Final master´s thesis title area

Calibration Process and Energy Simulation of a Building

FINAL MASTER´S THESIS

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Year: 2016

Master's degree in Energy Engineering

Master´s Degree in Energy Engineering

Application for the acceptance of the Final Master´s Thesis and application for the public defence

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Acceptance of the presentation of the thesis:

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The public defence of my Master´s Thesis.

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Paris, 5th of June 2016

Summary

In the current context of ongoing search for improvement of energy performance, the management of buildings' energy performance has become a very important stake. Openergy aims to revolutionize the energy monitoring of buildings thanks to dynamic thermal simulation. The calibration of the simulation consists in adjusting different input parameters in order to have results close to reality. This convergence is generally guided by an expert of the field, but it aims to become automatic, in order to ease the use of the simulation. This method could even be adapted for energy mutualisation between different buildings.

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Introduction

The excessive consumption of buildings has an environmental impact because this sector represents 25% of greenhouse gases emission, and 43% of France's final energy consumption, or 1.1 of ton of oil equivalent by year and by inhabitant. Thus realizing energy savings has become a real target.

Openergy is a start-up specialized in energy analysis of buildings in operation. The start-up developed an innovative platform in order to monitor buildings, associating data-mining with energy simulation. This platform is able to detect a "performance gap" between the real consumption of the building and what was planned by the time it was under construction.

Openergy uses simulation and calibration in order to identify the differences between the target model and the actual building. Once the model is calibrated, different scenarios can be imagined to make energy savings. For instance, it is possible to evaluate in case of rehabilitation works what would be the energy savings.

In this report we will first see the goals of Openergy, then we will explain how works the calibration of a simulation, and what are the outputs of the simulation that can be obtained. Finally we will study two cases in which the Openergy's method is used: the audit of a building, and the energy mutualisation between buildings.

Context

1. Presentation of the company

I realized my end-of-course internship in the company Openergy, a start-up created in November 2012 specialized in energy efficiency of buildings. Currently, Openergy offers a support to the clients throughout the whole value chain of energy data. It is also developing an innovative platform for building monitoring, that combines data-mining and energy simulation. Thus, Openergy is able to offer to its clients quantitative and relevant results concerning their building efficiency.

In order to offer its solutions in the market, Openergy decided to develop a cloud platform allowing to create a "virtual building", updated constantly to represent faithfully the operating energy of the building. This platform is based on two major technical components:

- Algorithms of data processing for an important volume of data (Big Data) able to identify the patterns of the building functioning, and to detect automatically any abnormal behaviour.
- Real-time energy simulation which gives life to the numeric digital mock-up of the building. Especially, it creates a link between the design study phase, where the simulation is more and more used, and the operational phase.

The approach is not only oriented "data", it also relies on physical simulation. A building cannot be understood without the physical part. Thanks to the simulation, Openergy acquires a detailed knowledge of the thermal characteristics of the building, which misses with the only data analysis.

2. Targets and marketing strategy

Openergy's platform answers to a need of verification of a building's performances after its construction or its renovation. Sometimes, a gap called "performance gap" is detected, and the platform will help explain the origin of this gap, and thus an optimisation of performance. The activity focuses on office buildings or dwellings. Openergy's clients belong to two categories:

- Project owners, who are willing to validate and optimize the energy performance of their buildings. By demonstrating the good performance of their building, the asset value of their goods would increase. Moreover, thanks to a continuous monitoring, operating costs can be reduced.
- Energy operators, who manage projects with performance-related incentives payments. For new or renovated buildings, they cannot use data to prepare their offer. Thus the energy simulation becomes a very interesting tool.

3. Time to Market

Nowadays the simulation starts to be used more commonly during the design phase with the emergence of BIM (Building Information Modeling) which are digital mock-ups and allow a better coordination between the different players (building, heating, electricity…). But this mock-up becomes useless once the building is built-up. Openergy's vision consists in accompanying during the design phase but then adapt and reuse the mock-up for the operating phase. Anyway, important groups will move towards this will of extending the lifetime of the mock-up for the operation. Openergy will then have a technical significant lead in this field, and will be able to save development time to big companies.

Simulation and calibration

1. Thermal dynamic simulation

1.1. A competitive advantage

Platforms of energy management are multiplying on the market, either in the USA or in Europe. Nevertheless, among this large panel of available products nowadays, just a few are direct competitors of Openergy. Indeed, most of them are willing to do energy monitoring without real analysis. Their platforms deliver bills online where it is possible to accede the consumption directly, but without knowing if this consumption is optimal given the building performance and use. Only two American companies (KGS Buildings and SkyFoundry) offer services comparable to Openergy's, by using data to detect abnormal behaviour of a building.

The method used by Openergy succeeds in explaining the consumption of a building by simulating digitally buildings and their behaviour. This last point is what makes the difference between Openergy and other companies, because only it can compare the performance of a building to the initially aimed performance during its design, or after its renovation, that is the best possible performance. For instance, simulation can answer questions such as: "Given my building, what should be my consumption? How much will I earn if I lower the set-point temperature by 2°C during a month? If I change the windows?" because the complete building can be simulated, when other companies only use measures.

1.2. Expected result

The operator in charge of energy performance of a building has an objective of total consumption (monthly or yearly) which has been determined during the design phase, or during the renovation of its building. In most cases, buildings are worse than expected during the first phase. The process suggested by Openergy can explain precisely the observed gaps. The client receives the results on a graph which shows item by item how the building reaches the observed consumption. Below is presented an example of this type of diagram.

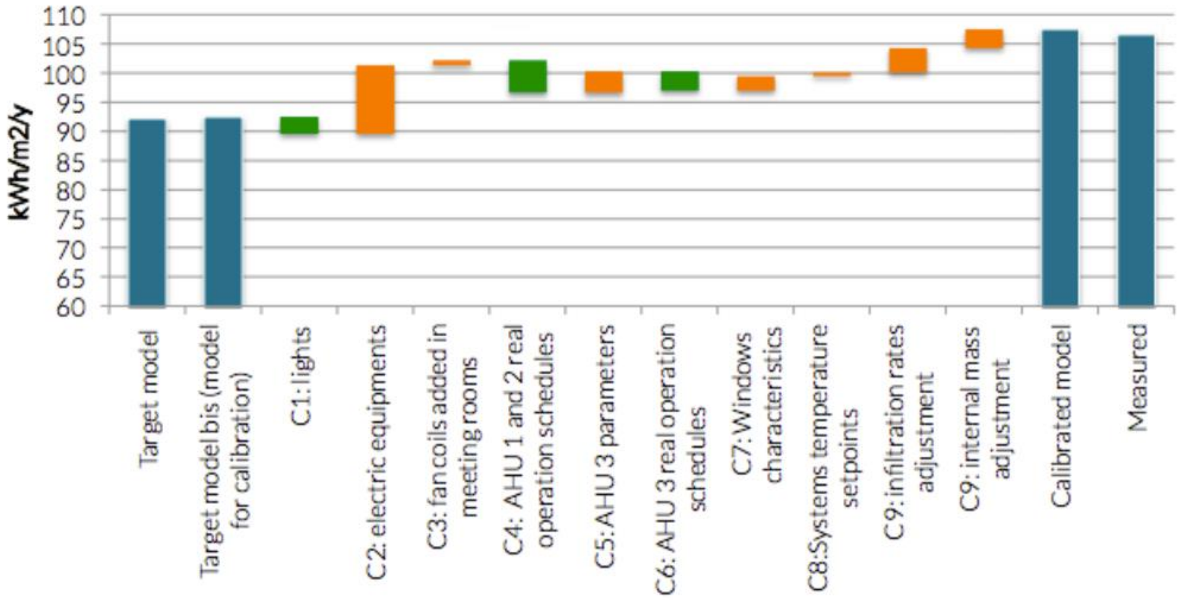


Figure 1 - Example of diagram explaining the gap between the target model and the real building

In orange are represented the overconsumptions and in green the underconsumptions between the initial prevision (Target Model) and the measured consumption (Measured). In this graph, we can directly see what the responsible items for overconsumptions are. In this example, it is mainly due to the electric equipment. Then, Openergy can give a list of suggestion in order to solve the problems.

1.3. Simulation process

Energy simulation can easily lead to false results of it is not made rigorously. This is why we try to have a clear process, and the most reproducible possible for all building. The method also relies on the data we receive for the building. For this reason, Openergy aims to work with building which have all necessary sensors. Otherwise, we propose to install these sensors in order to collect these data, and if it is not possible, some steps will have to be simplified.

The study followed three major steps, illustrated bellow.

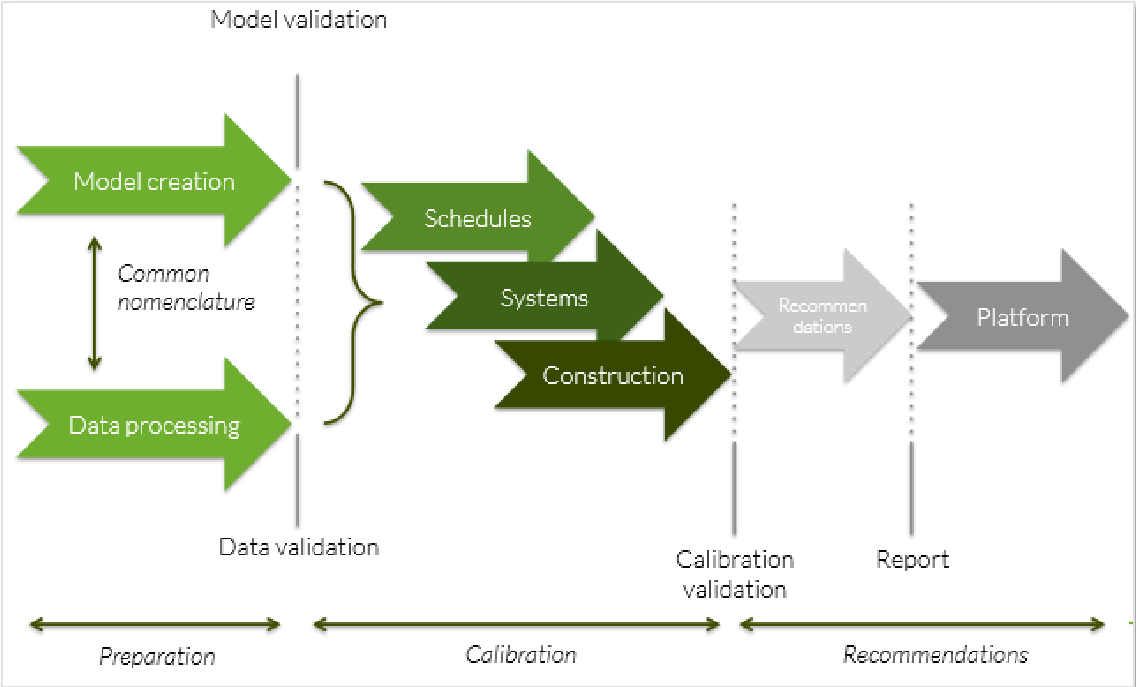


Figure 2 - The study's major steps

1. The preparation step: during this phase, the target model is created. In the meanwhile, real data are processed

2. The calibration phase: during this central phase, data and simulation are compared, and the model parameters is updated

3. The recommendation phase: based on the results of the two first phases, recommendations are provided in order to improve building operations. The final step, not finalized yet, will be the real time monitoring of the building based on the calibrated simulation.

1.4. Pre-study

1.4.1. Data processing

From the client we receive four types of data with time steps which depends of the client's installations:

- Lighting consumption
- Electric equipment consumption (computers, printers…)
- Heating/cooling consumption
- Temperature measures

Data processing is an essential phase of the process because it is a prerequisite to the accuracy of the simulation outputs. Thanks to algorithms developed by Openergy, we can guarantee the quality of data. We detect automatically aberrant data and lacks of data, but generally other details have to be fixed manually. If the time of error is not too long, it is possible to interpolate. Otherwise we will consider that the data are not exploitable for this period.

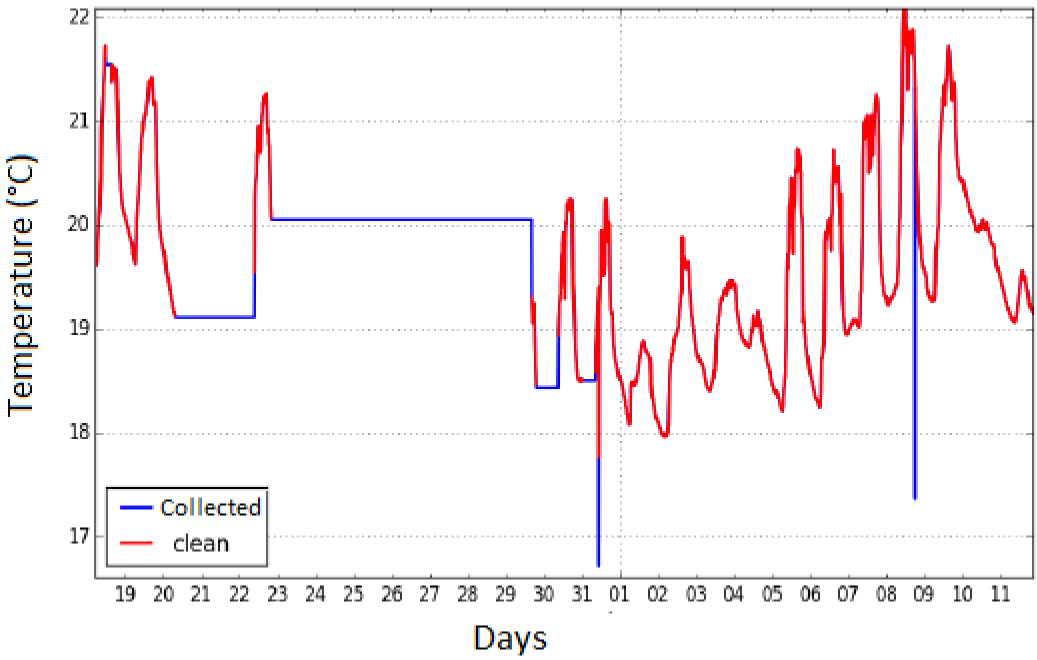


Figure 3 - Detection of anomaly in the data

On the example above the blue curve represents a part of the data received from the client, and in red the part which has been considered without default by our algorithms. The aberrant values are eliminated, and the lack of data are detected. In this case, the data had a time step of one minute, so we reasonably considered that a lack of more than two hours could not be filled.

1.4.2. Conception of the baseline

It is about conceiving a first approach of the building and to validate the model before going to the next step of calibration. In order to obtain a digital mock-up faithful to the building, we need the most possible information. This step depends on the good reliability of the data provided by the client.

In the best cases, we dispose of the technical data (equipment, systems, construction information…). When the client is enable to provide these documents, we realise an audit to know the characteristics of the building. Once these information collected, the digital mock-up can start.

The conception of the 3D-model uses the software DesignBuilder, which is based on the calculation engine EnergyPlus. DesignBuilder provides modelling tools in an easy-to-use interface. This enables the whole design team to use the same software to develop comfortable and energy-efficient building designs from concept through completion. In DesignBuilder, we can reproduce the building faithfully thanks to plans and information concerning the structure of the building (composition of walls, roofs, floors, windows…). EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption (for heating, cooling, ventilation, lighting, and plug and process loads) and water use in buildings. Its development is funded by the US Department of Energy Building Technologies Office (Crawley, 2000). Some of notable features and capabilities of EnergyPlus include:

- Integrated simultaneous solution of thermal zone conditions and HVAC system response that does not assume that the HVAC system can meet zone loads and can simulate unconditioned and under-conditioned spaces.
- Heat balance-based solution of radiant and convective effects that produce surface temperatures, thermal comfort, and condensation calculations.
- Sub-hourly, user-definable time steps for interaction between thermal zones and the environment, with automatically varied time steps for interactions between thermal zones and HVAC systems. These allow EnergyPlus to model systems with fast dynamics while also trading off simulation speed for precision.
- Combined heat and mass transfer model that accounts for air movement between zones.
- Advanced fenestration models including controllable window blinds, electrochromic glazing, and layer-by-layer heat balances that calculate solar energy absorbed by window panes.
- Illuminance and glare calculations for reporting visual comfort and driving lighting controls.
- Component-based HVAC that supports both standard and novel system configurations.
- A large number of built-in HVAC and lighting control strategies and an extensible runtime scripting system for user-defined control.
- Functional Mock-up Interface import and export for co-simulation with other engines.
- Standard summary and detailed output reports as well as user definable reports with selectable time-resolution from annual to sub-hourly, all with energy source multipliers.

Then, we have to add the occupants which turn the light on, the heat on, and use electric equipment. It is this step which needs more approximations compared to reality. We use standard schedules, which in reality are not strictly respected. In the case of recently built up buildings, a first simulation of its performance should have already been realised. Thus we can use the same hypothesis. Otherwise, we create ourselves the base model.

1.5. Calibration

At this juncture, we dispose of a model which is a good starting point. But in this first model, we applied standard hypothesis which can validate the performance of the building only “onto the paper”. Some parameters do not correspond to the real life, such as occupation, electric equipment, or lighting schedules.

The main difficulty of energy simulation resides in the important number of parameters. Among these, an important part is not directly measurable. For instance, the occupation rate, the losses, the internal mass… The calibration aims to estimate these parameters in real conditions. So we change the parameters and launch simulations, and by iterations, we try to make the results of the simulation converge towards the real measured data. When the results of the simulation coincide with the reality, we can affirm that the values of the parameters are representatives of the building. If these parameters can explain the behaviour of the building during the period in which we have the data, we are able to simulate its behaviour any time of the year.

1.6. Results acquisition

Now that we know all parameters related to our building, it becomes possible to detect overconsumptions, compared to the base model. Simulation is necessary because the only data analysis which consists in comparing real consumption curves with model consumption curves does not take into account thermal effects. These thermal effects are generally internal heat sources. A computer which stays turned on creates an overconsumption but constitutes also a heat input. This input will allow the heating system to consume less in winter, or to force the cooling system to overconsume in summer. This could not be detected without simulation.

