Towards a global optimisation of buildings integrated in eco-districts : from design to anticipative and reactive management in the perspective of the Internet of Energy

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A paradox as introduction !

- **Why ? On one side**
  - Complex modelisation with quite simple optimisation
    - Example: E+, TRNSYS, … with genetic algorithms like NSGA-II
- **And, on the other side:**
  - Complex optimisation with quite simple models
    - Example: analytic models with MILP or SQP optimisation
- **The talk will try to show:**
  - How adressing Smart Buildings, Smart-Grids and Internet of energy helps me to find some answers !
- **I will not focus on the Optimisation/Modelisation technics …**
  - But focus and how and why those technics should be used by … Designers and Stakeholders

Outline:

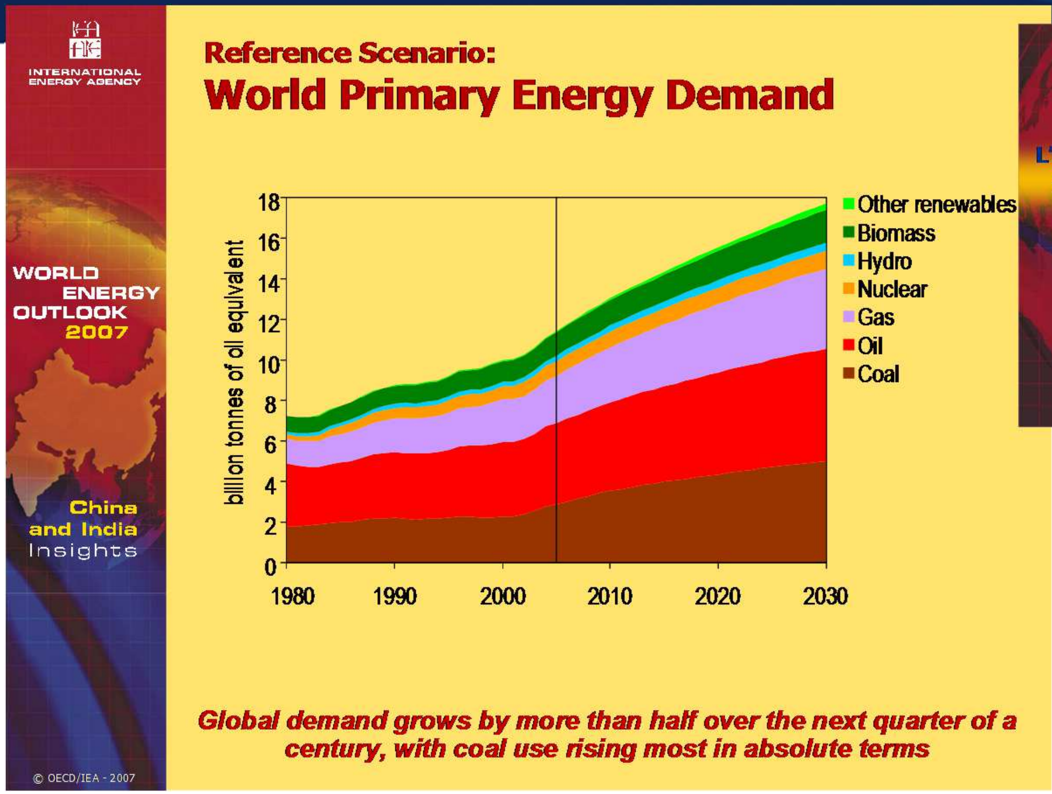
- **I - From energy transition to the revolution of Smart Buildings (SB)/Smart Grids (SG)/Internet of Ernegy (IE)**
- **II - The key pillar of the revolution ?: An engineering approach for SB based on modelisation and optimisation**
  - **Demand side management, demand Response and Anticipative Optimal supervision from building to district level**
  - **Design of buildings integrating Demand Side Management and Demand Response**
- **III - The need of a new vision of synergy between optimisation and modelisation**
  - **Why the need of a new vision**
    The importance of Preliminary Design (PD)
    The paradox "information-decision" of Preliminary Design (PD)
    The need of new compromises between modelisation and optimisation
    Imaginery System Design as a new paradigm for PD
- **IV - Examples of new compromises between Optimisation and Modelisation**
- **V - The need of a new inter-disciplinary approach with the « human in the loop »**
  - **In the study and design process**
  - **In anticipative and reactive management and supervision**
- **VI - The means of a research with the human in the loop**
  - **From the concept of living to the eco-sesa project**

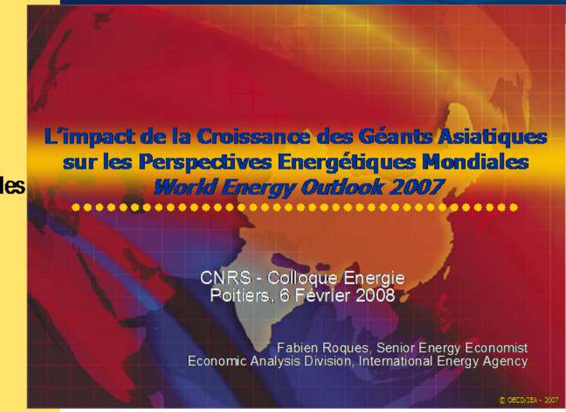
I - From energy transition to the revolution of

Smart Buildings (SB)
Smart Grids (SG)
Internet of Energy (IE)

-"Smart buildings" as key pillar of "Smart grids" and Internet of Energy
- Why SB in interaction with SG could be a main contribution for energy transition

The necessity of an energy transition for the climate issue





http://www.cop21.gouv.fr/

How can we inverse the curve and the trend ?
For the climate as electrical engineer !

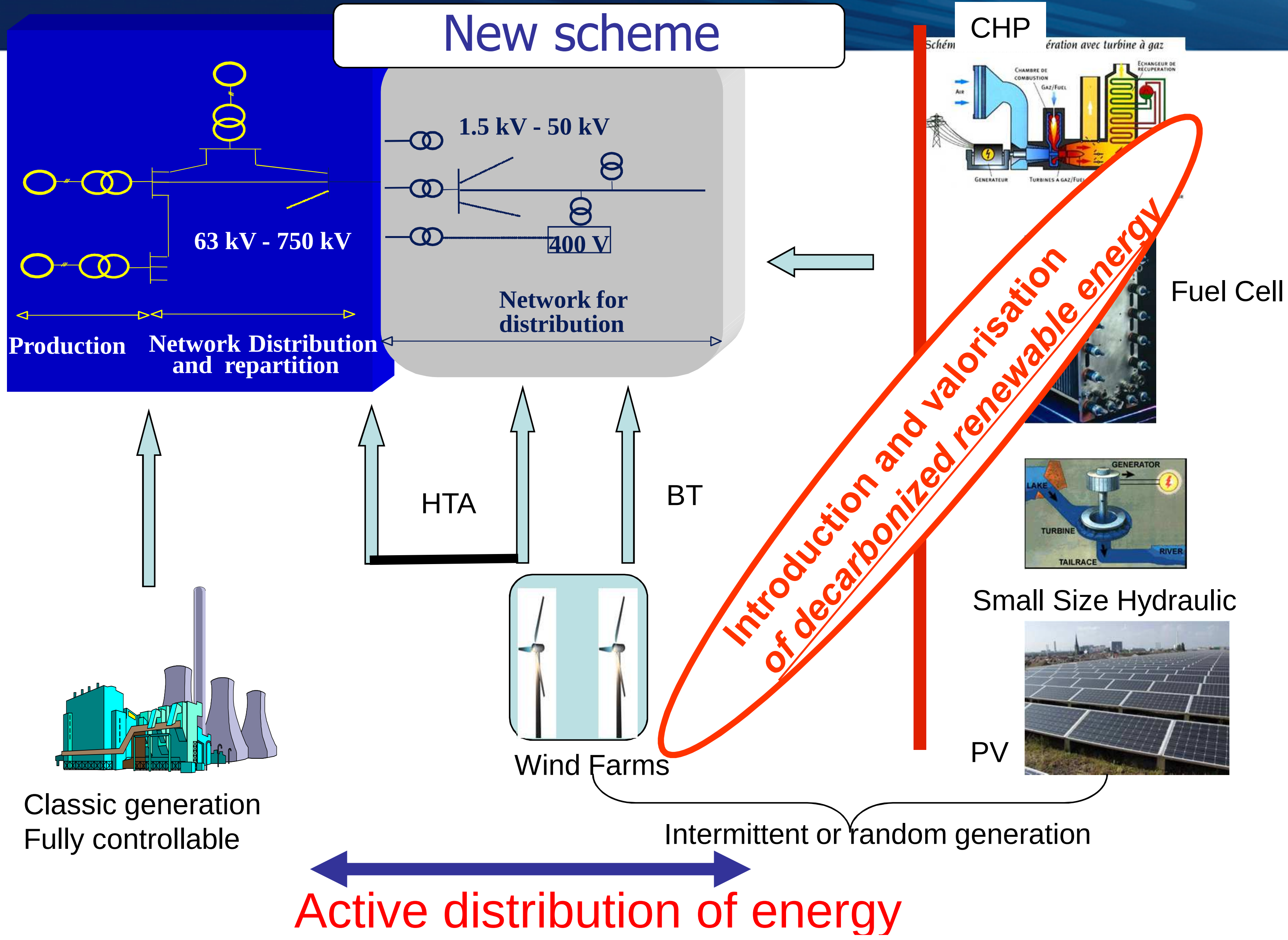
→ A necessity of the transition

The smart grid as part of the solution for the climate issue

Electrical networks Mutation

Toward Smart Grids

= Electricity
+
Internet



« Smart Buildings » as key allies of the «Smart-Grid»

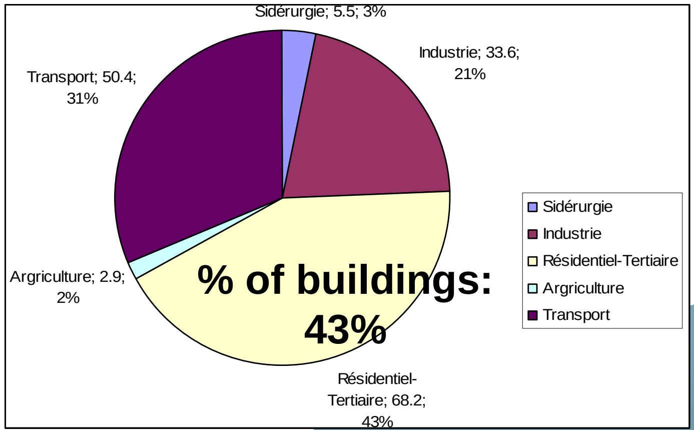
1st energy consumer
Could be one of the 1st energy producer
Valorization of heat fatal energy
Collective Self-Consumption
Internet of Energy

Buildings are the first consumers of energy – In France (mild climate)

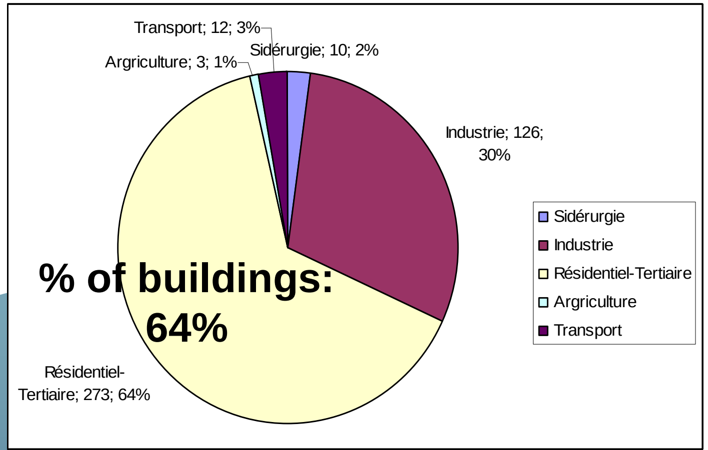
Buildings: main consumer of energy

The importance of energy in buildings in France

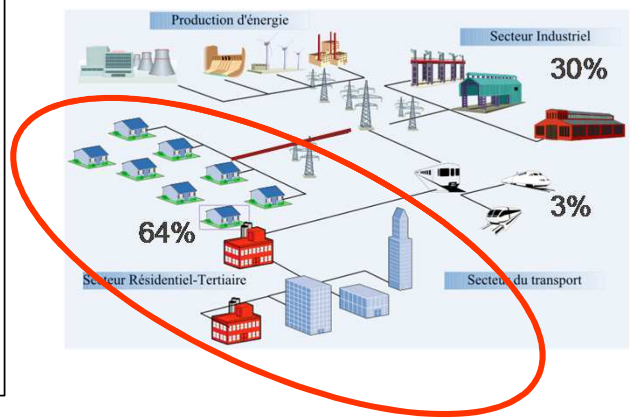
Source: http://www.industrie.gouv.fr



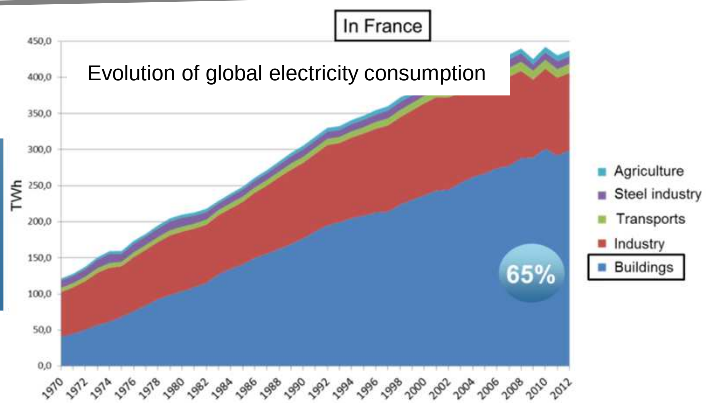
French final energy consumption 2005 (Mtep)



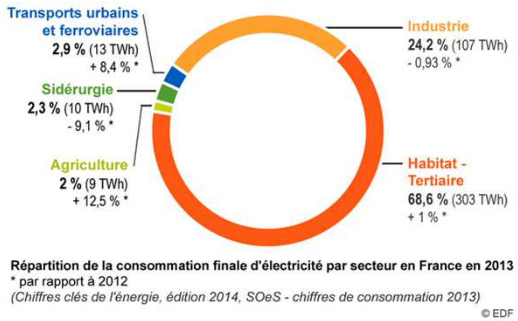
French electricity consumption 2005 (TWh)



From 2005 to 2013: Buildings are widely the greatest consumers in the network with a clear increase trend



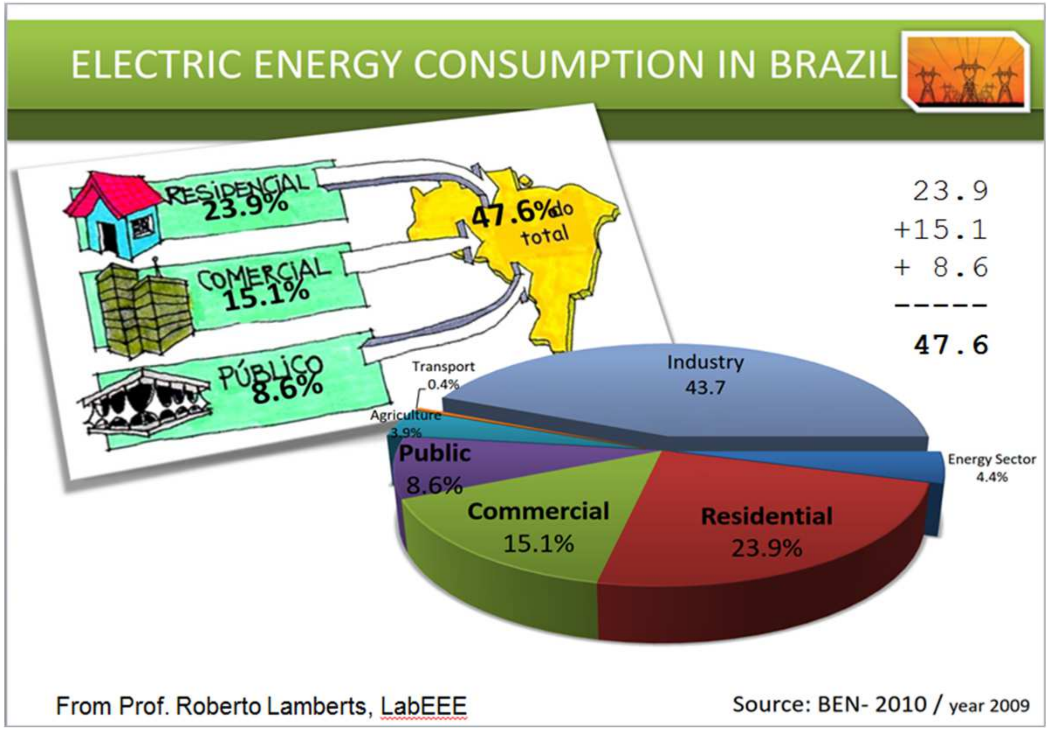
"Bilan énergétique de la France pour 2014", observations and statistics from the french government, but the data exist up to 2016
http://www.statistiques.developpement-durable.gouv.fr/donnees-densemble/1925/2019/

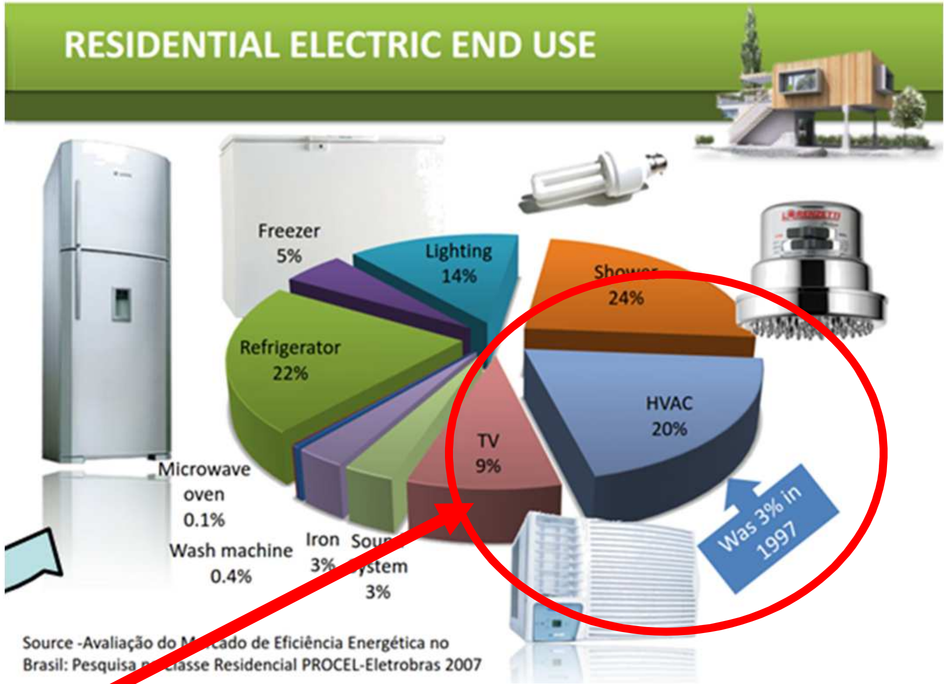


EDF, 2015. Electricité de France. La consommation d'électricité en chiffres :
https://www.edf.fr/groupe-edf/espaces-dedies/l-energie-de-a-a-z/tout-sur-l-energie/le-developpement-durable/la-consommation-d-electricite-en-chiffres

Buildings are the first consumers of energy – In Brazil (tropical climate)

- **Buildings: main consumer of energy**

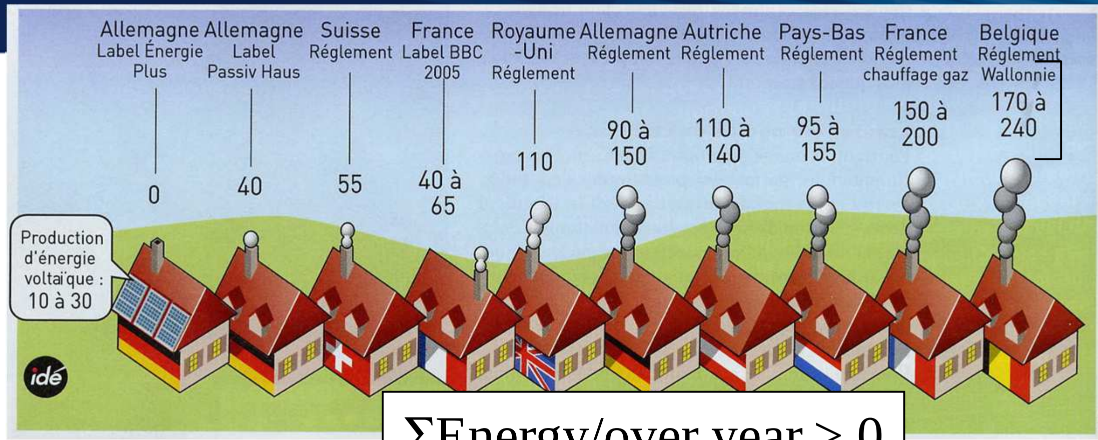




- Increase of HVAC

Buildings could be one of greatest producer of renewable energy

A building can get, over a year, more renewable energy that it needs



Consumption in kwh/year/m²

ΣEnergy/over year > 0

Buildings can help to:

- **Harvest**
- **Store**
- **Manage**

renewable energy

Building can produce more energy than they need (in average over 1 year)

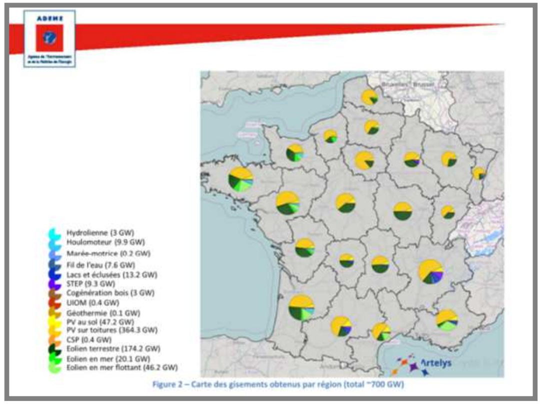
Buildings could be one of greatest producer of (decarbonized) renewable energy

Argued at the french level by an official study …

*www.**ademe**.fr/sites/default/files/assets/.../rapport100enr_comite.pdf*

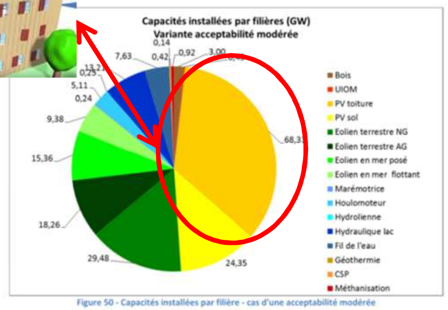
Toward a 100% electrical mix in 2050 for France

