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# Massive arrival of low-cost and low-consuming sensors in buildings: towards new building energy services

**B Delinchant<sup>1</sup>, H A Dang<sup>2</sup>, H T T Vu<sup>3</sup>, and D Q Nguyen<sup>3, 4</sup>**

1 Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, 38000 Grenoble, France

2 Hanoi University of Industry, Hanoi, Vietnam

3 University of Science and Technology of Hanoi, Vietnam Academy of Science and Technology, Vietnam

4 Institute of Energy Science, Vietnam Academy of Science and Technology

E-mail: [benoit.delinchant@G2Elab.grenoble-inp.fr](mailto:benoit.delinchant@G2Elab.grenoble-inp.fr)

**Abstract.** Building is one of the most consuming sector with 5 MWh per person per year. Building energy efficiency is already addressed by countries policies but is still a topic of research. In our paper, we are addressing a new way of improving energy consumption in building, based on Internet of Things (IoT). IoT is synonymous of increase of the amount and accessibility of measurements. How is this impressive growth possible? How to use these new data to reduce building energy consumption and bring new energy performance services? IoT technologies are analysed and future tendencies are proposed. Our analysis is illustrated on the experience acquired within 2 smart building research and teaching platforms, one in Grenoble France, and the other in Hanoi, Vietnam. These research platform aim at improving energy efficiency and sobriety, and prepare building to energy grid services.

## 1. Introduction

### 1.1. Building energy consumption

Building is one of the bigger consumer of energy and the bigger consumer of electricity in the world with 49.3% (27.1%: residential, 22.2% commercial and public services). Global use of electricity in buildings grew on average by 2.5% per year since 2010, and in non-OECD (Organisation for Economic Co-operation and Development) countries it increased by nearly 6% per year.

Energy demand per capita is stable with 5 MWh per person per year. It is growing by 1% per year in non-OCDE countries like Vietnam, while it is decreasing from a peak of 12 MWh in 2010 in OCDE countries like France, partially due to warmer winter since space heating accounts for 45% of the final energy use. It is recommended by the international energy agency<sup>1</sup> to reduce these figures by at least 10% from here to 2025.

In Vietnam, where energy access and economic development are equally important priorities (among others), effort is needed to face a rapidly growing demand for energy services without following an unsustainable pathway towards high building energy consumption per person.

An innovative way to address this issue can be based on data.

### 1.2. Building and occupants are creating lot of data

<sup>1</sup> <https://www.iea.org/etp/tracking2017/buildings/>



Buildings are more and more monitored, for a simple purpose of monitoring, regulation, security, diagnosis, to go to intelligent driving. But two things come to revolutionize this now classical approach. The first comes from the multiplication of connected things, whether they come from smart home or security, as well as objects worn by the occupants, used for example for "quantified self" or health-care. Thanks to the integration of physical sensors into micro-electronic mass production channels, a digital sensor associated with a wireless communication system costs less than \$2. In addition, energy recovery technologies can power these sensors making them autonomous, easy to install, but also without intervention. Interaction with the occupant (via the smartphone or other user interface) also generates rich data about their preferences. The trend is therefore to multiply measures within the habitat.

The second comes from the access to these data, because although coming from heterogeneous equipment, communicating in different protocols, they benefit from concentrators (home automation box) allowing to integrate the various technologies in an agnostic way [1]. A nano-computer (raspberry pi type) to centralize these measures, to process and archive them locally costs less than 50 €. Open source solutions have for several years shown their relevance.

### 1.3. Building energy services

The number and accessibility of these data, open new avenues for research and development, in line with Data Scientist's business, which has grown by 1500% over the last 3 years. It is thus possible to exploit algorithms that have shown their performance on data derived from simulation, artificial intelligence algorithms making it possible to construct [2] or to set in situ model predictive control (MPC) [3].

The number and accessibility of these data also allow us to consider radical changes in the creation of services and the provision of tools for comfort and energy efficiency in buildings. Thanks to the multiplication of sensors, it is possible to access complex quantities to be measured such as the occupation by correlation of multiple sources of information, to reduce uncertainties (eg redundancy, mean value), to access quantities spatially distributed (eg temperature), etc.

