MOBISTYLE

MOtivating end-users Behavioral change by combined ICT based modular Information on energy use, indoor environment, health and lifeSTYLE

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Summary

This report Deliverable 2.1 presents inventory of the sensor and technologies allowing measurements of energy consumption, indoor environment and occupant health. The specification of sensors includes performance factors and practical and economic considerations. Performance factors such as range, accuracy, etc. are discussed in the inventory itself. Afterwards are discussed practical considerations including compatibility with other components forming a monitoring system.

The goal of the inventory is to produce an overview of measuring equipment currently available on the market that will later in the project serve as a basis over which MOBISTYLE will define applicable solutions for different real situations (demonstration cases). Later in the project, specific sensors and sensor networks will be chosen that are feasible and interesting for the application on the MOBISTYLE demonstration cases. The architecture of the monitoring system will be devised where installation of sensors and systems will be carefully planned and carried out for each demonstration case individually. This will then certainly show which of the devices from the inventory can be applied to which situations (demonstration cases) and how different devices can be connected into one system. Deployment of a varied range of sensors for 5 real demonstration cases will be presented.

Several reviewed articles expose a problem due to the fragmentation of the Internet of Things (IoT) protocols (technology platforms) which are normally incompatible with each other [9, 25-27]. Recognized by many IT developers, there should be a single, open, secure and interoperable framework that would allow interoperability of all IoT products and services. This would be beneficial for the MOBISTYLE project where the aim is to connect different devices (e.g. temperature sensor from BMS with sensor measuring heart rate through wearables). The review showed that currently a platform fragmentation and lack of open standards leads to a difficulties to customize and interconnect different sensors and devices available on the market.

As discovered during this research, for successful implementation of different sensors (new & existing devices) it is important that in future the manufacturers will agree on working together and adopt open standards and make smart devices open for free competition on the market. Currently, there are available several standard protocols, hence, the main problem is when combing different sensors from different manufacturers into a single framework. These systems need to have an open seamless infrastructure delivering data in real time. By allowing interoperable systems using standard technologies, it would not be important who is the manufacturer of the subsystem (sensor) which is an issue now (also in MOBISTYLE).

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1 Introduction

Energy consumption in buildings has been significantly increased in the last half century throughout the whole world mainly due to economic developments and growing living standards [1]. This raises concern about the energy consumption in buildings, which are a substantial user of energy worldwide. Buildings themselves account for around 40 % of total energy use which makes the building sector the greatest energy consumer around the world [2]. Therefore design of energy efficient buildings and improvements in the energy performance of existing buildings are becoming of vital importance. Buildings are becoming more air-tight and with more advanced building service systems [3]. The embedded stationary devices in the buildings (sensors, information and communication technologies (ICT) tools) are capable of measuring raw data (power, flow, temperature) which than has to be translated to the user in an understandable way in order to achieve the main aim of these 'smart' systems: achieving improved building energy efficiency.

In recent years there has been a widespread of IoT in smart buildings, however, there is a lack of attractive information presentation that will motivate users to start behaving in an energy efficient way. If the captured data is analysed and presented in an attractive and understandable way to the building occupant, this can open doors to a lot of opportunities where end-users are triggered to behave in a more energy efficient and optimized way in their buildings. This deliverable, 2.1, is therefore concentrated on gathering and analysing state of the art technologies that allow such data monitoring.

The main part of the report presents a review of the in-home equipment (mostly sensors, personal handheld devices with built-in sensors, wearables) capable of capturing data related to three key fields of application: building energy consumption, indoor environmental quality (IEQ) and occupant's health. By bringing in the health aspect, gamification and anthropology (understanding occupant behaviour), information that triggers the residents will be provided to different end-user types. This makes MOBISTYLE different to what the current market offers.

1.1 Aim of the report

The review Deliverable 2.1 focuses on producing an inventory of Internet of Things (IoT) technology and commercial products capable of capturing data identifying the three key areas as mentioned earlier (energy, IEQ and health). The technologies were evaluated against several performance factors such as usefulness, cost effectiveness, applicability, availability etc. The main information and sensor characteristics were obtained by studying the product information and available data sheets from the manufacturers (company or product website). Hence, sometimes certain sensor characteristics were missing and could not be clarified (e.g. missing information about sensor's sensitivity). Furthermore, not only the analysis of the sensor layers but also the interoperability between different sensors was analysed (computation and application layer) where such information was available. It is believed the interoperability between different system- and (open) standards is an important issue that needs to be addressed in the future in order to achieve a wider development and better implementation of the state of the art efficient technologies and products. Moreover, this becomes a greater issue when expanding an existing home automation system installed in a building (allowing monitoring of building's energy consumption, IEQ) with built-in sensors in wearables (allowing monitoring of personal health).

2 Sensor fundamentals

A *sensor* is a device that converts a physical property or quantity into a measurable signal or effect. As such, sensors represent part of the interface between the physical world and the world of electrical devices, such as computers. Beside the measuring data, measurements may also include building identification number, metered location (sensor ID), date and time and the measured value. The other part of this interface is represented by *actuators,* which convert electrical signals (pulses) into physical values [4]. It must be defined how many pulses corresponds to a specific unit at the meter.

Sensors can measure various physical properties such as: temperature, flow, pressure, force, position, light intensity etc. Sensors are most often not individual instruments but are part of a larger system (measurement, data acquisition or process control system) consisting of signal conditioners and various signal processing circuits (analog or digital).

