LOAD MANAGEMENT IN MULTI-ENERGY BUILDINGS: A SIMULATION CASE STUDY

Aurélie Chabaud[1,2], Julien Eynard[1,2], and Stéphane Grieu[1,2]
[1]PROMES-CNRS, Rambla de la Thermodynamique, Tecnosud, 66100 Perpignan, France
[2]University of Perpignan Via Domitia, 52 Avenue Paul Alduy, 66860 Perpignan, France
aurelie.chabaud@univ-perp.fr, julien.eynard@univ-perp.fr, grieu@univ-perp.fr

ABSTRACT

This paper presents a comprehensive approach about energy resources management in buildings connected to the electricity grid and equipped with energy production and storage systems. The aim of the work is to find interesting configurations that favour energy self-consumption while minimizing the impact of the local production on the grid. Energy and economic criteria are proposed to evaluate the proposed strategy. A parametric study allowed the local systems to be optimally designed. So, we used first the TRNSYS software to model the thermal behaviour of a single-storey house, inhabited by four persons and equipped with photovoltaic solar panels, a vertical-axis windmill and batteries for electricity storage. The results we obtained in simulation prove that one can design in an optimal way the just-mentioned systems and find configurations that offer a very good compromise between energy self-consumption and renewable energy coverage rate while limiting the negative impact of the local production on the electricity grid.

INTRODUCTION

Changes in climate due to greenhouse gas emissions, the rarefaction of fossil energy resources and an increasing energy demand, mainly caused by population growth and economic development, are worldwide concerns. In addition, power breakdowns due to grid disturbances or overloading are important issues impacting networks safety. As a result, the energy market is being deregulated and decentralized energy production systems become more and more popular. That is why one needs to develop tools to improve safety and ensure a good balance between electricity supply and demand. In addition, spikes in electricity demand are forcing power companies to invest money in "peaking facilities" that are rarely used. Smart building automation approaches capable of trimming demand for electricity in response to real-time variations in prices could shave many peaks and help to improve generation and distribution networks reliability, in particular if penetration of intermittent energy resources in the power system is high, as well as cost effectiveness.

Initially, electricity networks were designed in a radial and unidirectional way to carry out electricity from centralized power plants to consumers (Carrive, 1991; Puret, 1991). However, distribution networks are no more passive networks and adapt to a massive penetration of renewable energy. This penetration requires dramatic changes in planning and operation practices because it affects the physical operation of the grid. In particular, it affects short circuit, transient and voltage stability, electromagnetic transients, protection, power levelling and energy balancing as well as power quality. As a result, load forecasting becomes highly valuable while managing reactive power consumption in an efficient way is critical to grid stability. This also includes dynamic reactive power requirements of intermittent resources (Alvarez, 2009; Courtecuisse, 2008; Fontela, 2008; Pham, 2006). In this sense, new and "intelligent" tools allowing decentralized energy production and storage systems to be managed while taking into account the status of the grid are needed to minimize the impact of such production. In France, the residential sector is the largest sector of energy consumption. It accounts for 28.7% of the final energy consumed. Besides, more than 60% of this consumption are due to heating systems (Ministère de l'écologie, 2011). That is why we propose in this paper a multi-criteria approach for energy resources management in buildings equipped with energy production and storage systems (Kolokotsa et al. 2005; Mathews et al., 2000). The impact of the local energy production on the grid as well as the way multi-energy buildings and the grid interact are taken into account. Dynamic pricing is also considered. The first part of the paper describes the management strategy we propose for a grid-connected house equipped with energy production and storage systems. The second part is dedicated to the modelling of a single-storey house inhabited by four persons and equipped with photovoltaic solar panels, a vertical-axis windmill and batteries for electricity storage. The end part focuses on the optimal design of the just-mentioned systems and the results we obtained in simulation using the proposed strategy.

ENERGY MANAGEMENT STRATEGY

Systems and objectives

We address a single-storey house, located in Perpignan (south of France) and connected to the grid. This house is equipped with photovoltaic solar panels, a vertical-axis windmill and batteries for electricity storage. Batteries favour energy self-consumption (because of a better balance between supply and demand) and allow the impact on the electricity grid of a local production of energy to be minimized.

Performance criteria

In order to evaluate the proposed energy management strategy, several criteria about energy and economic performance have been defined.

