IoTWORLD ®

End-to-End testbed for the Internet of Things

1. BASICS

The IoTWORLD® is an End-to-End experimental platform for the Internet of Things, which main focus lies on the wireless connectivity, the data analytics and middleware management. It features:

- Heterogeneity of wireless technologies
- Scalable design
- Integration with 5G technologies
- End-user involvement

The testbed employs different sensors and actuators, connected to a set of gateways, either with a direct connection or via multiple hops. These gateways are connected to the Internet, through an innovative middleware which makes the integration of new wireless technologies very simple. Thus, overcoming the heterogeneity barrier. It also provides the capability to retrieve and store data in the cloud from a web interface or a smartphone application. Among other functionalities, it supports data fusion, data compression and data analytics.

IoTWORLD® allows you to obtain valuable information from the data measurements by means of data analytics performed on the edge. For this purpose, software defined networking tools developed at CTTC are key enablers to realize a flexible communication between the different computing entities.

Although the testbed is currently deployed in several spaces, including both CTTC buildings, such as a controlled room or a real office environment, is not constraint to such deployments but adaptable to the different use cases of interest.

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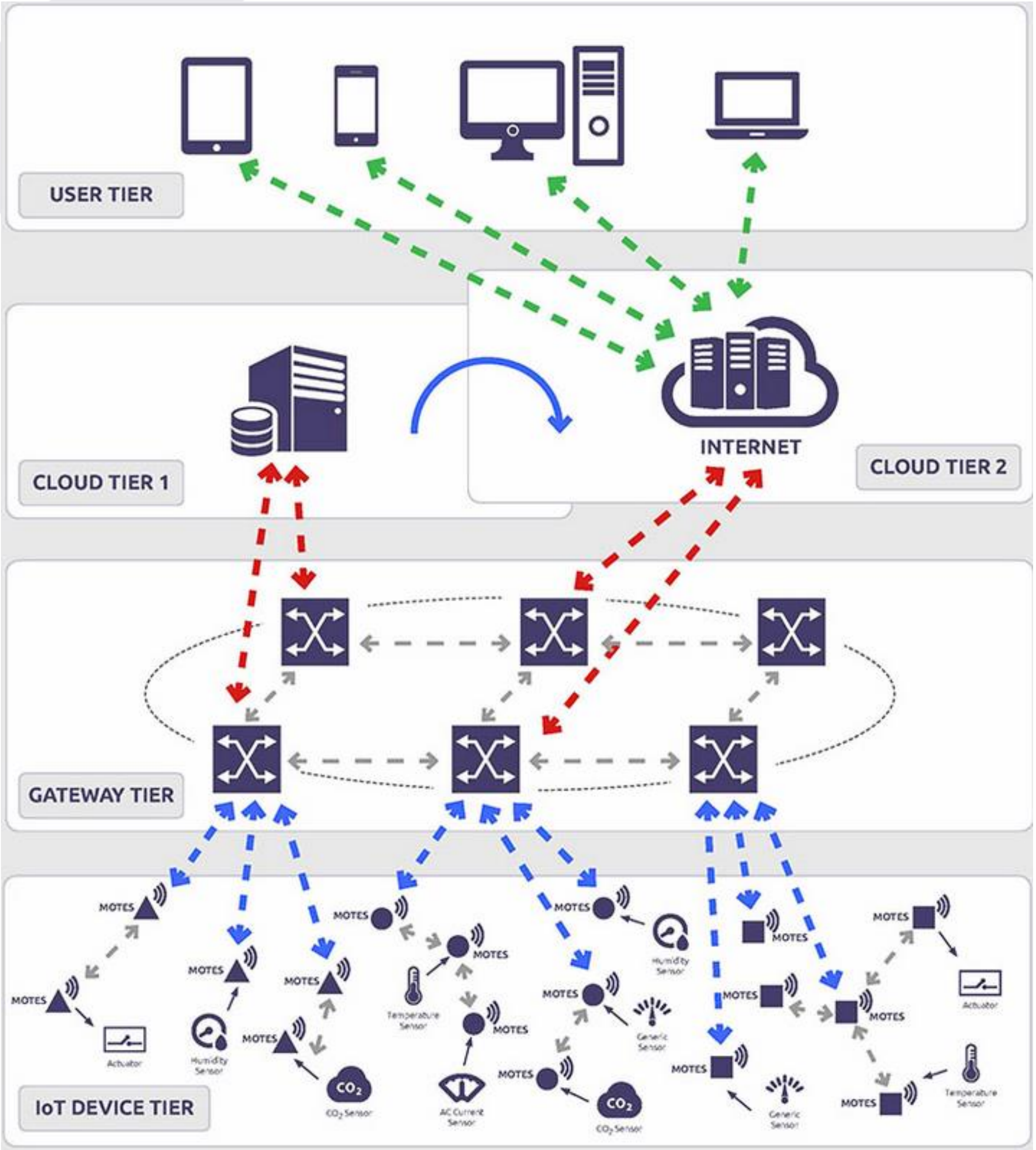
2. DETAILS

The heterogeneity of IoTWORLD® is realized in a variety of available sensors, actuators, wireless technologies, Internet connectivity, and use cases.

The IoTWORLD® testbed relies on the following 4-layer architecture,



The bottom layer consists of heterogeneous low power sensing devices and actuators which allow to interact with the real world. Sensor's devices include temperature, humidity, light, ultrasonic, accelerometers, CO2 level, power consumption meters, and a variety of eHealth sensors, among others. Actuators included in the IoTWORLD® are for instance smart DC plugs, lights, and moving robots.

The second layer of the IoTWORLD® consists of a set of gateways which permit to gather the data sent by the sensing devices via heterogeneous wireless technologies. This can be done either in a single hop or via multihop routes. Moreover, the gateways can also store and analyze the data measurements, and communicate with data centers on the edge via software defined networking. Thereby, data analytics on the edge are enabled.

Various wireless communication technologies are available in the IoTWORLD® to connect the sensors and actuators with the gateways. This includes Low Power Wide Area Networks, like LoRa and SigFox technologies, operating in SubGigahertz bands, as well as Zigbee and Low Power Wi-Fi.