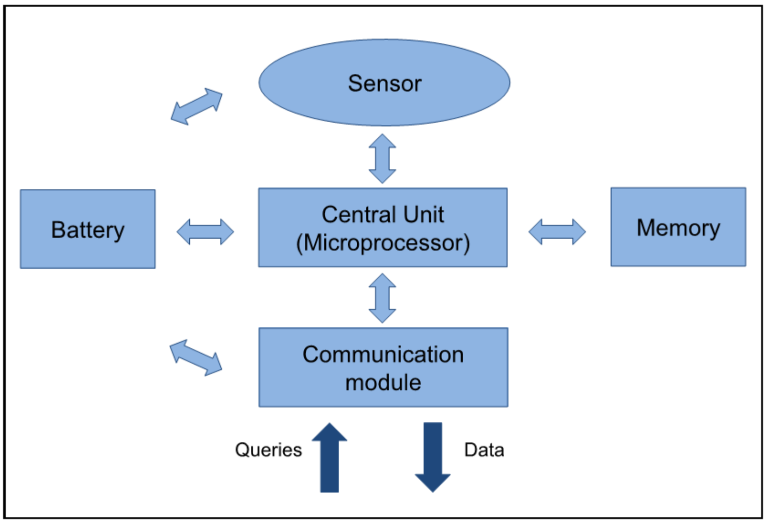


Figure 1: Architecture of a sensor node according to Verdone et al. [5

For further information on sensor technology it is referred to two books, Sensor technology handbook by Wilson [4] and Wireless sensor and actuator networks by Verdone et al. [5].

The specification of sensor includes performance factors and practical and economic considerations. Performance factors such as range, accuracy, etc. are discussed in the inventory itself, Chapter 3. Practical considerations including compatibility with other components forming a monitoring system are discussed in Chapter 4 and 5.

2.1 Why do we sensorize things?

Before the monitoring parameters are set for each MOBISTYLE demonstration case it is needed to decide why the sensorizing is even required. In general performance parameters are monitored to assess what needs to be changed to reach or stay in a target status or to observe a change indicating deterioration [6]. The main objective of the MOBISTYLE project is reducing building's energy consumption. Nevertheless, improving the generated indoor environment and monitoring occupant's health are other two important objectives to be satisfied. Still, for each of the demonstration buildings in MOBISTYLE project individual architecture will be devised based on building occupants needs and wishes and requirements of a specific building.

In this way, the final decision on what type of sensor network will be installed in the demonstration buildings will be done when answering the following question: ‘’What information do we want to obtain (data types), what we already have, how much accuracy we need and how much we are willing to pay?’’

Based on the gathered data and objectives of the measurements for each demonstration case, the assessment (ranking) of sensors will be done in terms of usefulness, cost effectiveness (life time costs), product’s lifetime, reliability, applicability, availability, etc.

3 Inventory of data measuring devices

Following chapter presents inventory of state-of-the-art equipment available on the market allowing measurements of energy consumption, indoor environment parameters and occupant health. The presented sensor types were chosen since they are commonly used for sensoring built environment, energy consumption (gas, electricity), indoor environment (thermal comfort and indoor air quality), outdoor conditions (outdoor temperature, rain, wind), occupant behaviour, presence and light control (lights, window opening) and health (metabolic rate, heart rate, steps). Sensors were identified and categorized according to the measuring phenomena and their main characteristics were described.

3.1 Sensor data sheet

Sensor data sheets can serve as a basis for the identification of the sensor characteristics. This documentation presents a commercial document, where manufacturers most often focus on description of the performance parameters that the sensors have been designed for. As discovered, such sensor data sheets are leaving out the information that might be important for different application than intentionally designed for or when integrating the sensor to existing building monitoring system developed by another commercial provider. In general, it is recommended that this information is obtained from the manufacturer (by contacting him) before the actual sensor application takes place [4].

3.2 Classification of monitoring technologies

This chapter presents a classification of monitoring devices allowing observations and analysis of buildings energy performance, outdoor conditions, indoor environment, occupants behaviour (presence, lights) and occupant’s health. Description of principles of the sensing technologies allowing observation of each parameter is presented in each subchapter. This is further supported with a description of advantages and disadvantages.

These sensor types were then characterized according to their accuracy, measuring range, response time, communication technologies, connectivity, resolution, sensor mounting, output, working voltage and cost. There are many commercial producers offering these types of sensors on the market and certain commercial products are also described in this report. Hence, which products to choose for each of the demonstration cases will be defined later on in the project when also building requirements and characteristics of the current installed monitoring system will influence the choice of new sensors to be installed.

3.2.1 Energy sensing and monitoring

To measure energy consumption (gas, electricity) energy meters, sub-metering, plug-load measurements, natural gas meters and other sources of energy meters are included. Sub metering allows facility managers to track energy consumption by carrier, area, department, tenant and an individual piece of equipment after the primary utility meter. With submetering, a clear and accurate picture of how and when energy is being consumed inside a facility is created.

Furthermore, MOBISTYLE partner Whirlpool will offer white good appliances to apply for a chosen demonstration building where various types of wireless sensors can be used to obtain appliance-state information. Within this information, consumer can get an insight in whether the energy inside a building is wasted and therefore turns the appliances off when not needed. Furthermore, the advanced technology also allows communication and exchange of information (data) between different devices and in future even further optimization will bring direct communication and control between different devices.

During this research, two measurement systems seem to be most feasible options. Smappee monitoring device is cheaper than Plugwise and both devices allow real time energy consumption monitoring. Hence, data per appliance measured by Smappee is often not really reliable and accurate. Furthermore, it takes a while before appliances are recognized (sometimes not recognized at all). The main disadvantage of Plugwise is that the device needs to be plugged to a wall outlet which is not always possible.

Energy meters

Gas meters such as diaphragm, rotary and turbine ones are most commonly installed gas meters. All three types of gas meters use dynamic mechanisms to measure the gas flow. The main advantages is low cost where the main disadvantage is high pressure losses and inability to indicate instantaneous flow rate value [6]. In the recent years, static devices such as ultrasonic flow meters (Table 1) have shown significant results regarding accuracy and non-intrusiveness. Fluidic meters are used for commercial buildings and are based on fluidic dynamic oscilliaton principle [7, 8].

Electricity meters are sensing the values of current and voltage to provide a measurement energy used (and possibly power demand). The most common energy meter is electromechanical watt hour meter (a 2-phase inductive motor) [6]. Still, it is expected that in the coming years in commercial as in residential buildings electronic (solid state/digital) advanced meters will be installed which do not require moving parts and are capable of storing and managing data [9]. They have higher accuracy, data storage and communication capability that allows managing energy and power data.

