Optimization models for energy management systems

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INTRODUCTION - Demand response

- The electricity sector has been open to **retail competition**, including to residential customers.
- Retail companies procure electricity in wholesale markets and offer flat or (slightly variable) **tariffs** to their residential customers, thus managing the risk involved.
- These tariffs do not convey **price signals** reflecting generation costs and grid conditions (e.g., congestion).
- Therefore, **consumers do not have sufficient incentives to adopt consumption patterns different from habitual behaviors**, which could be also beneficial from the perspective of grid management.

INTRODUCTION – Demand response

- **Flexibility** regarding **time of operation** of some **end-use loads**:
  - improving the system overall efficiency,
  - lowering peak generation costs,
  - facilitating the penetration of renewable sources,
  - reducing network losses

  while offering consumers economic benefits.

- **Time-differentiated retail tariffs** reflecting the system conditions (energy prices and network access costs) are expected to become a common tariff scheme in **smart grids**.

- Facilitated by the deployment of **smart meters** → more **active role of** consumers/prosumers regarding **energy decisions**.

INTRODUCTION – Demand response

theguardian

Winter electricity blackouts risk recedes, says National Grid

Extra power will mean lights will not go out this winter, says firm that operates UK's electricity transmission network

INSIDE ENERGY

Timing Is Everything When It Comes To Your Future Electricity Bill

By Stephanie Joyce, Wyoming Public Radio | March 3, 2016

Historically, electricity pricing has been relatively straightforward: the more you use, the more you pay. But today, that simple equation is not so simple. Increasingly, the time of day when you use electricity factors into the cost as well.

Los Angeles Times

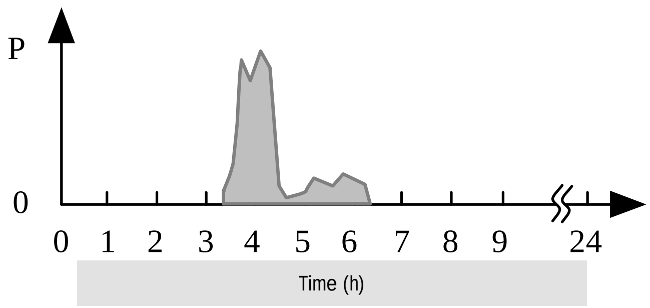
Why 'dynamic' pricing based on real-time supply and demand is rapidly spreading

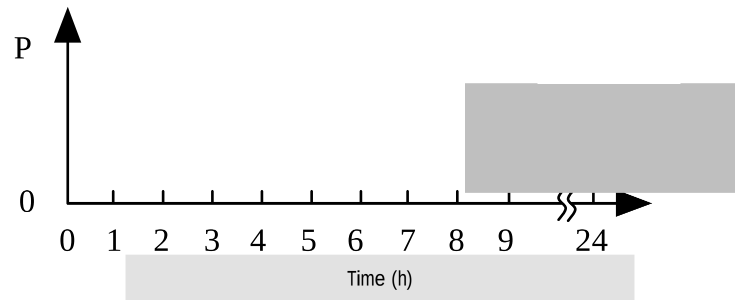
INTRODUCTION – Demand response

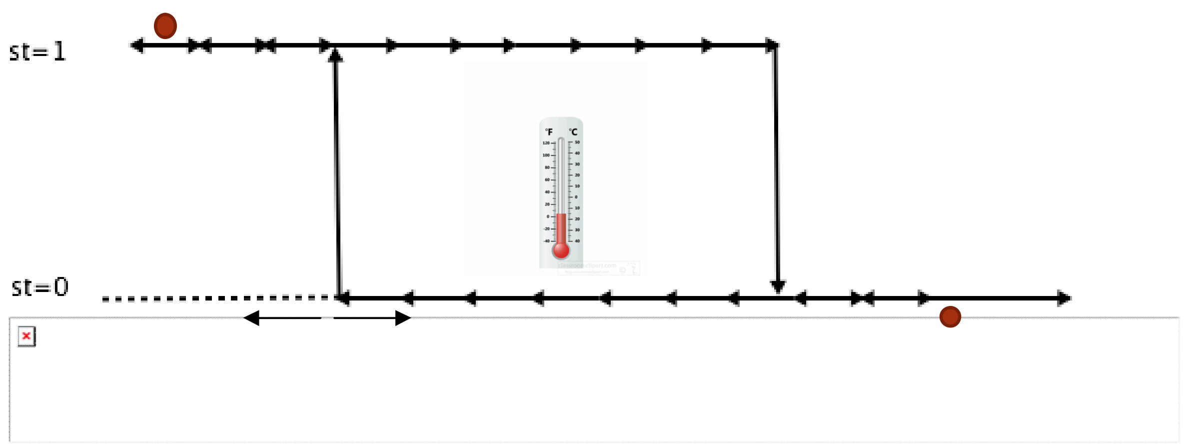
- **Dynamic time-of-use (ToU) tariffs** will motivate consumers to engage in different consumption patterns → making the most of the flexibility in the operation of some appliances through demand response actions affecting the provision of energy services.

- Consumers receive tariff information some time in advance (e.g. one day) and respond by **scheduling load operation** [shiftable and interruptible loads] and **changing thermostat settings** [air conditioning systems].

