Load management by optimizing operations of the radiators

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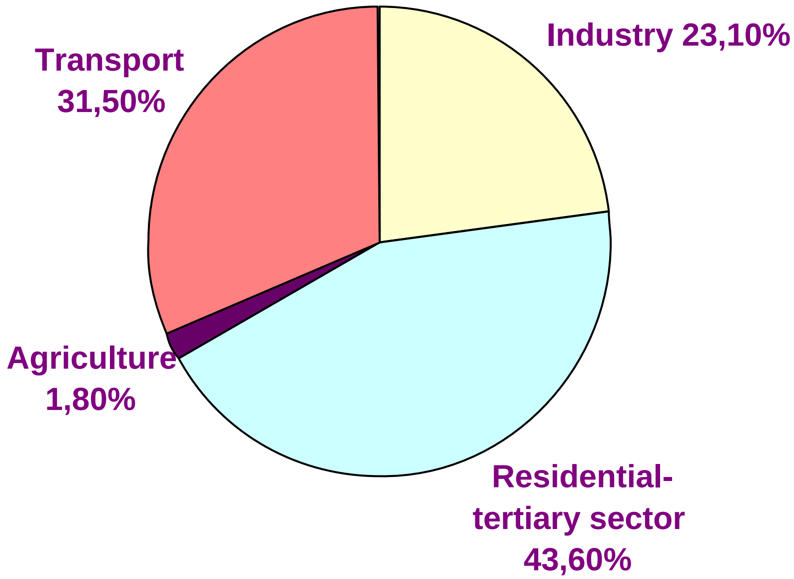
Context

In France in 2005, the sector of the building (residential and tertiary), with 43.6% of the final energy demand (64% of the electric demand)

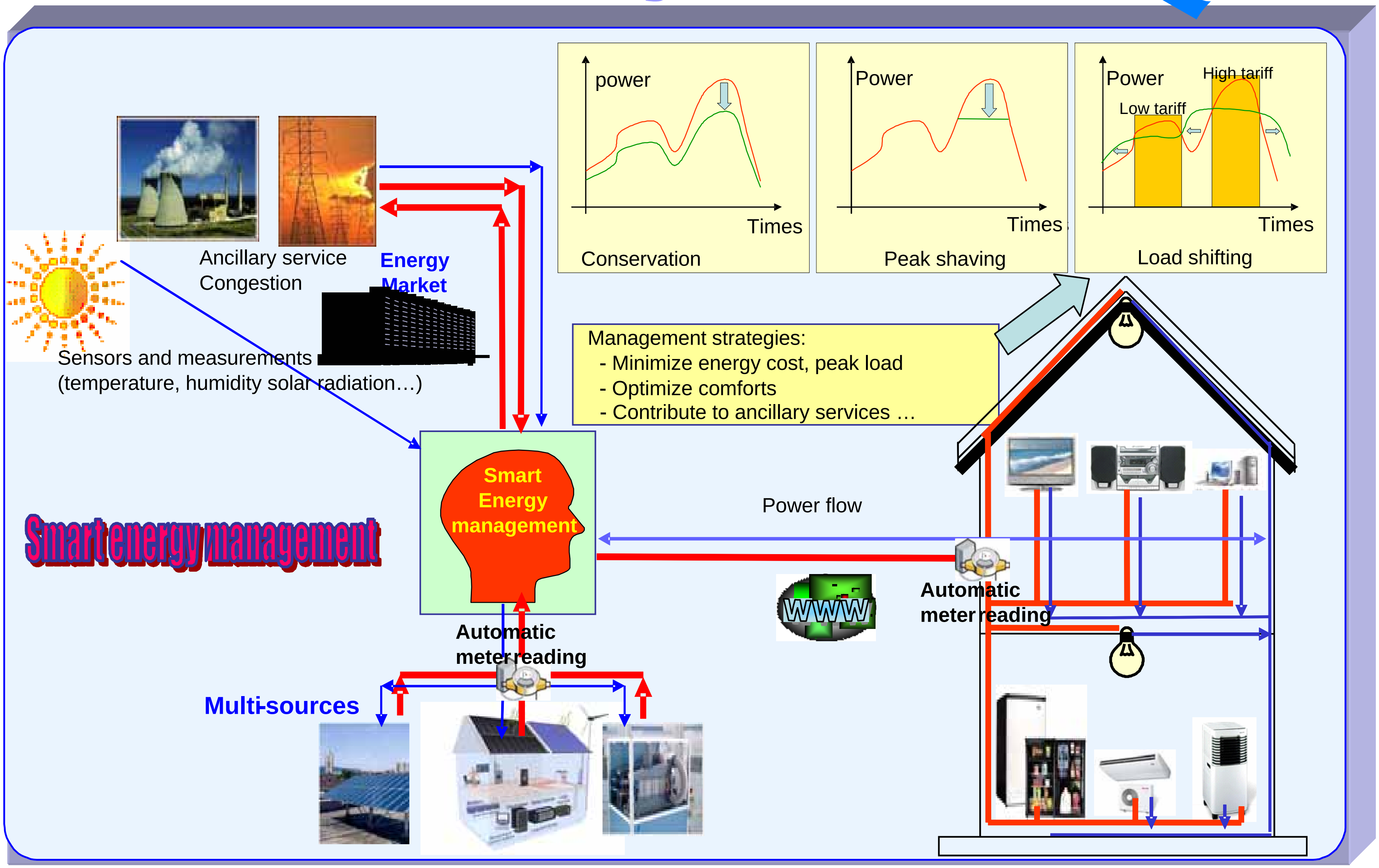
⇒ greatest potentials of energy efficiency and reduction of the gas emissions

