GreEn-ER Living Lab
A Green Building with Energy Aware Occupants

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Abstract: In the context of doubling energy use worldwide by 2030, with 80% remaining carbon energy, and in which buildings account for more than 40% of the total energy consumption, it is appropriate that buildings contribute "intelligently" to reduce consumption, contribute to the increase of renewable energy production and become a key node of the energy grid related to energy and transport of the eco-city. Moreover, these “smart buildings” will be in the near future aggregating a huge amount of data through numerous sensors. They will be connected to the neighbourhood, to the city and to the territory. Big data analytics and cloud computing will bring new services to inhabitant and citizen. We are presenting in this paper, the smart building “GreEn-ER”, which is a new building in the centre of the eco-city in Grenoble, France. It has been designed with many “green” ideas and is a “living lab” supporting research and teaching in the field of sustainability. This paper is focusing on the energy field and deals with electrical micro-grid interaction.

1 INTRODUCTION

1.1 The Building System

First of all, a building is composed by:

- a skin, which protects inhabitants from bad external conditions (climatic, pollution, noise, thieves…)
- systems to bring comfort (heating, ventilation, air conditioning, lighting, cooking, sleeping, entertainments, health care, security, …)

But we are not studing this building, we are working on a complex system, the BUILDING SYSTEM, which is composed by the previous building in addition with:

- the building users (inhabitants, owner, energy managers…)
- the building environment (weather, energy grids, information network, transportation, …)

This system is really complex since it is subject to many aspects such as:

- human (social, physiologic, phsycologic, etc)
- multi-physic (thermal, electric, mechanic, etc)
- economic (capex, opex)
- environmental (life cycle management, non-renewable resources …)

These items are ones we have to adress in our researches in the domain of energy in buildings.

1.2 Smart Building

Smart building is generally associated with home automation but it is far more complex. One of the challenges for energy based smart building success, is to work together with at least three sectors:

The energy sector, which needs to anticipate the consumptions and load shedding capabilities as well as decentralized energy resources (DER) potential in order to better manage production/consumption correlation.

The building automation industry which must move from classical BMS (building management system) that are most coming from the industry sector, to the city connected buildings and citizens.

The ICT sector which should collect the data of buildings in order to feed service platforms in the cloud for citizens, energy operators, and territorial decision makers.

Heating building correspond in France to the main consumption part as it can be seen with the strong correlation of consumption with temperature (Figure 1).

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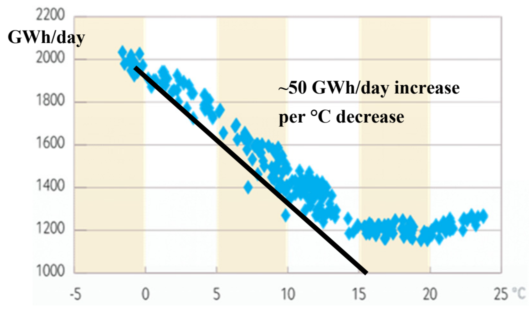

Figure 1: Correlation between temperature and electrical consumption in France – Gradient of daily consumption in France in GWh/day as a function of the average temperature in France (in °C).

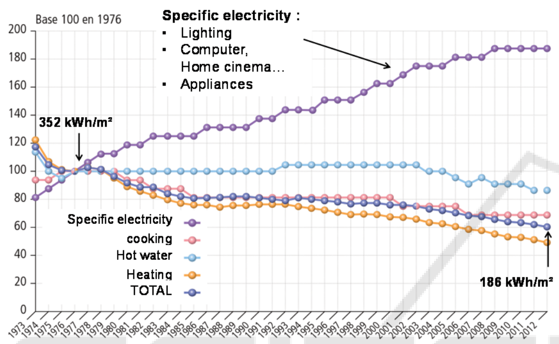

Figure 2: Evolution tendency of residential energy consumption /m² in France.

In Figure 2, while consumption reductions have been obtainded for heating thanks insulation improvement, the specific electricity is increasing a lot. This part is nowadays a big challenge for passive building where summer comfort becomes critical.

In Figure 3, we have put main topics around smart building in a single picture and it is clear that smart building is a complex system which has to deals with many challenges.

1.3 Smart Building Challenges

It is possible to define several objectives for smart buildings, according to social, environmental and economical aspects.