Both electricity and gas meters can be considered as smart meters where the measurement principle stays the same. Hence, smart meters contain electronic devices that convert pulse information to the reading and then store the reading and send it to the server [10]. As a consequence to the fact that there are many existing traditional meters installed in the existing buildings, many manufacturers developed automatic meter reading (AMR) solution which allows upgrade of a traditional meter to a smart meter in a fast and non-invasive way [11]. Here, it should be noted that the price of the metering device depends not only on the price of the meter itself but also on the measuring range, pulse output option and AMR compatibility. Still, energy companies in the end decide whether they want to upgrade the metering to smart metering. Often they do not add additional electronics to an existing electrical meter but rather change the electrical meter into an electronic smart meter which energy companies normally use for remote measuring and billing.

Table 1: Energy meters inventory.

Parameter identification and measuring device		Cost (€)	Sensor mounting	Measuring range	Output	Working voltage
Gas meter	Diaphragm for residential b.	125 - 200	Fixed	Up to 7 m^3/h	Odometer counter Pulse	
	Diaphragm for commercial b.	150 - 265		11.33 – 28.32 m^3/h	Odometer counter Pulse	
	Fluidic for commercial b.	2000 2600	Fixed	Up to 28.32 m^3/h Up to 84.95 m^3/h	Pulse	
Heat and cooling energy	Ultrasonic heat meter UH50		Fixed (horizontal or vertical)	Measuring range of flow 1:100 as per EN 1434, 1:1000 total range	Pulse RF, M-Bus module Analog module	Power pack or battery charge -Power pack AC 230 V, cable length 1.5 m -Standard battery (2 AA), for 6 years.
Domestic (hot) water usage	Single-jet dry dial meter with pulser		Fixed (in any orientation)	Model ETWDI for warm water up to 90°C 80H/40V (Q3/Q1) Model ETKDI for cold water up to 30°C 40H/40V (Q3/Q1)	Digital [m^3]	
	Pulse (hot) water meter	Installation 30 - 60	Fixed (in any orientation)	0.1-99999 m^3/h (Accuracy ± 1 %)		
Electricity	Power meter		Fixed	0 – 3000 W ±0.5% (time step 0.01 W)	Consumption measuring 1 Wh – 9999 kWh	Max recording time 2376 h
	Multimeter	*Measuring electric intensity (A), tension (V), apparent power (W), active energy (Wh), power factor (-), power peak (kW).				
	Pulse counter					

Outdoor conditions

When doing building's energy monitoring, climate data is clearly important due to the connection between the consumption and outdoor climate. Therefore, Table 2 presents sensors allowing

Table 2: Sensors allowing measurements of outdoor conditions.

Parameter identification and measuring device		Cost (€)	Measuring range	Accuracy	Response time	Communication	Resolution
Outdoor air temperature	Thermocouple	20 - 70	-40 – 80 °C	± 0.8 - 4 °C	10 – 80 sec	Wired Portable	≤ 0.05 °C
Outdoor relative humidity	Hygrometer		5 – 95 %	± 3 %			≤ 0.1 %
Wind velocity*	Anemometer	125 - 250	0 – 60 m/s 0 – 35 m/s	±0.5 m/s ± 3 %		Analog out: 0…10V/4…20mA	≤0.01 m/s
Wind direction*	Wind direction transmitter (wind vane)	170 - 250	0 – 358 °	0.5 °			
Outdoor illumination	Lux-meter		0 – 200000 lux	1 lux			≤ 3%
Solar radiation intensity	Pyranometer	300 – 600	0 - 2000 W/m² 0.3 µm-3 µm	±15 W/m²		Wired Standalone	≤1 W/m²
Outdoor CO₂ concentration	NDIR (Non dispersive infrared)	200 – 500	0 – 2000 ppm	± 30 – 80 ppm	30 – 50 sec	Wired Wireless	≤1 ppm

measurements of outdoor conditions such as temperature, humidity, wind velocity and direction, illumination, solar radiation and CO_2 concentration.
*Usually part of the weather station (also measured rain presence).

3.2.2 Indoor environmental quality (IEQ) sensors

Temperature, humidity, CO_2 sensors are most commonly used sensors when doing indoor environment surveys. Hence, in this inventory also sensors allowing more detailed IEQ assessments are described, allowing measurements of air velocity, CO, VOC particles.
Approximate range of values of sensing parameters, cost and relevant information of sensors allowing IEQ surveys is reported in Table 3. Prices are taken from datasheets and user manuals of some of the main manufacturers.

Temperature and indoor air velocity sensors for indoor thermal comfort

For the measurements of air temperature, most sensors are based on mechanical and operative principles [9]. Most commonly used commercial products in building sector present a wide variety of thermocouples, resistance temperature detectors (RTD's), thermistors (thermally sensitive resistors with negative temperature coefficient also known as NTC thermistors). In general all these sensors are accurate with a good response time. For the practical building applications, Celsius scale is normally used for European applications (°C).

As it can be seen from Table 3, *thermocouples* are the cheapest and therefore the most widespread type of thermoelectric devices. Furthermore, they can measure a wide range of temperature, are simple and robust, but have low accuracy (not sensitive). It is difficult to achieve the error of less than 1 °C. There is no requirements of the power supply. *Thermistors* are one of the most accurate and sensitive type of sensors (having high resolution). They are not quite as stable as RTD's but they present low-cost devices, easy to wire and have a wide range of application. Hence, they require a proper calibration. PRTs have higher accuracy and stability than thermocouples but have a longer response time and cost.
For more detailed explanation of different temperature sensors and their characteristics it is referred to the Chapter 20, book Sensor technology handbook by Wilson [4].

When there is a complaint about the draught inside a building, indoor air velocity is commonly measured (one-time measurement). Indoor air velocity plays an important role when defining thermal comfort. Most often, hot wire anemometers are used, nevertheless, improvement to hot wire anemometer is the low-speed hot sphere anemometer. These instruments are still quite expensive, and their sensitiveness limits a commercial use.