Renewable energy coverage rate

$\%_{EnR_c}$ is the ratio of the renewable energy produced and consumed *in situ* to the total energy consumed (equation 1). The total energy consumed is the sum of the amount of energy produced and consumed *in situ* (EnR_c) and the amount of energy extracted from the electricity grid (E_{EDF}). EnR_c and E_{EDF} are both expressed in kWh. This criterion has to be maximized to decrease the dependency on the grid of a building:

$$\%_{EnR_c} = 100 \times \frac{EnR_c}{EnR_c + E_{EDF}} \tag{1}$$

Energy self-consumption

$\%_{SC}$ is the ratio of the renewable energy consumed *in situ* (EnR_c) to the renewable energy produced (EnR_p) (equation 2). EnR_c and EnR_p are both expressed in kWh. This criterion has to be maximized to promote energy self-consumption:

$$\%_{SC} = 100 \times \frac{EnR_c}{EnR_p} \tag{2}$$

Use of renewable energy

In order to find a reasonable compromise between the renewable energy coverage rate ($\%_{EnR_c}$) and the energy self-consumption criterion ($\%_{SC}$) and, as a result, to avoid the optimization process to lead to non-realistic configurations (highly undersized or oversized systems), both criteria are combined in a single criterion (J_{EnR}) (equation 3):

$$J_{EnR} = \frac{\%_{EnR_c} \times \%_{SC}}{100} \tag{3}$$

Dynamic pricing and economic cost

A criterion dealing with economic cost J_{cost} (€) is also defined, not according to the purchase and sale prices currently charged by EDF (Electricité de France) but based on a future application of dynamic pricing in the coming years. Dynamic pricing is already in use in the energy market and consists in adjusting energy prices dynamically, with a short time step. Dynamic pricing reflects variations in electricity production costs as well as daily and seasonally variations in the grid load. So, a polynomial energy price model (P_{En}) has been identified from both the grid load (L_g) and outdoor temperature (T_{out}) (equation 4, with $i,j \in [\![1,5]\!]$). The mean square error is about 16%.

$$P_{En}(t) = \sum_{i,j} a_{ij} \times L_g^i(t) \times T_{out}^j(t) \tag{4}$$

Table 1: Coefficients of the energy price model

$j \setminus i$	0	1	2	3	4	5
0	$6{,}58.10^{1}$	$-0{,}38.10^{1}$	$7{,}67.10^{-2}$	$-5{,}12.10^{-4}$	$3{,}48.10^{-7}$	$6{,}37.10^{-9}$
1	$-1{,}77.10^{1}$	$9{,}27.10^{-1}$	$-1{,}64.10^{-2}$	$1{,}30.10^{-4}$	$-4{,}04.10^{-7}$	-
2	$6{,}04.10^{-2}$	$-3{,}12.10^{-3}$	$4{,}41.10^{-5}$	$2{,}29.10^{-7}$	-	-
3	$-5{,}16.10^{-4}$	$-1{,}96.10^{-4}$	$2{,}38.10^{-6}$	-	-	-
4	$4{,}11.10^{-4}$	$1{,}19.10^{-5}$	-	-	-	-
5	$2{,}01.10^{-5}$	-	-	-	-	-

The economic cost criterion J_{cost} is then calculated as the difference between the cost related to the purchase of energy and the gain resulting from the sale of energy. E_{inj} is the amount of energy injected to the grid and P_{En} is the electricity price (equation 5):

$$J_{cost} = \sum_t \left(E_{inj}(t) P_{En}(t) - E_{EDF}(t) P_{En}(t) \right) \tag{5}$$

Impact of a building on the electricity grid

The grid load (L_g) varies in daily (several peaks of consumption) and seasonal (demand is higher in winter than it is in summer) cycles (Figure 2).

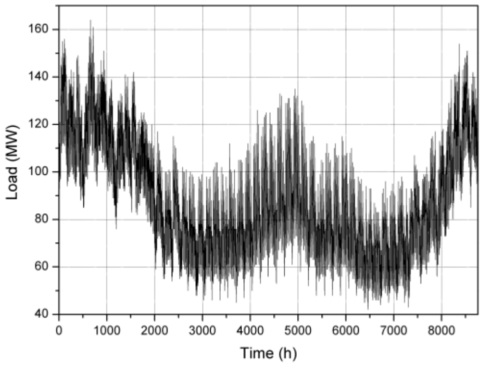

Figure 1: Load of the Perpignan grid in 2006

In order to define the status of the electricity grid, taking into account the daily and seasonal variations in its load, a daily load normalization $\widetilde{L_g}$ is firstly done. Then a daily threshold is defined to highlight a limit beyond which injecting energy to the considered grid is not appropriate. The difference between this threshold and the load allows ascertaining if injecting energy is more or less favourable. This difference is normalized between 0 and 1 when the load is higher than the threshold and from -1 and 0 when the threshold is higher than the load. When the threshold is high, the electricity grid is in need of energy only during peaks of demand. In opposition, when it is low, energy can be appropriately injected to the grid most of the time. So, the impact of the local production on the grid I_{inj} is defined from E_{inj} as well as the normalized deviation between the threshold and the status of the grid (ΔE_{thres}) (equation 6):

$$I_{inj} = \frac{1}{1000} \times \sum_t \left(E_{inj}(t) \times \Delta E_{thres}(t) \right) \tag{6}$$

