ANALYSIS OF RENEWABLE ENERGY POTENTIAL OF HYBRID SYSTEMS FOR DWELLINGS IN FRANCE

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ABSTRACT

In this study, the renewable energy potential for dwellings in France is analyzed. Generally, conventional solution consists in using solar panels and wind generator as energy resource. More precisely, the solar thermal panels are used to produce the thermal energy needs, and electricity is provided by wind generator and photovoltaic solar panels.

The goal of this work is to explore an alternative strategy based on an original hybridation of sources. In this alternative solution, a large part of the solar thermal panels is replaced by photovoltaic panels and a heat pump is introduced to ensure a crossover between the thermal energy flow and the electrical energy flow. The simulation results during one year for representative sites in France demonstrate a significant decrease of the missing energy.

This clearly establishes that a higher hybridation level improves the capacity of a renewable energy system to become autonomous.

Keywords: Renewable energy, Wind turbine, Photovoltaic array, Hybrid; Heat pump

1. INTRODUCTION

The main energy resources used in the world for more than one century have major drawbacks. They are fossils for almost 90% and the most optimistic projections about the depletion of oil and gas do not exceed one century (World Energy Council 2007).

They are also considered as the cause of global warming due to the release of carbon dioxide in the atmosphere. Moreover, their production is far away from the consumer because of their geographical distribution. Europe for example has no significant resources of oil, gas and uranium that are yet its main primary energy (World Energy Council 2007). Concerning France, the dwelling sector alone accounts for 25% of the total consumption of primary energy. In these 25%, more than 20% meet the thermal needs (hot water, cooking), and 4% the specific electrical needs (lights, electrical devices) (Ademe 2007).

Nowadays, in France, nuclear energy represents 40% of the primary energy consumption and provides 80% of electricity. This was and still presented as a gage of energetic autonomy. France is less oil dependant than other occidental countries, but its economic needs are dependent on uranium. Notice that, in the first hand, the uranium is also a limited resource, and in the other hand, France imports all its needs concerning uranium. Finally, Frances faces a similar problem than with oil.

Moreover, despite the excellent mastery of nuclear technology, the probability of a nuclear catastrophe is not null. This fact has to be seriously considered to develop green energies. Among the possible solution International Thermonuclear Experimental Reactor (ITER) project, a mass energy production system is now explored. ITER's mission is to demonstrate feasibility of fusion power, and prove that it can work without negative impact. Until the hypothetical success of this project, other solutions have to be explored.

These other solutions mainly consist of a better use of local energies. These local energies are solar energy and its derivative such as wind energy and biomass energy. Therefore, due to the variability of each local energy source, hybridation in sources and storage systems is necessary to meet the needs.

Therefore the configuration of the hybrid system will necessarily depend on geographical and socio-economic considerations. Thus, studies have been conducted on such energies potential in countries like Turkey (Ucar and Figen 2009), Tunisia (Elamouri and Ben-Amar 2009), Egypt (Ahmed-Shata and Hanitsch 2006), Syria (Al-Mohamad 2004), Saudi Arabia (Rehman and Al-Abbadi 2007), Kuwait (Al-Nassar, Al-Hajraf, Al-Enizi and Al-Awadhi 2007), Nigeria (Ngala, Alkali and Aji 2007), Cameroon (Tchindaa, Kendjioa, Kaptouoma and Njomob 2000), Hungary (Radics and Bartholy 2008), Lithuania (Marciukaitis and Katinas 2008), Greece (Bagiorgas, Assimakopoulos, Theoharopoulos, Matthopoulos and Mihalakakou 2007), Netherlands (Schenk, Moll, Potting and Benders 2007), Guadalupe- France (Tarkowski and Uliasz-Misiak 2003), Spain (Ordonez and Jadraque 2010) and Lebanon (Moubayed, El-Ali and Outbib 2009).

Generally speaking, in conventional renewable energy systems, thermal solar panels with water tanks are the most common solution to provide heat from solar radiations. To provide electricity, photovoltaic

NOMENCLATURE

η_0	Rated efficiency for the EN 12975 thermal solar panel model
τ	Time constant of the house (s)
a_{1a}	Coefficient of heat losses for the EN 12975 thermal solar panel model (W.m^{-2}.K^{-1})
a_{2a}	Coefficient of heat losses for the EN 12975 thermal solar panel model (W.m^{-2}.K^{-2})
a_i	Coefficient of the model of the heat pump rated absorbed power
b_i	Coefficient of the model of the heat pump rated produced power
G_h	Global solar radiation on horizontal surfaces (W.m^{-2})
G_i	Global solar radiation on inclined surfaces for the EN 12975 thermal solar panel model (W.m^{-2})
G_v	House global Coefficient of heat exchange (W.K^{-1})
K_{PV}	Coefficient of temperature of the cells for the photovoltaic panels model (K.W^{-1}.m^{-2})
K_u	Charge Coefficient of the heat pump
K_{wpv}	Temperature Coefficient of the maximum power for the photovoltaic panel (W.K^{-1})
P_{ec}	Electrical consumption (kW)
P_{ehp}	Electrical consumption of the heat pump (kW)
P_{epv}	Electrical power of the photovoltaic panels (kW)
P_{erhp}	Rated electrical consumption of the heat pump (kW)
P_{ewg}	Electrical power of the wind generator (kW)
P_e	Electrical power sent or extract from the electrical storage (kW)
P_{thp}	Thermal energy production of the heat pump (kW)
P_{trhp}	Rated thermal energy produced by the heat pump (kW)
P_{ttsp}	Thermal power of the solar thermal panels (kW)
Q_{max}	Thermal storage capacity (kWh)
Q_s	Thermal storage level (kWh)
t_a	Ambient temperature of the air for the EN 12975 thermal solar panel model (K)
t_{in}	Inlet temperature of the water for the EN 12975 thermal solar panel model (K)
t_m	Medium temperature of the water for the EN 12975 thermal solar panel model (K)
t_w	Heat pump outlet water temperature (°c)
t_{out}	Outlet temperature of the water for the EN 12975 thermal solar panel model (K)
t_{PV}	Temperature of the cells for the photovoltaic panels model (K)
t_{sp}	House temperature set point (°c)
t_{STC}	Temperature of the cells of the photovoltaic panels in Standard Test Conditions (K)
W_{emax}	Electrical storage capacity (kWh)
W_e	Electrical storage level (kWh)

