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Understanding Sciences Through Participatory Research

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ABSTRACT

The interest for a researcher to follow a participatory research approach compared to a conventional approach is multiple. The aim of this project is to make scientific research accessible to everyone, especially high school students. Our approach is a new concept of learning by doing for high school students that adopt the posture of a researcher to solve a problem presented to them. Students propose working hypotheses, imagine their protocol, experiment, discuss and communicate their results. High school students are supervised by the PhD students and the results from these studies are used for their research work. Currently several French and international Universities have approached us to implement this participatory research.

Keywords—participatory, science, renewable energy, learning methods, collaborative learning, renewable energy.

INTRODUCTION

Participatory science is a global phenomenon and France's share represents 4% of world publication production. These publications are rather derived from participatory devices related to agriculture, biodiversity and the environment but never in the field of energy management and control. We developed a new concept of participatory science[1,2,3] to encourage high school students to become more interested in science through a research project where they must imagine the built of a liner using new energy technologies and very low energy consumption. School students are supervised by the PhD students and benefits from these studies are integrated in their research work.Since 2009, University of Lorraine has equipped itself with a 200 m^2 laboratory of multi-sources of renewable energies from self funding or sponsored by private ventures and different local councils. This GREEN* (French acronym) platform laboratory is a first in France which welcomes all students of all levels on a long-term internship and offers studies and applied industrial research projects. Among the various use of the platform, we can quote the participatory research. By way of example, a foundation subsidises an innovative project called "All Researchers " since five years. The aim of this project is to make scientific research accessible to everyone, especially high school students. We propose to entire classes, research courses in spaces offering the conditions for learning such as "learning by doing". For three consecutive days, pupils adopt the posture of a researcher to solve the problem presented to them. They propose working hypotheses, imagine their protocol, experiment, discuss and communicate their results. As a result of these courses,it is remarkable to note that after several years of surveys of school teachers, this participatory research has been able to advise school students, particularly girls, to pursue postgraduate and scientific studies. On the other hand, the PhD student has been able to give a critical and reflexive look at a situation. It also gave an opportunity for postures change and ways of thinking, setting up a space for research dissemination.

* Gestion des Ressources Energétiques et Energies Nouvelles

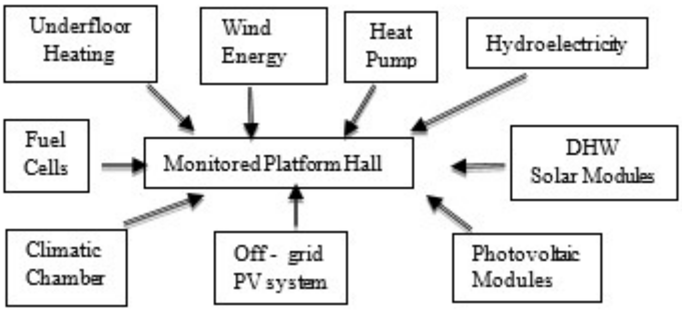
DESCRIPTION OF THE GREEN LAB- PLATFORM

GREEN is a French acronym standing for Energy Resources Management & New Energies. This platform is located in the department of Physics Institute building at the University of Lorraine, Metz, France. This platform is structured and described as follows:

- An AREVA Polymer Electrolyte Fuel Cells (PEFC), converting hydrogen, or hydrogen-containing fuels, directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water. Generating simultaneously 1 kWth heat and 1kWe power. The goal is to study Fuel cell components and their impact on performance and automotive applications.
- New method for Coefficient of Performance (COP) determination of an STIEBEL-ELTRON air to water heat pump.
- Sizing and modeling a compact PELTON turbine for a hydro project, requiring correct interfacing with the electrical, mechanical, hydraulic and civil aspects.
- Measuring and modeling heat transfer through new thermal insulating materials using a B.I.A climatic chamber.Thermal performances and properties determination through
- Measuring overall efficiency of VIESSMANN solar technology, flat-plate and vacuum tube collectors for energy-efficient Domestic Heat Water (DHW) heating, central heating backup and power generation.
- Underfloor heating experimental room, aims to more efficiently heat homes by using occupancy sensing and occupancy prediction to automatically control home heating.
- Simulating underfloor heating, REHAU software.
- Methods for accurate measurements of heat patterns, emissivity and temperature factors using different types of thermal camera.
- Softwares for dynamic simulation, design, yield for Photovoltaic, Solar Thermal and Heat Pump Systems as well as Home heat loss simulating software.
- Sizing off-grid PV systems and determination of technical and potential problems.
- Li-ion cells modeling for battery management system BMS, for electrical vehicle. New BMS around a heating/cooling system based on absorption thermodynamic cycle. Implementation of a low-power embedded system via FPGA reconfigurable circuit.
- Polycristalline modules of SCHÜCO technologies are interconnected in series and mounted on the south vertical wall of the platform building. Each module has a peak power of 205 Wp, at tilt angle of 60°, low ventilation and connected to a SCHÜCO inverter for a power level up to 1 kW. The two other modules are only for DC measurements in same experimental conditions.
- Amophous silicon modules from SOPREMA is on the rooftop of the building. Soprema's modified roofing material, SopraSolar, powered by UNI-SOLAR, integrating their PV laminates into the waterproofing function.More panels are needed to reach the polycristallline string power output. Each module has a peak power of 136 Wp, of nearly 5° inclination angle and connected to a 1500T SCHÜCO inverter.
- Residential Skystream three blades 2.6 kW horizontal axis wind turbine, which is at 12 m above the ground level in an urban complex zone. We have modeled the energy output.

All these technologies are monitored as represented in figure 1.

Figure 1: Monitoring equipment of the GREEN-Lab



The main monitoring hall is represented in figure 2.

Figure2 : Main hall of the GREEN Lab, 100m²

THE PARTICIPATORY PROJECT

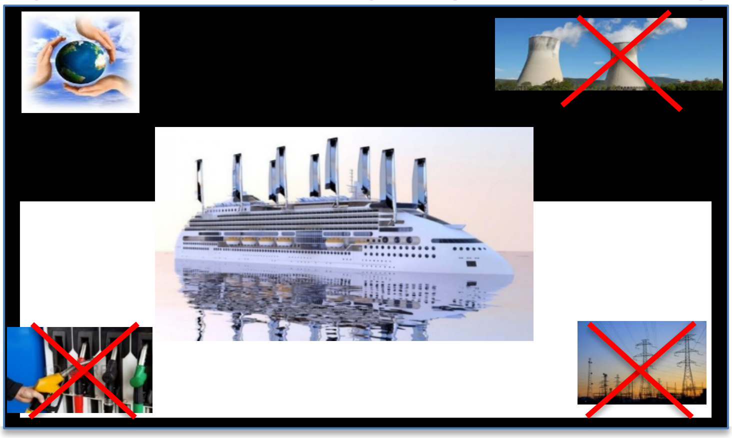
The participatory project is called “all researchers” and aims to educate and engage various public world (schools, patient associations, professionals, general public) in scientific research to understand how science is carried out in research laboratories. The goal is to give keys to everyone so that they can dissect a scientific result: by whom and how the results are obtained and validated. Knowing more about how scientific research is done should allow every citizen of any age to take an active role in science.

In this paper, the public concerned for this participatory project is school student. Entire classes of high school students are welcomed at the GREEN lab-platform to carry out mini-research projects on a theme related to their respective school course of study. School students spent three consecutive days putting themselves in the shoes of a researcher. For the students, it is about working as a team under the responsibility of a tutor to solve a science problem and sharpen their curiosity. They are sub-divided into groups and each group is supervised by a doctoral student. The most important thing is to learn to imagine solutions, to experiment with current research tools to test them, to analyse and verify their results, comparing them with what they had imagined, discussing them and presenting them orally to their peers. The whole process is presented in Fig. 3.

Figure 3 : School students implementing research processes

The main aims of the project is to get the students imagine building a new liner that works with clean energy resources avoiding polluting and dangerous technologies while respecting the environment. The initial observation is represented in figure 4.

Figure 4 : Building a liner without polluting energy while respecting the environment



A scenario is that students are in front of a series of images triggering their questioning about the factors that determine the operation of different technologies for generating electricity and producing domestic water from renewable energy technology or generating electricity from other new and clean technology, as the liner needs energy, for example to:

- move
- protect against climatic conditions (no overheat / cool)
- light up day and night
- produce hot water (sanitary, swimming pool, ...)
- cook and operate household appliances
-etc

However, students have to deduce the points listed above from observations from figure 5. Some on the technologies they will be using have been described in section II. Once the students have formalized their research questions, they are invited to put in place an appropriate experimental approach using the available equipment, to analyze the results they obtain.