Openergy created a method which allows to compare electric consumptions to the base model, by taking into account thermal effects. Once the model is calibrated, if we apply real consumptions item by item we find the total consumption of the building. In output, we can evaluate the consumption related to each item and its impact on the global consumption.

Another advantage of the simulation, is that we understand very precisely the functioning of the building, so it is possible to make a simulation of its behaviour in the future for instance, which would not be possible if the method was only based on data. Obviously, to simulate in the future, some hypothesis need to be made, such as weather forecasts.

2. From calibration to simulation

In the method developed by Openergy, calibration is the most difficult step, and the one in which more improvements can be realised. As a reminder, before the calibration phase, we realised a model of the building with all its characteristics. Then the calibration phase consists in adjusting the parameters which were not representative of the reality in order to simulate the real behaviour of the building. A few calibration methods have already been established, by there is no universal process.

2.1. Difficulties

2.1.1. Number of input parameters

The first question anyone will be asking is: "What are the parameters to adjust?". It is almost not possible for a non-initiated person to use an energy simulation software. The number of parameters is too important, and knowing the influence of each one needs a certain experience. Moreover there are more unknowns than equations, so there is not a unique solution. That is why numerous hypothesis need to be done.

2.1.2. Quality of the data

The goal of the calibration being to reproduce the reality, the most data we collect, the best the chances to have a building model close to the real one we have. Indeed, if we only have the monthly electric consumption, we can calibrate so that the total monthly consumption concords, but it does not mean that we have the good repartition by item. On the contrary, if we have all consumptions by item (lighting, electric equipment, heating…), then we can adjust every parameter so that the consumptions will concord with the real ones, which will give us a better understanding of the building behaviour.

2.2. Different calibration methods

Once the sensible parameters have been determined, we need to make them vary so that the results of the simulation get closer to the measured values. In other words, the calibration needs to make the outputs of the simulation converge towards the real data. Different methods have been identified in the literature. Whatever the method is, the calibration has not enough equations to lead to a unique solution. According to Kaplan et al. (1990), it will never be possible to identify the exact solution of a calibration, the attention would need to be paid to the rigour of the method.

Clarke et al. (1993) have distinguished four categories of calibration processes, which have also been resumed by Reddy et al. (2007):

- Manual calibration
- Calibration based on graphical methods
- Calibration based on special tests and analysis procedures
- Automatic calibration, based on a mathematical and analytic approach

These categories are not strict, because the studies can combine some of them in one method. Finally two categories can be used to class these methods: the manual calibration and the automatic calibration.

2.2.1. Manual calibration

Manual calibration consists in following a certain number of steps, relying on the user experience and judgement. It is currently the most commonly used method. It allows to obtain very satisfying results.

Manual calibration realised by Kaplan et al. (1990) showed the path by obtaining very good results. Nevertheless, authors go by nine steps of calibration which are not systematic. The method is not reproducible because it relies on the knowledge of the studied building.

The calibration realised by Westphal et al. (2005) is close to the process used by Openergy. It is done thanks to the calculation engine EnergyPlus. First light and electric equipment consumptions are adjusted, then a sensibility analysis permits to find the most influent parameters. There is still a part which relies on the user’s experience.

Yoon et al. (2003) will be the first ones to propose a method manual but systematic. They created a method in seven steps, using monthly bills of the buildings, but also the sub-counters located in the building. Unfortunately this method experienced in South Korea in not reproducible in Europe because we miss data on classical buildings.

Finally it is possible to integrate graphical methods to manual ones. Graphical methods aim to visualize better the differences between reality and simulation outputs in order to identify the causes. Two classes of graphical methods axis: 3D comparison (Bou-Saada, 1995) and characteristic signature (Liu, 2003).

2.2.2. Automatic calibration

The most studied method is the Bayesian method, which has first been used in geology, before being applied to building energy model. It is a statistic model using probability theory to calculate the distribution of an unknown parameter given observation data (Heo, 2012). Other attempts have been done by using “Meta-Models” which were defined by Van Gelder et al. as mathematic functions whose coefficients are determined by a limited number of input and output parameters. Among these technics: polynomial regression, radial basis functions networks (Van Gelder, 2014).

2.2.3. Openergy’s point of view

After these observations, Openergy chose a more systematic approach. However, as the aim of the company is to propose a platform which allow the operator to monitor its building, it will be necessary, in the long-term, that the process does not need the intervention of an expert, and becomes automatic.

1. Goals and methodology of the study

The study summarized in the present report aims at comparing the actual building performance with the performance expected during the design phase.

The study relies strongly on the concept of “simulation calibration”. The idea is to update the building model used in the design phase so that the updated simulation matches well the actual behaviour of the building. Doing so, one is able to identify the possible discrepancies between the target model and the actual building. The final goal is to be able to use this updated simulation to improve the building operations.

The different recommendations are submitted to a description, an estimation of the investments, a calculation of the energy and financial savings, and of the pay-back time. Thus the audit aims to help the project manager in his technical choices, by giving him elements already quantified, in order to decide the program of the interventions that the building needs.

2. Presentation of the site and of the study

2.1. Localisation

The dwellings of Convention correspond to the buildings located at the corner of the street of La Convention with the street of Lourmel, in the 15th district of Paris. These buildings are in a dense urban zone, surrounded by other dwellings, and by a square.

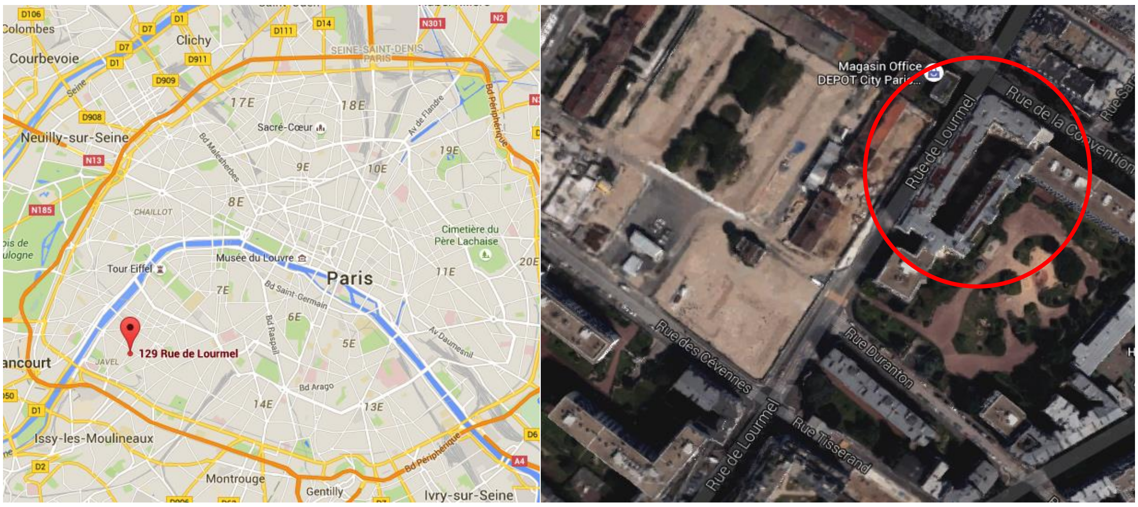


Figure 4 – Maps and aerial photography of the buildings

2.2. Global information

The main characteristics avec the building are presented in the tables below.

Administrative data		
VIENNE	Activity	Dwellings
	Localisation	88 rue de la Convention 29 rue de Lourmel, 75015 Paris
	Construction's year	1930's

Activity's data	
Number of structures	12
Number of zones	> 340
Heated volume	35 881 m^3
Heated surface	10 347 m^2
Compactness	0,6

Installations' data	
Heating	CPCU (Urban District Heating)
Air Conditioning	Without Air Conditioning
Domestic Hot Water (DHW)	Individual

2.3. Collected data

It is important to collect the most possible data in order to model the building. Here are the type of documents provided to Openergy.

Category	Type	Complementary information
Building	Plans	Documents provided
	Characteristics of the materials and the equipment	Exchanges with different persons (inspector, renovation company) Visit
	Works	Exchanges with different persons (inspector, renovation company) Documents
	Consumption	Bills Archives
Heating	Systems	Visits Information operator and manager

	Regulation and distribution	Visit (dwellings and boiler room) Information operator
	Works	Exchanges with different persons (operator and manager)
	Contract (exploitation and maintenance)	None
	Consumption	Documents (bills from October 2011 until December 2015)

2.4. Climate data

The site is in a climate zone called H1a. On the map below, this zone is in dark blue.

Figure 5 - Representation of the different climate zones in France

The figure below represents the climate of the site on the four last years (data measured by Météo France in the park of Montsouris, Paris 14ème). The DJU is the Degree Day which is a measure of heating or cooling. A degree day is computed as the integral of a function of time that generally with temperature. It is very used to estimate thermal energy consumption in function of the harshness of winter or the summer heat. Heating degree days are defined relative to a base temperature (the outside temperature above which a building needs no heating). The most appropriate base temperature for any particular building depends on the temperature that the building is heated to, and the nature of the building. The base temperature used in this study is 18°C.

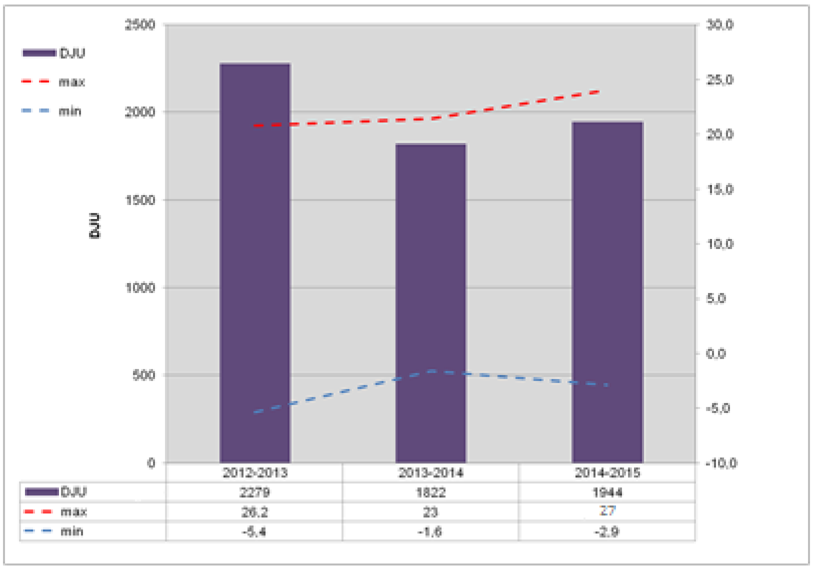


Figure 6 - Climate data of the site

2.5. Difficulties encountered

The client LFM (La France Mutualiste) being very implied in the project, no particular difficulty has been encountered during this audit, either for the collect of information, the exchanges with other persons, or the availability of implied people.

3. Presentation of the building's characteristics

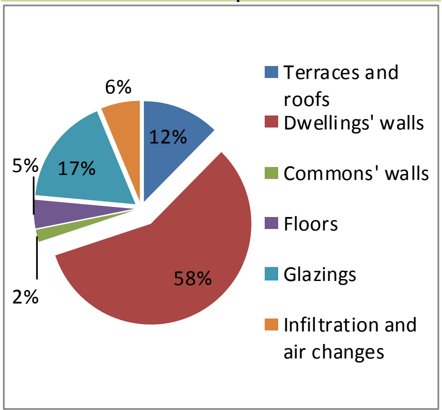
3.1. Synthesis

Administrative data	
Nom	Convention
Activity	Dwellings
Localisation	129 rue de Lourmel 88 rue de la
Construction's year	1930's

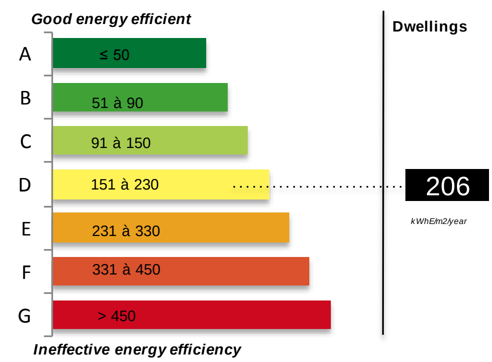
Activity's data	
Number of structures	12
Number of zones	> 340
Heated volume	35881 m3
Heated surface	10347 m2
Compactness	0,6

Installations' data	
Heating	CPCU
Air Conditioning	None
HDW	Individual

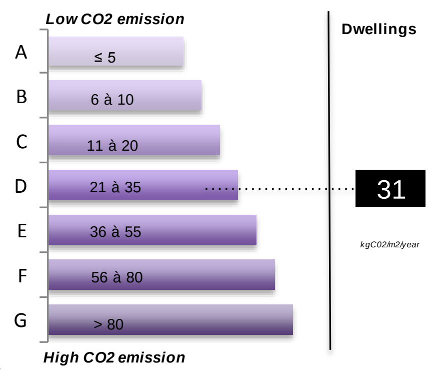
Losses' repartition



Energy consumptions
(consumption of primary energy)



Greenhouse gas emission
(based on the consumption of primary energy)

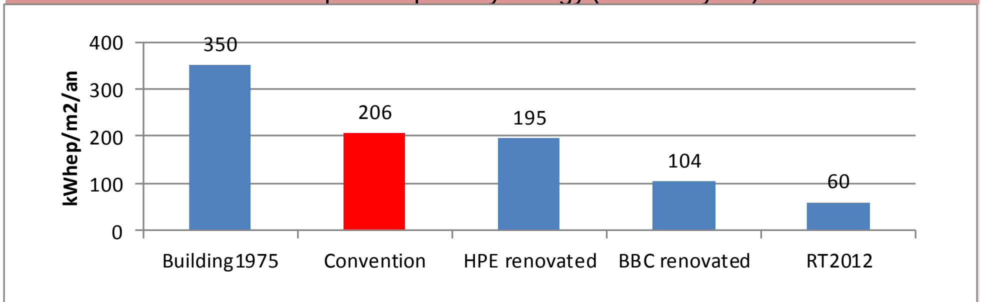


The heating consumptions are estimated thanks to the bills of the three last years.
The HDW consumptions are evaluated on the basis of estimated consumptions (method 3CL-DPE)

Average of energy consumptions in final energy (MWh/year)

	MWh/year
Heating (CPCU)	1269
Heating (Elec)	2,14
Lifts (Elec)	0,80
Others (Elec)	8,40
DHW (Elec)	-

Consumption in primary energy (kWh/m2/year)



Comments

In general, the global situation of the building and of the installations is good: The thermal performances of the building are corrects, thanks to a regular maintenance of the dwellings

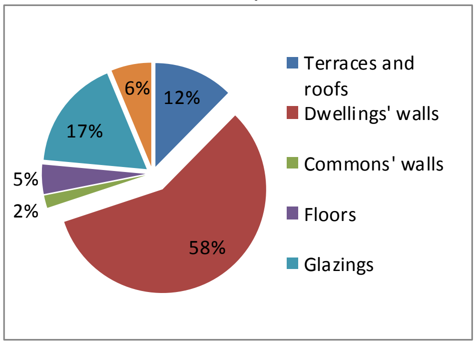
3.2. Analyse of the building

3.2.1. Synthesis

Activity's data	
Number of structures	12
Number of zones	> 340
Heated volume	35881 m3
Heated surface	10347 m2
Compactness	0,6

Thermal characteristics	Ubat	Uren-air
Convention	1,26	0,08

Losses' repartition



Thermal composition	
Name	Thermal conductivity (W/m2.K)
Wall - Outside	
Outside wall	2,1
Square	2,5
Inner courtyard	1,27
Roof	1,97
Mur - Inside	
Wall	2,7
Floor	2
Ground floor	1
Glazing	
Double	2,5
Simple	5
Name	Thermal conductivity (W/m.K)
Thermal bridge	
High floor - outside wall	0,14
Low floor - outside wall	0,2
Inside foor - outside wall	0,55
Junctiun outside walls	0,33

Plan et zoning

Convention - Lourmel: Ground floor

Convention-Lourmel: 4th floor

Installations' yield

Heating	%	DHW	%	Air conitioning	%
Production	100	Production	-	Production	-
Distribution	87	Distribution	-	Distribution	-
Emission	95	Emission	-	Emission	-

Remarques

The thermal characteristics of the building are similar to the ones of other buildings of the same type. The walls are mainly responsible for the building's losses.

3.2.2. Building geometry and shadings

Building geometry and materials have been modelled as closely as possible to the real ones. This includes architectural details, walls, windows, blinds, material types, thermal bridges, infiltrations, and roof and terrace characteristics.

As for the shadings, the masks are not explicitly described in the available documents. The surrounding buildings have thus been modelled from data available through Google Maps and from pictures of the neighbourhood.

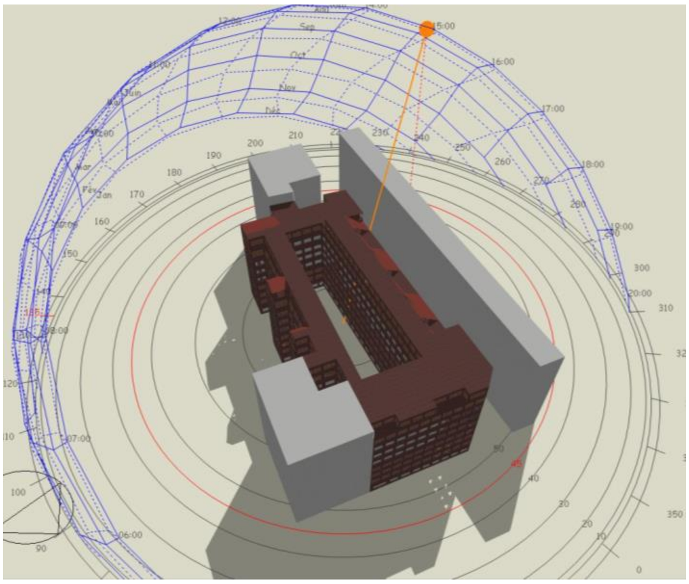


Figure 7 - Building general geometry and shadings

The details of the simulation model are presented in the next paragraphs. A plan of Convention's 4th floor is presented in the annexes.