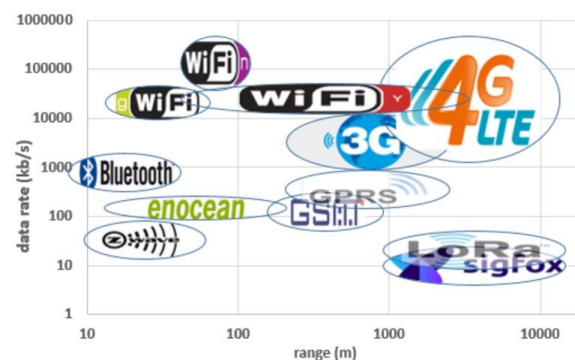
## 2. Massive introduction of sensors

### 2.1. Actual state and perspectives of IoT

The multiplication of connected objects is a fact. According to IDATE (Institute for Audiovisual and Telecommunications in Europe), there would be 11.2 billion connected objects in the world in 2017 against 4 billion in 2010. The markets that exploit these connected objects are agriculture, industry, automotive, logistics, transportation, commerce, sports, health, and of course the smart home and the smart city. The growth rate is about 10% per year, which should lead to a fleet of 35 billion units connected in 2030, 4 times more than the world population.

In general, the communication technologies used in IoT are based on wireless standards such as Wifi and Bluetooth for short-distance communication, which should also remain the case in the next 10 years, despite a fairly high consumption because of the data rates offered (Figure 1).

Low-Power Wide-Area (LPWA) low-power and long-distance technologies such as LoRa and Sigfox are growing strongly and are very well suited to the smart city area. These technologies are nevertheless well suited for buildings since they have a strong penetration (deep indoor) thanks to their spread spectrum modulation. But it is the cellular IoT (via the new standards NB-IOT, LTE-M) which should know the strongest growth with more than 55% per year by 2030<sup>2</sup>.



**Figure 1.** Scope / Flow of the main RF protocols.

<sup>2</sup> <https://en.idate.org/marche-iot-2018/>

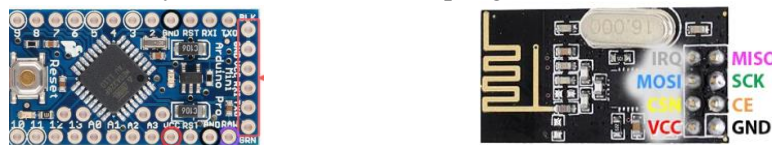
In this race for technology, it is sometimes difficult to target the technologies best suited to the field of Smart-Building. The experience we have gained through the use of these technologies over the past ten years as part of the Predis-MHI (Monitoring and Intelligent Habitat) research and teaching platform, allows us today to offer a few recommendations and trends towards internet of things.

### 2.2. Wired and wireless standard communication technologies for the smart building

The "smart" building act at the building level, so it is mostly using a local area network (LAN) or WLAN (W for Wireless). Indeed, the "wireless" is undoubtedly the solution of the IoT. Nevertheless, the building retains the traditional solutions of GTB (Technical Building Management), which they are still mostly wired because installed from the design phase of buildings. It is usual in the industrial, commercial and tertiary domain, to use "field protocols" such as DALI (specialized in lighting), MODBUS (generic, simple and widespread), KNX (generic but dedicated to the small tertiary) and protocols higher levels such as LON and BACNET for data reporting in a centralized architecture for relatively large buildings. These protocols are generally open and allow interoperability between different systems via gateways. In homes, there is wireless, but the solutions are often proprietary (in France: DeltaDore with its X3D protocol, Somfy with io-homecontrol, etc.) and therefore more difficult to interoperate with other solutions without agreement between suppliers of solutions. At the same time as these well-established companies, the field of "free" home automation is booming, especially thanks to IoT. Thus more open solutions are available, based on protocols such as ZigBee, EnOcean or Z-Wave. These technologies are widespread in France and many devices are available at more affordable costs than complete proprietary solutions, but they still remain expensive (more than \$50).

### 2.3. Alternatives using open hardware and open protocols

From previous solutions (ZigBee, EnOcean and Z-Wave), the development of wireless sensor and actuators devices in different technologies of wireless communication gave us opportunities to make building to be more intelligent and convenient. However, high investment cost of those devices causes difficulties for research and application of building energy services in developing country. Fortunately, with recent advances in wireless technologies and embedded systems, based on Open-Hardware (Arduino), ANT wireless technology (nRF24L01+ module), low-cost wireless sensors and actuators network (WASN) for building energy services is available. Moreover, unlike commercial products, this WASN is customizable and easy to be extended for adapting different research situations.



