apartments under investigation. a) Non-renovated apartment, b) Renovated apartment

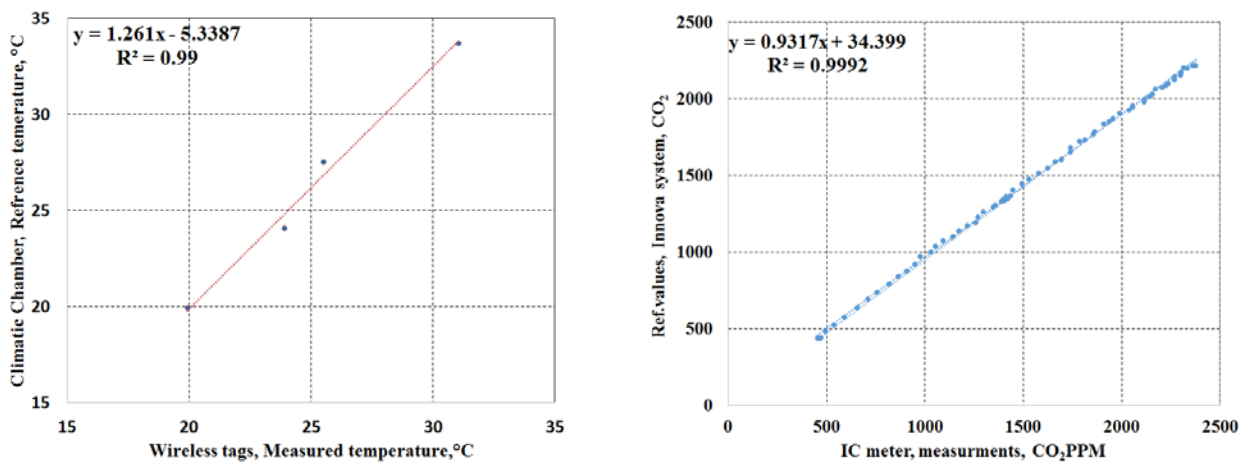
Both types of apartments have been equipped with wireless sensors to collect dynamic energy and indoor climatic performance data. Time step for the data collection is 5 minutes. The measurements of heating flowrates and energy has been carried out through an ultrasonic heating meter. The meter is implemented with a wireless M-Bus function, which enables the communication with a stationary multi utility controller, and it supports the open metering system through compliant data transfer

RESULTS

The results are subdivided into three parts, the lab level experiments that included *i)* the IW sensors calibration. Followed by analysis of the site level monitored data, which included *ii)* the indoor climate and *iii)* heating consumption.

Accuracy check and calibration of instruments

The performance of the sensors was compared for different levels of CO_2 concentrations, relative humidity and air temperature. Calibration profiles are shown in Figures 3a and 3b. The IC meters Root Mean Square Error (RMSE) values ranged from 0.1 to 0.3°C, 0.6 to 1.5 % RH, and 25 to 50 ppm, for temperature, RH and CO_2, respectively. For the sensor tags, RMSE values ranged from 0.3 to 0.7°C for temperature readings, and 2.5 to 3% for RH readings.



a) b)

Figure 3. Sensor calibrations. a) Wireless tag- Air temperature, b) IC meter- CO_2 levels

Indoor climate profiles

Figure 4 illustrates weekly temperature and RH profiles for the entrance area of the two apartments. The data were retrieved from the IC meter and wireless tag data cloud The decreasing air temperature between the 22nd and 24th of February in the non-renovated apartment reflects a reduction in the control setting of the radiator´s thermostat by the occupants due to their absence (winter vacation).

Heating energy profiles

Heating profiles for a renovated and a non-renovated apartment are shown in Figures 5a and 5b. For the non-renovated apartment, the heating consumption was 462Wh/m^2 per day, while it was 304 Wh/m^2 per day for the renovated apartment.

DISCUSSION

The measured data has shown that by improving the thermal characteristics of the building-envelope, the overall heating consumption has decreased the about 35%. The monitored air temperature in the entrance and living areas, which are shared by all family members, was between 20 and 22 °C. However, in the bedrooms, where individual preferences are dominating, opening the windows all night caused a drop of air temperature to 10 °C.