Humidity sensors for indoor thermal comfort

Modern devices to measure humidity levels use change in electrical capacitance or resistance. To monitor indoor humidity levels capacitive, dimensional change and ceramic resistance hygrometers can be used and are included in Table 3. Commercially developed humidity sensors are mainly made of thick film (polymer films and porous ceramic) which enables cost efficiency, robustness, flexibility in device design.
For more detailed explanation of different temperature humidity sensors and their characteristics it is referred to the Chapter 12, book Sensor technology handbook by Wilson [4].

CO_2, CO and VOC sensors for indoor air quality

Monitoring of CO_2 concentration levels allows for a relatively good assessment of indoor air quality (whether the airflows are sufficient) and to estimate occupancy within a building. In practical application non dispersive infrared detectors are mainly used which are based on the physical principle of gas absorption at a particular wavelength. Hence, there are also sensors using chemical methods which can ensure high accuracy but lack of stability and durability.

CO and VOC detection in building is mainly achieved by using the physical principle of gas adsorption on semiconductors [9].

Table 3: Sensors allowing indoor environmental quality (IEQ) assessments.

Parameter identification and measuring device		Cost (€)	Measuring range	Accuracy	Response time	Communication	Resolution
Indoor air (room) temperature	Thermocouple	5 - 50	10 – 40 °C -100 – 300 °C	± 0.8 - 4 °C	10 – 80 sec	Wired Portable	
	Thermistor	20 - 70	-50 – 180 °C	± 0.1 - 0.5 °C	10 – 30 sec	Wired Wireless	
	PRT	35 - 100	-50 – 100 °C	± 0.25 - 0.6 °C	3 – 8 min	Wired Wireless	
	Capillary thermostat	20 - 60	-35 – 65 °C	-	5 – 12 min	Closed control	
Mean radiant temperature	Globe thermometer	40 - 150	20 – 120 °C	± 1 - 3 °C	8 – 30 min (adjustment time)	Wired Portable	
Relative humidity	Hygrometer		5 – 95 %	± 3 %			≤ 0.05 °C
	Capacitive polymer	50 - 200	0 – 100 %	± 2 - 4 % RH	10 – 50 sec	Wired Wireless	
	Ceramic resistance	40 - 150	10 – 90 %	± 2 - 5 % RH	10 – 50 sec	Wired Wireless	
CO_2 concentration	NDIR (Non dispersive infrared)	200 – 500	0 – 2000 ppm	± 30 – 80 ppm	30 – 50 sec	Wired Wireless	≤1 ppm
Indoor air velocity	Hotwire	50 - 180	0.05 – 20 m/s	± 2 – 5 % of reading	0.2 – 5 sec	Wired Wireless	
	Anemometer		0 – 60 m/s	±0.5 m/s			≤0.01 m/s
CO and VOC concentration	MOSFET (Metal oxide semiconductor field effect transistor)	200 - 500	400 – 2000 ppm CO_2 eq.	± 50 – 100 ppm	<60 sec	Wired Wireless Portable	
Noise level	Phonometer, Smart phone (dB)						
Ozone concentration	Ozone Monitor						
Particle concentration	P-track model						

3.2.3 Light, space and occupancy sensors

There are several types of sensors indicating building's daily behaviour and their presence:

- Light detectors (switch, sensor).
- Movement and occupancy sensors, status sensors (e.g.: opening windows, shading devices).

Data on occupants can be gathered through surveys and building management in order to obtain data on age, gender, end-user profile (habits). Glass break detectors are used for intrusion detection.

Occupancy sensors are mostly used in building for lighting control purposes. Most common are passive infrared (PIR) detection systems and ultrasonic sensors. PIR sensors rely on detecting a change in temperature pattern in the observed space using pyroelectric detector. The sensitivity depends on the distance of the subject from the sensor and this is also the main drawback of these sensors. Ultrasonic sensors are based on Doppler effect. Ultrasonic sensors are reflected by room surfaces and do not require a fixed field of vision are therefore more reliable in detecting presence over a longer distances [12]. Hence, ultrasonic sensors are more expensive as compared to PIR sensors (Table 4). Sensors based on radio frequency identification (RFID) and imaging techniques available on the market in the recent years are mostly used in offices to detect personnel [13].

By having lighting detectors and control system, electricity consumption for lighting can be significantly reduced. As seen from Table 4, lighting sensors such as photo sensors are more expensive than photodiodes. It should not be forgotten that the cost specification only includes a cost of a device and not the installation and maintenance cost. Furthermore, daylight linked lighting control can allow adjusting artificial lighting according to the daylight contribution (dimming systems). Wireless sensors are normally more expensive than compared to wired connected sensors.

Table 4: Light, space and occupancy sensors inventory.

Parameter identification and measuring device		Cost (€)	Sensor mounting	Response time	Detection range/Accuracy	Communication	Power source
Occupancy (presence) sensor	PIR (Passive Infrared Detector)	30 – 90	Fixed		3-5 m radius or 5-12 m front and 3-8 m lateral	Wireless Wired Standalone	
	Inductance Sensor ES-P01A		Fixed Installation height 2-4.5m	Time setting: 5 sec – 10 ± 2 min	12m Detection angle: 120°		110-130 V/AC 220-240V/AC
	Ultrasonic	180 -350	Fixed	30 sec - 30 min	185 m^2	Wireless Wired Standalone	
Door open	Contact 0/1		Fixed	N/A	N/A	Wireless Wired	
Window open	Contact 0/1		Fixed	N/A	N/A	Wireless Wired	
Artificial light and daylight sensor	Rocker switch 0/1		Fixed	N/A	N/A		
	Photo-diode	60 – 150	Fixed	N/A	± 8 – 10 % of illum. (dimming compatibility)	Wireless Wired Standalone (dimming)	
	Photo-sensor	120 - 300	Fixed	N/A	± 8 – 10 % of illum. (dimming compatibility)	Wireless Wired Standalone (dimming)	
	Hagner luxmeter			N/A	0 – 2000 lux (≤5%)		
Shading state	Up/down/partial		Fixed	N/A	N/A	Wireless Wired	
Heating/cooling state	On/off						
Plug loads	On/off						

3.3.3 Health sensing and monitoring: Wearables

Introduction of smart gadgetries, mobile health applications, different wearables etc. in the recent years has allowed people to monitor their lifestyle and motivate them towards a healthier everyday life. Such wearables can provide users personalized health data which helps with self-diagnosis and behaviour change interventions.