Figure 5 : Deducing Energy needs by the liner

The proposals of students for the energy needs by the liner are as follows:

- Fuel Cells to move the liner forward
- Photovoltaic technology and Wind power for electricity generating
- Studying insulating materials to avoid heater and air conditioner

These technologies and results are dealt within the next section.

RESULTS & ANALYSIS

Polymer Electrolyte Fuel Cells (PEMFC)

The preferred fuel for a fuel cell [4] is hydrogen. The basic principle of a fuel cell system is based on the reversible process of water electrolysis. Hydrogen and oxygen are recombining, and an electric current is being produced. Another way of looking at the fuel cell is to say that the hydrogen fuel is being 'burnt' or combusted in the simple reaction as given as in equation 1:

$$2H_2 + O_2 \rightarrow 2H_2O \qquad (1)$$

To understand how the reaction between hydrogen and oxygen produces an electric current, and where the electrons come from, we need to consider the separate reactions taking place at each electrode. At the anode of a PEMFC, the hydrogen gas ionises, releasing electrons and creating H+ ions (or protons) as given in equation 2.

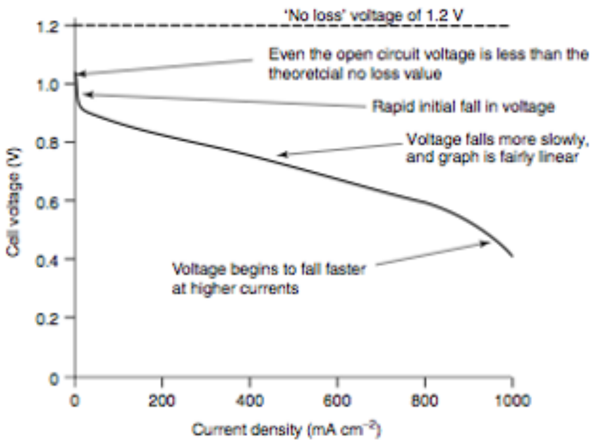
$$2H_2 \rightarrow 4H^+ + 4e^- \qquad (2)$$

This reaction releases energy. At the cathode, oxygen reacts with electrons taken from the electrode, and H+ ions from the electrolyte, to form water as represented in equation 3.

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \qquad (3)$$

Clearly, for both these reactions to proceed continuously, electrons produced at the anode must pass through an electrical circuit to the cathode. Also, H+ ions must pass through the electrolyte which is in our case is a polymer. The typical shape of the voltage/current density [5] graph operating at about 70◦C, at normal air pressure, is represented in figure 6.

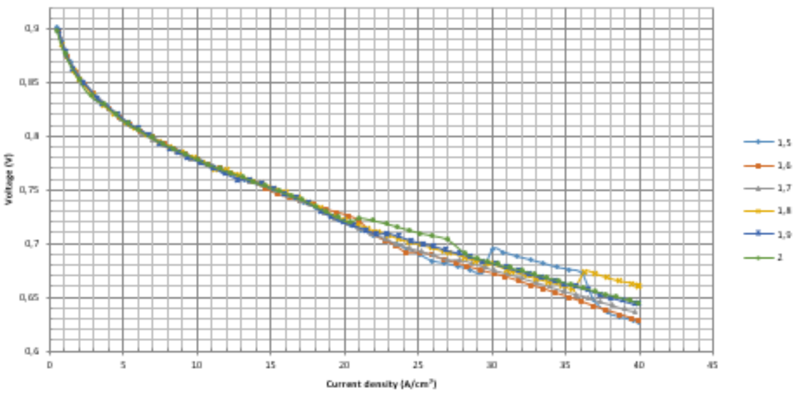
Figure 6: Graph showing the voltage against current density



Comparing equations 2 and 3 we can see that two hydrogen molecules will be needed for each oxygen molecule if the system is to be kept in balance. One of the protocol proposed by students of a sub group is to study the effect of oxygen stoichiometry on the fuel cell performance.