The impact on the grid related to energy extraction I_{ext} (equation 7) is defined in the same way as for I_{inj}, with E_{EDF} the amount of energy extracted from the electricity grid:

$$I_{ext} = -\frac{1}{1000} \times \sum_t \left(E_{EDF}(t) \times \Delta E_{thres}(t) \right) \tag{7}$$

Finally, an overall impact criterion I_{over} is defined as the sum of I_{inj} and I_{ext} (equation 8). With a positive criterion, electricity is injected to the grid when demand is high while electricity is extracted from the grid when demand is low:

$$I_{over} = I_{inj} + I_{ext} \tag{8}$$

Energy resources management strategy

Figure 2 describes the strategy we propose to manage energy resources in multi-energy buildings connected to the grid and equipped with energy production and storage systems. The status of the grid is taken into account. One can highlight the following three main cases based on :

① *The local systems overproduce*. Energy production is higher than instantaneous consumption. Thus, the renewable energy production covers 100% of the instantaneous consumption and, as result, no energy is extracted from the grid. The surplus of energy is managed, taking into account the status of the grid. If energy demand is high ($\widetilde{L_g}$ close to 1), the surplus of energy is injected to the grid. Otherwise, if the batteries are not already fully charged, the surplus is stored in whole or in part.

② *Energy production and local energy demand are balanced*. All the renewable energy produced is so consumed locally and there is no interaction with the grid and the batteries.

③ *The local systems under-produce*. So, energy consumption is higher than the renewable energy production. As a consequence, this local production of energy is completely auto-consumed and energy is released from the batteries, if they are charged. Otherwise, the missing amount of energy is supplied by the electricity grid.

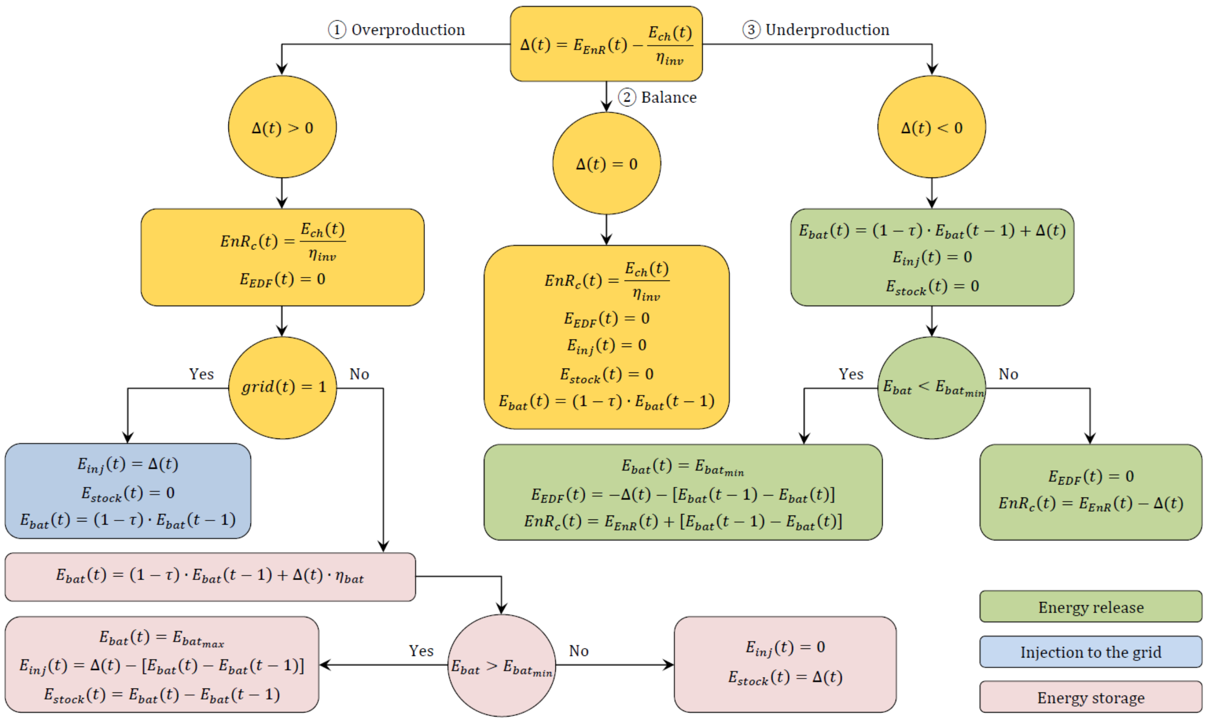

Figure 2: Energy management algorithm (see sections "Performance criteria" and "Batteries modelling")

BUILDING AND SYSTEMS MODELLING

This section of the paper focuses on the model of the building equipped with energy production (PV panels and, possibly, a vertical-axis windmill) and storage (batteries) systems we considered to test the proposed management strategy. Occupancy scenarios are also defined and presented.

