Wireless sensor technology for building monitoring

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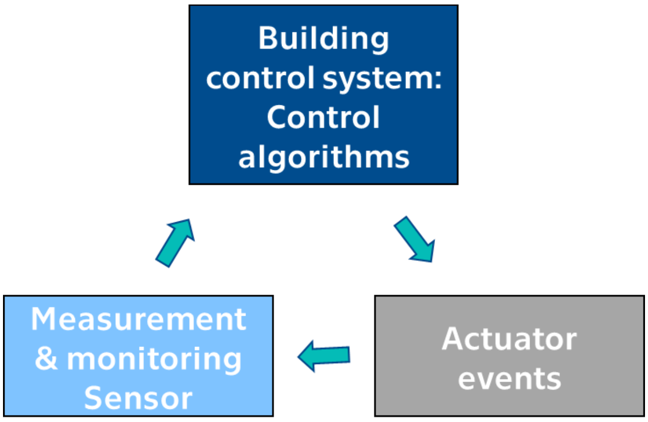
ARRS project J2-2504 – Technical report

Contents

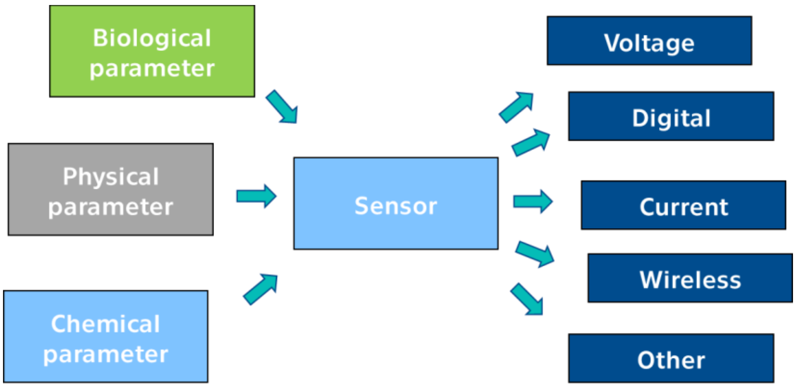
Introduction

Building automation and monitoring is a wide segment for applied electronics helping to control building systems, keeping safety operation of technologies and provide comfort and healthy indoor environment for the users. The basic topology of building automation systems is very often designed as a centralized system with three main components:

- Controllers
- Sensors
- Actuators



Building automation system architecture



Sensors interfaces

A wide range of controllers (Programmable logical controllers - PLC) is available on the market from the corporate global companies such as Siemens, Honeywell, ABB, Schneider, Johnson, Loxone, Wago and many others. In addition to controllers and actuators, sensors play a key role in providing accurate and reliable inputs for the control algorithms.

In many applications, in the building monitoring and control segment, a wired connection between sensor and controller is preferred due to reliability, unlimited service life or power related issues.

The number of wire communication interfaces and supported protocols is high and still most of the communications in the building automation segment is done over the cable.

Wireless technology is penetrating the building automation market in recent years. Improved life-time, reduced battery consumption and low investments in communication infrastructure allow the introduction of wireless sensors in many segments of building automation. Nowadays almost every control systems manufacturer offers a wireless solution for basic sensors and communication gateway or module to enable connection over wireless interface.

