Reduction of a building's electricity costs after a PV installation

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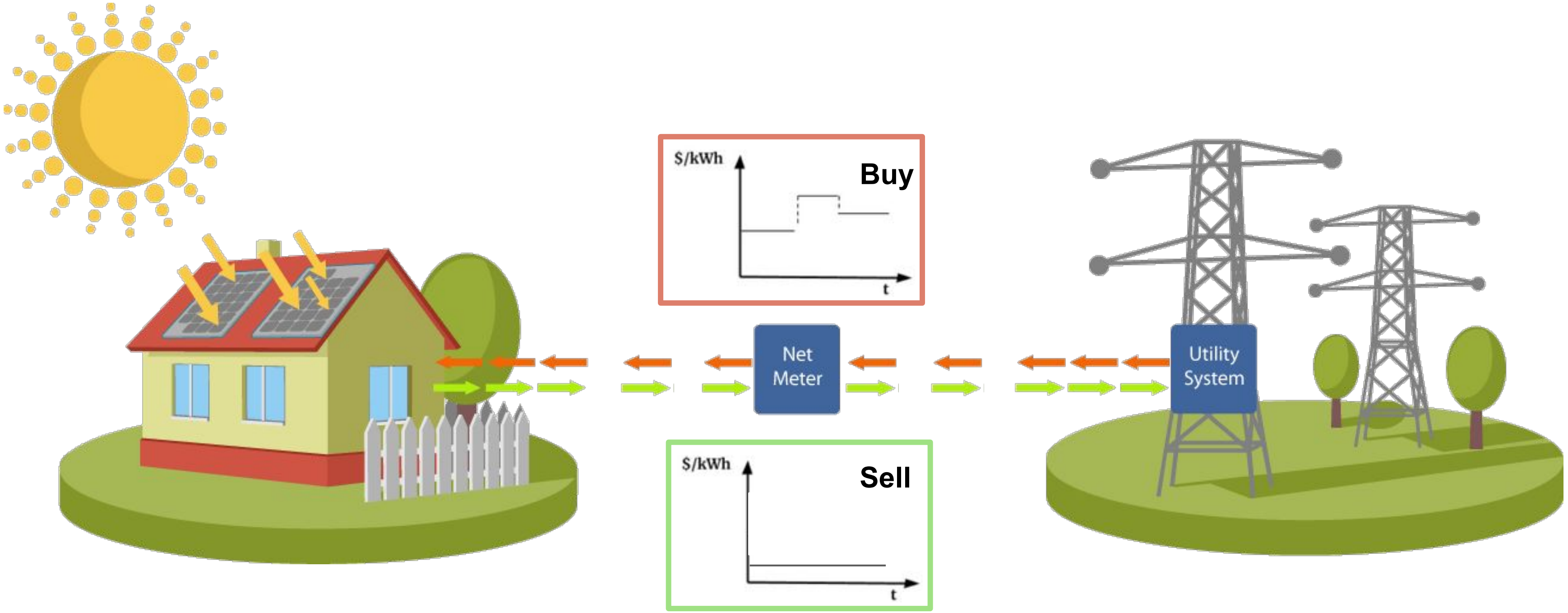
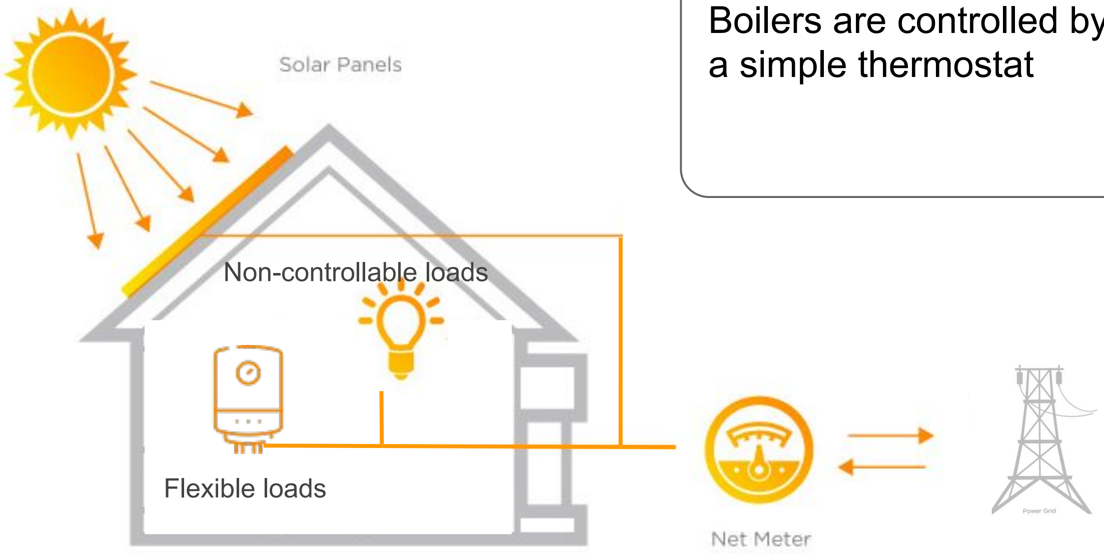
Outline