For example, heart rate can be measured with an oximeter built into a ring [14], muscle activity with an electromyographic sensor embedded into clothing [15], stress with an ectodermal sensor incorporated into a wristband and physical activity or sleep patterns via an accelerometer in a watch [16, 17]. Furthermore, levels of mental attention can be monitored with a small number of electroencephalogram (EEG) electrodes [18].

Tailor-made computerized solutions such as web based services, feedbacks via application or email can motivate a behaviour change for issues such as obesity [19], anxiety [20], panic disorders [21] and post-traumatic stress disorder [22]. Table 5 provides a list of measuring devices allowing assessment of user’s health, daily pattern, sleep quality etc. For some of these devices, the price remains the main issue preventing a wide-spread usage. It should be noted that the market development of wearables is so fast that there are likely to be better alternatives from other suppliers available in near future.

Table 5: Devices allowing monitoring of people's health and lifestyle.

Parameter identification and measuring device			Unit	Cost (€)	Sampling frequency (Hz) and Battery life	Connectivity	Notes (Website)
Heart rate	Polar Loop (Wrist worn device with Photopletysmography PPG)	3D accelerometer &Heart rate sensor (chest belt)	bmp	150	Rechargeable 100 mAh battery Battery life up to 2 weeks (used 24/7)	USB & Blootooth (Offline)	Measures also your activity resting, sitting, walking, sleeping. POLAR
	Chest worn device with Electrocardiography (ECG)			1000			e.g.: IMEC
	Garmin Vivofit	3D accelerometer &Heart rate sensor (chest belt)		200	Battery last more than a year	ANT+USB & Bluetooth (Offline)	www.sites.garmin.com/vivo/
	Microsoft Band						
Skin temperature	Wrist worn device	Skin temperature (distal skin)	°C	80			e.g.: iButton, Samsung
	Chest worn device	Skin temperature (proximal skin)					Measures also air temperature, humidity, e.g.: HIDALGO
Skin blood flow	Wrist worn device with Photopletysmography (PPG)	Photopletysmography	Perfusion units				e.g.: IMEC
	Perimed			30000			www.perimed.se
Sweat rate	Qsweat		ml/cm²/h	30000			http://www.wrmed.com/qsweat.aspx
Metabolic rate	Omnical		mL/h => Watts				www.maastrichtinstruments.com
Activity monitoring	Wrist worn device with accelerometry		Counts/g's	27.5/ device / month	25 Battery Life of 7d at 25Hz sampling rate		e.g.: MOXX, Fitbit
Gait p. 6MWT	Waist worn device with accelerometry		Counts/g's		100 Battery Life of 3.5d at 100Hz sampling rate		e.g.: MOXX
Body composition	Cosmed		Fat %, lean %, total mass				www.bodpod.com
Brain activity	EPOC sensor by EMOTIV	Electrodes measuring electrical waveforms					www.emotiv.com
	MinWave Mobile headsets	Portable EEG brainwave headset)biosensors		80	8-hour AAA battery life	Wireless	http://neurosky.com
Daily activity	Fitbit Flex wristband	3D accelerometer		120		Bluetooth (Offline)	www.fitbit.com Measures steps, calories burnt, at night quality of sleep
	Jawbone UP wristband	3D accelerometer		160		USB & Blootooth (Offline)	www.jawbone.com/up

4 Architecture of the monitoring system & communication and network technologies

When building a sensor network system, the challenging task is the architecture of the sensor system due to all the different requirements related to each sensor and devices connected to the system (communication protocols, database etc.). A protocol is the rule set standard for representation, signalling, authentication and error detection which allows sending the information though a channel of communication between the different connected elements. Closed protocols are specific protocols which are used by one manufacturer and only the manufacturer can make improvements and those devices that "speak" the same language. This limits the appearance for continuous development. On the other hand, open standard protocols have no patent on the protocol which allows that any manufacturer can develop applications that carry implicitly communication protocol (e.g. LonWorks and KNX).

Main architectures can be centralized, decentralized, distributed, hybrid/mixed. Due to different communication strategies, connection between existing sensor network and upgrading it with new sensors can be challenging. Ideally, communication structure needs to be designed as a multilayer architecture that covers the whole sensor network system where all devices should be seamlessly connected into one framework.

The following figure presents a generic monitoring system architecture of MOBISTYLE. This architecture will be defined according to the requirements of each demonstration case and MOBISTYLE requirements based on decision on which new sensors we want to integrate additionally (measuring new parameters related to health).