Communication technologies, interfaces and protocols

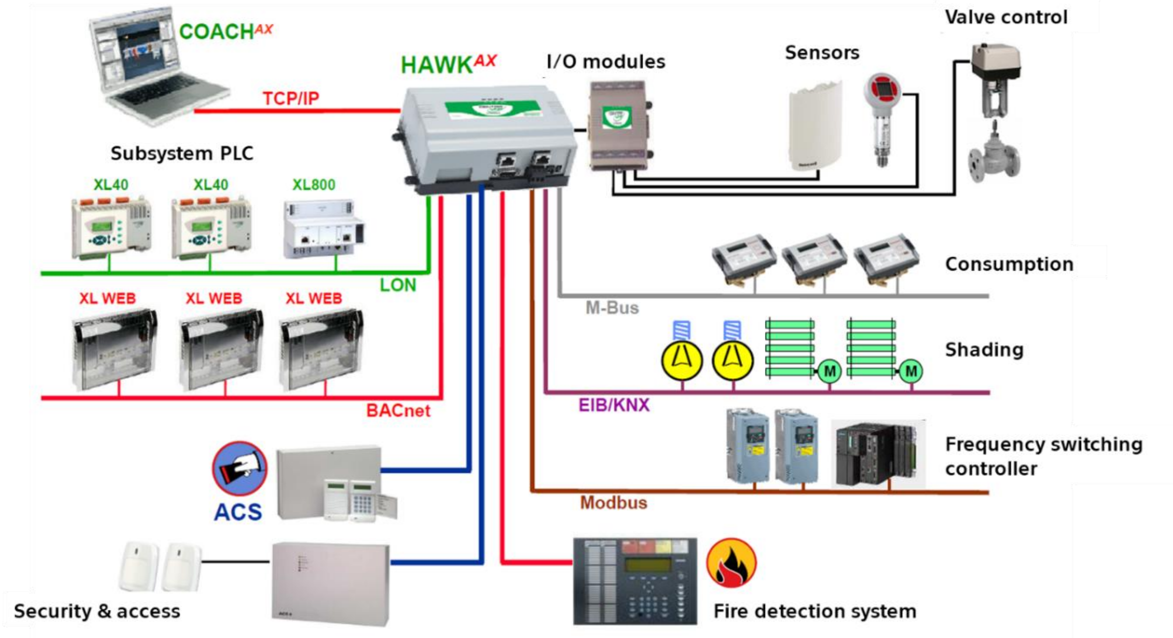
Sensor devices provide various wired or wireless communication interfaces and support many protocols over these interfaces. The most common interfaces together with their communication protocols are provided later in this section. Many sensors for home automation devices on today's market are designed to communicate data to vendor's cloud or third parties' cloud services (AQARA Cloud, Alexa, Apple HomeKit, GoogleHome). In many cases direct communication to sensor is not possible. To access the sensor data, it is possible to create scripts that download the data from the vendors portal using the provided APIs. In some cases, a portal registration fee is necessary to access the data via API.

Only few sensor devices are fully configurable and really open to communicate data to user defined platforms with standardized protocols such as MQTT or HTTP which are today the most common standards. In this case, the user defines the endpoint and provides authentication information no matter who designed or own the data portal. Such sensors allow local data pre-processing where the communication endpoint is still in the local network (local controller) and the whole solution is closer to edge/fog computing architecture.

A separate category includes wireless devices which need a separate dedicated gateway or infrastructure to relay their data to the Internet. IoT technologies such as LPWANs with global infrastructure LoRaWAN, SigFox or NB-IoT devices operating on LTE bands belongs to this class. Also, LP WAN local mesh wireless networks such as Zigbee or IQRF which need gateway to Internet or local network are within this group.

Wired interfaces and most common protocols

Wired communication is well accepted in the building automation segment and a lot of open or proprietary interfaces and protocols exist. Some of the wireless versions were created based on their wired twin (e.g. M-Bus and WM-Bus). Translation of the wireless communication to the wired one is usually provided by dedicated wireless gateway or directly available in the Programable controller.



Example of wired communication interfaces for building automation controller (source: Honeywell)

Examples of physical layers and common protocols:

- Ethernet
    - Protocols
        - MQTT
        - HTTP
        - Modbus TCP
        - BACnet
- RS485
    - Protocol Modbus RTU
- M-bus (for automated metering only)
- KNX (versatile communication for building automation)
- DALI (lightning systems only)
- LON (building automation)
- HART (industrial sensors)
- CAN (mainly for photovoltaic components)

Wireless interfaces, standards and protocols

Wireless communication is relatively new in the building automation segment but already many technologies and standards exist with differences in terms of range, data rate and application area.

