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# Monitoring the energy efficiency of buildings with Raman DTS and embedded optical fiber cables

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## ABSTRACT

To reduce greenhouse gas emissions and to promote energy savings in the building sector, a project named *Batimetre* has been set-up, to measure parameters affecting building energy consumption. For the first time, optical fibers have been deployed on internal and external faces of two experimental houses, designed for low energy consumption. With a DTS Raman system, these cables provide a distributed measurement of walls temperature every meter and every two minutes. Such instrumentation is able to deliver a very large number of data at a reduced operating cost. It allows to isolate thermal phenomena in dynamic thermal simulation tools, and to compare several intermediate predicted and measured parameters.

**Keywords:** Energy efficiency, Low Consumption Building, Positive Energy Buildings, Optical Fiber Sensors, Raman DTS.

## 1. INTRODUCTION

In France, the building industry consumes 44 % of total final energy spent. It uses about 70 million tons of oil equivalent, making it the biggest consumer of energy (transportation is ‘only’ 32 %, and industry 21 %) [1]. All of them contribute to CO<sub>2</sub> emissions: 25 % of the French national emissions are linked to the building sector, and will have to be divided by a factor 4 by 2050, according to the Kyoto agreement. Unfortunately, the annual volume of new construction (300 000 residences) is so small that one century will be required to replace the 30 million residences in the country. While the traditional conservatism of building sector have long been considered as an handicap compared for instance to industry and transport, experts say it is now set to play a significant part in tackling the troubling environmental challenges we are all facing. France has adopted a National Strategy for Sustainable Development, introduced in June 2003, and a Climate Plan, introduced in July 2004. More recently, following general elections in May 2012, the government made a stance on nuclear energy, vowing to increase France's commitment to renewable sources of energy instead. The government has called to drop France's dependence on nuclear power from 75 % to 50 % by 2025.

In the construction sector, one of the solutions promoted by a dedicated workshop, called *Grenelle de l'Environnement*, consisted to develop high energy efficiency buildings. The aim for 2030 is to achieve widespread implantation of such buildings and to make the technology available for constructing “positive energy” buildings. Another goal, devoted to existing building, is to have construction rules appropriate to rehabilitation solutions able to lower by 2/3 their energy consumption. The approach engaged last year with the concept of Low Consumption Building (called "BBC") must be applied at any new building [2], and by some tax incentives ("Scellier" and "Duflo" BBC laws) for investment rental that allow the owner to get taxes reduction if the

house is new and certified "low energy consumption" [3]. In addition, it is intended to impose, by 2020, the construction of so-called Positive Energy Buildings (BEPOS) including production of renewable energies, beyond what the building consumes. We may also highlight the recent thermal design rules in France, called RT2012 [4, 5], which require the "measurability" of any new building performances. That is why so-called "Energy Performance Guarantee" contracts appear, as the energy labeling has become a requirement for any transaction to purchase or to rent housing. Therefore, these approaches lead to diagnosis and monitoring of new buildings, first of all to ensure their initial performances fulfill the requirements and later, to detect possible deviations and their origins. In addition, the concept of smart buildings, with adaptative capabilities is also an interesting path. So, energy savings in the building sector are a matter of concern for governments, as well as for companies. Many hopes rest on the implementation of effective improvement of the energy performance of buildings. That is why, in recent years, many efforts have been engaged on evolving technologies, as well as diagnostic tools and simulations about the energy efficiency and the integration of new and renewable energies.

## **2. DISTRIBUTED SENSING FOR BUILDING MONITORING**

### **2.1 Monitoring of two dedicated experimental houses in the French Alps**

To improve experimental knowledge, the French National Research Agency (ANR) supports the project named *Batimetre*, dealing with the building efficiency monitoring, *i.e.* to develop instrumentation able to determine in real time the influence of several physical parameters involved in the energy efficiency of low consumption building, [6]. Experiments took place on the INCAS experimental platform based in Chambéry, France, where two experimental houses have been build and equipped with many sensors [7]. Instrumentation remains the main part of this project, but software development was also a matter of concern. About 150 sensors were installed on each house to determine in many locations: temperature, relative humidity, pressure, efficiency of heater, fresh air distribution, hot water, as well as meteorological conditions.

### **2.2 Measurement system and optical fiber cables**

Thermal considerations remain of prime importance to obtain the "low energy consumption" certification. Unfortunately, a lot of temperature sensors (some hundreds) are needed to completely map a house. Considering cost and complexity to deploy a so large number of traditional sensors, and also to collect their data, we have chosen the distributed optical fiber thermometers, *i.e.* a Raman DTS-based solution, as in a previous project dealing with temperature sensing in underground GeoExchange System [8]. Such thermal monitoring is important, as functionalities and specifications of materials used to build the external envelope of a building, especially if it is labelled "low energy consumption", as they impact strongly energy leaks, inertia, permeability to external air, solar influence... *i.e.* all the parameters involved in the energetic yield. Due to the possibility to get selective temperature measurements through the ratio of intensity of the anti-Stokes and Stokes lines produced by the Raman backscattering in fibers, DTS developments started during the 80s in UK [9-10], quickly leading to commercially available products. About 25 years later, DTS are used in several industrial sectors as oil & gas [11], for pipes and risers monitoring (to avoid slugs for flow insurance...) and civil engineering for fire detection in tunnels for instance [12]. The technology provides the fiber temperature profile, with about 1 m spatial resolution and a temperature resolution  $< 1^{\circ}\text{C}$ , on long ranges (up to 30 km with single mode fibers). Based on Reflectometry, the measurement time is relatively