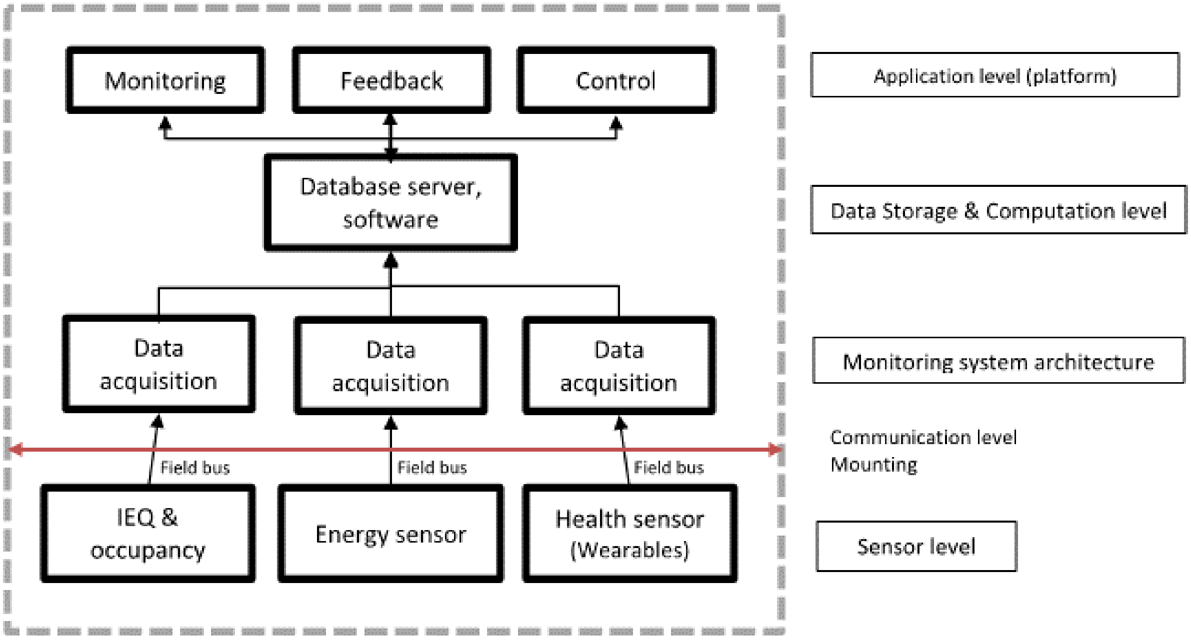


Figure 2: MOBISTYLE Generic architecture of building's management system.

In general, this architecture will include three main components:

- *Sensor layer & data acquisition:* Measuring devices, sensor, appliances monitored by a sensor configuration that collects the data. This information is then available to the computation layer for further data analysis.

- *Computation layer:* In order to analyse the collected data, the computation layer comprises of a database and computation software. The application layer will define what kind of software and analysis methods need to be adopted. Information will be generated by an appropriate combination of algorithmic calculations and statistical analysis. This then provides information catered for end user by informing the application layer.
- *Application layer:* This layer provides a user a possibility to monitor and download the data, control the systems and provide a user feedback. In MOBISTYLE, the goal is to adapt the information to the needs of the end-users.

When connecting different sensors in a building, two principles of the home network are important:

- A language (communication protocol) by which the devices communicate among each other and exchange information;
- A connection between the devices: a wired or wireless connection (radio signal).

4.1 Communication backbone

In order to connect different sensors efficiently and accurately, instrument selection and a network system plan needs to be established, including definition of a communication backbone in order to ensure the interoperability of different devices. A communication backbone ensures transmission of the data captured by the sensors [6]. Furthermore, highly reliable communication will be required to transfer a high amount of data.

Sensors can be connected with other buildings or smart devices into integrated packages through advanced communications. Nowadays, the systems consist of switches and sensors connected to a central hub called gateway from which the system is controlled via internet cloud services. In general, gateway acts as a router able to connect multiple devices (gathered data) and connect them to other networks (Internet). Low-cost sensors can be connected via sensor network (wired or wireless) [23].

Wireless sensor networks are the most common solutions in IoT field, however, in general different local-area networks (LAN) technologies are applied in buildings:

- Wireless IEEE standards 802.x: Wi-Fi, WiMax, ZigBee and Bluetooth.
- Wired Ethernet
- In-building power line communications (Home Plug and X10) [6].

Wireless connections allow faster and easier deployment of the systems, allow higher flexibility in installation, replacement and upgrade is easier than compared to wired connections. Hence, the main challenge of wireless connections is power consumption and reliability. In general, the power consumption of the sensors, radio links and sensor nodes should be minimized. Different communication technologies and protocols can be applied depending on the amount of data transmitted and the communication environment.

In wireless sensor networks, different adaptable low power radio integrated circuits options are available from commercial providers. If possible, it is recommended to use interfaces that are standard based since this allows the interoperability among different companies networks.

4.2 Interoperability

Interoperability allows products and services to work together and exchange the information without the loss of semantics [9]. To successfully ensure interoperability, ideally, open (universal) standards for communication protocol and central network hub (gateway) should be achieved. Hence, this is often not the case for the real applications especially when connecting a new sensor/device to an existing older home automation system having a closed communication standard or due to the communication protocols and technologies such as: ModBus, M-Bus, Ethernet, Cellular, ZigBee, WiFi etc [6]. This can rise a need to accommodate additional communication standards, hardware, adding time and money expenditure.

Several attempts were done involving a set of specifications to which new smart buildings technologies would have to be developed to ensure interoperability. Results of attempts to create such communication protocols are:

- UPnP (Universal Plug and Play)
- BACnet (Building Automation and Control Network)
- DLNA (Digital Living Network Alliance) [24].

Table 6: Short range communication: advantages and disadvantages.

System		Advantages	Disadvantages
Wired	Traditional wired	- Minimal cost - Reliable technology - High capacity for information and power transfer	- Complex, costly installation (wiring) - Restrictive, inflexible - Aging - Heavy
	Advanced wired (fibres, optical yarns, yarns)	- Minimization of number of components required in the system	- Still under development - More sensitive to breakage - Costly
Wireless	Wireless local area network	High capacity communication with a limited geographical area	- Power requirements - Occupied, can be interfered with other devices (not part of the MOBISTYLE).
	Bluetooth	Devices can find each other and communicate - Enables communication in any direction	- Smaller operational area than WLAN - Can be interfered with other Bluetooth devices (not part of the MOBISTYLE).
	Infrared	- Simple - Low cost	- Data transfer size limited - Limited range
	Radio frequency identification (RFID)	- Low cost	- Limited frequencies: Not all frequencies are allowed in all the EU countries.

Energy Performance of Buildings Directive (EPBD), 2002/91/EC directive encourages the installation of smart meters and intelligent metering systems. Most of regulations and legislations on energy sensoring in Europe are in response to Energy Performance of Buildings Directive (EPBD), 2002/91/EC directive. Hence, with a rapid recent development of the sensoring technology, there is a greater necessity to enhance and develop universal standards for communication protocols that would allow integration of new meters and sensors with existing technology [6]. Currently there is one remaining EU standard KNX (Konnex). The EIB (European Installation Bus), BatiBus and EHS protocol (European Home System) were combined into KNX which combines the best elements of the three previous standards.