Electric demand in 2005 in France



Sectoral structure of the final power consumption

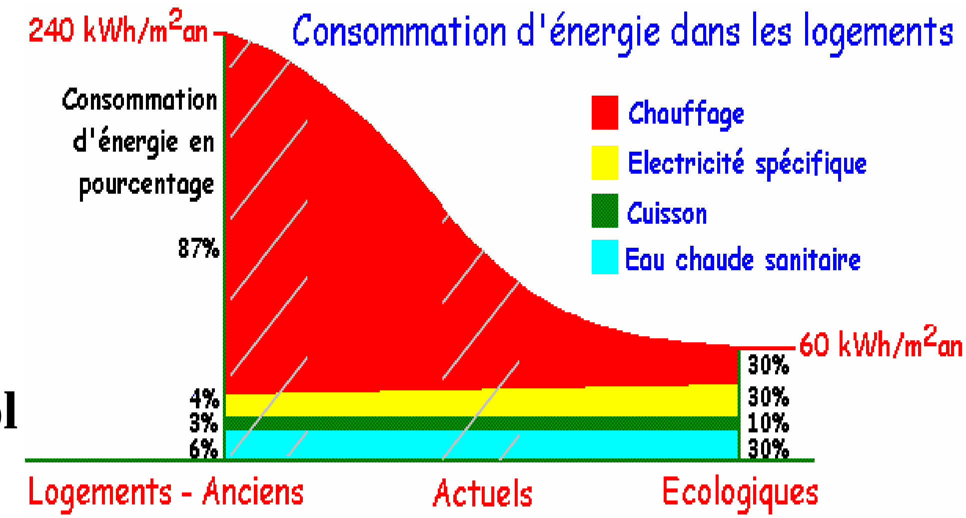
Objective


power
Times
Conservation
Power
Times
Peak shaving
Power
High tariff
Low tariff
Times
Load shifting
Ancillary service
Congestion
Energy Market
Sensors and measurements
(temperature, humidity solar radiation…)
Management strategies:
- Minimize energy cost, peak load
- Optimize comforts
- Contribute to ancillary services …
Smart Energy management
Power flow
Smart energy management
Automatic meter reading
Automatic meter reading
WWW
Multi-sources

Heating control - Why?

The heating is a controllable load:
- **75% for the residential sector**
- **30% for the tertiary sector**

DSM considers heating load to implement direct customer load control



In DSM, the room heating units => control modes by control signals issued from sub stations either via remote radio link or via PLC link at distribution level when the utility wants to exercise demand control during periods of power shortage.

For **customers**: reduce bill for subscription and consumption in rush hours
For **DNO**: avoid the congestion and the technical problems caused by overloads,
For **energy provider**: limit the purchase of an expensive energy.

Heating operation optimization

Propose three strategies of operation of the radiators:

- **Minimize of peak load of consumption**
- **Optimize the interior temperature**
- **Minimize the cost of electricity consumption**

First objective function: Minimization of peak load

Minimize peak load for n radiators: $\underset{u_{i,k}\in(0,1)}{Min}\left[P\right]=\sum_{i=1}^{D}\sum_{k=1}^{n}\left[P_k u_{i,k}\right]$

$u_{i,k}\in\left(0,1\right)$

Subject to: $T_k^{\min} < T_{i,k}^{\mathrm{int}}\left(u_{i,k}\right) < T_k^{\max}$ **(Comfort constraint)**

or $\mathrm{T}_\mathrm{k}^{\min} \le \mathrm{C}_{\mathrm{i,k}}(u_{i,k})\,\mathrm{e}^{-\frac{\Delta\tau}{\mathrm{K_k.R_k^{eq}}}} + \mathrm{T}_{\mathrm{i,k}}^{\mathrm{ext}} + R_k^{eq} p_k u_{i,k} \le \mathrm{T}_\mathrm{k}^{\max}$

$\sum_{k=1}^{n} p_k u_{i,k} \le P_{perm}$ **(Constraint of permissible or contractual power)**

With

$u_{i,k}$ operation state of the radiator k (stop: 0 or start: 1)

P_k rated power of the radiator k

$\Delta\tau$ calculating step

n : number of radiators

D : times of simulation

2nd Obj. Fun: Optimization of temperature to maintain comforts

The objective function is to maintain the internal temperature of each room nearest the temperature set-point value for each moment i

$$\underset{u_{i,k}}{Min}\left[T\right]=\sum_{k=1}^{n}\left[T_{i,k}^{\text{int}}\left(u_{i,k}\right)-T_{i,k}^{cons}\right]^{2} \qquad u_{i,k}\in\left(0,1\right)$$

$$\underset{u_{i,k}\in(0,1)}{Min}\left[F(u_{i,k})\right]=\sum_{k=1}^{n}\left[C_{i,k}e^{-\frac{\Delta\tau}{K_{k}R_{k}^{eq}}}+T_{k}^{ext}+R_{k}^{eq}p_{k}u_{i,k}-T_{k}^{cons}\right]^{2}$$

Subject to: $T_{k}^{\min}<T_{i,k}^{\text{int}}\left(u_{i,k}\right)<T_{k}^{\max}$ **(Comfort constraint)**

or $\mathrm{T}_{\mathrm{k}}^{\min}\leq \mathrm{C}_{\mathrm{i,k}}(u_{i,k})\,\mathrm{e}^{-\frac{\Delta\tau}{\mathrm{K_k.R_k^{eq}}}}+\mathrm{T}_{\mathrm{i,k}}^{\mathrm{ext}}+R_{k}^{eq}p_{k}u_{i,k}\leq \mathrm{T}_{\mathrm{k}}^{\max}$

$\sum_{k=1}^{n}p_{k}u_{i,k}\leq P_{perm}$ **(Constraint of permissible or contractual power)**

3rd Obj. Fun: Minimization of the cost of electricity consumption

Minimize the cost of electricity consumption

$$\underset{u_{i,k}\in(0,1)}{Min}\left[A_{i,k}\right]=\sum_{i=1}^{D}\sum_{k=1}^{n}\left[p_k u_{i,k} a_{i,k}^{elect}+Ab_k^{elect}\right]\Delta\tau$$

$$u_{i,k}\in(0,1)$$

Subject to: $T_k^{\min} < T_{i,k}^{\text{int}}\left(u_{i,k}\right) < T_k^{\max}$ **(Comfort constraint)**

or $\mathrm{T}_{\mathrm{k}}^{\min} \le \mathrm{C}_{\mathrm{i,k}}(u_{i,k})\,\mathrm{e}^{-\frac{\Delta\tau}{\mathrm{K_k.R_k^{eq}}}} + \mathrm{T}_{\mathrm{i,k}}^{\text{ext}} + R_k^{eq} p_k u_{i,k} \le \mathrm{T}_{\mathrm{k}}^{\max}$

$\sum_{k=1}^{n} p_k u_{i,k} \le P_{perm}$ **(Constraint of permissible or contractual power)**