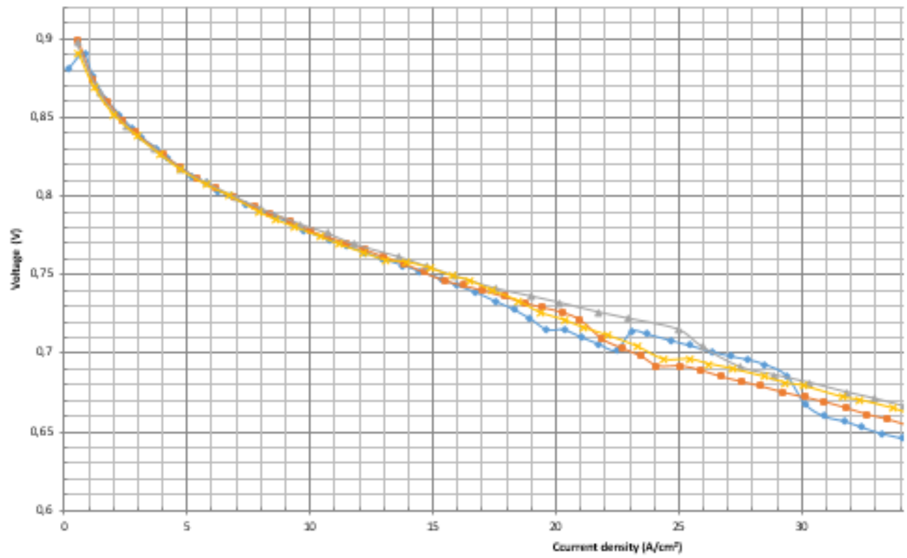
The issue is graphically shown in figure 7 that shows 6 graphs of voltage against current density for stoichiometry values between 1.5 and 2 and operating temperature is 70°C.The issue is graphically shown in figure 7 that shows 6 graphs of voltage against current density for stoichiometry values between 1.5 and 2 and operating temperature is 70°C.

Figure 7: Voltage varying with stoichiometry values



They then decided to analyse temperature effect on the chemical kinetic reaction at the electrodes. This is illustrated in figure 8.

Figure8. Temperature effect on kinetic reaction



One of the sub-group proposed to determine power efficiency for different current as represented in Table 1.

Table 1: Flow rates to detrmine power efficiency

I(A)	QH2 (l/s)	QO2(l/s)	PH2(W)	Pstack	Paux(W)	Putile	η système%
30	0,162333333	0,003175749	1738,27	450	150	300	17,259
35	0,147833333	0,002887044	1583,00	505	160	345	21,794
40	0,118944444	0,002309636	1273,66	555	165	390	30,620
50	0,104166667	0,002020931	1115,42	650	171	479	42,943
55	0,089666667	0,001732227	960,15	700	180	520	54,158

The power efficiency is deduced from the oxygen & hydrogen flow rates, respectively Q_{O2} & Q_{H2}. They showed that for a high power efficiency the current density should more than 60 A and deduced the energy output. Further studies are now undertaken by doctoral student.

Photovoltaic(PV)

The PV design of the GREEN Lab platform is an on grid connected system. Polycrystalline modules of SCHÜCO technologies are connected in a series wiring pattern and mounted on the south-south east vertical wall of the platform building as shown in figure 9. Each module has a peak power of 205 Wp, at tilt angle of 60°, low ventilation and connected to a SCHÜCO inverter for a power level up to 1 kWp.

Figure 9 : On grid polycristallin PV system, 1kW$_p$.

The two other modules respectively monocrystalline et polycrystalline on the right side of figure 9, are only for DC measurements in the same experimental real conditions.

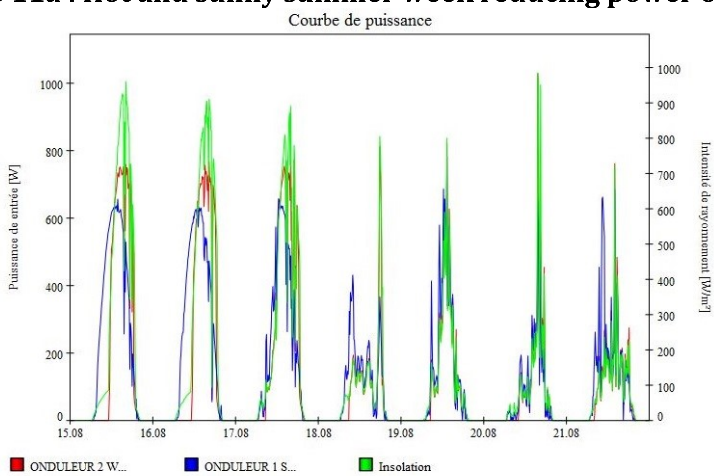
Figure 10 : Amorphous PV of 1kWp.

