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# IMPROVING ENERGY MODELING AND RENOVATION THROUGH THE MONITORING OF MICROCLIMATE AND INDOOR AIR QUALITY

# IZBOLJŠANJE ENERGETSKEGA MODELIRANJA IN PRENOVE Z MONITORINGOM MIKROKLIME IN KVALITETE NOTRANJEGA ZRAKA

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**Keywords:** Energy efficiency, microclimate, building renovation, indoor air quality, radon, formaldehyde, Arduino, Raspberry Pi, wider benefits, HVAC

## Abstract

This article examines the possibilities of supporting high-quality energy renovation projects that secure the optimal impact on the buildings' users, through the use of low-cost monitoring equipment. The demonstration pilot established a monitoring system in educational buildings and attempted to engage building users (primarily students) in several ways, from gathering information about their habits, level of understanding, willingness to be involved, co-creation workshops, information campaigns and application/testing of the developed tools.

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## Povzetek

Članek obravnava možnosti za podporo visokokakovostnih projektov energetske prenove stavb, ki zagotavljajo optimalen vpliv na uporabnike, z uporabo nizko-cenovnih rešitev za izvajanje ciljnega spremljanja rabe energije in drugih parametrov. V sklopu demonstracijskega pilota je bil vzpostavljen sistem monitoringa v izobraževalnih stavbah s poudarkom na vključenosti uporabnikov (predvsem študentov) na več nivojih, od zbiranja informacij o njihovih navadah, ravni razumevanja, pripravljenosti na sodelovanje, aktivne udeležbe na delavnicah za soustvarjanje, izvedbe informativnih kampanj in uporaba/testiranje razvitih orodij.

## 1 INTRODUCTION

According to the three main targets defined within the 2020 Climate and Energy package of the European Union, Member States will achieve a 20% improvement in energy efficiency, a 20% share of renewables in the overall energy consumption and a 20% reduction of greenhouse gas (GHG) emissions ($CO_2$ equivalent) by the year 2020, *[7]*. The total GHG emissions of the EU in 2016 (including emissions from international aviation and indirect $CO_2$ emission) were already down by 22.4 % in 2016 (relative to 1990), *[7]*; the EU is thus on its way to significantly surpass this target. However, in the same year, the EU had a dependency rate equal to 54%, meaning that more than half of the area's energy needs were met by net imports, mainly petroleum products (66%), natural gas (24%), and a smaller share of solid fuels, *[7]*.

Gross inland consumption of energy (total energy demand of the region) within the EU-28 in 2015 was 1627 million tonnes of oil equivalent (Mtoe) of which it was estimated that buildings represented almost 40 % of this amount. Naturally, reducing energy consumption in buildings, whether in households, industry or otherwise, has been seen as a clear priority by transnational decision-making bodies in the context of achieving the goals defined in the climate and energy package. In the past, the main focus in the area of facilitating energy renovation was on economic feasibility and alternative financing models, that would foster increased investment into the sector. However, energy renovation measures that often make the most sense from the technical and environmental perspectives (reducing energy consumption and GHG emissions) can be dismissed solely due to their lack of securing good investment value, which is especially true in countries and regions where energy, in general, remains cheap. Frequently, the return of investment for energy renovation is too low (or negative) even within a long-term horizon of 15 years or more, also if aid through co-funding sources is provided.

Nevertheless, buildings have their own purposes and should not be viewed as financial derivatives or other such products; rather renovation strategies should focus on the individual user, how they will be affected and what the relevance to the broader community is. While it is understood that a building's indoor environment is a critical factor contributing to the well-being of its users, data about specific parameters that can lead to optimized conditions for health and productivity are seldom available.

Furthermore, the investment perspective does not currently, on any meaningful level, consider the wider benefits of energy renovation, and what the value of the energy renovation to the building users is and not exclusively to the investor. According to a study published by Environmental Health Perspectives in 2016, *[6]*, the cognitive performances of workers in an improved (renovated) building environment were found to be 101% higher than in conventional buildings. Crisis response scores were 131% better, strategy scores 288% greater, and information usage scores a staggering 299% higher for employees not exposed to the sort of elevated levels of $CO_2$ and volatile organic compounds (VOCs) typically found in urban building environments. Moreover, the main issue of including these types of monitoring capability within existing or planned to be established Energy Management Information Systems is the cost associated with additional equipment. However, low-cost and open source platforms exist, through which the facility/energy manager can be provided with this information; these platforms can be designed in a portable and compact form, so that they are easily distributed over a larger number of building quarters compared to expensive data loggers, and can easily be designed or repurposed for specific, individual situations.

These platforms include microcontrollers from Arduino and Raspberry Pi. This article will present the establishment of a low-cost monitoring system for indoor air quality and microclimate parameters within an existing EMIS of a school centre in Velenje, carried out within the THE4BEES project (Transnational Holistic Ecosystem 4 Better Energy Efficiency through Social innovation) funded by the Interreg Alpine Space transnational programme.

## 2 OVERVIEW OF THE MONITORING SYSTEM

The monitoring system for acquiring data on indoor air quality and microclimate parameters was established as a part of the demonstration pilot activities implemented within six individual buildings of the School Centre Velenje (ŠCV). The key parameters measured by the established sensor network are air temperature, relative humidity, levels of $CO_2$, radon and formaldehyde found in the indoor air. The core sensing network, in which the trial phase is carried out, is placed within a pre-existing energy management system with which buildings of the ŠCV (buildings A, B, C, D, E) are equipped. The main tasks of the existing system are the acquisition, processing and analysis of the energy used and its costs at the real current level (for e.g. minute, hourly and daily consumption with built-in measuring devices on the counters) and the monthly level, which is realized with the help of received invoices from suppliers of energy products. Thus, they form the basis of real and invoiced data of consumed energy, which can be compared with each other, and, in particular, on the basis of energy analytics, plan daily or, monthly spending. Databases are formed on the school centres internal server.