3.2.3. Zoning

Convention has been divided by floors: the ground floor, a multifloor which represents floors from 1 to 6, the 7th floor and the 8th floor. The floors from 1 to 6 are similar in their losses, thus it is modelled as one unique floor. Then, an additional internal mass is added to simulate the floors which have not been modelled. Then, each floor has been divided in different zones: commons, apartments, stairs, shops, and attics. This is a simplified model, each room is not represented, but an internal mass is added to each zone to counteract the walls which have not been modelled.

The building is made of 343 apartments in total, and the full model contains 51 zones. In modelling the geometry of a building, it is often difficult to recover the exact surface for each zone. For instance, complex and geometrical shapes are usually simplified in thermal models, leading to small discrepancies in floor areas; similarly, walls widths can be included or not in the total area… That is why it is recommended to pay careful attention to this question, and to compare energy consumption on a square meter basis, rather than in absolute values.

In order to assign specific parameters and characteristics to all zones efficiently, we developed and implemented the concept of "metazone". A metazone regroups together zones with the same usage. In the case of Convention, we defined 6 metazones: apartments, commons, empty, multifloor apartments, multifloor commons, and shops. Metazone characteristics include:

- People occupancy ratio
- Lighting rate
- Electric equipment rate and schedule

- Schedules (occupancy, consumption, natural ventilation)
- Windows blind control
- Mechanical ventilation
- Infiltration rate
- Air renewal rate

Thermal bridges are not included at the metazone level, but rather at the zone level, in order to keep the specificity of each thermal bridge.

3.2.3. Walls

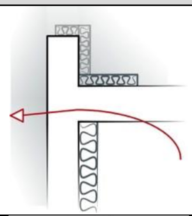
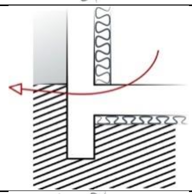
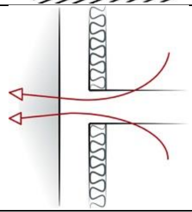
Each wall (inside or outside) has been created with its materials, its width and its thermal conductivity. The thermal conductivity coefficients are detailed in the previous paragraph 3.2.1.

3.2.4. Windows

There are simple and double glazing. The windows of the apartments have a double glazing, with a thermal conductivity of 2,5 W/K.m^2 whereas the windows of the commons have a simple glazing of a thermal conductivity of 5W/K.m^2.

3.2.5. Thermal bridges

Once we know the wall's composition, we can find in table the thermal coefficients. Some table with thermal linear conductivity coefficient for thermal bridges exist, and these are the coefficients used to construct base model. Below are presented the values from tables of thermal regulation (RT2012).

Name	Thermal conductivity (W/K.m)	Illustration
High floor / outside wall	0,14	
Low floor / outside wall	0,2	
Inside floor / outside wall	0,55	

Junction outside walls	0,33	

Unfortunately, it is difficult to make the exact list of thermal bridges of a building. And even when they are identified, the losses will depend of the quality of the construction, especially of the installation of an insulation layer.

3.2.6. Air infiltration and air renewal

The infiltrations and the flow of air renewal have been calculated with the method of calculation TH-BCE 2012. We also took into account the infiltrations of air vents in the apartments, and the air renewal due to the opening and the closing of windows in the apartments, considering an opening of fifteen minutes in winter. For the commons, the air flow due to the opening of the front doors has been evaluated for a door of $5m^2$ mainly opened at the beginning and at the end of the day.

3.2.7. Heat transfer coefficient

The heat transfer coefficient through the walls is called U_{bat}. Its value is calculated by EnergyPlus. For this building, we find a value of 1,26 $W/m^2.K$. The smaller the value of the U_{bat} is, the better the building is isolated. In this case, the value is quite good for a building of this year of construction.

The heat losses are characterized by the indicator $U_{bat} = U_{wall} + U_{windows}$ and by the air renewal by the indicator $U_{ren\text{-}air=}$. They have a direct influence on the heat consumption. Here are their distribution:

Name of the building	Type	Losses ($W/m^2.K$)	Distribution
Convention-Lourmel	U_{walls}	1,04	78 %
	$U_{windows}$	0,22	16 %
	$U_{bat} = U_{wall} + U_{windows}$	**1,26**	**94 %**
	$U_{ren\text{-}air}$	0,08	6 %
	Total	**1,34**	**100 %**

3.3. Analyse of the installations

3.3.1. Production of heat

There are two heat exchangers of BAELZ, each with a power of 710 kW. The primary circuit is isolated. There is no particular default. The secondary circuit of the unheated zones is thermally insulated. This takes into account the circuits in the basements, and under the carriageway between the buildings. The circuits covering the commons (unheated zones) are not isolated. The yield is estimated to 87%.

There are different size of heaters in the apartments, which is explained by the multiple renovations. The yield is estimated to 95%.

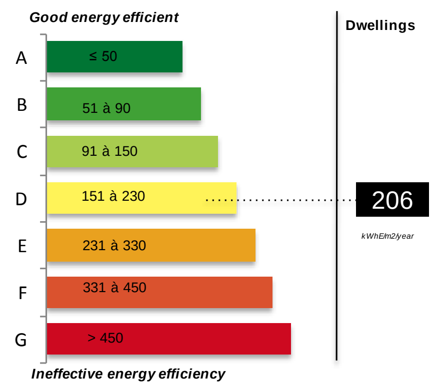
3.3.2. Water circuit

The regulation of the water temperature in the circuit is done by a water logic which depends of the outside temperature. The mean temperature of the dwellings measured during the audit is 21°C. We will choose this value for our simulations.

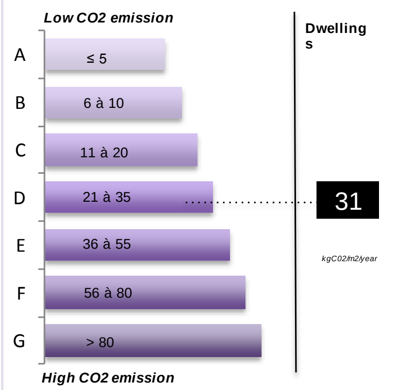
4. Analyse of the consumptions

4.1. Synthesis

Energy consumptions
(consumption of primary energy)



Greenhouse gas emission
(based on the consumption of primary energy)

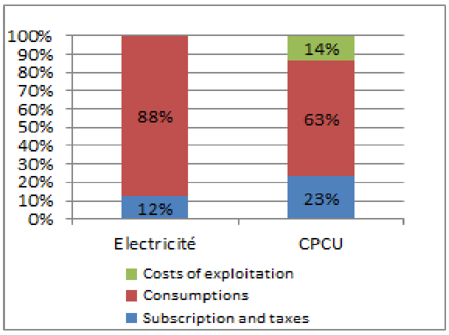


The heating consumptions are estimated thanks to the bills of the three last years.
The DHW consumptions are evaluated on the basis of estimated consumptions (method 3CL-DPE)

Average of energy consumptions in final energy (MWh/year)

	MWh/year
Heating (CPCU)	1269
Heating (Elec)	2,14
Lifts (Elec)	0,80
Others (Elec)	8,40
DHW (Elec)	-

Repartition of the consumptions by source



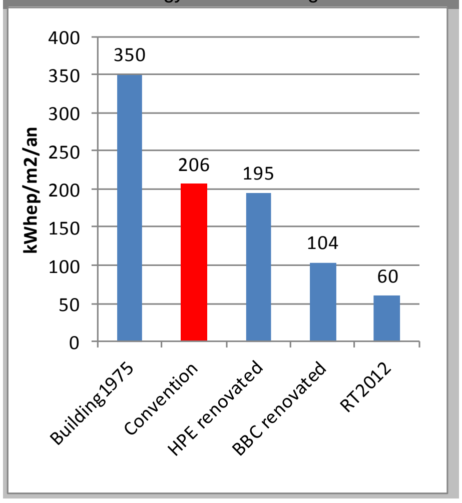
Summary of the consumptions in final energy by year

	2012	2013	2014	2015
Heating CPCU (MWh)	1384	1443	1039	1209
Electricity heating (MWh)	2,14	2,14	2,14	2,14
Electricity lifts (MWh)	0,80	0,80	0,80	0,80
Electricity others (MWh)	8,40	8,40	8,40	8,40
DHW (MWh)	332,7	332,7	332,7	332,7

Costs of the consumptions by year

	2012	2013	2014	2015
Heating CPCU (k€)	120,4	128,8	109,6	122,6
Electricity heating (k€)	0,28	0,28	0,28	0,28
Electricity lifts (k€)	0,13	0,13	0,13	0,13
Electricity others (k€)	1,08	1,08	1,08	1,08
DHW (k€)	-	-	-	-

Benchmark of the heating consumtions in primary energy of the dwellings*



* ADEME report

Comments

The global consumptions of the building are correxts (around 206 kWh/m2/year). This is mostly due to the good performances of the heat production systems.

4.2. Analyse of the heat consumptions

4.2.1. Model of the consumptions

The comparison is done for the years from October 2012 until May 2015, which corresponds to three heating seasons.

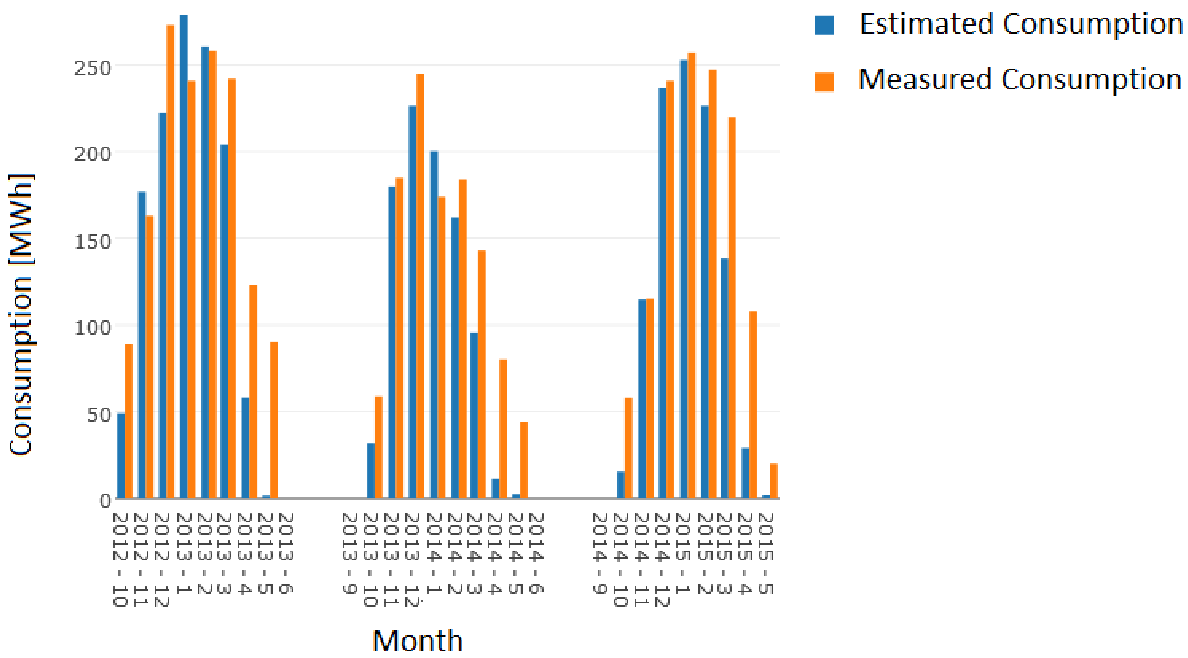


Figure 8 - Comparison of the monthly consumptions measured and estimated

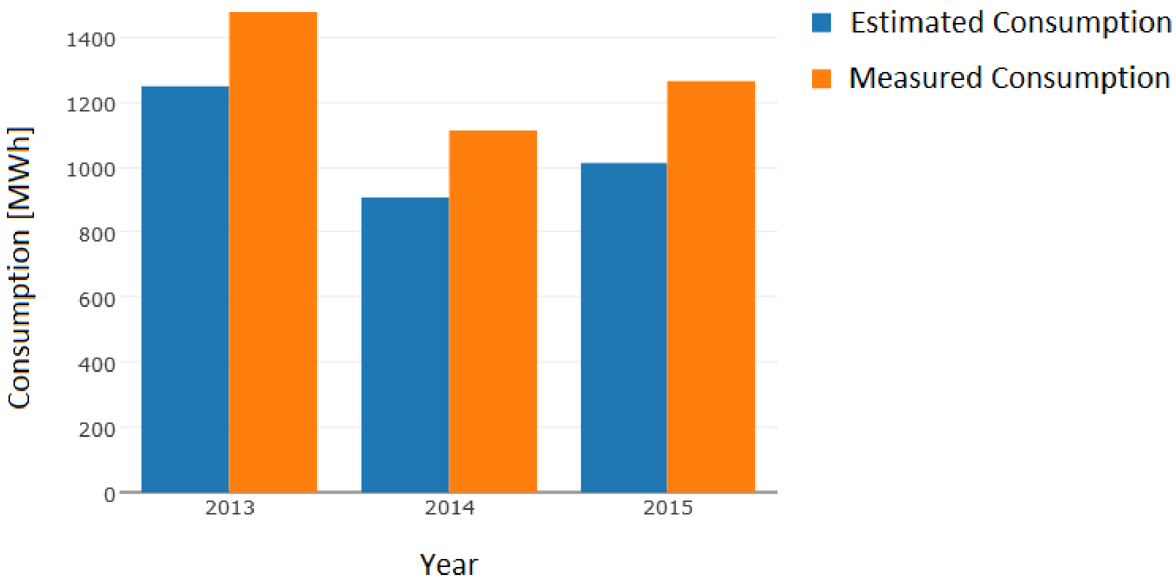


Figure 9 - Comparison of the yearly consumptions measured and estimated

We see on the first figure that there is a small difference for the coldest months. Nevertheless, we note an important gap between the measured and the estimated consumptions during the mid-season. This shows that the heating consumptions could be optimized, in particular by adapting the regulation in mid-season.

In order to highlight the performances, the graph below presents the monthly consumptions real and estimated in function of the Degree Day (DJU).

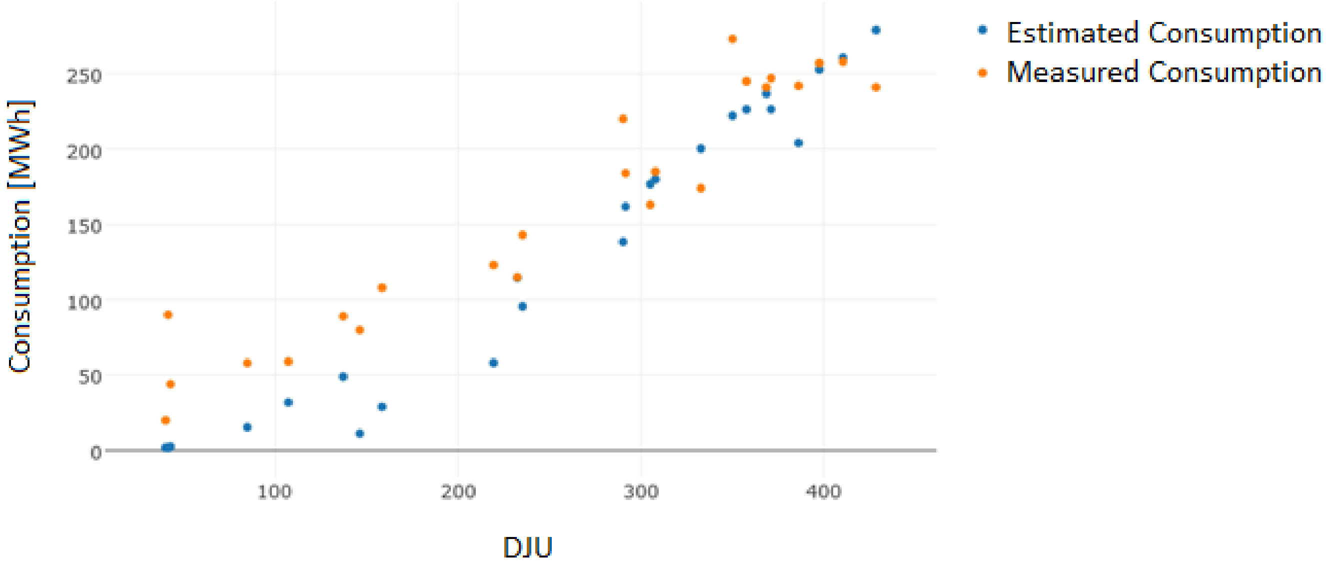


Figure 10 - Comparison of the monthly consumptions measured and estimated, in function of the DJU

There are differences for the small DJU. These points, corresponding to the mid-season months, are detailed thereafter.

4.2.2. Analysis of the differences estimated/measured

Beyond the good estimations, a few discrepancies can be noted for:

- The months of December 2012 and 2013, and of January 2013 and 2014: After a discussion with the different actors, the charged consumptions of December seem to correspond to consumptions estimated by the heat supplier. The error of estimation is then adjusted on the bill of the next month (January), which explains the overconsumption in December, and the underconsumption in January.
- The months of March, April, May and October of each year: we observe overconsumptions during these months which corresponds to almost 20% of the yearly consumption of the site. The mid-season months are harder to optimize than the coldest ones. Indeed the meteorological conditions and a non-optimized water logic can lead to a wrong temperature in the apartments. Moreover, it is frequent that the inhabitants open their window at this time of the year.