panels and wind generators are the most common solutions, and the storage solution is chemical batteries. Finally, the systems are composed by two independent systems. The first one meets the thermal needs and the second one meets the electrical needs.

The goal of this work is to explore an alternative strategy for energy production in France based on an original hybridation of sources and way of storage. To this hand, a local analysis of energy potential in France is necessary. Hence, the paper is dedicated to an analysis of energy autonomy of dwellings powered by renewable energy systems in France. This is done by introducing a cross over between the thermal energy flow and the electrical energy flow, using a heat pump. The electricity provided by photovoltaic panels and/or wind generator can also be converted into thermal energy by the heat pump. Thus, the energy management in this alternative solution is improved since one system manages the energy for all the needs.

The paper is organized as follows. In the second section, the configuration of the considered dwelling and two energy systems to power it are presented, and the characterizations of the system components are developed. This work is done under the hypothesis that the storage capacity for the thermal energy and electrical energy are similar for the two solutions. In the third section, results of the simulation are presented and compared. Finally, in the last part, a conclusion with perspectives is discussed.

2. DESCRIPTION OF SYSTEM COMPONENTS

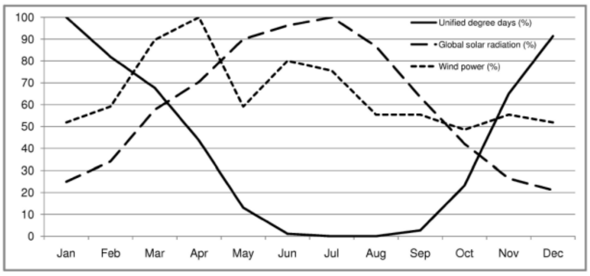
The goal of this section is to present the models used for the simulation of the whole system.

2.1. Weather data

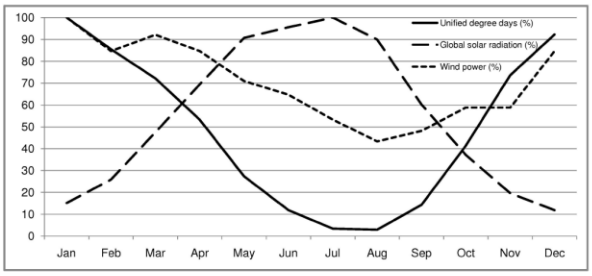
In renewable energy systems for dwellings, the difficulty is the hazardous energy production that is not synchronous with the needs, not only during the day but also throughout a year. Seasonal variations on solar radiation, wind potential and heating requirements are presented in this section for three different sites (see fig. 1).

The data (from Météofrance statistics, Météofrance is the French national meteorological organism) conducted over the period 1970-2000 are expressed as a percentage of the maximum to bring out seasonal fluctuations. Overall, the evolution of the solar radiation is not in phase with heating requirements quantified here by the Degree Day method, while wind power for these three areas the most populated in France shows a more regular evolution during one year, even in phase with the heating requirements.

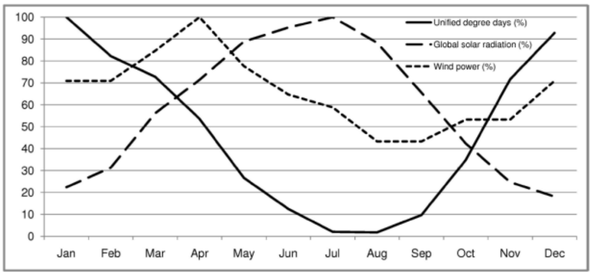
In this simulation, the hourly weather data are provided by the software METEONORM 6.1 (Edition 2009), which is a comprehensive meteorological reference, incorporating a catalogue of meteorological data and calculation procedures for solar applications and system design at any desired location in the world (Remund, Kunz, Schilter and Müller 2009). Hourly data for radiation on inclined surfaces, air temperature and wind speed are generated from meteorological statistics. These data are used to calculate the energy potential of different sites in France.



(a) Marignane



(b) Paris



(c) Bordeaux

Figure 1: Seasonal Fluctuation of Heating Needs and Energy Potentials

2.2. House under consideration

In this study, the building is a standard house of 100m2. This house has a global coefficient of heat exchange G_V (Flach-Malaspina 2004) and a time constant $\tau = 8h = 28800s$.