1. Context & building scenario
2. Control mechanisms
3. Simulation
4. First results & Coming work
5. Conclusion

Context: building connected to the grid

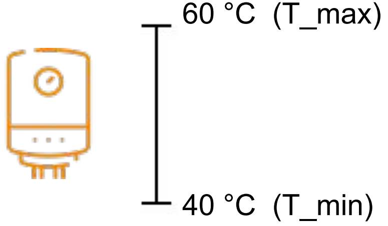


Building description and EMS

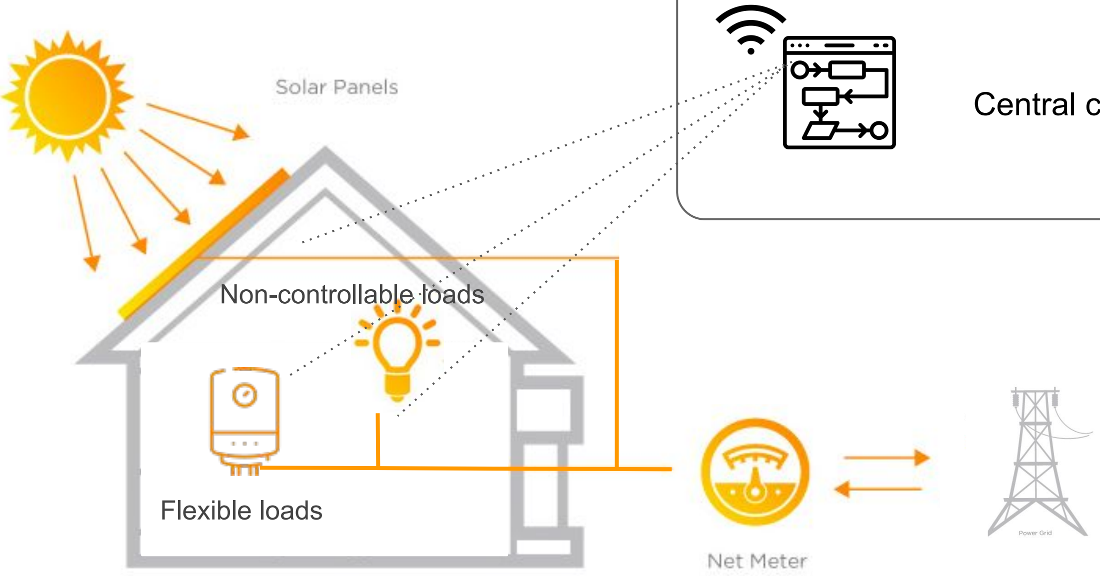


<u>Baseline scenario</u>:

Boilers are controlled by a simple thermostat



Building description and EMS



Future control strategies:

Central controller + Communication layer

Control strategies

tested to reduce building’s electricity bill.