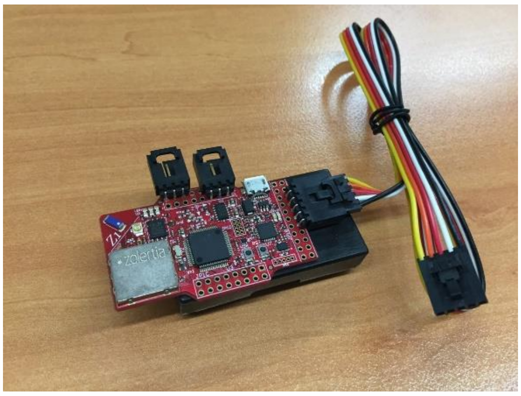
The gateways of the IoTWORLD® are implemented in Raspberry Pi 2 platforms. These are, essentially, small and low-cost computers which facilitate the flexibility and scalability of the IoTWORLD®. One of the functions of these gateways is to provide sensors and actuators with Internet connectivity to reach the cloud. This connectivity is provided in the IoTWORLD® via Ethernet, Wi-Fi, 3G and LTE, or operator-like Low Power Wide Area Networks. Another important function of the gateways is to provide distributed data analytics capabilities of the gathered measurements. Moreover, they can be connected to data centers in the cloud through software defined networking.

The third layer lies on the cloud, with distributed data storage and applications running on the cloud.

The top testbed layer consists of the user layer. Users can interact with the IoTWORLD® through applications running in their computing devices, such as tablets, smartphones, or personal computers.

The overall architecture is independent of the number of simultaneous running networks and connected nodes. Therefore, it is extremely flexible and scalable, as it is desired for a platform devoted to experiment with the Internet of Things.

TECHNOLOGICAL COMPONENTS



WSN MOTES – Z1 (Zolertia)

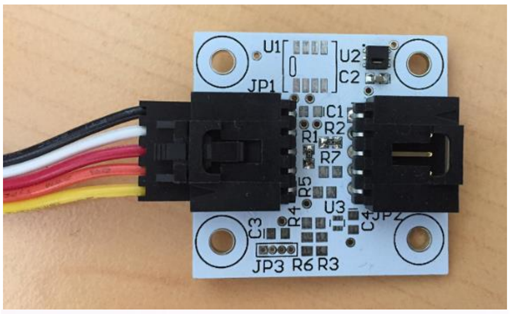
The WSN nodes deployed on the IoTWORLD® testbed are Z1 motes by Zolertia, equipped with a second generation MSP430F2617 low power microcontroller, which features a 16-bit RISC CPU @16MHz clock speed, a built-in clock factory calibration, an 8 KB RAM and a 92 KB Flash memory. They also include the CC2420 transceiver, which is IEEE 802.15.4 compliant, operating at 2.4 GHz frequency band with a data rate of 250 kb/s. The sensors support ContikiOS, an open-source Operating System for the IoT, which connects tiny, low-cost, low-power microcontrollers to the Internet and supports IPv6 through 6LowPAN. It is worth noting that each mote can operate either as a source or a sink node.

SENSORS

The testbed manages different types of sensors, such as:

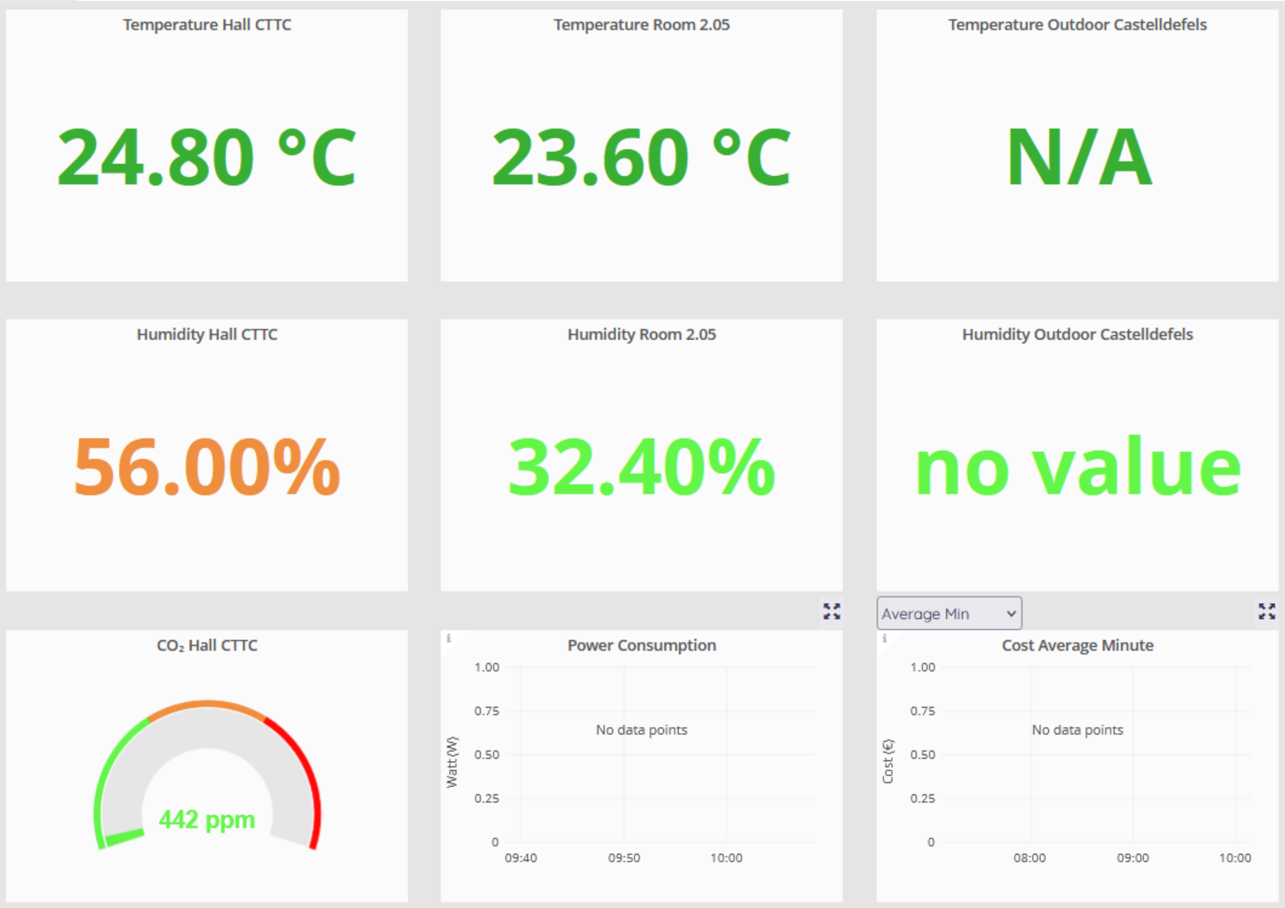
Current sensors (also called hall-effect sensors) which are the SCT-013-030 Non-invasive AC Current Sensors