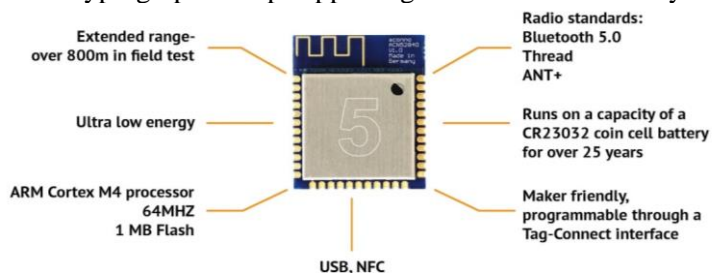
**Figure 2.** Arduino Pro mini and nRF24L01+ module.

RF24Network is a network layer for Nordic nRF24L01+ radios running on Arduino-compatible hardware (Figure 2). It's goal is to have an alternative to Xbee radios for communication between Arduino units. It provides a host address space and message routing for up to 6,000 nodes. The layer forms the background of a capable and scalable Wireless Sensor Network system. At the same time, it makes communication between even two nodes very simple. Nodes are automatically configured in a tree topology, according to their node address. Nodes can only directly communicate with their parent and their children. The network will automatically send messages to the right place.

On the other hand, connected things are not necessarily intended to fit into such a wireless network, but can simply be connected to the Internet through the mobile phone using bluetooth then 4G, or through the home automation box using Wifi then ADSL or fiber. Solutions integrating this type of communication become very affordable with the rise of the IoT and announce very low consumption. For example, Nordic Semiconductor's NRF52 (Figure 3) is based on an ARM Cortex-M4 processor incorporating a 2.4GHz transmitter for Bluetooth Low Energy (BLE) communication, as well as the Thread protocol, announced as the future protocol for Bluetooth IoT but has not yet taken off because of a certification procedure that has been slow to set up.

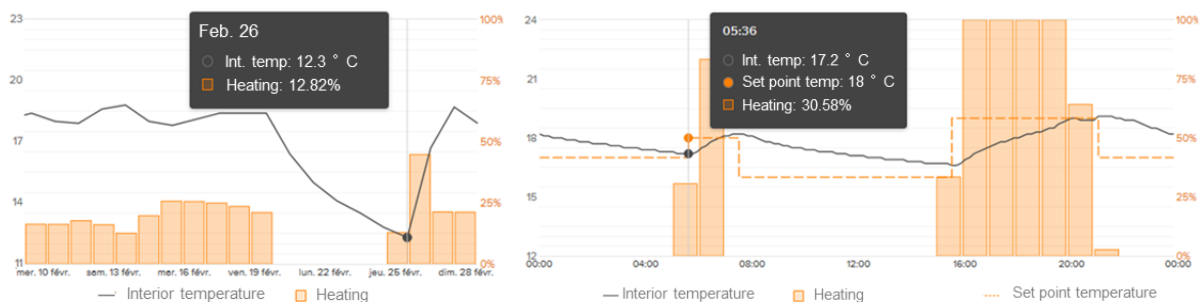


For its part, the Chinese company Espressif offers the ESP32 (about 5 €), a more powerful solution (double heart clocked at 240MHz backed by 4MB flash memory) integrating in addition to BLE, WiFi and a cryptographic chip supporting the latest data security standards.



*Some research are concerned with the recovery of energy from the numerous ambient RF signals of other IoTs, thanks to the antenna of this type of component, when it is not in the communication phase.*

**Figure 3.** nRF52 chip and its communication antenna which can also be used for energy harvesting. Netatmo, a French company that offers a connected thermostat, a weather station and a face recognition security system, use this communication principle. The product is first connected in Bluetooth to the phone, then after its configuration, it connects to the wifi and transmits its data to the server of the company. The data can be consulted by smartphone application, and by website. Figure 4 illustrates the Thermostat's web interface with remote re-launch and learning retries.