The potentiel of renewable energy exists



Estimated need: 422 TWh
Annual potential: 1268 TWh

For this option, one key pillar will be the buildings



PV on Buildings: could be the greatest capacity 34% (68 GW/196 GW)

Demand response of building will Help to manage the grid: 18 GW of demand response

Peak demand in France 102 GW
Demand response capabilities of buildings

- Hot water tanks: 4 GW (4/102=4%)
- Heater/HVAC (75%): 14 GW (14/102=14%)
- Oven/Washing machine: 0,695 GW (1%)

In global 18/102=17%

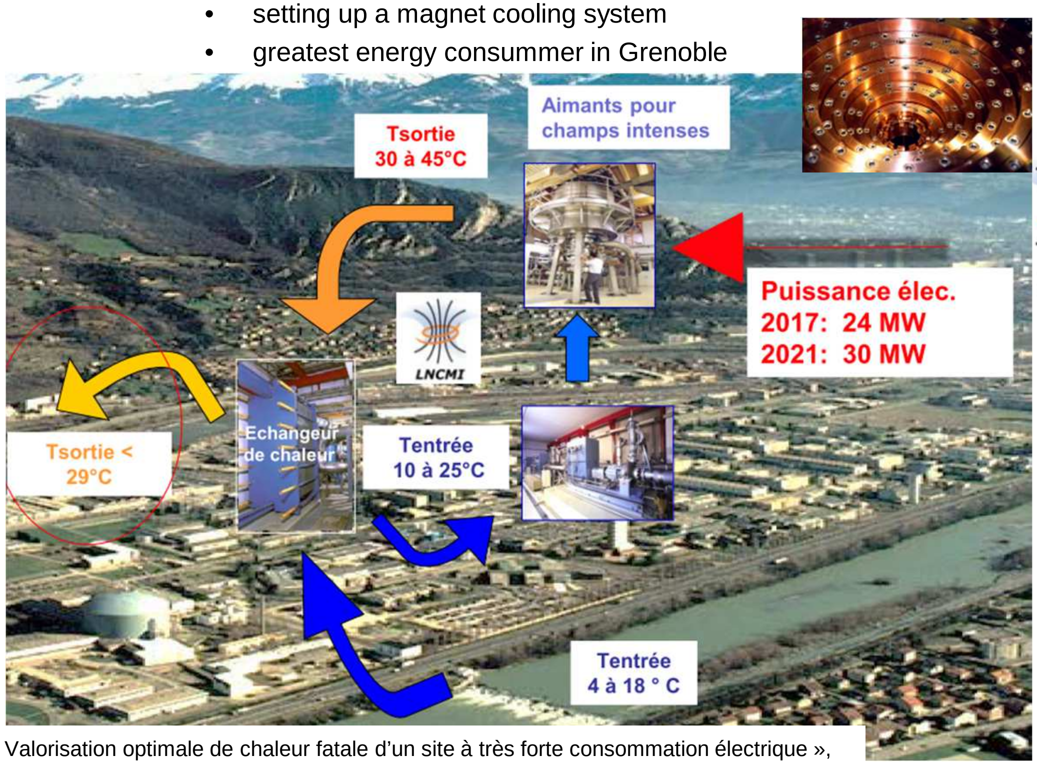
Buildings can value renewable and fatal energies at the neighborhood level

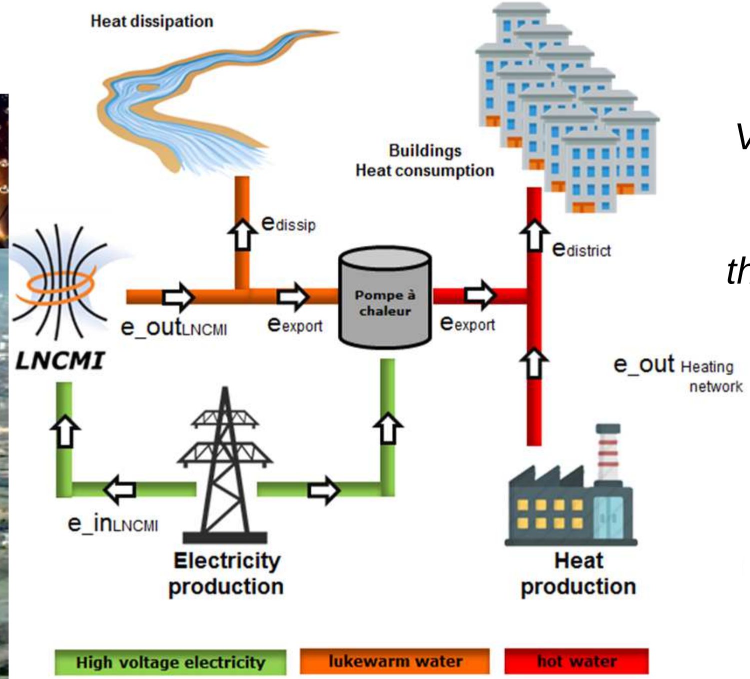
Example of LNCMI in the eco-district of Grenoble

LNCMI (Laboratoire National des champs magnétiques intenses)

- Grenoble (continuous fields up to 36 T)
  - setting up a magnet cooling system
  - greatest energy consummer in Grenoble

Energy: ~15 GWh/an - 3000 electric households
Power: 24 MW - 45 000 electric households





Valorisation of fatal energy by the buildings

Many actors

Valocal Project
CNRS interdisciplinary funding
MI-CNRS & INSIS-CNRS

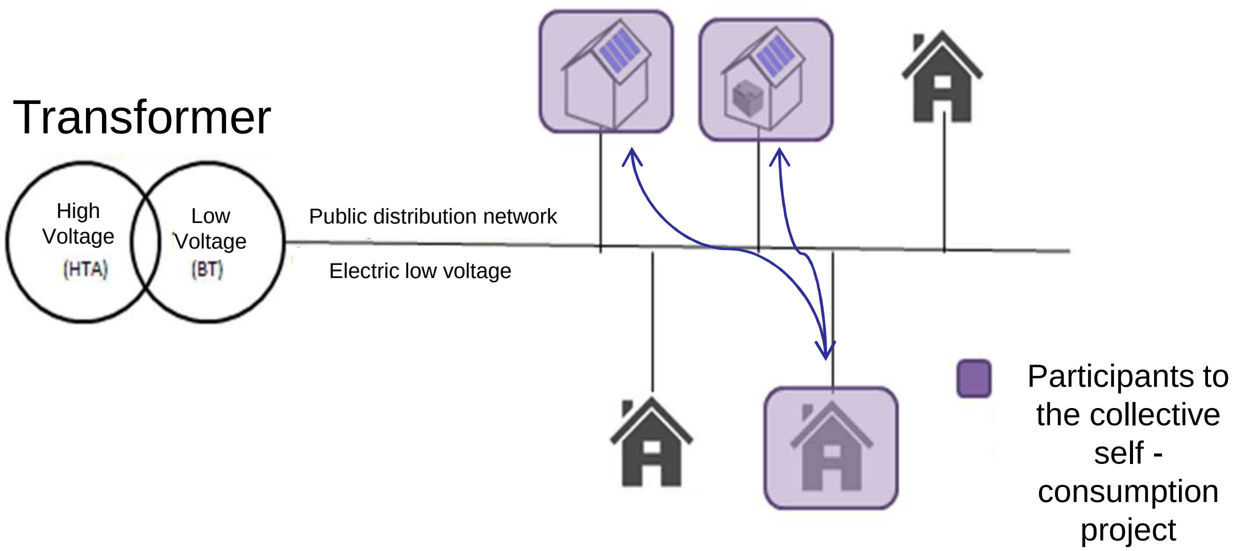
Electro-intensive actors (like data-center, …)

« Valorisation optimale de chaleur fatale d'un site à très forte consommation électrique », Camille PAJOT, Benoit DELINCHANT, Yves MARECHAL, Frédéric WURTZ, François DEBRAY, Benjamin VINCENT, JCGE 2017, Conférence des jeunes chercheurs en Génie Electrique, 30 mai au 1er juin 2017, Arras, France

Buildings can value renewable and fatal energies at the neighborhood level

Collective self-consumption

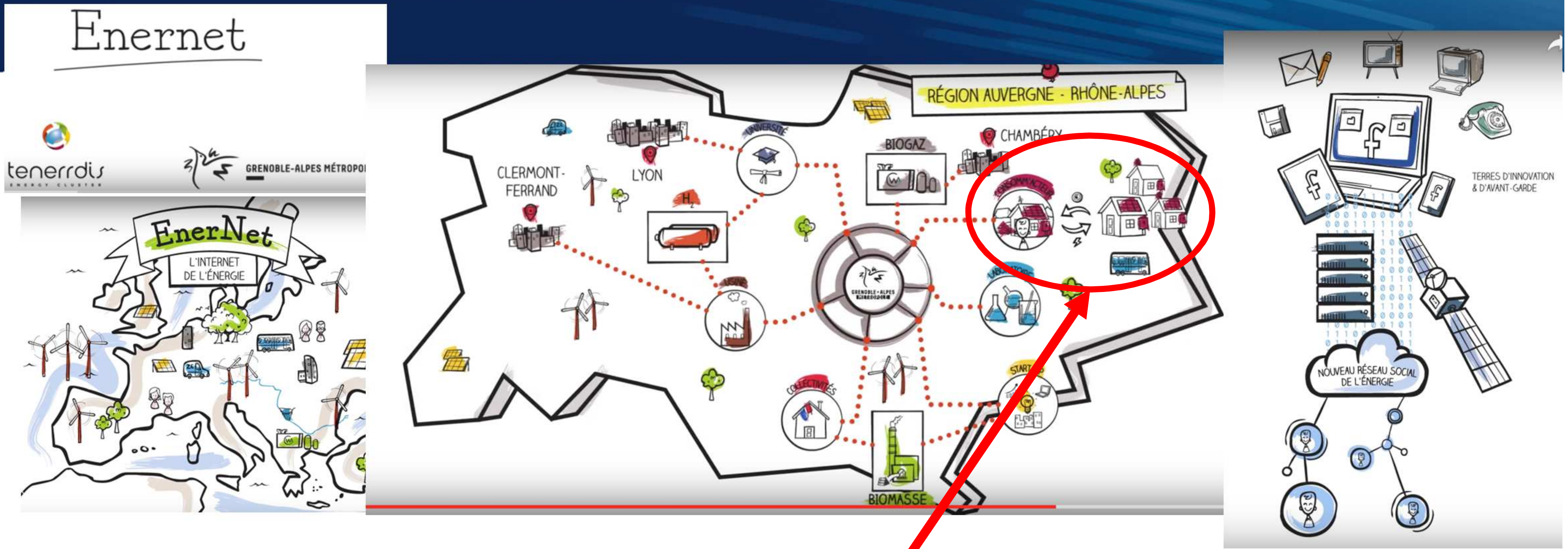
Possible since 2017 french laws



Collective production/consumption of renewable energy for the buildings at district level

L'ordonnance du 27 juillet 2016 relative à l'autoconsommation d'électricité :
https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000032938257&categorieLien=id
Loi de février 2017 relative à l'autoconsommation d'électricité :
https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000034080223&categorieLien=id
Décret d'application relatif à l'autoconsommation d'électricité :
https://www.legifrance.gouv.fr/eli/decret/2017/4/28/DEVR1707686D/jo/texte

A vision of the SG in interaction with the humans in their SB – Enernet or Internet of Energy



Voir: https://www.youtube.com/watch?v=jl53-LAziXg&utm_source=newsletter_94&utm_medium=email&utm_campaign=newsletter-tenerrdis-juillet-2016

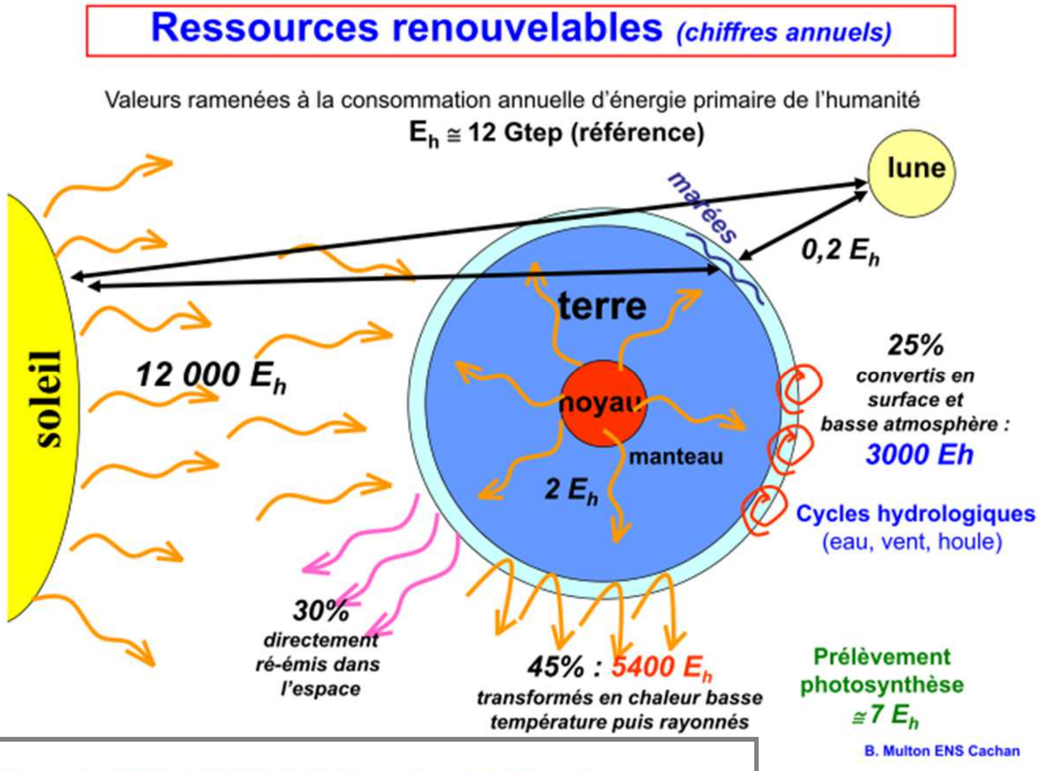
- **A revolution for energy industry with economic, social and territorial aspects**
- **That will be possible thanks to a new technological environment**
- **Major role of users in their building interacting via networks**

Why SB in interaction with SG could be a main contribution for energy transition

Energy transition scenario thanks to SB integrated in SG

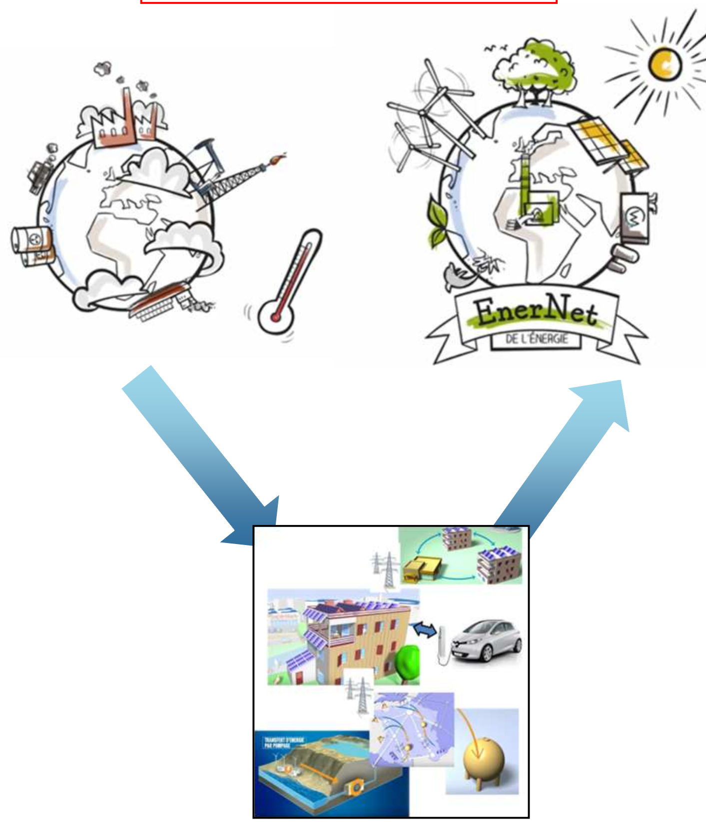
- **Smart-buildings & Smart-grids: collecting the potential of renewable energy at world level**

The potential



[PDF] Énergie et électricité - ENS Cachan Bretagne
www.bretagne.ens-cachan.fr/.../com.univ.collaboratif.utils.LectureFichier...
16 janv. 2013 - B. Multon ENS Cachan. Source ... Source des données AIE (Key World Energy Stat. ... Rayonnement solaire au sol : 100 000 Gtep... par an !

The strategy

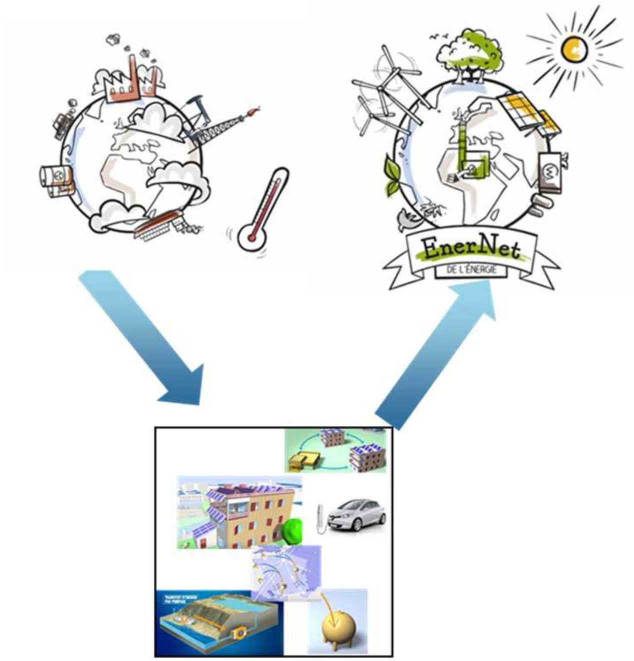


SG based on SB as a key pillar

EnerNet, Internet de l'énergie – YouTube (see https://www.youtube.com/watch?v=jI53-LAziXg)

Why SB in interaction with SG could be a main contribution of energy transition

The strategy



SG base on SB

The actors


Scénarios de Transition Énergétique en Ville
Acteurs, régulations, technologies
Sous la direction de Gilles Debizet (PACTE)
Préface de Gabriel Dupuy
avec Sylvie Blanco, Nicolas Buclet, Fabrice Forest, Caroline Gauthier, Stéphane La Branche, Philippe Menanteau, Patrice Schneeuwly, Antoine Tabourdeau.
La Documentation Française

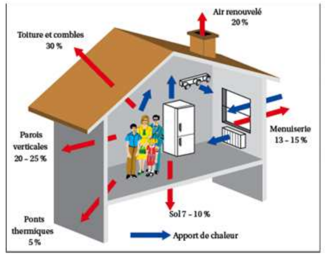
www.nexus-energy.fr

Companies
Citizens
Local authorities
States

The steps

buildings as a key contributor

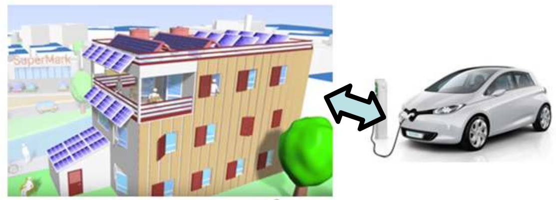
1° Increasing Efficiency & Sobriety



2° Substition by de-carbonised energy(**) : electricity, heat

http://www.energy-green.net/blog/articles/wind-power/wind-turbine-for-green-building.html

3° Electric mobility using decarbonized electricity



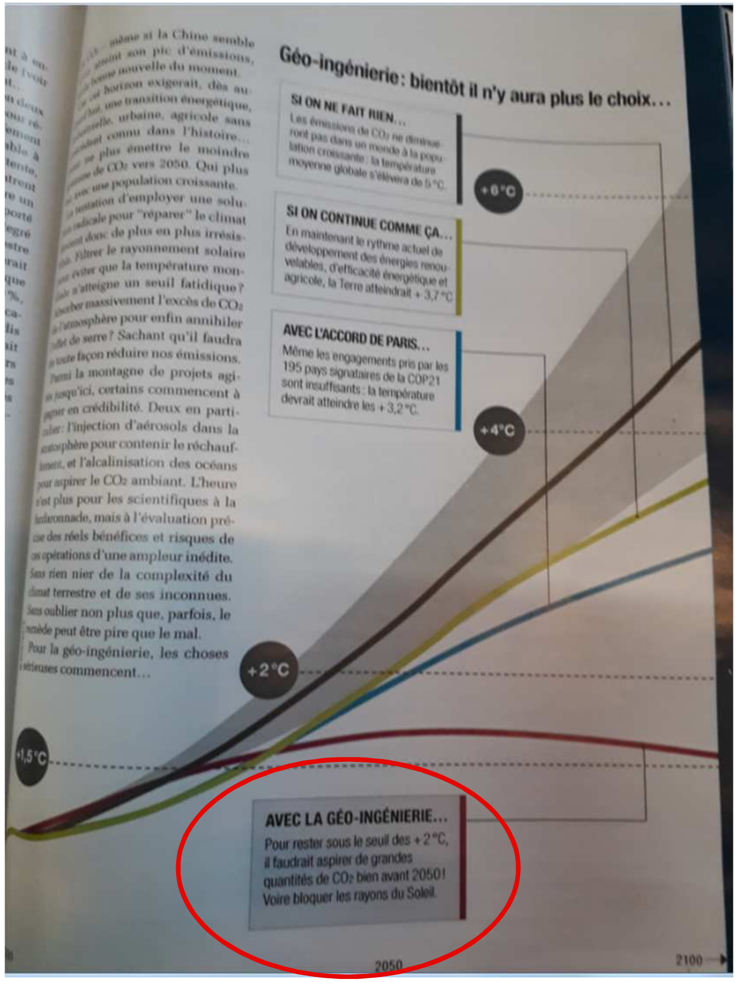
V2H(*) concept

(1°, 2°, 3° : Is the proposed strategy of most of scenarios for energy transtion
->See work of Patrick Criqui, member of GIEC, Lab EDDEN Grenoble –
Economie du développement durable et de l'énergiehttp://edden.upmf-grenoble.fr/
https://www.futuribles.com/fr/article/transition-energetique-quelle-trajectoire-genealog/

(*) V2H: Vehicule to Home
(**): Energy produced with no CO^2 émissions

Why SB in interaction with SG could be a main contribution of energy transition

- **Efficiency and Sobriety -> Obvious**
- **Decarbonization**
  - -> Mandatory straight away also !
- **Since the last news from GIEC group are**
  - To stay under 2° C of average increase of temperature, we should start to aspire great quantities of CO² from atmosphere well before 2050 !