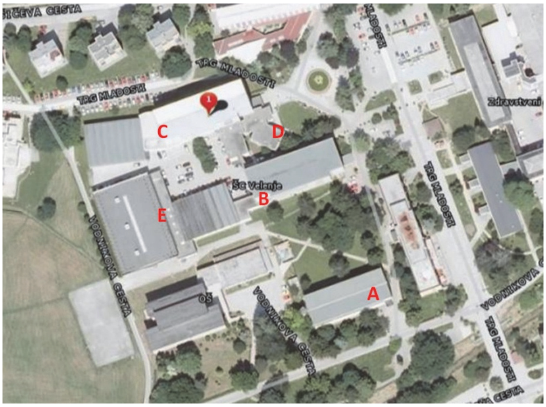


***Figure 1:*** *Buildings of the School Centre Velenje (Source: Google)*

This existing capacity allowed for the introduction of additional measurements, focused on indoor air quality and microclimate parameters (thermal comfort), to be installed within THE4BEES project. The figure below represents an overview of the key components of the sensing network installed within one of the buildings (Building C) in the school centre.

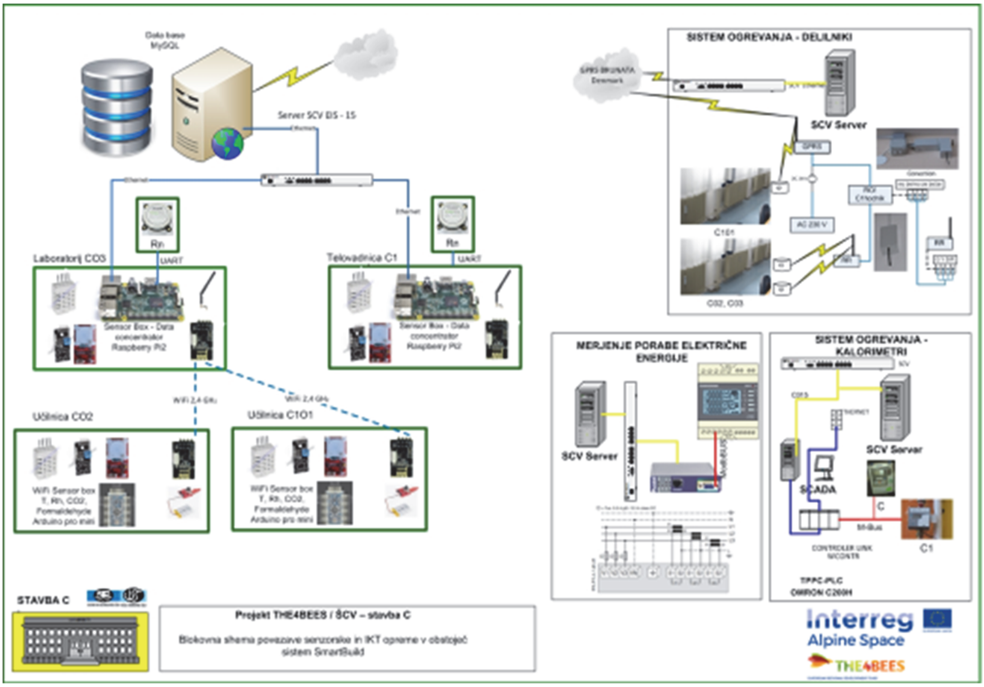


***Figure 2:** Schematic presentation of the sensing network used in ŠCV (Source: School Centre Velenje)*

The figure portrays a schematic of some of the key parts of the monitoring system, which includes the measurements of electrical energy consumption (DIRIS A10 multi-function meter for measuring electrical values in low voltage networks in modular format), heat (heat dividers and/or calorimeters paired with smart thermostatic valves type Micropelt MVA-B00X and Thermokon SAB05) and microclimate data (E+E Elektronik wireless integrated temperature, humidity and $CO_2$ sensor). In addition, the classrooms are equipped with motion sensors, smart window handles (measuring of the open/closed state of the window) and smart handles on doors, all connected via periphery units, such as programmable industrial routers, remote ethernet modules and similar. Thus, a wide array of monitoring equipment has been installed within several projects and initiatives, from which THE4BEES demonstration pilot benefited. The monitoring equipment installed within THE4BEES, which contributes to the further development of the EMIS system of ŠCV, especially in terms of user-focused measurements, is visible on the left of Figure 2. There were two key components developed for the purpose of monitoring various variables of the indoor climate, a standard sensor box based on Arduino™ and a sensor box in the role of a data concentrator based on Raspberry Pi™. In addition to standard microclimate measurements, due to the local specifics (new construction and refurbishment of school buildings, the location of buildings in the vicinity of an abandoned lignite shaft), the systems include the capability to measure formaldehyde and radon gases.

***Figure 3:*** ENIoTOR sensor box-Arduino (left) and data concentrator-Raspberry Pi (right)

# 3 COMPONENTS OF THE MONITORING SYSTEM

## 3.1. Standard sensor box - Arduino

The sensor box is based on the Arduino microprocessor on which sensors are wired. The focus of the design of the sensor box was to develop a compact system that can be easily installed on inner walls of indoor spaces or to function as a portable monitoring unit (LiPo battery with 150-200 mAh capacity), connecting to the server and sending data via the integrated WiFi module. The sensor box is used to measure temperature, humidity, $CO_2$, and formaldehyde levels.

***Figure 4:*** *ENIoTOR sensor box (Source: THE4BEES project)*

The sensor box was designed as a standalone system with its own power supply that can be charged by maintenance if and when required. The sensor box unit is composed of off-the-shelf components described in the following sections.

### 3.1.1 Microcontroller Arduino pro mini

The Arduino Pro Mini is a microcontroller board based on the ATmega168 high-performance Microchip (newer versions are equipped with ATmega328). It features 14 digital input/output pins (of which six can be used as analogue, PWM-Pulse Width Modulation outputs), six analogue inputs, an on-board resonator, a reset button, and holes for mounting pin headers. A six-pin header can be connected to an FTDI cable or a breakout board to provide USB power and communication to the board. The Arduino Pro Mini is intended for semi-permanent installation in buildings or exhibitions. The board comes without pre-mounted headers, allowing the use of various types of connectors or direct soldering of wires. The pin layout is compatible with the Arduino Mini. There are two available versions of the microcontroller, of which the one with a lower voltage of 3.3.V and 8 MHz was used.