Proposed algorithm

A system with n units, a variable *u* : started (one) or stopped (0)

These problems: integer variables and nonlinear constraints

⇒ Solved by applying the combination methods

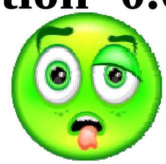
⇒ Difficult to solve if n very great

Ex: 7 units (radiators), each step = 1 min, simulation for one hour

⇒ $2^{(7*60)}$ = 2.7077e+126 combinaisons

⇒ if computing times for each combination=0.01s

⇒ 8.5861e+116 years of simulation =>

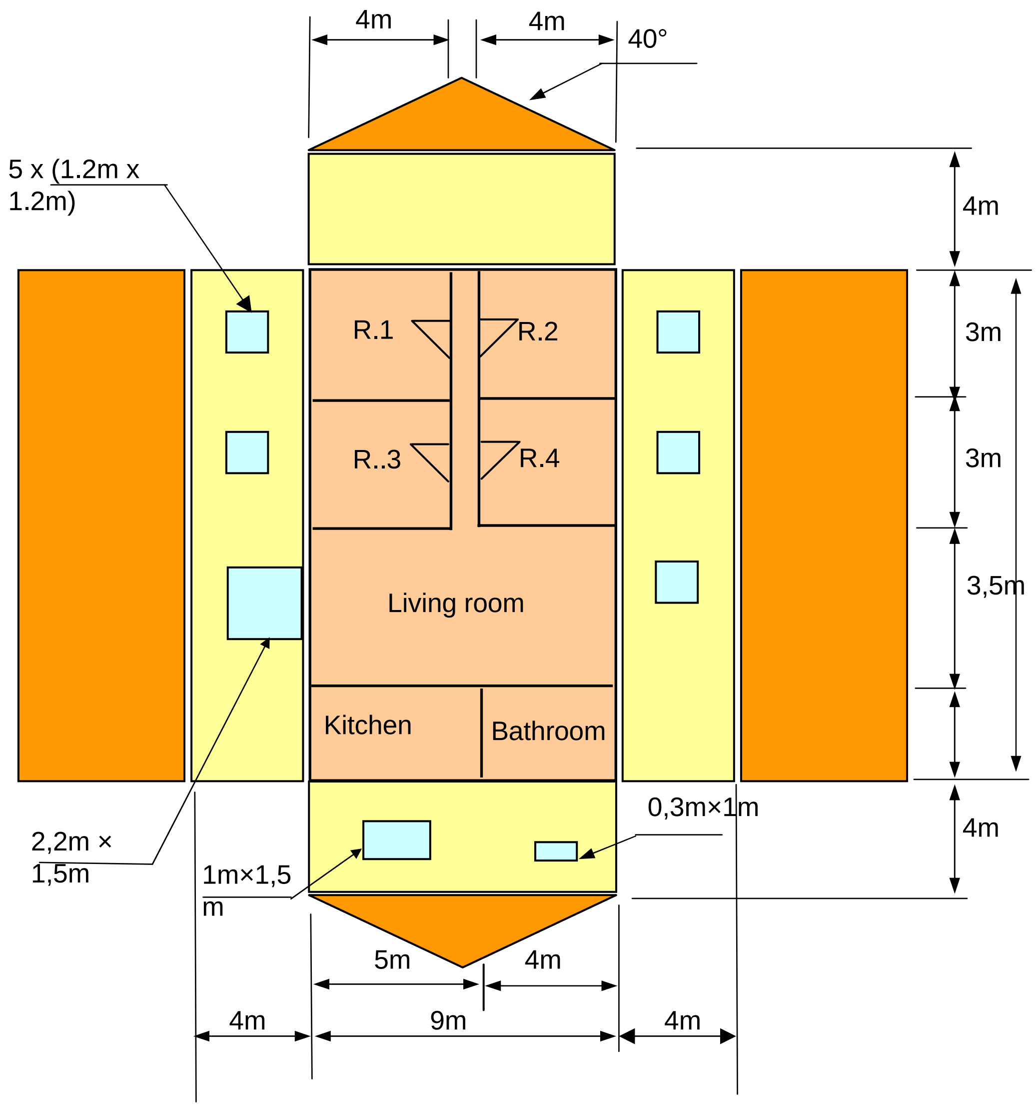


In order to solve this problem, we propose a mixed algorithm by using the algorithm "Branch and Bound" and the nonlinear programming

=>

Suggested method is applied for the thermal load management (heating)

Application case for a house



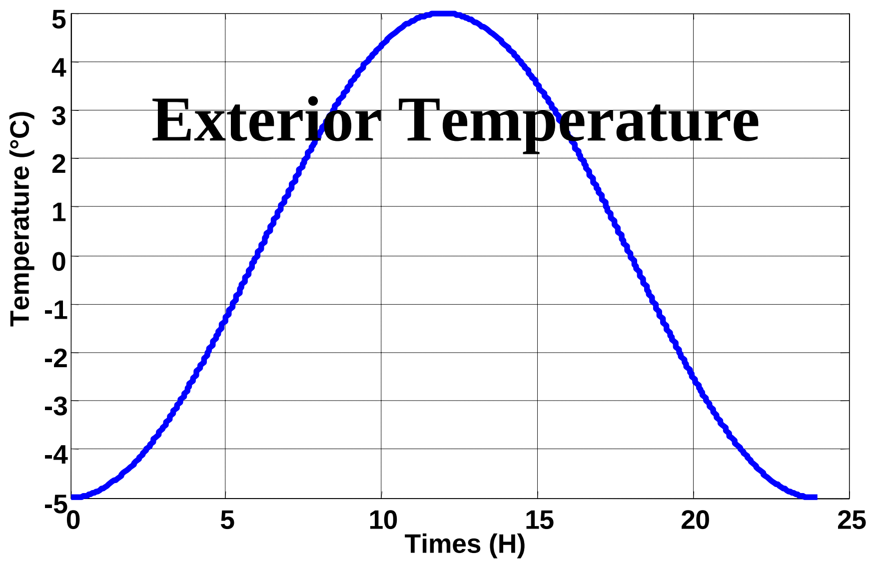
This house includes the following electrical appliances:

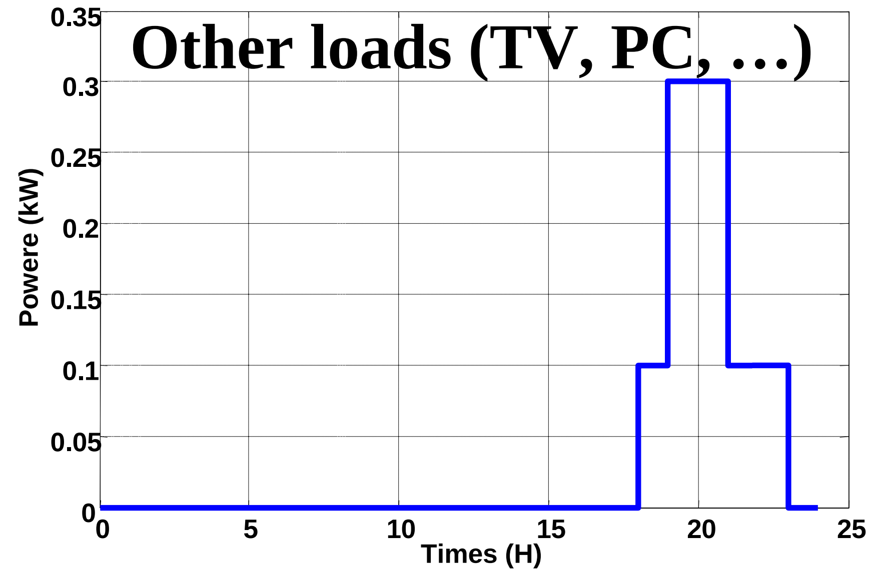
- 6 radiators x 1500 W = 9000 W (for Bedrooms No1, 2, 3, 4, Kitchen and Bathroom)
- 1 radiators 2000 W (for Living-room)
- 1 electric cooker 2500 W
- 1 electric cooker 1500 W
- 1 refrigerator 150 W
- 1 freezer 125 W
- 1 dishwasher 1600 W
- 1 washing-machine 2400 W
- Total power = 19275 W = 19.275 kW

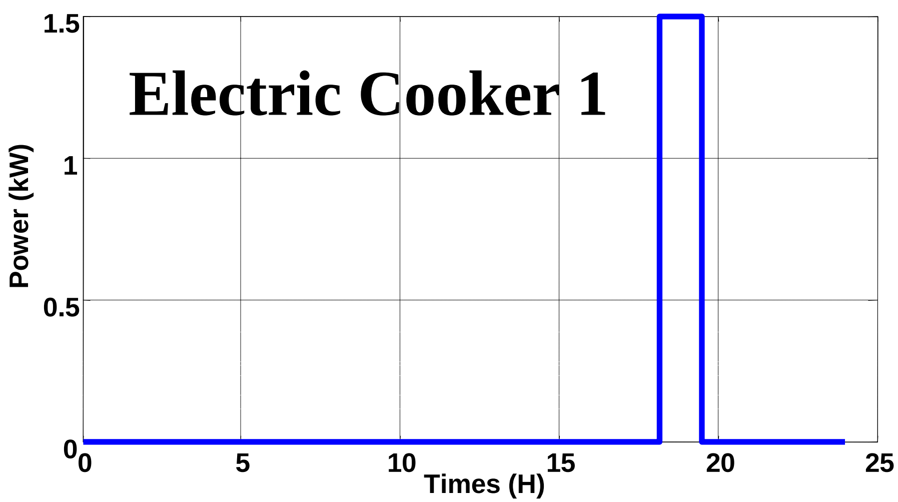
- Set-point temperature of all rooms: 20°C