II - The key pillar of the revolution ?: An engineering approach for SB based on modelisation and optimisation

- What is a "smart-building" ?
- Demand side management, demand Response and Anticipative Optimal supervision from building to district level
- Design of buildings integrating Demand Side Management and Demand Response

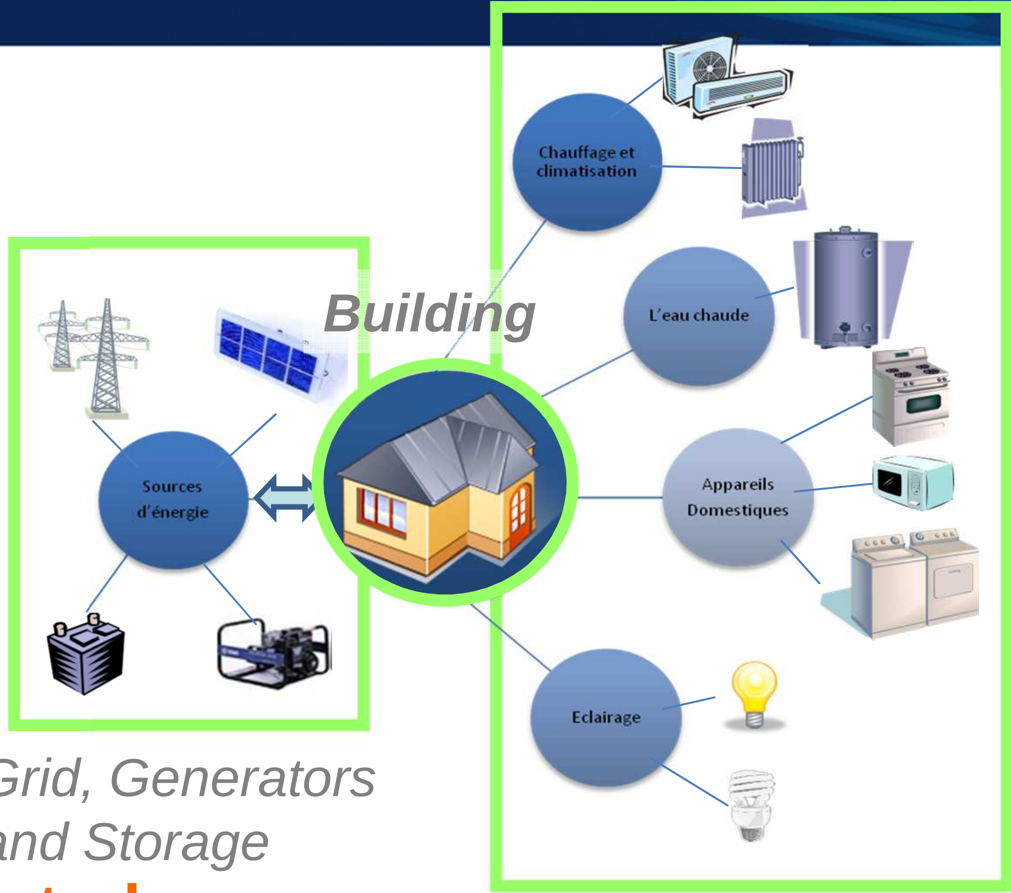
What is a SB ? – An engineering approach

- **Seen by Electrical Engineers**
- **Working on the "smart building" integrated in the "smart grid"**
- **Based on modelisation and optimisation**

What is a smart-building ? The functionnalities

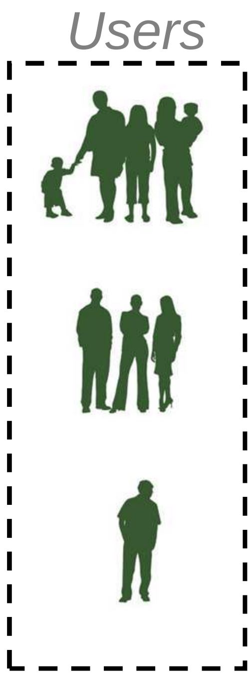
Anticipation capabilities :

- Weather forecast
  - -> PV, Wind
- Internal needs
  - Heating /cooling needs



Grid, Generators and Storage

Loads



Offers services:

- equip. usage
- comfort req.

Multi sources control :

- arbitration between generators
- scheduling production / storage
- uncertainties on availability

Load management :

- uncontrolled load prediction
- scheduling / adjusting / shedding

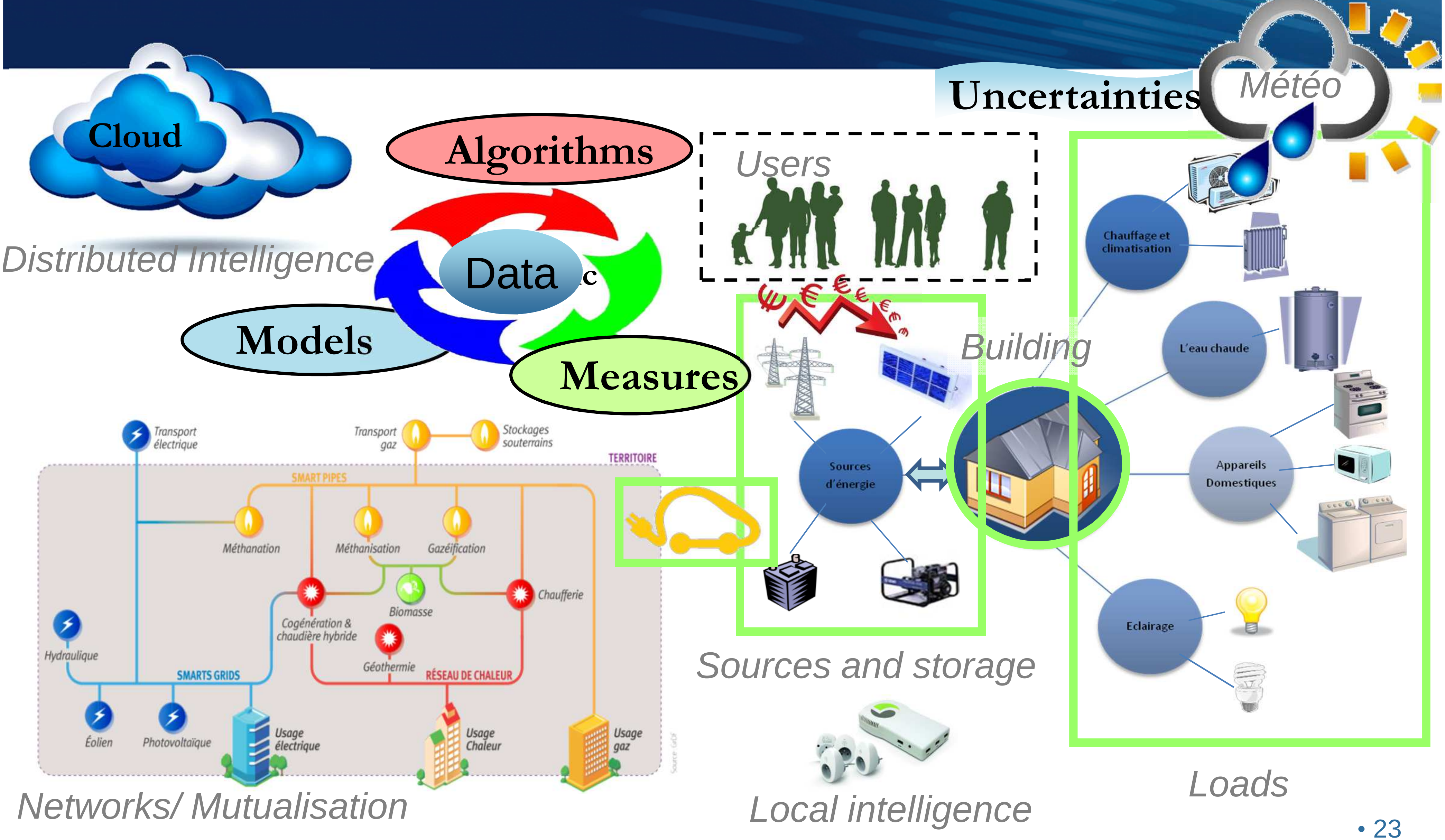
What is a smart-building ?
Canopea - Solar Decathlon 2012

The French Rhône Alpes centered in Grenoble won the competition

http://www.g2elab.grenoble-inp.fr/grand-prix-international-solar-decathlon-2012--497448.kjsp
http://www.g-scop.grenoble-inp.fr/accueil/la-team-rhone-alpes-remporte-le-solar-decathlon-europe-2012--499021.kjsp
http://www.echosciences-grenoble.fr/articles/la-team-rhone-alpes-remporte-le-solar-decathlon-2012

« Prise en compte de la complexité de modélisation dans la gestion énergétique des bâtiments », Yanis Hadj Said,thèse de Docteur, docteur de l'université Grenoble alpes, 20 juillet 2016

What is a smart-building ?



Demand side management, demand Response and Anticipative Optimal supervision by using modelisation and optimisation

Optimization trade-off between :

- **Energy consumption (or energy price)**
- **Human comfort**

From Building level to district level

Issued and objectives for scientific and technological research about SB integrated in SG

Main issues and objectives

- Improve efficiency of lighting, appliances, fans and pumps
- Help the grid with local production : PV on the roof to supply HVAC
- Improve the usage of energy :
  - Awareness of people when using energy
  - Automation / Regulation : automatic sun shading, cooling using fresh air during nights, controlling HVAC according to meteorological forecast…

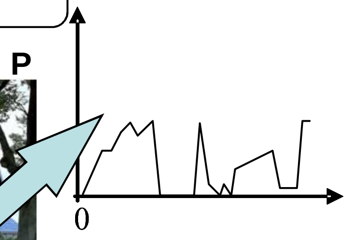
=> Improve interaction between grid and buildings:

- Optimal power flow including buildings :
  - Production : disturbed energy resources management
  - Consumption : demand side management
- For the whole grid / for micro-grids (autonomy)
- Building active solution for Demand Response

Smart Buildings offering Demand Side Management, Demand Response, Anticipative optimal supervision

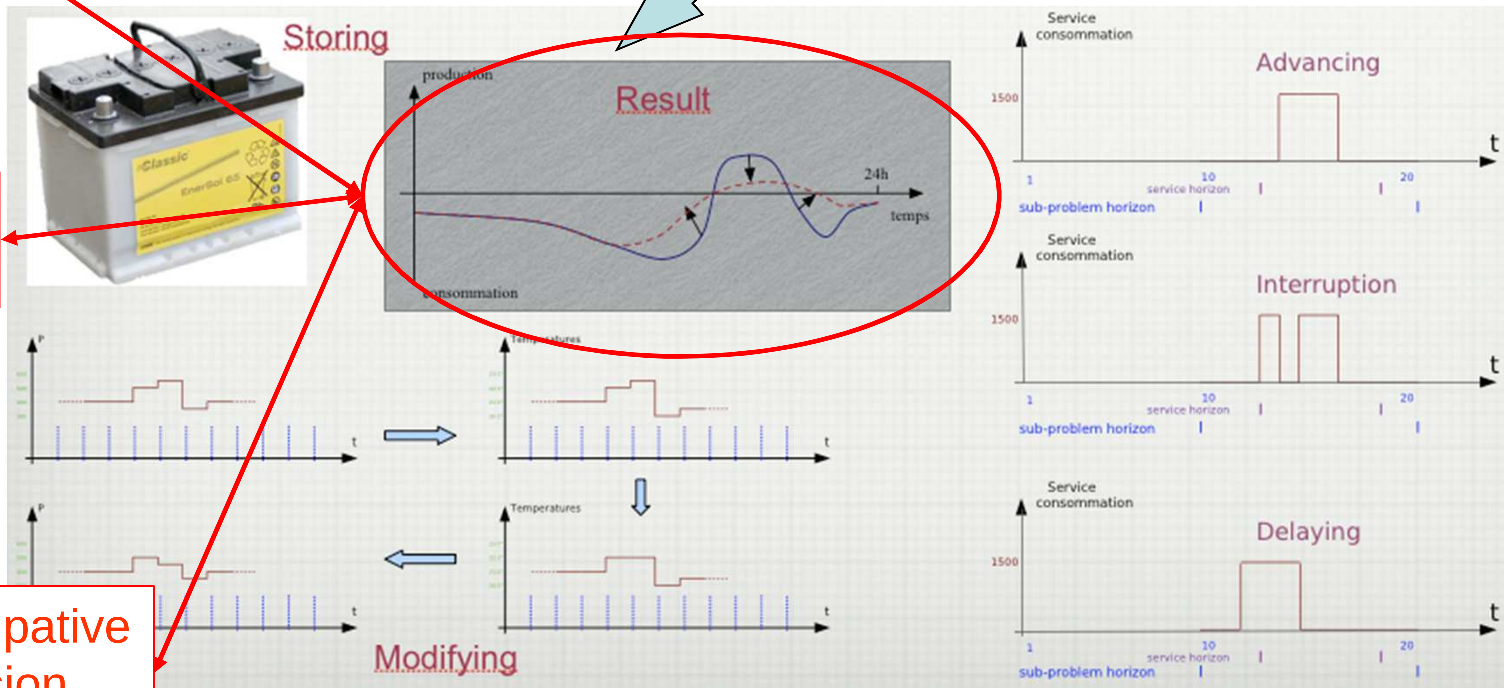
The scientific problematic

At the scale of the building: locally adaptation of production to needs



- Demand side Management
- Load Matching

- Demand Response



24 hours prevision

Weather

Dynamic prices

- Anticipative supervision

G2E Lab
Grenoble Génie Electrique
Grenoble Electrical Engineering

Anticipative management and demand Response

The approach used: Optimization

Formulation : Mainly Mixed Linear Programming

Objective function to minimize : $f^T x$

Under constraints :

$Ax \leq b$

$A_{eq}.x = b_{eq}$

$lb \leq x \leq ub$

With :

x are the variables (continue, binary or integers)

A, A_{eq} are matrixes;

f, b, b_{eq} are vectors

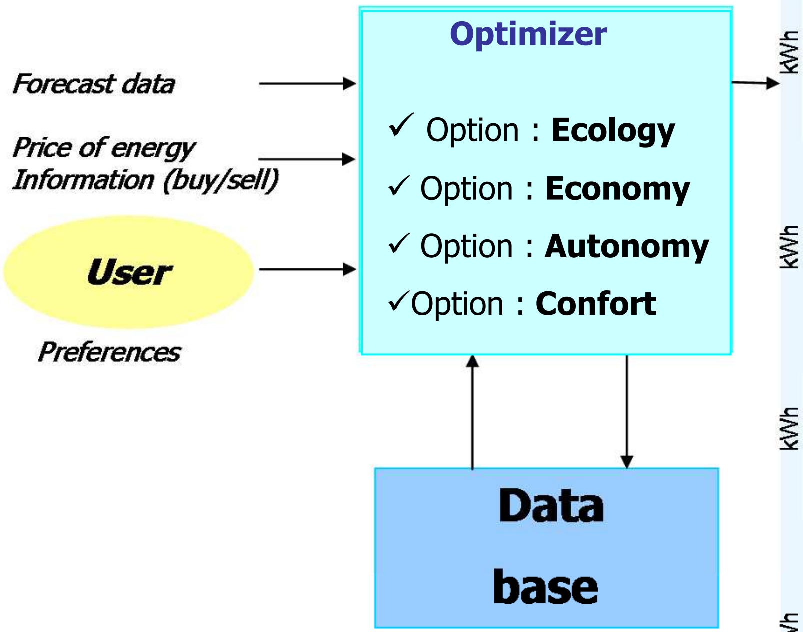
But also : MILP, MINLP, SQP and dynamic approaches

Solved with : Matlab
CPLEX (Ilog), GUROBI

"Optimal Household Energy Management and Economic Analysis: From Sizing To Operation Scheduling",T. T. HA PHAM, C. CLASTRES, F. WURTZ, S. BACHA, and E. ZAMAI, publié dans Advances and Applications in Mechanical Engineering and Technology, Vol. 1, n° 1, pp. 35-68
https://halshs.archives-ouvertes.fr/halshs-00323581

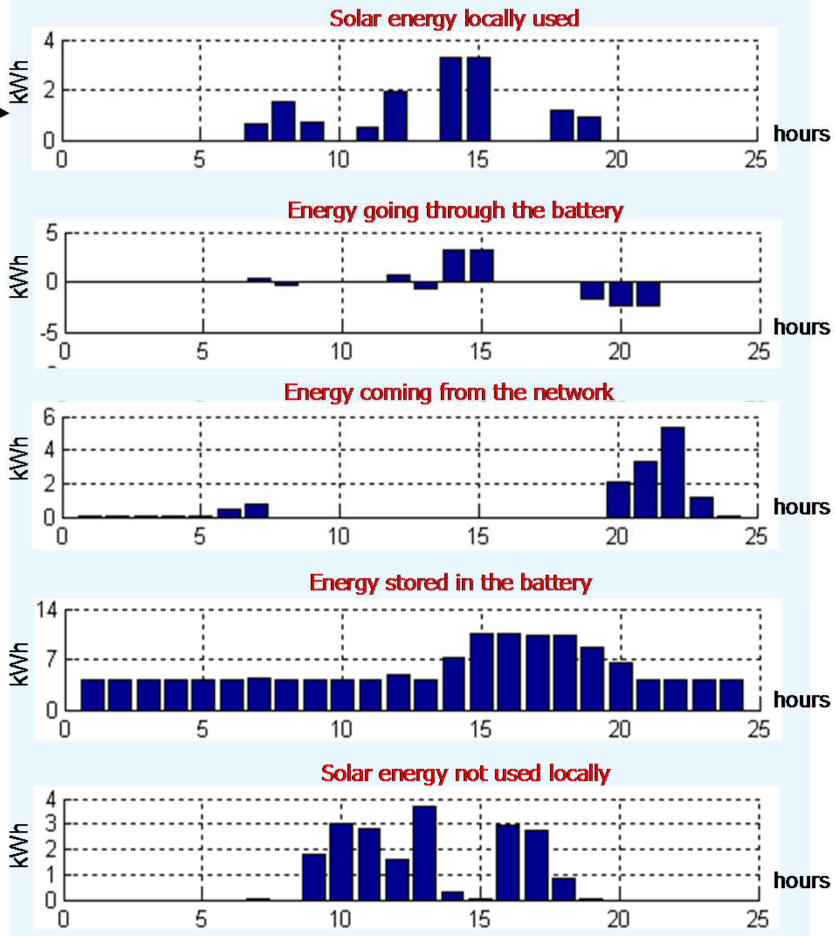
The approach used: Resulting optimisation tools

- Some typical results



Option	Gain in cost	% of solar energy sold
OFEcology	*-0.25 €/day*	*56.251%*
OFEconomy	*-0.27 €/day*	*58.704 %*

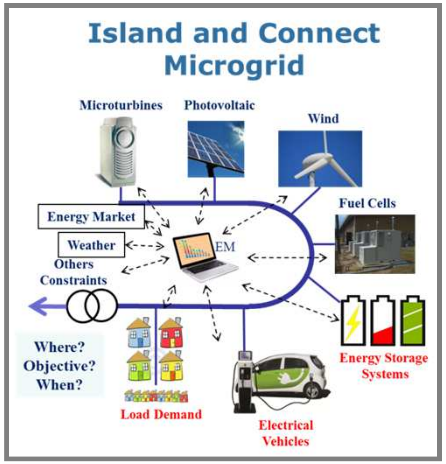
Option Economy

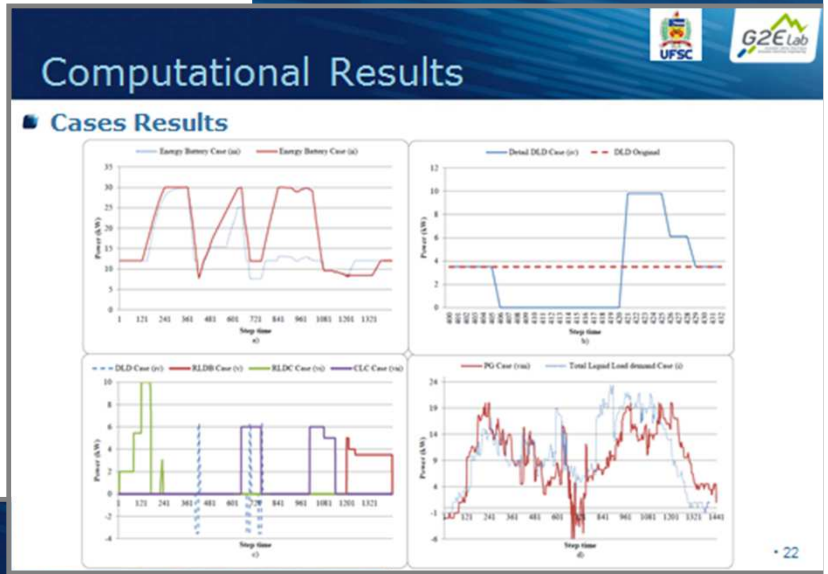


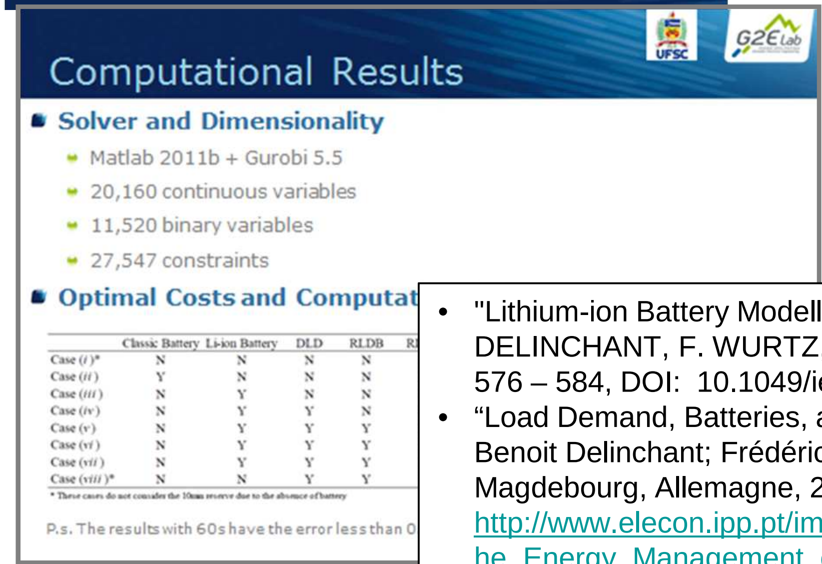
"Ancillary services and optimal household energy management with photovoltaic production«
C. CLASTRES, T.T. HA PHAM, **F. WURTZ**, S. BACHA, ***Energy,*** ISSN 0360-5442, DOI: 10.1016/j.energy.2009.08.025.**,** volume 35 issue 1, Elsevier Publication, 2010, pp. 55-64, https://hal.archives-ouvertes.fr/halshs-00323576v1