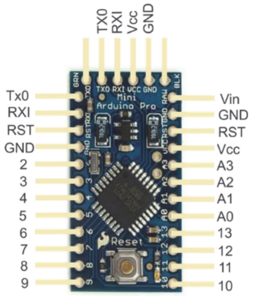


***Figure 5:*** *Arduino Pro Mini microcontroller pins8*

### 3.1.2 Digital Temperature and Humidity Sensor DHT22/AM2302

The sensor box features the standard version of the DHT22 digital temperature and humidity sensor. The sensor was chosen for the application because of its relevant features, including a very compact design, low power consumption in normal operation as well as a long transmission distance (up to 100 m). The connection of the sensor is straightforward because of its four pins located in a single row.

### 3.1.3 Wi-Fi module NRF24L01P

To create a connection between two microcontrollers, the sensor box utilizes the nRF24L01P transceiver Wi-Fi module based on the nRF24L01 semiconductor by Nordic. The module uses a 2.4 GHz band and can operate with baud rates from 250 kbps up to 2 Mbps. The connection can reach up to 100 metres in open spaces at the lower baud rate. It can use 125 different channels, which enables it to connect a network of 125 independently working modems. Moreover, each channel can have up to six addresses, or each unit is capable of communicating with up to six other units at any given time.

***Figure 7:*** *Wi-Fi module NRF24L01P (Source: How to mechatronics)*

### 3.1.4 Carbon dioxide sensor mh-z19

The MH-Z19 is a compact non-dispersive infrared (NDIR) sensor for monitoring the presence of carbon dioxide in the air. Its main features include excellent selectivity (monitoring not disrupted due to varying concentrations of other gases), a built-in temperature sensor for compensation, and long-life span.

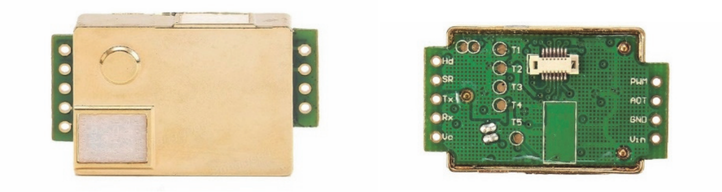


***Figure 8:*** *Carbon dioxide sensor mh-z19*

### 3.1.5 Formaldehyde sensor ze08-ch20

The sensor box is equipped with a general-purpose, portable, miniature electrochemical detection model, which monitors the presence of formaldehyde ($CH_2O$). Its main features are high selectivity and stability, built-in temperature sensor as well as digital output and analogue voltage output at the same time.

***Table 1:*** *Ze08-ch20 technical specifications*

| | |
|---|---|
| Model No. | ZE08-CH2O |
| Target Gas | CH2O |
| Interference Gas | Alcohol, CO, etc. |
| Output Data | DAC(0.4~2V standard voltage output )<br>UART output(3V Electrical Level) |
| Working Voltage | 3.7V~9V (with voltage reverse connect protection) |
| Warm up time | ≤3 minutes |
| Response time | ≤60s |
| Resume time | ≤60s |
| Detection Range | 0～5ppm |
| Resolution | ≤0.01ppm |
| Operating Temp. | 0～50℃ |
| Operating Hum. | 15%RH-90％RH(No condensation) |
| Storage temp. | 0～50℃ |
| Working life | 2 years（in air） |

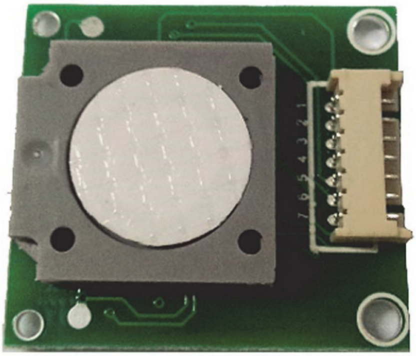


***Figure 9:*** *Formaldehyde sensor ze08-ch20*

### 3.1.6 Power supply

The sensor box is charged via a standard micro USB connector/charger, with an output of 5.0V/0.7A (input ≈ 240V/50Hz). The unit is also able to function independently from a power source for up to six hours due to an integrated lithium polymer (LiPo) cell rechargeable battery with a capacity of either 150mAh or 200mAh and a voltage rating at 3,7V. The battery is charged through a constant voltage/current linear charger type TP4056.

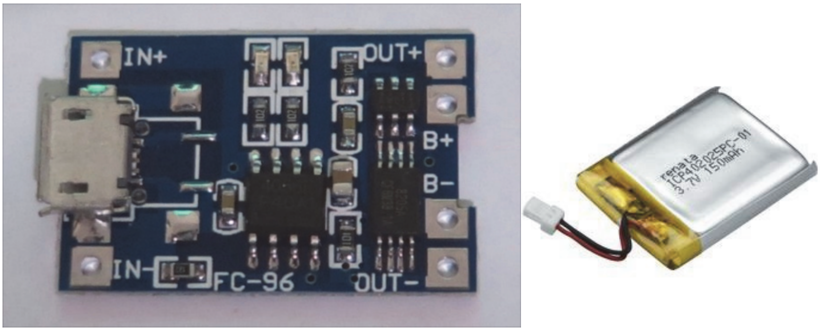


***Figure 10:*** *Linear charger type TP4056 (left) and Renata Lithium Polymer rechargeable battery (right)*

## 3.2 Sensor box/Data concentrator – Raspberry Pi

The data concentrator is based on the Raspberry Pi (Raspberry Pi 3 model B) microprocessor platform that is used to gather data from sensor boxes and connect to the school's server. It allows for the independent measurement of temperature, humidity, $CO_2$ and radon concentrations.