The mid-season periods should be followed with more attention in order to optimize the heating consumptions. One solution could be to adjust the temperature schedules and use the reduced mode during the day for these months. Therefore the heating could be optimized, while keeping the comfort temperatures of the occupants. In order to ensure that this comfort is respected, it is important to make temperature's readings as frequently as possible.

4.2.3. Tariff analysis of heat consumption

There are four important billing items P1, P2, P3 and P4, each one representing a principal service of the contract.

P1 concerns the energy or fuel provision by the operator (for instance: purchase of natural gas or domestic fuel). According to the markets, there are different ways of remuneration for this item: lump sum, corrected by the climate, based on real consumptions… Whatever the way of remuneration is, this service is almost always corrected in function of the price of the fuel. The main benefit is that the condominium property does not have to worry about the energy provision administratively and the operator should be able to get better prices for the energy. But the cost of the P1 generally is not a reflection of the real consumptions.

P2 is related to the maintenance of the installations. This is the basis of such a contract, thus any contract has at least a P2. For small building, the contract is generally only made of this P2. With this item, the operator has to ensure the control and the annual maintenance of the installations, the preventive maintenance of heating equipment, the monitoring and the troubleshooting of DHW's installations, and finally the monitoring of the right temperature of heat zones.

P3 is about substantial maintenance work and material replacement. This is also called the complete guarantee, and it covers replacement of old material. The operator guarantees the reparation or the change of damaged installations. The condominium property does not pay an extra for substantial work. Most of the time, P3 covers the material in the boiler room, and is limited to the collective material of the dwellings. Thus, radiators, mostly located in private places are not in this item.

Finally, P4 is associated with the funding of substantial work such as the renovation of the boiler room, important works to ensure compliance…

Here is represented in the building of Convention the distribution of the heating bills. P3 and the investments are gathered in one item.

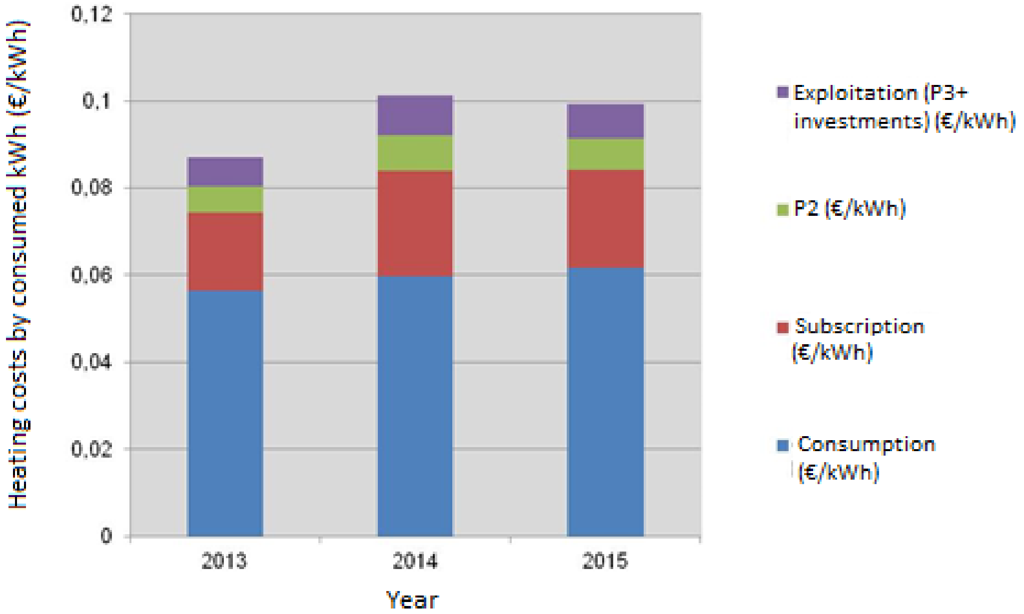


Figure 11 - Distribution of the heating bills by year

The higher cost is due to the consumption, but the subscription remains important. Indeed, the CPCU's subscription is very expensive, especially compared to natural gas. Moreover, this graph is not exact because the investments have not been communicated, so the exploitation cost might be higher.

4.2.4. Analysis of the contract

The operator has an objective of heating consumption indexed on the climate through the DJU (degree day). This amount has been evaluated on the basis of consumptions for a reference year, and correspond to an objective of consumption by DJU of 0,617 MWh/DJU.

The consumption estimated by the simulation for 2012 until 2015 is 0,52 +/- 0,05 MWh/DJU. The highest value of this simulation correspond to a limit of 0,57 MWh/DJU, which is lower than the limit set in the contract. It is recommended to lower the limit of consumption to 0,57 MWh/DJU.

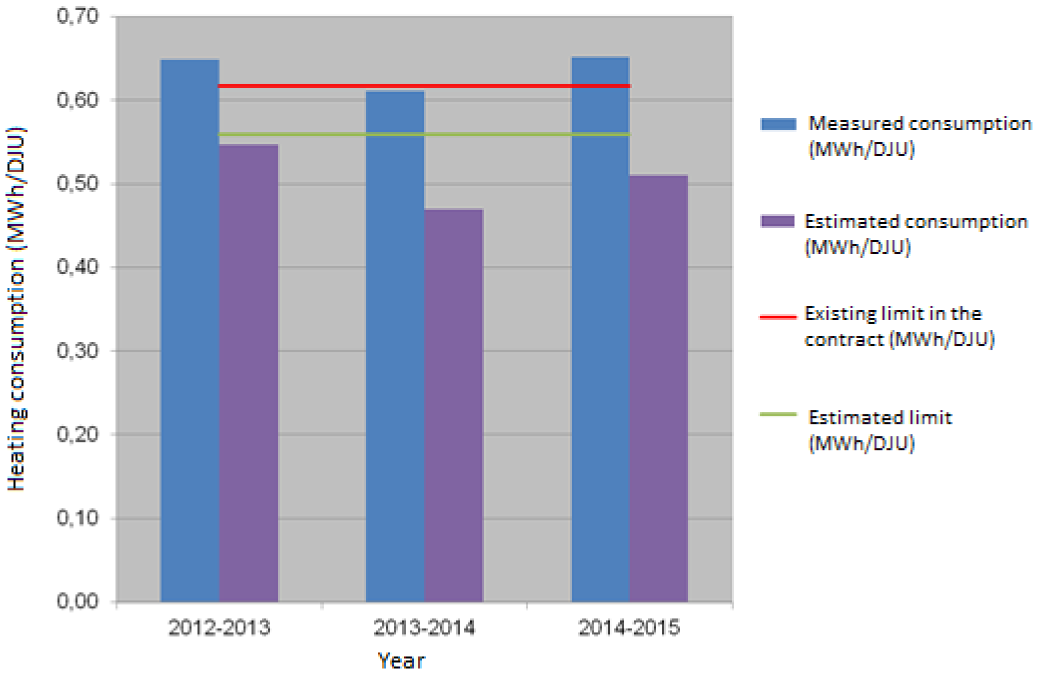


Figure 12 - Estimated and measured heating consumption by DJU, and limits

The measured consumptions exceeded the limit in 2012-2013 and 2014-2015. This is due to overconsumptions during the mid-season. According to the estimations, the limit could be lowered to 0,57 MWh/DJU.

In addition to the heat consumption, the subscription paid to the energy provider depends on the customer's contract power. This contract power is of 1165 kW for Convention-Lourmel. Based on the building model, we estimated the heat losses at 778 kW. Given the distribution losses and the security factor, we find a limit of subscribed power of 1128 kW, which is really close to the existent contract power. So it is not possible to negotiate this power with CPCU.

4.3. Electricity consumption

The distribution of the electricity bills is also done between the consumption and the subscription.

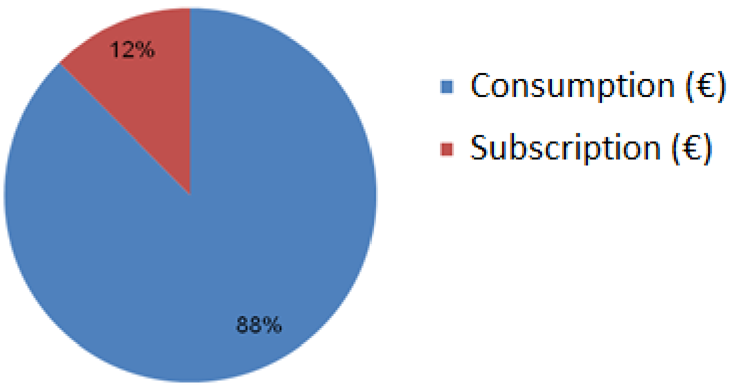


Figure 13 - Distribution of the electric costs

This diagram has been done thanks to the electric bills of 2014. In this case, the subscription represents 12% of the total cost, which is a less important part than for the CPCU's subscription. These consumptions can come from additional heaters, to the lifts, or to common electrical appliances.

5. Presentation of the scenarios and recommendations

5.1. Hypothesis

All the calculation of energy savings presented in the report are based on theoretical consumptions coming from simulations. These simulations are done the same way as presented in the previous part.

The used climatic conditions correspond to a typical year in Paris. The calculations are made for hourly steps, which allows to take into account very precisely the thermal phenomena (solar gain, ventilation…)

For electricity we take a price of 0,11 €/kWh and for CPCU of 0,06 €/kWh for the consumption, and of 0,003 €/kWh for subscription.

5.2. Description of the actions

The description of the actions corresponding to energy savings are attached as appendices. The table below is a synthesis of all actions. Some interactions exist between the different measures, if different measures are set up, the energy saving will not necessarily be the sum of the energy savings related to each measure.

ACTIONS			
Name action	Investment (k€)	ROI (year)	Energy savings (%)
n°1: Insulating roofs	65,5	> 100	4
n°2: Insulating walls	831	52	23
n°3: Turning off heat in the commons	0	0	1
n°4: Lowering set-point temperature	0	0	13
n°5 : Renovating simple glazing windows	145	> 100	1
n°6 : Changing the production system (CPCU –> gas)	184	4	0

Figure 14 - Summary table of the recommended action for energy savings

5.3. Recommended scenarios

Unlike the action descriptions where the calculation of energy saving is made independently from the other actions, the scenario can combine them and simulate the entire works. Interactions can happen on energy and financial savings. Financial saving are given for information only. Indeed, interactions have not been taken into account for simplicity reasons.

From elementary actions easy to implement and relevant in terms of energy, two scenarios have been studied:

- Scenario 1 : Zero cost
- Scenario 2 : Complete insulation (roofs and walls) of the building

Here are the results of the study:

SCENARIOS				
Name scenario	Number of the action	Investment (k€)	ROI (year)	Annual energy savings (%)
Zero cost	3,4	0	0	14
Complete insulation of the building	1,2	896	48	26

Figure 15 - Summary table of the recommended scenarios for energy savings.

Convention-Lourmel has an important potential for energy savings on the heating part of the building (insulation), but at a high cost. A substantial decrease of consumptions can be made at a cost of nil by reducing the set-point temperatures, and by stopping the heating of commons.

The calculations are made for final (FE) and primary energy (PE). Primary energy consumption measures the total energy demand. It covers consumption of the energy sector itself, losses during transformation and distribution of energy, and the final consumption by end users. Final energy consumption is the total energy consumed by end users. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself.

Scenario n°1	Zero cost

Description

The objective of this scenario is to estimate energy savings by reducing heating consumptions in the flats or in the commons without reducing people's comfort.

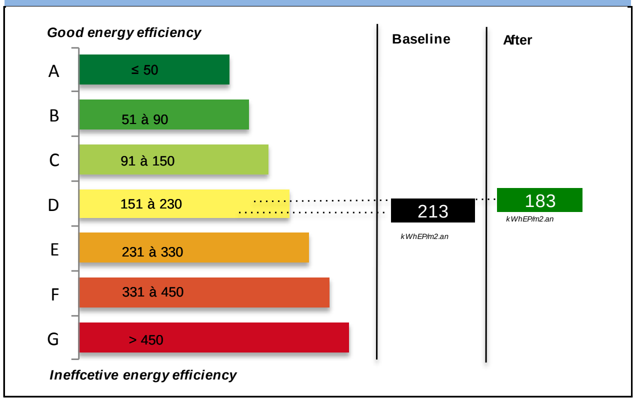
N°	Name action	Investment (k€)
3	Turning off heat in the commons	0
4	Lowering set-point temperature	0
	Total	0,0

Results

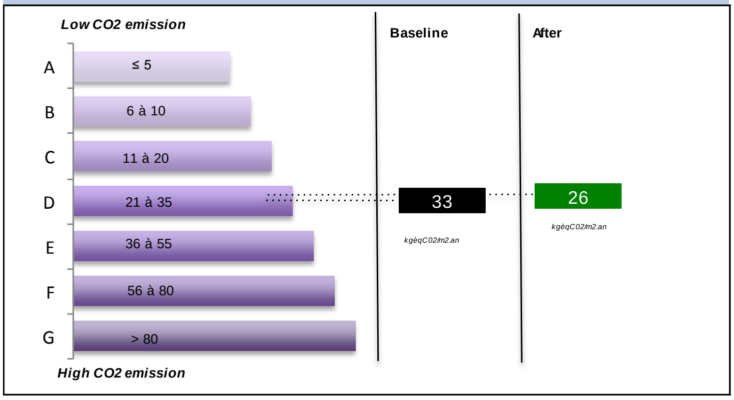
Before			After			GAIN		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1352	1896	272	19%	14%	21%

Investment & ROI	
Estimated yearly savings (k€)	18,84
Return on investment (year)	0

Energy consumptions
(consumption of primary energy)



Greenhouse gas emission
(based on the consumption of primary energy)



Estimations comesfrom simulations using the reference climate of Paris Orly

Scenario n°2	Complete insulation of the building

Description

The objective of this scenario is to estimate energy savings in case of total insulation of the building

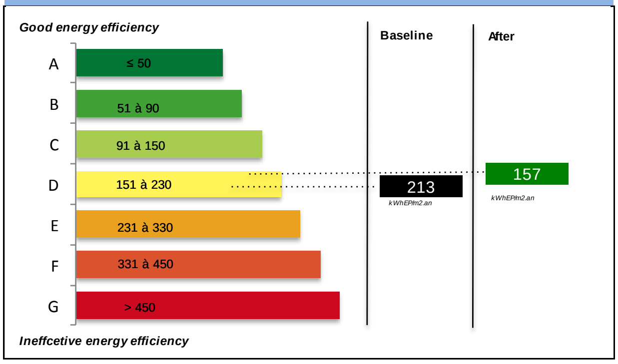
N°	Name action	Investment (k€)
1	Insulating roofs	65,5
2	Insulating walls	830,9
	Total	896,4

Results

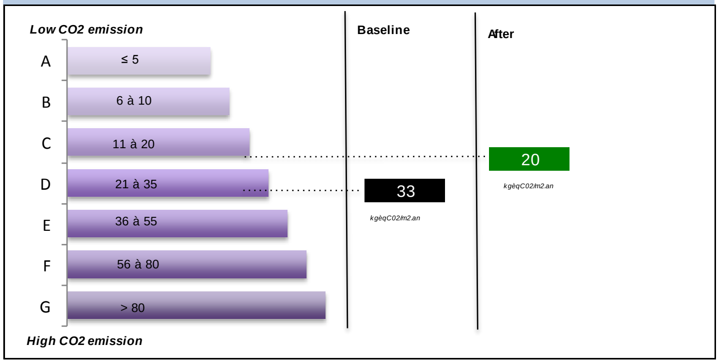
Before			After			GAIN		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1085	1629	210	35%	26%	39%

Investment & ROI	
Estimated yearly savings (k€)	34,86
Return on investment (year)	48

Energy consumptions
(consumption of primary energy)



Greenhouse gas emission
(based on the consumption of primary energy)



Estimations comesfrom simulations using the reference climate of Paris Orly

DataCity

1. What is DataCity?

The DataCity bootcamp was created to test the project of five selected startups on the scale of a European capital: the city of Paris. Because constructing a city that is sustainable, creative and connected can only be a team sport, DataCity is an experimentation accelerator initiated by NUMA and The City of Paris bringing together industry leaders – Vinci Energies, Setec, Suez, Nexity and Cisco. On the program, tailor-made support and services to respond better to the challenges of today's cities by testing the projects on the wonderful playground that is Paris.

In order to become smarter, today's cities are going to have to develop new services in a range of sectors: better use of energy, responsible travel, intelligent urbanization and housing, sustainable environment. The City of Paris, along with several partner organizations, is opening a unique field of experimentation to anyone who can propose a project with the aim of taking up these challenges.

The complexity of contemporary cities profoundly impacts the behaviours of their dwellers. The way they are designed, organized and governed constantly evolves. If we want to overcome these new challenges, all stakeholders must work in a collaborative approach. The goals of DataCity are to:

- Scrutinize, analyse, synthesize: cities produce plenty of data, and studying it means that we can develop services that truly answer the needs of users
- Collaborate, associate, confederate: a successful project is one that involves many actors bringing all their expertise together.
- Work it out, test it out, check it out: all the projects are tested under real conditions so that Smart City doesn't just stay a wonderful idea.
- Model it, propose it, build it: project promoters propose practical solutions so that tomorrow's cities stand the test of time.

2. The Openergy's project

To participate to this event, a contest with different topics was launched. More than 200 start-ups presented their projects and five of them were selected. The category in which Openergy applied was called "Consolidating energy flows to design "positive energy islands" and decreasing the size of our carbon footprint". In most big French cities, reflecting the situation in Paris, any construction of new dwellings is quite limited. Efforts to rationalize energy consumption must now involve the improvement of existing structures. One of the main opportunities we have identified involves the development of energy exchanges between buildings and facilities. What we're talking about here is a change of scale, going from positive energy buildings to positive energy islands, which means multiplying opportunities and enhancing the impact.