The key enablers for the wireless technology in the building automation and monitoring were the following:

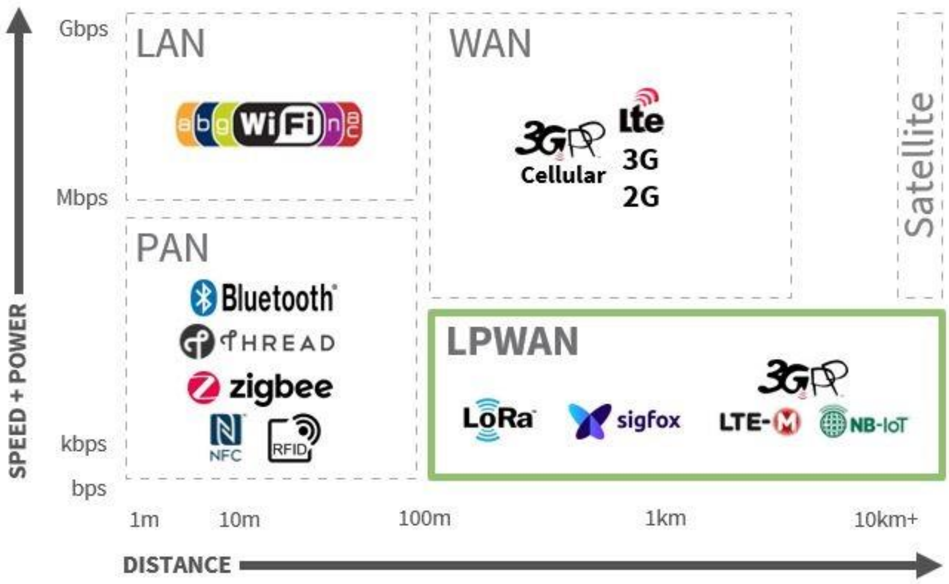
- Price reduction of all RF components, including gateways and infrastructure components,
- Miniaturization of RF interfaces, antennas, and integrated chip,
- Reduction of power supply for the transceivers,
- Introduction of new modulation techniques (spread spectrum) and protocols that are immune to interference, extend the communication range and lower the bit transmission energy,
- overall mature wireless infrastructure,
- IoT networks with nation-wide or global coverage, roaming,
- reduction of data costs over IoT networks.

RF technologies are used more and more in building automation and replacing the wired components. The core infrastructure, back-bone infrastructure and critical components are still created using optic fibre or metallic wire networks. A comparison table between commonly used technologies is given in the Figure below.

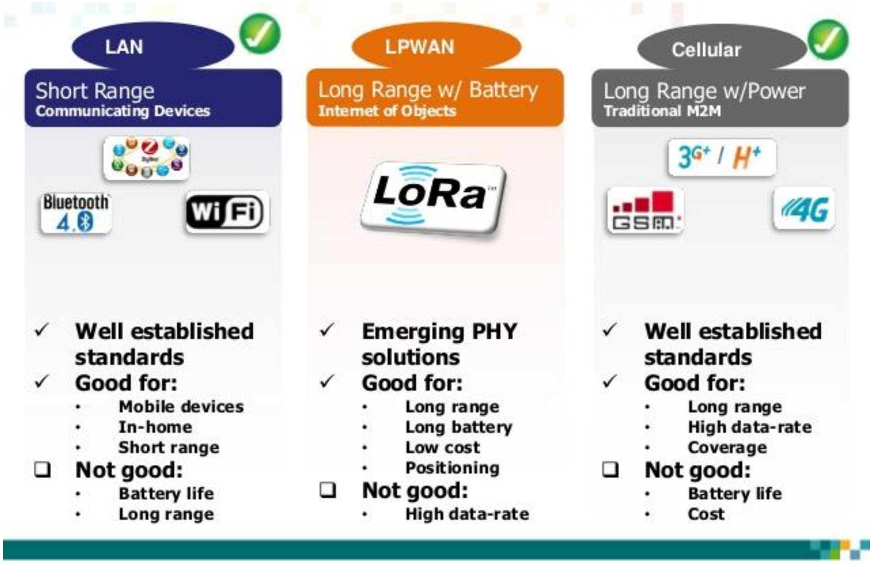
Some examples of wireless technologies used in building automation are:

- WiFi
    - MQTT
    - HTTP
    - Modbus TCP
- Active, passive or battery powered RFID
- EnOcean
- BlueTooth BLE,5.0
- LTE/GSM/GPRS
- WM-Bus wireless M-Bus
- LP WAN/PAN
    - LoRaWAN
    - Sigfox
    - NB-IoT
    - Zigbee
    - IQRF
    - Z-Wave

Typical examples of wireless IoT technologies commonly used in buildings nowadays



Comparison of the wireless technologies used in building monitoring and automation from the data rate and range perspectives



Comparison of common wireless IoT technologies with respect to advantages and disadvantages.

Wireless sensor technologies in building automation

Wireless technologies are suitable to replace wired solution only in some specific applications in building automation. The main reason for that is the limited service life of battery-powered devices and the necessity to replace batteries periodically which increases maintenance cost and requirement for staff. Combination of cord-powered sensors with WiFi connection is also a possible solution which eliminates necessity for battery replacement but uses the local power distribution grid in the building. Segments of user control and monitoring is one of the sectors where wireless technologies are replacing the wired solutions. Usually, the time-critical or control-critical inputs and sensors are connected by wires to keep the reliability level high.

Emerging markets for wireless technologies in buildings are:

- Utility metering
- Monitoring and diagnostics
- Indoor environment monitoring
- Technologies control (home automation, heating/cooling/air handling)

Utility metering

Utility metering is finally the segment where the wireless IoT technologies are used nowadays as a standard solution. Typical examples of wireless enabled products are:

- Electricity meters
- Gas meters
- Heat calorimeters
- Water meters

Utility metering is using mainly the IoT networks with nation-wide coverage but in some cases private local infrastructures are also used (LoRa or LoRaWAN). The range as well as the power consumption is adjusted to the use-case and the operation costs are reduced to the level where the wireless technology brings advantages in terms of reduction of human resources as well as additional benefits in terms of the smaller data granularity which allows advanced analysis of consumption. Data is communicated to the local gateway or to the national infrastructure which is subjected to operation costs paid to the national operator.

Examples of wire-less water meter and electricity meter. (Arad and Sagem)

Indoor environment parameters

Indoor environment quality could be assessed by various parameters. The parameters are not evaluating only air quality but the whole topic is much broader. Typically, indoor environment quality covers light conditions, acoustic conditions but also architectural design, in addition to air quality. Wireless technologies could serve as a good data transmission between the sensor and gateway especially in the case of extension to an already installed wired building automation system because the installation of extra cables would be most likely more costly than the sensors themselves.

Indoor Air Quality sensors – measured parameters

Air Temperature and Humidity

Air temperature and relative humidity are the most important and sensitive basic parameters; therefore, they are measured in almost every building also to control heating and cooling technology. Air temperature and humidity sensors are often combined in a single device and are very precise and cheap. However, the enclosure and PCB design can negatively influence the accuracy of measurement. Typical temperature accuracy is app 0.5 degree and relative humidity 2%. It is necessary to mention that relative humidity is strongly influenced by temperature and therefore these sensors are usually combined.

Concentration of Carbon dioxide (CO2 ppm)

The concentration of carbon dioxide gives basic information of how fresh the air is inside. Carbon dioxide is produced by humans and animals during natural breathing. The outdoor concentration of carbon dioxide is 400 ppm. The indoor environment is considered to be good if the level of carbon dioxide is less than 1200 ppm. If the level is higher people are losing the concentration, are subject to headache and feeling sleepy. People are not able to evaluate the concentration of CO_2 on their own since it does not smell. CO_2 is a bit heavier than the air so usually the concentration is higher closer to floor or in lower spaces of the buildings. The sensors used to measure concentration of this gas are today based on NDIR (Non-dispersive infrared) optical technology which is not affected by high drift such as electrochemical sensors.