4.3 Fragmentation

Currently, a platform fragmentation and lack of open standards leads to difficulties to customize and interconnect different sensors and devices. Several articles expose a problem due to the fragmentation of the protocols (technology platforms) which are normally incompatible with each other [9, 25-27]. Recognized by many IT developers, there should be a single, open, secure and interoperable framework ('design for all') that would allow interoperability of all IoT products and services. This would be beneficial for the MOBISTYLE project where the aim is to connect different devices from different manufacturers (e.g. temperature sensor from BMS with sensor measuring heart rate through wearables).

4.4 Accessibility of data

Often energy or measurement providers restrict or disallow access to their past and/or current measurement recordings. It is needed to communicate early enough to secure buy-in and establish a legal agreement on how, when and which data are going to be shared.

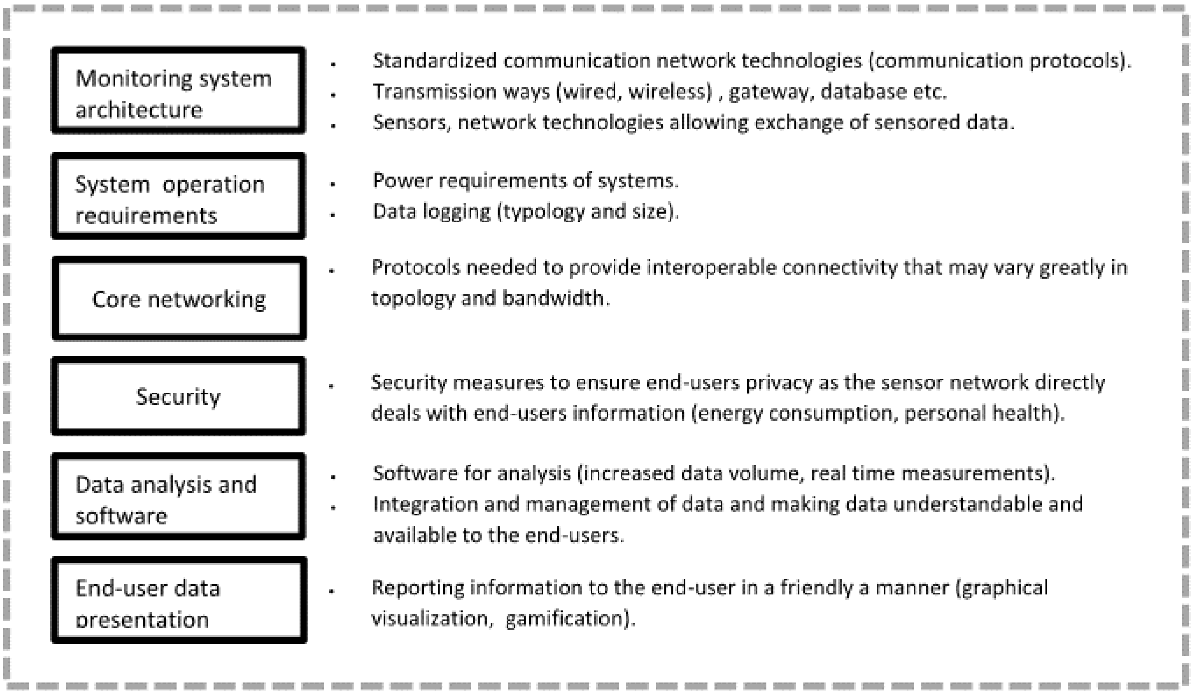
Furthermore, for the MOBISTYLE project the individual monitoring plan for each demonstration building will be communicated with technical staff responsible for the buildings (building managers, maintenance staff etc.) in order to discuss the technical requirements and make the staff aware of the MOBISTYLE services and how they are going to benefit from them

4.5 Privacy and data protection

Privacy and data protection are two important issues that need to be ensured when connecting our buildings with an advanced technology [9]. Security concerns will differentiate preferences for the different building technologies available. In order to tailor its systems to different end-users and users' lifestyle, MOBISTYLE demonstration buildings may collect information about them, such as their physical movements and daily routines (energy habits, usage of electrical appliances, opening windows), energy use and bills or even information about their personal health. Safeguarding personal data and developing secure systems, especially for remote control of smart building services (e.g.: Turning lights or heating on and off with a mobile phone), is one of the key challenges addressed in MOBISTYLE. The data protection plan is further described in the deliverable 8.1 on Ethics requirements in MOBISTYLE.

It is important that the end-users are carefully educated about the data protection plan and explained on how their data will be used and protected. Before implementing additional sensors in buildings, it will be checked that all MOBISTYLE services are treated according to national data privacy standards. The end-users will be asked to sign the data protection agreement.

Following figure presents an expended view of relevant areas that need to be taken into consideration when designing a sensor network.



Monitoring system architecture	- Standardized communication network technologies (communication protocols). - Transmission ways (wired, wireless) , gateway, database etc. - Sensors, network technologies allowing exchange of sensored data.
System operation requirements	- Power requirements of systems. - Data logging (typology and size).
Core networking	- Protocols needed to provide interoperable connectivity that may vary greatly in topology and bandwidth.
Security	- Security measures to ensure end-users privacy as the sensor network directly deals with end-users information (energy consumption, personal health).
Data analysis and software	- Software for analysis (increased data volume, real time measurements). - Integration and management of data and making data understandable and available to the end-users.
End-user data presentation	- Reporting information to the end-user in a friendly a manner (graphical visualization, gamification).

Figure 3: Areas that need to be addressed when designing sensor network.

5 Building application and practical assessment of sensors usability

The technical requirements of sensor network were already explained in chapter 4. Chapter 5 provides an overview of more practical design considerations that need to be considered when applying sensors in a building.

5.1 Objectives of the measuring system

First, it is important to find the optimum number of sensors and communication links. For each individual building, this requires assessment and definition of the systems that needs to be (remotely) monitored, accessed or controlled and which devices will provide services that respond to the needs of the end-users (architecture of the sensor network). Such connected buildings are normally equipped with:

- Communication network (through which devices talk to each other),
- Linking sensors, measuring devices (collecting data), and
- Other control systems (managing the system).