The PV series string of amophous silicon modules from SOPREMA is illustrated in figure 10, on the rooftop of the building. Soprema's modified roofing material, SopraSolar, powered by UNI-SOLAR, integrating their PV laminates into the waterproofing function.More panels were needed to reach the same polycristallline string power output. Each module has a peak power of 136 Wp, of nearly 5° inclination angle and connected to a 1500T SCHÜCO inverter.

As, PV are effected by operating temperature [6] which is primarily a product of the ambient temperatures or module as well as the level of irradiation.The sub-group for PV system have decided to analyse the temperature effect on the power output of each PV technologies. They searched through the data base of the GREEN-Lab and plotted the power output for summer and winter seasons for each PV technology.

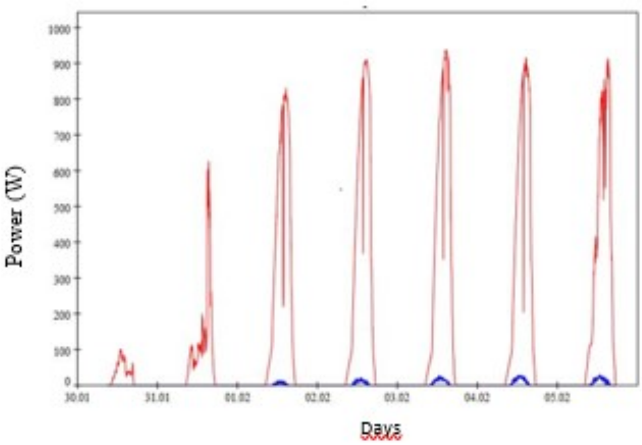
This is represented respectively in figure 11a & figure 11b. The red curve represents the power output of the polycrystalline PV and that in green represents the illumination coming from a sensor which is installed under the same conditions as the polycrystalline PV. Finally, blue curve represents the power output from amorphous PV modules. the decline in power output during the first two days for polycrystalline modules is blatant due to a very sunny day and where the ambient temperature was 35 ° and the measured modules temperature close to 75 ° C

Figure 11a : Hot and sunny summer week reducing power output.



The power output of the PV modules for a cold and sunny winter week is displayed in figure 11b, where the ambient temperature was close to 0°C, the power output polycrystalline is clearly at a higher level due to cooling condition. Snow on the horizontal surface of the amorphous photovoltaic modules indicates a close to zero power output.These results indicate the importance of considering the temperature characteristics for the solar module power output determination which cannot be estimated only from the performance in Standard Test Conditions (STC).

Figure 11b : Cold and sunny winter week normal power output.

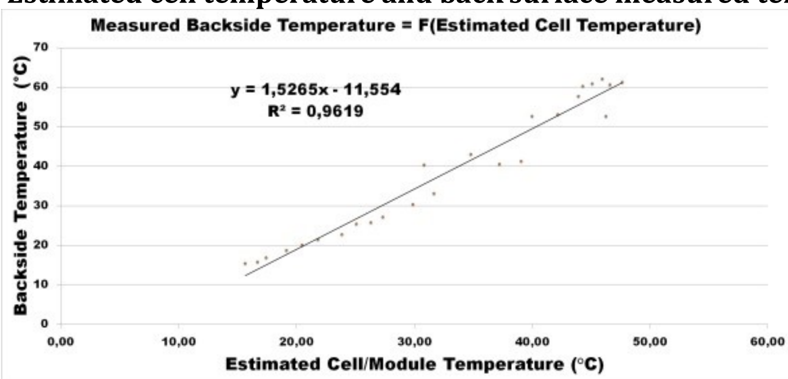


They then decided to determine the relationship between real conditions measured temperature and model temperature of polycristallin PV system. The model equation is given as in:

$$T_c = 30.006 + 0.0175\,(G - 300) + 1.14\,(T_{backside} - 20) \qquad (4)$$

Where G is the irradiation factor. The corresponding graph is given in figure 12. The correlation coefficient R is high enough to equal the estimated temperature T_c (cell temperature) to the measured back surface temperature.

