Active Room-Human Feedback System: Design and Discussion

A set of communicating sensors with a microcomputer is designed to enable an interaction between the room and the occupant through a dynamic feedback system and easy-to-understand signals. This approach represents a method of using the new advances in microcontroller technology to promote indoor air quality especially in residential buildings.

Keywords: Eco-Feedback, Information and communication technology, CO_2-meter, Human-Room Interaction

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People in industrialized societies spend most of their lives indoors. In the past decades, energy saving measures have led to the construction of airtight buildings. This can negatively impact the indoor air quality by allowing a build-up of air contaminants within a building section if sufficient ventilation is not provided. In residential buildings in Germany the dominant mode of ventilation is natural ventilation through hand operated windows. Healthy indoor air depends on the rate of delivering fresh air to the environment and also on the indoor production rate of the contaminants. Especially in heating season an excessive ventilation time or an incorrect ventilation type can result in higher heating energy consumptions, whereas a less-than-necessary ventilation time leads to an accumulation of contaminants in a room and therefore causes dissatisfaction of the occupants.

Poor indoor air quality (IAQ) in residential buildings can also have direct economic drawbacks. An increasing number of employees working from their homes signify the economic importance of the IAQ in residential buildings. Better IAQ results in more productive and happier occupants. While it is difficult to exactly quantify these benefits, there is continuing evidence of higher productivity in areas with better IAQ.

The sensitivity towards the actions controlling air quality is very diverse. About 59% of Europeans seem to lack information about the air quality issues in their country [1]. The survey was conducted mainly to assess the topic of general air quality, but it gives an impression of the number of people who may also be uninformed about the topic of IAQ in their homes.

Many studies have shown the effectiveness of feedback systems in persuading occupants to have a more IAQ-aware and energy-efficient ventilation in their buildings (see e.g. [2] and [3]). The advantages of feedback systems are twofold. They represent a low-cost method to promote efficient behaviour and therefore decrease energy consumption, and behavioural persuasions are less likely to produce the undesired rebound effect.

In most cases feedback is carried out through information campaigns and printed media, which address the general consumer and aim at listing and describing all relevant cases of efficient behaviour. With the advent of modern low-cost sensors and communication, as well as data processing technology, there is an opportunity for a dynamic and active feedback system. The purpose of this study is to provide the proof of concept for a personal feedback system using low-cost sensors with a controller unit to increase awareness of the state of the IAQ and to promote better indoor air quality, and efficient ventilation behaviour in naturally ventilated rooms among occupants in residential buildings.

System description

The ambient status is gathered by a set of sensors that relay data to a single-board computer (Raspberry Pi with a USB power source) where the processing and storing of the data are carried out using an open source robust data collection and automation software. The data is stored locally on a memory disk and on an external hard drive for further analysis. The concept of this system does not introduce actuators like in classical smart home systems therefore eliminating the related investment, maintenance and operational costs. The system acts as a suggestion platform and actively provides feedback to the occupants. **Figure 1** shows the schematic of the design principle.

The recorded data includes temperature, relative humidity, CO_2 concentration, illuminance and occupant presence. Also, the duration of certain occurrences (such as the duration of a temperature drop, or open window status or the time it took for the occupant to react on the recommendation) can be recorded. These data can generally be used to give feedback in the areas of lighting, window shades' status, heating and ventilation. The setup is compact and can be placed near the sitting area in a living room or on the work desk in a home office. In the current stage, the feedback rules are kept simple and straight-forward. The recommendations are given using messages on displays, optional short beeps and coloured LEDs. **Figure 2** demonstrates the test values of the CO_2 concentration, the type of the display used and the possibility of input parameters through the software used.

Feedback possibilities that can be achieved using these sets of sensory data are very diverse and still in development. In the following, an example of active IAQ-feedback on efficient natural ventilation behaviour is described.