Building model

The TRNSYS software has been used to model the thermal behaviour of a 150 m^2 single-storey house located in Perpignan (south of France), facing south and inhabited by four persons (TRNSYS 17, 2010). The building can be equipped with photovoltaic solar panels, a vertical-axis windmill and batteries for electricity storage. Perpignan experiences a warm and windy Mediterranean climate, similar to much of southern France. Figure 3 presents the plan of the house and the volume of the different rooms. This single-storey house (TRNSYS model 56) features a living room, a kitchen, three bedrooms, a bathroom, a corridor and a garage. Table 2 depicts the materials used in that house as well as their characteristics. Common materials were considered and the overall thermal insulation of the structure agrees with new French standards. U is the heat transfer coefficient of the materials used while U_{RT2005} is the French thermal regulation RT2005 value (Legifrance, 2006). The photovoltaic solar panels (TRNSYS model 194) and the vertical-axis windmill (TRNSYS model 90) have also been modelled. The TRNSYS model 194 is based on the calculation method presented by DeSoto (DeSoto et al., 2006) and allows determining both the current and power of a photovoltaic array at a specified voltage. This method uses various semi-empirical equations. The TRNSYS model 90 is based on the work of Quinlan (Quinlan, 2000) and allows the power output of wind energy conversion systems to be calculated on the basis of a power versus wind speed characteristic. The impact of air density changes as well as wind speed increases with height is also considered in the model.

Figure 3: Plan of the 150 m^2 single-storey house. Windows are represented in blue

Table 2: Characteristics of the materials used in the considered single-storey house

Element	Material	Thickness [m]	U [$W.m^{-2}.K^{-1}$]	U_{RT2005} [$W.m^{-2}.K^{-1}$]
External wall	BA13	0.013	0.602	0.45
	Rockwool	0.06		
	Cinderblock	0.2		
	Surface coating	0.02		
Internal wall	BA13	0.013	0.845	/
	Glass wool	0.04		
	BA13	0.013		
Floor	Tiles	0.022	0.415	0.4
	Mortar	0.05		
	Heavy concrete	0.16		
	Expanded polystyrene	0.08		
Ceiling	BA13	0.013	0.196	0.34
	Glass wool	0.1		
	Air knife	0.5		
	Terracotta	0.01		
Garage ceiling	BA13	0.013	2.37	0.34
	Terracotta	0.2		
Window	Double glazed	0.2	1.43	2.6

The way energy is consumed in the house has been also studied. Because of its significant impact on energy consumption, the inhabitants' lifestyle has been also considered via occupancy scenarios fixed by the French thermal regulation RT2005 (CSTB, 2006). The zoned HVAC (Heating, Ventilation and Air-Conditioning) system (maximum power is 1kW) is properly managed thanks to local regulators (TRNSYS model 56). Indoor temperature regulation is based on set-point profiles and the above-mentioned occupancy scenarios. Inhabitants are at home during working days from 0 a.m. to 10 a.m. and from 6 p.m. to 12 p.m. During weekends, they are present from 0 a.m. to 12 p.m. So, the indoor temperature set-point is defined as follows: 19°C for heating and 28°C for cooling during occupancy periods and 16°C for heating and 30°C for cooling if people are out the house (non-occupancy periods). Figure 4 depicts the annual power consumption of the considered 150 m^2 single-storey house for heating and cooling. When consumption is negative (respectively positive), heating (respectively cooling) mode is on. Finally, we used real data collected on site to validate the models. As a key point, one can note that energy production and consumption is impacted by climatic, geographical and physical conditions. Such conditions are part of the models. The meteonorm software provided meteorological data (meteonorm 7, 2012). Monthly, hourly and minute values are available for any location worldwide.

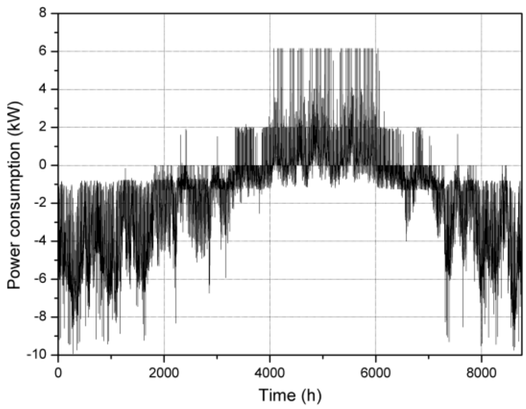

Figure 4: Annual power consumption for heating and cooling

Batteries modelling

The model describes the functioning of the batteries, i.e. the charge and discharge processes. At time *t*, the status of the batteries is related to their status at time *t-1* and the production/consumption of energy at time *t*. Equations 9 and 10 are about charging mode and discharging mode, respectively:

$$E_{bat}(t) = (1-\tau)\cdot E_{bat}(t-1) + \left(E_{EnR}(t) - \frac{E_{ch}(t)}{\eta_{inv}}\right)\cdot \eta_{bat} \quad (9)$$

