Introduction of flexible monitoring equipment into the Greenlandic building sector

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Abstract

Greenlandic winters are long and cold so living inside a heated and properly ventilated space requires quite some energy. It is assumed that in mechanically ventilated buildings, significant amounts of energy for heating can be conserved by adjusting ventilation flow rates according to the actual demand of occupants. Traditional solutions available on a market consist of a controller and the sensors in a living space detecting occupancy and activity (movement sensors, CO_2 sensors, Humidity sensors, etc.). The controller needs to be programmed and maintained by an expert and the sensors need to be hardwired to the controller. In Greenland where price of labor is very high and availability of experts is limited, installation of such control system becomes expensive. Particularly in case of renovation of existing buildings the costs of hardwiring the sensors can be very high. One possible solution to the above is to use wireless sensor network (WSN) technologies. A prototype wireless monitoring and control system is demonstrated on a renovation of a ventilation system in the new dormitory Apisseq in Sisimiut, Greenland. The existing mechanical ventilation was running at a constant air flow even during unoccupied hours which resulted in a very high heat demand. It was estimated that installing the WSN system will bring annual savings of 1,600 € at the investment of 8,000 €. This paper describes a setup of the system and discusses its advantages and drawbacks.

1. Introduction

The Arctic climate is cold, so living inside the heated buildings requires great amounts of energy. In Greenland households account for 25 % (85 % is heat and 15 % is electricity) of total energy consumption (Statistics Greenland 2011). The average heat consumption of households in Greenland was 387 kWh/m^2 in 2009 (Statistics Greenland 2011). Additionally, another 25 % of the Greenlandic energy is used to deliver energy and water to consumers (including households) hence a real contribution of households to the overall energy use is higher than 25 %. With intention to reduce the CO_2 emissions, the overall energy use needs to be reduced accordingly. Given the amount of energy used in buildings, these cannot be excluded from the process of energy conservation. To reduce the energy use, buildings have become more insulated and air tight. Furthermore, the buildings need to be equipped with advanced heating, ventilation and air conditioning (HVAC) systems to ensure healthy and comfortable indoor environment. It has been shown that by optimizing the operation of HVAC systems according to occupants' actual demands can bring substantial energy savings (Nielsen and Drivsholm 2010; Laverge et al. 2011). However, installing the conventional wired control systems may become costly as the expenses related to installation of these systems are high.

Special cases are buildings in remote regions like Greenland where availability of professionals is limited and price of labor is expensive. Advanced monitoring and control systems might get rejected for their high initial price and thus long payback time.

The possible way to reduce installation costs is use of WSN to monitor and control buildings. In the previous paper (Heller and Orthmann 2014) the requirements for use of WSN in buildings were discussed and the current literature reviewed. It was concluded that the WSN technology has by far not been developed to its full potential. Studies dealing with this topic are mostly theoretical (based on computer simulations) (Tachwali, Refai, and Fagan 2007, 439-444; Sklavounos and others 2013) or pilot studies without full scale implementation of the technology (Bhattacharya, Sridevi, and Pitchiah 2012, 422-427; Kim, Jung, and Kim 2010, 145-150; Preethichandra 2013, 1306-1310).

The purpose of this study was to implement a WSN based monitoring and control system into an existing building in use. This should bring energy savings without negative effects on indoor air quality (IAQ). Moreover it should be demonstrated that the return on investment is higher than in case of conventional wired solution. The ease of installation and functionality should be introduced to the local construction community.

2. Building description

The studied building is a dormitory for engineering students in Sisimiut, Greenland. It was built in 2010 with the intention to demonstrate energy efficient building in which modern technologies not yet commonly used in the Arctic could be installed and tested. Previous studies undertaken in this building have shown, that the poor design of ventilation system causes that the building is constantly over-ventilated (Kotol and Rode 2012) which in such cold climate results in very high energy use.

2.1 Layout

The building has a circular shape and consists of three floors: a ground floor with technical rooms and two upper floors with flats, laundry and common room. There are 33 single room flats for one student and 4 double room flats at the gables of the building (see Figure 1).