In the context of the bootcamp, the City of Paris, together with certain partners in the challenge, have access to building equipped with sensors. This unique experiment opportunity allows an approach which can mix instrumentation, modelling and data analysis. The changes seen in energy consuming habits and the identification of levers enabling the energy exchanges are major issues for cities. The micro-local level and the precision of the analysis of available data are ideal to carry out the type of experimentation whose methodology could be extrapolated for use in other infrastructure projects. The solutions found here could possibly be replicated in other contexts and in other cities in conjunction with the partners of the experimentation.

One of the aims of the challenge is to model energy flows in order to detect potential exchange opportunities. The main exchange opportunity involves complementary buildings for which the use and requirements balance out. One of the first steps to take would thus be to identify suitable fields and to calculate potential aggregated margins (in terms of financial savings, energy savings, infrastructures…). Different types of exchanges could be considered such as exchanges between buildings, on a neighbourhood or "island scale" or exchanges within buildings.

Usually Openergy studies the energy performance of one building, but in the context of DataCity it decided to expand its expertize to more buildings. In order to have complementary schedules the three buildings selected were an office, dwellings, and a nursery.

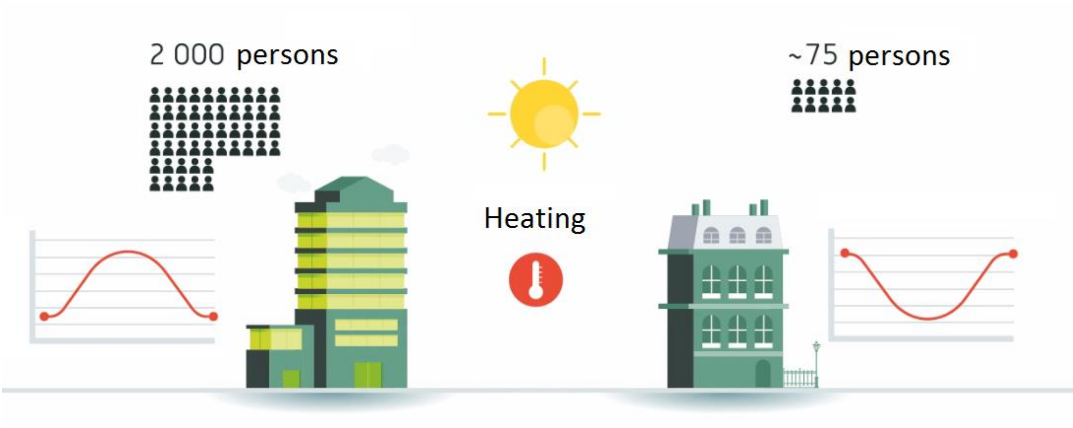


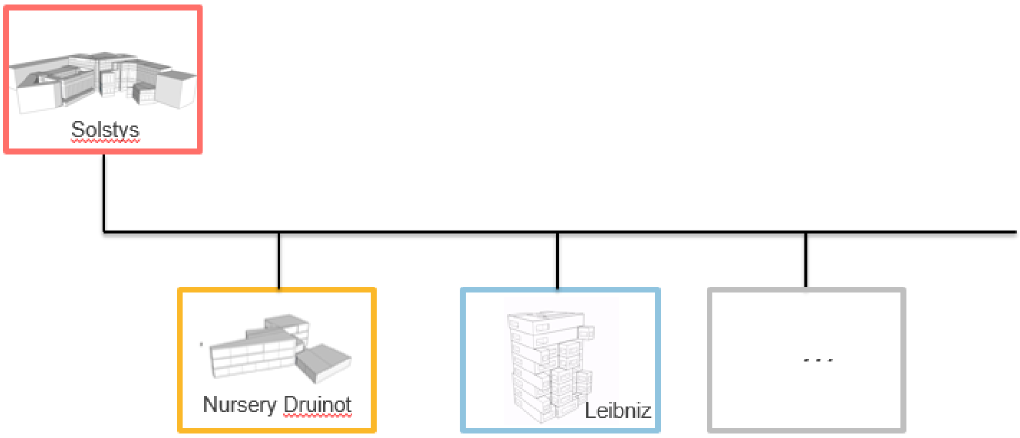
Figure 16 - Example of two buildings with complementary schedules: an office (left) and dwellings (right)

On the picture above, the office is represented on the left, and the dwellings on the right. The office has approximately 2000 persons whereas the dwelling is much smaller and represents only 75 persons. What is noticeable is that the office is occupied during the day (from 9 am to 8 pm) when the dwellings are empty, and the other way around on the night. Hence the interest of an exchange of energy.

3. Presentation of the three buildings: first approach

For this experimentation the three buildings selected were: Solstys (Offices), Leibniz (Dwellings), and Druinot (Nursery).

These buildings are not really close, but for the experimentation, we will do the study as if they were adjacent. Solstys is almost twenty times bigger than the others, so it could be considered as the energy supplier of the island.



In this part, we will model the buildings thanks to the documents we received and our knowledge of these kinds of buildings. Unfortunately, as a first step, we did not have access to the energy meter readings.

3.1. Solstys

3.1.1. Localisation and global information

Solstys is the offices' building, located in the 8th district of Paris, in a densely populated area. It is constituted with two different buildings, one called Vienne and the other Rocher. Vienne was created in 1911, and Rocher in 1935.

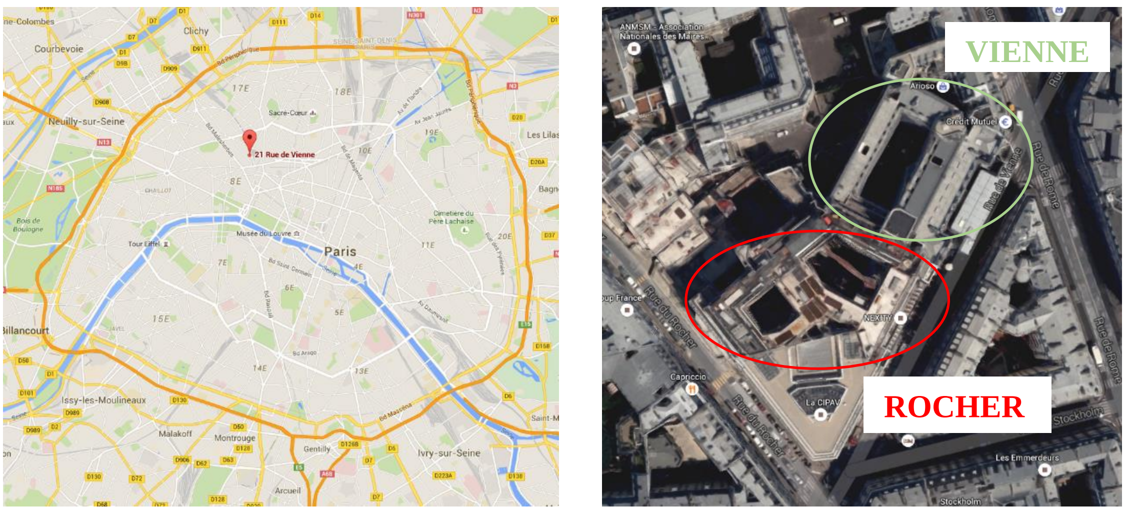


Figure 17 – Maps and aerial photography of the buildings

Administrative data		
VIENNE	Activity	Office
	Localisation	19 à 23 bis rue de Vienne
	Construction's year	1911
ROCHER	Activity	Office
	Localisation	38 à 46 rue de Rocher
	Construction's year	1935

Activity's data	
Number of structures	2
Number of zones	37
Heated volume	131 864 m^3
Heated surface	35 538 m^2

Installations' data	
Heating	CPCU (Urban District Heating)
Air Conditioning	With Air Conditioning
Domestic Hot Water	Collective

3.1.2. Characteristics of the building

The file used for the technic report of the building was not accessible. Therefore a new energetic model was created, which respects the geometry and the characteristics of the building. The picture below shows the global geometry of the building.

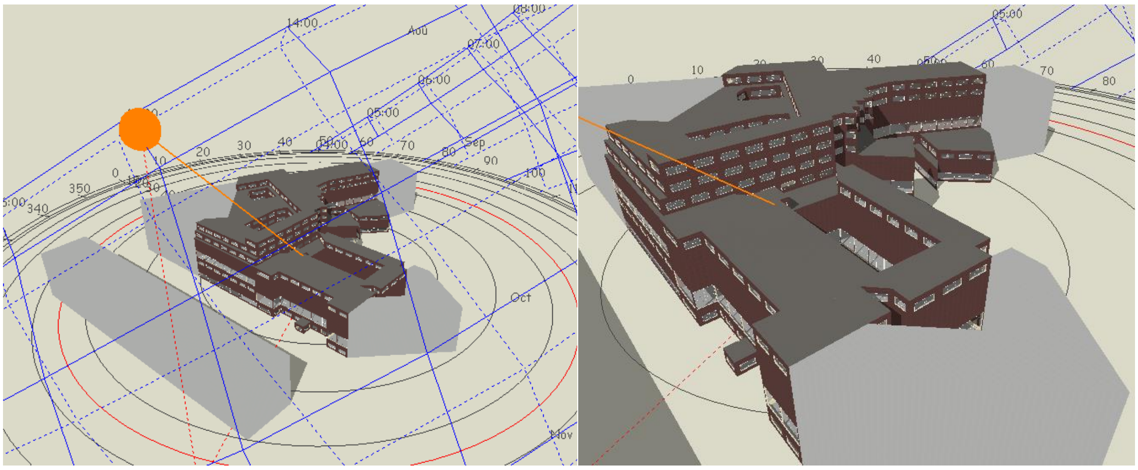


Figure 18 - Global view of the energetic model of Solstys

The shadows and the masks are not described in the documents, so they have been constructed with the images of Google Maps. The delimitation of the zones has been done by separating the four zones of offices (A1, A2, B1, B2), the toilets and the computer room.

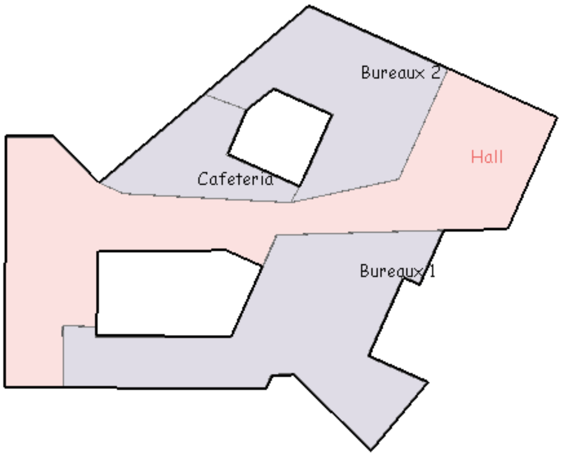


Figure 19 - Zoning of the ground floor of Rocher

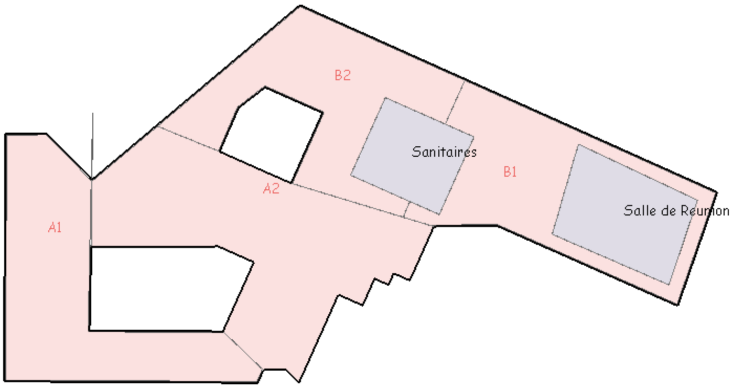


Figure 20 - Zoning of the 2nd floor of Rocher

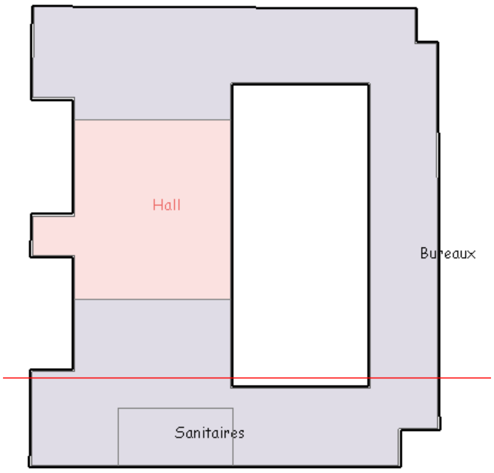


Figure 21 - Zoning of the ground floor of Vienne

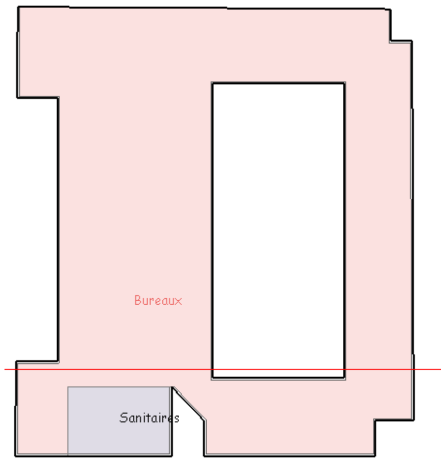


Figure 22 - Zoning of the 2nd floor of Vienne

We remind that U_{bat} represents the mean heat transfer coefficient through the walls, and its value is calculated by EnergyPlus.

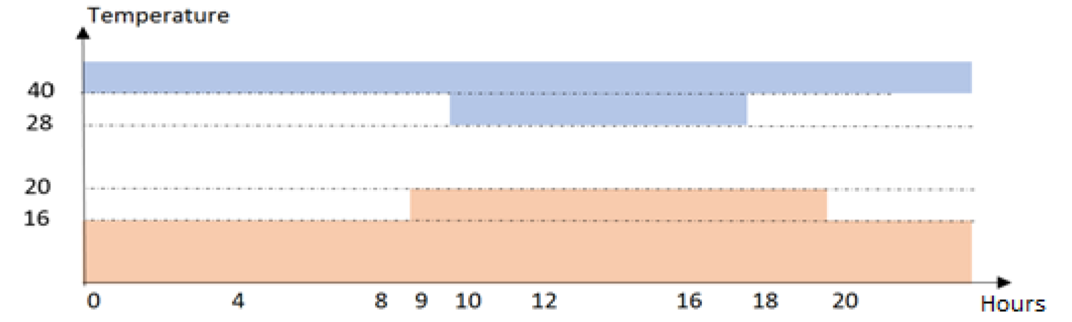
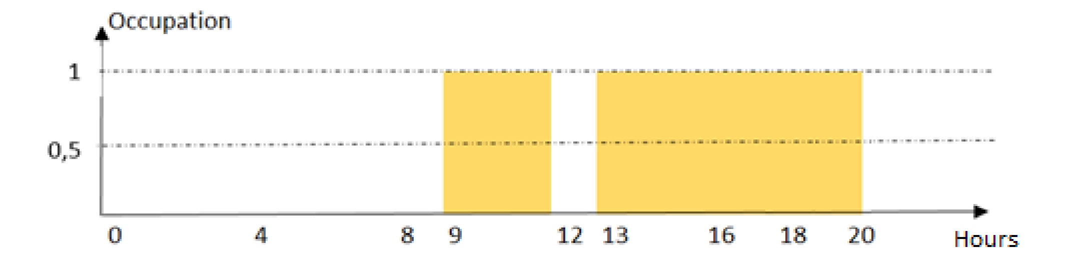
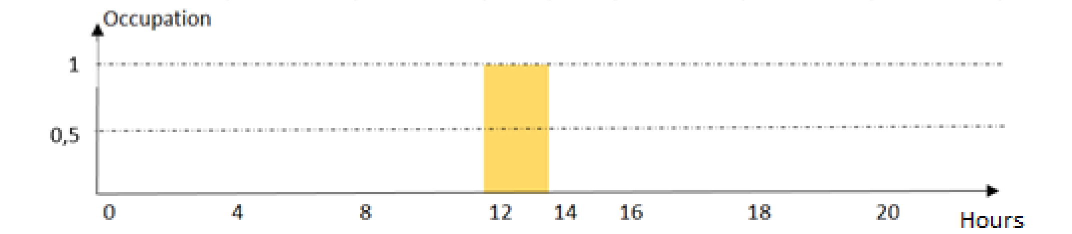
Name of the building	U_{bat}
Solstys	0,78

Below is described the distribution of the losses between the walls, the windows, and the air renewal.

Name of the building	Type	Losses ($W/m^2.K$)	Distribution
Solstys	U_{walls}	0,62	69 %
	$U_{windows}$	0,16	18%
	$\mathbf{U_{bat} = U_{wall} + U_{windows}}$	**0,78**	**87%**
	$U_{ren\text{-}air}$	0,12	13 %
	Total	**0,90**	**100 %**

3.1.3. Uses

In order to calculate the needs of heating, it is important to know the temperatures of the offices. In this case, we chose common temperatures of offices since we do not know the temperature readings.

<table>
<tr><th>Type</th><th>Working days</th></tr>
<tr><td>Set-point temperature of the offices</td><td>
</td></tr>
<tr><td>Occupation of the offices</td><td>
</td></tr>
<tr><td>Occupation of the cafeteria</td><td>
</td></tr>
</table>

Another parameter which has to be taken into account is the electrical consumption of the lights and of the electrical appliances. Therefore, we looked into the tables to find the corresponding contributions.

Site	Contribution	
	Light	Machine
Offices	7 W/m^2	16 W/m^2
Restaurant	10 W/m^2	-
Hall	10 W/m^2	-
Toilets	8 W/m^2	-
Plant room	7 W/m^2	5 kW
Circulation	6 W/m^2	-

3.1.4. Analyses of heating consumptions

Once all these parameters are saved in the document, we can run the simulation, and calculate the heating needs. The simulated consumption is compared to the gas bills. The comparison is done on the consumption of gas only from July 2015 since it is from this date that we had access to the data. Moreover, the simulation during the months of January, February and March is done on the year 2015 because we did not have access to the weather forecasts files of 2016, but the data are given for the year 2016.