$$E_{bat}(t) = (1-\tau)\cdot E_{bat}(t-1) + \left(\frac{E_{ch}(t)}{\eta_{inv}} - E_{EnR}(t)\right) \quad (10)$$

with η_{inv} the inverter performance, η_{bat} the charge performance, E_{ch} the amount of energy available to charge the batteries, E_{bat} the amount of energy stored, E_{EnR} the amount of energy produced by the local production systems after taking into account the energy losses due to the controller and τ the hourly self-discharge rate (equal to 10^{-4}). Performance is supposed to be constant and equal to 85% in charging mode while it is equal to 1 in discharging mode. The amount of energy stored in the batteries is used when the local production is not sufficient to meet demand. In opposition, energy is stored when the power supplied by the renewable energy systems exceed the house demand. However, it should be noticed that the amount of energy one can store in the batteries is related to $E_{bat_{min}}$ and $E_{bat_{max}}$ (equation 11):

$$E_{bat_{min}} \leq E_{bat}(t) \leq E_{bat_{max}} \quad (11)$$

Here, the maximum batteries capacity, $E_{bat_{max}}$, is equal to the rated capacity. The minimum capacity, $E_{bat_{min}}$, is determined from the Depth of Discharge (DoD), as shown in equation 12. DoD is used to describe how deeply the batteries are discharged:

$$E_{bat_{min}} = (1-DoD)\cdot E_{bat_{max}} \quad (12)$$

According to the various specifications given by the manufacturer, the life of the batteries can be extended if the DoD is between 30% and 50% (Ai et al., 2003). So, we considered a conservative DoD of 50%.

ENERGY RESOURCES MANAGEMENT AND DESIGN OF ENERGY PRODUCTION AND STORAGE SYSTEMS

Parametric study and optimal design

The management strategy presented in the first part of the paper has been applied to the single-storey house whose model is presented in part two. Using this model and the models of the energy production and storage systems, a parametric study has been carried out to optimize the power of both the PV solar panels (power is related to the available surface on the roof and its orientation; maximum power is so 8 kWp) and the vertical-axis windmill (maximum power is 25 kWp) as well as the capacity of the batteries (capacity is related to size; maximum capacity is so 200 kWh what is equivalent to batteries of 2 m³). The optimization process aims at maximizing an objective function, according to different values of the grid threshold. We choose J_{EnR} as function to be maximized. Let us remember that J_{EnR} is a compromise between the renewable energy coverage rate and the energy self-consumption criterion. We highlight in the next section the most remarkable configurations we obtained, with or without energy storage. Let us remember that we want energy self-consumption to be promoted and the impact of the local production on the electricity grid to be limited.

Results analysis

Table 3: Configurations 1, 2 and 3 (no batteries)

	Config. 1	Config. 2	Config. 3
PV panels (kWp)	3	6.9	3.8
V.-a. windmill (kWp)	-	-	11
EnR_c (kWh)	3305	5345	10994
EnR_{inj} (kWh)	1132	4860	9124
E_{EDF} (kWh)	26078	24038	18390
$\%_{SC}$ (%)	74.49	52.38	54.65
$\%_{EnR_c}$ (%)	11.25	18.19	37.41
J_{EnR} (%)	8.38	9.53	20.45
J_{cost} (€)	-1281.30	-977.20	-468.52

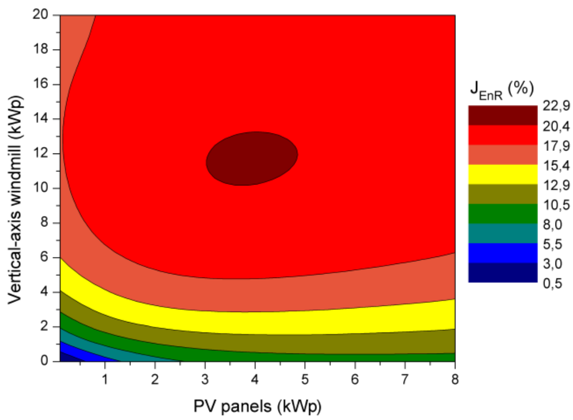

Figure 5: PV panels and vertical-axis windmill sizing. Impact on J_{EnR}

First, we highlight three configurations as well as the results we obtained in simulation (one year) (Table 3). In addition, Figure 5 shows the impact of the sizing of the local energy production systems on J_{EnR}. Configuration 1 is based on standard photovoltaic solar panels of 3 kWp only (no vertical-axis windmill and no energy storage). Configurations 2 and 3 are based on optimally designed systems: photovoltaic solar panels of 6.9 kWp for configuration 1 and PV panels of 3.8 kWp as well as a vertical-axis windmill of 11 kWp for configuration 2. At this time, energy storage (using batteries) is not considered. Taking configuration 1 as a reference, configuration 2 allows energy self-consumption to be increased by 61.7% and energy extraction to be reduced of 7.8%. In addition, energy costs are reduced of about 25% (310 €). With configuration 3, energy self-consumption is increased by 50% while energy extraction is reduced of about 11% (in comparison to configuration 2). Moreover, from configuration 1 or 2 to 3, J_{EnR} increases in a significant way (from 8.38 or 9.53 to 20.45%). Figure 6 depicts the way energy is managed annually in the considered house when using configuration 3.