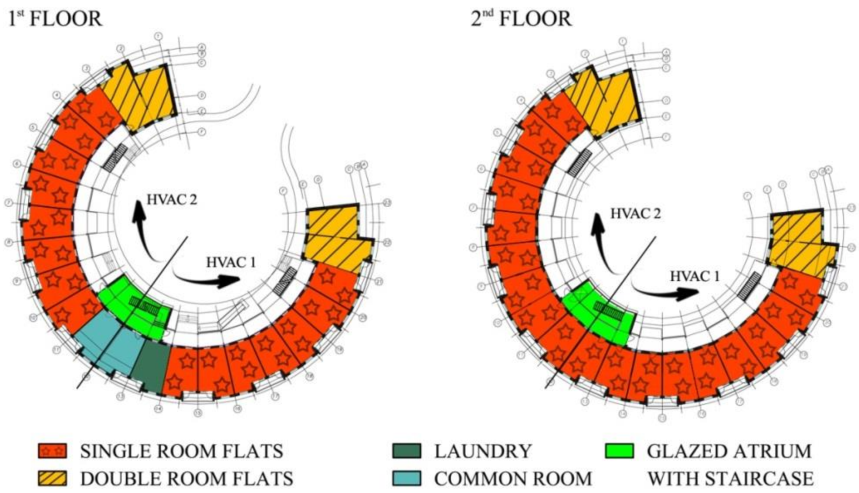

Figure 1. Floor plans of the engineering dormitory Apisseq

More detailed description of the building can be found in (Kotol and Rode 2012; Vladyková et al. 2010). The annual heat demand was estimated to 160 MWh/yr for space heating and 80 MWh/yr for domestic hot water (DHW). In total the predicted annual heat demand was 240 MWh/yr or 169.7 kWh/(m^2·yr). However, the measured annual heat demand in 2012 was 310 MWh/yr or 219.7 kWh/(m^2·yr). Out of which, 18 % (55.8 MWh) was dedicated to heating of the ventilation air. This in terms of running costs resulted in total annual energy bill of 30,000 € in 2012 (of which 5,400 € was related to ventilation air heating).

2.2 Ventilation system

The ventilation system consists of two identical HVAC units. Each of them is venting half of the building as shown in Figure 1. The units deliver fresh air to living space of each flat and extract the polluted air through range hoods and bath rooms in each flat. The supply air is delivered at a constant rate whereas the exhaust air flow can be increased in case of increased humidity in bathrooms or cooking activities but under normal operation the ventilation is balanced and provides an air change of 1.1 h^{-1}. Nevertheless, the current Greenlandic building regulation (GBR) (Direktoratet for Boliger og Infrastruktur 2006) requires a minimal air change of 0.5 h^{-1}. The GBR also requires that the following rooms should be equipped with air extraction: Kitchens (20 l/s) and bathrooms (15 l/s). This additional requirement was likely the reason for designing the constant ventilation rate of 20 l/s (air change of 1.1 h^{-1}). Nevertheless, the required extraction from kitchens and bathrooms is meant to be available when needed and does not have to be on at all times. It is expected that substantial energy savings can be achieved by reducing the ventilation air change according to the actual demands (occupancy) without negatively affecting the indoor air quality.

3. Methodology

To detect the actual occupancy and estimate the right amount of ventilation air needed for the space, CO_2 concentration is often used. Some European standards suggest that in case of demand controlled ventilation where indoor CO_2 concentration is used as an IAQ indicator the ventilation rate can be adjusted in order to maintain the indoor CO_2 concentration below certain level [1000 ppm (Danmark. Erhvervs- og Byggestyrelsen 2010) or 500 ppm above outdoors (Dansk Standard 2007)]. The minimal air change of 0.05 l/s·m^{-2} to 0.1 l/s·m^{-2} (Dansk Standard 2007) should however always be maintained.

3.1 Experimental setup

In this study the ventilation system in one half of the building will be adjusted to reduce ventilation rates according to actual demands of the occupants. The other half of the building will remain unchanged to provide a reference case for evaluation of the improvements.