Strategy 1:

<u>Rule-based control logic</u> → at each timestep, maintain boilers between temp bounds and supply PV power surplus to boilers to the extent possible

Inputs:

T_B1, p_B1

p_nc

T_B2, p_B2

p_pv

Outputs: u_B1 , u_B2

Start
$p_x = p_{PV}[h] + p_{nc}[h] + p_{B1}[h] + p_{B2}[h]$
sort $\hat{\boldsymbol{T}}_{\boldsymbol{B}}[h]$ in ascending order
for each boiler k **do**
  if $T_{B,k} \leq \underline{T}_{B,k}$ **then**
    $u_{B,k} \leftarrow \overline{P}_k$
    $p_x = p_x - p_{B,k} + u_{B,k}$
  else
    if $p_x > 0$ **then**
      $e_k^T[h] = max(0, \overline{T}_{B,k} - T_{B,k}[h])$
      $u_{B,k} \leftarrow max[-C_w \frac{e_k^T[h]}{\Delta t}, \overline{P}_k, -(p_x - p_{B,k})]$
      $p_x = p_x - p_{B,k} + u_{B,k}$
    end
  end
end
return Control variables
End

<u>Limitations</u>: 1) myopic approach, 2) oversimplificated boiler model, 3) inefficient action around T_min

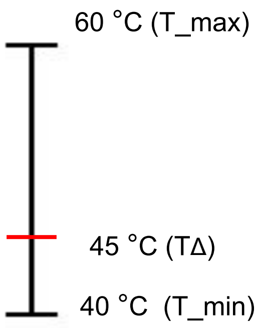
Strategy 2: hysteresis control

<u>Same rule-based control logic</u> + hysteresis to avoid constant switching around lower bound temperature

Inputs: *T_B1, p_B1,* ***s_B1*** *T_B2, p_B2,* ***s_B2*** *p_nc* *p_pv*

Outputs: *u_B1 , u_B2*

if $T_{B,k}[h] \geq T_{\Delta,k}$ **then**
  $s_{B,k}[h] = 0$
end
if $T_{B,k}[h] \leq \underline{T}_{B,k}$ **then**
  $s_{B,k}[h] = 1$
else
  $s_{B,k}[h] = s_{B,k}[h-1]$
end



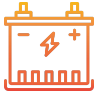
<u>Limitations</u>: 1) myopic approach, 2) oversimplificated boiler model

Strategy 3: adding battery storage

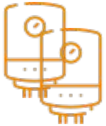
Similar rule-based control logic **+** battery backup:

→ only charged when boilers are at their T_max, only discharged when needed to keep boilers above T_min.

Inputs:



x_bat, p_bat



T_Bk, p_Bk, s_Bk

p_nc

p_pv

Outputs: *u_bat, u_B1 , u_B2*

$$p_x = \hat{p}_{PV}[h] + p_{nc}[h] + p_{B1}[h] + p_{B2}[h] + p_{bat}[h]$$

take care of boilers as usual

if $p_x \geq 0$ **then**

$u_{bat} \leftarrow max[\frac{x_{bat}[h] - \overline{C}_{bat}}{\Delta t}, \overline{P}^{ch}_{bat}, -(p_x - p_{bat}[h])]$

else

$u_{bat} \leftarrow min[\frac{x_{bat}[h] - \underline{C}_{b}}{\Delta t}, \overline{P}^{disch}_{bat}, -(p_x - p_{bat}[h])]$

end

Limitations: 1) myopic approach, 2) oversimplificated boiler model

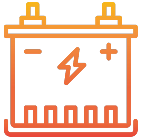
Strategy 4: adequate modelling

Same rule-based algorithm, with control action computed according to more accurate models:

$$T_B[h+1] = T_B[h] - \frac{p_B \Delta t}{C_B}$$

$$T_B[h+1] = (1 - \frac{d_B[h]}{V_B})\, T_B[h] - \frac{\Delta t}{C_B} p_B[h] + \frac{d_B[h]}{V_B}\, T_{cold}$$

V: boiler volume   d: hot water consumption [litres]



$$x_b[h+1] = x_b[h] - p_b[h]\, \Delta t$$

$$x_b[h+1] = \alpha_b\, x_b[h] + \eta_b^+\, u_b^+[h] + \eta_b^-\, u_b^-[h]\, \Delta t$$