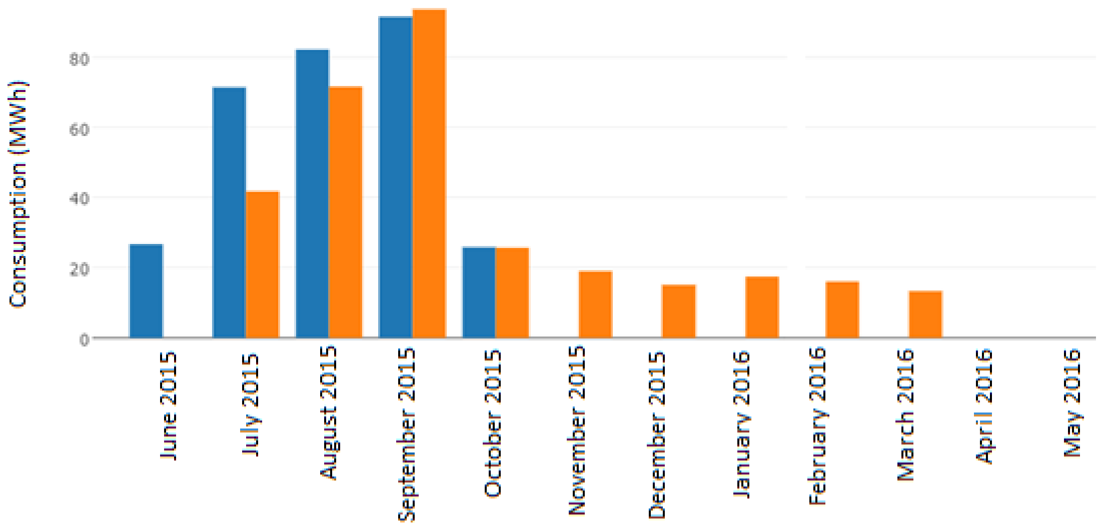


Figure 23 – Comparison of the gas consumption for the cold between the data (in orange) and the simulation (in blue)

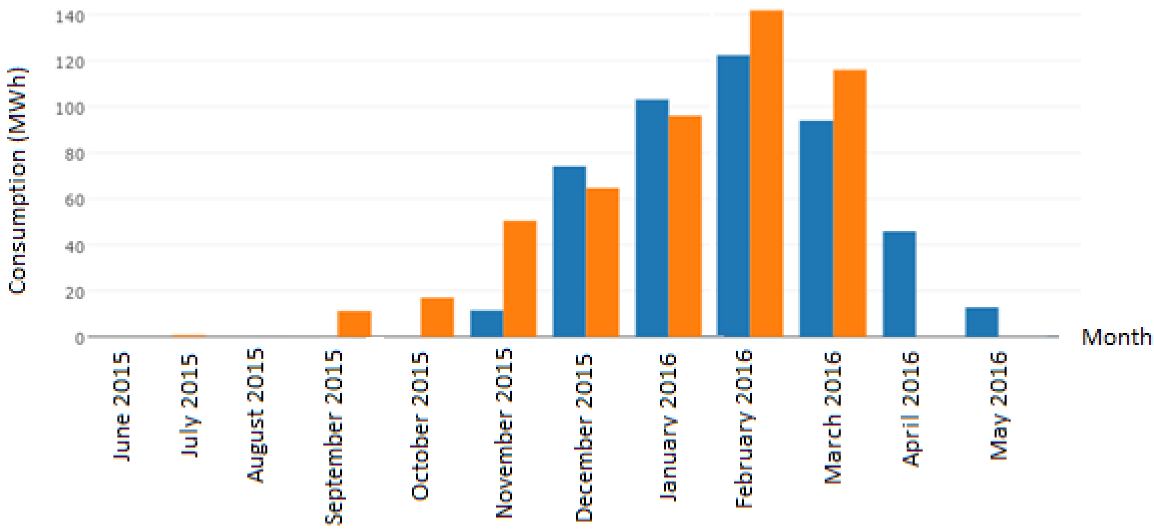


Figure 24 – Comparison of the gas consumption for the heat between the data (in orange) and the simulation (in blue)

The estimation of the production of cold is relatively good for the summer months (from July to September). The main differences between the observed and estimated consumption are:

- A production of cold in winter (from October to March) in the bills which is not shown in the simulation. This is most likely explained by the presence of a server room which always needs to be cooled. Given that we did not have any information about this room, it has not been drawn yet, but the consumption of cold of this room can be estimated thanks to the values of the production of cold in winter.
- During July, an under-consumption could be explained by the fact that the bills do not start on the 1st of July. Indeed, we only have access to monthly data which start in July, but the month might not be complete.
- We do not have the data for the month of June 2015.

Concerning the estimation of production of heat, it is also quite good. Nevertheless, we observe a few differences:

- An over-consumption in October which is probably due to an overheating of the offices.
- A slight difference in January and February which comes from the fact that we did not have access to the weather forecasts of 2016. Hence, the simulation has been done with the weather forecasts of 2015, whereas the bills are of 2016.

3.2. Leibniz

3.2.1. Localisation and global information

The building Leibniz is a dwelling which has been created in 2013.It is located in the 18th district of Paris, surrounded by other buildings.

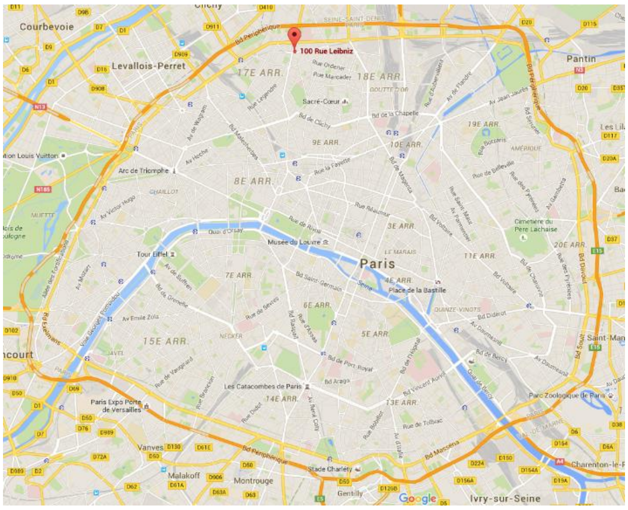



Figure 25 – Map and photo of the building

The main propriety of the building are presented in the tables below.

Administrative data	
Name	Leibniz
Activity	Dwellings
Localisation	100 rue Leibniz, 75018 Paris
Construction's year	2013

Activity's data	
Number of structures	1
Number of zones	16
Heated volume	6160 m^3
Heated surface	1730 m^2

Installations' data	
Heating	Boiler
Air Conditioning	Without Air Conditioning
Domestic Hot Water	Collective

3.2.2. Characteristics of the building

As well as for the other buildings, the software DesignBuilder is used to create the geometry of Leibniz, using the information given by the documents available and Google Maps for the buildings around.

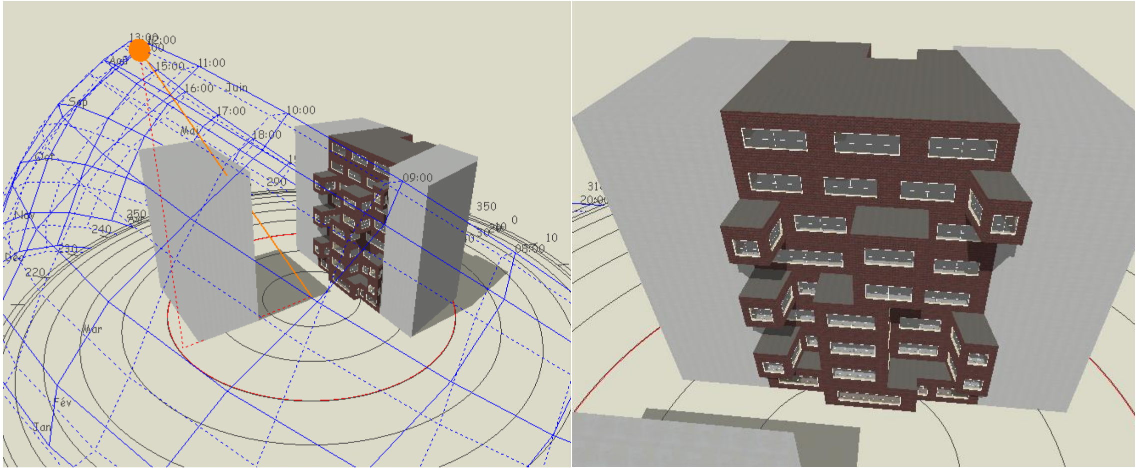


Figure 26 - Global view of the energetic model of Leibniz

The zoning has been done by separating the commons from the apartments. Indeed, the apartments are heated, whereas the commons are not. So it is necessary to separate these zones.

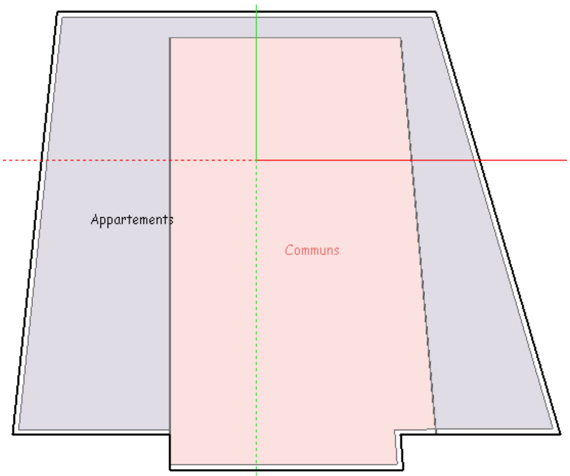


Figure 27 - Zoning of the ground floor

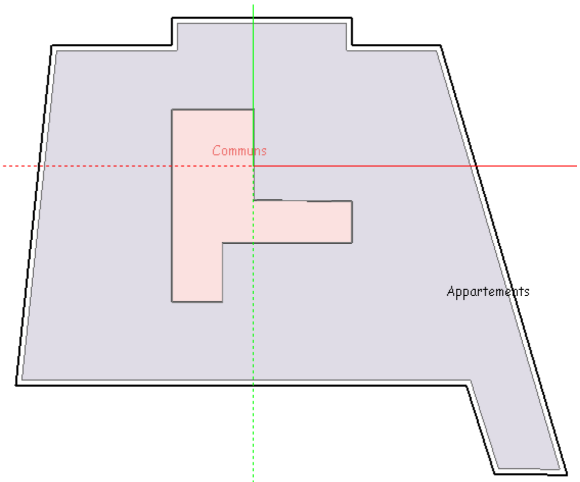
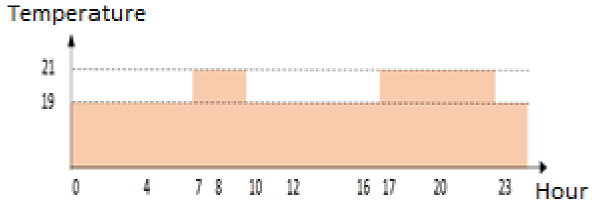
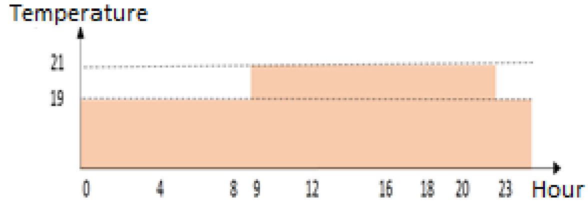
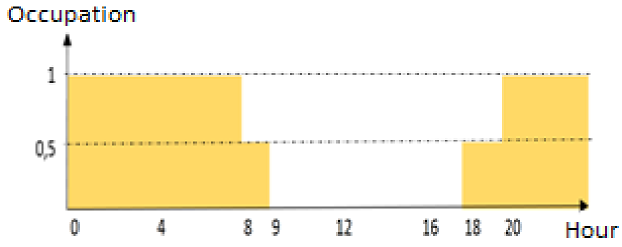
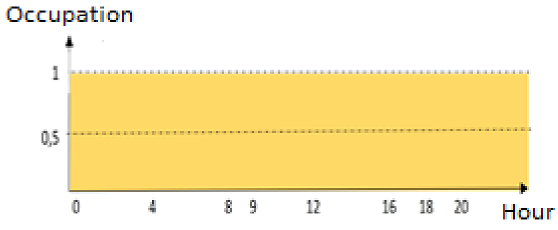


Figure 28 - Zoning of the 6th floor

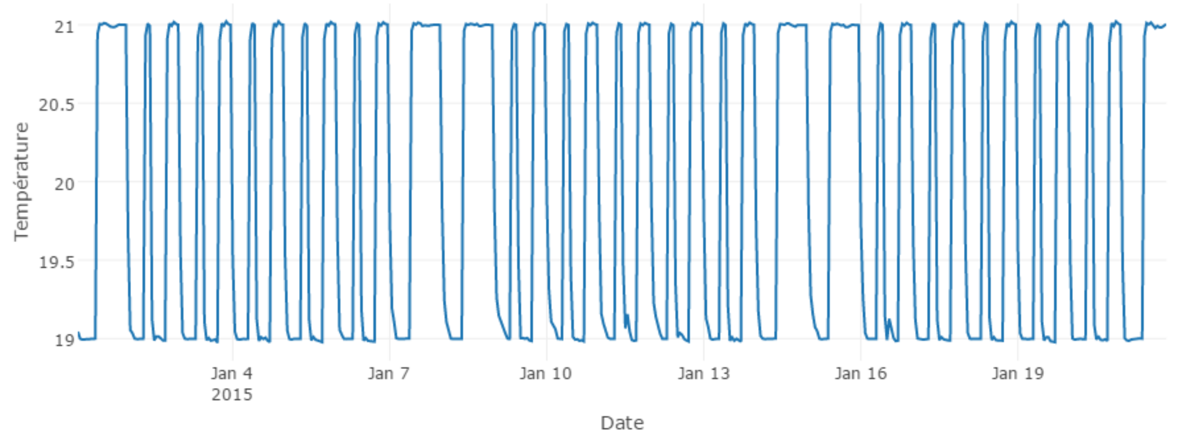
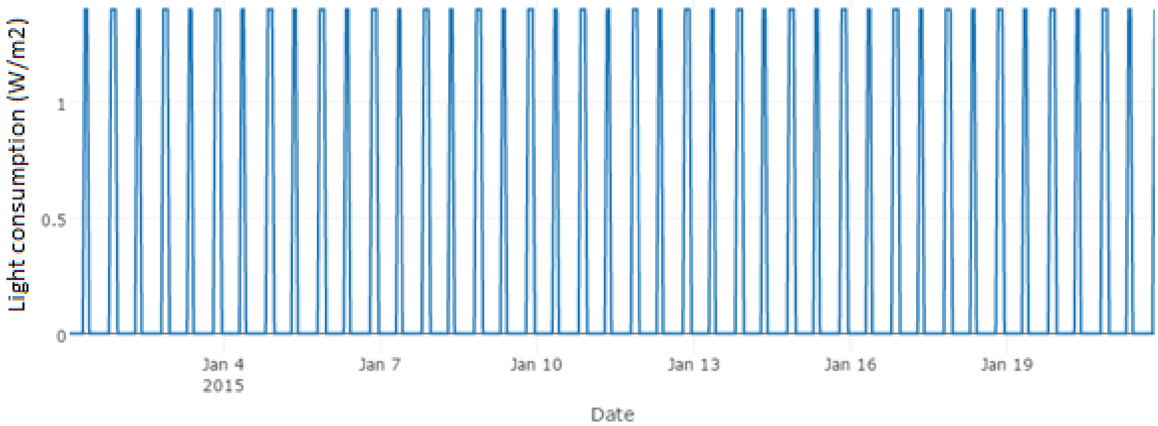
The coefficient U_{bat} calculated has a value of 0,497, which is low. It means that the building is well-insulated.

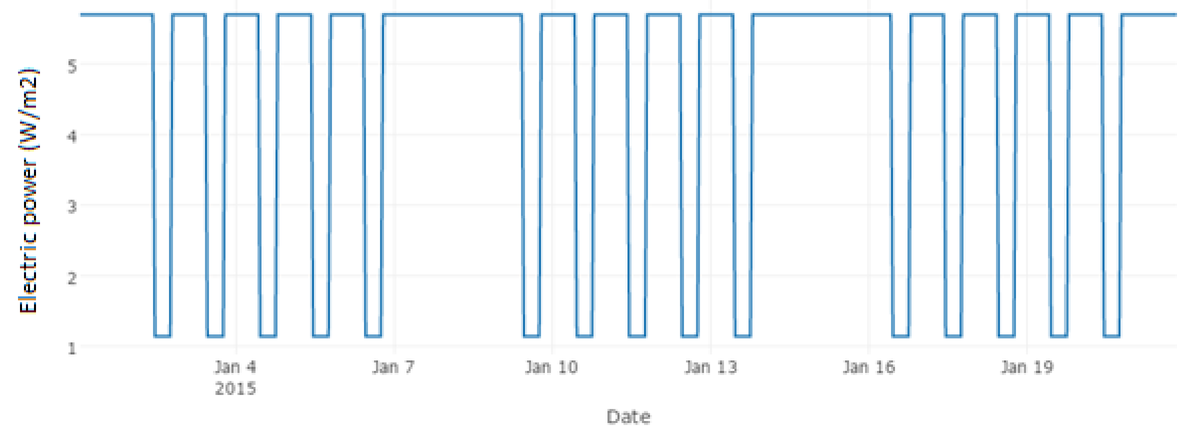
3.2.3. Uses

Then we chose the schedules and the values of the setpoint temperatures, of the light's consumption, and of the electric equipment. Most of the information are in the documents, and for the others we chose typical values for dwellings.