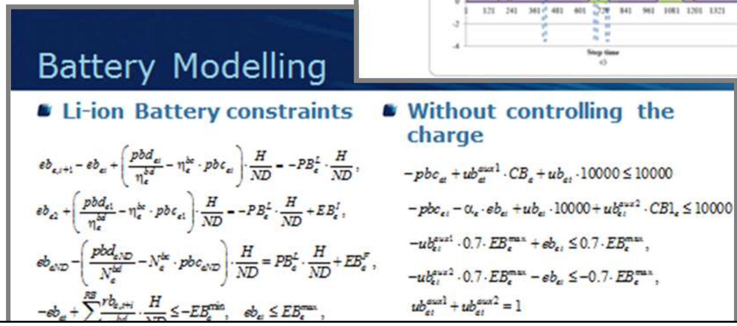
Smart Buildings offering Demand Side Management, Demand Response, Anticipative optimal supervision

Exemple of demand Side Management





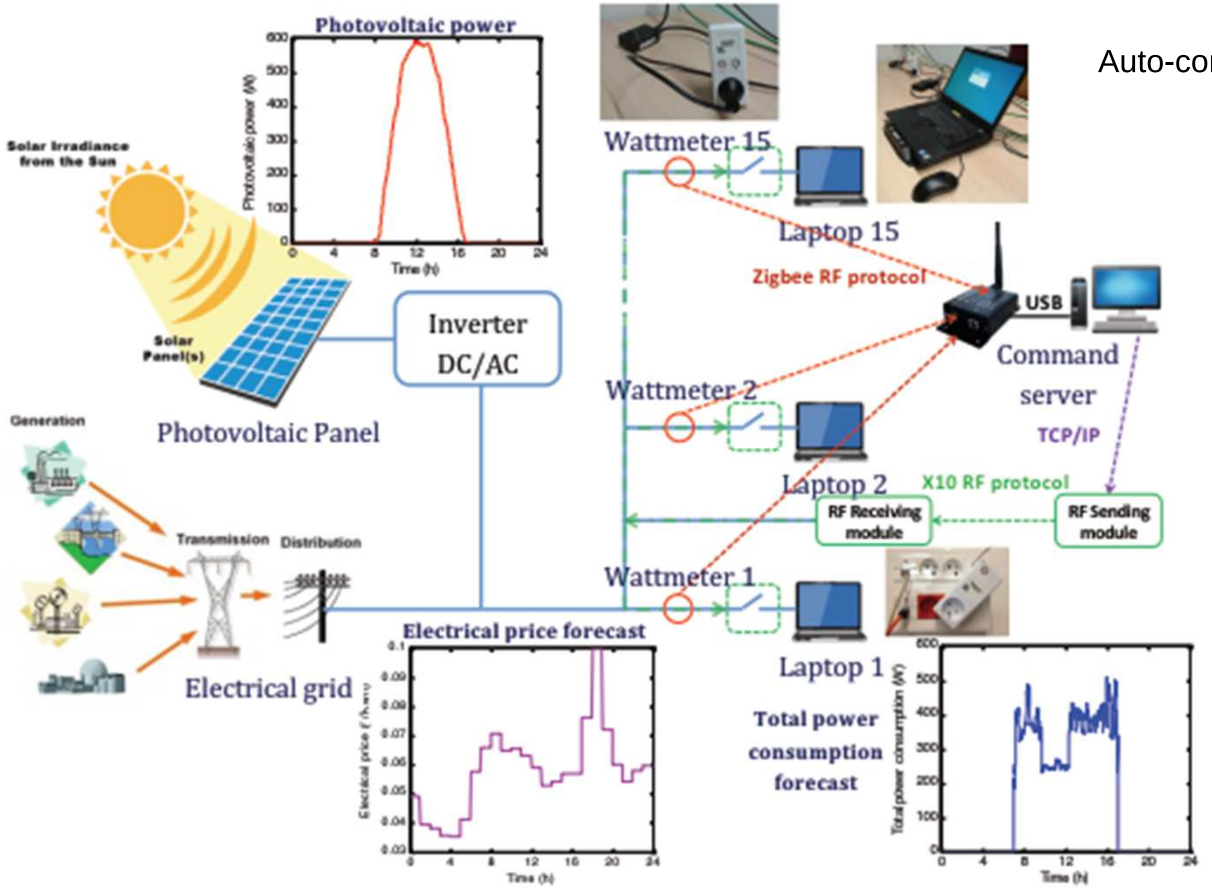


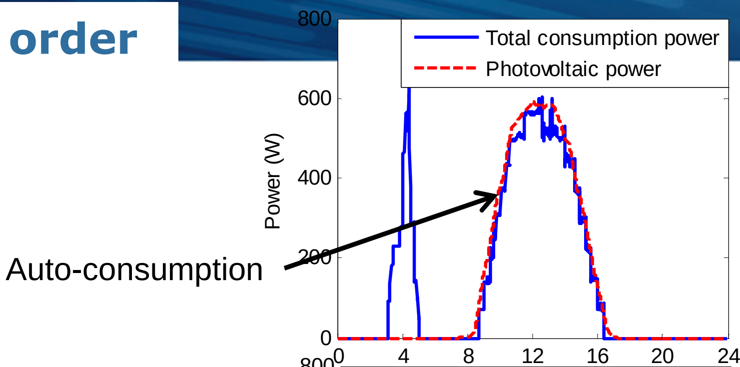


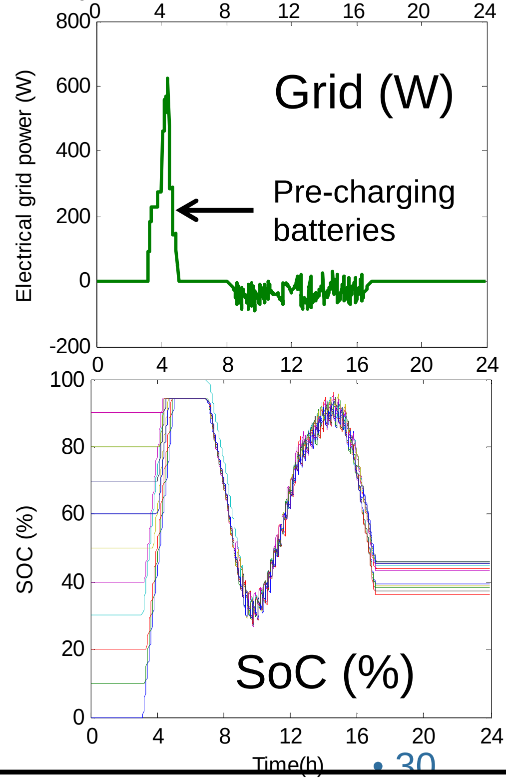
- "Lithium-ion Battery Modelling for the Energy Management Problem of Microgrids", D. TENFEN, E. C. FINARDI, B. DELINCHANT, F. WURTZ, IET Generation, Transmission & Distribution, Volume 10, Issue 3, 18 February 2016, p. 576 – 584, DOI: 10.1049/iet-gtd.2015.0423 , Print ISSN 1751-8687, Online ISSN 1751-8695
- "Load Demand, Batteries, and Electric Vehicles Modelling to the Energy Management of Microgrids", Daniel Tenfen*; Benoit Delinchant; Frédéric Wurtz; Erlon C. Finardi; Jaqueline Rolim; Rubipiara C. Fernandes, 2nd Elecon Workshop, Magdebourg, Allemagne, 28-29 octobre 2014 available at http://www.elecon.ipp.pt/images/Workshop2/Papers/Load_Demand_Batteries_and_Electric_Vehicles_Modelling_to_the_Energy_Management_of_Microgrids.pdf

Smart Buildings offering Demand Side Management, Demand Response, Anticipative optimal supervision

- **Optimal operating of laptops power supply,in order to maximize autonomy**



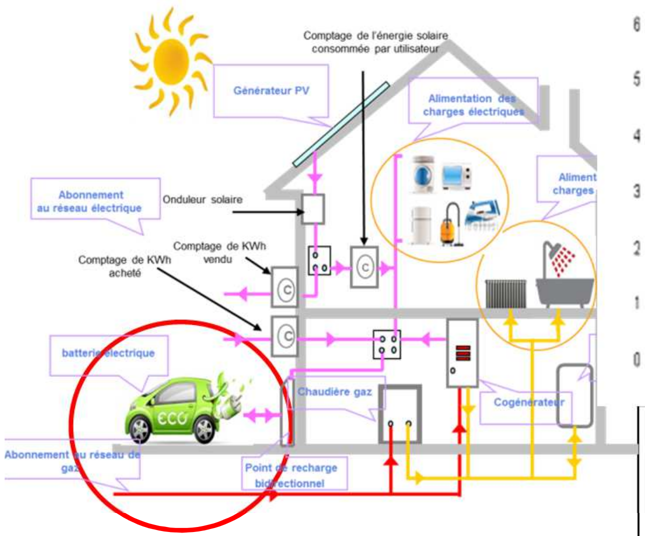


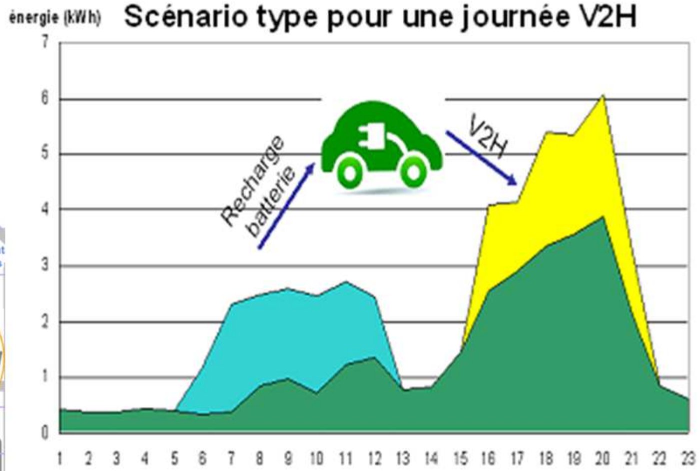


Hoang:Anh Dang, Benoit Delinchant, and Frederic Wurtz, "Toward autonomous photovoltaic building energy management: modeling and control of electrochemical batteries", IBPSA 2013, Chambery, August 2013, http://www.ibpsa.org/proceedings/BS2013/p_2095.pdf

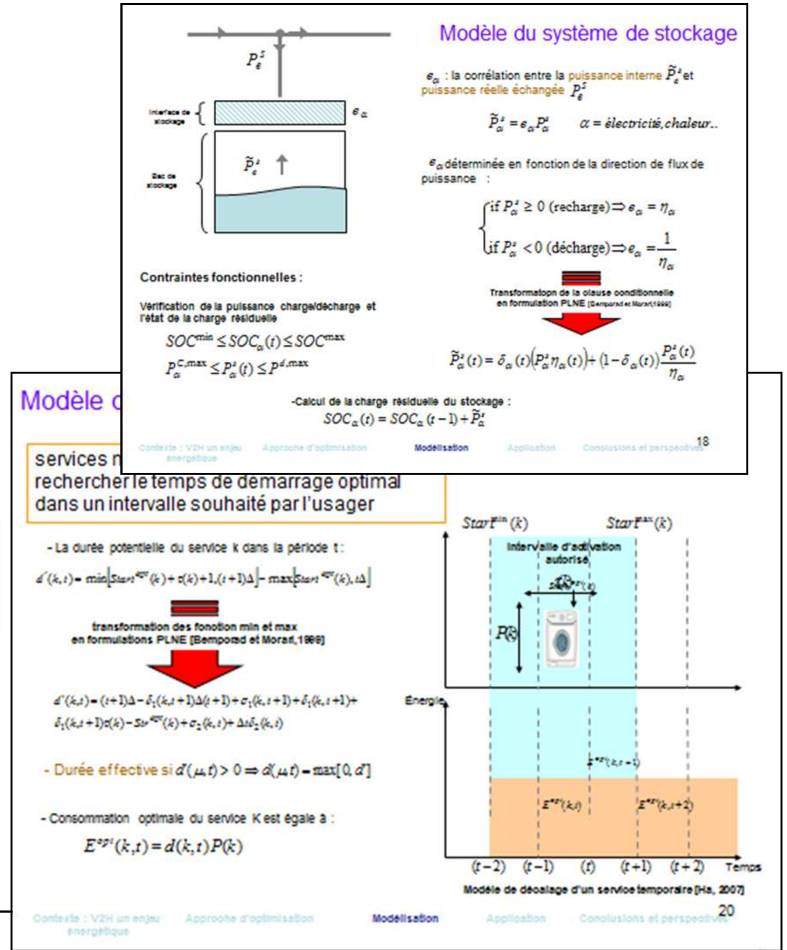
Smart Buildings offering Demand Side Management, Demand Response, Anticipative optimal supervision

Anticipative demande side Management of Vehicule to Home (V2H)





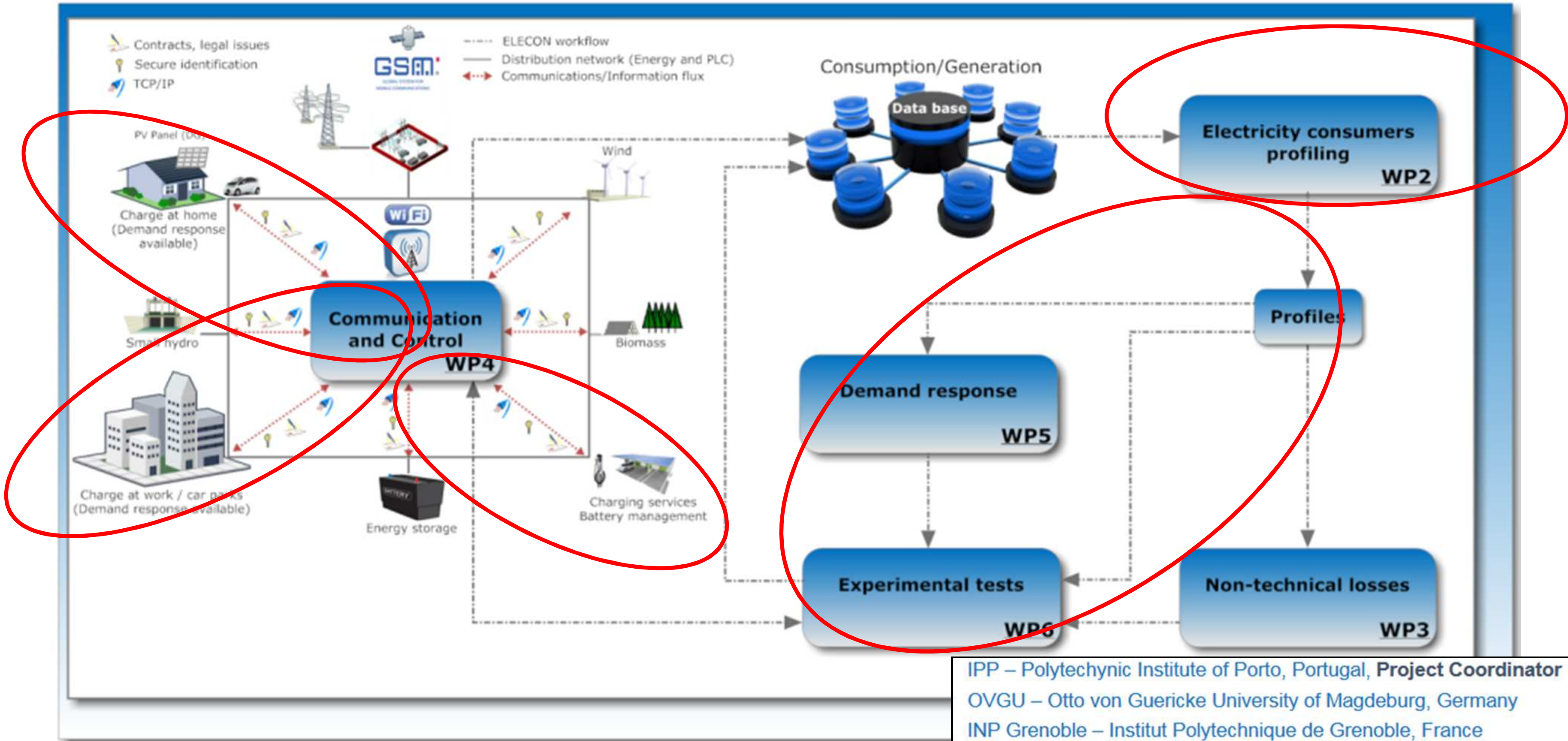
- Charging of the battery with carbon free energy during the day
- Use of the energy stored in the battery for shaving the peek demand of the evening



- 185 inputs
- (50x24)+11=1211 continues variables
- (24x24)= 576 binary discretes variables
- (178x24)+1=4273 constraints

- « Gestion des flux multi-énergie pour les systèmes V2H», A. Dargahi, thèse de l'Université de Grenoble, 26 Septembre 2014, https://tel.archives-ouvertes.fr/tel-01111994
- A. Dargahi, S. Ploix, A. Soroudi, F. Wurtz, (2014) "Optimal household energy management using V2H flexibilities", COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, Vol. 33 Iss: 3, pp.777, DOI:10.1108/COMPEL-10-2012-0223

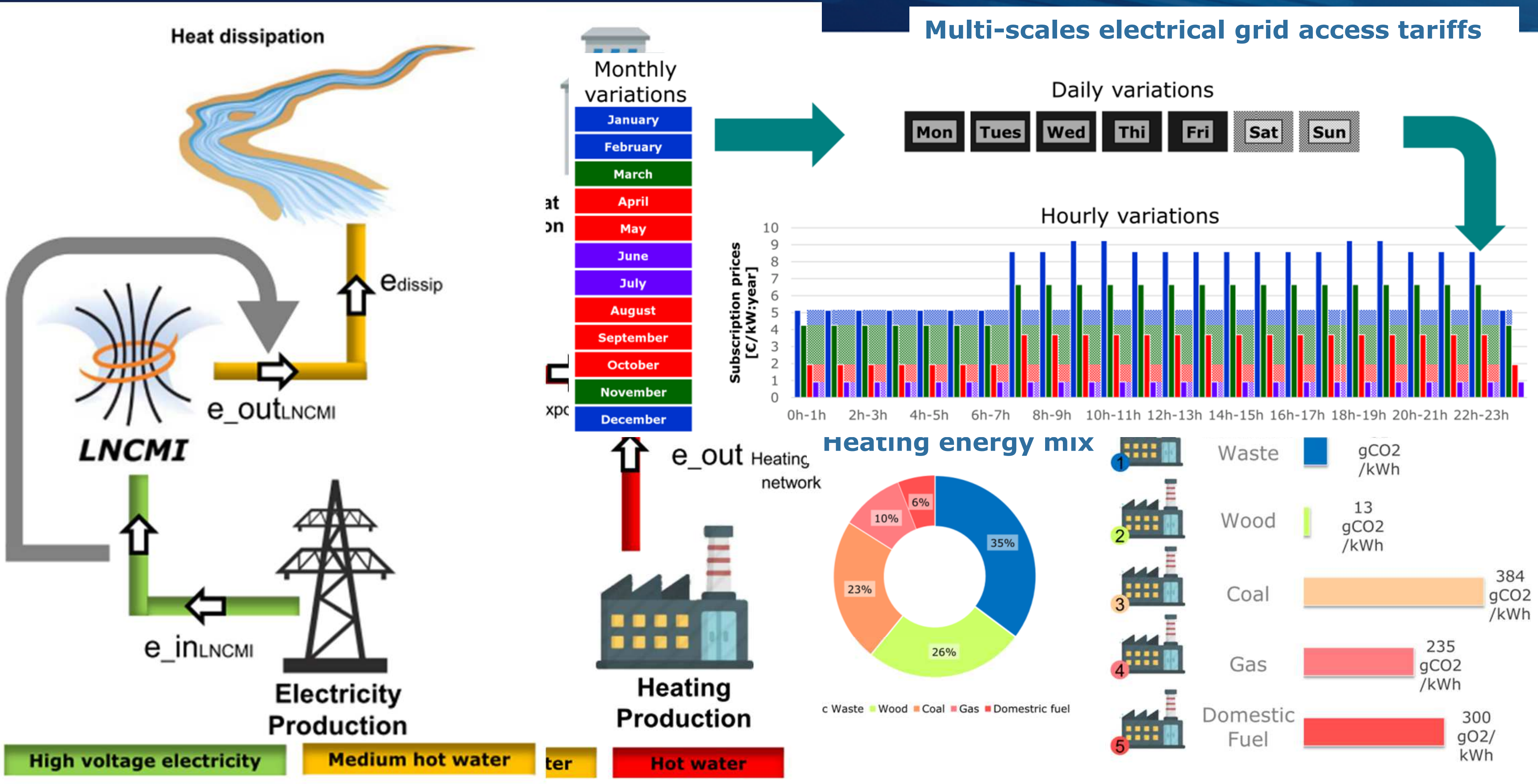
Smart Buildings offering Demand Side Management, Demand Response, Anticipative optimal supervision



http://www.elecon.ipp.pt/

IPP – Polytechynic Institute of Porto, Portugal, **Project Coordinator**
OVGU – Otto von Guericke University of Magdeburg, Germany
INP Grenoble – Institut Polytechnique de Grenoble, France
UNESP – Universidade Estadual Paulista, Brazil
UFSC – Universidade Federal de Santa Catarina, Brazil
IF-SC – Instituto Federal de Educação Ciência e Tecnologia de Santa Catarina, Brazil
USP – Universidade de São Paulo, Brazil.