Figure 12 : Estimated cell temperature and back surface measured temperature.



They proposed then to determine energy output of the polycristallin PV system from the power output relationship which is represented as follows:

$$P_{output}\,(W) = A\,(0{,}12G - 0{,}239.10^{-3}\,T_{backside}) \qquad (5)$$

They displayed their results in Table 2.

Table 2.Comparing power output model and measured ones

Time (H)	Back Surface Temperature (°C)	Estimated Power (W)	Measured Power (W)
06:00	15,46	0,00	0,00
06:30	15,85	9,66	0,00
07:00	16,93	28,45	0,00
07:30	18,80	46,33	0,00
08:00	20,16	60,87	0,00
08:30	21,55	76,15	0,00
09:00	22,80	90,57	100,00
09:30	25,45	129,91	105,21
10:00	25,80	113,27	110,48
10:30	27,25	129,08	149,43
11:00	30,40	215,67	197,73
11:30	33,20	320,18	211,22
12:00	35,06	508,15	530,04
12:30	40,40	191,93	250,00
13:00	40,60	610,97	650,39
13:30	53,20	937,91	803,70
14:00	60,33	1069,26	890,91
14:30	60,95	1127,73	915,38
15:00	62,16	1181,26	858,81
15:30	52,70	1154,23	920,22
16:00	57,76	901,27	860,58
16:30	61,30	1197,30	915,36
17:00	60,70	1161,62	816,80
17:30	52,70	655,35	410,17

These results have been used for further studies such modelisation of the energy output through Weibull principle and have been published [7,8,9].

Wind Energy

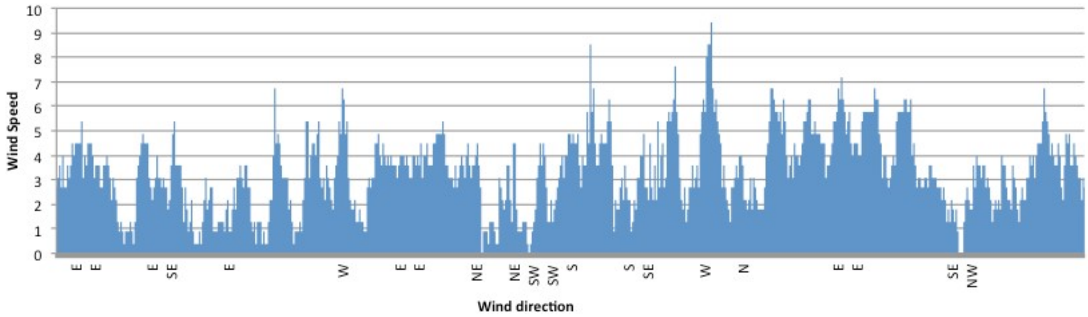
One student group investigated the performance of a micro-wind turbine in a complex urban area and show that due to long time period and very subtle onsite measurements the ideal position for the wind turbine can be determined et thus deducing the energy output.

The GREEN Lab-platform is equipped with a residential SKYSTREAM [10] three blades 2.6 kW horizontal axis wind turbine, which is at 12 m above the ground level as represented in figure.13

Figure 13 : Horizontal axis wind turbine 12m high

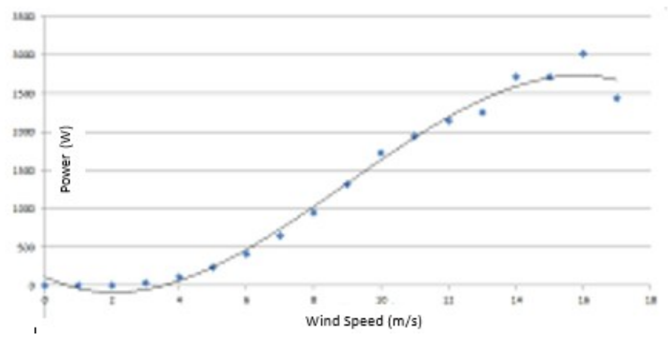
The students proposed to determine the wind direction details from the real measured wind direction of the used micro-wind turbine which is in concordance to local wind forecast where the maximal wind field is at the direction East and South-East with 5.5
m/s as indicated in figure 14.