The temperature set point inside house is assumed to be T_{sp} = 19°c (292,15K) for every time. Then, the thermal needs for heating can be expressed :

$$\frac{G_{v\times(T_a-T_{sp})}}{1+\tau p}$$

with T_a the outside temperature of the air (K)

The house is south oriented, and has a $A_{gs} = 6m^2$ glass surface south exposed. The efficiency of glass surfaces concerning the solar radiations is given to be 80%. In that condition, the energy provided by glass surfaces is equal to $0.8 \times G_{90}$ (the global solar radiation on vertical surfaces [$W.m^{-2}$]).

The daily electrical consumption is 17kWh (see fig. 2). Forty percent of the electrical energy consumed is Joule losses which heat the house. A part of the losses of the storage tank, due to its localization in the house, also heat the house. The area available for roof integrated solar systems is $60m^2$. A garden can receive a wind turbine without major embarrassment for the neighborhood.

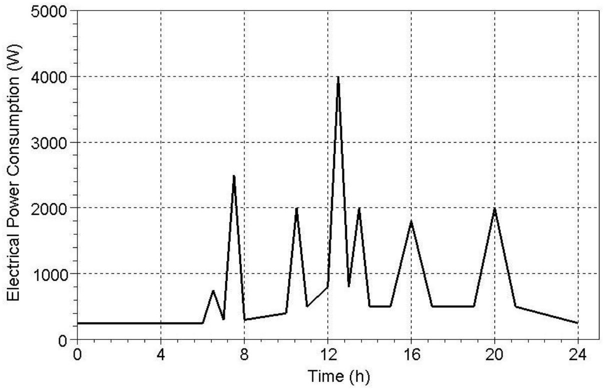


Figure 2: Profile of Daily Electrical Consumption

The usable area of roof is facing south and has a slope of 30°. The air volume to heat is $250m^3$ and the air change rate is 0.3 volume per hour. The heating system is a low temperature heating floor, with a maximal temperature of 35°c (308,15K).

2.3. First configuration

The first configuration is as in figure 3 and figure 4. In that configuration, $40m^2$ of useful surface for panels are used for photovoltaic panels, and $20m^2$ for the thermal panels.

A 10kW heat pump (for a 7°c air temperature and a

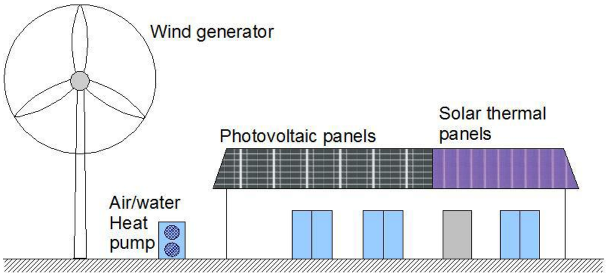


Figure 3: Implantation of the Hybrid System

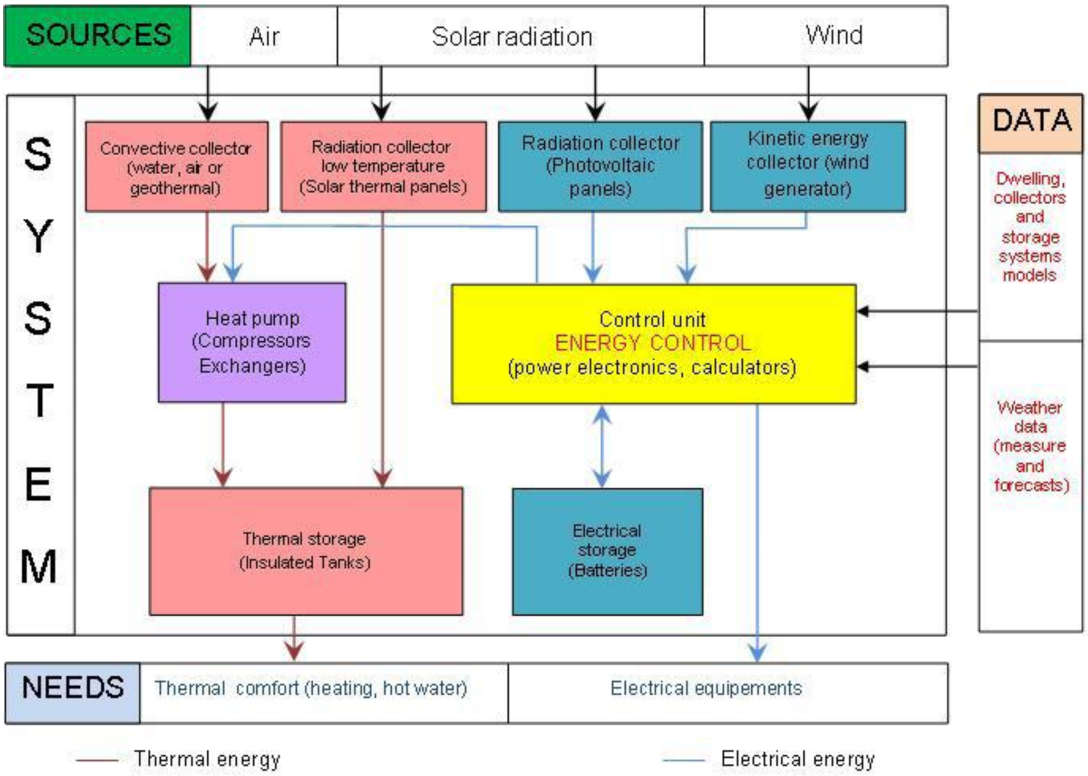


Figure 4: Configuration of the Hybrid System

35°c water temperature) is used to produce heat from the electricity provided by photovoltaic panels and wind generator. Then, this configuration produces heat from thermal panels, photovoltaic panels or from wind generator. Electricity is assumed to be produced by both photovoltaic panels and wind generator.