- Sobriety, efficiency and energy optimization
- User comfort and services through internet of things
- DER (Decentralized Energy Resource), renewable energy produced
- Main contributor node of the city micro grid multi-fluid energy management
- Mobility: link between Building – Transport
- New services associated with the Big Data Analytics / Cloud computing

In Figure 3, we are defining several research topics related to these challenges:

- Load management: load scheduling / adjusting / shedding, uncontrolled load prediction

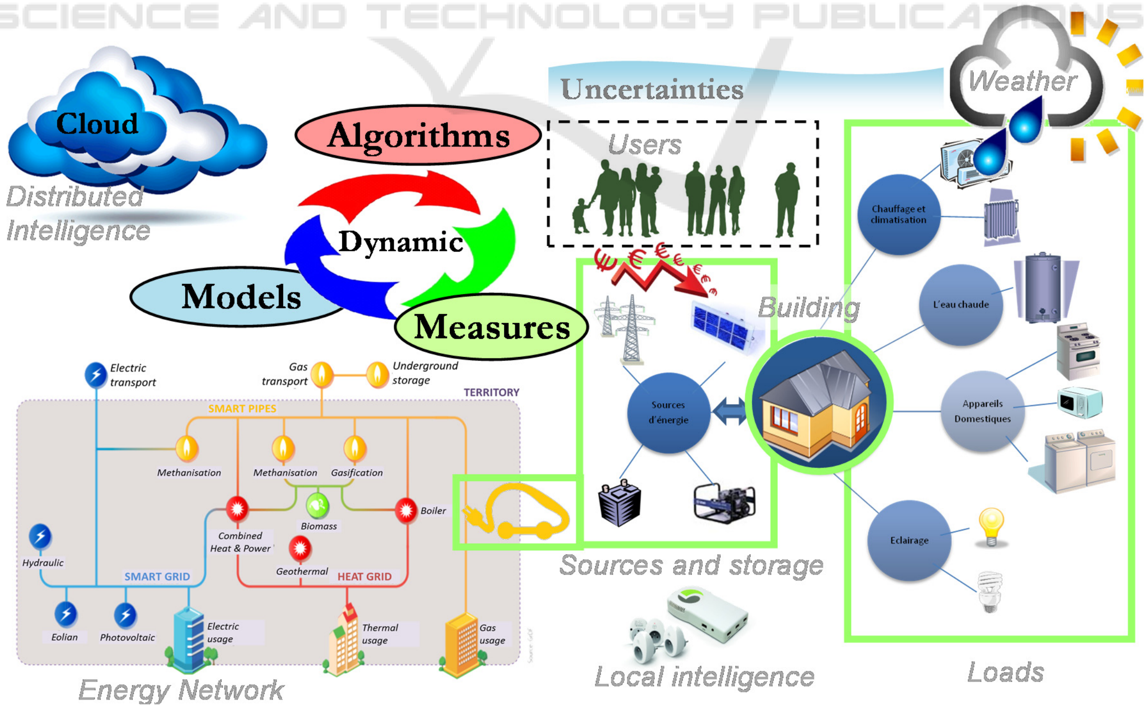

Figure 3: What a smart building has to manage.

- Local or distributed multi energy sources and storage management: arbitration between generators, scheduling production / storage.
- Uncertainties management: regarding users (equipment usage, comfort requierment), regarding weather (heating/cooling needs, renwable production), regarding energy price
- Local and distributed intelligence: energy and comfort monitoring for inhabitants and service providers, system actuation and control, data mining, cloud computing.
- Life cycle management: adaptative modelling, robust optimization, plug & play predictive control…

Some of these challenges have been already adressed by researchers and there is already a lot of work in the litterature. For instance, starting from the smart grid context, smart meter have been widelly considered enought to make the grid smart but Sharma has shown metering vulnerability and has defined what is smart metrology meter (Sharma, 2015). In order to improve the knowledge about end-users, load curve dissagregation must be applied on the non-intrusive load-monitoring techniques. Rowlands published recently a review and recommendations on the end-user monitoring in order to increase the measurments to loads, production and storage. Numerous data are requiered to model load demand at the level of the day. Torriti has made a review of data and methods of time use studies such as Markov chain technics (Torriti, 2015), while Fumo has widely use linear regressions but is claiming that the increase of sensors will lead to individual models instead of statistical ones (Fumo, 2015). Home energy management systems (HEMS), based on such modelling, enabled demand response in electricity market, Khan review demand response programs in various scenarios as well as incorporates various architectures and models (Khan, 2015). Multi-agent strategies are especially well suited in this building-grid interaction or negociation (Labeodan, 2015). Building energy management is not enough, users comfort is critical to ensure sustainability engagment of people. Shaikh conducted a state-of-the-art intelligent control systems for energy and comfort management in smart energy buildings (Shaikh, 2014).