The data concentrator has two main functions:

- Independent measurements of microclimate parameters and air quality
- Data concentrator (receiving and sending data from other sensor boxes in the network)

The data concentrator mostly utilizes the same sensors and equipment on the periphery (*Digital Temperature and Humidity Sensor DHT22/AM2302, Carbon dioxide sensor mh-z19, Wi-Fi module NRF24L01P*) as the sensor box built on the Arduino platform, with the exception of the radon eye external sensor with Bluetooth connectivity, described in this section. In addition, the temperature and humidity sensor is placed within a cylindrical extrusion on the ENIoTOR data concentrator in order to mitigate the measurement error due to excessive waste heat from the Raspberry Pi. In addition, the Wi-Fi module used in this configuration is connected to a standard antenna (original for the module) to improve connection signal and range.

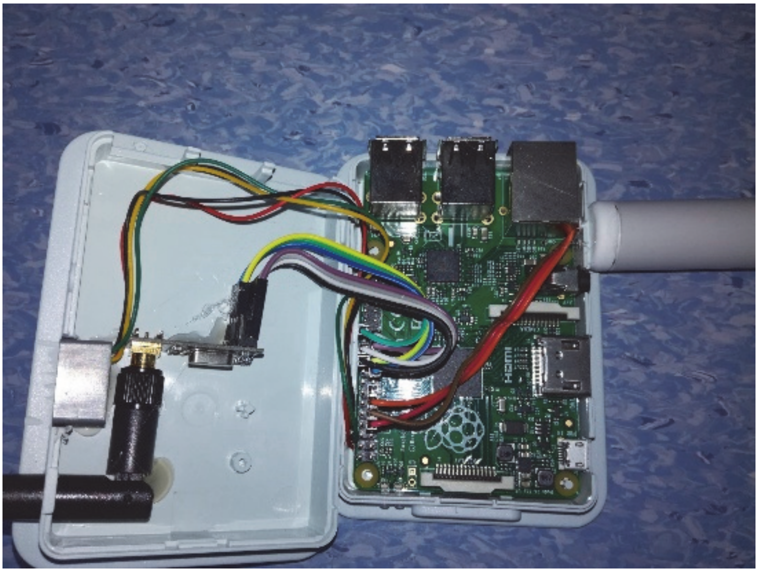


***Figure 11:*** *ENIoTOR Sensor box/Data concentrator – Raspberry Pi (Source: THE4BEES)*

### 3.2.1 Raspberry Pi 3

The Raspberry Pi 3 Model B is the earliest model of the third-generation Raspberry Pi. It replaced the Raspberry Pi 2 Model B in February 2016 (see also the Raspberry Pi 3 Model B+, the latest product in the Raspberry Pi 3 range).

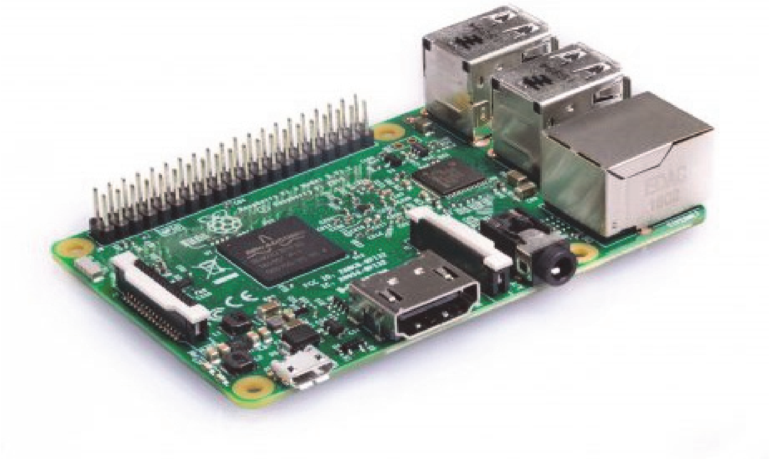


***Figure 12:** Raspberry Pi 3 Model B (Source: Raspberry Pi portal)*

## 3.3 External sensors

### 3.3.1 Radon Eye

Radon Eye RD 200 is a smart radon detector with high sensitivity that can provide reliable data (in real time) less than one hour after the start of the measurements. Its measurements are based on detecting the radioactive decay of α-particles using a 0,2l pulsed ionization chamber and an individual amplifier circuit.

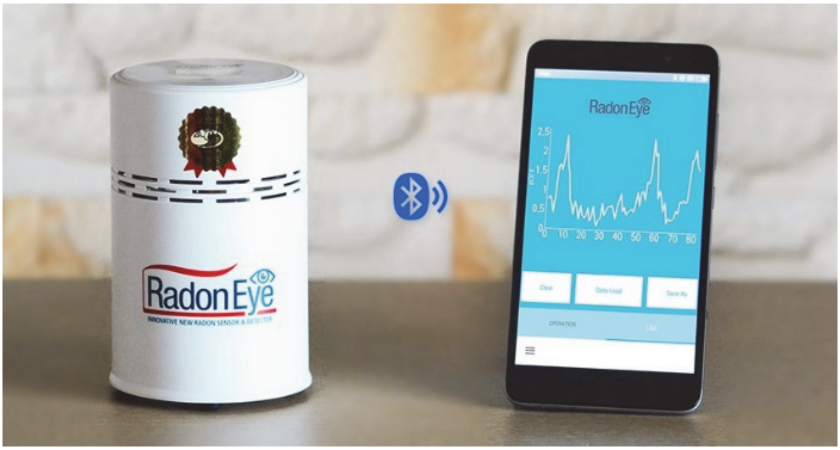
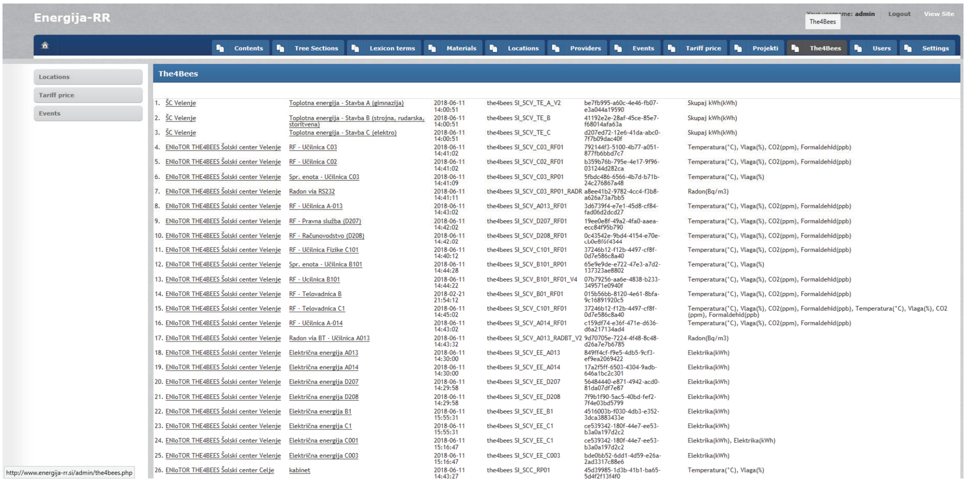