(a) during 1 month, with manual remote heating before the come back from holidays

(b) during 1 day with recovery by apprentice ship

**Figure 4.** Netatmo thermostat data viewed on the Internet server.

#### 2.4. Access to sensor data

We have just seen that Netatmo data is accessible from a remote server. The data is automatically uploaded from the Wifi sensors and is accessible as long as the company maintains the service. But the data is also available through API (Application Programming Interface - dev.netatmo.com) so that everyone can develop applications using these sensors. The owner of the IoT can then give access to his data for a third-party application and benefit from new services.

It is important to know the data access possibilities of connected systems that appear on the market. The first precaution concerns the property of the data which must remain with the owner of the IoT, and which must enjoy all the rights, including the suppression of these. Then, the security of the data, if those data are available on a server, they must be accessible by secured manner, and if accesses are authorized, to know the treatments and objectives of these treatments.

Another architecture allows to keep its data locally with the possibility or not to expose them on the Internet. The difficulty is then to administer the information system, but more and more solutions appear to the general public. We can mention Synology as a very affordable NAS (Network Attached Storage) solution provider and perfectly accessible for non-IT specialists. The IoT must then be connected to this hub, which must therefore communicate in all the protocols involved, and have physical equipment supporting the communication. Conventionally, a module (expansion card or USB key) is required per protocol, hence the need to limit the number of protocols in a single installation to facilitate interoperability.

This hub must then have software layers for coding / decoding the communication frames transmitted

to / by the communication devices. This layer can be provided with the device, available as open source (OpenZWave), or reimplemented in specific environments. This is the case for example with 2 free environments (OpenHab and Jeedom) where the EnOcean driver is reimplemented. The main feature of these environments is to integrate the different technologies in an agnostic way [1] in order to treat them later independently of the communication chain. They generally allow to interact directly with the system in read / write (sensor / actuator), to archive the data in databases, and to visualize them.

### 3. New building energy services

It is now illustrated some new services, relying on two platforms, first in Grenoble-France, and the second in Hanoi-Vietnam.

*Predis-MHI platform in GreEn-ER building of Grenoble University* [4]. GreEn-ER is a building that hosts the G2Elab and the engineering school "Energy, Water and Environment" (Grenoble INP ENSE3) in France. In a few figures, it is a building of 6 floors with 4500 m<sup>2</sup>, 2000 people welcomed, including 1500 students.

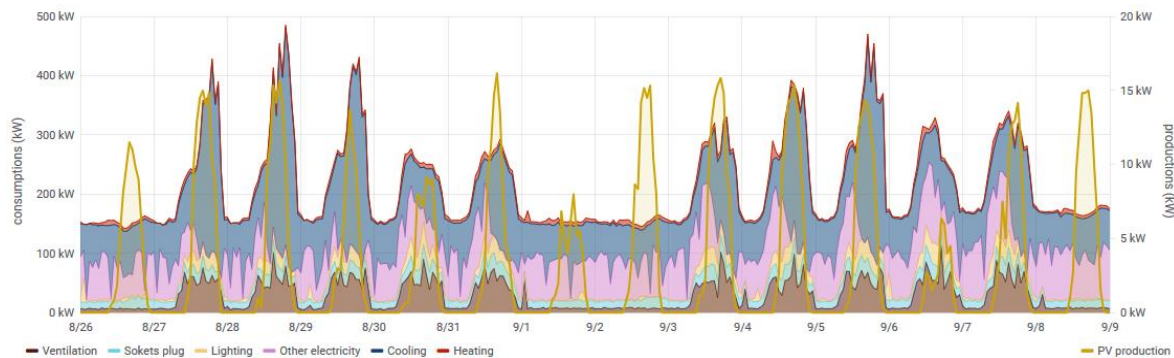
*HUI Smart Office platform* is an experimental platform based on OpenHardware and OpenSource to initialize building energy efficiency research in Hanoi University of Industry in Vietnam. Our idea is to create a co-research project which could initiate a network of international experimental platforms toward further researches of Renewable Energy Integration in Building and Net Zero-Energy Building

#### 3.1. Building Management System (BMS)

BMS is available de facto in new buildings, but also in renovated buildings. It aggregates in particular a more or less large set of sensors and actuators through SCADA (Supervisory Control And Data Acquisition). The GreEn-ER BMS consists of 1125 measurement points made during construction in 2015 and the Smart Office platform consists of 42 measurement and control nodes installed in two offices in administrative building of Hanoi University of Industry in 2018.