<table>
<tr><th>Type</th><th>Working days</th><th>Holidays</th></tr>
<tr><td>Setpoint temperature of the apartments</td><td>
</td><td>
</td></tr>
<tr><td>Occupation of the apartments</td><td>
</td><td>
</td></tr>
</table>

We can check in the simulation if the temperatures are respected and the consumption of the lights and of the electric equipment.

<table>
<tr><td>Temperature</td><td>
</td></tr>
<tr><td>Lights</td><td>
</td></tr>
</table>

Electric equipment	

We see on these graphs that the setpoint temperature is respected, and that during the weekends, the apartments are heated all day long, whereas during the week it is only heated on the mornings and on the evenings.

3.3. Nursery

3.3.1. Localisation and global information

The nursery Druinot was created in the 18th district of Paris in 2007.

Figure 29 - Map and photo of the building

Administrative data	
Name	Nursery Druinot
Activity	Nursery
Localisation	4-6 impasse Druinot, 75012 Paris
Construction's year	2007

Activity's data	
Number of structures	1
Number of zones	3
Heated volume	6244 m^3
Heated surface	1784 m^2

Installations' data	
Heating	Natural Gas
Air Conditioning	Without Air Conditioning
Domestic Hot Water	Collective

3.3.2. Characteristics of the building

As for the others buildings, we used Design Builder to do the geometry of the nursery. There are not exterior walls, only windows.

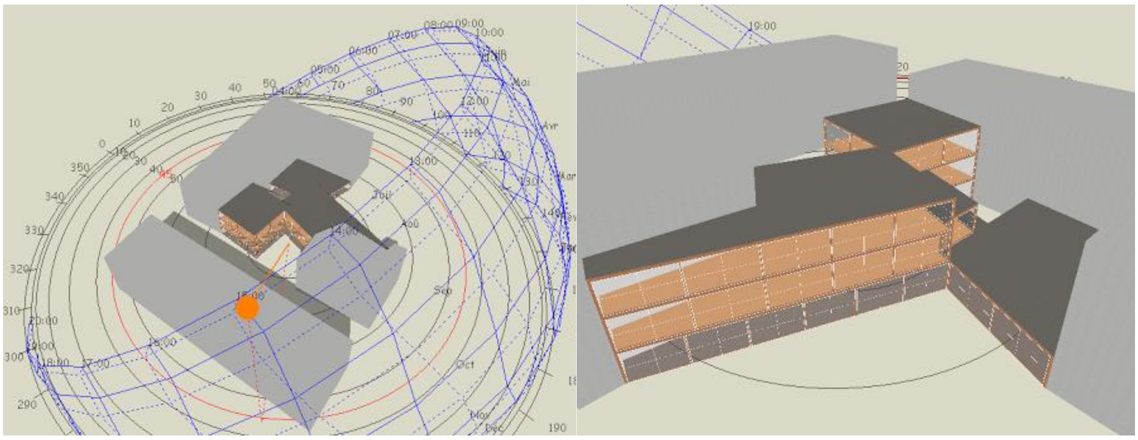


Figure 30 - Global view of the energetic model of the nursery Druinot

Here are presented the drawings of each floor. No zoning has been done, each stair is considered as one unique zone. What is notable on this building is that there are only windows, almost no walls.

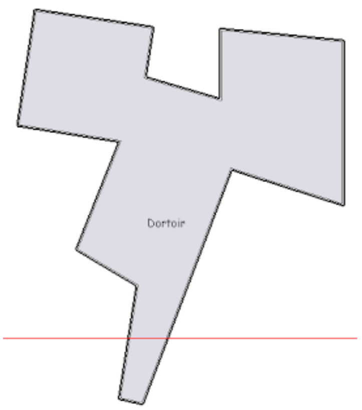


Figure 31 - Drawing of the ground floor

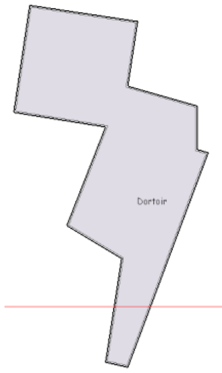


Figure 32 - Drawing of the 1st floor

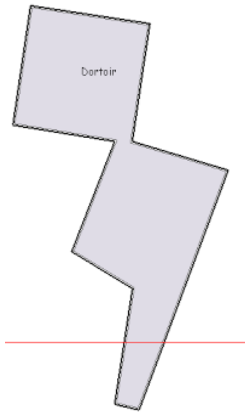


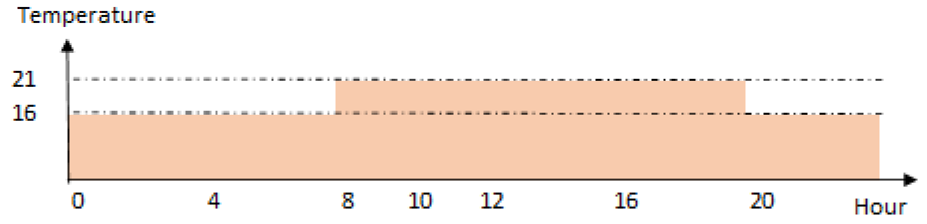
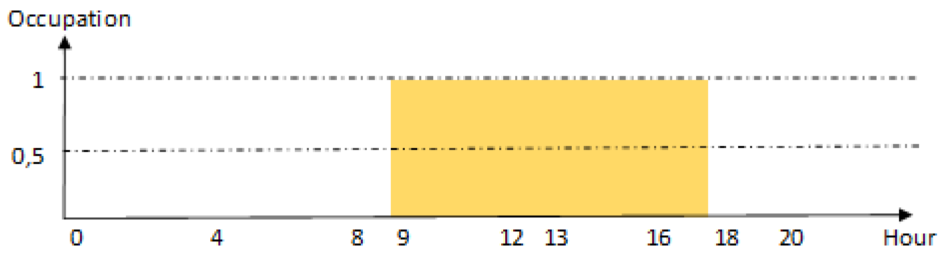
Figure 33 - Drawing of the 2nd floor

The repartition of the heat losses is presented on the table below:

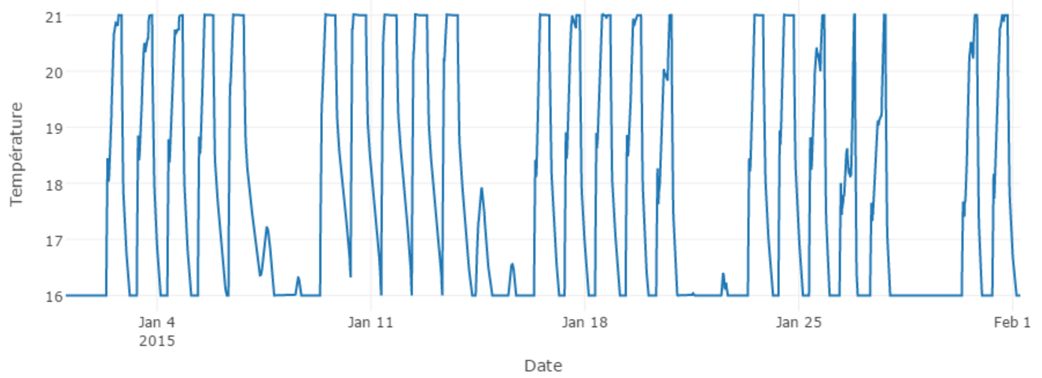
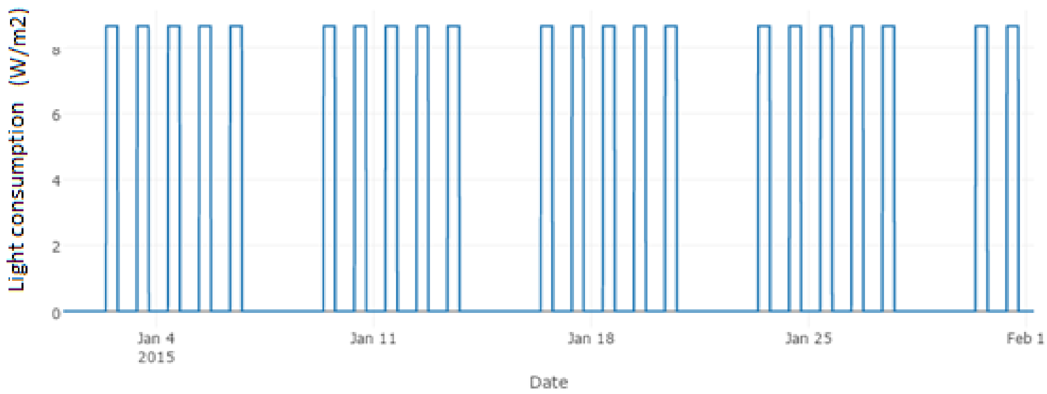
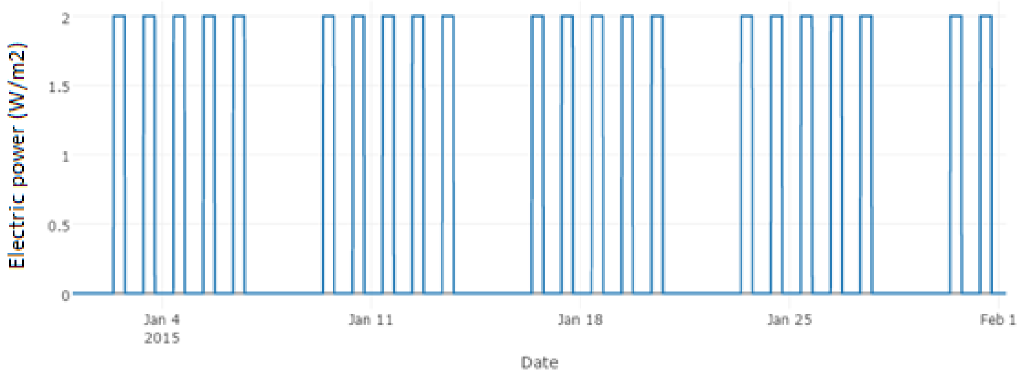
Name of the building	Type	Losses ($W/m^2.K$)	Distribution
Nursery Druinot	U_{walls}	0,87	53 %
	$U_{windows}$	0,69	42 %
	$U_{bat} = U_{wall} + U_{windows}$	**1,56**	**95 %**
	$U_{ren\text{-}air}$	0,08	5 %
	Total	**1,63**	**100 %**

3.3.3. Uses

The occupation of a nursery is quite similar to the occupation of an office. People arrive around 8am and leave around 6pm.

Type	Working days
Setpoint temperature	
Occupation	

Thanks to the information given by the City of Paris, we can model the electric consumption of the equipment and of the lights.

Temperature	
Lights	
Electric equipment	

4. Energetic mutualisation: second approach

After having done the first approach, we finally got access to the energy meter readings. From these readings, we could analyse the needs for air heating for the three buildings:

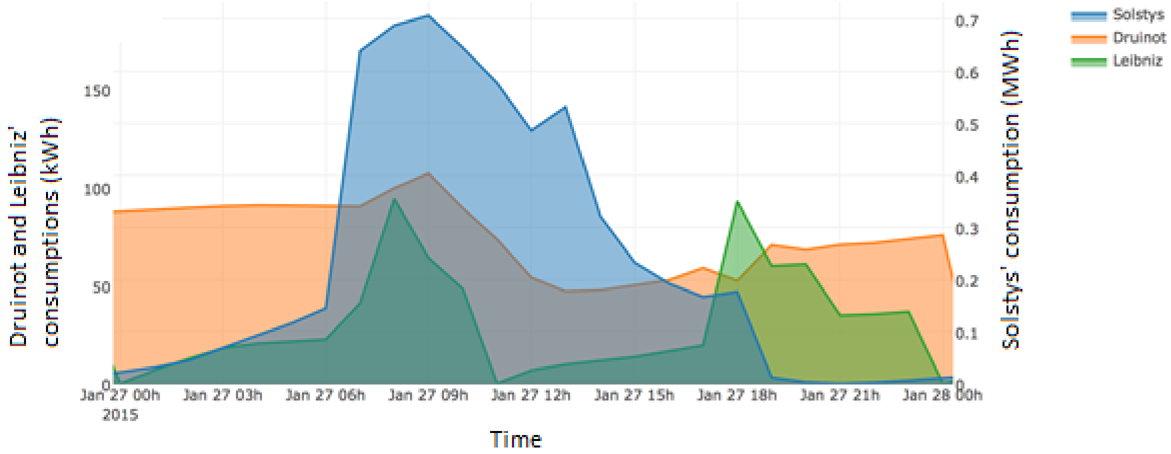


Figure 34 - Needs for air heating of the buildings

On this graph, there are two scales. Indeed, Solstys is more than twenty times bigger than the others, so its heating needs are much more important. Solstys' consumption is read on the right scale, whereas Druinot's and Leibniz' consumptions are read in the left one.

First, we can notice that the consumption's peaks of the different buildings are not disjointed. In the first approach, we were supposing that the peaks of Solstys and the nursery would be after the one of Leibniz. But the truth is that the morning peak is around 8am for all buildings. Another thing is that the consumption of the nursery is almost constant at every time of night and day.

Three scenarios have been considered to mutualize energy.

4.1. First scenario: share of production means

The first scenario would be to share the production means. Indeed, instead of having three boilers, three transformers… there could be just one, which would reduce the prices of installation and maintenance. This scenario would have been more interesting if the heating peaks were disjointed. In this case, there is no energy saving, the savings are only economical ones.

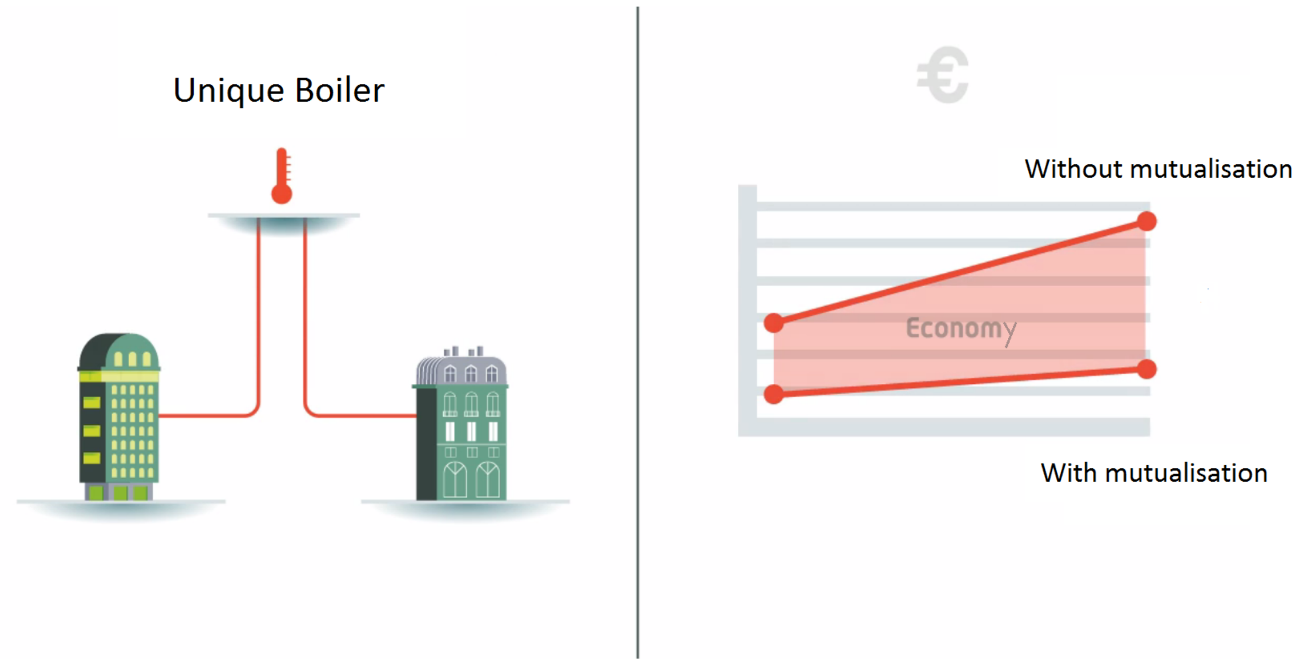


Figure 35 – Share of production means

In this case, each building which would share the production means would save 5 000€.

4.2. Second scenario: use of untapped overpower

Solstys uses pumps which can make heat and cold only for the production of cold since it is CPCU (Urban District Heating) which handle the heating. But this pumps could be used to produce heat for other buildings. Moreover, the systems are always oversized, so there is an untapped overpower in Solstys which could be used to heat other buildings. This overpower is so important that it could be used to heat around 12 buildings of the same size as Leibniz. Nevertheless such an island does not obviously exist, that's why we will focus on our virtual island. Once again, the gain for this scenario would be of 5 000€ by building concerned.

4.3. Third scenario: Recycling unavoidable energy to pre-warm domestic hot water

The last scenario would be to recycle the unavoidable energy of Solstys for the pre-warming of domestic hot water of Leibniz. In a large majority of offices, there are server rooms which need to be cooled. But to cool a room, there is a production of heat which is not used for now. This has no cost, because this production of heat is done anyway. So it will be "free energy" for other buildings. This energy produced could warm the water of twenty buildings like Leibniz.

Figure 36 – Use of the unavoidable heat produced when cooling the server rooms of Solstys to warm domestic hot water of Leibniz

This installation would cost 12 000€ in total but would allow a profit of 7 000€ each year. So it is more interesting in a long-term view. And with this scenario there are energy savings because this unavoidable heat would be lost otherwise.

4.4. Implementation of the scenarios

This last scenario seems to be the easiest to implement. The problem with the other scenarios is that, even if it is economically interesting, the owner of the dwellings might be reluctant to be dependant of the office's building. To make this solution work, it should be the responsibility of the operators to guarantee the security of the production of energy. Thus the owners of dwellings would not be depending on another building, they would directly deal with the operator. On the contrary, the third scenario is really simple to implement, it only consists in recovering the energy lost.

