DOI 10.5162/SMSI2025/A1.2

Wireless Network Architecture for Comprehensive Indoor Environmental Quality Monitoring in Public Schools

Fabian Sievers[1], Nils Langer[1], Stefan Palzer[1]
[1] TU Dortmund, Professorship for Sensors, Friedrich-Wöhler Weg 4, 44227 Dortmund, Germany
stefan.palzer@tu-dortmund.de

Summary:
School buildings require a high level of thermal comfort and good indoor air quality to provide a healthy environment. At the same time, automated heating, ventilation, and air conditioning systems are too costly, thus public school buildings typically feature a low level of automatization. Retrofitting by means of low-cost components has the potential to improve overall building performance until they can be reformed. Here a scalable wireless sensor and actor system architecture that is suitable for large scale monitoring and control of thermal comfort in entire buildings with single room resolution is presented.

Keywords: Indoor environmental quality, Wireless Sensor and actuators network, thermal control systems, air quality, thermal comfort

Introduction

Many public-school buildings in Germany lack investments in thermal insulation and digitization of building operation [1]. This leads to increased operating costs with schools having a particularly high energy consumption. For example, public buildings in Germany feature an energy consumption of 211,4 kWh/m^2 [2]. At the same time, large scale, complex retrofitting is not feasible on a short timescale thus highlighting the need for cost-effective, scalable solutions to reduce energy consumption in buildings that may be quickly implemented.

To optimize energy consumption of complete buildings, continuously monitoring the environmental quality in all rooms is a prerequisite. The collected data can then be used to characterize the thermal behaviour and point towards weaknesses that may be addressed using small-scale, cost-effective energetic renovations. Furthermore, adding wireless thermostats, the room temperature can be controlled based on environmental data to reduce energy consumption while maintaining high thermal comfort. Controlling individual rooms is knows to increase environmental air quality [3] and a reduction in energy consumption [4] of 21,81 – 44,36 % can be achieved while improving the average comfort.

Network architecture

To monitor the environmental quality at an individual room level, a sensor node for monitoring humidity and temperature featuring a Sensirion SHT31 and a carbon dioxide (CO_2) sensor by SenseAir (K30) has been developed in three schools in the town of Holzwickede. In total 155 sensor nodes and 328 thermostats were installed in 149 rooms. The data from each sensor node is collected in a time-series database on a central server and transmitted via the respective WLAN networks. The hand adjusted thermostats at the school have been replaced with custom-designed, wireless battery-powered thermostats, which are remotely controllable from the central server.

The system is implemented as a mesh network between sensor nodes, thus increases flexibility for node placement, lowering the dependence on WLAN range, and alleviating congestion on the WLAN and stress on WLAN access points, because less network participants need to be managed.

Crucially, the connection of radiator thermostats has to be low power consuming in order to ensure a sufficiently long battery lifetime. To this end, the ESP-NOW wireless protocol by Espressif Systems has been established since it provides a suitable connectionless communication protocol for IEEE802.11-enabled IoT allowing for power consumption reduction of more than 30% as compared to WiFi [5].

For the low power communication, the sensor nodes are configured to answer to specific thermostats only, based on their mac address. All communication is initialized by the thermostat with a broadcast message. The configured sensor node answers with a unicast message. After the thermostats have received the message successfully it responds with sensor data. This communication sequence ensures that the thermostat's microcontroller (MCU) does not have to listen for wireless messages continuously and therefore can sleep most of the time saving energy.

Fig. 1 shows an exemplary network topology made up of sensor nodes, thermostats and a router. It marks the connections and their type between all network participants.

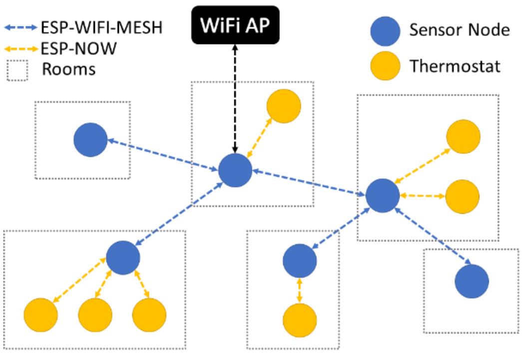

Fig. 1. Exemplary network topology made up of sensor nodes, radiator thermostats and a WLAN access point. The access point provides internet connectivity for the sensor node mesh. The thermostats connect through ESP-NOW for low power communication.