2.4. Second configuration

The second configuration is as in figure 3 and figure 4, except there is no heat pump and no photovoltaic panels. So, the 60m^2 of useful surface for panels are integrally used for thermal panels. Then, this configuration produces heat only from thermal panels and electricity only from wind generator.

2.5. The solar energy collectors

2.5.1. The thermal solar panels

The model used is the standard EN 12975. The functional dependence of the collector efficiency on the meteorological and system operation values can be expressed by the following mathematical equation :

$$\eta_{(G,(t_m-t_a))} = \eta_0 - a_{10}\frac{t_m - t_a}{G_i} - a_{2a}\frac{(t_m - t_a)^2}{G_i}$$

with $t_m = \frac{t_{in}-t_{out}}{2}$.

The coefficients η_0, a_{10}, a_{2a} have the following meaning:

- η_0: efficiency without heat losses, which means that the mean collector fluid temperature is equal to the ambient temperature
- Coefficients a_{10} and a_{2a} describe the heat loss of the collector. The temperature dependency of the collector heat loss is described by:

$$a_{10} + a_{2a}(t_m - t_a)$$

The parameters used for the simulation are determined from the absorber area of a commercial solar panel (Teknoenergy 2008):

- $\eta_0 = 0.721$
- $a_{10} = 4.4\, W.m^{-2}.K^{-1}$
- $a_{2a} = 0.018\, W.m^{-2}.K^{-2}$

2.6. The solar photovoltaic panels

The solar photovoltaic panels are also modeled by an efficiency rate. In fact, associated with a MPPT controller (Maximum Power Point Tracking), 95% of maximum power can be assumed to be always available (Lucque and Hegedus 2005).

It is also assumed that the power provided by the association of photovoltaic panels and regulator is then nearly proportional to solar radiation. The efficiency of the panel used in this study decreases of 5.8% when the solar radiations decrease from 1000W.m^{-2} to 200W.m^{-2}.

We must also take into account the temperature of photovoltaic cells has a significant influence on performance.

To estimate the temperature t_{PV} of the cells, the approximation to be made is to consider that the difference between ambient temperature t_a and the cell is proportional to solar radiation G_i (Lucque and Hegedus 2005):

$$t_{PV} = t_a + K_{PV}.G_i$$

For the characteristics of the panels included in the model (Kyocera 2010), the reference used in this estimate is that for an irradiation of 800W.m^{-2} and a air temperature of 20°c, the temperature of the cell under these conditions (NOCT: Normal Operating Cell Temperature) is 47.9°c. The power was then supplied to 95W, and $K_{PV} = 3.49 \times 10^{-3}$. Then, the energy P_{epv} supplied by the association photovoltaic panels together and MPPT regulator can then be expressed for one square meter of installed panel:

$$P_{epv} = \eta_0.G_i - (t_a + K_{PV}.G_i - t_{STC})K_{WPV}$$

The value of K_{WPV} is given to be 0.614W.K^{-1} and the value of t_{STC} is given to be 20°c. The value of η_0 is given to be 0.12.

2.7. The wind energy and the wind generator model

To collect the kinetic energy of air, the use of wind turbines has grown since the middle Ages with the mills to grind grain. Currently, if wind turbines are still relevant, they are predominantly coupled to an alternator to produce electricity. This make the energy collected portable and usable for more applications.

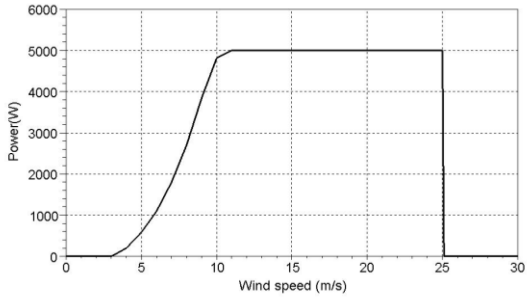


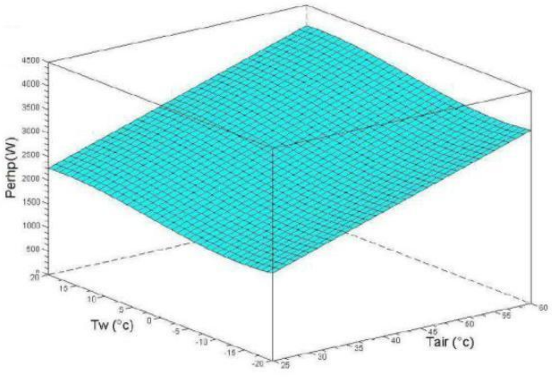
Figure 5: The Wind Generator Power Curve

In this simulation, a typical wind generator curve (see fig. 5) was implemented in the simulation model (Burton, Sharpe, Jenkins and Bossanyi 2001).