Temperature and **humidity** sensors from Zolertia, model ZIG001



CO_2 sensors from Senseair, model CO_2 Engine K30

EXAMPLE OF MONITORING DISPLAY



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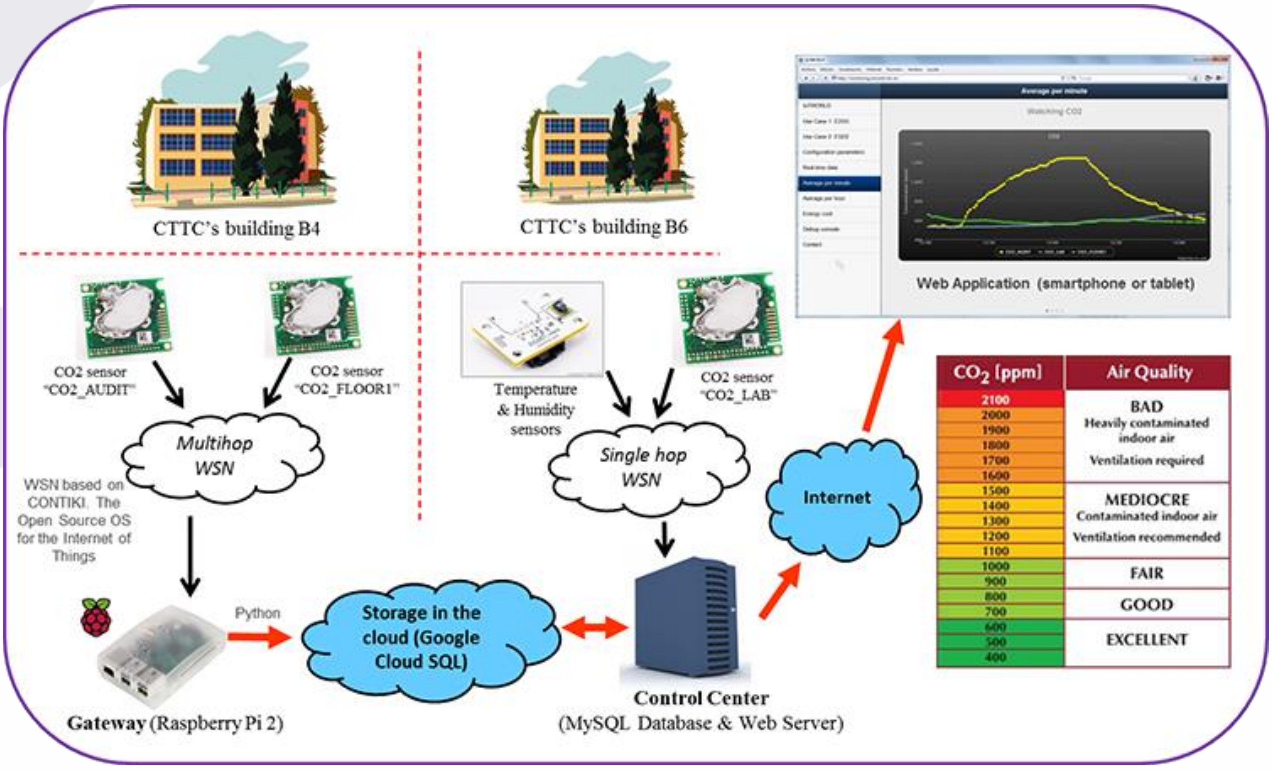
3. USE CASE #1: AIR QUALITY CONTROL

Air quality monitoring in smart buildings is of paramount importance for both people well-being and for the energy efficient management of HVAC (Heating Ventilation and Air Conditioning) systems. Regarding people's well-being, Carbon dioxide (CO2) levels are regarded as a standard for air quality. In fact, according to the Standard of The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), CO2 concentrations above 1000 ppm provoke severe effects on people's well-being such as discomfort, feel dizzy or feel headache. In this regard, next table (introduced by Max von Pettenkofer) establishes the relation between CO2 concentration levels and the indoor air quality.

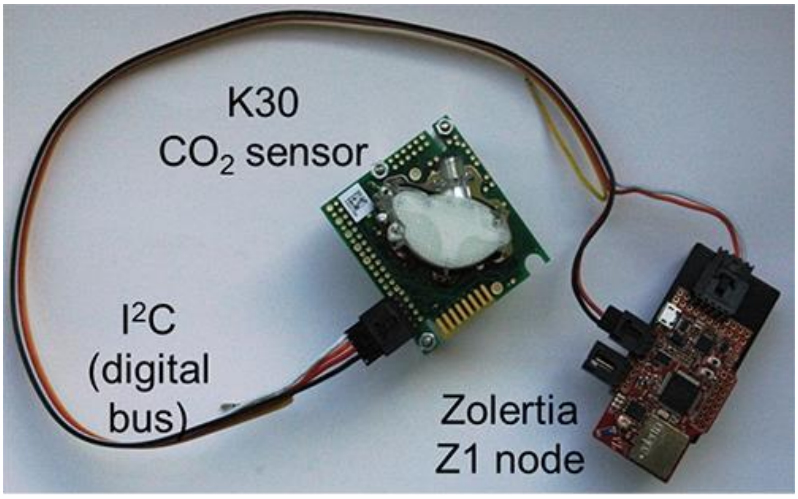
CO_2 [ppm]	Air Quality
2100	BAD Heavily contaminated indoor air Ventilation required
2000	
1900	
1800	
1700	
1600	
1500	MEDIOCRE Contaminated indoor air Ventilation recommended
1400	
1300	
1200	
1100	
1000	FAIR
900	
800	GOOD
700	
600	EXCELLENT
500	
400	

The air quality is monitored in two different buildings by means of CO2 sensors as CO2concentration level is the standard parameter to assess the air quality. Moreover, temperature and humidity sensors are deployed, as these are parameters directly related to the people's well-being. More specifically, the IoTWORLD® implementation for this setup is described next.