INTRODUCTION – Demand response





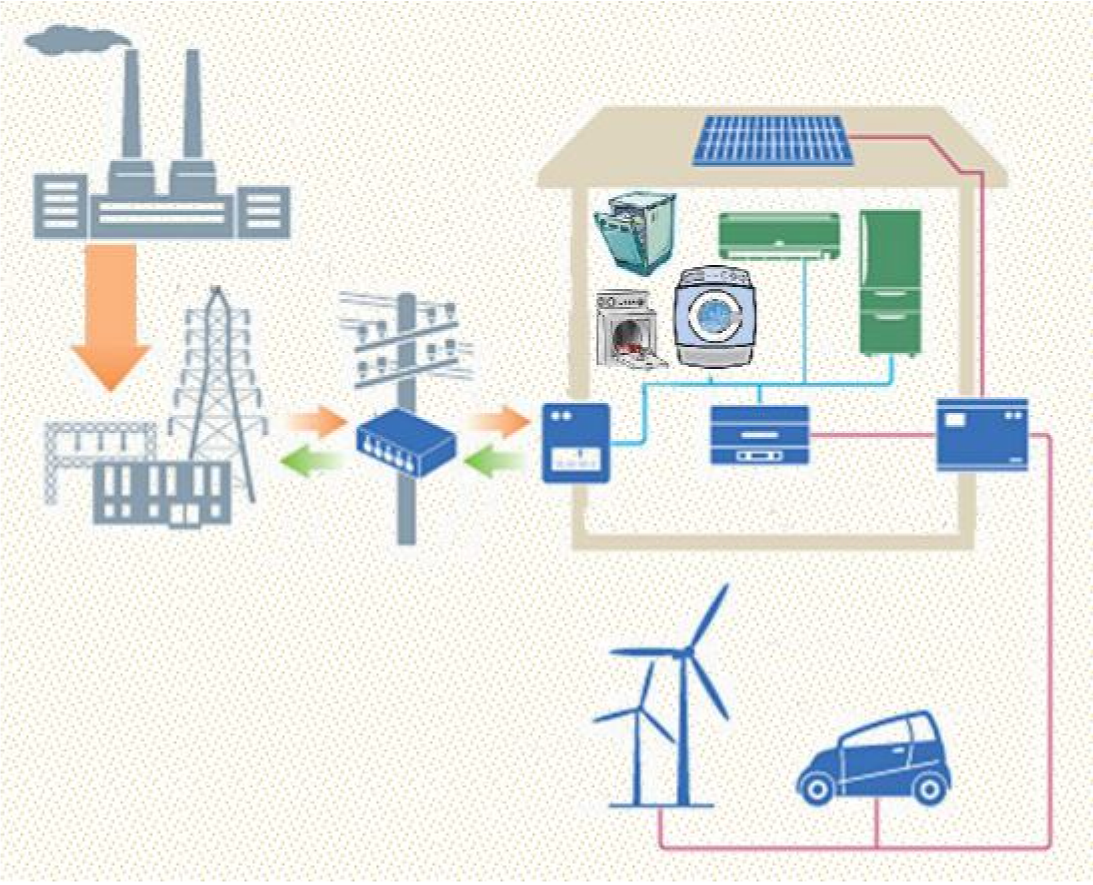


INTRODUCTION – Demand response

- Trading-off **electricity bill** (to profit from periods of low energy prices) and **comfort** (associated with appliance operation according to preferences and requirements).

- Load operation scheduling is performed by a **home energy management system (HEMS)** parameterized with the consumer's energy usage profile, with communication capabilities to receive grid information (prices and other signals) and control appliances.

INTRODUCTION – Energy management system



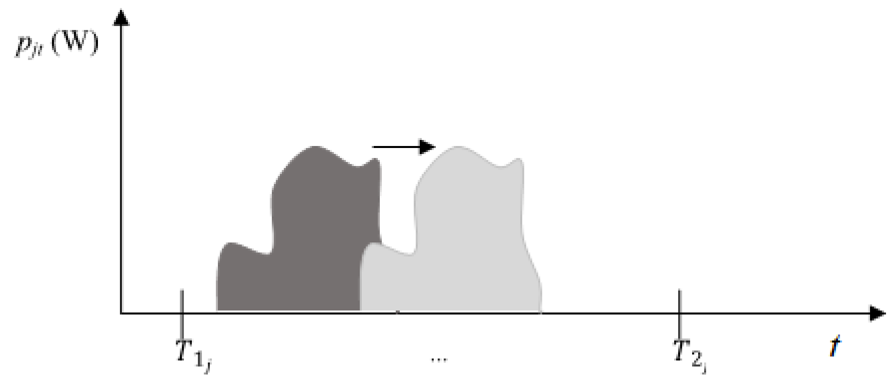
Source: http://www.hd-plc.org/images/feature/090619_1_en.jpg