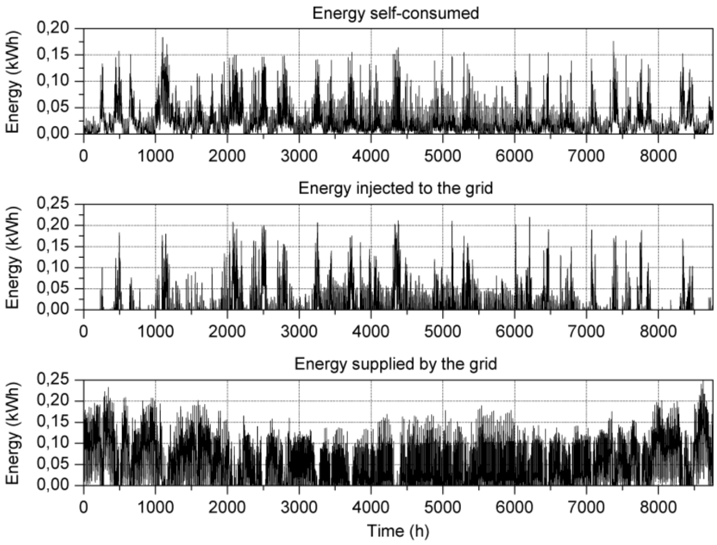

Figure 6: Energy management with configuration 3 (Table 3)

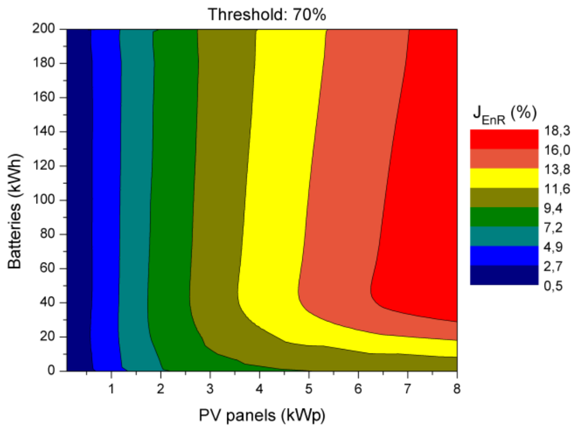

Figure 7: PV panels and batteries sizing. Impact on J_{EnR}, for a grid threshold of 70%

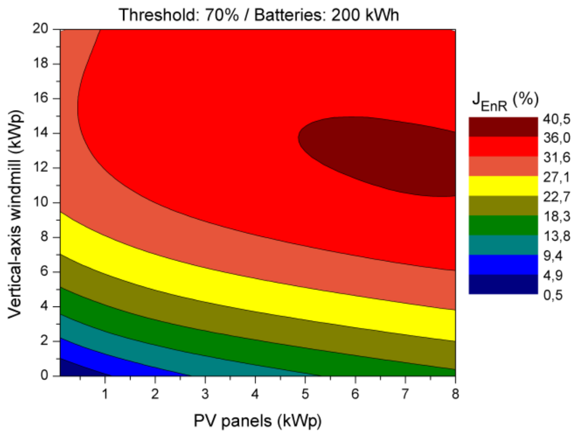

Figure 8: PV panels and v.-a. windmill sizing. Impact on J_{EnR}, for a grid threshold of 70% and batteries of 200 kWh