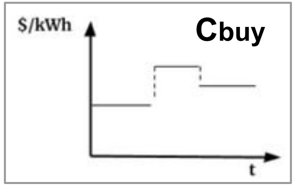
$$u_b^+[h] = \max(0, u_b)$$

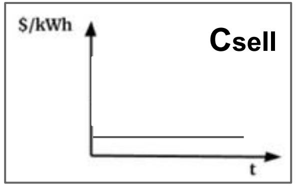
$$u_b^-[h] = \max(0, -u_b)$$

α: leakage coef   η: charging(+)/discharging(-) efficiencies

<u>Limitations</u>: 1) myopic approach

Strategy 5: MPC for boilers





$$\boxed{min_{\hat{\mathbf{u}}_B} \sum_{h=0}^{H-1} C_{buy}[h]\, p_g^+[h] - C_{sell}[h]\, p_g^-[h]}$$

$$
\begin{aligned}
& s.t. \\
& p_g[h] + \hat{p}_{PV}[h] + \hat{p}_{nc}[h] + \sum_{k=1,2} u_{B,k}[h] = 0 \\
& p_g^-[h] = max(0, -p_g[h]) \\
& p_g^+[h] = max(0, +p_g[h]) \\
& \overline{P}_{B,k} \leq u_{B,k}[h] \leq 0 \quad \text{for } k = 1,2 \\
& T_{B,k}[h+1] = A\, T_{B,k}[h] - B\, u_{B,k}[h] + C\, \hat{d}_{B,k}[h] \quad \text{for } k = 1,2 \\
& \underline{T}_{B,k} \leq T_{B,k}[h] \leq \overline{T}_{B,k} \quad \text{for } k = 1,2
\end{aligned}
$$

<u>Limitations</u>: need for forecasts (PV, loads, hot water consumption) and more computing time

Strategy 6: MPC for boilers and battery

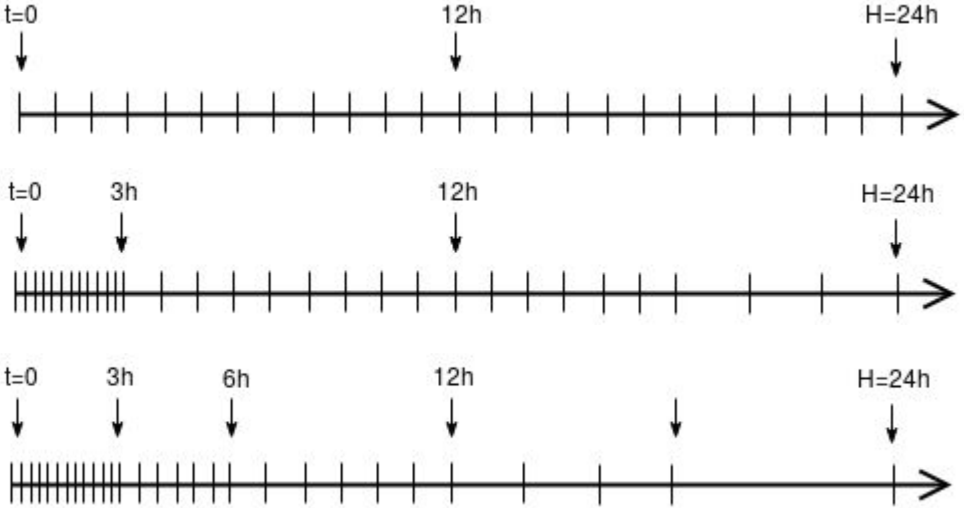
$$\boxed{min_{\hat{\mathbf{u}}_{\mathbf{B}}, u_{bat}} \sum_{h=0}^{H-1} C_{buy}[h]\, p_g^{+}[h] - C_{sell}[h]\, p_g^{-}[h]}$$