APPLIANCE CONTROL – SHIFTABLE LOADS

Dishwasher

Clothes dryer

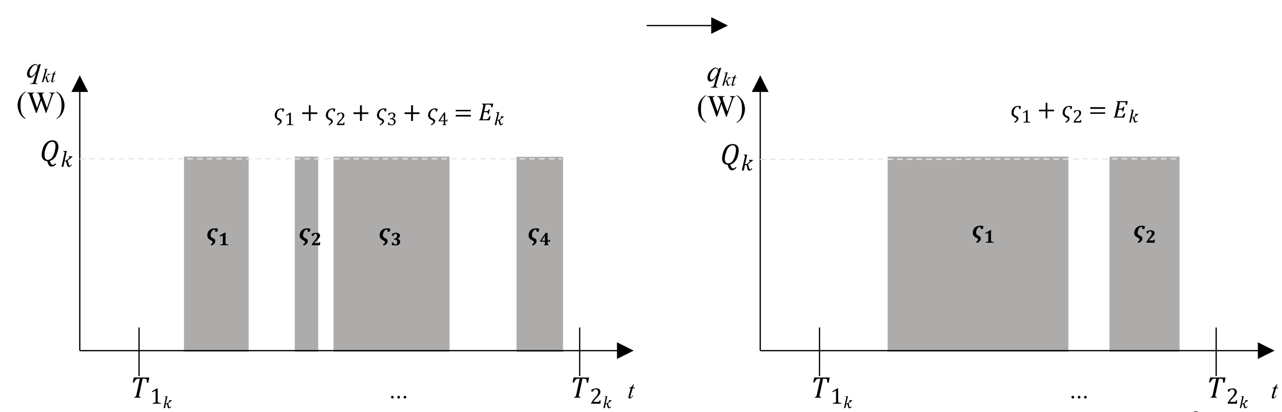
Washing machine



APPLIANCE CONTROL – INTERRUPTIBLE LOADS

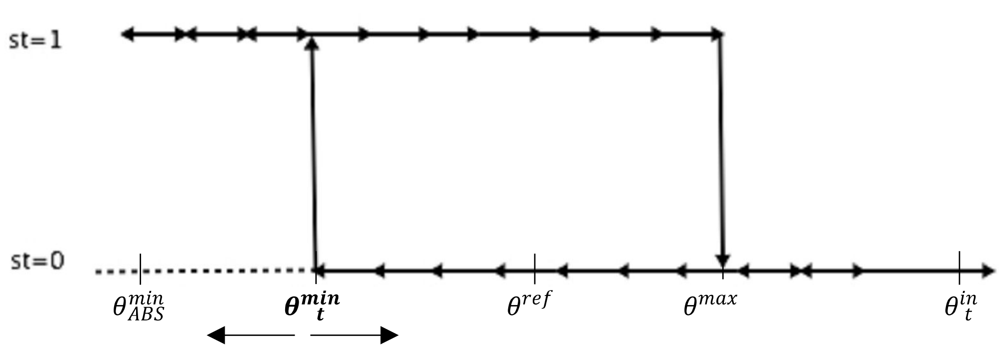
Electric water heater

Electric vehicle



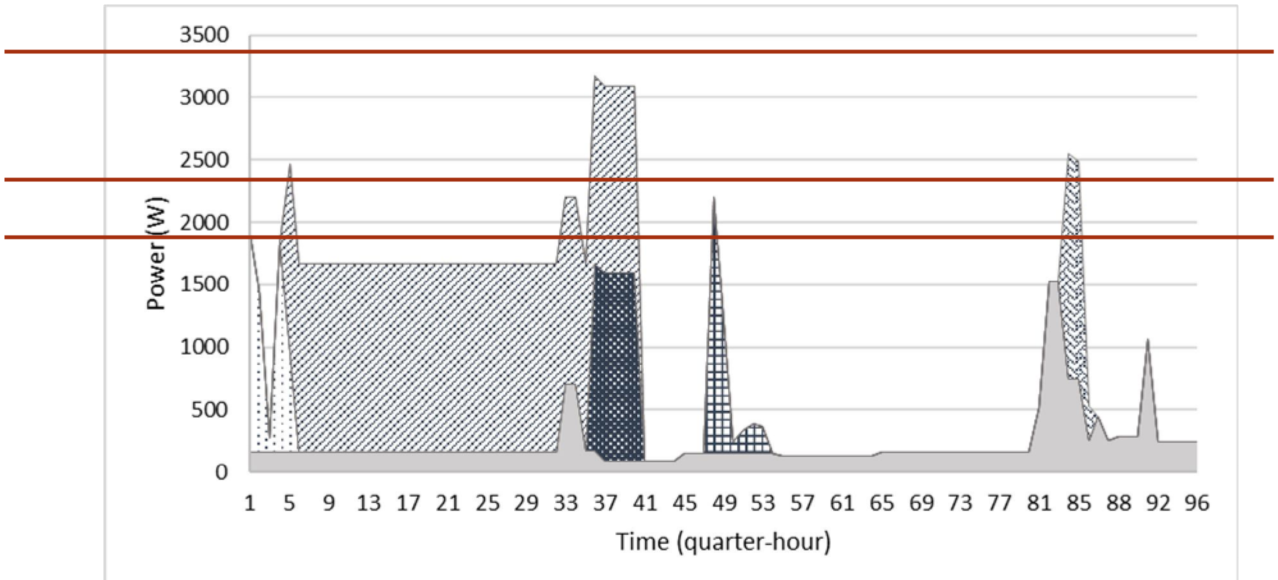
APPLIANCE CONTROL – THERMOSTATIC LOADS

Air conditioning in heating mode



POWER COST COMPONENT

Power levels

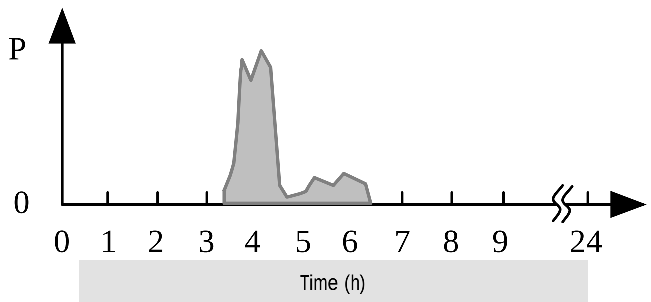


OBJECTIVE FUNCTIONS: MIN COST, MIN DISSATISFACTION

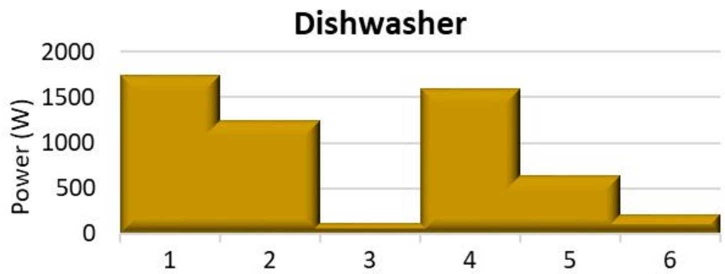
Cost of the energy consumed by uncontrollable, shiftable, interruptible and thermostatic loads + power cost:

Penalizing positive and negative deviations (Δ_t^+ and Δ_t^-) of the thermostat lower bound , θ_t^{min}, from the reference temperature θ^{ref} :