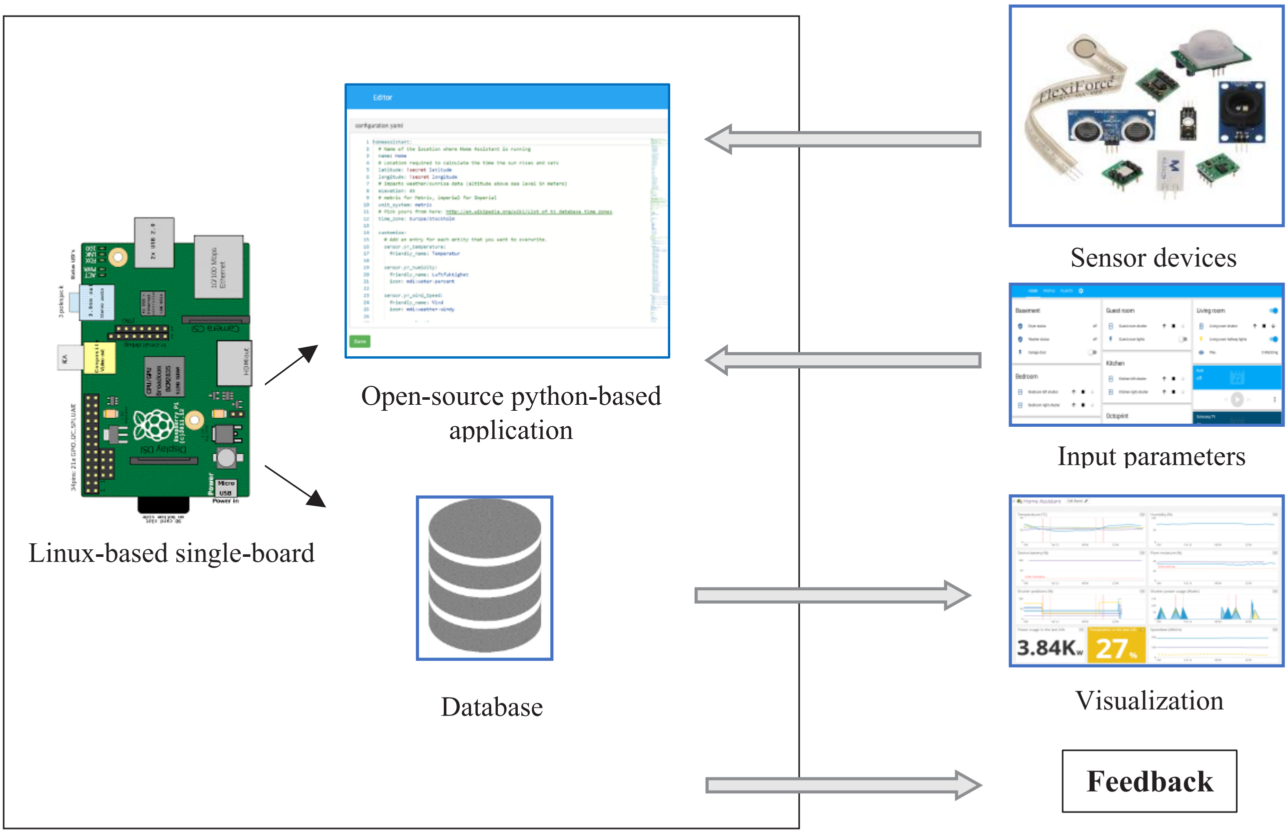

Figure 1. Schematic of the design principle.

Efficient natural ventilation habit

In this study, the basis of identifying the quality of indoor air is the CO_2 concentration. There are two operational modes for the IAQ-Feedback: "continues monitoring" and "feedback on demand". In both modes, an average is taken every minute from continuous measurements. The value is used in the following feedback algorithm of the "continues monitoring" mode and also stored for further analysis.