$$
\begin{aligned}
s.t. \quad & p_g[h] + \hat{p}_{PV}[h] + \hat{p}_{nc}[h] + \sum_{k=1,2} u_{B,k}[h] + u_{bat}[h] = 0 \\
& p_g^{-}[h] = max(0, -p_g[h]) \\
& p_g^{+}[h] = max(0, +p_g[h]) \\
& u_{bat}^{+}[h] = max(0, u_{bat}[h]) \\
& u_{bat}^{-}[h] = max(0, -u_{bat}[h]) \\
& x_{bat}[h+1] = \alpha_b\, x_{bat}[h] + \eta_b^{+}\, u_{bat}^{+}[h] + \eta_b^{-}\, u_b^{-}[h]\, \Delta t \\
& \underline{C}_{bat} \leq x_b[h] \leq \overline{C}_{bat} \\
& \overline{P}_{bat}^{ch} \leq u_b[h] \leq \overline{P}_{bat}^{disch}
\end{aligned}
$$

<u>Limitations</u>: need for forecasts (PV, loads, hot water consumption) and more computing time

Future work: MPC with variable period

Idea: give more weight to short-term conditions than to long-term

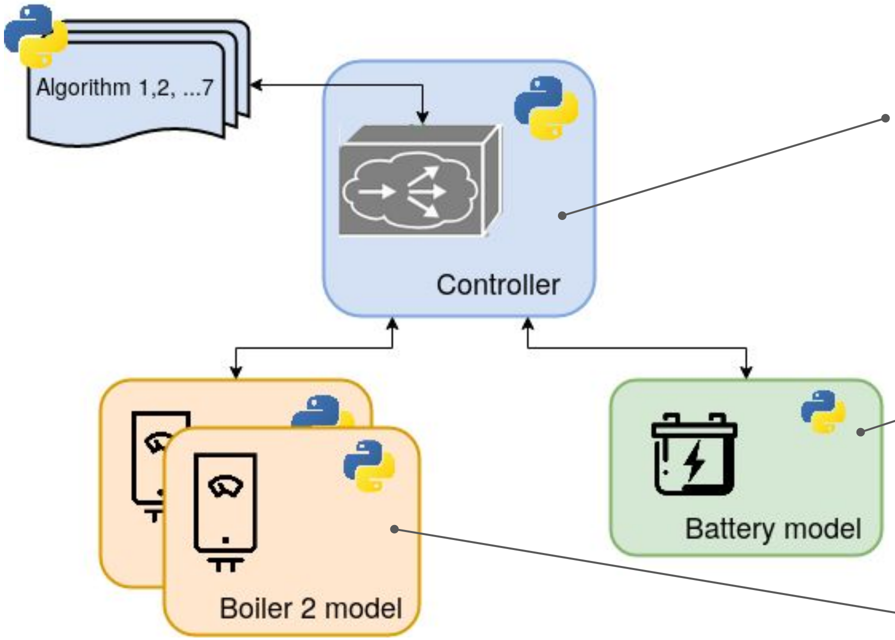


Faster control period with same computing cost as constant-period MPC.

Simulation framework

to allow us to compare all of the controller algorithms in the same building conditions.

Simulation environment



- Read config
- Spawn the simu units accordingly
- *Subscribe* to units sensors
- *Publish* control actions

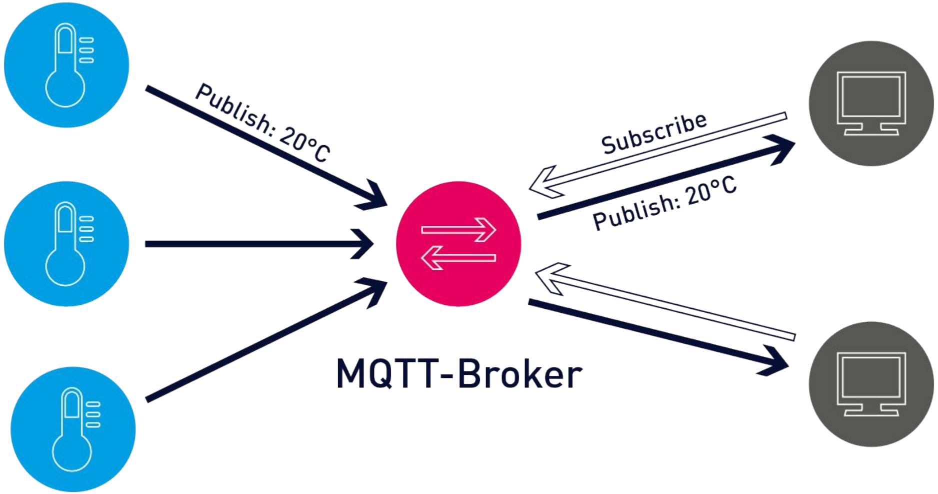
- Simulate battery SoC evolution
- *Publish* power and Soc