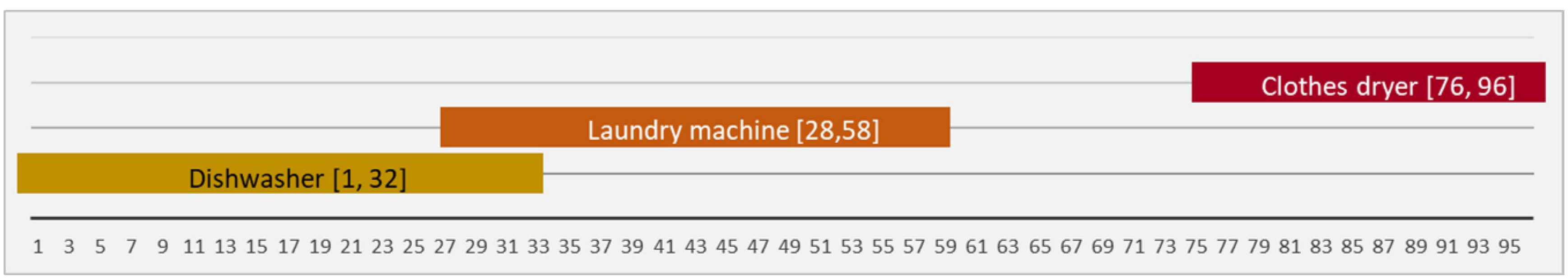
SHIFTABLE APPLIANCES



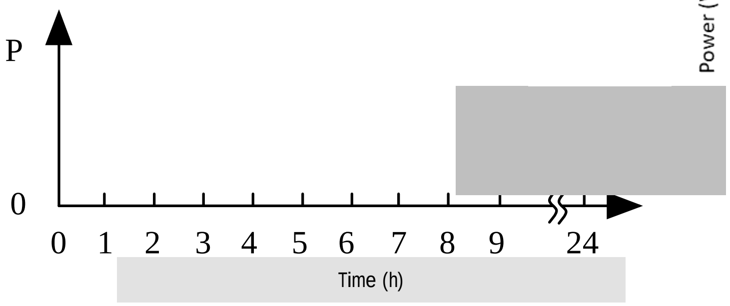
Power required:



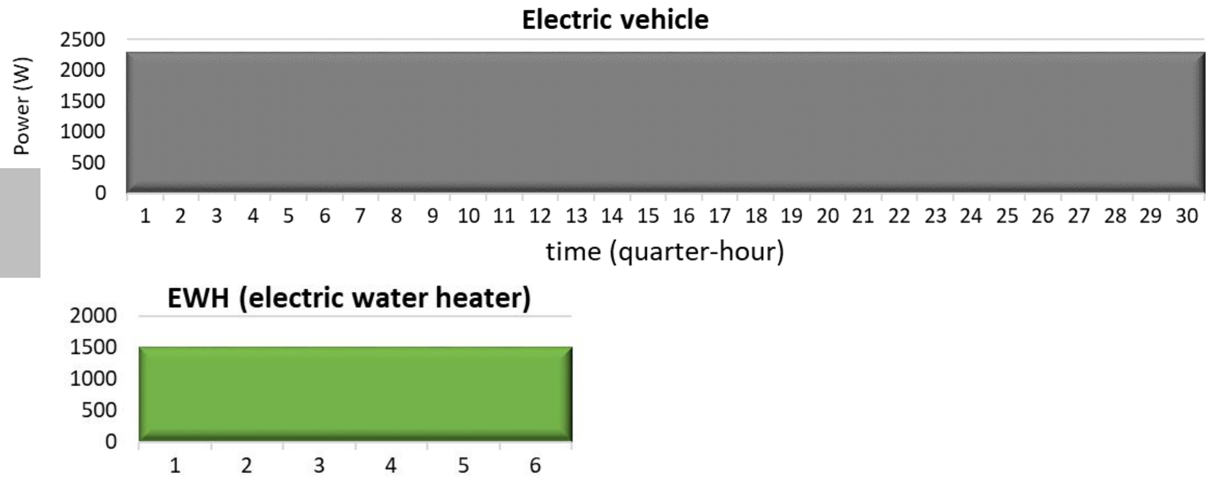
Comfort time slots allowed for the operation of shiftable appliances:



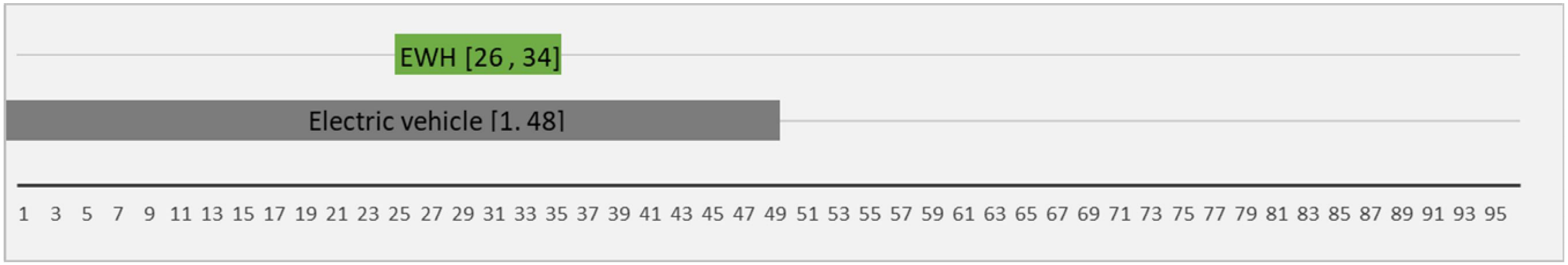
INTERRUPTIBLE APPLIANCES



Energy required to provide the service:



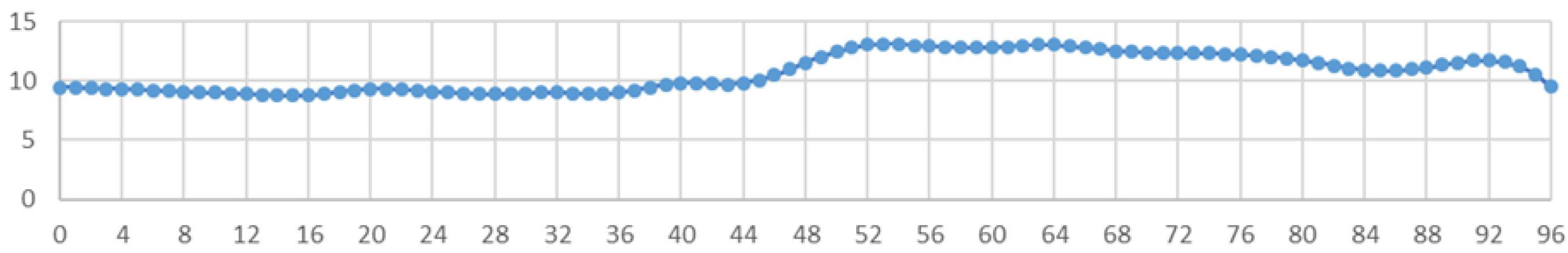
Comfort time slots for the operation of interruptible appliances: :