Carbon monoxide (CO ppm or mg/m3)

Carbon Monoxide is a dangerous odourless and colourless gas in building mostly produced by non-ideal combustion processes. Exposures even to lower concentration might cause permanent health issues but also cause adverse reactions, including confusion and memory loss. Special detectors are designed to detect CO separately and are usually not combined with other gas detectors. CO is not usually contained in multi-sensor units for indoor air quality assessment.

Volatile organic compounds (VOC or TVOC, ppb, eCO2, VOC index)

Volatile organic compounds are mostly artificial but also natural gases emitted from a wide range of materials. Long-term exposure can have effects on the health of inhabitants. Most common sources of VOCs in the buildings are common household products, furniture, carpets, plastics, plywood, paints and varnishes, and obviously sprays and perfumes. Formaldehyde, ethanol, acetone also belongs to also one of the most common VOCs. Exposure to high concentrations of VOCs leads to throat irritation, nausea, fatigue, and other minor complaints. Long-term exposure to high concentrations might cause permanent health issues.

VOCs detectors are usually combined with other type of sensors. The VOC detection technology is usually based on electrochemical sensors, which are detecting any combustible substance and thus cannot differentiate between individual substances. That is why Total VOC (TVOC) is often used, instead of VOC. VOC concentration is expressed in units of ppb or more often as an VOC index or eCO2 (CO2 equivalent) which expresses VOC level in values of CO2 concentration which would have similar effect to human as the current VOC level.

VOC sensors are not very precise and as other electrochemical sensors suffer from high drift as well as necessity of periodic recalibration.

Radon activity (Bq/m3)

Radon is a naturally occurring colourless, odourless gas which is present in the regions with higher natural radioactivity (natural uraninite). Long-term exposure causes lung cancer. The buildings in affected areas must be well ventilated. The source of radon might be soil or water. Even if radon is known as a problem in some areas, it is rarely measured and devices to measure radon are not common. Radon sensors are still quite expensive devices sometimes combined with other sensors to provide complex information of the indoor environment. In affected buildings the Air Handling Units are controlled with respect to current radon concentration. Radon activity is described in units Bq/m3 (Becquerels per cubic meter).

Particulate matter level (ug/m3)

Weight of particles in cubic meter of air is expressed by Particulate matter (PM). Particles differ in size and shape. The smaller the particle the worse are the consequences on the health of humans. Particles are classified in the common classes with respect to their size. Most common classes are 1um (particles in size less then 1um), 2.5um, 4um and 10um. The most dangerous are particles with size less then 1 um. Exposure to high concentration of particles leads irritation to eyes, nose, throat. It can negatively affect lungs, causing allergy or asthma.

Dust are produced by industry, construction, power generation from fossil fuels as well as transportation and combustion engines.

PM sensors work on light dispersion technology and are usually equipped with active fan to lead the air into measurement chamber. The sensors need to go through periodic cleaning procedure where the light source and detector as well as the whole inner measuring chamber is cleaned from the dust using a strong air flow.

Other indoor environment parameters

Light intensity (Lux)

Light intensity also belongs to important parameter of indoor environment. Standards define minimal light intensity for the working environment. Design recommendations are also valid for residential buildings. The light quality is not only about intensity but today more and more often about light temperature (color). Light intensity is measured in units called Lux. Light intensity can be measured by cheap sensors, but correct placement and positioning is required for precise values. Therefore, the integration of light sensors in multisensory units is far away from ideal and values provided are only indicative.

Noise Level (dBA)

Noise is also a parameter that influences indoor environment. Noise can be measured by cheap microphone sensors. Commonly noise is expressed as average value over period, followed by minimal and maximal values in the period. Also, the placement of microphone is not ideal in the sensor and thus the values are also very indicative.