To minimize active time of the thermostat's MCU the communication window is optimized to be as short as possible

Results

The current consumption for data transfers between sensor node and a thermostat have been optimized and determined. The thermostat uses two AA alkaline batteries in series resulting in a supply voltage of 3 V. In Fig. 2 two different scenarios are shown. Initially the thermostat searches for the sensor node, which takes approximately 1493 ms. The usual data exchange is shorter with a total current consumption of 3,8 µAh per exchange.

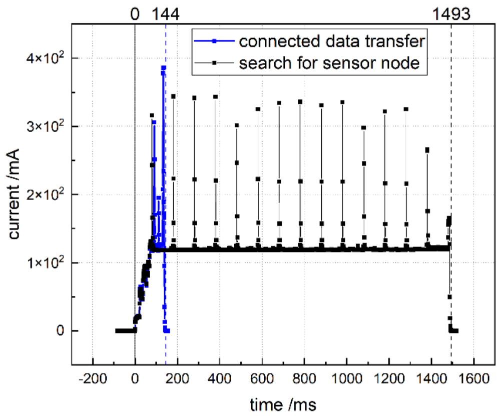

Fig. 2. Current consumption over time of a thermostat (a) while searching for a sensor node without success, (b) during successful data exchange between connected sensor node and thermostat

Data is exchanged in an interval of 4 minutes leading to a total current consumption of 1,37 mAh per day for communication. This leads to an expected lifetime of approximately 1459 days assuming 2000 mAh battery capacity.

Fig. 3 shows data collected with the novel installation for one room during the 27.11.2024. Collected is high resolution data for CO_2, relative humidity and temperature.

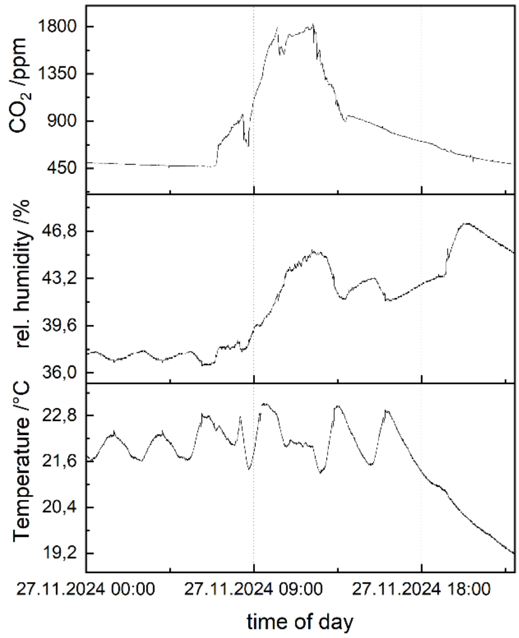

Fig. 3. Collected data for one room during 27.11.2024. Captured temperature, humidity and CO2 concentration data.

References

[1] S. Brand, J. Salzgeber: „Kosten steigen schneller als die Investitionen: Bedarfe für Schulen weiter hoch“, *KfW Research*, Nr. 401, KfW

[2] Kluttig, H.; Dirscherl, A.; Erhorn, H.: Energieverbräuche von Bildungsgebäuden in Deutschland. *gi-Gesundheits-Ingenieur* 122, Heft 5, Seite 221-233

[3] A. Ortiz Perez et al., "A Wireless Gas Sensor Network to Monitor Indoor Environmental Quality in Schools," *Sensors*, vol. 18, no. 12. MDPI AG, p. 4345, Dec. 09, 2018. doi: 10.3390/s18124345.

[4] G. Halhoul Merabet et al., "Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques," *Renewable and Sustainable Energy Reviews*, vol. 144. Elsevier BV, p. 110969, Jul. 2021. doi: 10.1016/j.rser.2021.110969.

[5] [1] D. Urazayev, A. Eduard, M. Ahsan, and D. Zorbas, "Indoor Performance Evaluation of ESP-NOW," *2023 IEEE International Conference on Smart Information Systems and Technologies (SIST)*. IEEE, pp. 1–6, May 04, 2023. doi: 10.1109/sist58284.2023.10223585.