PARAMETERS OF THE THERMOSTATIC LOAD (AC)

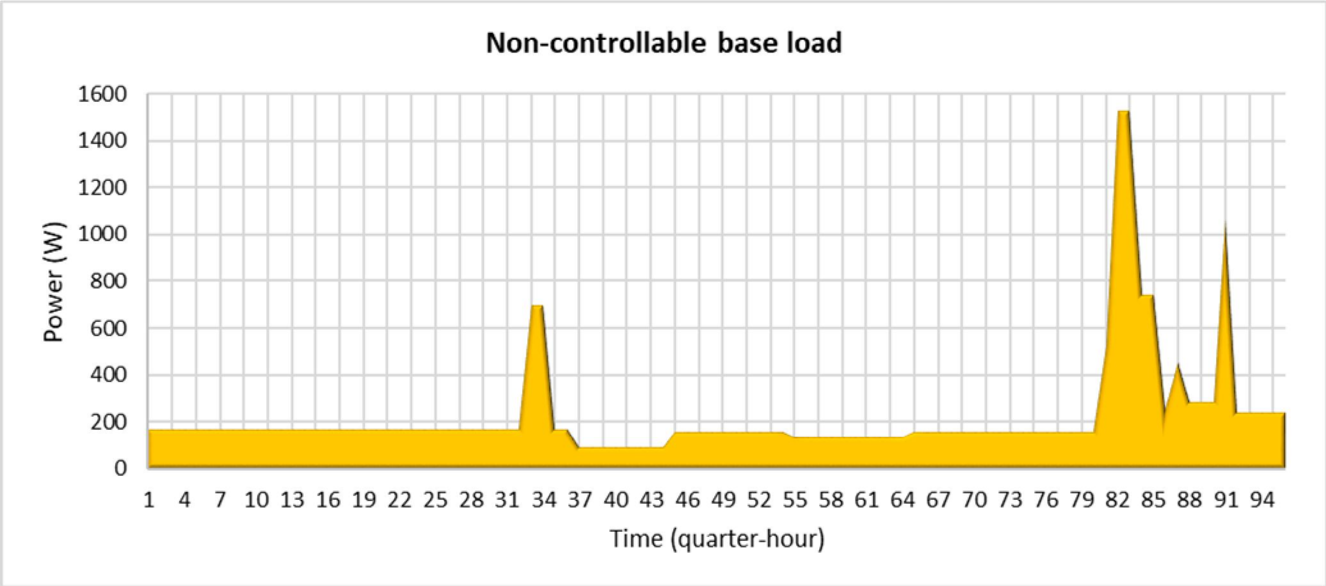
θ^{max}	θ^{min}_{Abs}	θ^{ref}	θ^{in}_{0}	P^{nom}_{AC}	s_0
24ºC	18ºC	20ºC	12ºC	1400W	0

Outdoor temperature:

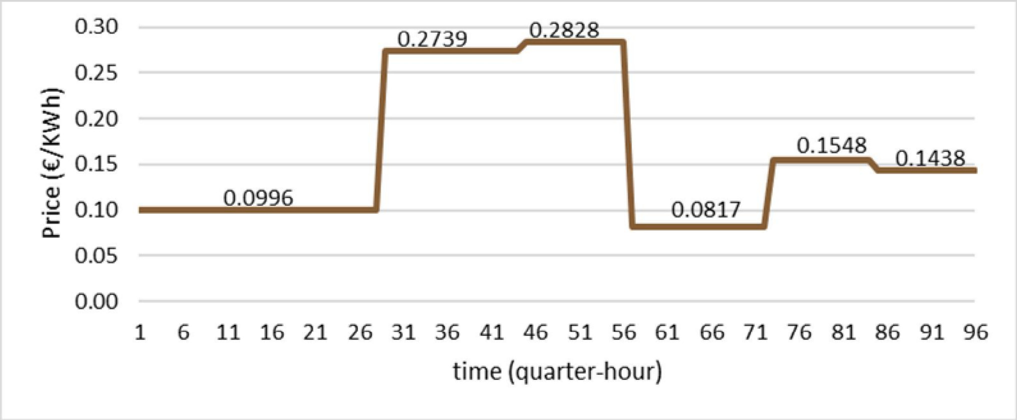


BASE LOAD AND ToU TARIFFS

Base load:



Electricity Prices:



POWER LEVEL PRICES

	Prices (€/day)	Maximum Power (W)
1	0.2047	2300
2	0.2206	3450
3	0.2834	4600
4	0.3492	5750
5	0.4198	6900
6	0.6280	10350
7	0.8302	13800
8	1.0324	17250
9	1.2351	20700