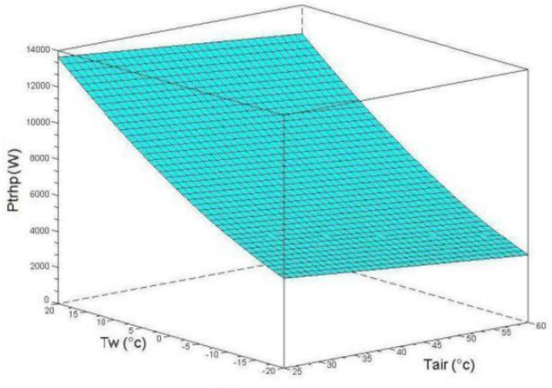
2.8. The geothermal energy and the heat pump model

The principle of a heat pump is to transfer calories from a cold source to a warm source, reversing the natural cycle of heat transfer. In the case of heating a home with a heat pump, the pump collects the calories in the environment outside the house and returns inside. These calories can be collected in either the groundwater or in soil or in the air.

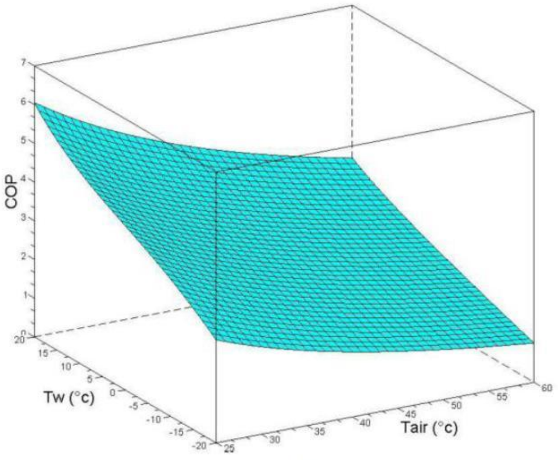
The transfer of heat is done using a coolant which undergoes a cycle of compression and relaxation, and it is just necessary to provide compression energy to initiate the transfer.



(a) Perhp(W)



(b) Ptrhp(W)



(c) COP

Figure 6: Heat Pump Characteristics

The coefficient of performance (COP) of a air/water heat pump, for air temperature of 7°C and an outlet temperature of water of 35°C for floor heating must be present at 3.5 minimum in order to qualify this equipment for a tax credit in France. This means that under these conditions, for 1 kW of electricity consumed on the electricity network, the pump returns 3.5 kW of heat into the building. The 2.5 kW of variance are collected in the air or soil. Even in winter, outdoor air, water and soil contain enough calories to heat a building.

However, the COP of a heat pump decreases as the temperature difference between the hot source and cold source increases (Auzenet and Clerc-Renaud 2004). Heat pumps in this process collect an indirect solar energy (the heat of the air or the ground) and concentrate that energy in the reduced volume of the house. These systems can be reversible concerning the heat transfer, and they can be used to heat in winter and cool in summer. The heat pumps have long been regarded as not forming part of renewable energy systems, since the primary energy needed to produce the electricity they need are overwhelmingly fossil. The development of electricity generation by renewable resources has nevertheless helped to change this opinion and it is now accepted that heat pumps are an integral part of renewable energy systems.

In the simulation, the heat pump is used as the "energy amplifier" of the energy provided by photovoltaic panels and the wind generator. The model implemented for the simulation is as in Flach-Malaspina (2004):

$$P_{trhp} = a_0 + a_1 t_a + a_2 t_w + a_3 {t_w}^2 + a_4 {t_w}^3$$
$$P_{erhp} = b_0 + b_1 t_a + b_2 t_w + b_3 {t_w}^2 + b_4 {t_w}^3$$

The coefficients a and b are here correlated from the characteristics of a commercial heat pump (CIAT 2009) (see fig. 10) as follow:

$$\begin{aligned} P_{trhp} &= 9345.1127 - 35.247773 t_a + 219.69055 t_w \\ &\quad + 2.0963582 {t_w}^2 - 0.00667885 {t_w}^3 \\ P_{erhp} &= 703.03721 + 51.719762 t_a + 21.123712 t_w \\ &\quad + 0.1548888 {t_w}^2 - 0.0282035 {t_w}^3 \end{aligned}$$

The heat pump selected for this study is a variable pump power, with a power variation range from 40 to 100%. This allows operating over a wide range of electrical energy supplied by wind generator and solar photovoltaic panels. The operation at lower power improves the COP, but this fact is neglected in the model. Indeed, the exchangers of the heat pump are sized for full power, and they end up oversized when operating at reduced power.

2.9. The energy storage

Due to the intermittent nature of solar radiations and wind, development of renewable energy systems is intimately linked to the development of reliable and economic energy storage systems. Solar energy is stored spontaneously in nature through the phenomenon of photosynthesis and biomass. To store it in a usable form, several technologies exist: thermal energy