***Figure 13:** Radon Eye RD 200 radon detector*

The sensor network was calibrated with professional (semi-professional) data loggers and compared to measurements carried out by existing monitoring systems in place at the location of the national pilot. Amongst the key equipment used to secure reliable measurements of the monitoring system were the Metrel POLY MI6401 and the Correntium plus/Canary pro II. The MI 6401 Poly is a multipurpose handheld instrument for measuring microclimate and lighting parameters inclusive of relative humidity, air temperature, air velocity and luminosity. The Canary pro II is a data logger for accurate and reliable measurement of the concentration of radon gas. It also offers additional functionality in terms of integrated sensors for temperature and humidity and air pressure as well as a comprehensive analytical capability (Correntium Report and Analysis software).

# 4 DATA MONITORING INTERFACES

Altogether, 73 additional data streams are collected with the monitoring system, primarily on a dedicated portal (http://www.energija-rr.si/admin/the4bees.php) from which they are transferred to the Yucca Smart Data Platform, operated by one of the Italian partners participating on THE4BEES project, CSI Piemonte. The data streams relevant to the pilot project of THE4BEES are gathered in a dedicated subsection within the portal.

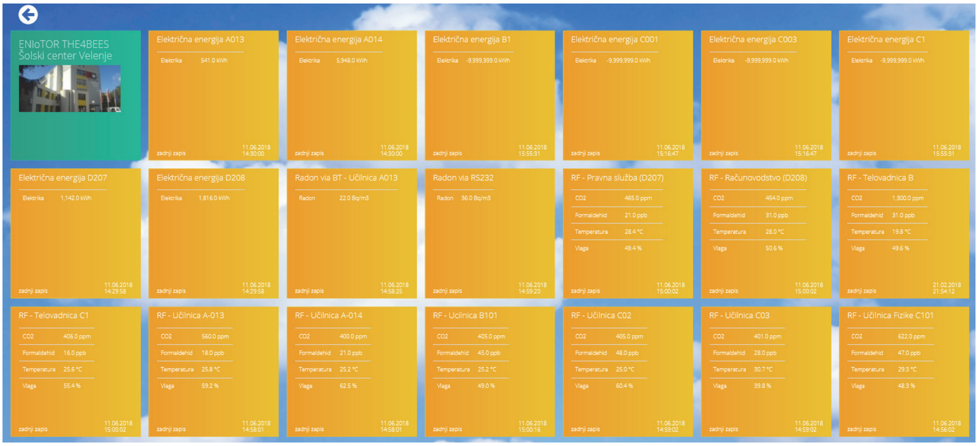


The4Bees

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. | ŠC Velenje | Toplotna energija - Stavba A (gimnazija) | 2018-06-11 14:00:51 | the4bees SI_SCV_TE_A_V2 | be7fb995-a60c-4e46-fb07-e3a044a19590 | Skupaj kWh(kWh) |
| 2. | ŠC Velenje | Toplotna energija - Stavba B (strojna, rudarska, storitvena) | 2018-06-11 14:00:51 | the4bees SI_SCV_TE_B | 41192e2e-28af-45ce-85e7-f68014afa63a | Skupaj kWh(kWh) |
| 3. | ŠC Velenje | Toplotna energija - Stavba C (elektro) | 2018-06-11 14:00:51 | the4bees SI_SCV_TE_C | d207ed72-12e6-41da-abc0-7f7b09dac40f | Skupaj kWh(kWh) |
| 4. | ENIoTOR THE4BEES Šolski center Velenje | RF - Učilnica C03 | 2018-06-11 14:41:02 | the4bees SI_SCV_C03_RF01 | 792144f3-5100-4b77-a051-877fb6bbd7c7 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 5. | ENIoTOR THE4BEES Šolski center Velenje | RF - Učilnica C02 | 2018-06-11 14:41:02 | the4bees SI_SCV_C02_RF01 | b359b76b-795e-4e17-9f96-031244d282ca | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 6. | ENIoTOR THE4BEES Šolski center Velenje | Spr. enota - Učilnica C03 | 2018-06-11 14:41:09 | the4bees SI_SCV_C03_RP01 | 5fbdc486-6566-4b7d-b71b-24c276867a48 | Temperatura(°C), Vlaga(%) |
| 7. | ENIoTOR THE4BEES Šolski center Velenje | Radon via RS232 | 2018-06-11 14:41:11 | the4bees SI_SCV_C03_RP01_RADR | a8ee41b2-9782-4cc4-f3b8-a626a73a7bb5 | Radon(Bq/m3) |
| 8. | ENIoTOR THE4BEES Šolski center Velenje | RF - Učilnica A-013 | 2018-06-11 14:43:02 | the4bees SI_SCV_A013_RF01 | 3d6739f4-e7e1-45d8-cf84-fad06d2dcd27 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 9. | ENIoTOR THE4BEES Šolski center Velenje | RF - Pravna služba (D207) | 2018-06-11 14:42:02 | the4bees SI_SCV_D207_RF01 | 19ee0e8f-49a2-4fa0-aaea-ecc84f95b790 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 10. | ENIoTOR THE4BEES Šolski center Velenje | RF - Računovodstvo (D208) | 2018-06-11 14:42:02 | the4bees SI_SCV_D208_RF01 | 0c43542e-9bd4-4154-e70e-cb0e8f6f4344 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 11. | ENIoTOR THE4BEES Šolski center Velenje | RF - Učilnica Fizike C101 | 2018-06-11 14:40:12 | the4bees SI_SCV_C101_RF01 | 37246b12-f12b-4497-cf8f-0d7e586c8a40 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 12. | ENIoTOR THE4BEES Šolski center Velenje | Spr. enota - Učilnica B101 | 2018-06-11 14:44:28 | the4bees SI_SCV_B101_RP01 | 65e9e9de-e722-47e3-a7d2-137323ae8802 | Temperatura(°C), Vlaga(%) |