As explained in chapter 2.1, the requirements for accuracy (uncertainty) of the measurements need to be considered when establishing the objectives of the measurements of a certain phenomenon. Most often, people would like to achieve the lowest possible uncertainty but that might not be economically feasible or even necessary. Even further, many modern data acquisition systems are capable of much greater accuracy than the sensors making the measurement. Users must not be misled by thinking that high resolution in data acquisition system will produce a high accuracy data from a low accuracy sensor [4].

When installing the sensors, the sensors must be carefully matched and integrated into the total measurement system. The calibration needs to be assured and documented or the uncertainty of any measurement is unknown. Either each sensor needs to be calibrated and an overall uncertainty calculated or the total system must be calibrated as if it will be used.

5.2 Sensor's lifetime and costs

When designing the building's monitoring system, product's (sensor's) lifetime needs to be considered and the length of warranty. Normally the initial purchase cost is identified as a primary driver when deciding on monitoring, hence operating costs should not be forgotten. Furthermore, when purchasing sensor the price of the sensor is only a smart portion of the lifetime cost of a sensor. In general, the purchase of the sensor can be less than 20 % of the product's lifetime cost [4]. All costs related to the operation and maintenance should be also considered. The life time costs are related to:

- Initial purchase costs and shipping costs;
- Installation and operation costs (including additional instrumentation: cabling, connectors, signal conditioning, power supplies);
- Calibration and maintenance costs;
- Repairs, disposal costs.

5.3 Product's availability

When deployment of sensor will be planned for each MOBISTYLE demonstration site, an important factor will be product's geographical availability. The choice of a particular manufacturer's meter will depend whether there will be product available and will be a reasonable time for delivery and provision of technical support and additional parts.

5.4 Installation and positioning of the sensors

Even completely advanced state-of-the-art sensors can give erroneous data if not correctly applied. Therefore, positioning of the sensors is an issue that must not be neglected.

Positioning energy meters gives less flexibility in installation since it needs to be installed on the relevant pipe in the building. This is also normally the reason why there are not many sub-meters installed in the buildings (finding a suitable location that can be easily accessed, minimising disruption, meeting safety legislation).

In general, wireless sensors will reduce the installation cost and can offer a greater flexibility in installation especially when reconfiguration is needed. However, the acquisition of data in wireless infrastructure is less secured than in comparison to wired solutions. Furthermore, a wired infrastructure is more reliable since there is a lower chance of data loss.

Once the sensors and system are thoughtfully selected, careful installation into the environment needs to be achieved in order to provide accurate data. This includes checking the condition of the sensors, following the guidelines for mounting provided with the commercial data sheet, checking the mounting surface, inspecting whether the connection units (cables) are in good condition and ready to use etc. Wired sensors are usually logged time-based, therefore it is needed to define how and how often the wired (also wireless) sensors and wearables are synchronized.

6 Conclusion

MOBISTYLE project as one of several other research and innovation (R&D) projects funded under EU-scheme programmes (e.g. iNSPiRe [28], A2PBEER [29], ENTROPY [30], BeAware [31]) can help improving the current usage of sensor technologies and contribute to a more wide-scale application of sensoring technologies. According to Siemens, 30 % more energy savings can be obtained for buildings equipped with smart sensor networks due to a more precise climate, air quality and occupancy sensors than compared to buildings with traditional automation technologies [32].

The review showed that there exists a large amount of sensors allowing for a measurement of different parameters related to energy, indoor environment and health. Furthermore, the price of sensoring devices is not anymore the main issue when deciding to sensorize a building. With the fast development of ICT solutions in the recent years, the price of sensors is falling rapidly. The main bottleneck in current sensor networks is related to the architecture, protocols and software issues. The collection and transfer of the recorded data into an existing network can be an issue due to the closed standards. Further development of ICT solutions and open standards is needed in order to allow for a wider adaptation of this technology in the existing buildings which would consequently also lead to lower costs and easier connections. Nevertheless, in order to maximize the energy savings available from the use of smart technologies and services, there needs to be an accompanying change of the building occupant behaviour. Concerning the MOBISTYLE project and its demonstration cases, there is a risk to end up with several sensor networks in the existing buildings due to the problem of interoperability between different data transfer technologies of new and existing devices. There is a need for better cooperation between the different manufacturers in order to offer a standardized solution that would fit ‘design for all’ concept.

Nevertheless, sensorizing environment is not enough to achieve energy savings. It is important that adequate and relevant information is provided to occupants so they become aware how their everyday life habits affect the building’s consumption and surrounding environment. By providing users valuable information obtained through the analysis of the recorded data, there is the potential to get all building occupants on board to start taking energy-efficient measures. MOBISTYLE aims to educate end users in such way so they become aware of the importance of energy savings. Providing tailor-made persuasive feedback information on user’s energy usage, IEQ and health is therefore a key aspect in MOBISTYLE approach in order to motivate the user behaviour to conserve energy usage. As shown in several previous European projects (Energy@Work [33], Energy@Home [34], EnerGAware [35]), providing real-time feedback to the building occupants through application of different communication strategies (easy comprehensible visualization of real-time data, integrating competition, self-imposed targets, providing constant feedback, peer comparison, serious games etc.) can be efficient in reducing the overall building’s consumption while not comprising people’s comfort. The goal of MOBISTYLE project is to offer the end users feedback devices that raise occupant’s energy awareness and lead to long-term behavioural change.

As a prerequisite for the development of MOBISTYLE studies of occupants everyday habits will be done. Through the five demonstration studies it will be validated whether the use of MOBISTYLE technologies help optimizing buildings performance by providing the users understandable attractive information on building’s performance, their personal health and in this way contributes to overall buildings energy efficiency. Through feedback surveys it will be analysed how viable and effective are the developed solutions and whether there need to be done some changes in order to reach the MOBISTYLE goal.

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