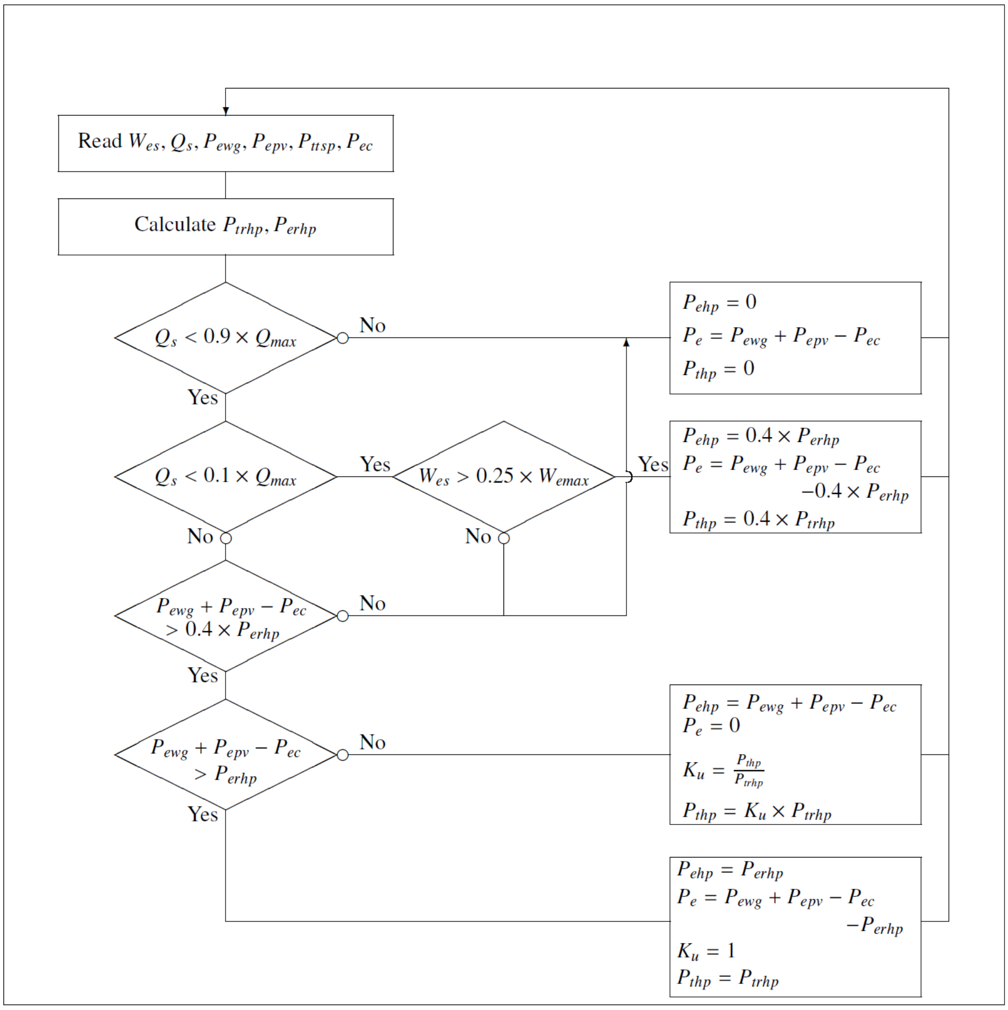


Figure 7: Algorithm of the Electrical Energy Management

storage, electrochemical batteries, supercapacitors, flywheels, hydrogen, compressed air, two-phase materials, etc. Some processes are well mastered and widely used, but for others it remains to be done.

2.9.1. Thermal storage

This is the most used and easiest way to store solar energy. In the case of systems of hot water, it is simply an insulated water tank which uses the heat capacity of water (4185J.kg^{-1}.K^{-1}). For this application, water is indeed a material which has one of the best characteristic and is cheaper. For comparison, the heat capacity of steel is nearly ten times lower than the water's one.

2.9.2. Chemical batteries

Different technologies exist: lead-acid, nickel cadmium, lithium, zinc air, etc. Their main interest is due to their high energy density (up to 150kWh.kg^{-1} for lithium) and their technological maturity, at least for a few kWh of capacity. Their main disadvantage is their short lifespan of around 1000 cycles of high amplitude cycling. The main application is embedded systems and emergency systems such static uninterruptible power supply (UPS).

When performing a charge-discharge cycle, the energy efficiency of a battery varies from 70% to 90% depending on the technology (Multon and Ben Ahmed 2007).

2.9.3. The energy storage in the simulation

The thermal energy storage (W_{ths}) consists of insulated water tanks. The energy level is considered to be empty when the water temperature is 35°c, and to be high when the water temperature is 55°c. The storage capacity is 150kWh; this represents a volume of 6.45m^3. The energy losses are for the simulation are 5W.K^{-1}.

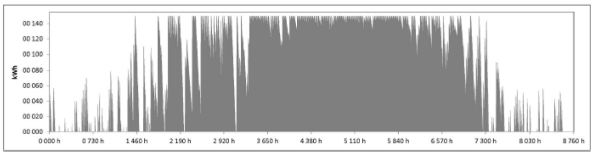
The electrical energy storage (W_{es}) consists of typical lead-acid batteries, with a charge efficiency of 85% and a discharge efficiency of 85% too. This means that when the electrical production is in excess (Pe > 0), $\frac{dW_{es}}{dt} = 0.85P_e$, and when there is not enough electrical energy produced (Pe < 0), $P_e = 0.85\frac{dW_{es}}{dt}$.

The storage capacity W_{esmax} for the simulation is 50kWh. This kind of electrical storage is probably not the best way to store electricity in a large scale, so other way will be discussed in the fourth part.