| 13. | ENIoTOR THE4BEES Šolski center Velenje | RF - Ucilnica B101 | 2018-06-11 14:44:22 | the4bees SI_SCV_B101_RF01_V4 | 07b79256-aa6e-4838-b233-349571e0940f | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 14. | ENIoTOR THE4BEES Šolski center Velenje | RF - Telovadnica B | 2018-02-21 21:54:12 | the4bees SI_SCV_B01_RF01 | 015b56bb-8120-4e61-8bfa-9c16891920c5 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 15. | ENIoTOR THE4BEES Šolski center Velenje | RF - Telovadnica C1 | 2018-06-11 14:45:02 | the4bees SI_SCV_C101_RF01 | 37246b12-f12b-4497-cf8f-0d7e586c8a40 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb), Temperatura(°C), Vlaga(%), CO2 (ppm), Formaldehid(ppb) |
| 16. | ENIoTOR THE4BEES Šolski center Velenje | RF - Učilnica A-014 | 2018-06-11 14:43:02 | the4bees SI_SCV_A014_RF01 | c159df74-e36f-471e-d636-d6a217134ad4 | Temperatura(°C), Vlaga(%), CO2(ppm), Formaldehid(ppb) |
| 17. | ENIoTOR THE4BEES Šolski center Velenje | Radon via BT - Učilnica A013 | 2018-06-11 14:43:32 | the4bees SI_SCV_A013_RADBT_V2 | 9d70705e-7224-4f48-8c48-d26a7e7b6785 | Radon(Bq/m3) |
| 18. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija A013 | 2018-06-11 14:30:00 | the4bees SI_SCV_EE_A013 | 849ff4cf-f9e5-4db5-9cf3-ef9ea2069422 | Elektrika(kWh) |
| 19. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija A014 | 2018-06-11 14:30:00 | the4bees SI_SCV_EE_A014 | 17a2f5ff-6503-4304-9adb-646a1bc2c301 | Elektrika(kWh) |
| 20. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija D207 | 2018-06-11 14:29:58 | the4bees SI_SCV_EE_D207 | 56484440-e871-4942-acd0-81da07df7e87 | Elektrika(kWh) |
| 21. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija D208 | 2018-06-11 14:29:58 | the4bees SI_SCV_EE_D208 | 7f9b1f90-5ac5-40bd-fef2-7f4e03bd5799 | Elektrika(kWh) |
| 22. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija B1 | 2018-06-11 15:55:31 | the4bees SI_SCV_EE_B1 | 4516003b-f030-4db3-e352-3dca3883433e | Elektrika(kWh) |
| 23. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija C1 | 2018-06-11 15:55:31 | the4bees SI_SCV_EE_C1 | ce539342-180f-44e7-ee53-b3a0a197d2c2 | Elektrika(kWh) |
| 24. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija C001 | 2018-06-11 15:16:47 | the4bees SI_SCV_EE_C1 | ce539342-180f-44e7-ee53-b3a0a197d2c2 | Elektrika(kWh), Elektrika(kWh) |
| 25. | ENIoTOR THE4BEES Šolski center Velenje | Električna energija C003 | 2018-06-11 15:16:47 | the4bees SI_SCV_EE_C003 | bde0bb52-6dd1-4d59-e26a-2ad3317c88e6 | Elektrika(kWh) |
| 26. | ENIoTOR THE4BEES Šolski center Celje | kabinet | 2018-06-11 14:43:27 | the4bees SI_SCC_RP01 | 45d39985-1d3b-41b1-ba65-5d4f2f13f4f0 | Temperatura(°C), Vlaga(%) |

***Figure 14:** Overview of data streams at energija-rr .si web interface for THE4BEES project*

For a visual representation of the gathered monitoring data, quick testing and demonstration, a second web interface is used, available at http://www.klima.beri.si. It allows for the effective monitoring of several locations and a quick overview of the data-sending activity.



ENIoTOR THE4BEES
Šolski center Velenje

Električna energija A013
Elektrika 541.0 kWh
zadnji zapis 11.06.2018 14:30:00

Električna energija A014
Elektrika 5,948.0 kWh
zadnji zapis 11.06.2018 14:30:00

Električna energija B1
Elektrika -9,999,999.0 kWh
zadnji zapis 11.06.2018 15:55:31

Električna energija C001
Elektrika -9,999,999.0 kWh
zadnji zapis 11.06.2018 15:16:47

Električna energija C003
Elektrika -9,999,999.0 kWh
zadnji zapis 11.06.2018 15:16:47

Električna energija C1
Elektrika -9,999,999.0 kWh
zadnji zapis 11.06.2018 15:55:31