Figure 14 : Wind direction of the GREEN platform experimental zone.



They then deduced the relationship between power output and wind speed from GREEN Lab data as represented in figure15.

Figure 15 : Power output as a function of wind speed

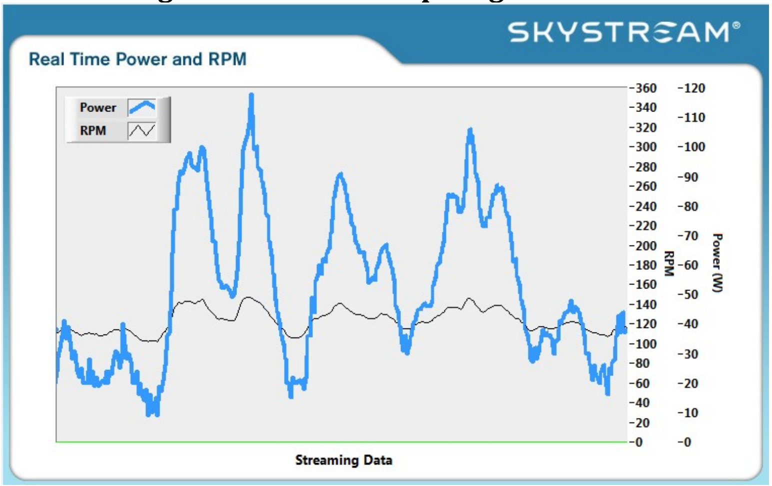


The also looked for the final relationship for the mechanical power generated by the wind turbine at the shaft as given in the following relationship.

$$P(W) = \frac{1}{2} C_p \rho S V^3 \qquad (6)$$

From Eq.6, S is the area swept by blades, Cp is the rotor power coefficient, ρ is the air density and V is the wind speed. The same group then studied the energy output from the real time power output as represented in Fig.16. The energy output for a period is given the the area under the curve.

Figure 16 : Power output against time



As this method seemed tedious, the students searched for another method and proposed the Weibull probability distribution function [11] for this zone as given in:

$$F(V)=(2{,}37/A)\ (V/A)^{1{,}37}\ (\exp(-V/A))^{2{,}37} \qquad (7)$$

Where V is the wind speed and A is the mean annual speed. The energy output is then obtained from the following relationship:

$$E(kWh)=\ \Sigma\, P_{i,output}\, F_i(V) T_i \qquad (8)$$

Where P is obtained from Eq.6 and F(V) from Eq.7 and T is the working time. They then compared results of the proposed method to the measured ones from year 2012 to year 2016 as illustrated in Table 3.

Table 3.Comparing model and measured values

Year	Energy (kWh) (Weibull)	Measured Energy (kWh)
2012	372,77	279,83
2013	329,92	346,94
2014	311,36	297,14
2015	348,12	361,16
2016	314,16	295,17

These results have been used for further studies by doctoral student and have been published [12,13].

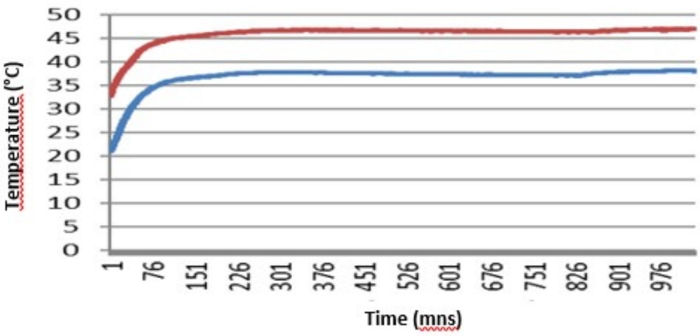
Materials Thermal Characteristics

The students were asked to study the characteristics of the materials for the liner construction. They used a climatic chamber with an opening on the side as represented in figure.17. The tested materials were placed in this opening and they set the temperature and humidity of the climatic chamber.

Figure 17. Climatic Chamber with a side opening.