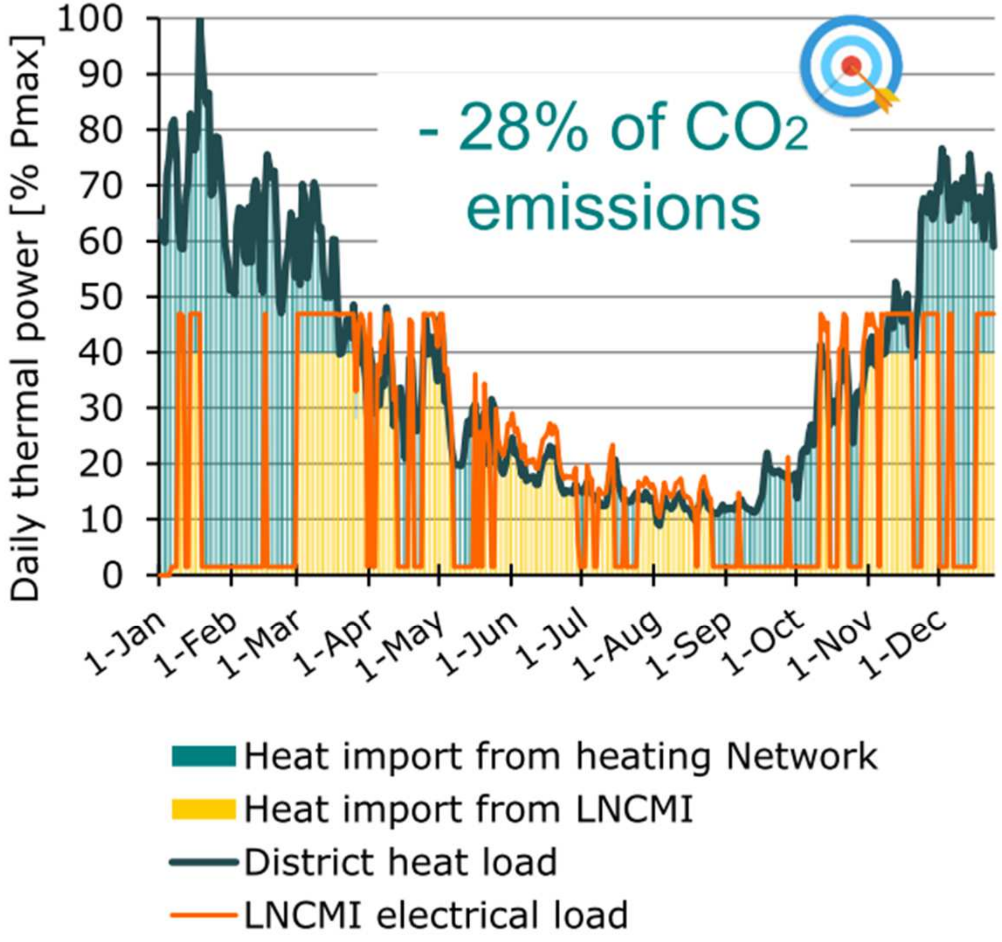
Modeling and Optimization researchs
Waste Heat Recovery by Optimal Operation Planning



Pajot C., Delinchant B., Maréchal Y., Wurtz F., Morriet L., Vincent B. and Debray F. (2018). Industrial Optimal Operation Planning with Financial and Ecological Objectives. International Conference on Smart Cities and Green ICT Systems

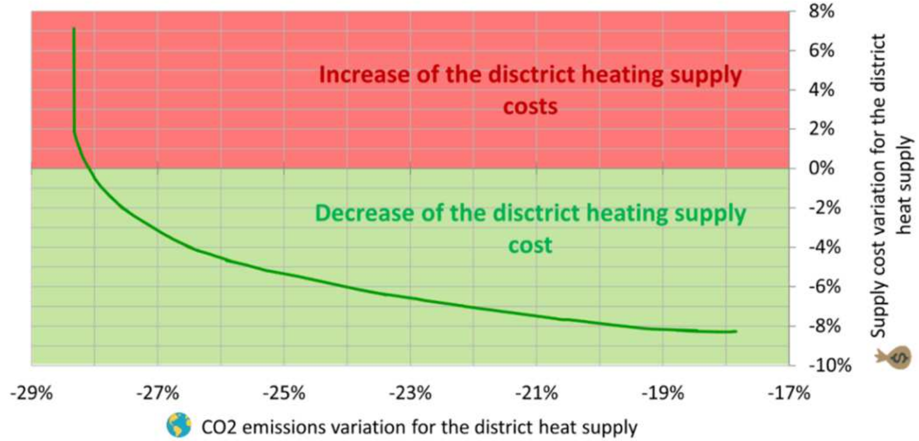
Optimization results

- **CO_2 emissions**



- **Tradeof between CO_2 and costs**

$$\alpha \sum_t \frac{CO_{2_{district}}(t)}{MAX(CO_{2_{district}})} + (1-\alpha) \sum_t \frac{Cost_{district}}{MAX(Cost)}$$



Camille Pajot & Lou Morriet - PhD

Open – Source Framework – OMEG'ALPES

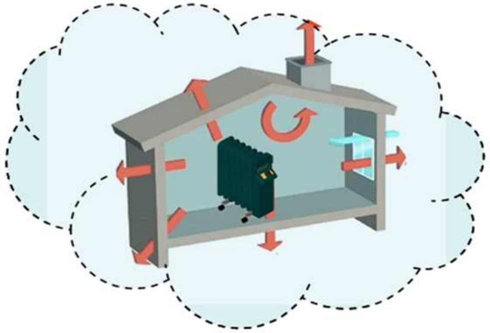
Optimal design of buildings integrating Demand Side Management and Demand Response

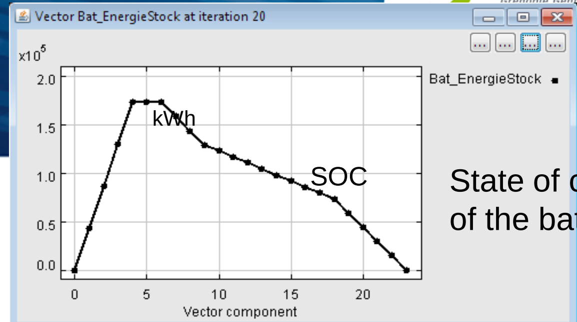
Especially in sketch phases

Optimal design of buildings integrating Demand Side Management and Demand Response

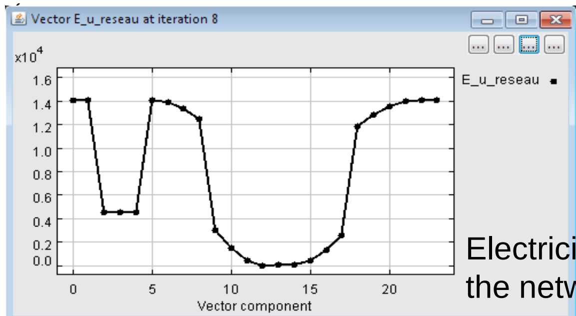
The scientific problematic

Do it simultaneously!





State of charge of the battery



Electricity from the network

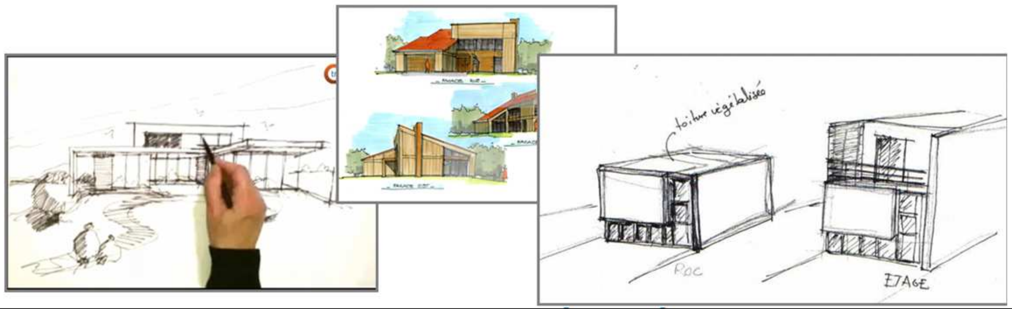
Chauffage, Ballon, ...

Électricité prise sur le réseau

Sizing envelope

Size of energy systems

Optimal strategy control



As early as possible in the design Process: Integrate Demand Response and Anticipative Management

- "Sketch Systemic Optimal Design Integrating Management Strategy, Thermal Insulation, Production And Storage Energy Systems (Thermal And Electrical): Application To An Energy- Positive Train Station"**F. WURTZ**, J. POUGET, X. BRUNOTTE, M. GAULIER, Y. RIFONNEAU, S. PLOIX AND B. L'HENORET , IBPSA 2013 – FRANCE, http://www.ibpsa.org/proceedings/BS2013/p_2376.pdf
- "On The Sizing Of Building Envelope And Energy System Integrating Management Strategy In Sketch Phase", IBPSA 2015, http://www.ibpsa.org/proceedings/BS2015/p2142.pdf

The approach used: Optimization

Formulation : We explored Non linear optimisation approach

$$P1 \Longrightarrow \left[\begin{array}{l} \min_{E_j} fob(E,P) \quad \text{avec} \\ Smax_i \leq S_i(E,P) \leq Smax_i \\ Emin_j \leq E_j \leq Emax_j \end{array} \right.$$

With :

E_j: the optimisation variable

P: parameters fixed during the optimisation

Fob: objective function, cost, comfort,

Si: constraints,

We are exploring: SQP

But also possible with: MILP after linerizarion of the models

Solved with : Matlab

CPLEX (Ilog), GUROBI – Linear approach

Own developed tools (CADES, SML – Composer) ,Non Linear approach

"Optimal Household Energy Management and Economic Analysis: From Sizing To Operation Scheduling",T. T. HA PHAM, C. CLASTRES, F. WURTZ, S. BACHA, and E. ZAMAI, publié dans Advances and Applications in Mechanical Engineering and Technology, Vol. 1, n° 1, pp. 35-68
https://halshs.archives-ouvertes.fr/halshs-00323581

Optimal design of buildings integrating Demand Side Management and Demand Response

The approach used: Resulting optimisation tools

User

Geographical localization

Preferences of the user

Typical loads

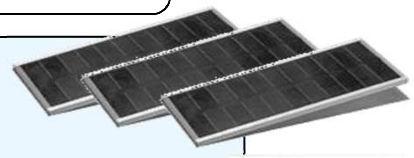
(devices, typical practices …)

Optimizer

- ✓ Option : **Ecology**
- ✓ Option : **Economy**
- ✓ Option : **Autonomy**
- ✓ Option : **Confort**

Data base

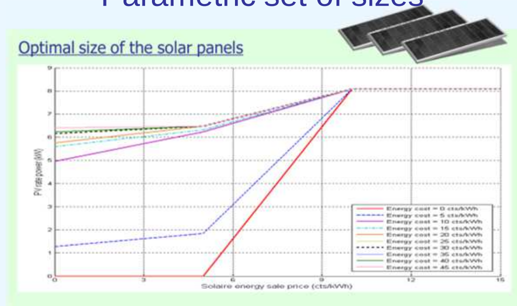
Sizes:



- ✓ *Power of the photovoltaic panels: 4 kW*
- ✓ *Capacity of the batter y: 1140 Ah*
- ✓ *Power subscription on network: 9 kW*
- ✓ *Rated power of generating set : 0 kW*

or

Parametric set of sizes



Typical hypothesis
- PV : 3.5 Euros/Wc
- Price of power electronic : 1000 Euros + 1 replacement over 20 years
- Batteries : 150 Euros/kWh + 3 replacements over 20 years

or

Set of solutions in case of Compromises – Pareto Fronts

Sizing including an optimal control strategy

"Optimal Household Energy Management and Economic Analysis: From Sizing To Operation Scheduling",T. T. HA PHAM, C. CLASTRES, F. WURTZ, S. BACHA, and E. ZAMAI, publié dans Advances and Applications in Mechanical Engineering and Technology, Vol. 1, n° 1, pp. 35-68
https://halshs.archives-ouvertes.fr/halshs-00323581

Optimal design of buildings by optimisation ?

The kind of model we use

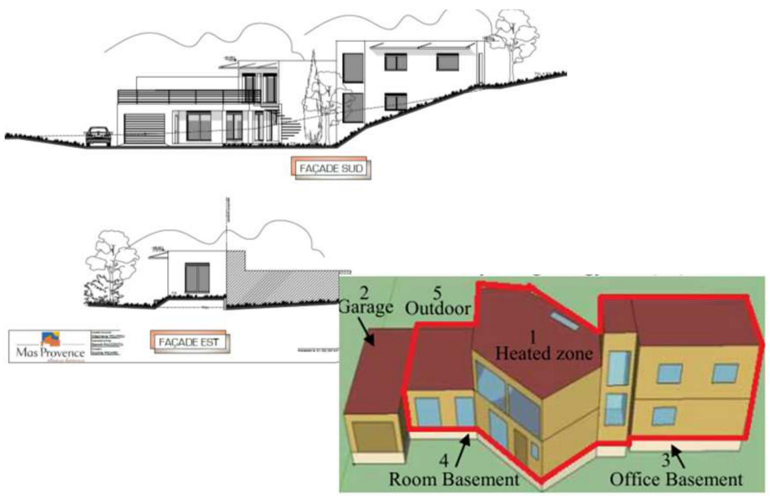
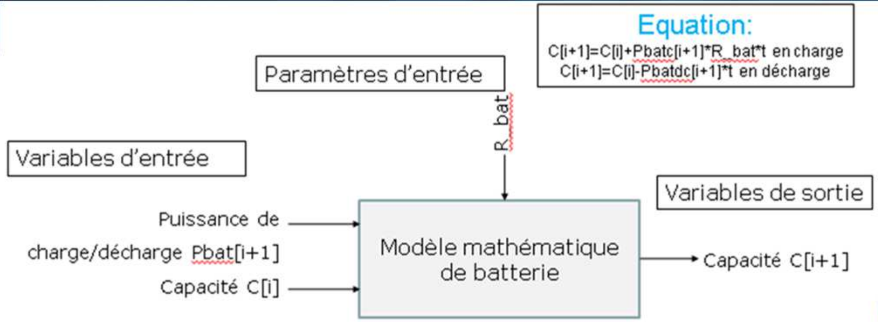
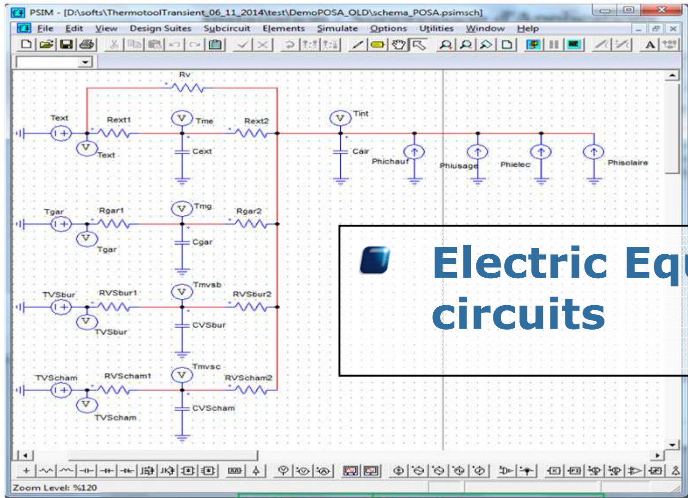


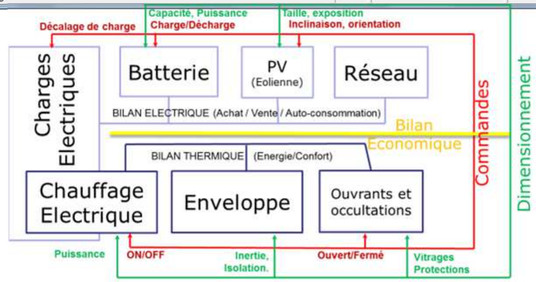
Figure 1 Energy Plus model





Electric Equivalent circuits

The right level of model composed at system level

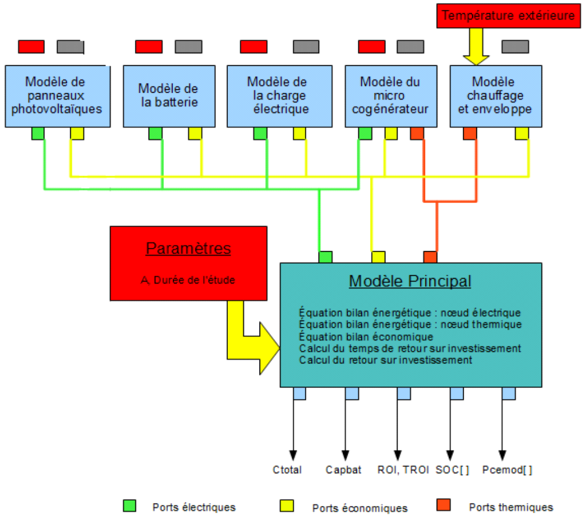


« Optimal Sizing Of A Complex Energy System Integrating Management Strategies For A Grid-connected Building », Van-Binh Dinh, Benoit Delinchant, and Frederic Wurtz, IBPSA 2015, http://www.ibpsa.org/proceedings/BS2015/p2141.pdf

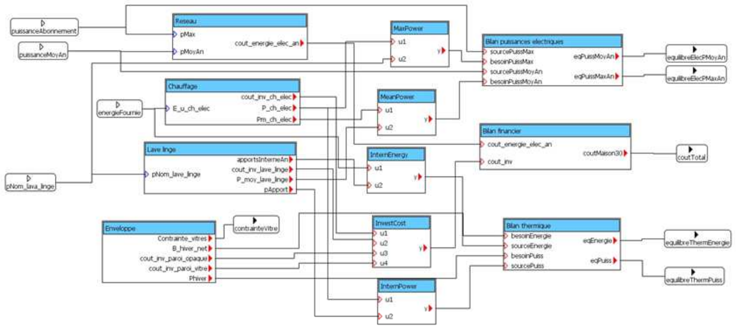
Optimal modeling and design of buildings ?
The exemple of an Energy positive railway Station

An example of use case

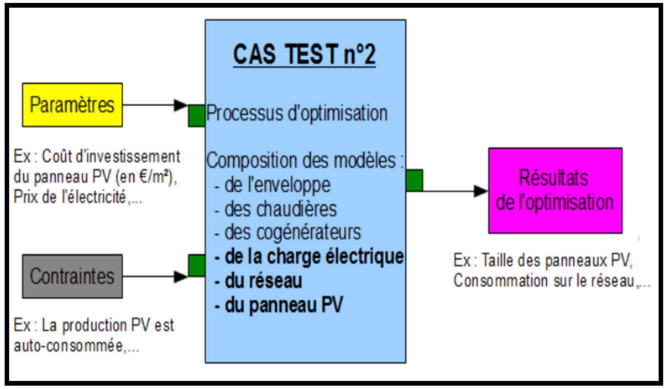
Projet VEGEP



Model composer CADES V3.0



Solved optimisation problem



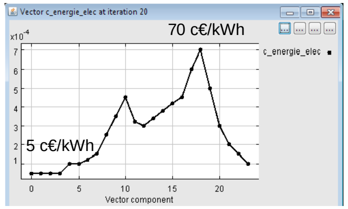
$$P1 \Longrightarrow \left[\begin{array}{l} \min\ fob(E,P) \\ \quad E_j \qquad\qquad avec \\ Smax_i \le S_i(E,P) \le Smax_i \\ \quad Emin_j \le E_j \le Emax_j \end{array} \right.$$

Methods:
- *Déterministes Non Linéaires (Gradient SQP)*

« Les enjeux de la conception en phase d'esquisse pour les systèmes du génie électrique : illustration sur le cas des systèmes énergétiques pour les bâtiments », F. Wurtz , B. Delinchant , Van Binh Dinh , Julien Pouget , Xavier Brunotte, *SGE 2014 - Symposium de Génie Electrique 2014*, Cachan : France (2014), http://hal.archives-ouvertes.fr/hal-01024644

Optimal modeling and design of buildings ?
The exemple of an Energy positive railway Station

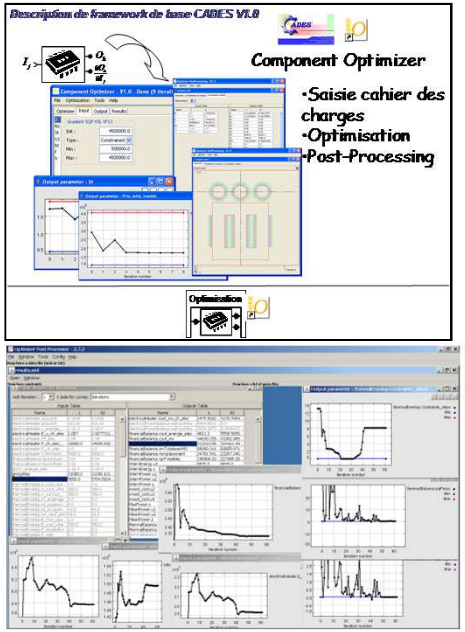
The tools developed and some results



Dynamic tarif energy

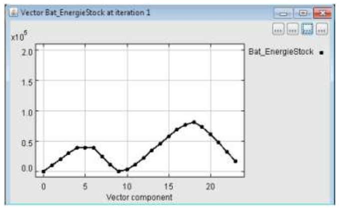
- Area
- Cost of technology
  - Building
  - Systems (PV, Battery ,heating, co-generator, ...)
- Life-time (30 ans)
- Discount rate

Optimiser CADES

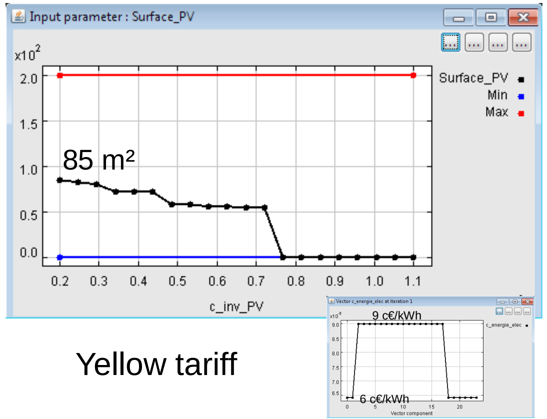


Optimisation with hundreds to thousants Parameters and constraints

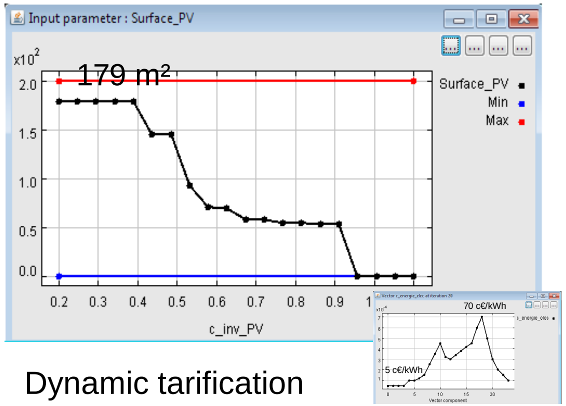
- Optimal results
- Building Envelop
- Systems
- Management
- strategy



Parametrized optimisation results



Yellow tariff



Dynamic tarification

- "Sketch Systemic Optimal Design Integrating Management Strategy, Thermal Insulation, Production And Storage Energy Systems (Thermal And Electrical): Application To An Energy- Positive Train Station"**F. WURTZ**, J. POUGET, X. BRUNOTTE, M. GAULIER, Y. RIFONNEAU, S. PLOIX AND B. L'HENORET , IBPSA 2013 – FRANCE, http://www.ibpsa.org/proceedings/BS2013/p_2376.pdf
- "On The Sizing Of Building Enveloppe And Energy System Integrating Management Strategy In Sketch Phase", IBPSA 2015, http://www.ibpsa.org/proceedings/BS2015/p2142.pdf

III - The need of a new vision of synergy between optimisation and modelisation *For Design*

Why the need of a new vision
The importance of Preliminary Design (PD)
The paradox "information-decision" of Preliminary Design (PD)
The need of new compromises between modelisation and optimisation
Imaginery System Design as a new paradigm for PD