Now, smart grid is dealing with ubiquitous computing of smart building in which the home environment is monitored by ambient intelligence to provide context-aware services and facilitate remote home control (Alam, 2012). A general trend for new building is the nearly net zero energy buildings (Task 40/Annex 52, 2011). In Europe, the directive on energy performance of buildings establishes the goal of ‘nearly net zero energy buildings’ for all the new buildings from 2020.

In France, all new buildings should comply with energy positive by 2020. We are involved in COMEPOS Project (www.comepos.fr) aiming at constructing twenty five positive energy buildings in France by 2018 in order to prepare this new regulation. When energy generation is available in the building neighbourhood it may become smarter since it is possible to use more degrees of freedom. Lu et al. has recently made a review on design optimization and optimal control of grid-connected and standalone nearly/net zero energy buildings (Lu, 2015).

In our team, our main challenges are to find methodologies and to develop software for energetic systems design and operation in their environment, and during life cycle. This includes:

- the optimal design with operating costs (Capex + Opex).
- the optimal operation of consumption/ production/storage.
- “human in the loop”, to define comfort/cost trade-off, to give sobriety advices…

In the following parts of this paper, it will be presented through our experimental platform how we are dealing with these challenges through the following activities:

- <u>Modeling</u>: systemic approach, multicriteria tradeoff, scalability and uncertainty
- <u>Optimization</u>: dedicated algorithms and strategies
- <u>Smart Ubiquity</u>: information network, local and distributed computing
- <u>Transdisciplinary Approaches</u> : working with: sociologist, economists, computer scientists

2 ENERGY EFFICIENCY

2.1 GreEn-ER Building

GreEn-ER is a new building in Grenoble, dedicated to develop creativity, entrepreneurial spirit, and sustainability popularization in an environment combining training students, researchers, and end users. GreEn-ER is hosting master level training, for students of “Energy, Water and Environmental Engineering School” (Grenoble INP ENSE3).
Some figures:

- A 6 floors building with 4500 m² space per floor for platforms teaching / research

- 2000 people welcomed in the building, including 1,500 students.
- 1 research laboratory
- 2 restaurants (a brasserie and a university restaurant)
- 500m² of space at the Library

Figure 4: GreEn-ER: a building for energy learning and research.

2.2 Designed with Green Ideas

Many green ideas are in experiment, such as energy recovery. Data server room calories are reused to heat an atrium (Figure 5). Free cooling strategies using natural convection through the atrium (Figure 6), and forced convection in offices.

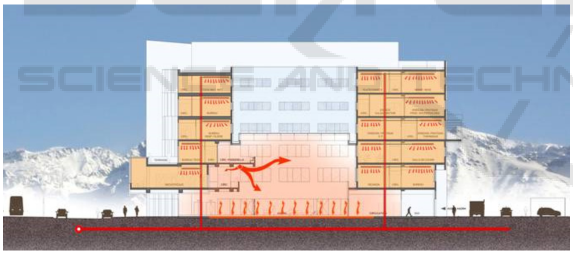

Figure 5: Server room calories recovery for atrium heating.

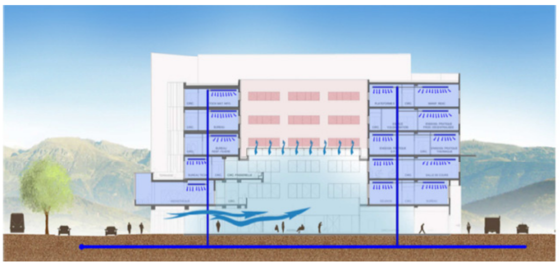

Figure 6: Natural ventilation through the atrium.