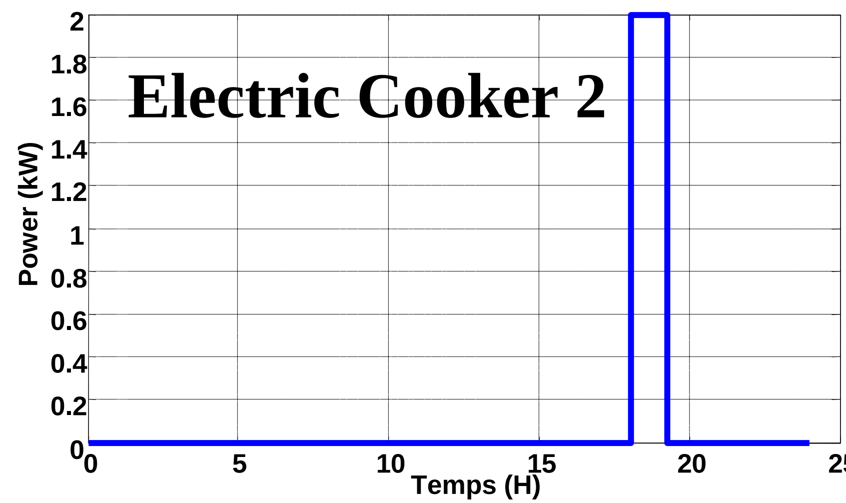
T_{ext} = -5±5°C

Load modelling

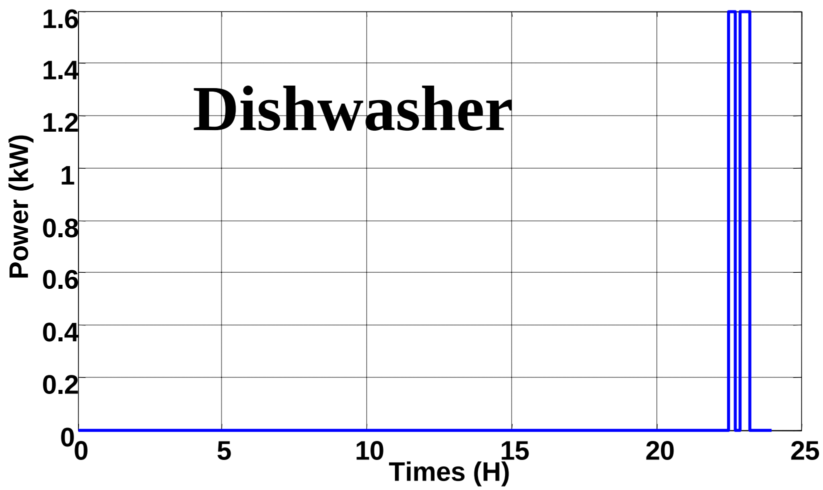


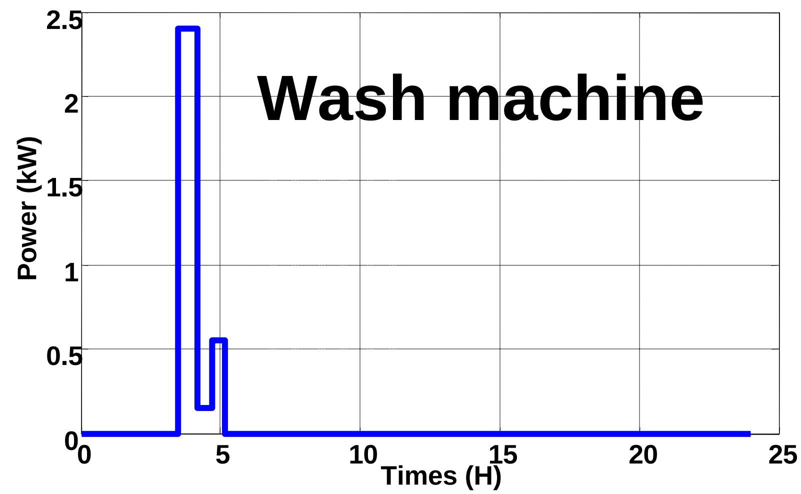


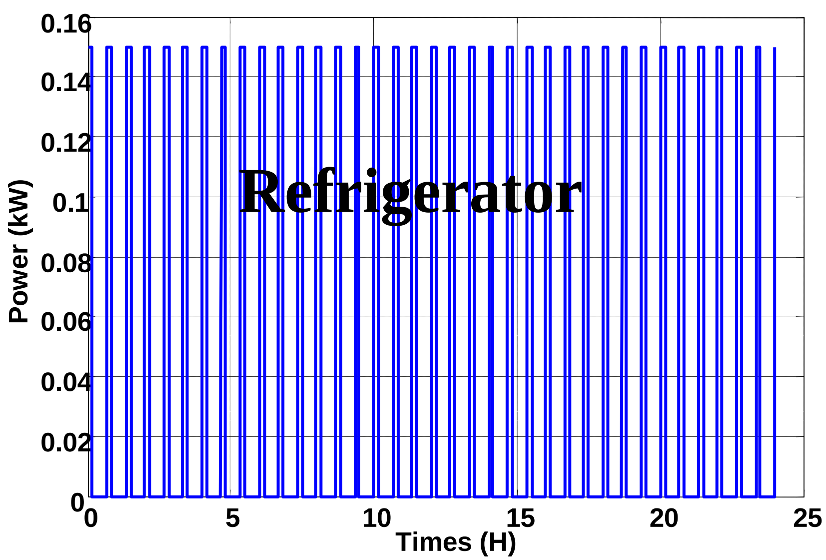


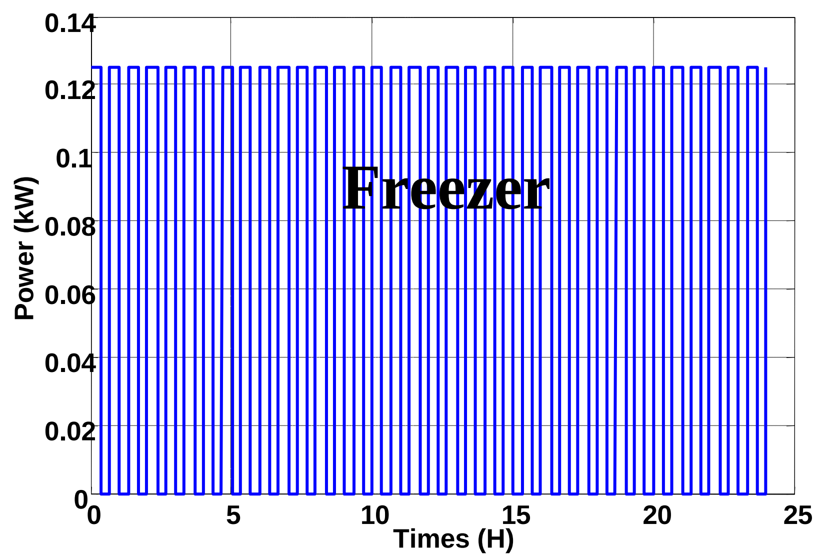


Load modelling

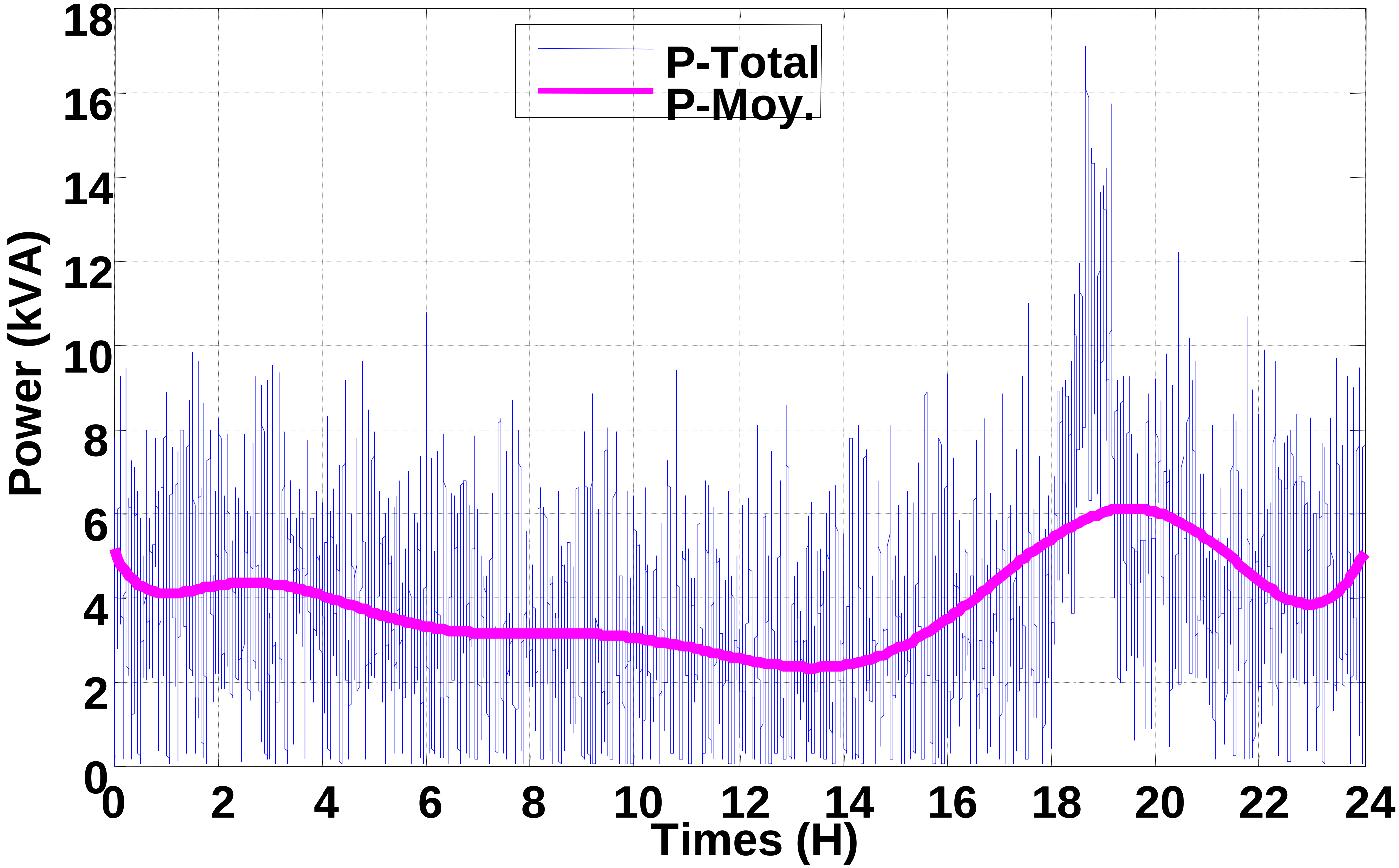






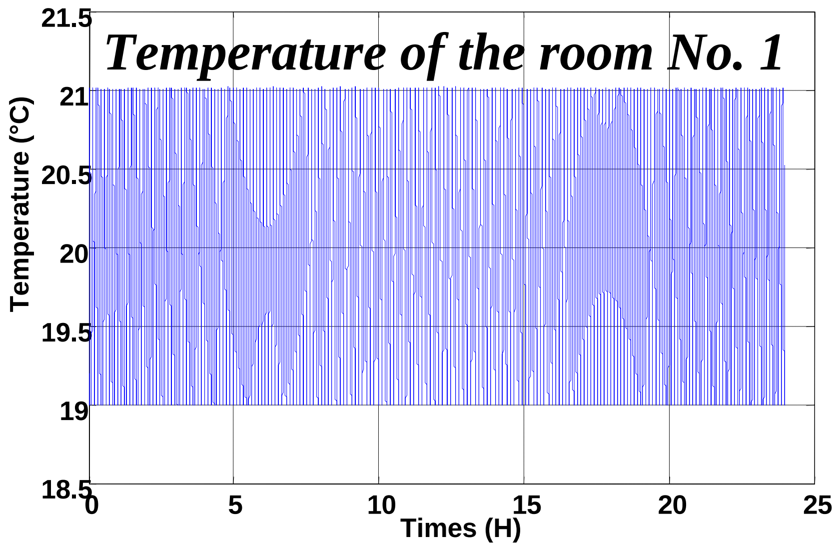


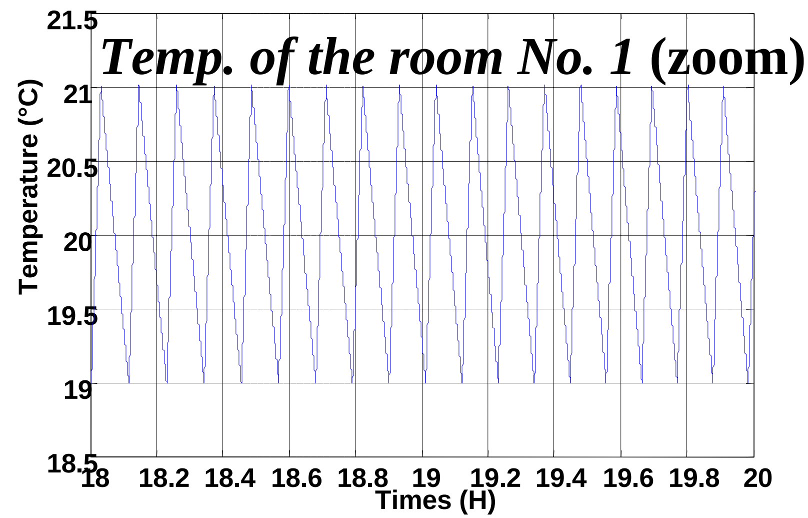