- Simulate boilers temperature evolution
- *Publish* power and temp

Simulation environment

MQTT messaging protocol (Message Queuing Telemetry Transport)

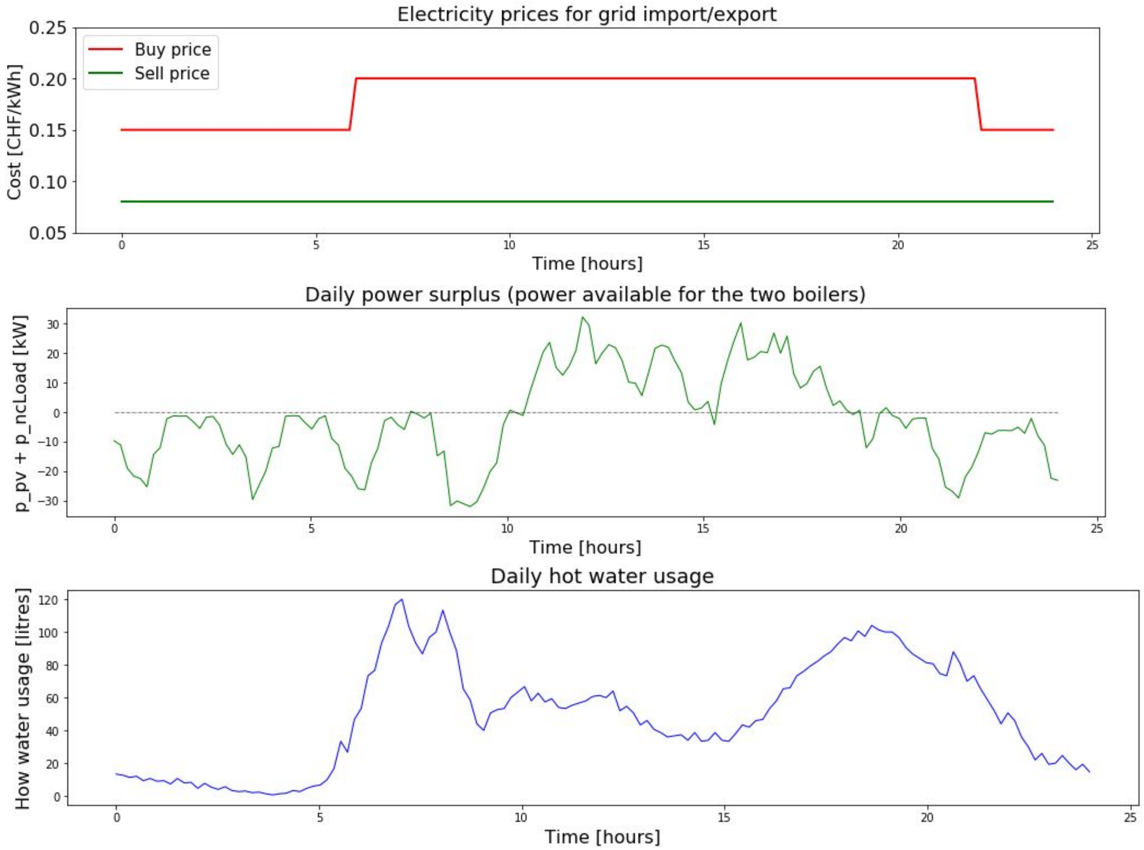
→ publish-subscribe network protocol that transports messages between devices.