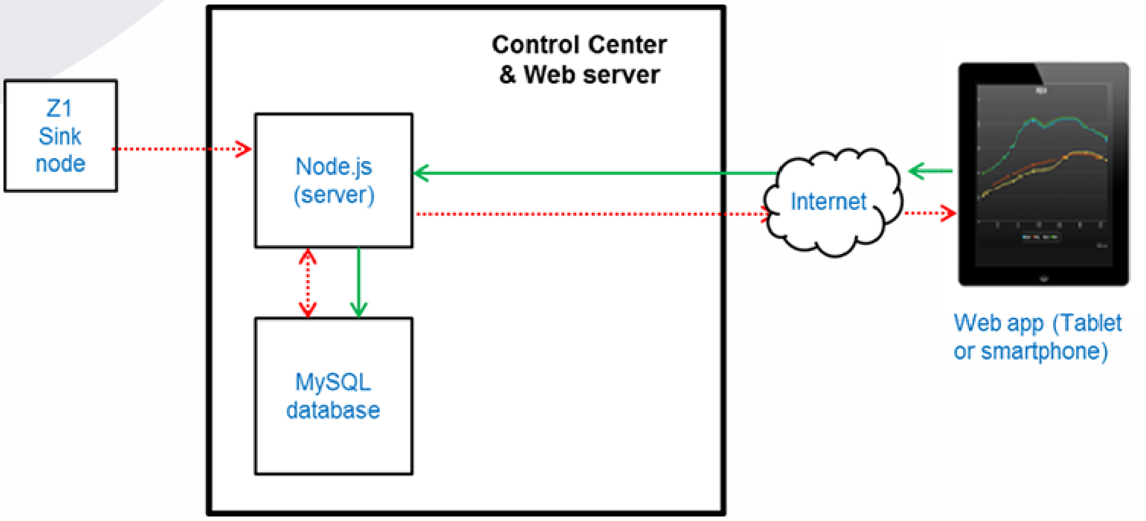
In CTTC's building B6, the air quality of one room is monitored by means of one CO2 sensor and two humidity and temperature sensors. The CO2 sensor is connected to a WSN node whereas each pair of humidity and temperature sensors is connected to a WSN node. The CO2Engine K30 sensor by SenseAir was considered to obtain the desired CO2 measurements. Regarding the WSN node, the Zolertia Z1 mote is used.

The connection between the CO2 Engine K30 sensor and the Zolertia Z1 WSN node is done through I2C (Inter-Integrated Circuit) communication protocol, see next figure:



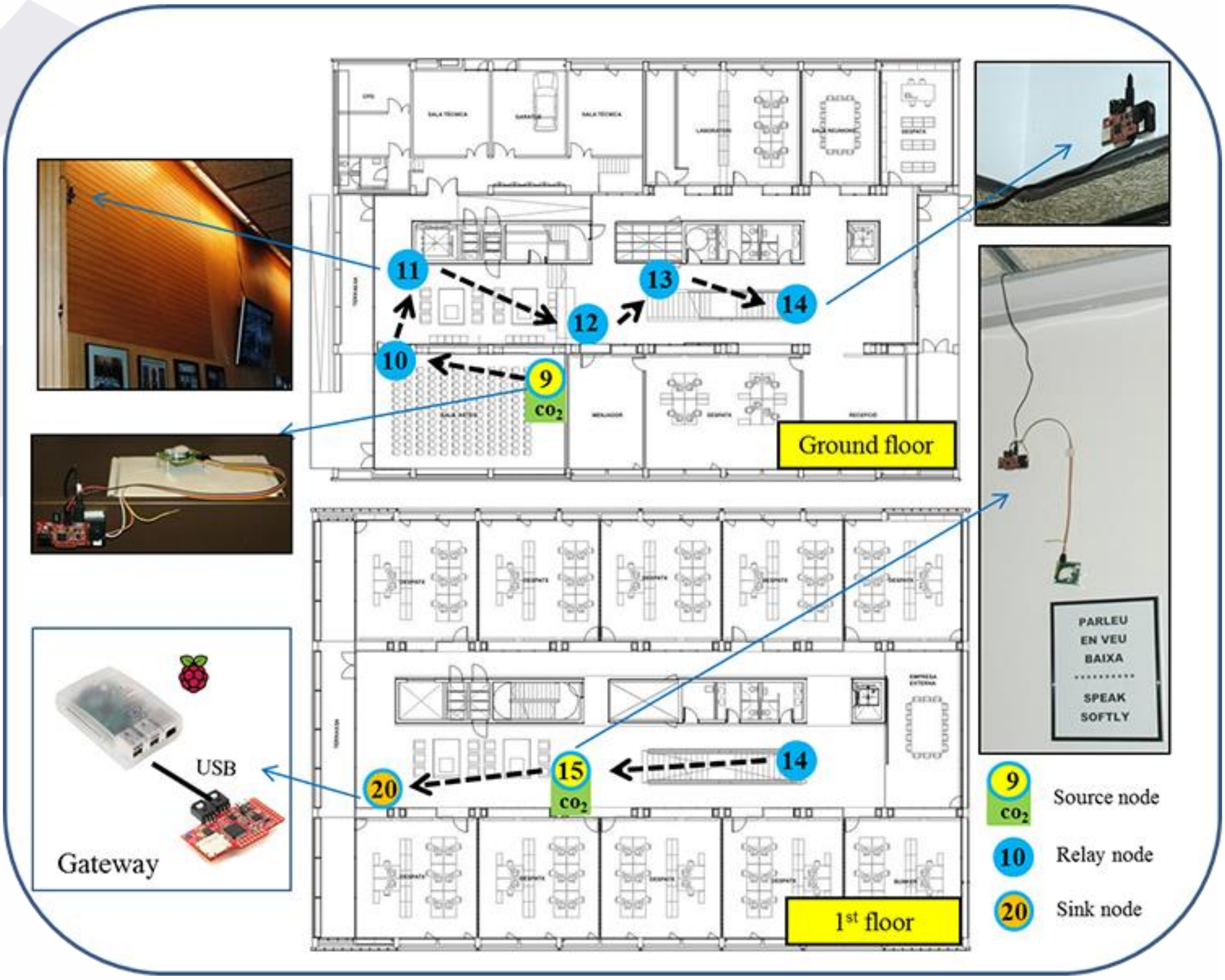
Regarding the temperature and humidity sensors, the SHT11 sensors by Sensirion have been selected. The WSN nodes gather the measurements, provided by the sensors, and send them periodically to a WSN node sink by means of a one hop wireless channel. On its turn, the WSN sink is connected via USB to the control centre. It is worth mention that the WSN nodes support Contiki OS, an open-source operating system for the Internet of Things (IoT). Contiki permits to manage easily the communication between the peripherals, i.e. the sensors, and the WSN nodes and also between WSN nodes.