In order to make these solutions interoperable, we have developed bindings through web-services. A web-service offers a way to interact with computer codes at a very high level of abstraction, regardless of operating systems, programming languages, and equipment location. This technology also allows us to be interoperable with dynamic thermal simulation models and optimization engines [5][6].

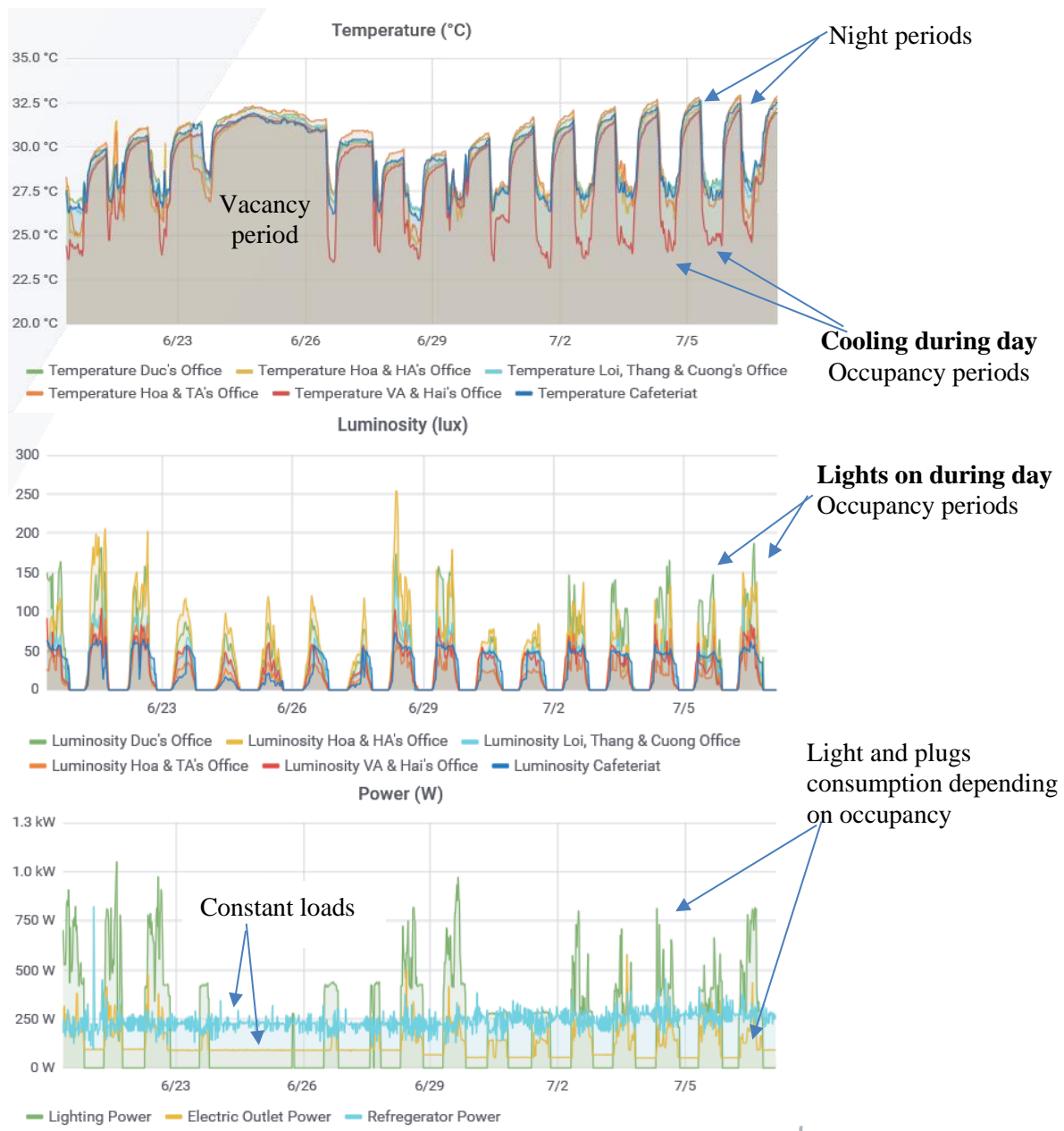
#### 3.2. Data visualization



**Figure 5.** Real time GreEn-ER energy consumption (left axis) and PV production (right axis).

Available on <https://snapshot.raintank.io/dashboard/snapshot/dlgrvaSSRBxRxFvdJ3SmAEwMgEbyeA26u>

Figure 5 plots energy consumption (decomposed in usages) and PV production of GreEn-ER building. plots comfort measures (temperature and luminosity) as well as consumption of HUI Smart office. These data are accessible using InfluxDB/Grafana open source solutions, enabling very fast dashboard creation, and enabling easy access to data using web service (influxDB API) or CSV file exports. A very fast analysis is showing that consumption depends mainly on occupancy, which is during the day in offices, then can be mainly compensated by photovoltaic production.