Dual flow ventilation with high efficiency recovery and low temperature supply (Figure 7):

- heating: 30/25°C (occupation/inoccupation)
- cooling: 19/23°C (occupation/inoccupation)

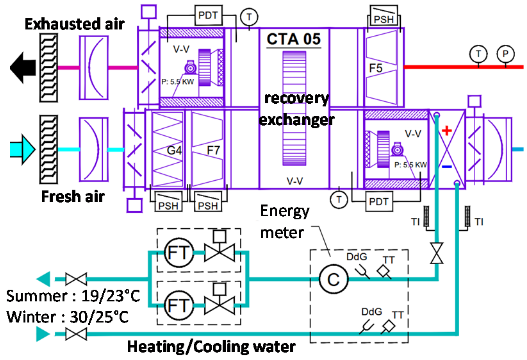

Figure 7: HVAC system.

And some other sustainable solutions:

- <u>Automation</u>: HVAC, lighting and blinding are based on local sensors of temperature, luminosity, CO2, and occupancy.
- <u>Energy Sobriety</u>: limited air conditioning, no hot water in toilets. Power supply switching
- <u>Water Sobriety</u>: 40% of the water consumption is from rainwater.
- <u>Green Roof</u>: free spaces on the roof are covered by vegetal plants.

Total primary energy consumption will be less than 2200 MWh / year which correspond to 110 kWh/m².

2.3 Energy Autonomy and Micro Grid

In GreEn-ER, PREDIS-MHI is 600 m² platform energy systems (Figure 8), has been specifically designed to reach zero energy building, and to study building or neighbourhood autonomy.

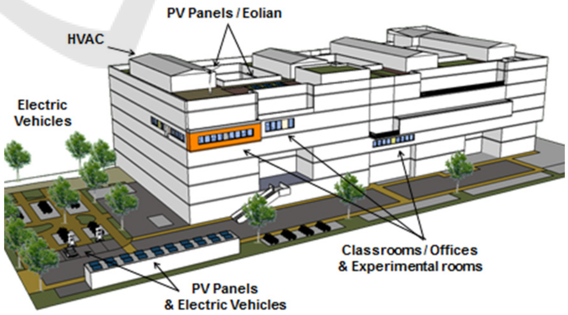

Figure 8: PREDIS MHI, production and storage.

20kW of photovoltaic panels installed on vehicles roof, and other are planned to be installed on the building roof. Other electrical productions are available in PREDIS platform such as a fuel cell and combined heat & power (CHP) which is also able to heat our platform. Storage capabilities have also been installed with electrical vehicles, and laptop rooms. A 50kWh stationary battery will be added.

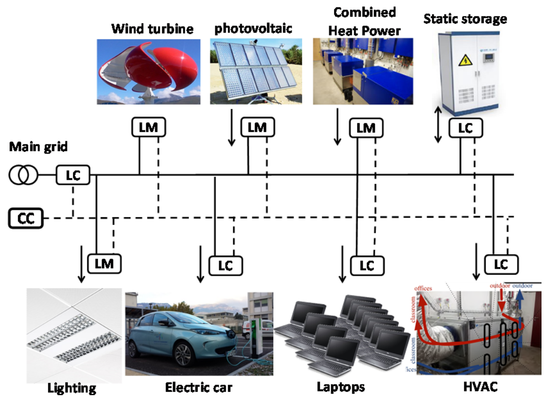

Figure 9: PREDIS MHI micro grid structure. LC: Local Controller, CC : Central Controller, LM : Local Monitor.

Optimal control solutions based on predictive models will be tested in this platform. Solving the problem of demand response requires determining a generation and a controllable load demand policy that minimizes, over a planning horizon, an objective function subject to economic and technical constraints. This policy is used as reference for the voltage and frequency control in microgrid real-time operation.

Load demand can be classified by priority and type as critical:

- Critical Load Demand: has to be full supplied all the time, otherwise, it will cause deficit in the system.
- Reschedulable Load Demand: has a particular characteristic of being able to be allocated across a range of time.
- Curtailable (shedable) Load Demand: may have the power supply cut, as a non-priority load, if necessary.
- Diffuse Load Demand: is a new concept made to deal with a thermic load demand, having the diffuse effect or the pre-diffuse behavior.

We are solving such an energy management using a deterministic mixed-integer linear programming problem, where the planning horizon is 24 hours with one-minute time steps (Tenfen 2014).