Tables 4 and 5 present new configurations as well as the results we obtained in simulation (one year). Configurations 4A, 4B, 5A, 5B, 6A and 6B (Table 4) are based on optimally designed photovoltaic solar panels and batteries. With this design, the criterion J_{EnR} is maximized. Results are given for three thresholds allowing the status of the electricity grid to be taken into account: 30%, 50% and 70%. A threshold of 30% is representative of a grid able to accept most of the time the decentralized production (configurations 6A and 6B). In opposition, a threshold of 70% is typical of a grid having a preference for injection of energy during peaks of demand (configurations 4A and 4B). Finally, a threshold of 50% is for a balanced electricity grid (configurations 5A and 5B). Whatever the threshold, the first configuration proposed (i.e. 4A, 5A or 6A) is based on photovoltaic solar panels of 6.9 kWp (design is from configuration 2) (Table 3) and optimized batteries. The second configuration (4B, 5B or 6B) is based on optimally designed PV panels and batteries. Configurations 7A, 7B, 8A, 8B, 9A and 9B (Table 5) are based on optimally designed photovoltaic solar panels, vertical-axis windmill and batteries. Configurations 7A, 8A and 9A derive from configuration 3 (PV panels of 3.8 kWp and a windmill of 11 kWp). Figures 7 and 8 highlight the impact of the sizing of the energy production and storage systems on J_{EnR}, for a grid threshold of 70%. In a general way, optimally designed batteries favour energy self-consumption (approximately +25% for a threshold of 70%, with or without vertical-axis windmill) and allow injection to the grid to be reduced (for example, for a threshold of 50%, energy injection is reduced of about 35% in case of windmill and about 15% without windmill). In addition, with optimally designed batteries, the amount of energy supplied by the electricity grid is also generally reduced (considering PV panels as well as a vertical-axis windmill, this amount is reduced of about 10% for a threshold of 70% and 2% for a threshold of 50%; amount is almost the same for a threshold of 30%). Clearly, optimally designed batteries allow interaction between the single-storey house and the grid to be minimized. However, batteries increase I_{inj} and reduce I_{ext}. In some cases, for example when considering a threshold of 70%, the overall impact of the considered house on the grid is increased. Periods of interaction seem to be less favourable for the grid when considering a storage system. Figures 9 and 10 depict the way energy is managed annually when using configuration 4B or 7B. Furthermore, batteries do not reduce economic costs. Depending on both the configuration and the threshold, one can observe a slight increase in costs when using batteries. As a key point, the lowest the threshold, the lowest the impact of the batteries on the management of the available energy resources. Finally, as highlighted by the results we obtained, energy storage is one of the best ways to overcome intermittency in local production and allows a better match between production and demand.

CONCLUSION

The paper focuses on a multi-criteria approach for energy resources management in buildings equipped with energy production and storage systems. This approach takes into account the way the building and the electricity grid interact. The aim of the proposed strategy is to favour energy self-consumption while minimizing the negative impact the local production can have on the grid. Energy and economic criteria are proposed to evaluate this strategy we applied in simulation to a single-storey house inhabited by four persons. This house can be equipped with photovoltaic solar panels, a vertical-axis windmill and batteries. We used the TRNSYS software to model the thermal behaviour of the building. A parametric study allowed the design of the local production and storage systems to be optimized. We obtained several configurations allowing energy self-consumption to be promoted while avoiding the impact of the house on the grid to be clearly negative. With the proposed management strategy, a good equilibrium between decentralized energy production, energy needs and integration into the grid can be found. Future work will focus on improving the strategy using a predictive approach. We want the availability of the renewable resources, variations in energy demand and the status of the grid to be anticipated and the storage system management to be refined. We will also consider the impact of the geographical situation, insulation and lifestyle habits on energy resources management.

Table 4: Configurations 4A, 4B, 5A, 5B, 6A and 6B with or without (in brackets) energy storage

Threshold (%)	70		50		30	
Configuration (-)	Config. 4A	Config. 4B	Config. 5A	Config. 5B	Config. 6A	Config. 6B
PV panels (kWp)	6.9	8	6.9	8	6.9	7.9
Batteries (kWh)	40 (-)	50 (-)	20 (-)	50 (-)	10 (-)	50 (-)
EnR_c (kWh)	7117 (5345)	7959 (5746)	5626 (5345)	6199 (5746)	5326 (5345)	5748 (5711)
EnR_{inj} (kWh)	2695 (4860)	3370 (6087)	4191 (4860)	5476 (6087)	4561 (4860)	5861 (5974)
E_{EDF} (kWh)	22266 (24038)	21425 (23638)	23757 (24038)	23184 (23638)	24058 (24038)	23635 (23672)
E_{stock} (kWh)	2166 (-)	2717 (-)	452 (-)	611 (-)	82 (-)	112 (-)
$\%_{SC}$ (%)	69.74 (52.38)	67.26 (48.56)	56.08 (52.38)	52.39 (48.56)	52.99 (52.38)	49.19 (48.88)
$\%_{EnR_c}$ (%)	24.22 (18.19)	27.09 (19,55)	19.48 (18.19)	21.10 (19.55)	18.41 (18.19)	19.56 (19.44)
J_{EnR} (%)	16.89 (9.53)	18.22 (9.49)	10.92 (9.53)	11.05 (9.49)	9.75 (9.53)	9.62 (9.50)
J_{cost} (€)	-997.27 (-977.20)	-927.33 (-901.44)	-982.12 (-977.20)	-909.55 (-901.44)	-978.44 (-977.20)	-905.67 (-901.83)
I_{inj}	1034 (616)	1292 (762)	2100 (1979)	2625 (2468)	2815 (2785)	3454 (3415)
I_{ext}	6383 (6645)	6238 (6634)	2124 (2048)	2217 (2144)	-2518 (-2538)	-2382 (-2384)
I_{over}	7417 (7261)	7529 (7396)	4224 (4027)	4842 (4612)	298 (247)	1072 (1031)

Table 5: Configurations 7A, 7B, 8A, 8B, 9A and 9B with or without (in brackets) energy storage