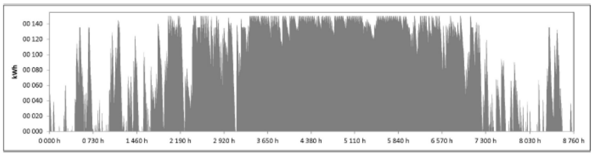
3. RESULTS OF THE SIMULATIONS

The algorithm implemented to manage the electrical energy is described in figure 7. Globally, the priority is the thermal needs. When the thermal level storage is under 10% of its maximum capacity, the electrical storage is used to produce heat with the heat pump, and this until the electrical storage level is over 25%.Thermal energy production

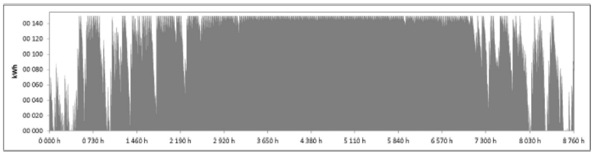
Considering the total duration on one year of missing thermal energy, the first configuration provides more better results than the second one (table 1) . Even in less sunny regions as Macon or Clermont-Ferrand, a significant decrease of the total duration of missing thermal energy is observed. The missing thermal energy decreases significantly with the configuration 1 (table 2). The gain estimated is up to 50% for sites as Caen, Millau and Perpignan.



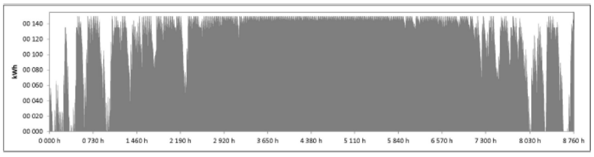
(a) Evolution of the thermal storage level for the site of Trappes in configuration 2



(b) Evolution of the thermal storage level for the site of Trappes in configuration 1



(c) Evolution of the thermal storage level for the site of Marseilles in configuration 2



(d) Evolution of the thermal storage level for the site of Marseilles in configuration 1

Figure 8: Evolution during a Typical Year of the Thermal Energy Storage Level for the Configuration 1 and 2 for the Sites of Trappes and Marseille

Tableau 1: Total Duration of Missing Thermal Energy for some Sites in France (hours)

Site	Config.1	Config.2	Variation
BORDEAUX	788	860	-8%
BREST	820	1535	-47%
CAEN	765	1601	-52%
CLERMONT	1159	1263	-8%
LIMOGES	1118	1487	-25%
MACON	1812	1894	-4%
MARSEILLE	242	303	-20%
MONTPELLIER	232	347	-33%
NANTES	1013	1399	-28%
NICE	119	173	-31%
PARIS	1415	2352	-40%
PERPIGNAN	108	249	-57%
RENNES	1021	1703	-40%
STRASBOURG	2225	2356	-6%
TRAPPES	1293	1898	-32%

Tableau 2: Total of Missing Thermal Energy for some Sites in France (kWh)

Site	Config.1	Config.2	Variation
BORDEAUX	2417	2633	-8%
BREST	2414	4186	-42%
CAEN	2455	4957	-50%
CLERMONT	4052	4426	-8%
LIMOGES	3688	4800	-23%
MACON	6036	6363	-5%
MARSEILLE	759	952	-20%
MONTPELLIER	785	1066	-26%
NANTES	3185	4316	-26%
NICE	313	456	-32%
PARIS	4512	7065	-36%
PERPIGNAN	330	735	-55%
RENNES	3295	1021	-37%
STRASBOURG	8406	9054	-7%
TRAPPES	4382	6247	-30%

Then, from the thermal point of view, replacing 66% of the thermal solar panels by photovoltaic panels associated with a air/water heat pump has beneficiary consequences on the thermal energy production. The figure 8 shows the evolution of the thermal energy storages level for the two configurations and the sites of Trappes and Marseilles.

3.1. Electrical energy production

Considering the total duration on one year of missing thermal energy, the first configuration provides better results than the second one (table 3). A spectacular decrease of the total duration of missing electrical energy is observed for all the localizations. The best gain is obtained during the summer season. The configuration 2 is thermally oversized during this season, whereas the configuration 1 provides really more electricity during that period.

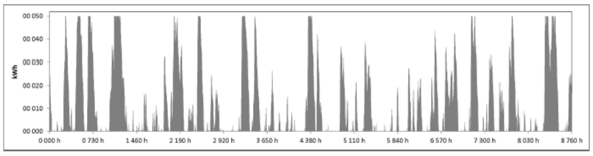
Tableau 3: Total Duration of Missing Electrical Energy for some Sites in France (hours)

Site	Config.1	Config.2	Variation
BORDEAUX	937	4819	-81%
BREST	686	3263	-79%
CAEN	386	2253	-83%
CLERMONT	1378	5301	-74%
LIMOGES	1081	4481	-76%
MACON	2004	5934	-66%
MARSEILLE	199	1650	-88%
MONTPELLIER	254	2788	-91%
NANTES	725	3788	-81%
NICE	98	2923	-97%
PARIS	1013	3408	-70%
PERPIGNAN	52	1942	-97%
RENNES	674	3269	-79%
STRASBOURG	2335	5858	-60%
TRAPPES	986	3766	-74%

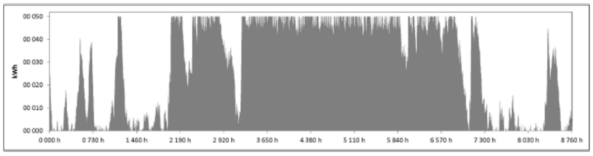
Tableau 4: Total of missing Electrical Energy for some Sites in France (kWh)

