# Sensor networks for existing residential buildings performance evaluation

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**Abstract**
Enhancing residential building energy efficiency has become a critical goal to take up current challenges of human comfort, urbanization growth and the consequent energy consumption increase. In a context of integrated smart infrastructures, sensor networks offer a relevant solution to support building energy monitoring, operation and prediction. The amount of accessible data also opens new prospects to better consider key parameters such as human behavior and to lead to more efficient energy retrofit of existing buildings. However, sensor networks planning and deployment is a particularly complex task facing many challenges and affecting the performances of such a promising solution. The present paper highlights watchpoints from the implementation of an instrumentation solution for the study and evaluation of a deep energy retrofit of existing collective residential buildings. Observations will be grouped in four categories. They will be illustrated with actual field situations and discussed to provide potential solutions for efficient future sensor networks deployment.

## 1. Introduction
Residential buildings are one of the major energy consumers and greenhouse gas (GHG) emitters, with 38.1% of the final energy consumption and 36% of the GHG emissions in Europe [1]. Efforts have been made to reduce the impact of residential buildings on energy consumption with various codes, standards and thermal regulation mandatory compliance for designs of new buildings [2], [3]. However, given the slow turnover of the building stock in European countries, the effect of these regulations is limited [4]. Hence, existing building retrofit turns into a priority [5]. On the other hand, ambitious massive smart sensor networks plans [6]–[8] have been launched in recent years to enhance buildings energy efficiency.
Smart sensor networks have been largely deployed in buildings for energy monitoring and operation [9], [10] or building energy consumption forecasting [11], [12]. Studies have used sensors to highlight and characterize the link between energy efficiency and inhabitants' behavior [13]–[16], identified as one of the main source of energy performance gaps [17]. Data collection solutions have also been proposed to supervise building energy retrofits [18]–[21]. However, instrumentation solutions deployment is a complex task, facing many challenges and difficulties. Thus, it directly impacts on the quality of the analyses and the efficiency of related energy savings measures [13], [19], [20].
In this context, we present a case study of an instrumentation solution deployed in existing residential buildings. The instrumentation takes part in a larger project that aims to study the impact of deep energy retrofit measures on building energy consumption.
The present paper is organized as follows: Section 2 presents the project case study and Section 3 describes details of the instrumentation solution. Then a feedback on encountered watch points for sensor networks implementation is proposed in Section 4. Watch-points will be illustrated in the presentation with examples of field situations. They will be discussed to help provide feedback on sensor network deployment.

## 2. The case study

In the present project, a group of three existing social residential buildings – 63 apartments over a 4,600 m$^2$ living area – is considered for field experimentation. Buildings were built in 1974 and are located in Paris (France) eastern suburb. They only had minor retrofit actions and are now planned to undergo deep energy retrofit measures over an eighteen-month period in 2019-2020. Retrofit measures will be implemented in occupied site as apartments will be occupied by tenants during the whole retrofit period.

## 3. Instrumentation methodology

### 3.1. Instrumentation plan

Instrumentation is performed in two steps and includes more than 280 sensors.

The first step covers communal areas and entire building level and involves 10% of the total number of sensors. The second step covers 10 households. Step 1 sensors have been installed and data collection is operational. Step 1 serves as a test to gain knowledge on sensors operation, and to identify the key issues and watch points. Step 2 is currently being implemented.

The sensor network aims to provide a four-level instrumentation scale (residence, building, apartment and room level) with a particularly fine time-step granularity (from one-minute to one-hour time-step). Types of collected data can be divided into five categories: 1) Outdoor environment quality (OEQ) is provided by a weather station measuring outdoor temperature, humidity, rain level, solar irradiation, wind speed and direction 2) Indoor Environment Quality (IEQ) provided by sensors in communal areas as well as apartments which measure indoor temperature, humidity, luminosity, $CO_2$ level and indoor surface temperature of exterior walls at one-hour time-step 3) Inhabitants' behavior characterized with presence and windows opening detection, 4) energy consumption which is monitored through electricity, natural gas, heating and domestic hot water consumption metering at one-minute time-step and 5) the building thermal insulation through walls surface temperatures and heat fluxes.

All sensors communicate using LoRa technology, on operated or private communication networks, exception made of two types of electricity sensors directly communicating data with GPRS network. Therefore, gateways have been installed to enhance the network communication capabilities. All data are stored on an FTP server with one data file per sensor per day.

### 3.2. Description of the instrumentation management process

The overall instrumentation of the present project can be divided into six different stages, spread out over an estimated timespan of one year (started in October 2018 and expected to end in September 2018). All the six stages have a crucial impact on the success of the instrumentation and require different knowledge and skills. First is the accurate definition of the instrumentation specifications (1) to meet the needs of the project. In parallel, a review of service providers offering adapted solutions is done (2) and apartments are recruited to participate to the instrumentation study (3). Once specifications are organized in a clear framework, they are submitted to identified service providers (4). Several rounds of discussions allow modifications on specifications to adapt to the reality of the market and for service providers to refine their offer to meet the needs of the project to the best of their capabilities. Every round dismisses several service providers to select the most relevant one. Once the quote is signed, sensors can be ordered, delivered and installed (5). Finally, once the sensor network is functional comes the hand-over of the instrumentation solution (6).

## 4. Watch-points from sensor network implementation

During the planning and deployment of the first phase of the building instrumentation, several watchpoints and issues have arisen. These are reported in the present paper and are grouped in five categories: (1) onsite installation conditions and environment, (2) characteristics and purpose of instrumentation, (3) service provider and (4) project tracking and management.
The experimentation site directly impacts on the challenges and success of building instrumentation. Indeed, a main feature of the present project is to collect data on existing and occupied buildings. Therefore, identification and verification of the facilities to be instrumented is critical. Moreover, characteristics of the instrumentation environment can impact on the sensor communication quality and installation feasibility, inducing additional costs and delays. A particular attention should also be given in the technical characteristics of the instrumentation solution. Specifications on the data to be collected is impacting on many related factors such as the choice of an adapted data collection method (wired or wireless), the communication networks, the requirements on the sensor operation (time-step, adaptability to the environment, lifespan). Also, because of the purpose of the study – a research project on inhabited building energy performance – the solution has to comply to other constraints such as being non-intrusive and ensuring personal data protection.
The service provider for the instrumentation solution has also a significant impact on the execution of the sensor network deployment plan. Indeed, it may be difficult to find a service provider ensuring the provision of relevant sensors, their integration in a data collection platform and installation onsite. It is often necessary to contact more than one provider to have the whole range of services required. It becomes even more complex when custom services are needed, such as specific sensor characteristics or sensor network maintenance. Finally, a rigorous project tracking and management process is critical for all six stages described. Many details may induce important delays, additional costs and other issues.
The four categories of watchpoints will be illustrated with various examples and situation encountered during the implementation of the first instrumentation phase of the present project. Discussions will also aim to provide a guideline for sensor network deployment for future projects.

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