Električna energija D207
Elektrika 1,142.0 kWh
zadnji zapis 11.06.2018 14:29:58

Električna energija D208
Elektrika 1,816.0 kWh
zadnji zapis 11.06.2018 14:29:58

Radon via BT - Učilnica A013
Radon 22.0 Bq/m3
zadnji zapis 11.06.2018 14:58:25

Radon via RS232
Radon 36.0 Bq/m3
zadnji zapis 11.06.2018 14:59:20

RF - Pravna služba (D207)
CO2 465.0 ppm
Formaldehid 21.0 ppb
Temperatura 28.4 °C
Vlaga 49.4 %
zadnji zapis 11.06.2018 15:00:02

RF - Računovodstvo (D208)
CO2 454.0 ppm
Formaldehid 31.0 ppb
Temperatura 28.0 °C
Vlaga 50.6 %
zadnji zapis 11.06.2018 15:00:02

RF - Telovadnica B
CO2 1,300.0 ppm
Formaldehid 31.0 ppb
Temperatura 19.8 °C
Vlaga 49.6 %
zadnji zapis 21.02.2018 21:54:12

RF - Telovadnica C1
CO2 406.0 ppm
Formaldehid 16.0 ppb
Temperatura 25.6 °C
Vlaga 55.4 %
zadnji zapis 11.06.2018 15:00:02

RF - Učilnica A-013
CO2 560.0 ppm
Formaldehid 18.0 ppb
Temperatura 25.8 °C
Vlaga 59.2 %
zadnji zapis 11.06.2018 14:58:01

RF - Učilnica A-014
CO2 400.0 ppm
Formaldehid 21.0 ppb
Temperatura 25.2 °C
Vlaga 62.5 %
zadnji zapis 11.06.2018 14:58:01

RF - Ucilnica B101
CO2 405.0 ppm
Formaldehid 45.0 ppb
Temperatura 25.2 °C
Vlaga 49.0 %
zadnji zapis 11.06.2018 15:00:16

RF - Učilnica C02
CO2 405.0 ppm
Formaldehid 48.0 ppb
Temperatura 25.0 °C
Vlaga 60.4 %
zadnji zapis 11.06.2018 14:59:02

RF - Učilnica C03
CO2 401.0 ppm
Formaldehid 28.0 ppb
Temperatura 30.7 °C
Vlaga 39.8 %
zadnji zapis 11.06.2018 14:59:02

RF - Učilnica Fizike C101
CO2 622.0 ppm
Formaldehid 47.0 ppb
Temperatura 29.3 °C
Vlaga 48.3 %
zadnji zapis 11.06.2018 14:56:02

***Figure 15:*** *Visual representation of sensors/measuring units, last measurements value and time*

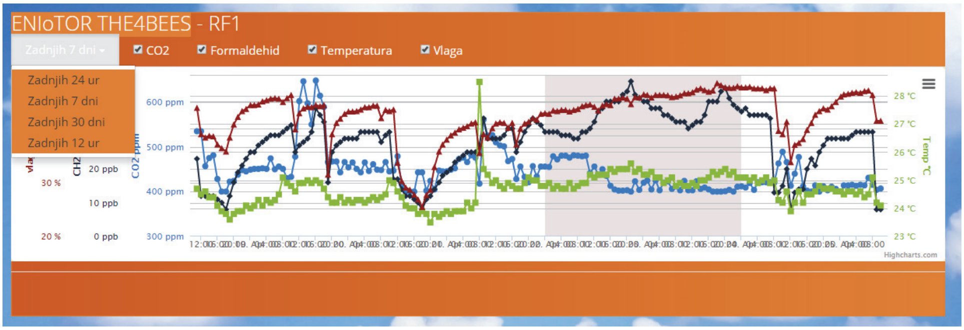


***Figure 16:*** *Visual representation of monitoring data (microclimate and CO2)*

# 5 CONCLUSION

The demonstration pilot carried out within THE4BEES project was designed to influence the behaviour of persons involved in the educational process on the secondary and tertiary levels. The activities, as well as the general design of the monitoring network, were focused on addressing students. Although awareness-raising activities were carried out non-selectively for all persons related in any way to the educational process, particular focus was dedicated to actively engaging students with an acquired skill set that was/is relevant to the scope and activities of THE4BEES project. Specifically, the students that participated in the largest extent in the pilot activities had previous experience in electrotechnics, electronics, automation, computer programming or any of the multidisciplinary related fields. This approach was applied to achieve the greatest possible impact and multiplicator effect (students become teachers, mentors and ambassadors) of the co-creation activities. The core sensing network was developed and tested for the purposes of pairing data on energy use (pre-existing energy monitoring information system) with monitoring data on microclimate parameters and indoor air quality within six buildings (6 classrooms, 2 gymnasiums and 2 offices) of the School centre Velenje (ŠCV), located at Trg mladosti 3. The sensor equipment was primarily tested and calibrated on the premises of a dislocated unit, the Interbussiness educational centre (MIC) Velenje, located at Koroška cesta 62a, 3320 Velenje, where certain co-creation activities were carried out mostly due to great access to laboratory equipment (development, testing, programming, first calibration). Particular focus was attributed to measurements of indoor air quality, that is defined as a prerequisite and benchmark for monitoring and optimizing energy use with reference to existing health and safety standards. To this end, the developed sensing network measures indoor levels of carbon dioxide ($CO_2$), formaldehyde ($H_2CO$) and radon (Rn) gases. $CO_2$ was chosen due to its negative effects on concentration and overall learning ability. Formaldehyde and radon are highly hazardous gases that were assumed to be problematic in the context of energy renovation of the thermal envelope, which generally reduces the air exchange rate between the interior and exterior, causing in many cases increases of formaldehyde and other VOCs (volatile organic compounds).

Furthermore, radon is formed from radium in the uranium decomposition series within the earth’s crust and rises to the surface where it enters the atmosphere or accumulates in enclosed spaces, such as caves, mines and buildings. Velenje has a long tradition of lignite mining and has also been very active in energy renovation in previous decades. A combination of these two factors points to the potentially hazardous build-up of radon levels on the ground/lower storeys.