Site	Config.1	Config.2	Variation
BORDEAUX	464	3219	-86%
BREST	347	2167	-84%
CAEN	190	1469	-87%
CLERMONT	685	3563	-81%
LIMOGES	526	3000	-82%
MACON	1045	4038	-74%
MARSEILLE	90	1046	-91%
MONTPELLIER	112	1771	-94%
NANTES	359	2513	-86%
NICE	47	1882	-97%
PARIS	509	2278	-78%
PERPIGNAN	25	1231	-98%
RENNES	325	2157	-85%
STRASBOURG	1219	3956	-69%
TRAPPES	528	2493	-79%

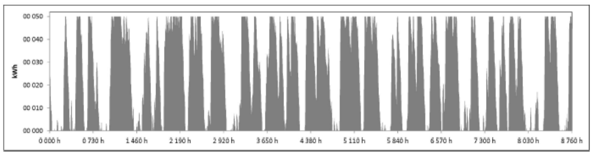
The gain for the non-used electricity can reach more than 5000% for a site such Strasbourg. The figure 9 shows the evolution of the electrical energy storages level for the two configurations and the sites of Trappes and Marseilles.



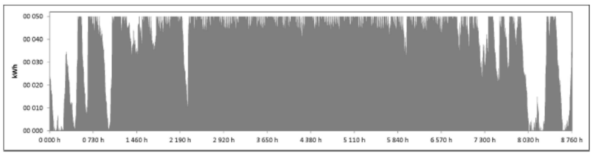
(a) Evolution of the electrical storage level for the site of Trappes in configuration 2



(b) Evolution of the electrical storage level for the site of Trappes in configuration 1



(c) Evolution of the electrical storage level for the site of Marseilles in configuration 2



(d) Evolution of the electrical storage level for the site of Marseilles in configuration 1

Figure 9: Evolution during a Typical Year of the Electrical Energy Storage Level for the Configuration 1 and 2 for the Sites of Trappes and Marseille

The gain is essentially obtained during the summer time, where the configuration 2 is thermally oversized.

The missing electrical energy decreases significantly with the configuration 1 (table 4). The gain estimated is up to 90% for sites as Marseille, Montpellier, Nice or Perpignan.

4. DISCUSSION

The configuration of the studied hybrid system was the same for all the studied sites. The aim was to prove that whatever is the chosen site, a higher level of hybridation improves the energy management in renewable energy systems. The choice of the configuration can be adapted to the site meteorological characteristics to improve the exploitation of local energies. This will be the aim of another article. The electrical storage chosen should evolute up to a reversible fuel cell or compressed air system. In renewable energy systems, hydrogen is produced by electrolysis and then compressed to be stored in tanks, like compressed air. Energy efficiency is about 70%. The hydrogen is stored to power a fuel cell that produces the reverse of electrolysis and can therefore restore the energy stored as hydrogen into electrical energy. The fuel cell itself can not constitute a renewable energy system; it is just a way of stored energy release. The performance of a fuel cell is also close to 70%, the yield of chain-electrolyzer stack is about 50%.

Research has already shown that a simple hybrid battery-electrolyser-fuel cell storage for electric refund reduces the overall cost of storage by 91% compared to a solution based entirely on batteries (Vosen and Keller 1999). Other studies (Santarelli, Cali and Macagno 2004; Onar 2008) show about the site significance on the choice of elements of a hybrid system of energy production by renewable sources, given the specific climate of each site.

Thus, it is certain that the explosion risk of hydrogen remains a major obstacle to developing this technology. Strict regulations should be established to oversee the development and dissemination of such technology. The security problem is less critical with compressed air. Investigation and optimization of hybrid electricity storage systems based on compressed air and supercapacitors have been conducted and seem to be full of promises (Lemofouet-Gatsi 2006).

5. CONCLUSION AND PERSPECTIVES

In this study, a configuration of a renewable energy system was proposed. A part of the solar thermal panel surface is covered with photovoltaic panels, and a heat pump is installed to create a crossover between the electrical energy flow and the thermal energy flow. It can be concluded as follows concerning the configuration with a heat pump:

1. The thermal needs of a dwelling on one year are as well met than for a full thermal solar panel configuration. An improvement up to 50% is estimated for some sites.
2. The electrical needs of a dwelling on one year are as really better met than for a full thermal solar panel configuration. An improvement up to 90% is estimated for some sites of the study.
3. The improvement of the unused electrical energy is significant, and is a perspective of a better autonomy when the storage technologies will enable to use that energy. That energy could be used per example to produce hydrogen with electrolysers, and so to power hydrogen cars per example.

Finally, due to the different sources and forms of renewable energy, and due to the different energy needs, a higher level of hybridation in a renewable energy system improves clearly the autonomy of the system, and this, for the same implantation of energy collectors. Creating crossovers between different energy forms allows a better useful of the collected energy.

In this study, a simple algorithm of energy management was implemented. The implantation of more sophisticated algorithm, including the weather forecasts, should allow with the same material configuration to improve the autonomy. Weather forecasts are in the context of renewable energy based on solar radiations and wind energy a way to estimate the energetic potential of the next days. Included in the algorithm, this can only improve the management of the energy.

Finally, one configuration was proposed for each site of this study, but a work has to be done to find the best configuration for each one. A methodology to find that specific configuration has to be developed too.

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