Home automation

Home automation and control segment is also suitable market for wireless technologies. Penetration of wireless technologies is relatively high in case of home automation systems but less in case of bigger buildings where backbone infrastructure is usually created by wired metallic or optical media. A lot of devices and system platforms is available on the market focusing on following segments:

- Switches, blinds control etc.
- Appliance control
- Lighting system control
- Room temperature control, heat valve control
- Relative humidity and temperature

Typical example wireless systems in home automation are EnOcean, Z-Wave or Zigbee

Examples of EnOcean wireless light switch, EnOcean receiver, wireless heat valve (EnOcean)

Sensor for indoor parameters monitoring – examples

Picture	Manufacturer	Type	Link	Est price (E	Meas Var.	Interfaces	Protocols	Power		note1	note2
	ASCOELGAP	CO868LR	https://ww	407	CO2/T/RH	LoRaWAN	LoRaWAN	LiSoC		LCD display	Data availible from LoRaServer
	GlobalSat	LS-111	https://ww	188	CO2/T/RH	LoRaWAN	LoRaWAN	USB adapter		LCD display	Data availible from LoRaServer
	URSALINK	AM107	https://ww	327	CO2/T/RH/VOC/Move/	LoRaWAN	LoRaWAN	2xAA		LCD display	Data availible from LoRaServer
	Humatech	HUMA-I HI300	https://ob	260	T/RH/CO2/VOC/PM	WiFi	Mobile APP, A	USB-C		Mobile App or Cloud	Vendor cloud only
	AirThings	2930 WavePlus	https://ww	248	Radon/CO2/TVOC/T/R	Bluetooth	Mobile APP	2xAA		Needs Mobile App	Vendors cloud only
	NetAtmo		https://ww	80	CO2/T/RH/Noise/	WiFi	Mobile APP/ C	Ac adapter		Integration to AppleHomekit, Google assistant	Vendors cloud only
	EVE	Eve Room	https://ww	100	T/RH/AirQuality	Bluetooth	Mobile APP/ Cloud			Mobile App or Cloud	Vendors cloud only
	AQARA	AQARA TVOC	https://ww	56	TVOC/RH/T	ZigBee	AQARA HUB gateway, mobile app,			AQARA cloud, Alexa, GoogleHome, IFTTT, Needs AQARA ZigBee gateway	Zigbee gateway necessary
	AWAIR	AWAIR Element	https://ww	140	T/RH/TVOC/CO2/PM2.	WiFi/Bluetooth/LoRaWAN		battery backup, Adapter		Mobile App or Cloud	Vendors cloud only
	Protronix	NLB-CO2+RH+T-5	https://ww	240	T/RH/CO2	IQRF/RS48	IQRF/ SigFox/	2x AA		IQRF needs local gateway, open protocols	Open communication API
	UniPi	RW-THC	https://ww	240	T/RH/CO2	WiFi/RS485	MQTT/HTTP/N	MicroUSB		Open configurable protocols	Open communication API
	Edimax	AI-2002W	https://ww	160	T/RH/PM2.5/PM10/CO	Wifi	proprietary	Adapter		Needs EdiGreen Mobile App	Vendors cloud only
	BleBox	airSensor	https://ww	87	PM1/PM2.5/PM4/PM1	WiFi	HTTP/JSON	Adapter		PM only, open communication protocols	Open communication API
	UCEEB/InoSens	IAQ_04	https://ww	215	T/RH/CO2/TVOC	WiFi/RS485	MQTT/HTTP/N	MicroUSB		Open configurable protocols	Open communication API