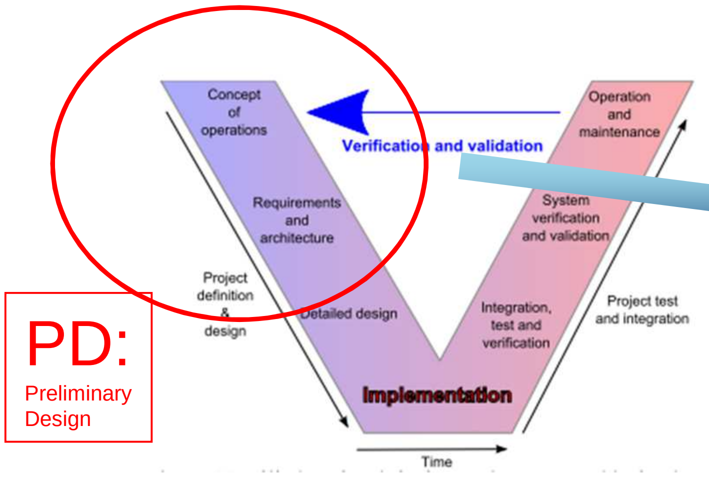
Why the need of a new approach

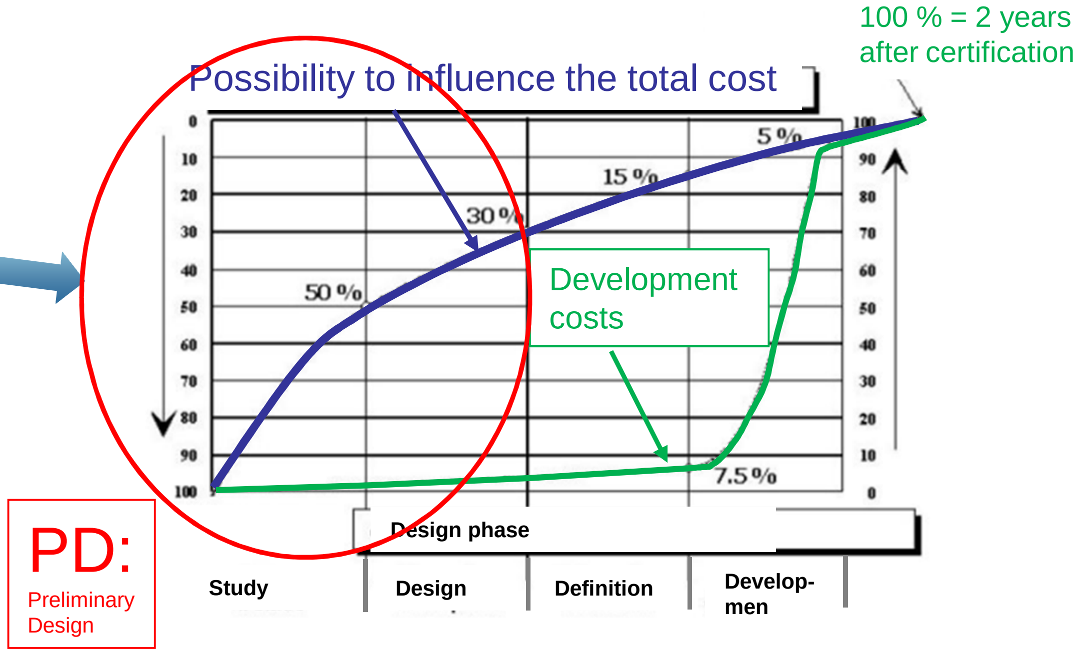
- **With SB, SG and Internet of Energy … the complexity of design increases dramatically**
- **In space**
  - Integration, interactions with global networks
    - Physical energy networks (electricity, heat, gaz, …)
    - Social
    - Econonomical
    - Territorial
    - ….
- **In time**
  - From very early design phase
  - To anticipative and reactive management
    - Demande response, Load Matching, …
- **The previous presented works**
  - Complex optimisations problems
  - With quite simple and macroscopic models – Why ?

The importance of Preliminary Design (PD)

The importance of PD

- The early steps of a design process (Preliminary Design (PD) or sketch phase design) represent only a fraction in the total cost of an engineering project (about 5% to 10%).
- **<u>But</u>**, the choices made during these first steps will impose the greatest part of the final costs , up to 80% [1], [2]





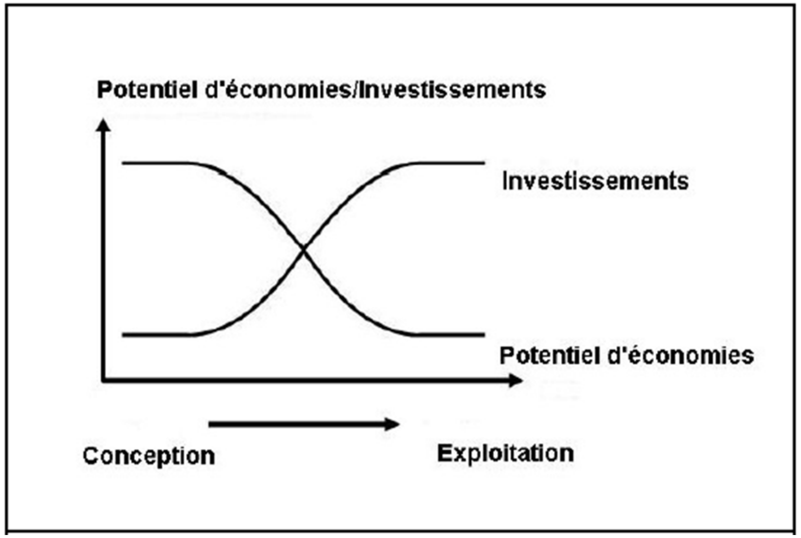
[1] - L. Zimmer and P. Zablit, "Global aircraft predesign based on constraintpropagation and interval analysis," in CEAS Conference on Multidisciplinary Aircraft Design and Optimization, Köln, Germany, 2001

[2] – A. Hubert, P.-A. Yvars, Y. Meyer et L. Zimmer« Conception préliminaire optimale des systèmes électriques. Une approche par synthèse », SYMPOSIUM DE GENIE ELECTRIQUE (SGE 2016) : EF-EPF-MGE 2016, 7-9 JUIN 2016, GRENOBLE, FRANCE

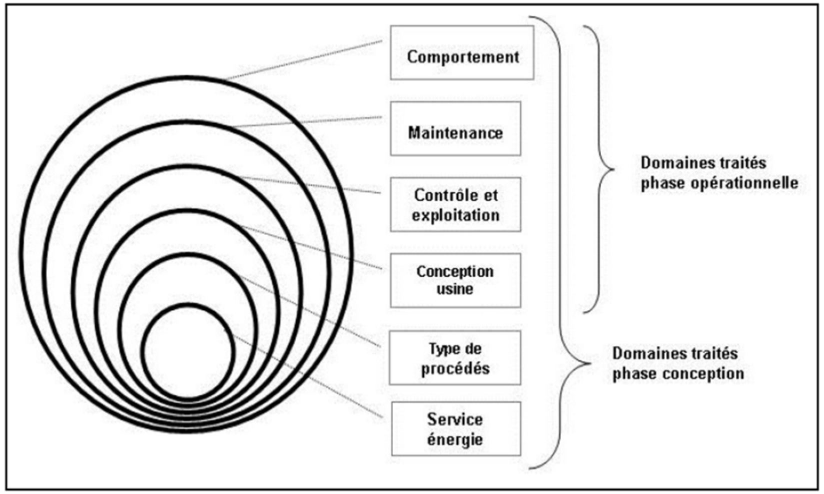
Importance des phases d'esquisse

Selon le document de référence sur les meilleures techniques disponibles (CE, 2009), établi après des l'échanges entre les Etats membres de l'Union Européenne et les industriels, l'efficacité énergétique devrait être prise en compte dès la phase de conception au lieu d'en phase d'exploitation pour maximiser les potentiels d'économie

Ce document indique des économies de 20 à 30% sur la consommation d'énergie totale dans de nombreux projets qui appliqueraitant l'efficacité énergétique dèsà leur phase de conception, et il recommande aussi une approche intégrant les cycles d''exploitation dèsen la phase de conception pour, par exemple pour une usine



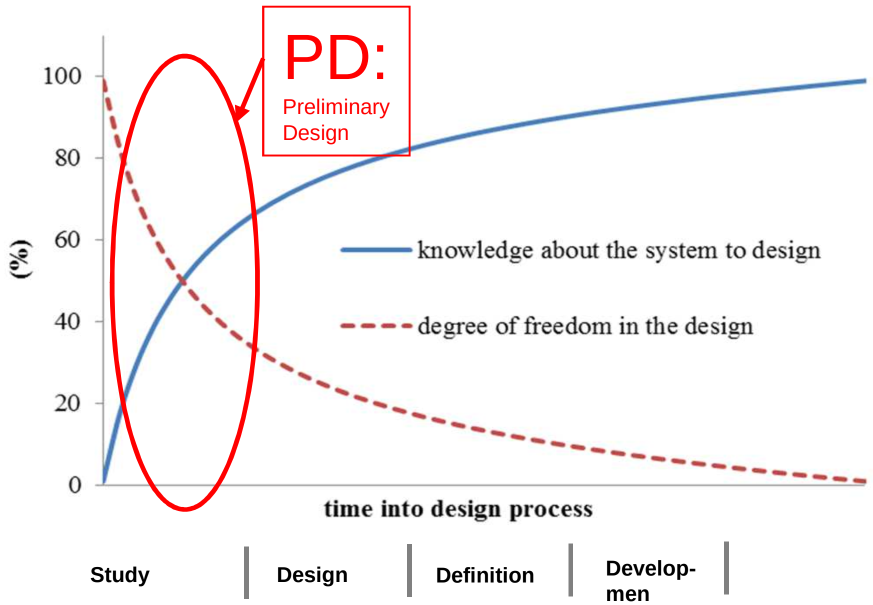
CE, 2009. Commission européenne. Document de référence sur les meileures techniques disponibles, Efficacité énergétique



The paradox of Preliminary Design (PD)

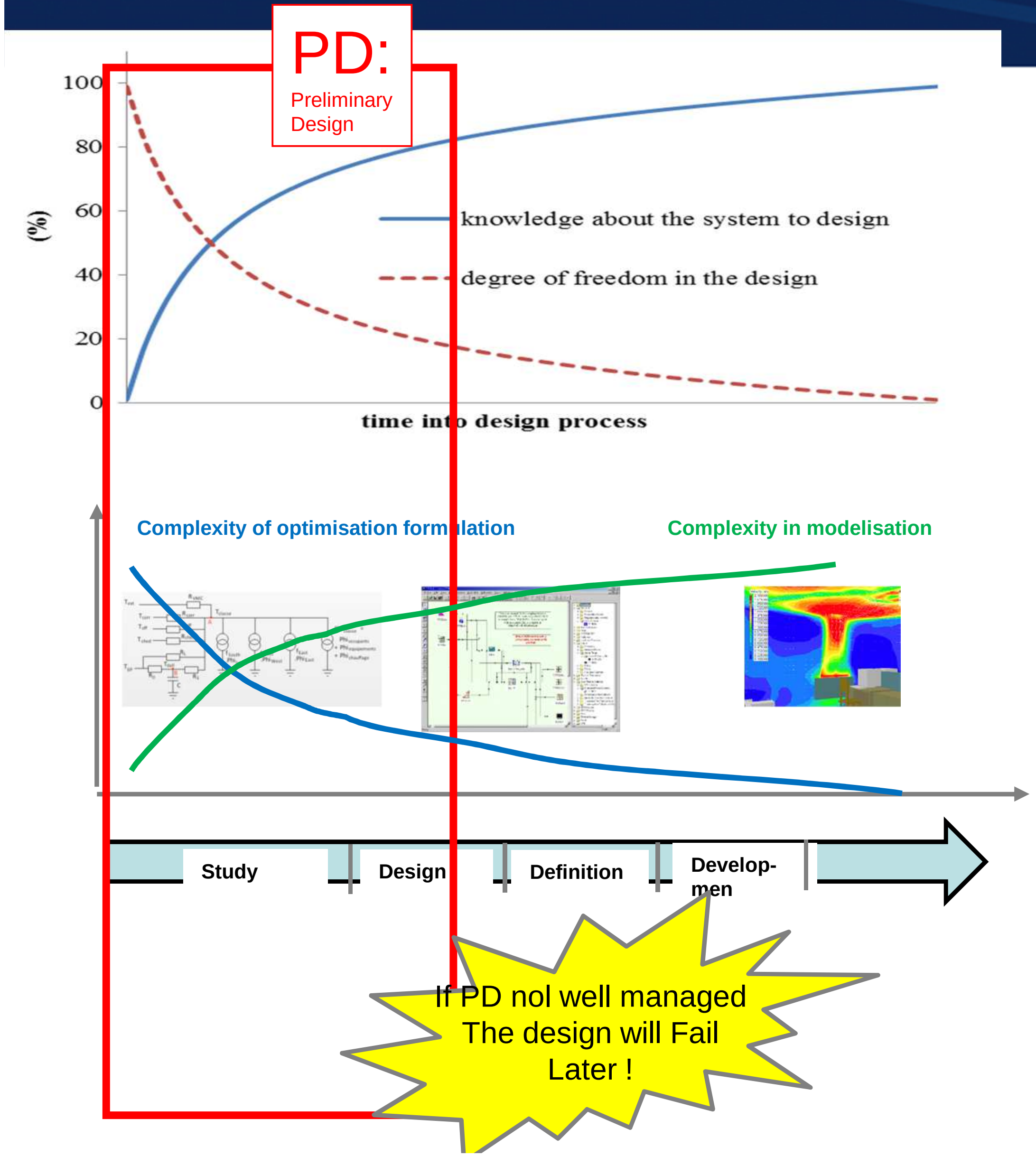
The Paradox of PD – The Information/Decision Paradox

- The highest the impacts of choices and degrees of freedom ,the more the details are unknown



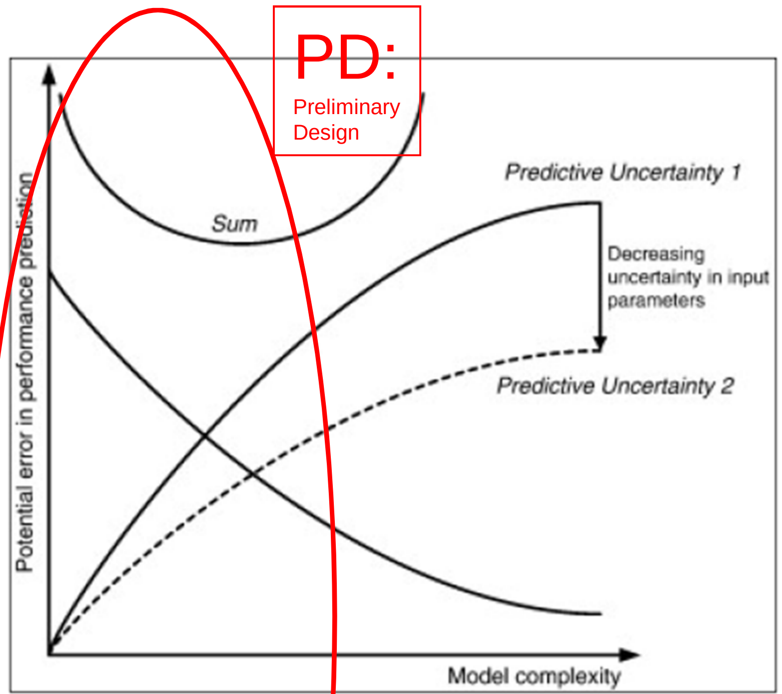
The need of new compromises to address Prelimary Design

The Paradox of Preliminary Design (PD) calls new compromises



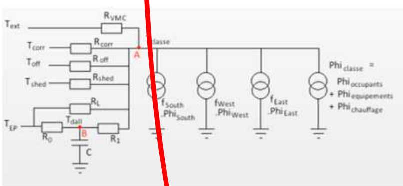
- **Due to the Information/Decision Paradox in PD**
- **New compromises needed for PD phase**
  - Less complexity in models
  - More complexity in optimisation problem formulation
- **For major and fundamental issues**
  - Avoid risks of bad choices in PD
    - Bad defined Problem
    - Ill defined Problem

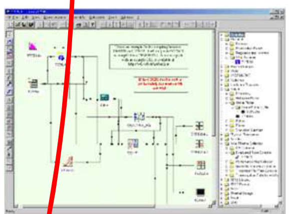
The Paradox of Preliminary Design calls new compromises

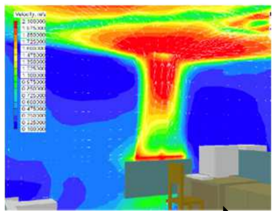


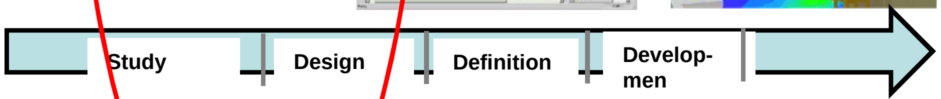
Jan Hensen, "Building performance simulation: current state and challenges", Expert meeting on"Evaluating and Modelling Near-Zero Energy Buildings; are we ready for 2018?" 30-31 January 2012, University of Strathclyde, Glasgow

Marija Trčka, Jan L.M. Hensen, « Overview of HVAC system simulation », Automation in Construction, Volume 19, Issue 2, 2010, Pages 93-99, ISSN 0926-5805, https://doi.org/10.1016/j.autcon.2009.11.019.,(http://www.sciencedirect.com/science/article /pii/S0926580509001897)









Analytic

Semi analytic

Numeric

0D

1D

2D

3D

Static

Dynamic

- **Explains especially why it is inefficient to have complex models … Too early, especially in preliminary design phase**
- **The efficient compromise for PD**
  - Analytical and semi analytical models
  - That are essentially continuous models

Imaginery System Design as a new paradigm for PD

- **Imaginery System Design:**
  - A strategy, concepts, methodology, technics and tools for Preliminary Design (PD) with associated concepts and tools
    - Tools, technics since tools 2006 – (OIPE Sorrento)
    - Concepts since 2012, strategies – (ICEM Conference)
    - Many applications, some users (see the authors of the present paper)
  - Time to try a synthesis

- **The concept of Imaginery System (IS)**
  - IS can be defined relatively to Real Systems (RS).
  - IS are defined by continuous and differentiable parameters and performances
  - IS cannot be built in the Real World
    - However IS can be perfectly designed and/or optimized
  - Whereas RS have discrete parameters and topologies
    - RS can be at last built and tested in the real world

Imaginery System Design based on FOO rather than Zoo

For First Order Optimization

- What is FOO ?
  - deterministic algorithms like SQP or Interior Point Method (IP-Opt)
  - gradients differentiable models
  - white box model approach
    - For symbolic computation, automatic code differentiation, …
- Even if not so popular, because
  - can be trapped by local optima
    - Not great importance for PD, where we focus on « problem setting » and not « problem solving »
    - Need continuous and differentiable models
- Very adapted for PD,Why ?
  - very efficient in time
  - High complexity in optimisation problem formulation:
    - SQP: 1000 to parameters and constraints
    - IP-Opt:From 10000 to 100000

PD: Preliminary Design

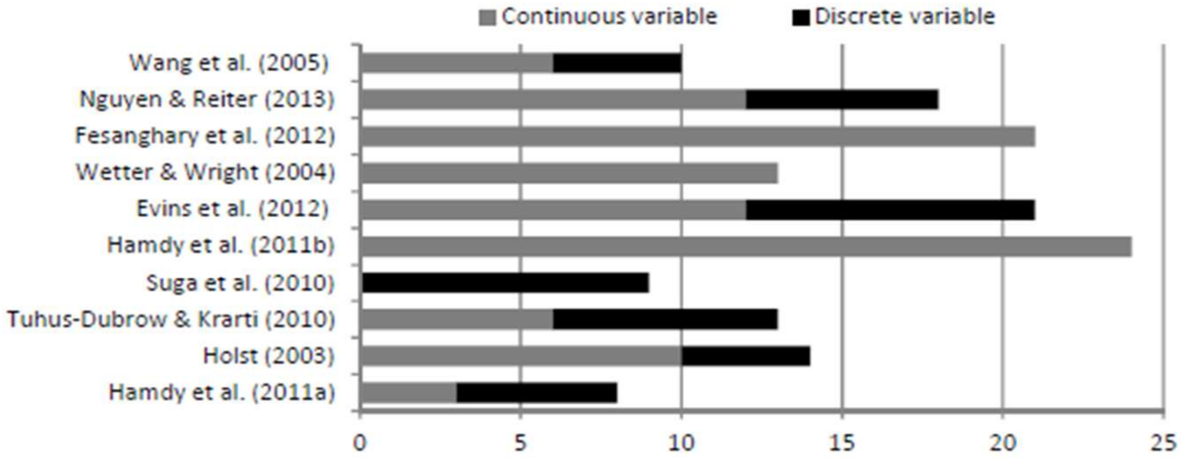
Versus a Zero Order Optimization

- What is ZOO ?
  - algorithms like GA, NSGAII, swarm particles, …
  - Use direct simulation model seen as a blackboxes, providing only outputs as functions of inputs
- Even if very popular because
  - Quite easy to implement
  - Use only black-box models
  - Efficient for detailed and advanced optimisation
- Not adapted for PD, why ?
  - can be slow and time consuming
  - Complexity of optimisation problem formulation limited
    - From 10 to 20 parameters

AD: Advanced Design

CONTEXT: a state of art with a majority of ZOO approach in Building Simulation Community

- **Building optimization problem:** **order of 10 variables**



Statistical result : Number of optimization variables in some arbitrary studies
(Nguyen et al., 2014)

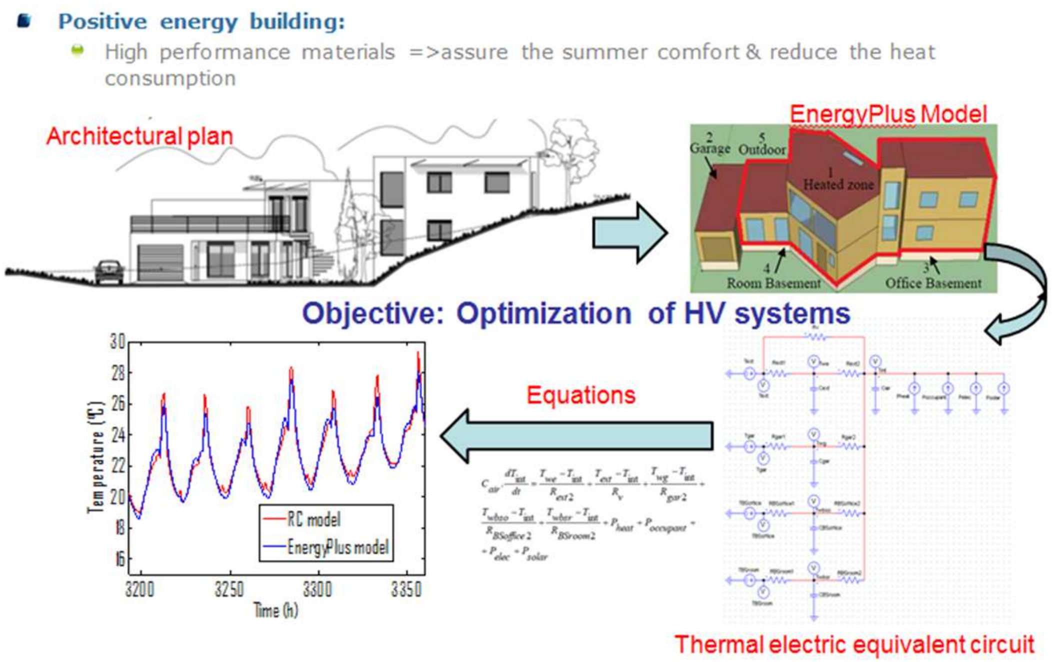
- **80% of the studies are bio-inspired algorithms (ie Zero Order Optimisation)**
  - Genetic Algorithms, NSGA-II, …

(Evins, 2013) Evins. *A review of computational optimisation methods applied to sustainable building design*. *Renewable and Sustainable Energy Reviews*, 22, 230-245

(Nguyen, 2014) Nguyen, A., Reiter, S. & Rigo, P.(2014). *A review on simulation-based optimization methods applied to building performance analysis*. Applied Energy, 113, 1043-1058

Imaginary System Design (ISD) – Applied to E+ Buildings

- **High complexity of optimisation problem formulation**
  - Simultaneously design of System + Envelop + Energy system + Anticipative Strategy Control
- **With quite low/macroscopic complexity of modelisation**



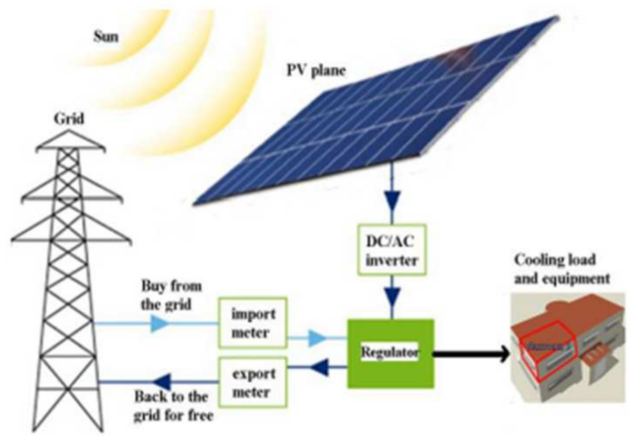


Figure 3. PV-grid-load system architecture.