2.4 Real Time Energy Management

In our platform, several hundred measuring points and control have been set up such as HVAC, dimmable lighting, blind, electrical plug consumption measure and switch…

These measures and commands are accessible through the building network infrastructure and the internet. Its communication protocol is web service based enabling interoperability.

Many devices are added from the delivered building such as wireless sensors (433MHz, ZigBee, EnOcean, DeltaDore). In SmartGreen 2014, Abras has presented the interoperability framework that we have developed in order to manage this interoperability through web-services (Figure 10, Abras, 2014)

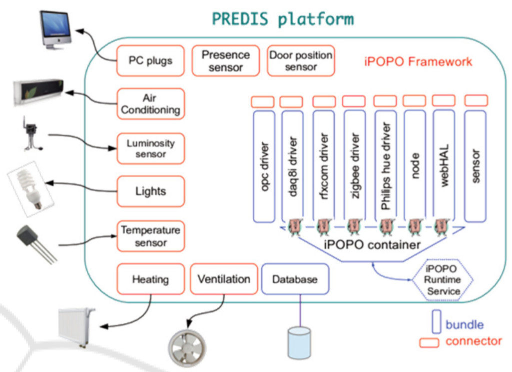

Figure 10: Sensor/actuators interoperability framework.

In 2013, Dang has presented the optimal control of laptops charging/discharging to fit photovoltaic production (Figure 11, Dang, 2013). This experiment was done in our previous building and will be deployed in the new one since it allows load shedding and photovoltaic energy storage.

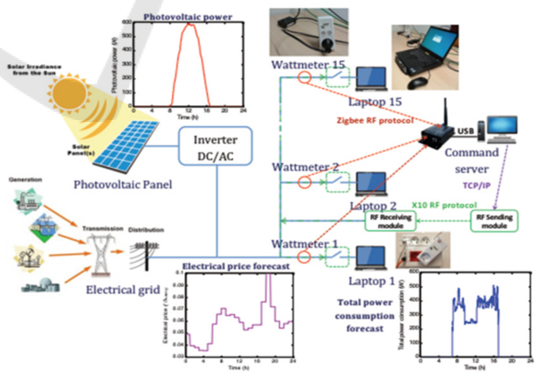

Figure 11: Real time control of 15 laptops charging/discharging for demand response.

In this automation of energy management, users / occupants are integrated in the loop. At this moment, occupants are able to define set points such as temperature, CO2 concentration, luminosity, heating mode. Moreover, their feedback is required and individual comfort will be learned progressively.

Beside this automation, many things can be done to help users to understand their own consumption and to let him acting on the system in order to learn about it. It will be discussed further in the part 3.

2.5 Multi-flow Energy Optimization

Both electric and thermal energy flow must be taken into account in smart buildings since one of the main consumption in building is HVAC (heating, ventilation and air conditioning). Predictive models for both electrical and thermal equipments are then required for the optimal operation.

Regarding thermal behaviour of buildings, dynamic simulation are done based on thermal properties of the skin (Figure 12), depending on weather conditions, occupancy and control set points. The results are the energy consumption with peak power, and occupant comfort criteria.

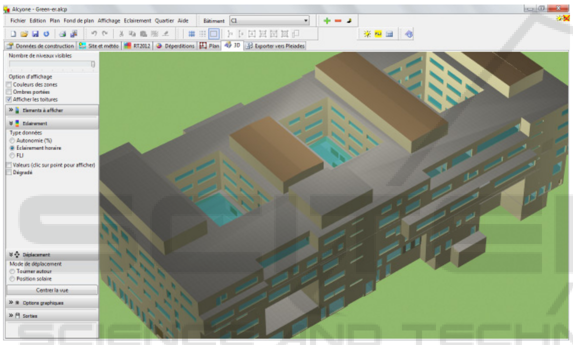

Figure 12: Thermal dynamic simulation of GreEn-ER (COMFIE software).

The previous software (COMFIE) is mainly used for design stage (not in control), since occupancy is predefined by scenario. In order to make a control depending on the occupant behaviour, we are able to make a co-simulation with this software and agent based modelling occupants (Gaaloul, 2013). This co-simulation is allowed thanks to our interoperability framework based on software component (ICAr/MUSE, http://muse-component.org).

Moreover, predictive control is done using optimization algorithms and requires dedicated modelling. The electric equivalent circuit method is recognized to be a good compromise between pure physical modelling which are too expensive and require too many information, and black box model based on mathematics which are not enough robust regarding prediction uncertainties. Robust self learning technics of physical equivalent circuit have been developed (Le Mounier, 2014).