ŠCV is primarily focused on the practical aspects of learning, so that students can achieve higher professional and technical education that is very specifically focused on market and industry needs, while the dislocated unit MIC has become a centre of excellence and modern technologies; in its classrooms and laboratories students can achieve quality functional knowledge in the field of energy, computer science, mechanical engineering, business, ICT and so on. In addition, the MIC is located in the vicinity (on top) of an abandoned mine shaft, assumed (and later confirmed) to pose an increased risk of radon gas presence. In addition, the entire complex is constructed around an advanced energy technology learning and demonstration course (including solar PV, solar collectors, geothermal applications, nZEB-nearly zero energy buildings, wind turbine, etc.) that unites the learning process within one study visit for pilot participants about energy, from production to consumption.

With the intent of gaining a better understanding of the needs and requirements of educational institutions within the region as well as establishing a stronger platform for promoting policy adaptation, it was necessary to engage additional schools that were willing to carry out the activities of the project and consent to installing the sensor equipment and support the monitoring processes. To this end, measurements were carried out within the premises of three additional educational institutions, the School Centre Celje (ŠCC), School Centre Ravne na Koroškem (ŠCR) and the elementary school Črna na Koroškem (OŠ Črna). Students from the School Centre Celje and the School Centre Ravne actively participated in the co-creation labs as well as follow up activities. The elementary school Črna na Koroškem, in contrast, was included in the monitoring system as a test-site for determining and quantifying negative effects of improper energy renovation on indoor air quality as wider consideration of associated health risks. Each of the three associated partner schools was provided with a set of measuring equipment, containing one Arduino sensor box, one Raspberry Pi sensor box data/concentrator, and the external radon sensor.

Pilot participants of ŠCC have been carrying out monitoring and awareness-raising activities in a specially designed classroom for extracurricular activities, equipped for enthusiasts and tinkerers of the vocational programmes, as well as for preparing for themed school competitions. SCR has placed the monitoring equipment in a joint classroom frequently used for addressing school visitors, taking every opportunity to point out the importance of securing excellent indoor air quality and provide information about THE4BEES project. The elementary school Črna na Koroškem used the equipment to successfully identify the shortcomings (in terms of microclimate parameters and indoor air quality) of the recently completed energy renovation of their buildings. Each school that engaged in the pilot was characterized by strong support from their principals and will continue make measurement and build upon existing knowledge and experience. The management and coordination team of the Slovenian pilot consisted of four educators (two from the School Centre Velenje in charge of operating and maintaining the internal EMIS system of the organization as well as carrying out organizational and awareness raising activities associated to energy efficiency, as well as one mentor from ŠCC and one from ŠCR), two representatives of a local SME that was chosen in a public tender to supply the equipment and oversee/support the development process, two students from the technical college programme at ŠCV, that each developed their final diploma thesis on the topic of monitoring indoor air quality/energy use (one focused on the deployment of the sensor box-Arduino unit and the other on the data concentrator-Raspberry Pi unit) and participated in the co-creation activities as mentors to the students of the secondary vocational programmes in addition to the constant engagement from the side of project partners KSSENA and EZAVOD. The core group that participated in co-creation pilot activities consisted of 22 students from the schools mentioned above, age from 14-18 and male. The monitoring system and pilot activities, in general, were very well received by the participating students. There is clear opportunity to engage students in innovative co-creation activities as demonstrated by THE4BEES project to complement the traditional classroom (education vs regurgitation) approach. Presenting specific problems to the students has a positive effect in terms of presenting a challenge, providing a sense of accomplishment once it has been met.

A major issue with using innovative approaches to conveying complex messages is the prohibition of the use of electronic devices on school grounds. The potential of supporting the learning process by such devices (like mobile devices and free applications) is substantial; therefore, the experience of the Slovenian pilot clearly indicates that such bans should be re-defined or lifted all-together.

From the Slovenian pilot experience, the feedback functionality is an essential part of addressing energy users and should be expanded within future project activities. It was clearly demonstrated that further personalization of applied IT tools that would be tailored to the individual and would learn from their past behaviour (login, UI customization, customized level of thermal comforts, etc.) would be necessary to improve their ability to engage and impact behaviour on the level of final consumers. Visualization of complex data was seen as a key factor for effectively conveying the message to the students, particularly in the form of demonstrations and infographics. An approach similar to workout or learning applications would be welcomed (30-day workout program, Endomondo, Duolingo, etc.), whereby the user is confronted with challenges and alerts that are designed to produce internal motivation and action. The applications should also allow the comparison between the present and past performance in order to quantify and stress the improvement an individual was able to achieve. Comparison and competition, in general, are great ways to engage and motivate students (users in general) in energy virtuous behaviour. The issue remains to secure good comparability of data and clear rules that unify the efforts and activities of each participant, which is very difficult in the field of energy use. A good way forward would be to organize such competitions in the form of training "boot camps", where participants would be able to demonstrate their knowledge/behaviour in a comparable setting. It was found that for households the information that motivated energy consumers the most was not, for example, the amount of money they were wasting with unnecessary energy use, but that they were consuming more (having a more significant impact on the environment, in essence doing worse from a sustainable perspective) than their neighbours.

Finally, virtuous behaviour (once quantified) should be rewarded. The capability to motivate energy users by making them part of the energy savings would go a long way. Great success was demonstrated past initiatives, such as implementing the 50/50 methodology in schools; however, more efforts should be made to reward the individual responsible for the desired outcome, rather than the organization or the managing authority. In its current state, the legislation and administrative procedure is prohibitive in the sense that it does not to any extent define the structure for rewarding virtuous energy consumption behaviour amongst users and managers and does allow even the minimal flexibility in public budgets for such causes; therefore, this option was not further explored within the Slovenian pilot. Part of the financial savings could be reinvested in new electronic equipment that students could use to build gadgets and tools in their school electronics/robotics classes, especially equipment used for building and learning on the field of energy, energy measuring, and energy consumption. In this case, both learning and awareness raising could be achieved, but there would have to be consistent support from the school/managing authority. Newly obtained knowledge about the importance and impact of indoor air (understanding of the impact of indoor air quality and microclimate on cognitive ability and health) should be argued primarily on the level of energy renovation.

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