MODEL SIZE

binary variables = 848

continuous variables = 865

constraints = 2040

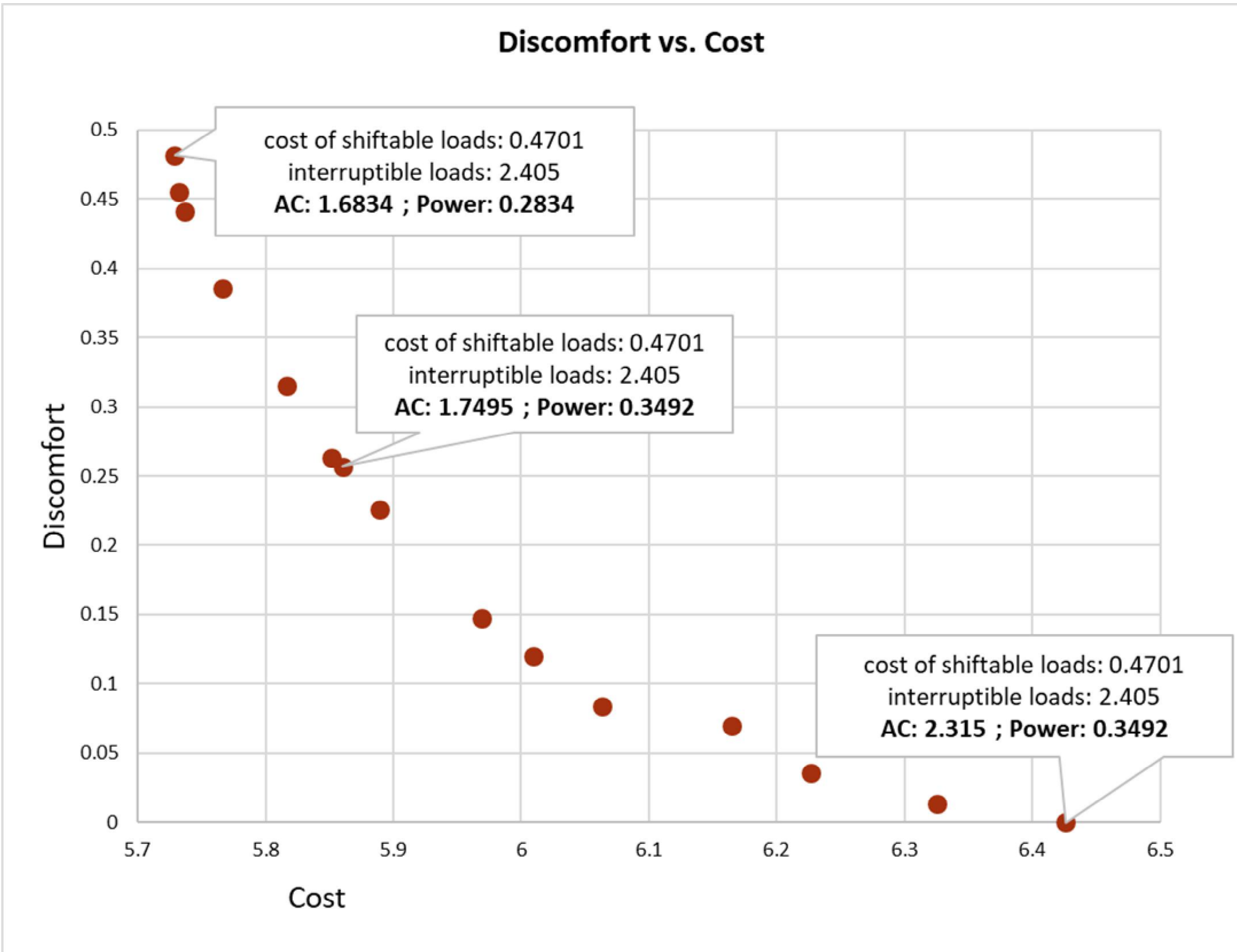
After the pre-processing phase of the solver:

binary variables = 838

continuous variables = 522

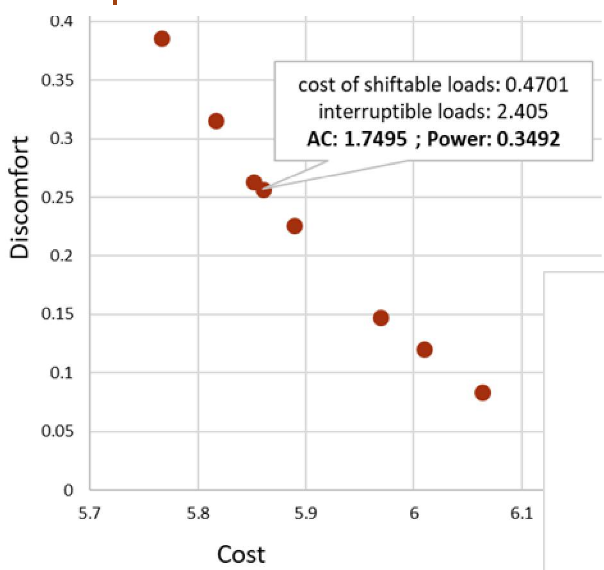
constraints = 1485

RESULTS



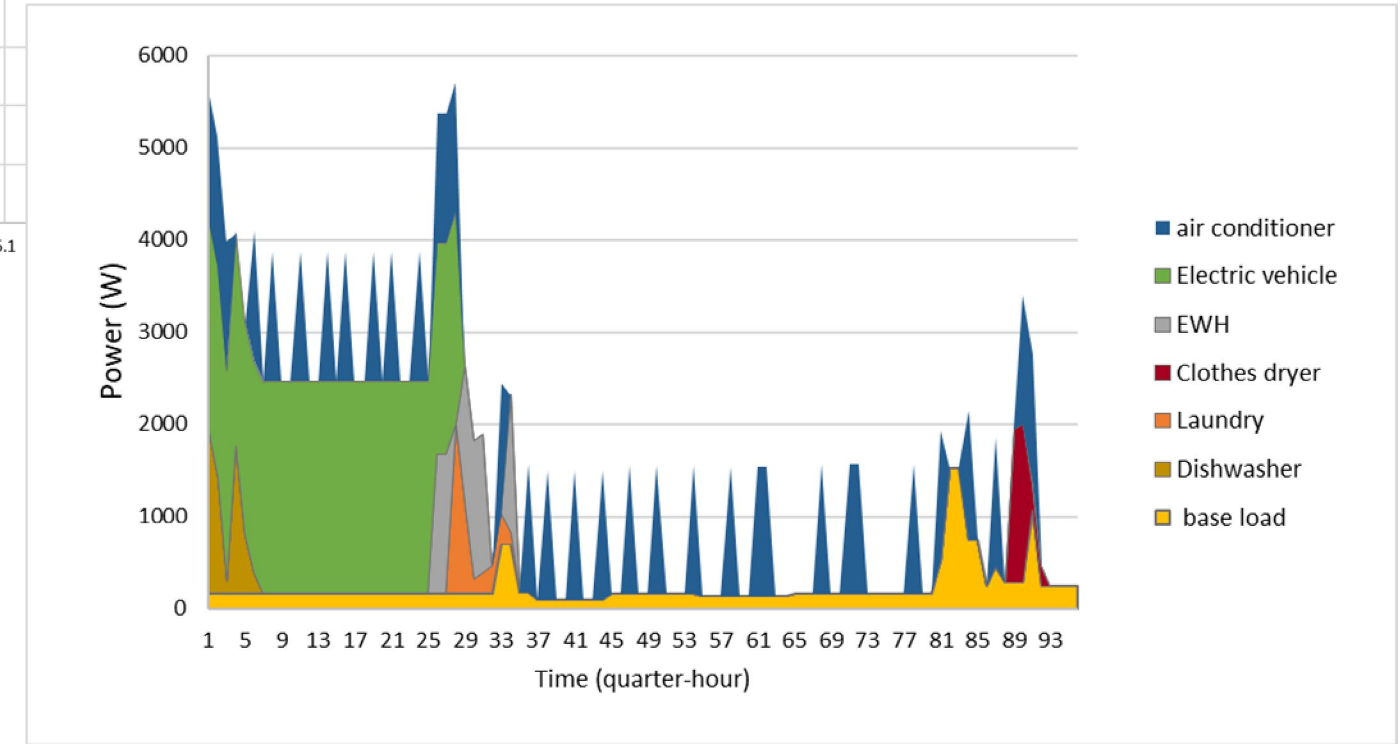
Discomfort vs. Cost
cost of shiftable loads: 0.4701
interruptible loads: 2.405
AC: 1.6834 ; Power: 0.2834
cost of shiftable loads: 0.4701
interruptible loads: 2.405
AC: 1.7495 ; Power: 0.3492
cost of shiftable loads: 0.4701
interruptible loads: 2.405
AC: 2.315 ; Power: 0.3492
Discomfort
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5.7
5.8
5.9
6
6.1
6.2
6.3
6.4
6.5
Cost