**Figure 6.** Real time HUI Smart Office temperature, luminosity, and electrical consumption.

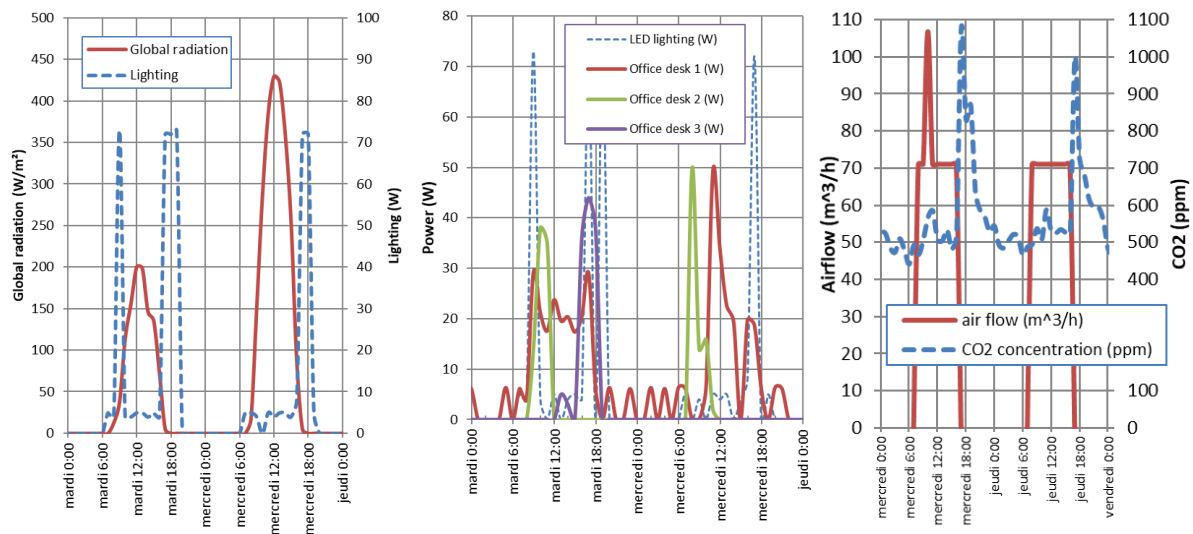
### 3.3. Interactions with people

Moreover, data are accessible from different levels, from the building operator to the occupants. Interactive touch screen, smart phone applications, and online web access have been developed to inform and interact with peoples on figures relative to energy, comfort or the environment. Notifications on smartphone and office computer can be done automatically based on data values and algorithms. This approach, which aims to put the occupant in the loop [7] is also a source of data on occupant preferences.