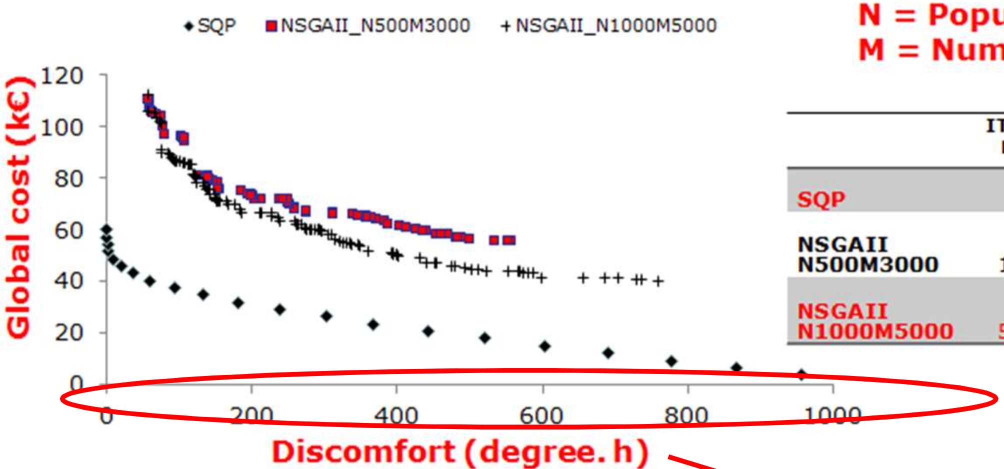
A typical discrete parameters released to continuous constraint are width of wall, insulation, size of windows, size of PV, size of batteries, …

"The Importance of Derivatives for Simultaneous Optimization of Sizing and Operation Strategies: Application to Buildings and HVAC Systems", Van-Binh Dinh, Benoit Delinchant, and Frederic Wurtz, Proceedings of the 3rd IBPSA-England Conference BSO 2016, Great North Museum, Newcastle, 12th-14th September 2016, http://www.ibpsa.org/proceedings/BSO2016/p1043.pdf

The concept of Imaginary Pareto Front (IPF) for Imaginary System Design

IPF illustrated for an E+ building

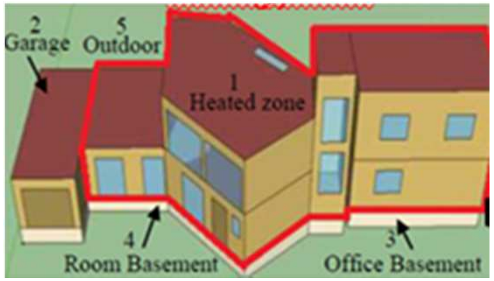
Test 2: 337 variables+504 constraints



Non-dominated solutions obtained with NSGAII and SQP

N = Population size
M = Number of generation

	ITERATION NUMBER	COMPUTATION TIME
SQP	69	3min
NSGAII N500M3000	1501001	5h57min
NSGAII N1000M5000	5002001	20h3min



Obtained with an ε constraint approach

*: "The Concept of Imaginary Machines for Design and Setting of Optimization Problems: Application to a Synchronous Generator « , **F. WURTZ**, P. KUO-PENG, E. S. DE CARVALHO, XX[th] International Conference On Electrical Machine (ICEM'2012), September 2 - 5, 2012, Marseille, France

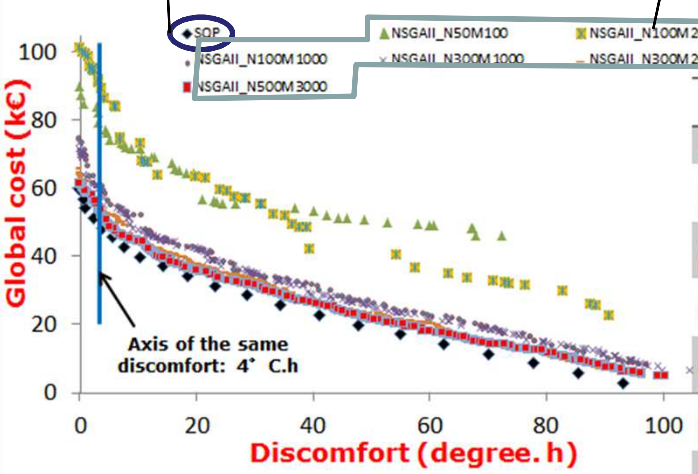
Illustrated by « smart-building » optimal design

Complexity solvable by FOO&ZOO

Imaginary Pareto Front (IPF) obtained very quickly with FOO

Pareto Front obtained with a high computing cost with ZOO

Test 1: 49 variables+48 constraints



Non-dominated solutions obtained with NSGAII and SQP

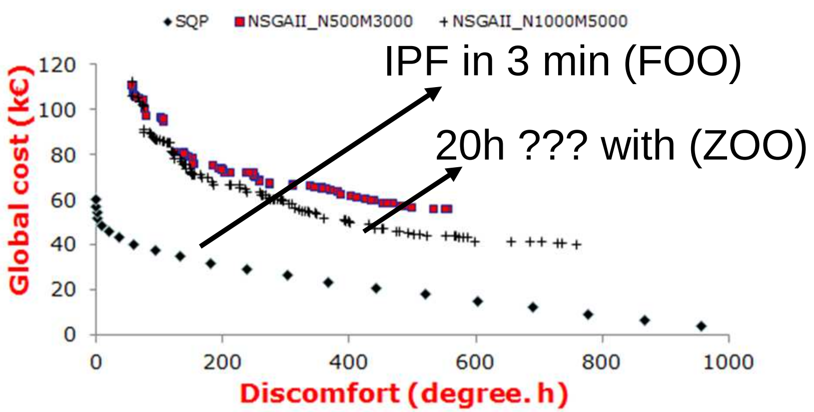
N = Population size
M = Number of generation

	ITERATION NUMBER	COMPUTATION TIME (seconds)
SQP	180	10s
NSGAII N50M100	10101	19s
NSGAII N100M200	20201	38s
NSGAII N100M1000	100201	174s (3min)
NSGAII N300M1000	300601	537s (9min)
NSGAII N300M2000	600601	1072 (18min)
NSGAII N500M3000	1501001	2795 (46min)

Comparison for obtaining the Imaginary Pareto Front (IPF) with FOO vs ZOO for energy positive buildings – From [2]

Complexity unreachable by FOO

Test 2: 337 variables+504 constraints



Non-dominated solutions obtained with NSGAII and SQP

N = Population size
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	ITERATION NUMBER	COMPUTATION TIME
SQP	69	3min
NSGAII N500M3000	1501001	5h57min
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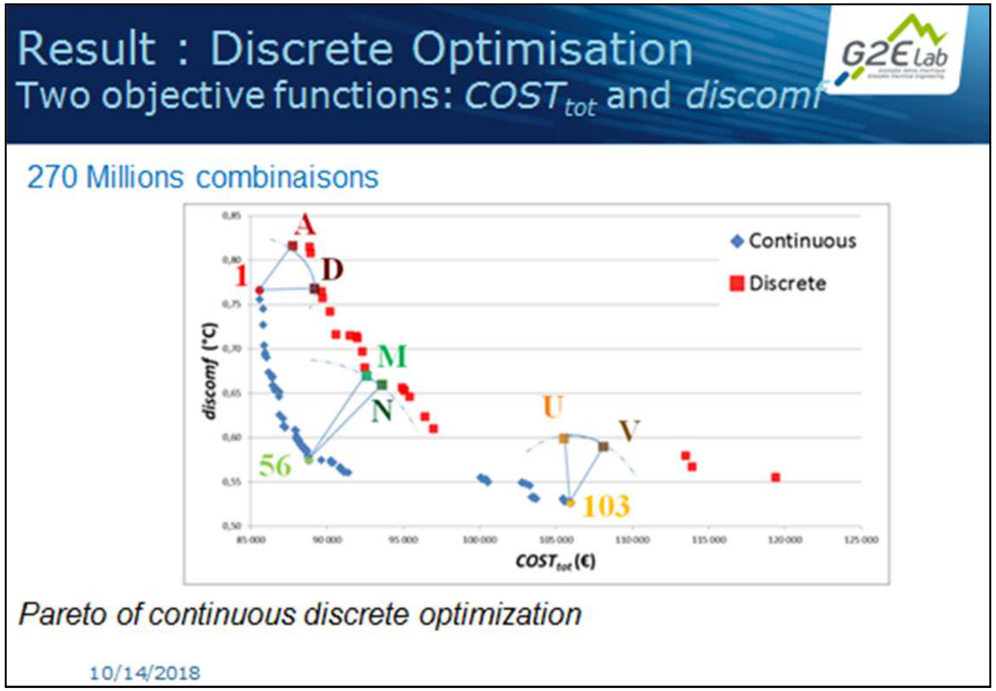
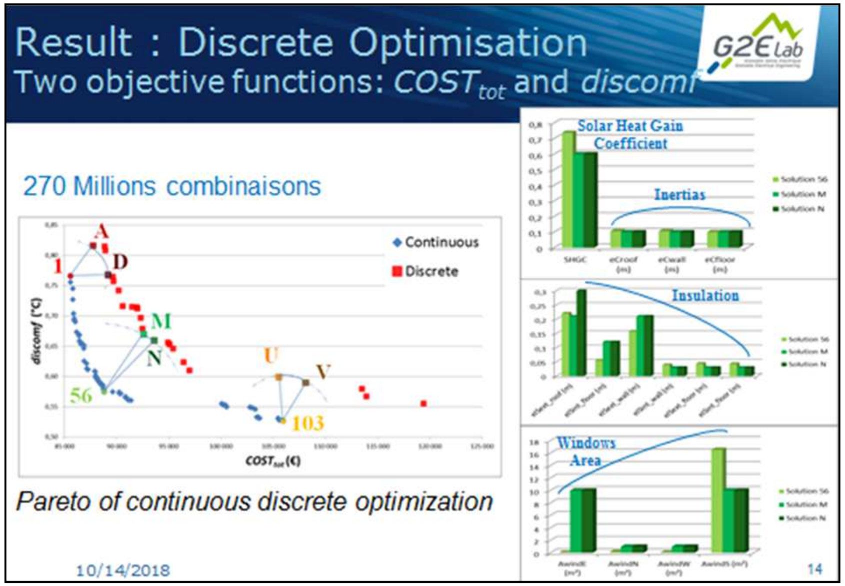
"The Importance of Derivatives for Simultaneous Optimization of Sizing and Operation Strategies: Application to Buildings and HVAC Systems", Van-Binh Dinh, Benoit Delinchant, and Frederic Wurtz, Proceedings of the 3rd IBPSA-England Conference BSO 2016, Great North Museum, Newcastle, 12th-14th September 2016, http://www.ibpsa.org/proceedings/BSO2016/p1043.pdf

Efficacity in time and for complexity optimisation to test **« problem formulation »**

From Imaginary System Design to Real Discrete Design

- **Phd Abbass Raad**

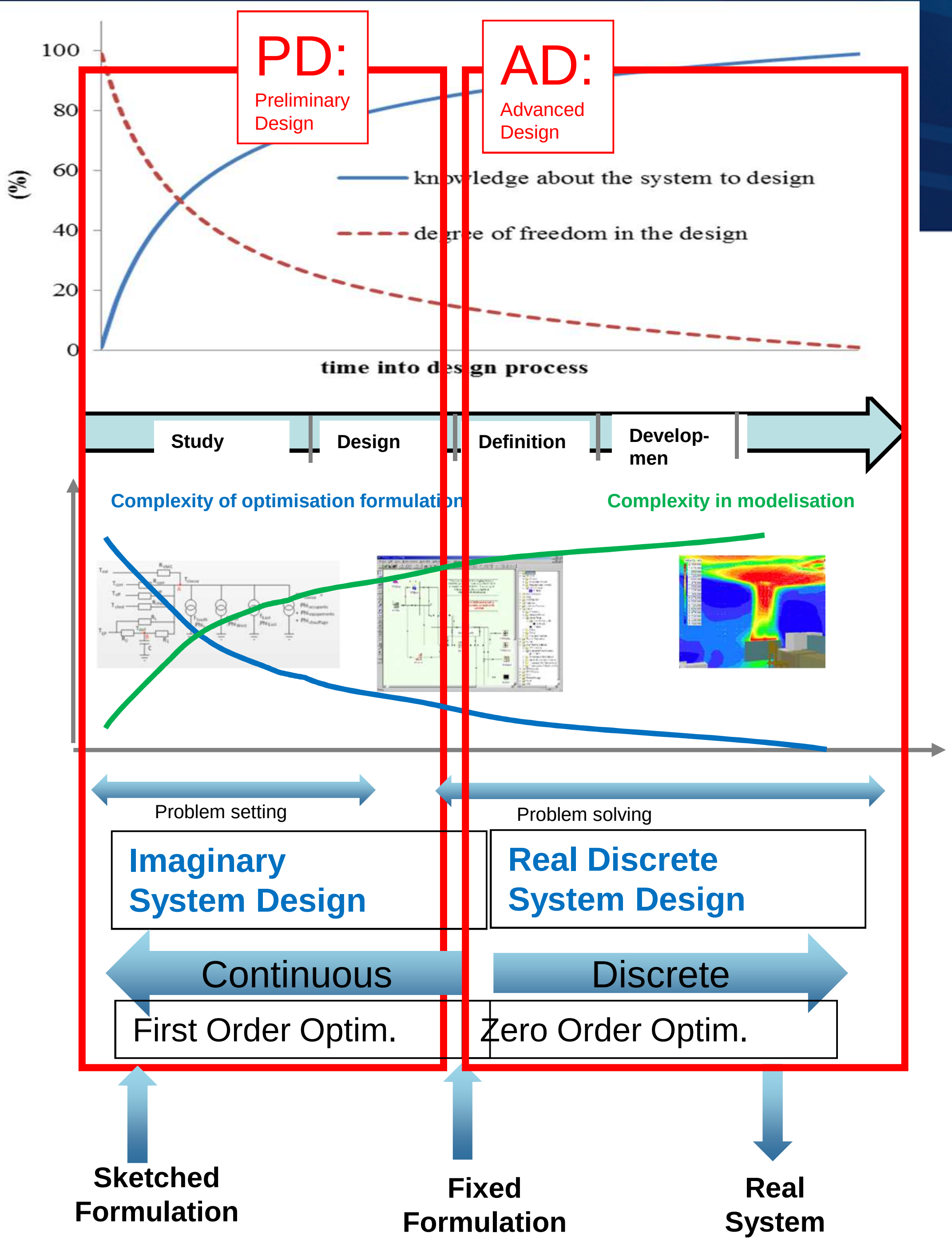




"Hybrid Discret Continuous Multi Criterion Optimization
For Building Design", Abbass RAAD, Van-Binh Dinh,
Jean-Louis Coulomb, Benoit Delinchant and Frederic Wurtz,
Proceedings of the 3rd IBPSA-England Conference BSO 2016, Great North Museum, Newcastle, 12th-14th September 2016, http://www.ibpsa.org/proceedings/BSO2016/p1034.pdf

Synthesis

- **Imaginary System Design in the global design landscape**

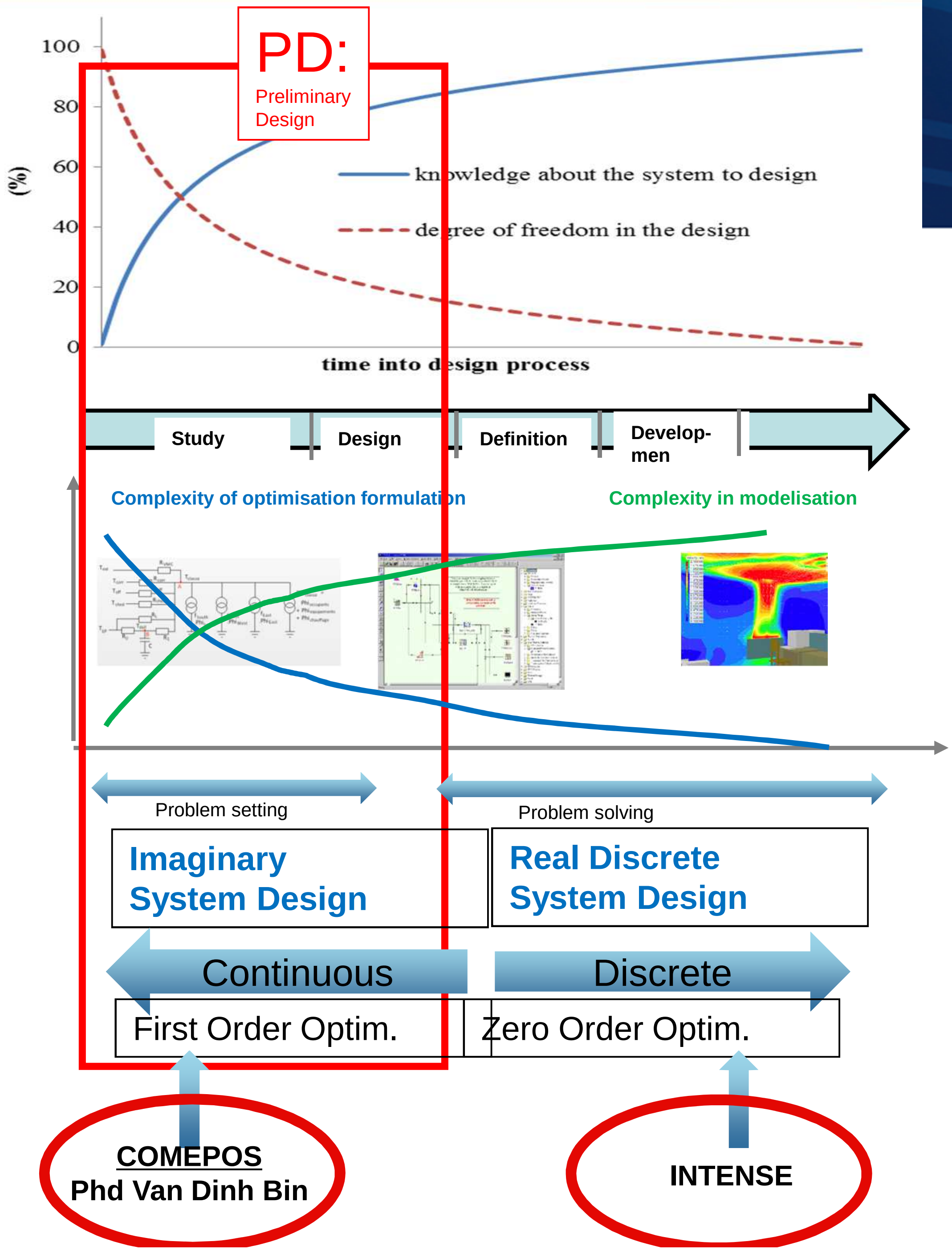


Built House

IV - Examples of compromises
Complexity of Optimisation
versus
Complexity of Modelisation

-COMEPOS Project – PhD Van Din Binh
-INTENSE Project

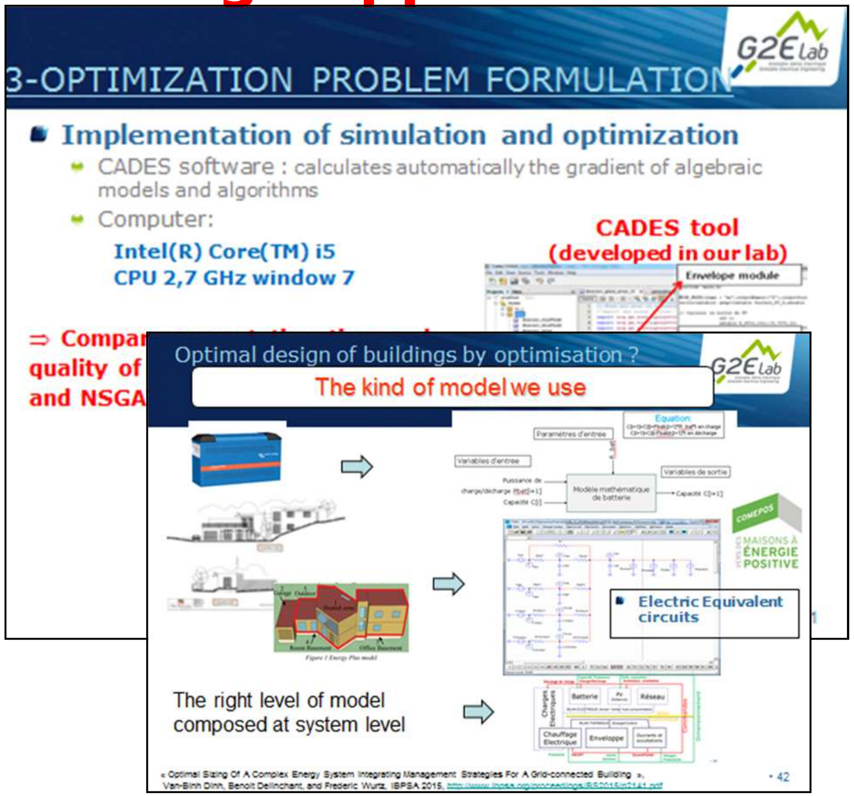
Compromises between Optimisation and Modelisation