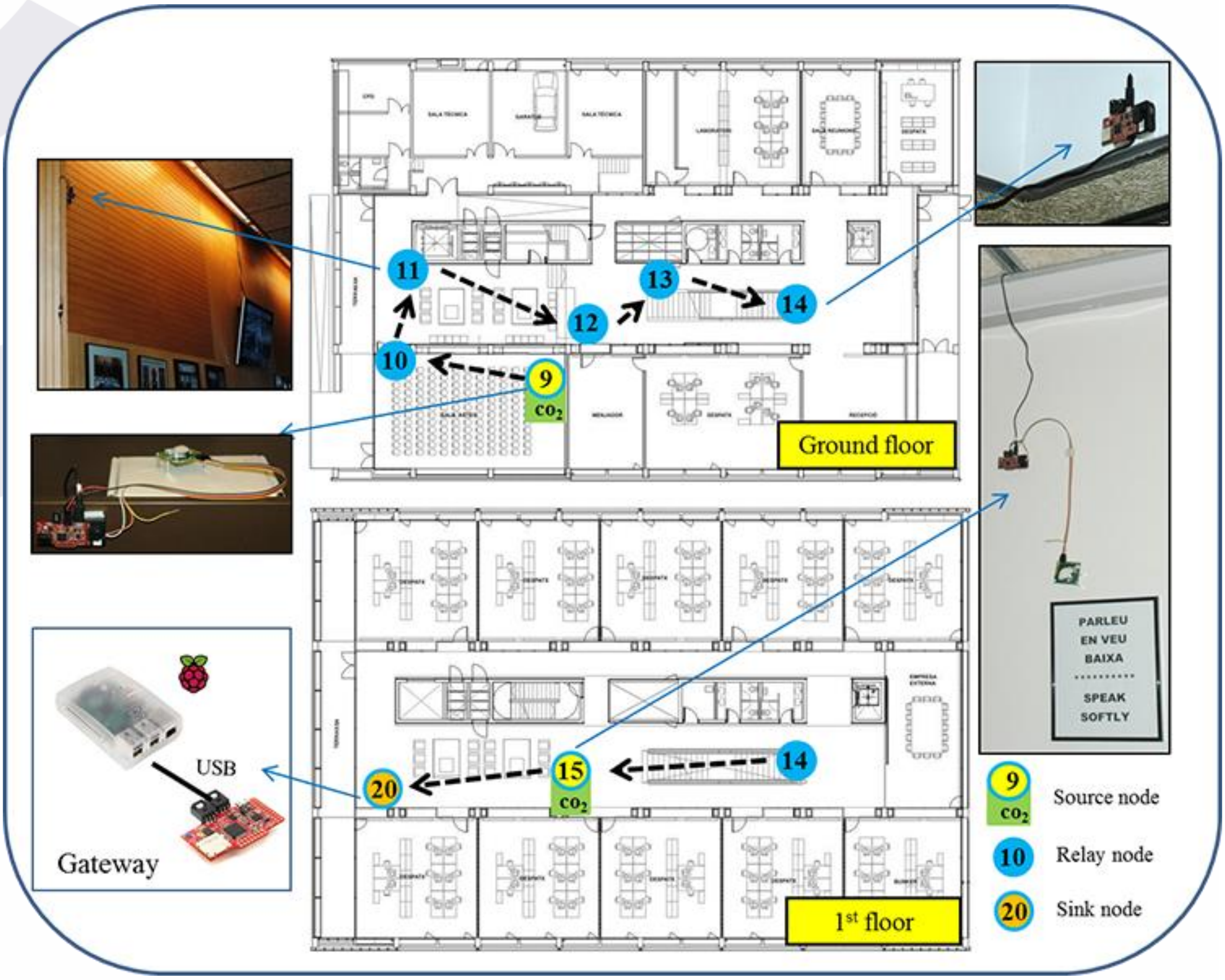
The control centre, consists of several sub blocks and has several functionalities which will be described next, by means of the next figure, which contains a detailed description of the control centre.



First, the WSN sink receives the measurements sent by the WSN sources. These data are sent to the server, which stores the measurements in a database. The server is written in JavaScript and the communication with the database is done by means of SQL queries. Moreover, the server manages the communication through internet with remote users. This permits the users to visualize remotely the air quality. To this end, in the user side we use a web application. More specifically, we rely on *Sencha Touch*, which is a high-performance HTML5 mobile application framework, which enables developers to build powerful applications for various operating systems, including iOS and Android. Thereby, by means of this web application, the user can see plots of the CO2 measurements. More specifically, real time plots and statistics of the last minutes and hours are displayed.

As it is shown above, the air quality is measured in another CTTC building called "CTTC building B4". The experimental setup in this building is as follows and it is detailed in the next figure.