Due to the design of the ventilation system and fact that the building is already in use, the space for improvement is rather limited. For that and for economic reasons it would not be economically feasible to control the air flow on a room level. Nevertheless, as the building is a dormitory for students with similar schedule, it can be expected that their daily routines will have a similar pattern for majority of the time. Therefore the air flow will be regulated centrally on the ventilation unit level.

Although the air flow will be adjusted centrally for the entire half of the building, it is still important to make sure that none of the flats will be insufficiently ventilated. Therefore a CO_2 sensor will be placed in each flat. To avoid excessive installation costs related to hard wiring each sensor, the sensors will communicate wirelessly with the central node. The central node will evaluate levels of CO_2 in the rooms and send a control signal to the actuators which will adjust the air flows. The actual air change will be controlled in a range between 0.02 h^{-1} and 1.1 h^{-1} in order to maintain the CO_2 concentration in each room below 1000 ppm.

Furthermore the central node will be accessible on-line which will further reduce the costs as all the programming, calibration, software maintenance, troubleshooting and data collection and evaluation can be done remotely from anywhere in the world.

4. Hardware

The Libelium Waspmote platform creates the foundation of the setup and was preferred because of its modularity, which made it possible to build custom nodes for specific purposes.
The experimental setup consists of three different node types (each designed for a specific purpose), a signal amplifier and damper actuators which control the airflow.

4.1 Central Node

The central node creates the wireless network, it can be used as a router for message passing and it saves data from the network in persistent storage. Additionally, the node enables the online access and remote control. The coordinator node selected for this experimental setup is the Meshlium ZigBee-PRO-AP.

4.2 Sensor Nodes

The sensor nodes monitor CO_2 concentration in each flat and send the data to coordinator node. The proposed system contains 18 sensor nodes (one in each flat). The main components of the nodes are Waspmote ZigBee PRO, Gases Sensor Board v2.0 and solid electrolyte CO_2 Sensor TGS 4161. Each node has a 6.6 Ah battery which will be able to power the node for a year. However, for the experimental purposes each node will be powered from the electrical grid as a backup.

4.3 Control Node

The control node (Waspmote ZigBee PRO) receives the commands from central node and by means of two actuators (Belimo TF24-SR) adjusts the supply and exhaust damper positions (and thus air flows). Because the voltage range given by control node is 0 V to 3 V and the actuators require a signal from 0 V to 10 V an amplifier was needed. For this purpose a programmable relay Siemens LOGO which is already a part of the building's inventory was used.

5. Economy

Excluding the Belimo actuators and Siemens LOGO relay (which are already installed in the building), the retail price of the wireless solution is 8,000 € (according to Table 1).

Table 1 Price estimation for the wireless solution

Item	Price (incl.VAT)
19x Waspmote ZigBee PRO	3,800 €,
18x Gases Sensor Board v2.0	2,160 €
18x Solid electrolyte CO_2 Sensor TGS 4161	880 €
Meshlium ZigBee-PRO-AP	660 €
Installation of the sensors	500 €
Total	**8,000 €**

For comparison the price of the wired solution would be 16,000 € (according to Table 2).

Table 2. Price estimation for the wired solution

Item	Price (incl.VAT)
18x CO_2 sensors (Vaisala CARBOCAP® GMW 22)	6,000 €,
Programmable logic controller with web server (Prolon PID 4000) including installation	4,000 €
Installation of the sensors	6,000 €
Total	**16,000 €**

Costs of programming the hardware were neglected as they will likely be similar in both (wired and wireless) solutions and will be marginal compare to the whole investment.