Whenever the value raises above 1000 ppm the feedback device performs a short beep and using its displays, gives a recommendation on the necessity of acquiring fresh air through fully opening the windows and a hint on closing the radiator valves. If the concentration value continues to increase, another beep at 1500 ppm will alert the user(s). At the concentration of 2000 ppm a red light emitting diode (LED) points out the importance of conducting ventilation with blinking and subsequent on-status. If the system assesses a drop in the CO_2 values, the red LED will go off.

A beep is provided when a concentration of 700 ppm is reached as a sign of sufficient air quality and the display message will vanish. In this design, the limits of the CO_2 concentration follow the Pettenkofer value and the recommendation of the German environmental agency (UBA) for a traffic lights concept for schools. These limits can be adjusted as input parameters.

In "feedback-on-demand" mode the feedback on the CO_2-based quality of the room air is only given when the user asks for feedback by pressing a button. In the background, however, the concentration measurements are carried out continuously. If the feedback-on-demand button was not used on one day or if the CO_2 concentration values were above 1000 ppm, a short

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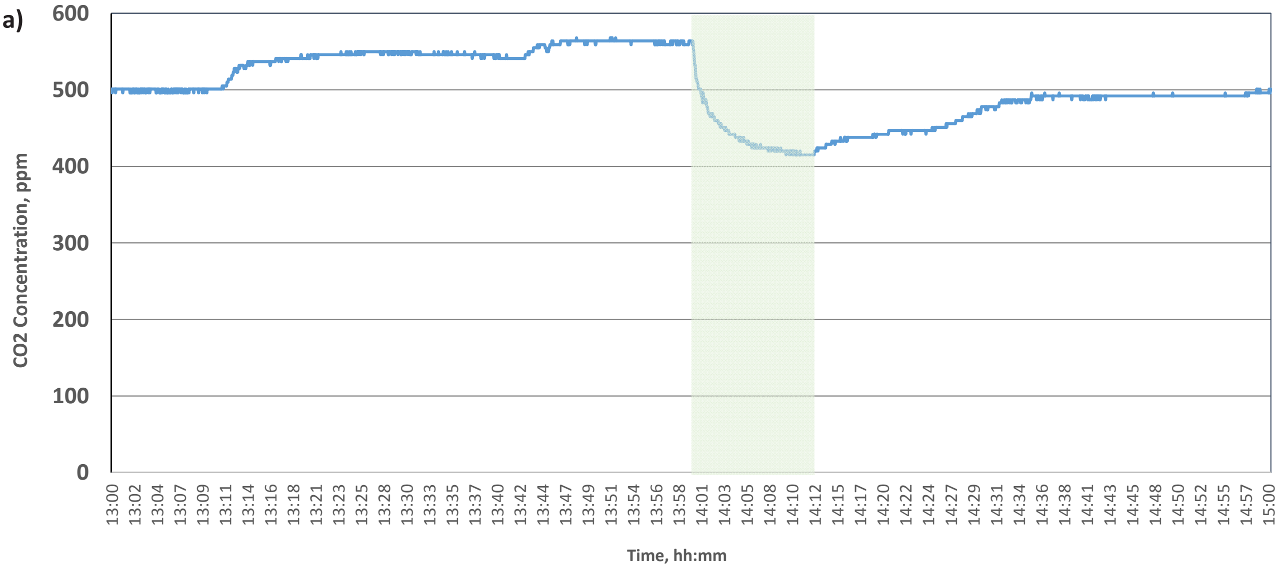

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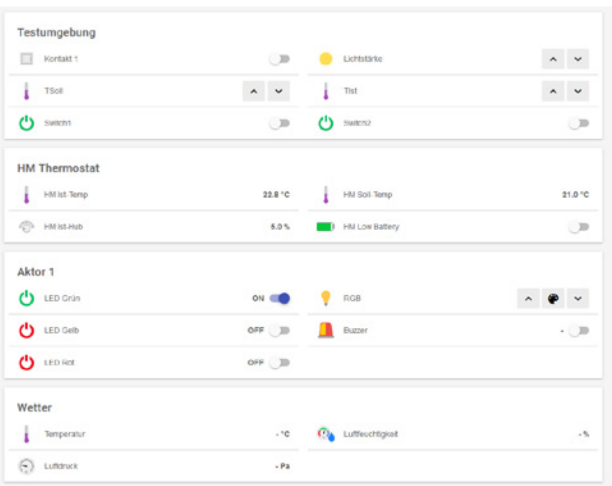

c)