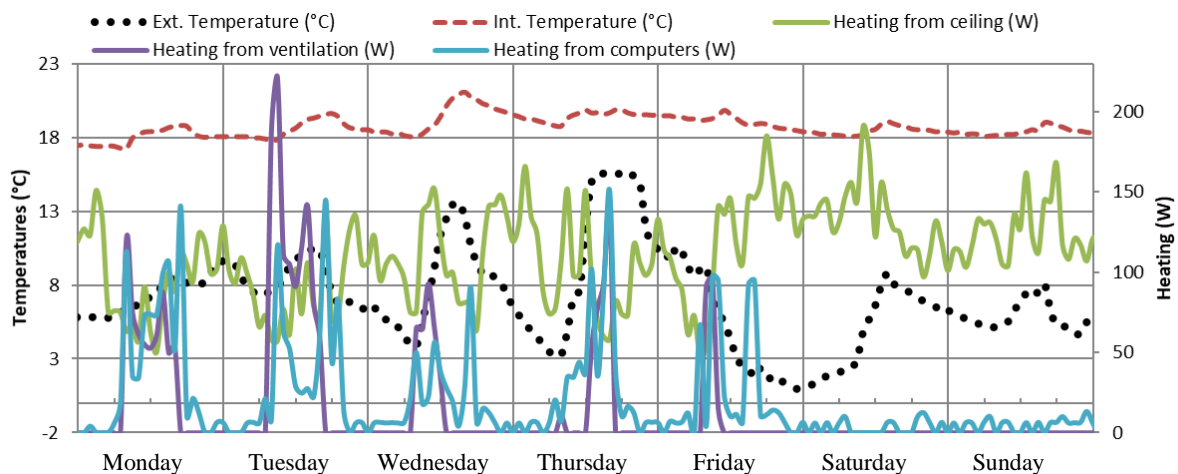
### 3.4. Data analysis

Our platforms are heavily instrumented and prefigures what may be the amount of data collected in future buildings. In an office area, about fifteen figures related to comfort and energy are observable. The analysis of the data starts with the correspondence of the quantities between them. The measurements plotted by time series in the 3 following figures (Figure 7) inform us in particular about the occupation and the internal contributions related to the uses.





(a) solar radiation / indoor lighting (b) consumption / occupation (c) ventilation / CO<sub>2</sub> concentration

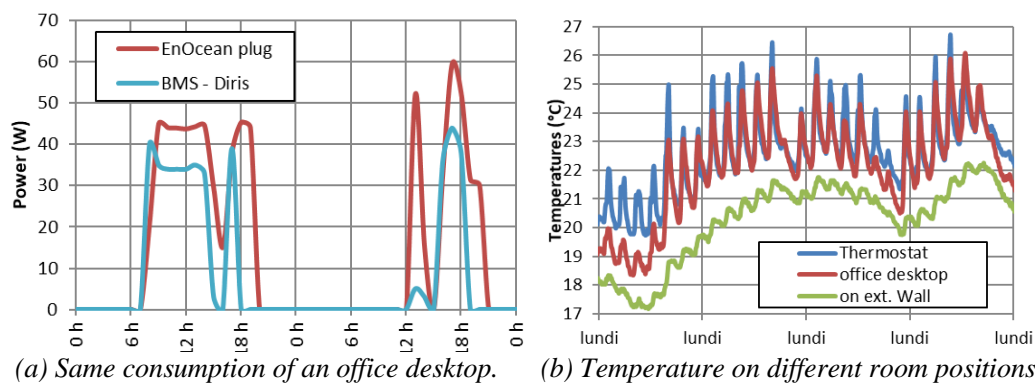


**Figure 7.** Correlation between data in Predis-MHI office in France.

All these measures can make it possible to build more or less relevant indicators, in particular with respect to occupant behavior and their presence [8]. The sensors embedded on the occupants themselves (Quantified self, Wearable devices) can come to supplement this information until now difficult to access or reconstructed and tainted with uncertainties [9].

From reconstructed information such as presence, and a set of measurements located in each room, models can be made either by machine learning algorithms [2] or by models more or less complex physics, corrected in real time for anticipatory piloting in situ [3].

In addition to these measures that can provide a very rich information to comfort and energy management services, it appears that the multiplication of measures in building, thanks to the IoT can lead to redundancy of information. This redundancy must in particular make it possible to limit measurement uncertainties resulting from inexpensive and uncalibrated equipment by averaging. It also reduces the risk of data loss to which monitoring systems are sometimes subject. It is thus possible in the following figures to compare the measurements made on the consumption of a workstation (Figure 8a), or the temperatures at different locations of the office (Figure 8b).



**Figure 8.** Exploitation des redondances de mesure.

#### 4. Conclusion

It is highlighted a strong growth in the number of real time measurements available within buildings, associated to occupants and their energy consumption. This availability is due to the technologies of transmission and power supply of distributed sensors, which are less and less expensive. Although many heterogeneous technological solutions persist, it is increasingly easy to concentrate and to archive them for the purpose of analysis. Local or distributed data access solutions each offer advantages and disadvantages, and must guarantee respect for the ownership and use of this data. Energy services to occupants and building operators can then be developed, based on the correlation of these data, their analysis and the construction of added value. As a perspective, energy services related to the electricity grid can also be imagined, such as flexibility and peak shaving, thanks to occupant behaviour and consumption prediction algorithms using this increasing amount of data.

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