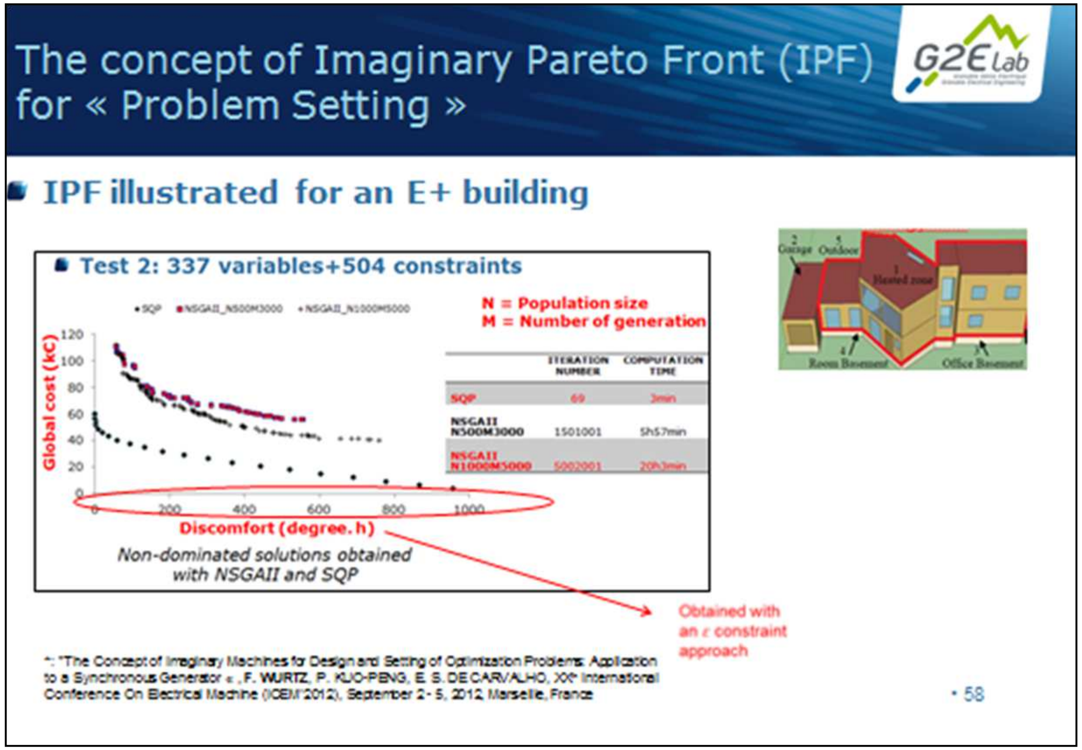


Real System

COMEPOS

FOO (First Order Optimisation) and Imaginary System Design approach for Preliminary Design



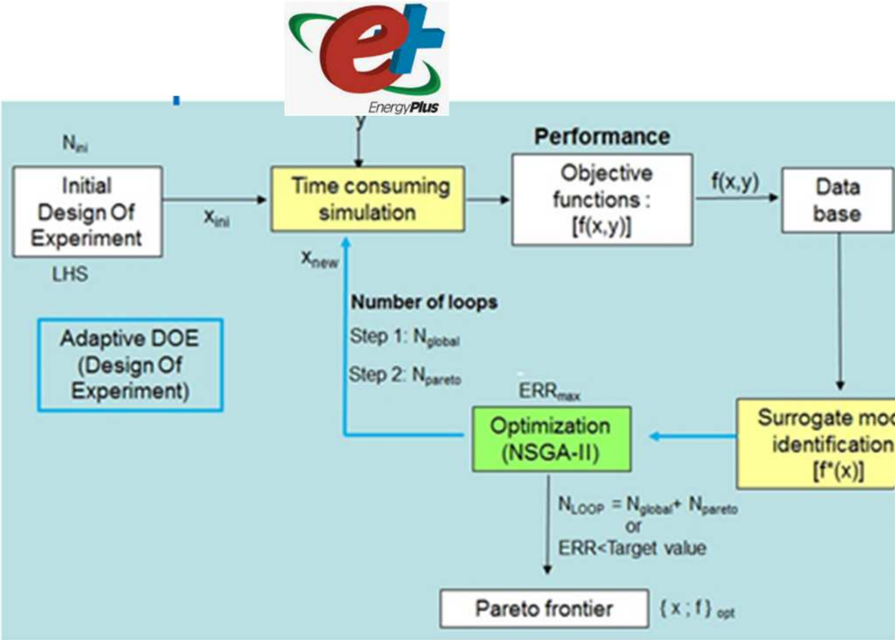


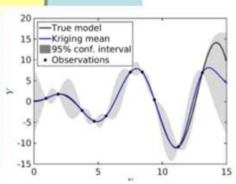
PHD
Van Din Binh

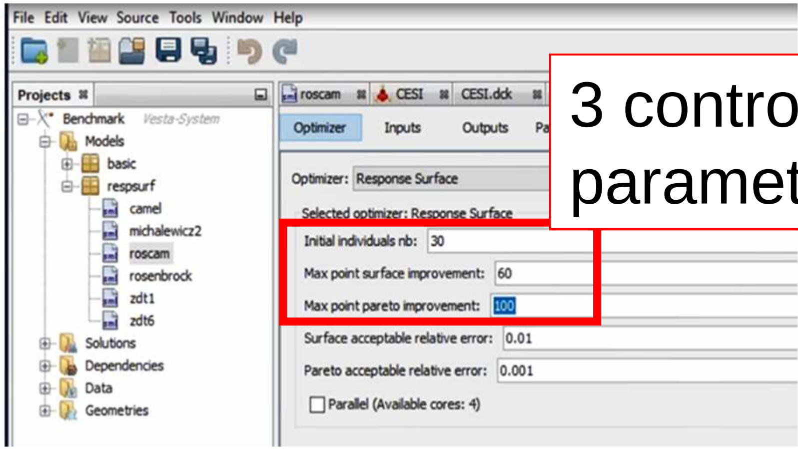
"The Importance of Derivatives for Simultaneous Optimization of Sizing and Operation Strategies: Application to Buildings and HVAC Systems",
Van-Binh Dinh, Benoit Delinchant, and Frederic Wurtz, Proceedings of the 3rd IBPSA-England Conference BSO 2016, Great North Museum, Newcastle, 12th-14th September 2016, http://www.ibpsa.org/proceedings/BSO2016/p1043.pdf

INTENSE

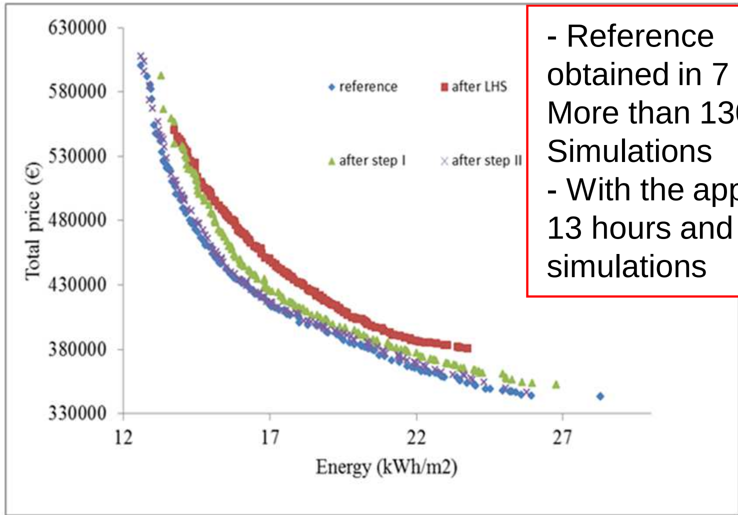
ZOO (Zero Order Optimisation) with meta modelisation for more advanced Design Steps







3 control parameters



- Reference obtained in 7 days More than 1300 E+ Simulations
- With the approach 13 hours and 105 E+ simulations

6 Optimisation parameters

* G. Fraisse, B. Souyri, F. Wurtz, X. Brunotte, P. Enciu, B. Peuportier, M. Robillart, M. El-Mankibi, N. Stathopoulos, S. Truchet, E. François, Shyama,
« Towards holistic building optimization using a computing environment that enable interoperability
between numerical tools», ECOS 2018 - 31st International Conference on Efficiency, Cost, Optimization,
Simulation and Environmental Impact of Energy Systems,
June 17th to 21st 2018, Guimarães, Portugal

V - The need of a new inter-disciplinary approach with the « human in the loop »

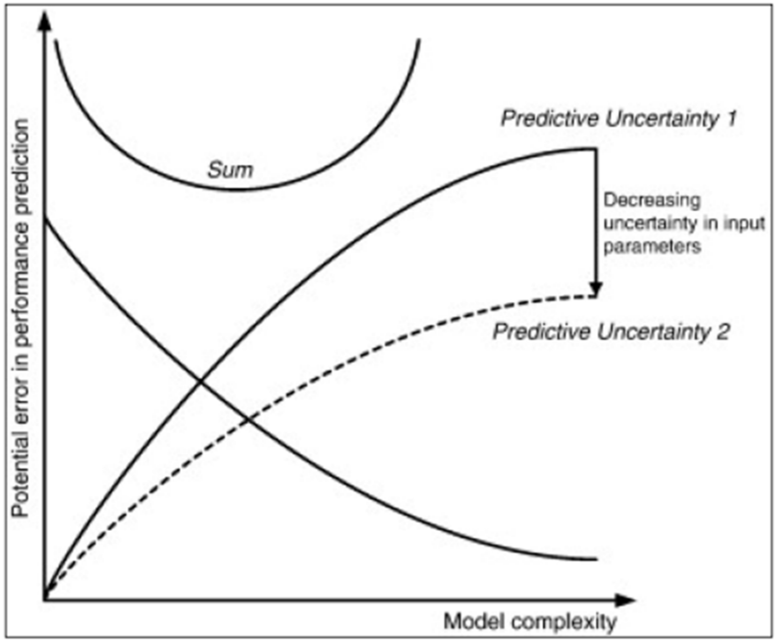
-Why ?
- In anticipative and reactive management and supervision

The need of a new inter-disciplinary approach with the «human in the loop» - Why ?

- **Uncertainty linked to human actors and usage**
- **Relatively to heating**
  - “identical houses can have heating consumption that vary with a factor 2-3 depending on user practices, and thus that user practices are at least as important as building physics”
    - See references available in: “Smart buildings” integrated in “smart grids”: A key challenge for the energy transition by using physical models and optimization with a “human-in-the-loop” approach”, F. Wurtz, B. Delinchant, Comptes Rendus Physique, Volume 18, Issues 7–8, September–October 2017, Pages 428-444, https://doi.org/10.1016/j.crhy.2017.09.007
  - Study on 26 Energy Positive Buildings
    - “factor 3 in variations in heat consumption depending on user practices” – from 46 kWh/m²/year to 144.9 kWh/m²/year
      - Z. M. Gill, M. J. Tierney, I. M. Pegg, N. Allan, Measured energy and water performance of an aspiring low energy/carbon affordable housing site in the UK. Energy and Buildings 43, 2011,117–125
- **Relatively to electricity**
  - when comparing households living in similar houses, electricity consumption can vary with a factor 5, thus indicating that electricity consumption is even still less linked with building size type than heating consumption
    - Gram-Hanssen, K. (2011). Households' energy use - which is the more important: efficient technologies or user practices? In Proceedings of the World Renewable Energy Congress 2011 (WREC 2011) Linköping: Linköping University Electronic Press

Modeling with the right level of complexity in relation to the uncertainties

Jan Hensen, "Building performance simulation: current state and challenges", Expert meeting on "Evaluating and Modelling Near-Zero Energy Buildings; are we ready for 2018?" 30-31 January 2012, University of Strathclyde, Glasgow (UK)



Numerous uncertainties among

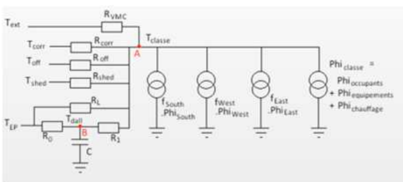
design *construction* ***operation***

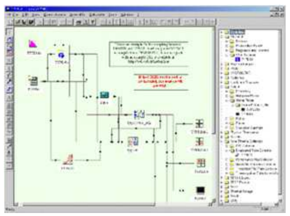
Uses and practices (*):

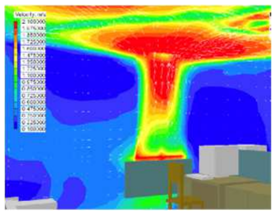
- 49 to 79% of bad practices
- 15 to 29% of good practices

The main source of uncertainty ?

It is necessary to introduce **the human in the loop**







Analytic Semi analytic Numeric

0D 1D 2D 3D

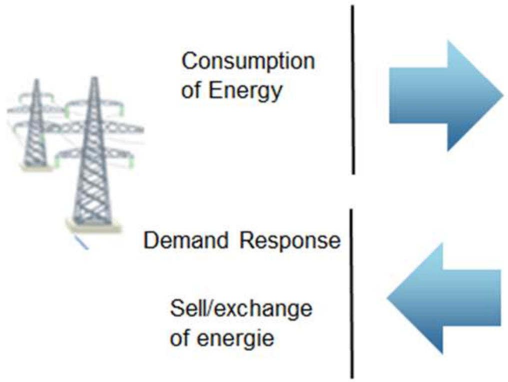
Static Dynamic

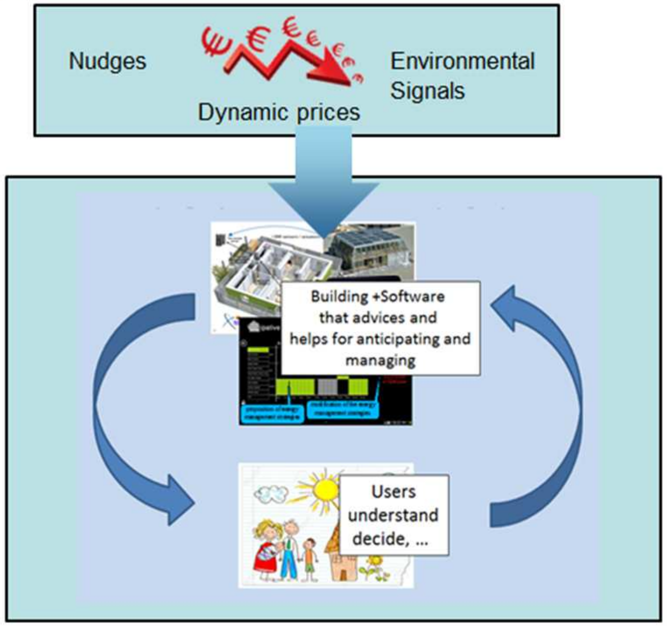
(*) S. WANG, X. XU, Simplified building model for transient thermal performance estimation using ga-based parameter identification, IJTS, 2006

In anticipative and reactive management and supervision

The need of a new inter-disciplinary approach with the « human in the loop »

- **In Smart-Building will everything be automatic ?**
  - Was, may be, our first idea, but …
  - Our current hypothesis is that the **user/inhabitants** must be involved
    - Inhabitant want to decide, must understand, …
    - If they can not decide, and do not understand -> **Reject**
- **The consumer will become an active pro'sumer**





VI - The means of a research with the human in the loop

- The inter-disciplinar eco-sesa project at he university of Grenoble
- The concept of living lab

An inter-disciplinar reseach structure and program: Eco-Sesa

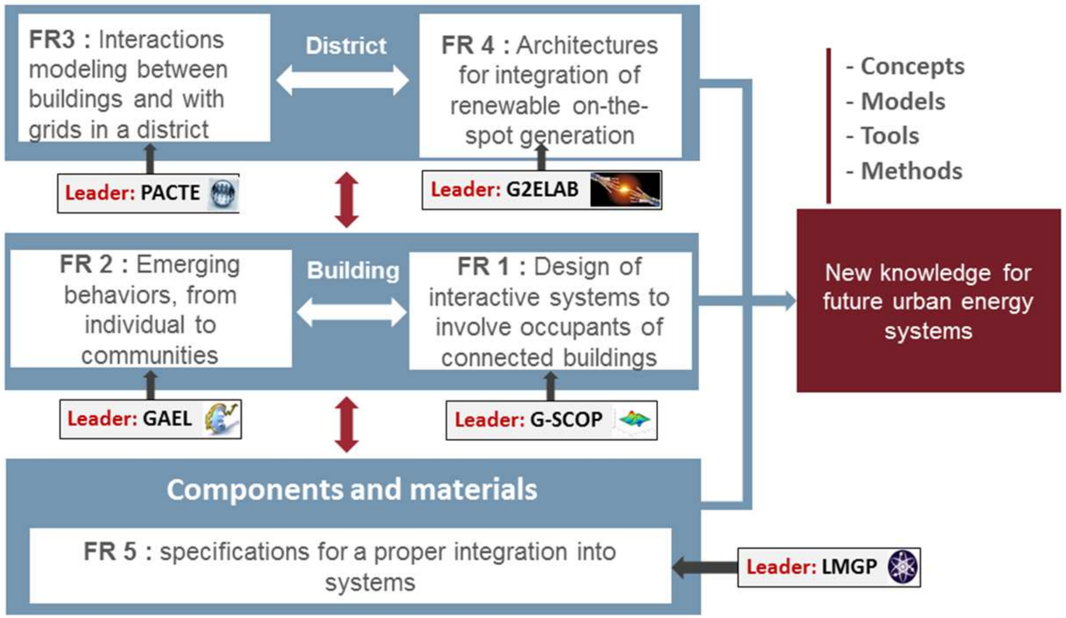
Cross-Disciplinary Program

financé par
IDEX Université Grenoble Alpes

Eco-SESA
Univ. Grenoble Alpes
Smart energies in districts

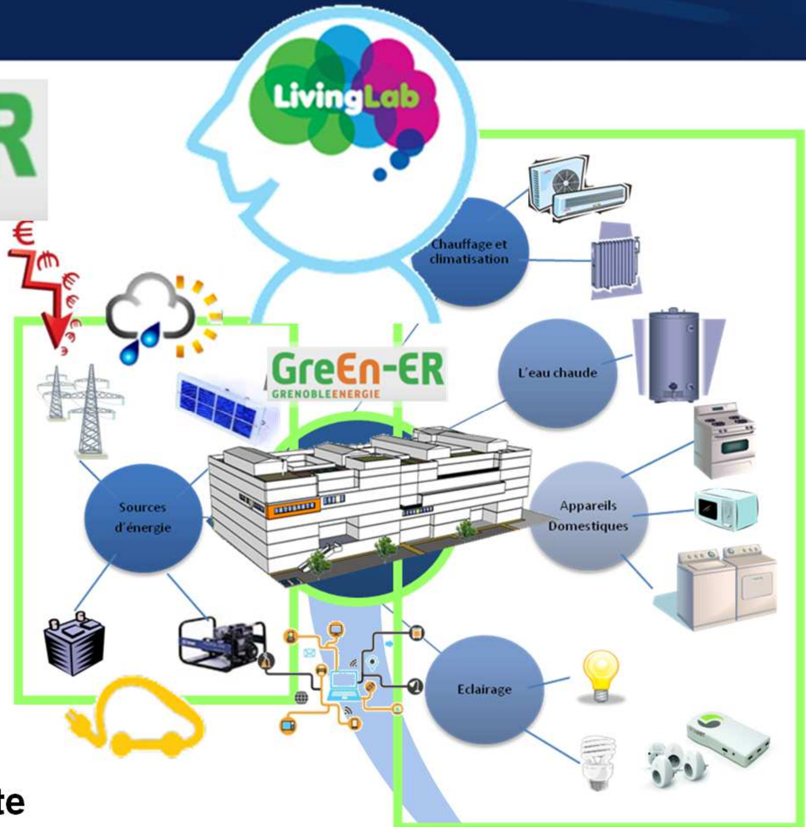
Systems
Practices and organisation
Components and materials

Observation:
- Monitoring
- Database
- Field survey
- Economic experimentation
- Urban Transect



https://ecosesa.univ-grenoble-alpes.fr/

GreEn-ER at the heart Grenoble Eco-District



A Living Lab to innovate

- Energy efficient building
- With the aim of involving users (CUBE2020)
- With an autonomous and positive energy part (Predis MHI)
- Student associations (Enactus, ACE, connected hives, ...)

A "Smart-Building" to integrate into the "Smart-Grid" of the eco-city, involving all local actors and citizens

Conclusion

- **The need of the energy transition**
- **Smart-Buildings, Smart-Grids, Internet of Energy as a solution**
- **By using Optimisation & Modelisation for new challenges**
  - Spatial complexity
  - Time complexity
- **From design steps to anticipative and reactive management**
- **Need of compromises**
  - Optimisation Complexity versus Modelisation Complexity
- **Need of new concepts and point of views**
  - Especially Imaginary System Design for Problem Setting
- **Compromises depends from humans in the loop:**
  - Designers in the design loop
  - Users in the anticipative and management loops
- **What calls an inter-disciplinar research approach**
  - As the eco-sesa initiative (see https://ecosesa.univ-grenoble-alpes.fr)

Research and point of view in details

C. R. Physique 18 (2017) 428–444

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ELSEVIER

Demain l'énergie – Séminaire Daniel-Dautreppe, Grenoble, France, 2016

"Smart buildings" integrated in "smart grids": A key challenge for the energy transition by using physical models and optimization with a "human-in-the-loop" approach

CrossMark

Le « bâtiment intelligent » intégré dans les « réseaux intelligents » : un défi clé pour la transition énergétique. Modèles physiques et optimisation associés à une approche intégrant l'acteur humain dans la boucle

Frédéric Wurtz, Benoît Delinchant

Université Grenoble Alpes, CNRS, Grenoble INP, G2Elab, 38000 Grenoble, France

"Smart buildings" integrated in "smart grids": A key challenge for the energy transition by using physical models and optimization with a "human-in-the-loop" approach", F. Wurtz, B. Delinchant, Comptes Rendus Physique, Volume 18, Issues 7–8, September–October 2017, Pages 428-444, https://doi.org/10.1016/j.crhy.2017.09.007