There are Optimization technics using mixed linear integer programming (MILP) which needs linear modelling. These technics are especially efficient for smart grid and microgrid (Tenfen, 2014) but have limitation for non linear models which have to be discretized (Le Mounier, 2014). The difficulty in using non-linear model is to compute partial derivatives in order to couple it with gradient based optimization algorithms. We are using two different technics, the automatic differentiation (Dinh, 2015), and the adjoin method (Artiges, 2015), depending on the nature of the model.

Energy optimization is also strongly related to measurements. In (Artiges, 2015), we are able to control energy system but also to determine which sensors are best suited to perform this control.

3 GREEN-ER: A LIVING LAB

3.1 The Living Lab Concept

A definition is given by the European Network of Living Labs (ENoLL: www.openlivinglabs.eu), which is "a real-life test and experimentation environment where users and producers co-create innovations".

Academic institutions such as Harvard, Yale and Cambridge have adopted this concept within their strategy for sustainability (Graczyk, 2015). In most living lab concepts, the key components have been identified to be the ICT & Infrastructure, management, partners & users, research.

ENoLL defines four main activities:

- Co-creation: co-design by users and producers
- Exploration: discovering emerging usages, behaviours and market opportunities
- Experimentation: implementing live scenarios within communities of users
- Evaluation: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria.

3.2 AmiQual4Home Project

GreEn-ER and more especially the PREDIS platform is involved AmiQual4Home project which stands for Ambiant Intelligence for Quality of Life. It is an Innovation Factory which is an open research facility for innovation and experimentation with human-centred services based on the use of large-scale deployment of interconnected digital devices capable of perception, action, interaction and communication.

The Amiqual4home Innovation Factory is a unique combination of three different innovation instruments:

- Workshops for rapid prototyping of devices that embed perception, action, interaction and communication in ordinary objects,
- Facilities for real-world test and evaluation of devices and services,
- Resources for assisting students, researchers, entrepreneurs and industrial partners in creating new economic activities.

3.3 Workshops for Co-creation and Innovation

We have defined several workshops for users in order to develop ideas, innovative products & solutions. Each workshop is a set of tools available in the lab.

- Brainstorming: to produce innovative ideas for the developing of new services.
- Role Playing: to test how users are interacting together or with the system (a person may simulate the response of the system).
- Wizard of OZ Prototyping: to simulate new user-specialized interfaces to monitor and control things.
- Sensors: to develop and test new sensors technology, positioning and usefulness. Interaction of sensors with occupants.
- Integration of Industrial Solutions: to test existing energy and control systems by integration in our platform in order to study the interaction with other systems in the whole building.
- Data Mining: to discover patterns in large data sets in order to discover trends and behaviour of smart buildings usages.
- Data Processing: to develop algorithms that use data and transform it into actions or meaningful information.
- Simulation: software for building simulation (energy, human behaviour, control …).
- Adaptive Modelling: development of algorithm to fit predictive models and data in order to prevent uncertainties and improve robustness.

Some workshops can be already targeted such as:

- User Monitoring: Analysis of user behaviour and comfort
- Smart Grid Monitoring: Analysis of electricity exchanges between building and distribution grid.
- Demand Side Management: Development of solution for participating in grid support strategies such as demand response, load shedding, etc.

These workshops are now in development and will be sources for future research publications. These workshops are end-user side view and will merge smart grid requirements (such as energy peak reduction, decentralized renewable energy integration), and end-user requirements (such as comfort, economy and sustainability).

4 CONCLUSIONS

The energy context and the potential of buildings in order to improve sustainability are introduced in this paper. GreEn-ER is then presented and the energy efficiency of the building is highlight for its design as well as for its operation. This building is presented as a support for research in the domain of energy and sustainability. We have presented scientific results based on previous publications that have been realized through this platform, such as energy autonomy of building or micro-grid, real time energy management, multi-flow energy optimization.

But GreEn-ER, with the PREDIS MHI platform, is now becoming a "Living lab". Building users are researchers and students and they are able to improve their own environment through several workshops which have been presented in this paper. Thanks to these tools, users can do innovations by themselves. This interaction between the building and users are our experimental field for the near future.

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