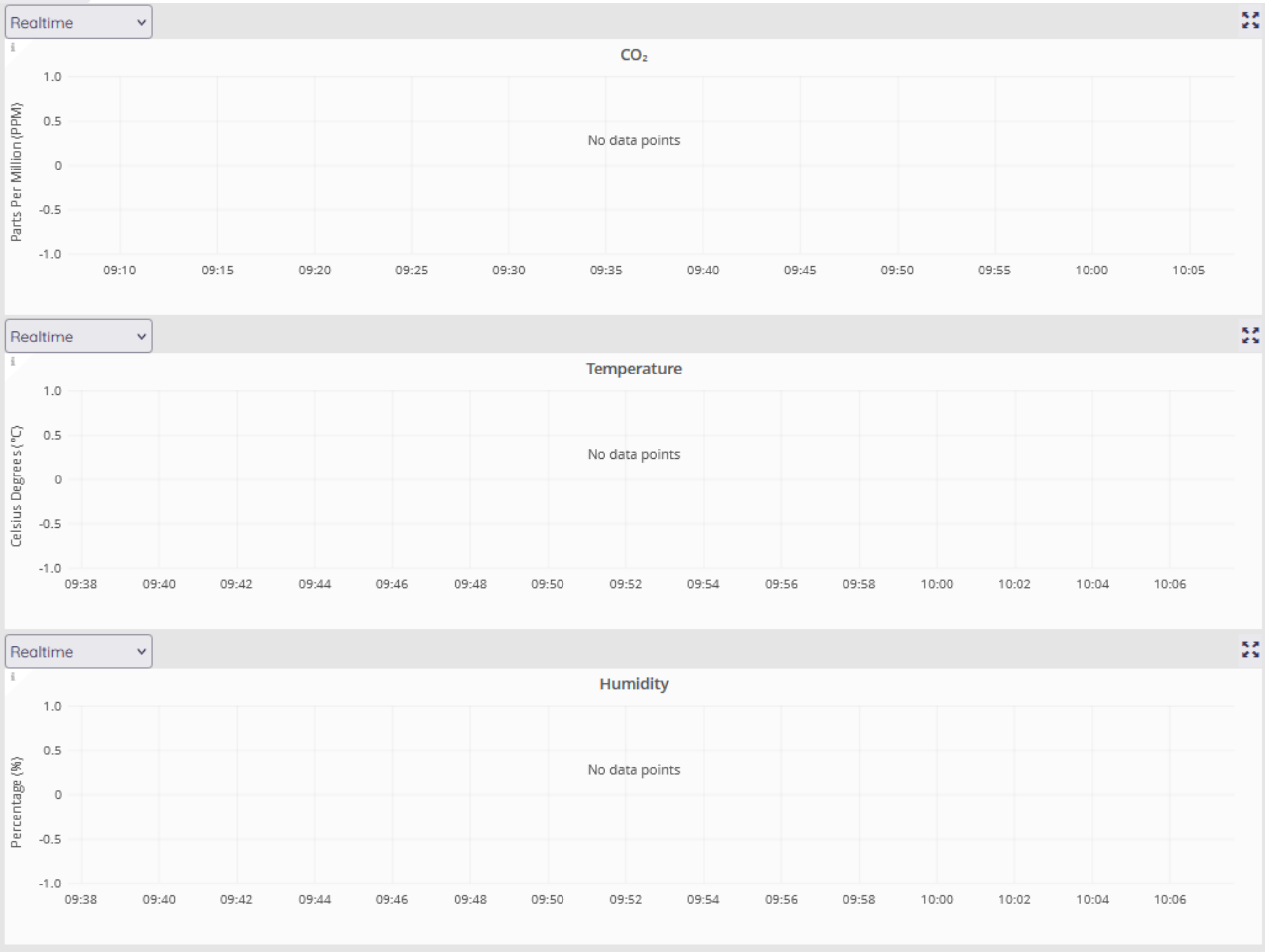

11
12
13
14
10
9
CO2
Ground floor
USB
Gateway
20
15
CO2
14
1st floor
PARLEU
EN VEU
BAIXA
SPEAK
SOFTLY
9
CO2
Source node
10
Relay node
20
Sink node



The air quality is measured by means of CO2 sensors in two different places of the building. The first one is located in the ground floor of the building, and its identifier is "9", whereas the other sensor is located in the first floor and its identifier is "15". As it can be observed, a multihop WSN is considered between the CO2 sensors and the gateway (GW). The GW consists of two components. The first one is a WSN sink, which receives the CO2 measurements forwarded by the multihop WSN. The WSN sink node is connected via USB to a Raspberry Pi 2, whose aim is to take the measurements of the WSN sink and to send them via SQL queries to the Cloud database. It is worth to mention that the software that permits to perform the SQL queries is based on Python language.

Last but not least it is important to specify how the multihop WSN relays the CO2measurements from the source nodes to the sink node. The protocol implemented for this purpose is called Routing Protocol for Low power and Lossy Networks (RPL). The main objective of RPL protocol is to address the routing problem in sensor networks, i.e. setting up and maintaining reliable paths as well as promptly detecting link failures without wasting energy and communication resources.

Air Quality Dashboard



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4. USE CASE #2: SMART GRIDS

The smart grid is envisioned as the evolution of the current energy grid, which faces important challenges, such as blackouts caused by peaks of energy demand that exceed the energy grid capacity. A proposed approach to alleviate this problem is to incentivize the consumers to reschedule their energy consumption to different time intervals with lower expected power demand. These incentives are based on dynamic pricing tariffs that consider a variable energy price.

Heating, Ventilation and Air Conditioning (HVAC) modules are considered as the most energy demanding appliances in buildings. The significant energy consumption of the HVAC systems, along with their direct influence on the user's well-being, highlights the necessity for effective HVAC management algorithms that reduce the power consumption in buildings, taking into account the end-user's comfort.