Without load management

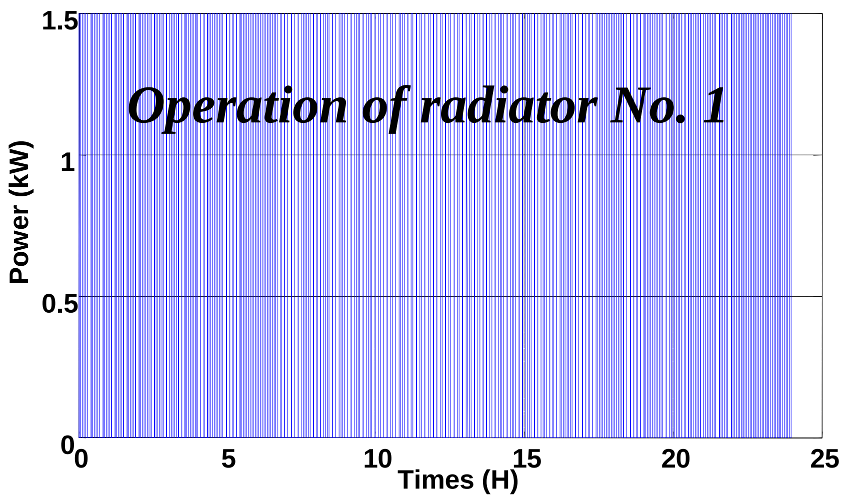


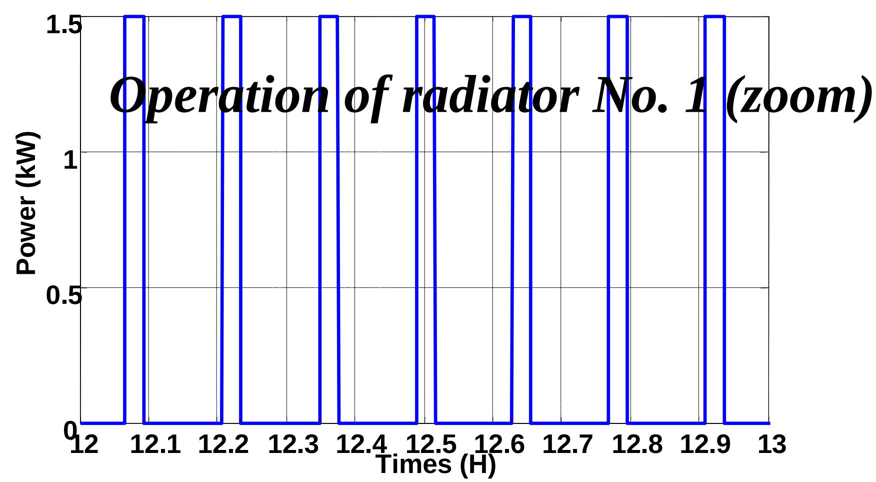
Pmax = 17.27 kVA

Without load management

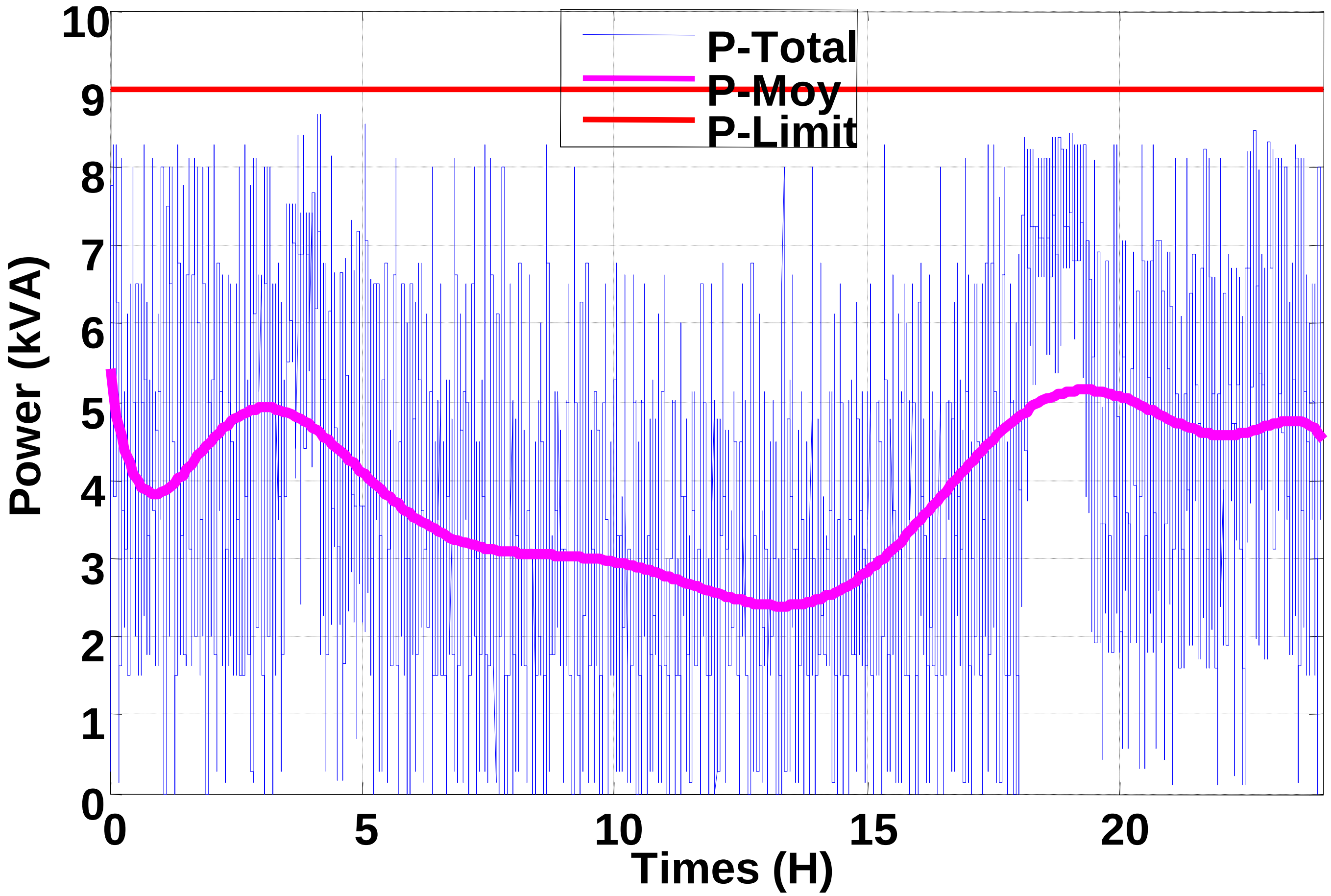






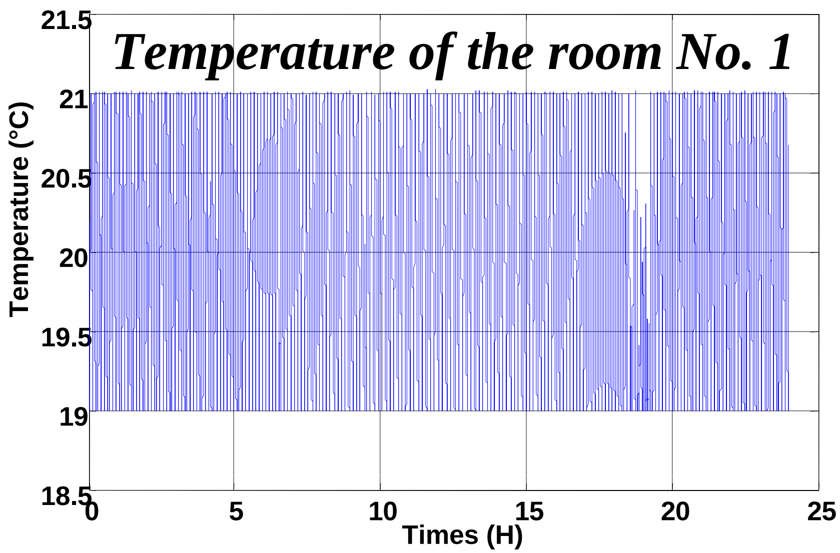


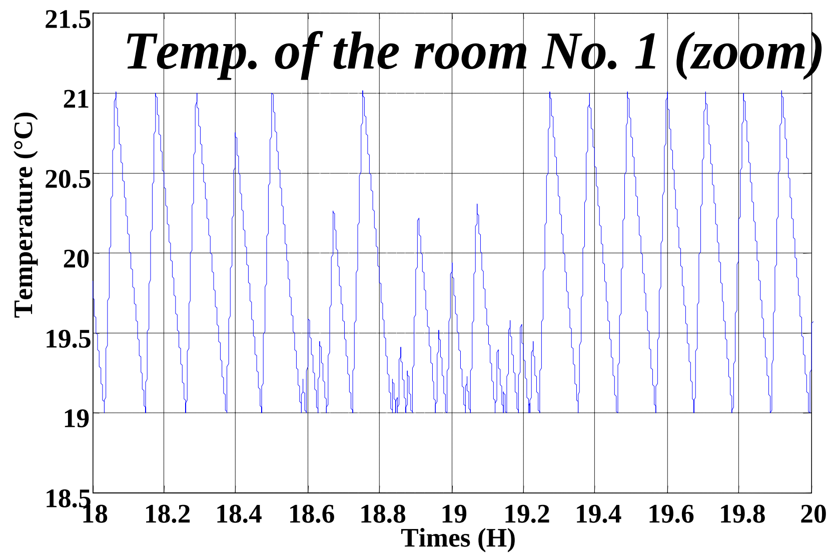
With load management



Pmax < 9 kVA

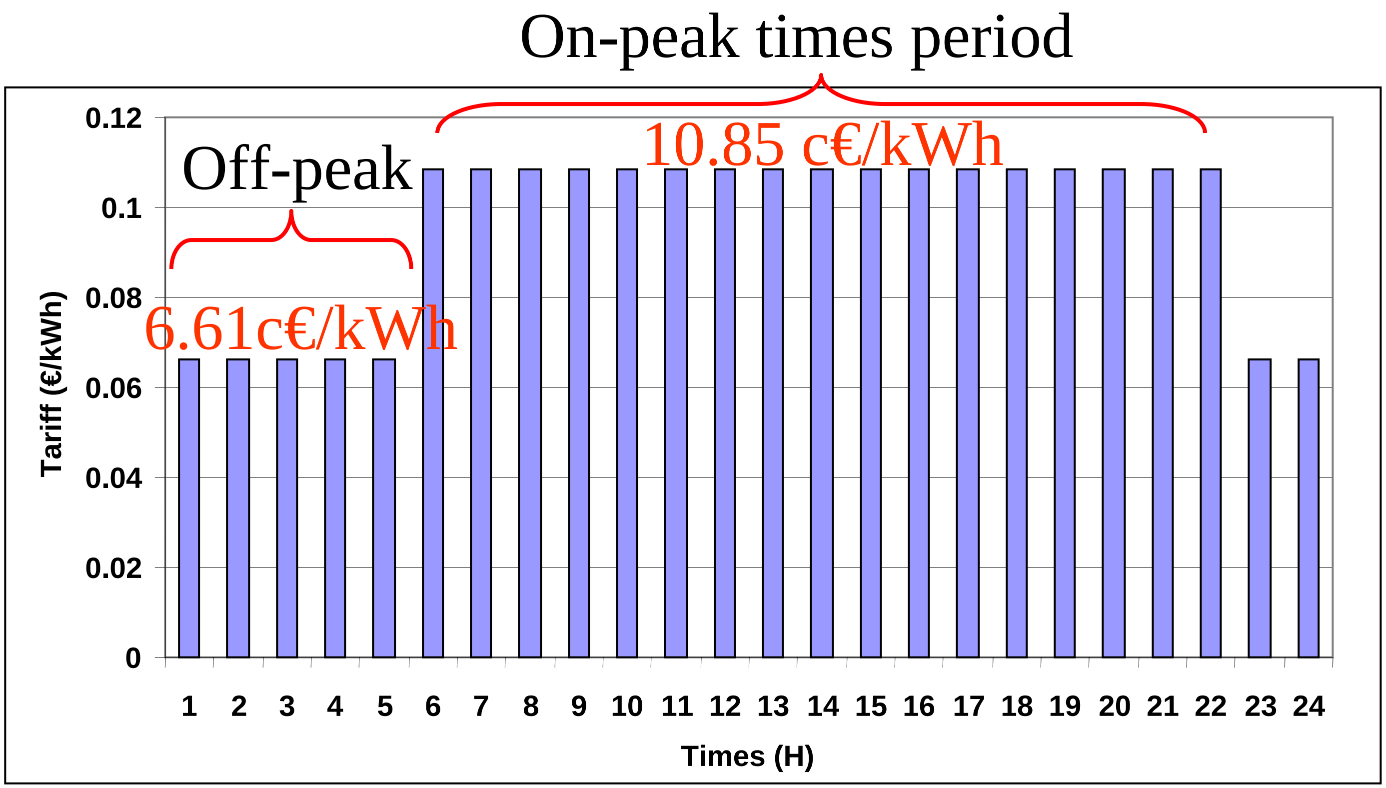
With load management





Results of minimization of the cost of consumption

Application for a system with two tariff (France case)



System of two tariffs

Results of minimization of the cost of consumption

	Contractual power (kVA)	Cons. (kWh/ day)	Cost of cons. (€/day)	Subscription (€/day)	Total (€/day)	Saving (%)
Without Manage ment	15	92.39	19.00	0.99	19.99	-
With Manage ment	9	92.39	8.49	0.53	9.02	54.92

CONCLUSIONS

The results of simulation show that:

- Permit to reduce efficiently peak consumption by maintaining thermal comfort

- Adapt to the conditions for a new context (by taking into account of the dynamic tariffs, of the signals of the provider or the manager of the network)

- Applied to a group of loads or buildings (virtual consumer)

- Permit to avoid congestion in a distribution network