Wireless technologies comparison

	LTE	GSM/GPRS	NB-IoT	WiFi	BlueTooth	LoRaWAN	Sigfox	IQRF	Zigbee	Z-wave	EnOcean	RFID
Standardisation	3GPP, ITU-R	ETSI 3GPP	3GPP, EC-GSM-IoT	IEEE 802.11	IEEE 802.15.1	no	no	no	IEEE 802.15.4	ITU-T G.9959	ISO/IEC 14543-3-10	ISO/IEC, ASTM
Alliance	no	no	no	WiFi Alliance	BlueTooth SIG	LoRa Alliance	Sigfox	IQRF Alliance	Connectivityu standards Alliance	Z-Wave Alliance	EnOcean Alliance	no
Supported topologies	Star of stars, cells	Star of stars, cells	Star of stars, cells	Star	P2P	star with gateways	star with gateways	star/mesh	star/mesh	star/mesh	star	P2P
Frequency band	800,1800,1900 MHz	800,900,1800, 1900 MHz	800,900,1800, 1900 MHz	2.4,5 GHz	2.4 GHz	868 MHz	868 MHz	868 MHz	868 MHz, 2.4 GHz	868 MHz	315 MHz, 868 MHz	125/134 kHz, 13.5 MHz ,868 MHz,
Licensed band	yes	yes	yes	no	no	no	no	no	no	no	no	no
TX power	23dBm	26dBm	23dBm	up to 100mW	2.5mW	25mW/14dBm	25mW/14dBm	12.5mW	1mW	1mW	device dependent	application dependent
Range	3-30km	3-15 km	2-20km	50 - 250m	10-50m (version dependant)	up tp 20km	up tp 20km	up to 700m	10-100m	up to 800m	30-100	10cm-up to 5m
Datarate	75/300 Mbps	up to 80 kbps	200 kbps	100 Mbps	1Mbps - 48Mbps	0.3 - 55kbps	0.1 kbps	19.2 kbps	20-250 kbps	9.6 - 40 kbps	125 kbps	20-100 kbps
Advantages	Mature, availible infrastructure, global coverage,	Mature, availible infrastructure, global coverage,	Emerging new technology, availible componets, relative low fees and low power consumption, suitable for battery powered devices, relatively high datarate	Mature, componetns availible, very high datarates, license free operation	Mature, componetns availible, high datarates, license free opeartion, low power consumption	Relatively new but already established in most of EU countries, license free, very low power consumption, suitable for long-life battery operated devices with low payload, private networks possible, very long range	Established in most of EU countries, very low power consumption, suitable for long-life battery operated devices with very low payload, very long range	very low power consumption, mesh networks possible, suitable for long-life battery operated devices	Industrial standard for home automation and appliance control, widely used, low power consumption, lowcost solution, many type of devices availible	New emerging technology complementary to zigbee, higher range, very low consumption, many new devices and gateways availible	Supporting energy harvesting, good for home automation, designed for extra low power	extremely low consumption, power RF harvesting possible in specific applicaitons, passive battery-free simple sensors for construciton monitoring availible, small sensors easy to integrate, no need to access
Disadvantages	Licensed bands, only thru national providers, subscriotion and Tx data fee, high power consumption not suitable for battery powered devices	Licensed bands, only thru national providers, subscriotion and Tx data fee, high power consumption not suitable for battery powered devices	Licensed bands, in some countries not availible, subscriotion and Tx data fee	high power consumption, nost suitable for battery powered devices, limited range	Suitable for battery powered devices with acessible battery charging, limited range	Limited payload capacity and duty cycle, possible interference	Limited 12byte payload and 144 messages a day, sigfox certification required	Not used as standard, project oriented solution, basic componetns availible only from single vendor, limited range	very limited range	higher cost, certification program, range still limited	very limited range, limited functionality due to energy harvesting	Limited range and limited payload, energy harvesting works on very limited distance

Conclusion

In the previous tables, we provide a comparative view of the most famous wireless technologies available on the market today and the most famous products that provide measurements of indoor air quality. In the context of the project, we will adopt the UCEEB/InoSens IAQ04 sensor for their capacity to be USB powered, and provide Wifi connection, easy configuration, data access, and programmable interface through the Arduino IDE.