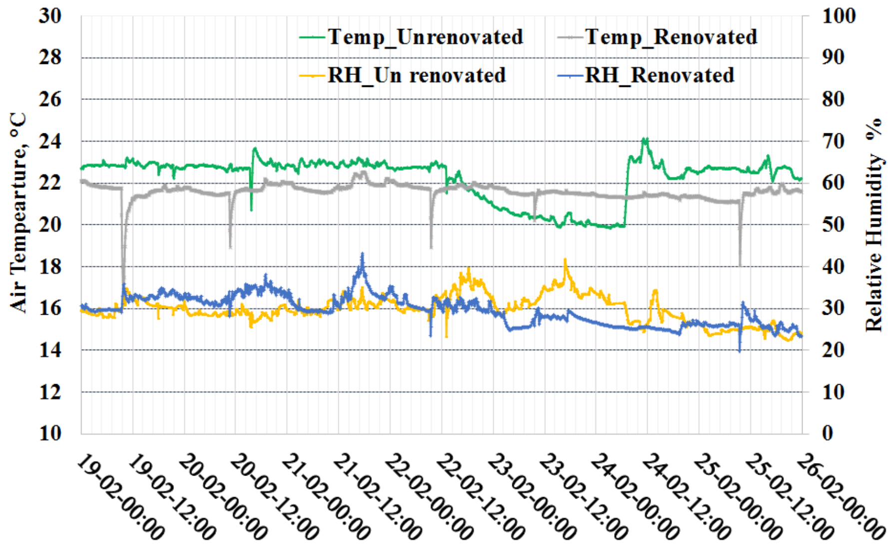
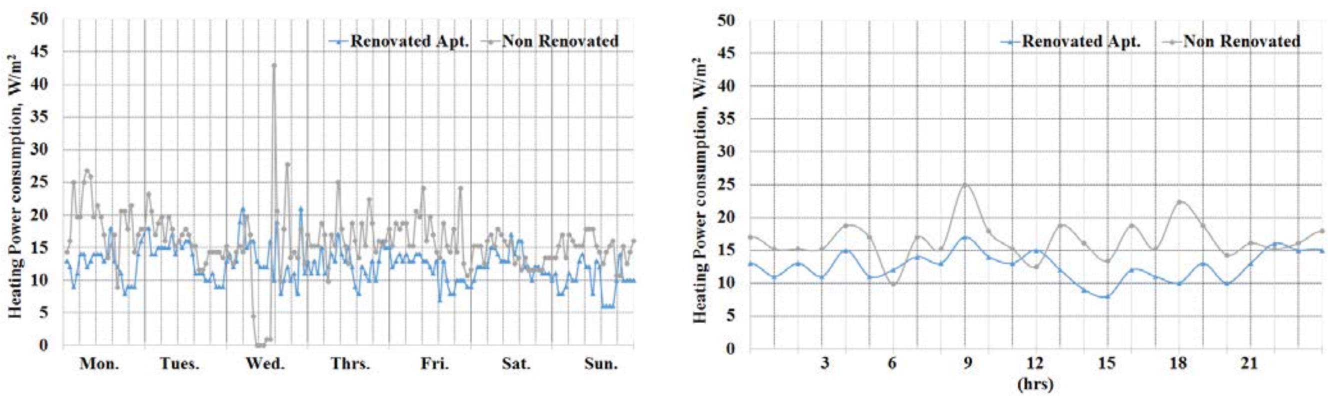


Figure 4. Indoor air temperature and Relative humidity profiles



a) b)

Figure 5. Heating consumption profiles for both apartments. a) a weekly profile, b) a day profile

CONCLUSIONS

Continuous measuring of the building performance provides opportunity for better design and operative improvements. Integration of wireless sensors as a non-invasive measuring system could be considered an applicable solution for both the tenants and the social housing company to monitor and analyze building performance through the renovation and operation phase. . Implementation of a wireless system saves time and installation efforts, and facilitates distance monitoring of all measured data . The increasing availability of user-friendly monitoring and feedback systems will facilitate the involvement of occupants in their energy use and quality of the indoor environment. However, further investigations of the accuracy and reliability of the wireless sensor systems under different boundary conditions have to be carried out. In addition, it will be desired to have all the different sensors collected in a single data cloud to ease the retrieving and analysis of the saved data.

ACKNOWLEDGEMENT

This study was carried out under the framework of the REBUS project, *Renovating Buildings Sustainably*, www.rebus.nu, funded by the *Innnovation Fund Denmark*, *Realdania*, *Grundejernes Investeringsfond*, and companies involved in the project.

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