Figure 2. a) Test values of the CO_2 concentration. b) Possibility of input parameters. c) Prototype display used for message communication (© RaspberryPi)

report will mention the number of minutes with a CO_2 concentration above 1000 ppm on the next day.

Discussion

Feedback systems on CO_2 can also represent a low-cost solution to increase the energy efficiecny in resdential buildings, since a fundamental factor in energy-efficiency of heating a household is the behaviour of the occupants, particularly how they ventilate rooms. This approach belongs to the category of behavioural interventions. A recent study also showed that a 'CO_2-meter' can change user's behaviour and improve indoor air-quality [4].

Furthermore, surveys have shown that a determining portion of the society in Germany is still feeling 'uneasy' with the increasing amount of automated processes in their homes [5]. Some mention that they would like to have the feeling of control over the events more often. The product resulting from the prototype in this study can represent a solution for this part of the society to still benefit from the advantages of the modern technology to receive environmental feedback, yet keep the decision-making power for themselves.

It is important to remember that the feedback system does not fully replace the decision-making or judgment ability of the occupant. It suggests that the occupant has the opportunity to improve the indoor air quality by opening the windows if possible. If the outdoor air is of particularly low quality the user does not have this option. In these cases (for example in polluted cities) the feedback system of next generation will use an outdoor unit and focus on delivering feedback on the time of the day where outdoor air pollution (defined according to DIN EN 16798 or WHO – World Health Organization - Air quality guidelines including PM10 and PM2,5) is lower than the indoor air pollution.

Conclusion and future steps

The described solution is at the design stage. The CO_2 sensor is integrated on a sensor box (see **Figure 3**) which includes further sensors for future applications. In the next generations,

- the window state will be available directly using wireless magnet sensors.
- the temperature data will be integrated to dynamically determine the feedback time for closing the windows.
- the concepts of the design of human-building-interaction are applied to promote the interaction between the occupant and the room and raise the probablity of action on feedbacks.

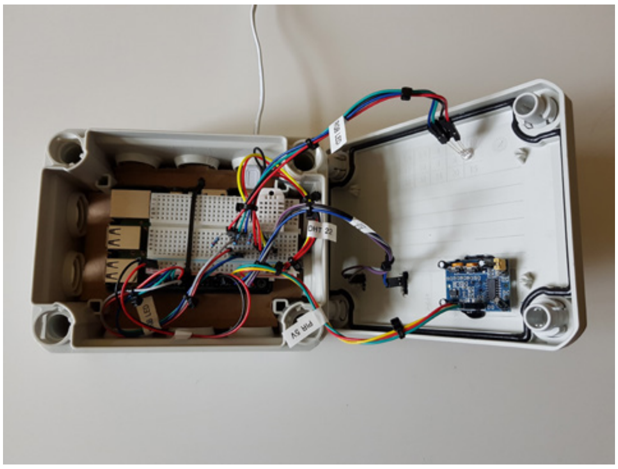

Figure 3. Prototype of the sensor box (© D.Boehnke)

The significance of integrating occupants into the operation of the building is increasingly acknowledged by the building research community. The author's vision is to combine the effective know-how on the positive influence of eco-feedbacks with the new possibilities of the modern information and communication technology (ICT) to develop a system for real-time human-centred interactions between rooms and humans with a focus on improving indoor environmental quality and energy efficiency. In the concept of human-room interaction, the rooms in residential buildings will not be considered only as places of rest and gathering but as active dynamic entities interacting with the occupants resulting in increased satisfaction and wellbeing of the citizens. ■

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