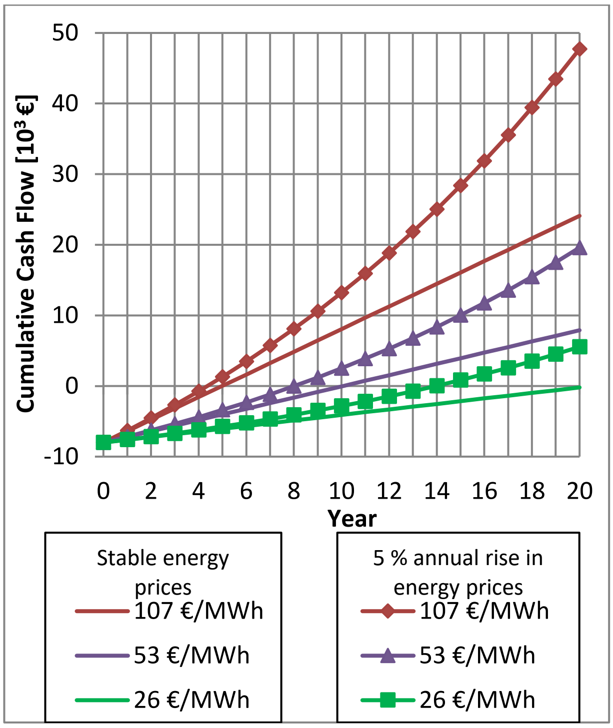

Figure 2. Return on investment wireless solution

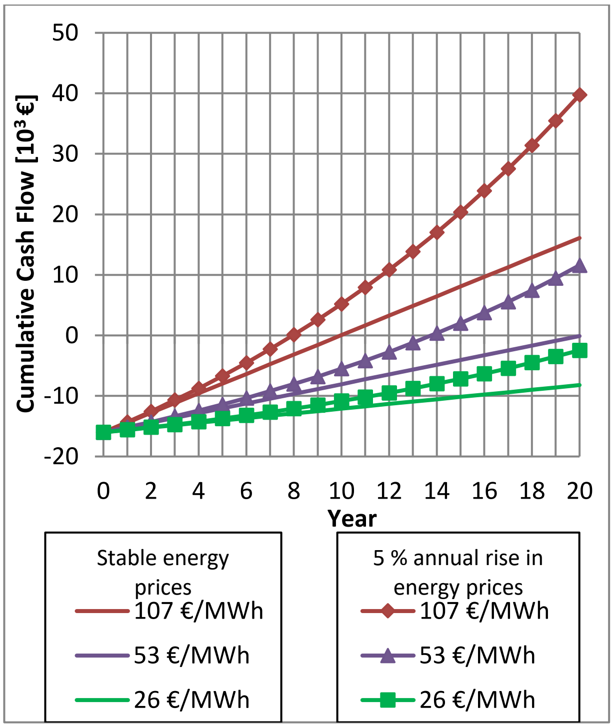

Figure 3. Return on investment wired solution

It is expected that the adjustment will reduce the heat demand of the actual ventilation unit by 50 %. That yields an annual energy savings of approximately 15 MWh/yr or 1,600 €/yr at current heat price (107 €/MWh). The return on investment for wired and wireless solutions is shown in *Figure 2* and *Figure 3*.

6. Discussion

The price of wired solution is higher partially due to use of different CO_2 sensors. The Vaisala sensors use more accurate technology and do not require such frequent calibration (the manufacturer guaranties 5 % accuracy over the course of five years). On the other hand the wireless solution allows remote calibration as frequently as required by the sensor manufacturer, therefore more accurate sensors might not be needed.

Installing the wireless solution only requires attaching the sensor nodes to a wall in each flat and connecting the central node to the internet (the rest is done remotely). This is apparently less labor intensive than wiring each sensor through the finished building in use. Moreover it does not require highly skilled professionals to perform this work.

The actual payback period will strongly depend on the real energy savings and will also be affected by the energy price as shown in *Figure 2* and *Figure 3*. However, even if the energy price remains constant (107 €/MWh), a payback time of the WSN solution is 5 years compare to 10 years in case of wired solution.

One of the advantages of WSN solution is its flexibility/expandability. If in the future the system needs to be expanded by large number of sensors (e.g. controlling the ventilation system in the other half of the building), these can simply be added to rooms without a need for additional central node. Contrary the wired solution has a limitation in maximum number of inputs from sensors. Once this number is reached, additional hardware must be installed.

A possible drawback of the WSN solution can be its robustness and long term reliability. These will be tested during the experiment.

7. Conclusions

It was found that it is economically beneficial to use WSN instead of traditional wired solutions in remote areas with expensive labor and limited availability of highly skilled professionals. The simple payback period is 5 years which will likely be even shorter due to increasing price of energy. The real energy savings and actual payback period along with the reliability of the WSN system needs to be confirmed by the experiment.

Acknowledgements

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