low (several minutes), as many traces must to be averaged to improve the Signal-to-Noise-Ratio. These figures were in good agreement with our project specifications. So, 50/125 multimode optical fibers inserted in 'loose-tube' cables labelled as « temperature sensors » were chosen and tested in an oven, to characterize their performances. Later, several fiber cables have been deployed during construction (Fig. 1), on many locations (embedded into internal and external walls, attics, crawlspaces). These optical cables have been fusion-spliced and connected to a 4 m-long temperature-reference box and to the DTS through an 8-channel optical switch. The reference box was equipped with 2 PT100 probes to adjust both DTS slope and offset. Temperature profiles are transferred to a PC through an Ethernet link. For easy use and maintenance, DTS, optical switch and PC (signal processing & data storage), are localized in an industrial cabinet.

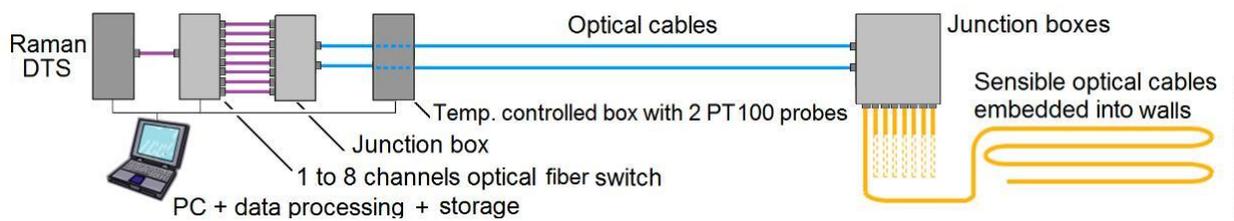


Figure 1. Schematic diagram of optical fiber topology and associated temperature measurement system.

A dedicated LabView® software, including an user friendly Man-Machine-Interface has been developed, allowing end- users, i.e. non-optician people, to easily visualize and manage temperature sensing for their own needs (energy efficiency calculations). This interface allows to adjust main sensing parameters and functionalities (the acquisition speed, i.e. the averaging), the fiber cables switching (optical switch channel timing), signal processing parameters, storage in local data base, temperature profiles, viewing on real time or on demand, data transfer to the site control system...). The software includes LabView® VIs, devoted to adjust the profiles slope and offset, to extract useful zones from the temperature profiles... or to scan on request the data base, in order to visualize temperature measurements previously recorded.

### 3. INSTALLATION AND RESULTS

After laboratory testing, the full instrumentation has been installed on site. First of all, optical cables have been deployed on, or into, the walls, during houses building. To prove the industrial feasibility of such technology, optical fiber cables were installed by subcontractor in charge of electrical cabling, i.e. people not skilled with optics nor with fibers. The only advice we provided them was “Please, take care with the cables: do not bend them too much, and do not walk on them”!

The houses were equipped as follows: one optical cable routed on both internal and external wall surfaces of house one, called BB, and a fiber cable on the outside of the internal walls of the second house, called DM (Fig. 2 and Fig. 3).

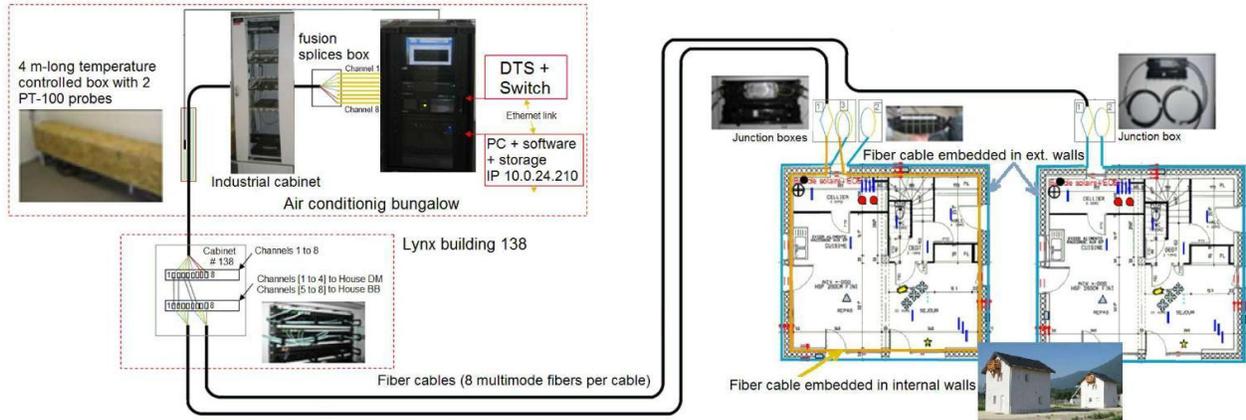


Figure 2. The houses' map including cables routing and distributed temperature measurement system configuration