Threshold (%)	70		50		30	
Configuration (-)	Config. 7A	Config. 7B	Config. 8A	Config. 8B	Config. 9A	Config. 9B
PV panels (kWp)	3.8	5.8	3.8	4.2	3.8	3.5
V.-a. windmill (kWp)	11	15	11	18	11	20
Batteries (kWh)	200 (-)	200 (-)	190 (-)	200 (-)	100 (-)	200 (-)
EnR_c (kWh)	14251 (10994)	17313 (12917)	12659 (10994)	16000 (13162)	11868 (10994)	15305 (13688)
EnR_{inj} (kWh)	4621 (9124)	9373 (15431)	6645 (9124)	12669 (16774)	7848 (9124)	15190 (19327)
E_{EDF} (kWh)	15132 (18390)	12070 (16466)	16725 (18390)	13383 (16222)	17515 (18390)	14079 (15696)
E_{stock} (kWh)	4504 (-)	6058 (-)	2479 (-)	4105 (-)	1276 (-)	2997 (-)
$\%_{SC}$ (%)	70.84 (54.65)	61.07 (45.57)	62.92 (54.65)	53.45 (43.97)	59.00 (54.65)	48.53 (41.46)
$\%_{EnR_c}$ (%)	48.50 (37.41)	58.92 (43.96)	43.08 (37.41)	54.45 (44.79)	40.39 (37.41)	52.09 (46.58)
J_{EnR} (%)	34.36 (20.45)	35.99 (20.03)	27.11 (20.45)	29.10 (19.69)	23.83 (20.45)	25.28 (19.31)
J_{cost} (€)	-531.54 (-468.52)	-136.38 (-52.35)	-509.71 (-468.52)	-34.81 (26.89)	-488.84 (-468.52)	55.02 (106.62)
I_{inj}	942 (-662)	911 (-1166)	2755 (1551)	3920 (3574)	3978 (3208)	6901 (4013)
I_{ext}	3790 (4634)	3036 (4326)	844 (1024)	677 (-583)	-2413 (-2459)	-1995 (-525)
I_{over}	4732 (3972)	3947 (3160)	3599 (2575)	4598 (2991)	1565 (749)	4906 (3488)

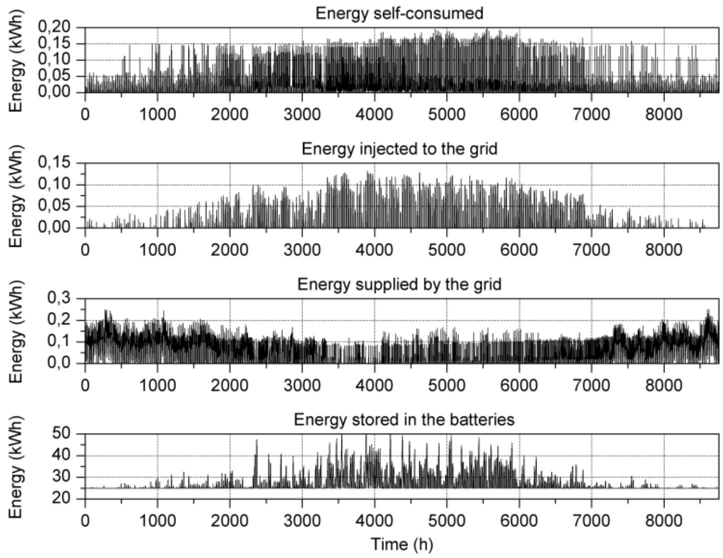

Figure 9: Energy management with configuration 4B (Table 4)

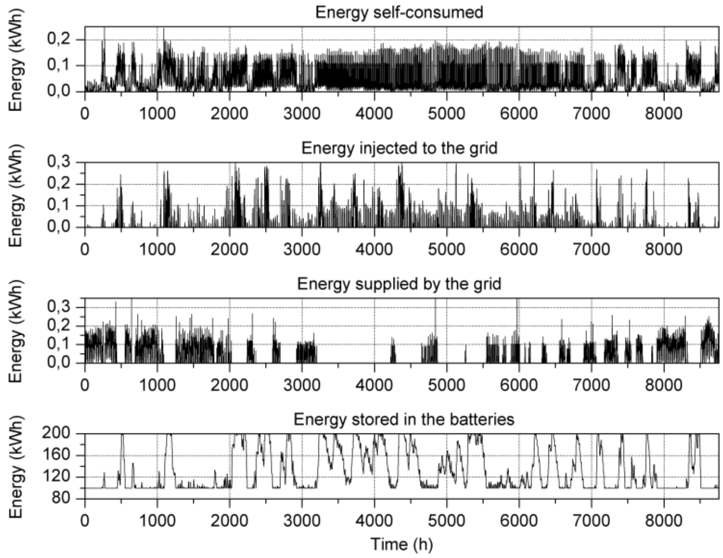

Figure 10: Energy management with configuration 7B (Table 5)

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