In the long-term, the aim of this project would be to create many islands in the city, each one of the optimal size to optimize energy savings, depending on the area of the buildings, and of their capacity of production.

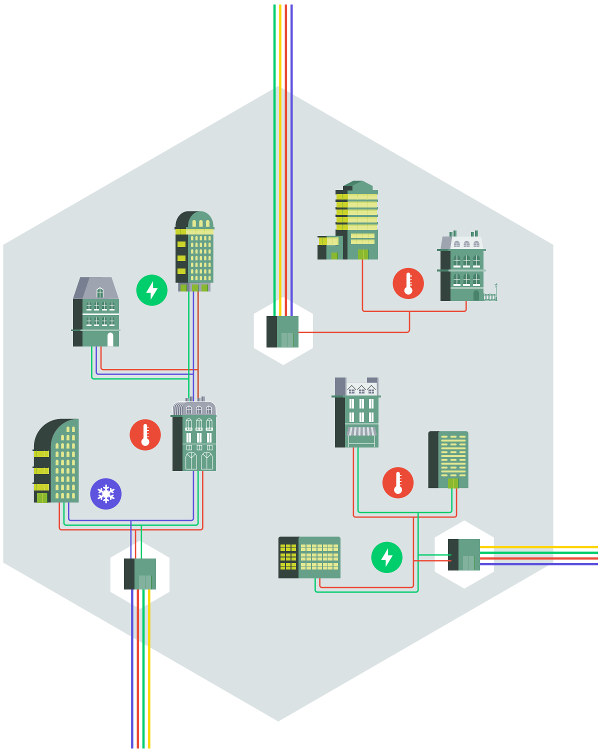


Figure 37 - Long-term view of the grid

In the figure, one heating amenity is shared by different buildings. The number of buildings can vary, depending on the size of each one, and of its function and its schedules. Then a study should be made to identify places in cities with a real potential of energy mutualisation.

Conclusion and possible prospects

Openergy is aiming to revolutionize the energy monitoring of buildings by offering a digital platform which integrate data analysis combined with dynamic thermal simulation. If the data analysis has already been automatized, the simulation should be as well, progressively, in order to be integrated to the platform.

This report presented a method of calibration of energy simulation giving satisfying results. It is about calibrating the model by giving real electric consumptions, and its real set-point temperatures, and then changing the values of other parameters such as infiltration or internal mass in order to find the good heat consumption.

The audit of a building shows that the simulation can also be used in order to evaluate the possible energy savings. Indeed, the calculation of the simulation gives the heat needed to respect the comfort of the inhabitants, if there are overconsumptions, it can easily be detected and fixed. For instance, it is common that buildings are overheated during mid-season months. A regulation of the temperature could allow important energy savings.

But the “simulation calibration” is not limited to one building. Indeed Openergy experimented a work on energy simulation, using its experience but enlarging its point of view from one to more buildings. The DataCity experience was really enriching, but it was concerning a virtual island. Now, it would be interesting to apply the developed technic to real adjacent buildings.

In the future, we will have to realize a study for a military base which includes more than 150 buildings. In order to do so in a reasonable time, it becomes necessary to automatize the most part of the study. Thus a preliminary study will be lead to determine how reduce to a minimum the number of parameters which have to be controlled manually.

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<u>Website:</u>

DesignBuilder: www.designbuilder.co.uk

Annexes

Annex 1: Plan of Convention’s 4^{th} floor

Annex 2: Description of the actions

Action n° 1	Insulating roofs

Description

The roof is not insulated, and therefore represents an important cause of losses. The implementation of an attic insulation (5cm of glass whool) is easily achievable

Localisation	Roof
Installation	Insulation
Area	2185 m2
Cost of works	30 €/m2

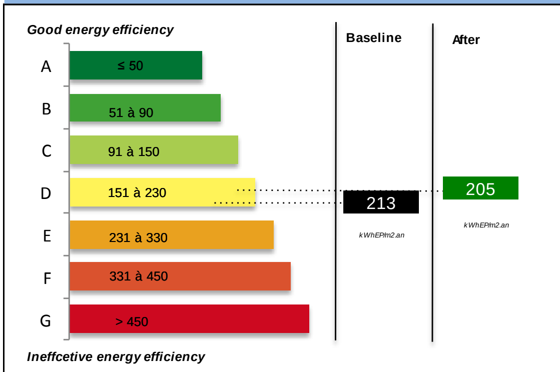
Thermal characteristics : glass whool

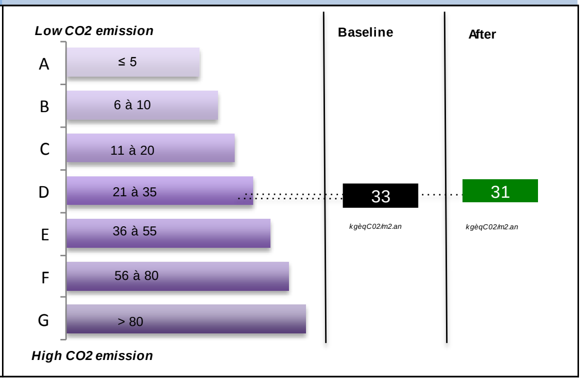
λ	0,04	W/m-K	Thickness	0,05	m
R	1,25	m2.K/W			

Results

Before			After		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1580	2124	326
GAIN			**Investissement & ROI**		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Investment (k€)	Estimated yearly savings (k€)	Return on investment (year)
5%	4%	6%	66	5,2	> 100

Energy consumptions (consumption of primary energy)	Greenhouse gas emission (based on the consumption of primary energy)





Comments:

The estimation of the savings associated to the roof insulation is of 4% of the total consumption. The losses by the roof are reduced of 86 MWh/year, for a relatively small renovated area. But the gain is not enough to make the renovation profitable.

Estimations come from simulations using the reference climate of Paris Orly

Action n° 2	Insulating walls

Description

The walls of the dwellings represent more than 50% of heat losses of the building, because it is not sufficiently insulated. In this action, we insulate them by a layer of glass whool of 5cm. Insulating from the outside seems easier.

Localisation	Outer wall
Installation	Insulation
Area	8309 m2
Cost of works	100 €/m2

Thermal characteristics : glass whool

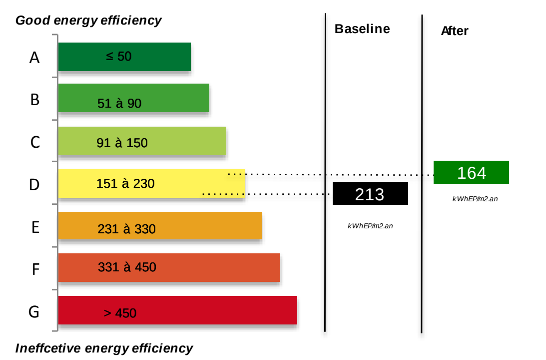
λ	0,04	W/m-K	Thickness	0,05	m
R	1,25	m2.K/W			

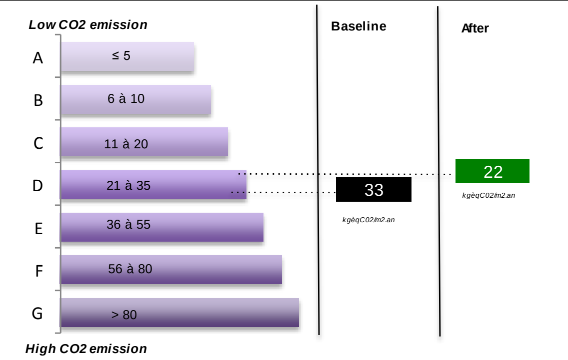
Results

Before			After		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1154	1698	226

GAIN			Investissement & ROI		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Investment (k€)	Estimated yearly savings (k€)	Return on investment (year)
31%	23%	35%	831	30,7	52

Energy consumptions (consumption of primary energy)	Greenhouse gas emission (based on the consumption of primary energy)





Remarques:

The decrease of heat losses by the walls allows a gain of 512 MWh, which represents 23% of the total energy. However, the total investment that represent the insulation of all outer walls is important in comparison to the gains created.

Estimations come from simulations using the reference climate of Paris Orly

Action n° 3	Turning off heat in the commons

Description

The heat in the commons represent approximately 3% of total heat. Decreasing the temperature, or turning off in these parts of the building would allow savings without investment.

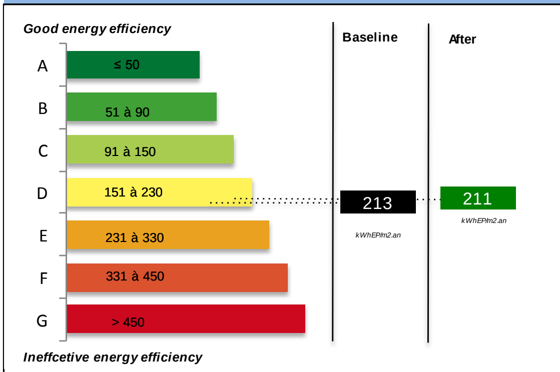
Localisation	Radiators
Installation	Heating regulation
Area	1195 m2
Cost of works	0 €/m2

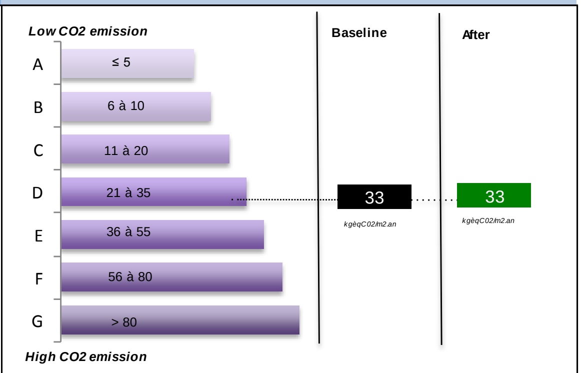
Thermal Characteristics

Results

Before			After		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1647	2191	341
GAIN			**Investissement & ROI**		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Investment (k€)	Estimated yearly savings (k€)	Return on investment (year)
1%	1%	1%	0	1,1	0

Energy consumptions (consumption of primary energy)	Greenhouse gas emission (based on the consumption of primary energy)





Comments:

Turning off heat in the commons can make heat consumption decrease of 1%, this without investment. However, the acceptation of this measure by the occupants needs to be evaluated.

Estimations come from simulations using the reference climate of Paris Orly

Action n° 4	Lowering set-point temperature

Description

The temperature in the building is comfortable (21°C in winter). The following estimation presents the potential energy gain due to the change of the set-point temperatures.

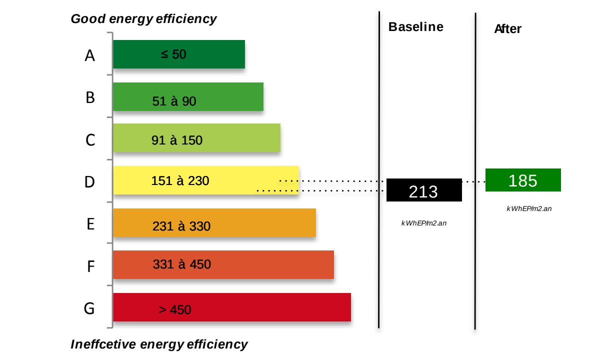
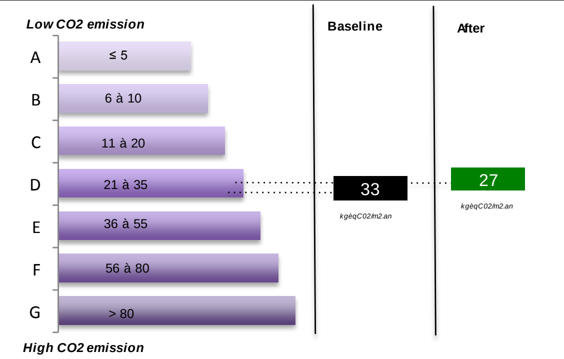
Localisation	Boiler room
Installation	Heating regulation
Area	10347 m2
Cost of works	0 €/m2

Caractéristiques techniques

Winter reduced temperature	16	°C	Winter comfort temperature	20	°C

Results

Before			After		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1370	1913	276
GAIN			**Investissement & ROI**		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Investment (k€)	Estimated yearly savings (k€)	Return on investment (year)
18%	13%	20%	0	17,8	0

Energy consumptions (consumption of primary energy)	Greenhouse gas emission (based on the consumption of primary energy)
	

Comments:

The estimation of energy savings associated to this action raises 13%.

Estimations come from simulations using the reference climate of Paris Orly

Action n° 5	Renovating simple glazing windows

Description

Windows constitute an important cause of losses. Indeed they have lower thermal resistances than other type of walls.

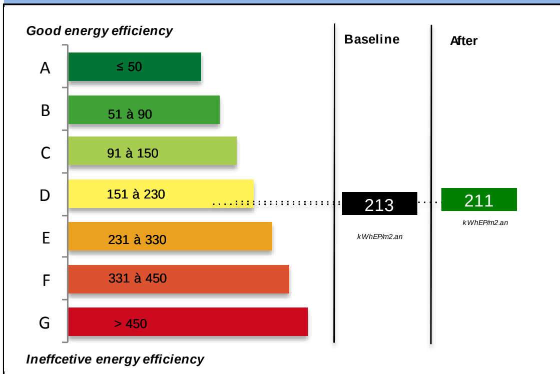
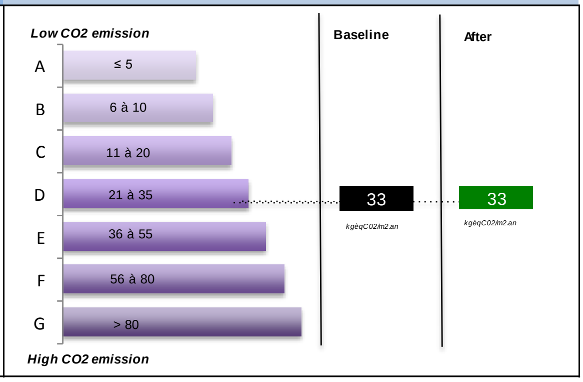
Localisation	Commons
Installation	Windows
Area	223 m2
Cost of works	650 €/m2

Thermal characteristics : glass whool

U	2	W/m-K	Solar transmittance	65 %
R	0,50	m2.K/W	Visible transmittance	80 %

Results

Before			After		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1642	2186	340
GAIN			**Investissement & ROI**		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Investment (k€)	Estimated yearly savings (k€)	Return on investment (year)
1%	1%	2%	145	1,4	> 100

Energy consumptions (consumption of primary energy)	Greenhouse gas emission (based on the consumption of primary energy)
	

Comments:

Dwellings already own double glazing windows. Renovation of simple glazing in the commons would bring an energy gain of 24 MWh/year. The renovation cost is very high, so the return on investment is very long.

Estimations come from simulations using the reference climate of Paris Orly

Action n° 6	Changing the production system (CPCU -> gaz)

Description

Estimation of financial gain and of pay-back time if we changed the system of heat production, and if instead of CPCU we used natural gaz. Given the operation bills and boilers' consumption, the P2 are considered equals for CPCU and gas.

Localisation	Boiler room
Installation	Heating system
Area	10347 m2
Cost of works	0,158 k€/kW

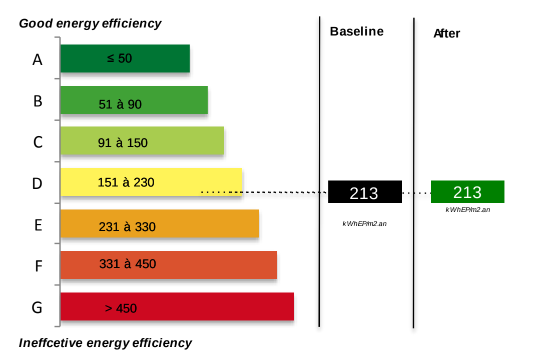
Thermal characteristics

Installed power	1165	kW	Annual profit on subscription	26,1	k€

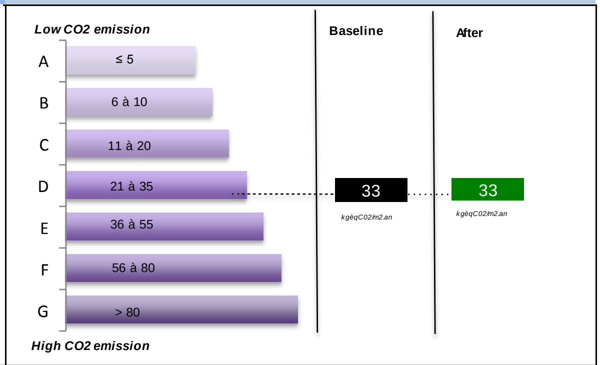
Results

Before			After		
Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year	Consumption MWh FE/an	Consumption MWh PE/an	Greenhouse gas emission teq C02/year
1666	2210	346	1666	2210	346
GAIN			**Investissement & ROI**		
Consumption MWh FE/an	Consumption MWh FE/year	Greenhouse gas emission teq C02/year	Investment (k€)	Estimated yearly savings (k€)	Return on investment (year)
0%	0%	0%	184	40,6	4

Energy consumptions
(consumption of primary energy)



Greenhouse gas emission
(based on the consumption of primary energy)



Comments:

The change of the heat production system would generate a profit of 40,6 k€.

Estimations come from simulations using the reference climate of Paris Orly

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Màsters Universitaris

Evaluation of the Final Master´s Thesis

Course:
UPC Code: **820775**

Date of defense:

Qualification:

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President:
Member of Tribunal:

Deputies:

Observations

Signature

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Surname, Name (President)	Surname, Name (President)
Surname, Name (Member of Tribunal)	Surname, Name (Member of Tribunal)
Surname, Name (Member of Tribunal)	Surname, Name (Member of Tribunal)