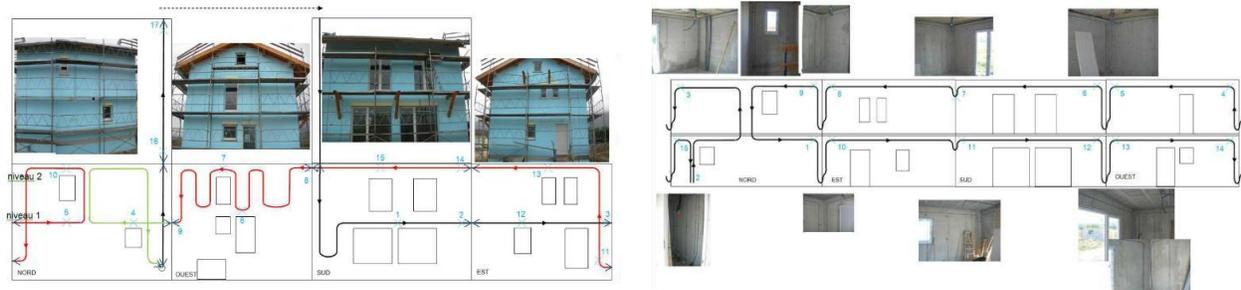


Figure 3. Optical fiber cables routing under the thermal insulation of external walls of house BB (left), Fiber routing under the house BB internal walls decoration (right).

As the DTS provides thermal profiles (Fig. 4) along optical fiber cables, a physical localization of such fibers is required when embedded into the walls, to follow their physical location on the ground plane. Their full localization may be obtained by local heating, provided by an heat gun, at several specific locations (windows, corners of the house...). The very first DTS profiles have been used to validate this procedure thanks to temperature changes, due to solar radiation evolution on walls, all along the day. Specific locations, as attics, are characterized by small or strong thermal variations, depending on their location into the house. Thermal variations of some other locations are limited (house DM), as internal temperature being more homogenous in this house, and also due to the fact that the sensing cables embedded into its external walls remain less exposed to solar lighting, considering the house orientation.

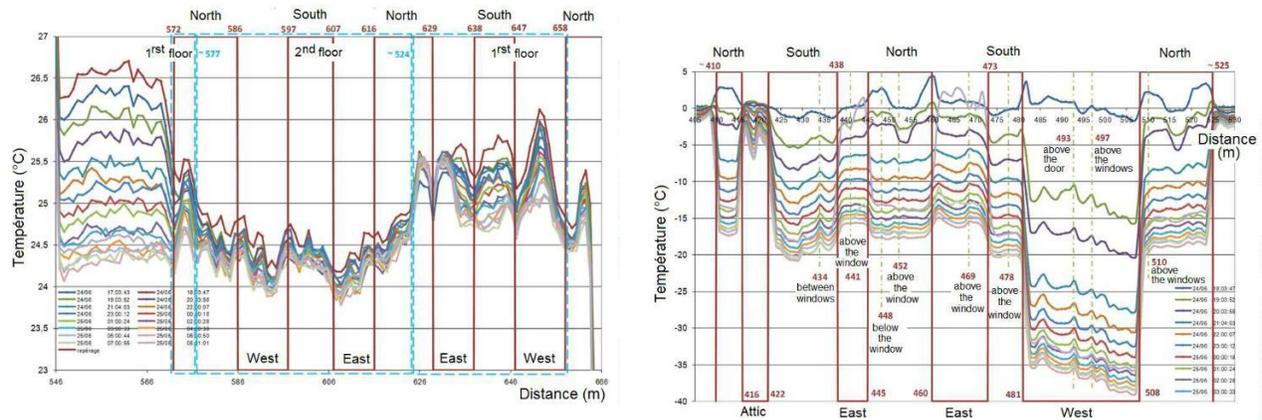


Figure 4. Temperature profiles recorded in house "BB" (left). Temperature differences determined from profiles recorded with fibers embedded into the house BB outside walls (right). Both figures are from 5 PM up to 8 AM the day after, in June.



Figure 5. Routing at room corners. Cable drum. Routing through an internal wall, Deployment on external surface.



Figure 6. The two houses after building completion.

#### 4. CONCLUSION

For the first time, optical fibers have been embedded into internal and external walls of two buildings (Fig. 5 and Fig. 6), to characterize their energy efficiency. Based on Raman DTS, the equipment provides a measurement every meter and every 2 minutes to monitor their thermal behavior. This equipment is now operational and able to deliver a large amount of data, at a low operational cost. The energy consumption performance may be analyzed thanks to traditional and fiber-based data stored in a dedicated data base. Every day, 213 000 new data are recorded. They may be used to estimate the relative influence of thermal phenomena taken into account by thermal simulation tools and so to compare results of modelling to experimental

measurements of many intermediate parameters, as glass window temperature, solar irradiation, external air temperature, internal temperature...).

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