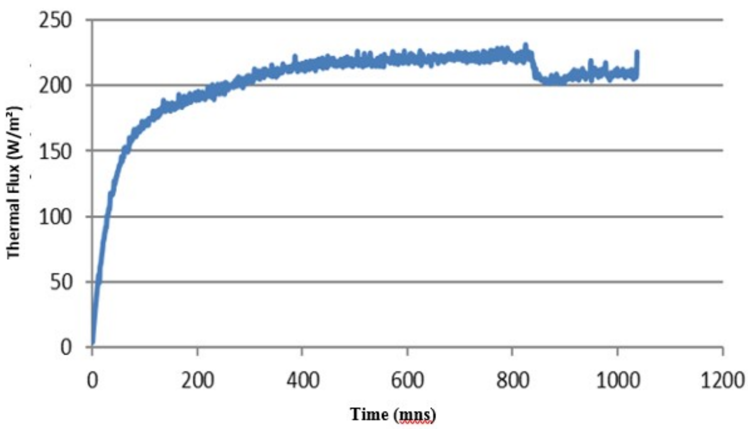
They wanted to know how will evolve the temperatures of interior and exterior surfaces of a material. This is represented in figure 18.

Figure 18: Temperature on both surfaces side



They proposed to measure the thermal flux flow U (W/K m^2) through a metal such as steel and to determine the thermal conductivity from the flat part of figure19.

Figure 19 : Thermal Flux flow through steel



Then they deduced the thermal resistance R (m^2 K/W) given as in:

$$R = 1 / U \qquad (9)$$

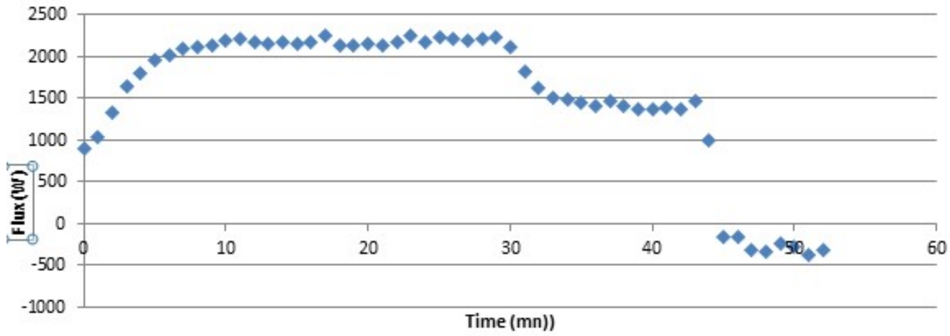
Finally from Eq.9, the determined λ thermal conductivity (W/m K) given as in:

$$R = e / \lambda \qquad (10)$$

Where e is the material thickness.

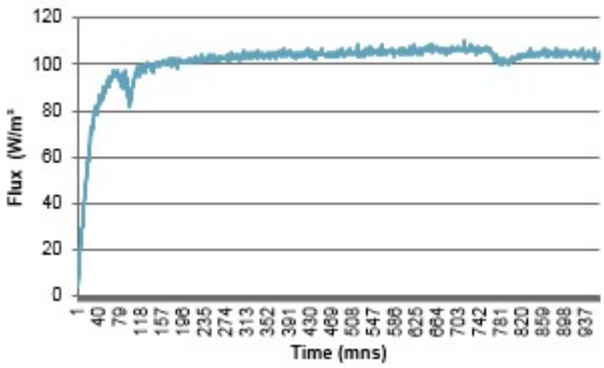
They repeated the experiment for an insulating material such as rock wool as represented in Fig.20.

Figure 20 : Flux flow in rock wool



They also measured flux through a double glazing window as given in figure.21.

Figure 21 : Flux flow of a double glazing window



The final step was to model a wall with several building material layers and also with smart [14] insulating materials but this is in progress by doctoral student [15].

CONCLUSION

The objectives of the job of researcher are diversified, bringing new knowledge, questioning, ensuring knowledge transmission through teaching. In participatory research, the researcher brings efficiency in understanding the phenomena and therefore an adequacy of tools and methods to solve the problem encountered. This project lasted for 5 years and the objectives were achieved. The pedagogy used for student's immersion in a research world was found to be very innovative by the school teachers as well as the supervision of the students by the doctoral students. Students have become aware that they are all capable by reasoning and setting up adapted experiments to solve a given problem. Other teachers have considered that this new approach has forced students to think critically and asked for their curiosities. Before this research project, doctoral students had difficulty explaining with simple words their research works to any public. Now they feel that this innovative method has made task easier. Currently several French and international Universities have approached us to implement this participatory research.

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