RESULTS

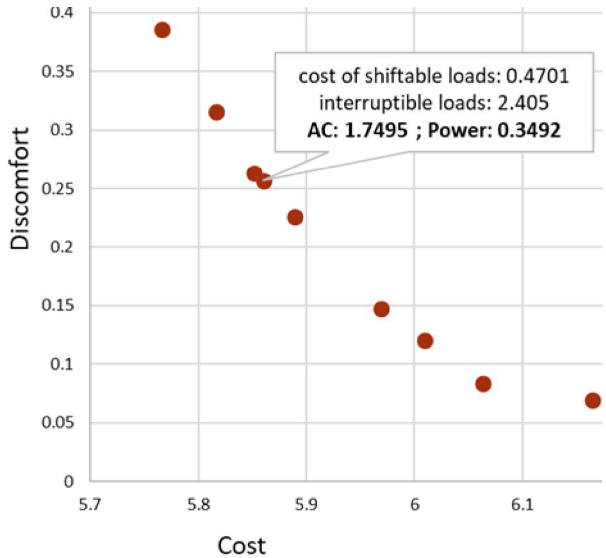


← weighted-sum with equal weights

Load diagram:

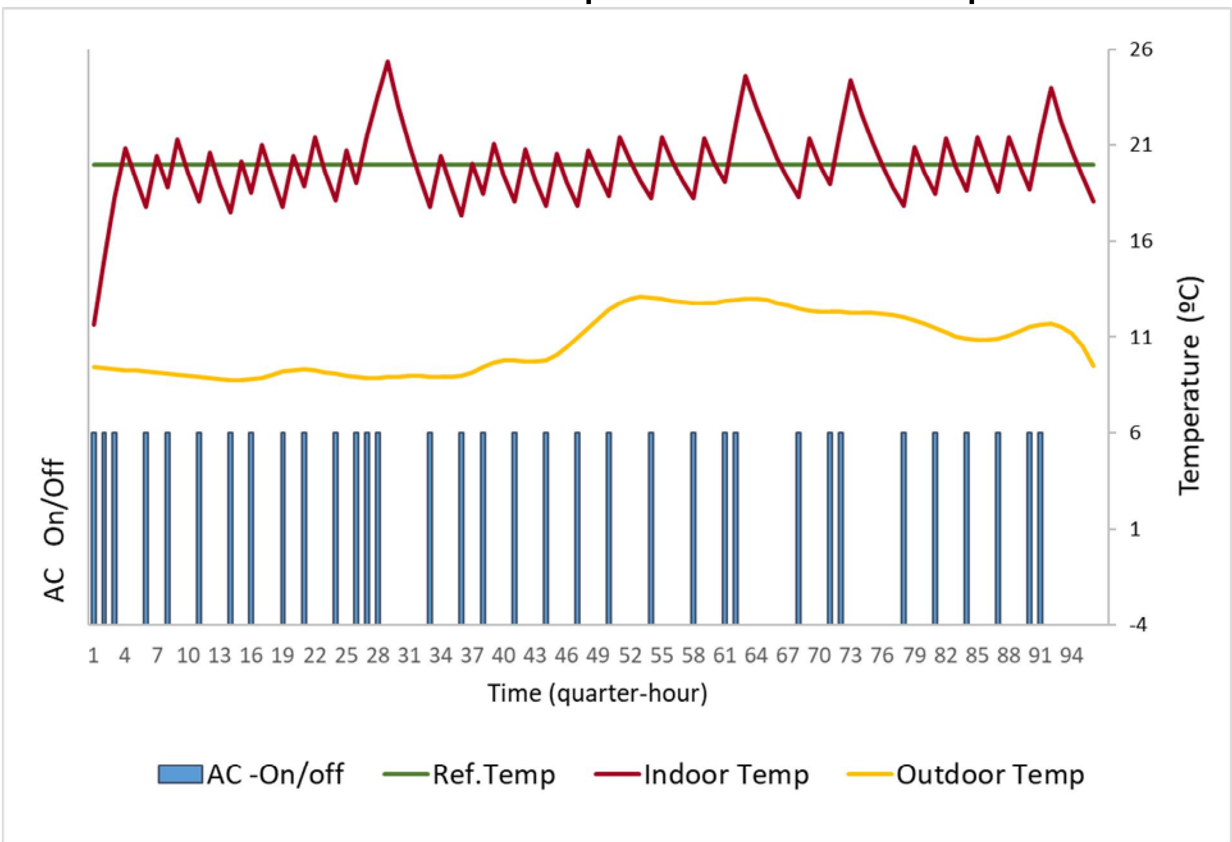


RESULTS



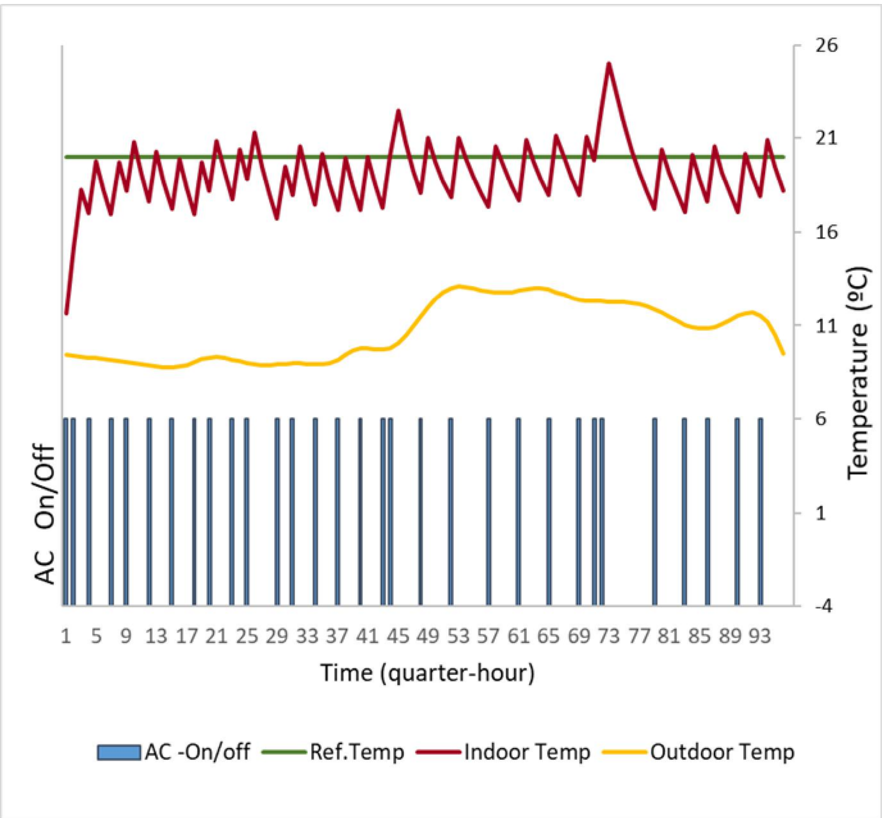
← weighted-sum with equal weights

Air conditioner operation and temperatures:

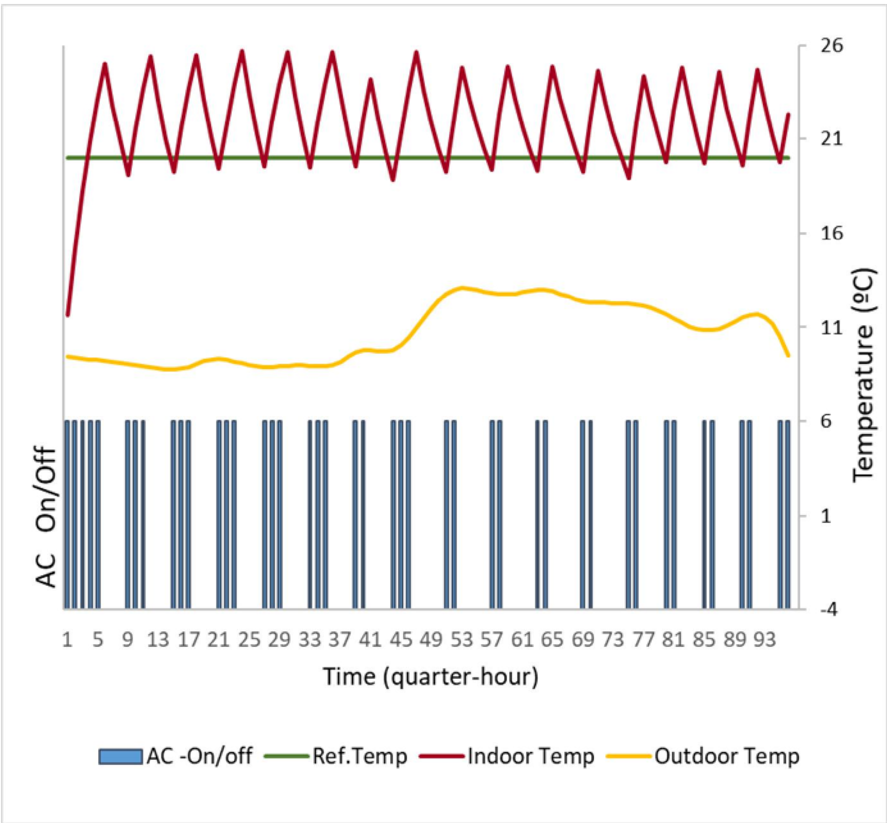


EXTREME NONDOMINATED SOLUTIONS:
AIR CONDITIONER AND TEMPERATURES

Minimum cost solution:



Minimum discomfort solution:



CONCLUSIONS

- Dynamic (ToU) tariffs provide **price signal incentives** for consumers to engage in **demand response** by means of HEMS.
- Bi-objective MILP model to optimize demand response in face of dynamic tariffs → minimization of energy costs and minimization of the discomfort associated with changes regarding most preferred settings or time slots.
- For finer time discretization of the planning period the model cannot be solved to optimality with a commercial solver due to its combinatorial nature → Customized meta-heuristic approaches are necessary to obtain good quality solutions in an acceptable computational time.
- Implementation on a Raspberry Pi low cost processor

Thank you

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