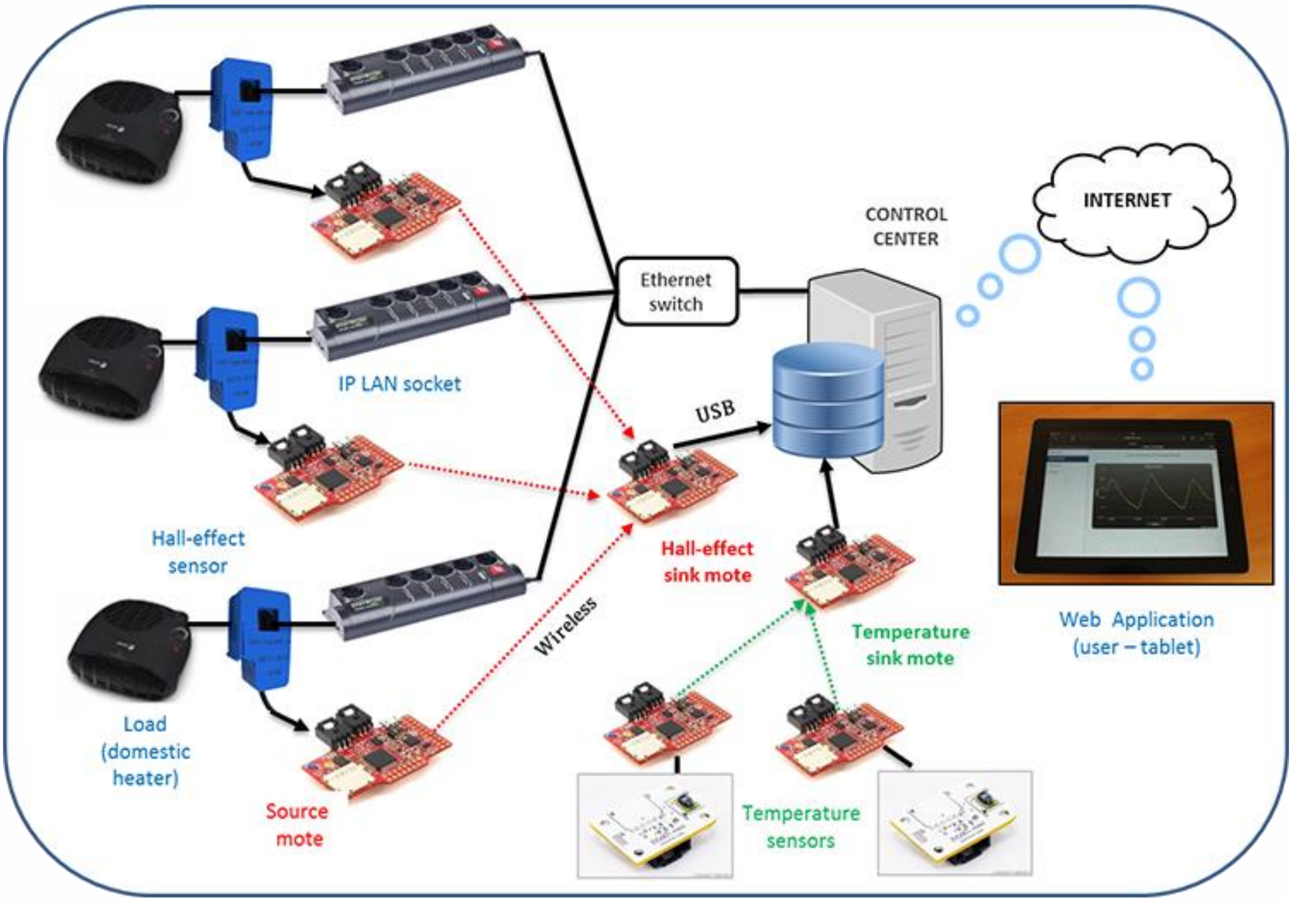


Figure 1 Proposed HVAC energy management system with comfort constraints in the context of IoT.

To this end, a system relying on energy scheduling methods was designed, see Fig. 1. These techniques assume a specific smart pricing tariff and various time periods. For each of these time intervals, the scheduler determines the operational power (ON or OFF) of the HVACs modules both to minimize the energy consumption cost and to respect the users' comfort constraints. These decisions are sent to actuators through an Ethernet connection. The actuators consist on programmable sockets where the HVACs are connected. To assess the comfort, the temperature is measured at several building positions by different sensor nodes that form a wireless sensor network (WSN), thus providing a more accurate measure of comfort compared to traditional methods. Thanks to the Internet of Things (IoT) paradigm, the user may interact remotely with the HVAC control system. In particular, a web server application was developed, which permits the user to decide remotely the temperature of comfort. Moreover, by means of this web application the real-time temperature and energy consumption information is sent through Internet and displayed at the end user's device. The energy scheduler, the web server application and a database, that stores the data measurements, form part of the Gateway subsystem. This is exemplified in more detail in Fig. 2, where a block diagram of the overall system is displayed.

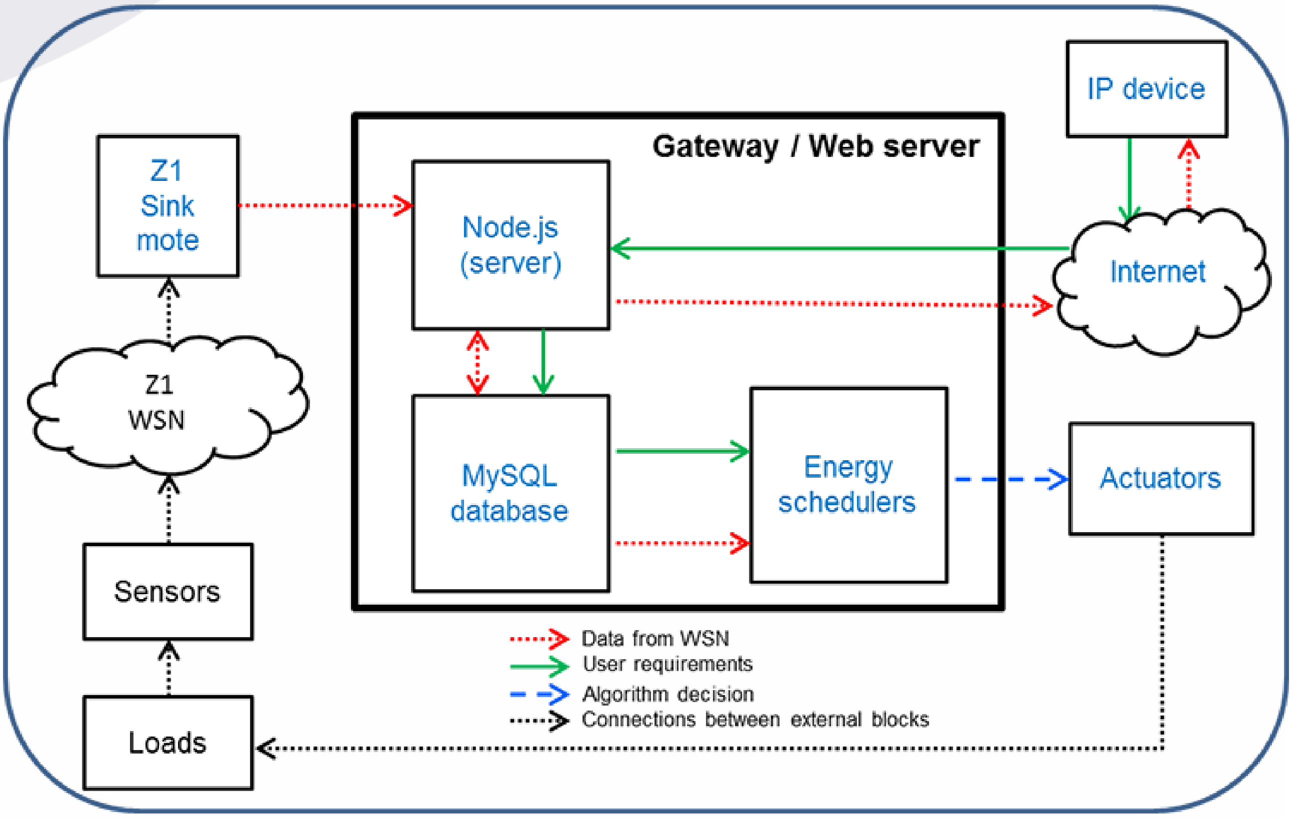


Figure 2 Gateway subsystem and its interaction with the rest of blocks.

Fig 3. shows in more detail the inputs (Smart pricing tariff, temperatures measurements and the user constraints) and the outputs (the decision to switch on or off a load) of the energy schedulers proposed.

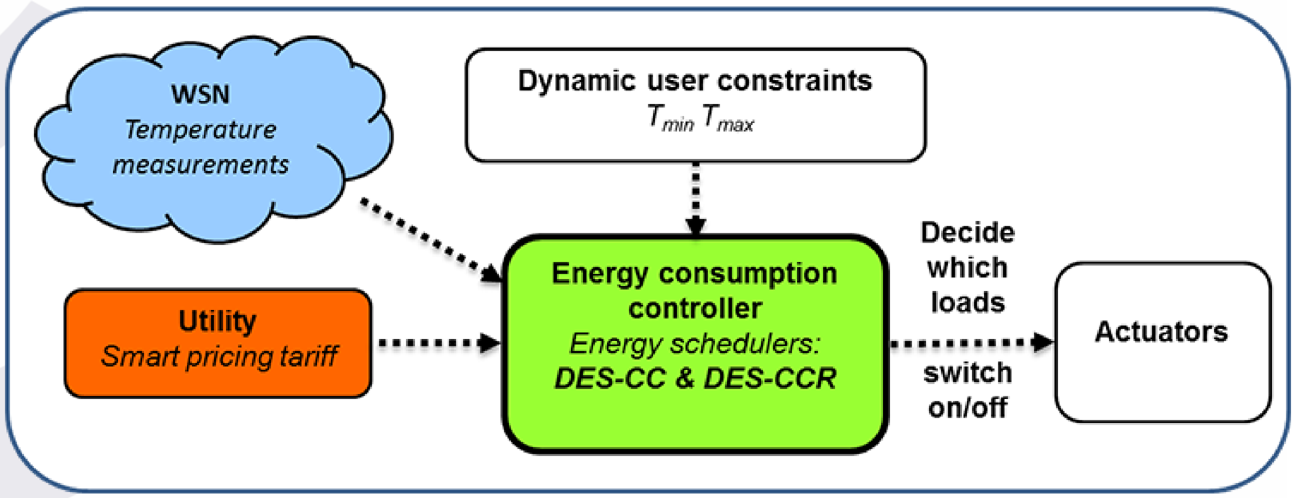
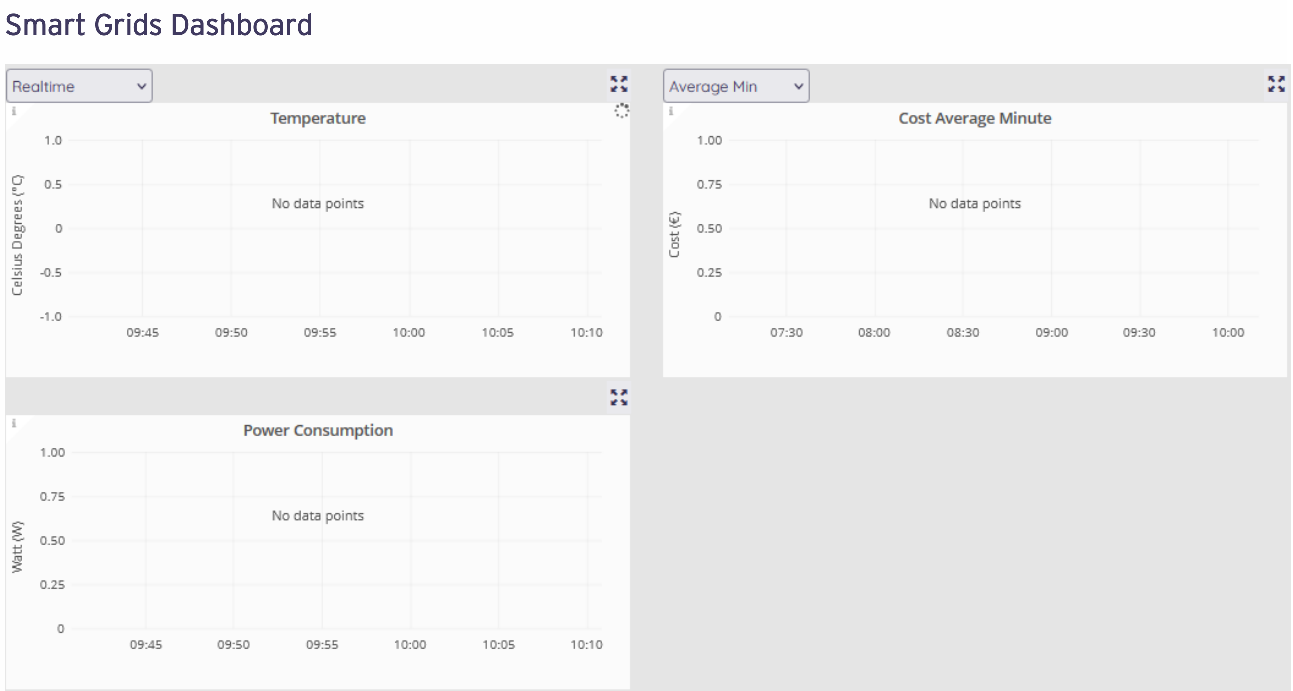


Figure 3 Energy scheduler inputs.



5. USE CASE #3: IoSENSE Project

The european project IoSENSE for "Flexible FE/BE Sensor Pilot Line for the Internet of Everything" (http://www.iosense.eu/) aims to improve the manufacturing capability in Europe and the time-to-market for innovative and competitive sensors and sensor systems

AdCon - IoSense project

PHOTO GALLERY