First simulations

Cost attractiveness of implementing a simple rule-based control algorithm

Simulation conditions



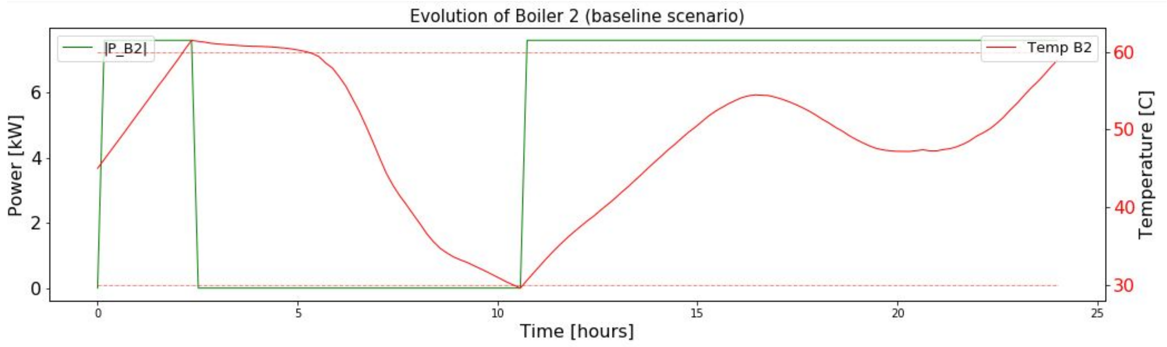
Day in march, power profile of a big building with multiple households

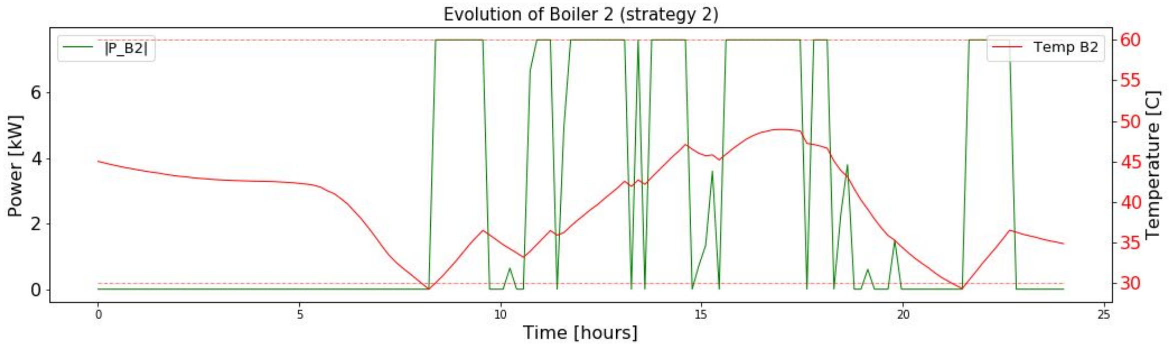
Boilers models:

- Volume: 800 litres
- Temp bounds: [40°C; 60°C]
- Cold water temp: 20°C

First results

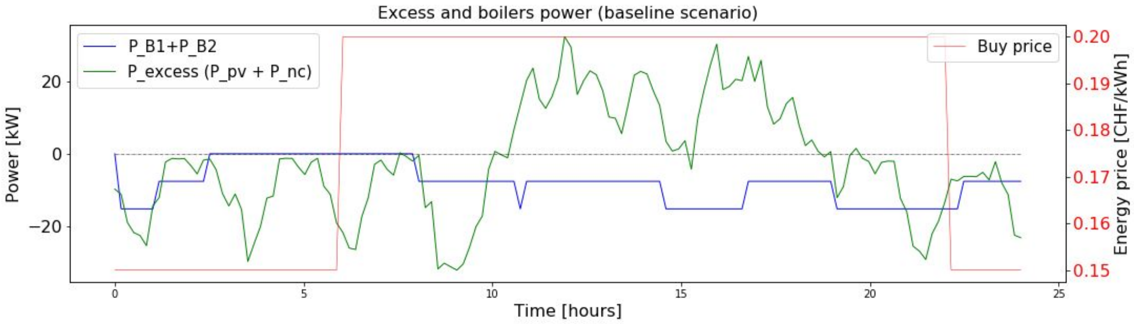
Comparing a basic rule based logic (strategy 2) with a no-EMS strategy (baseline scenario):



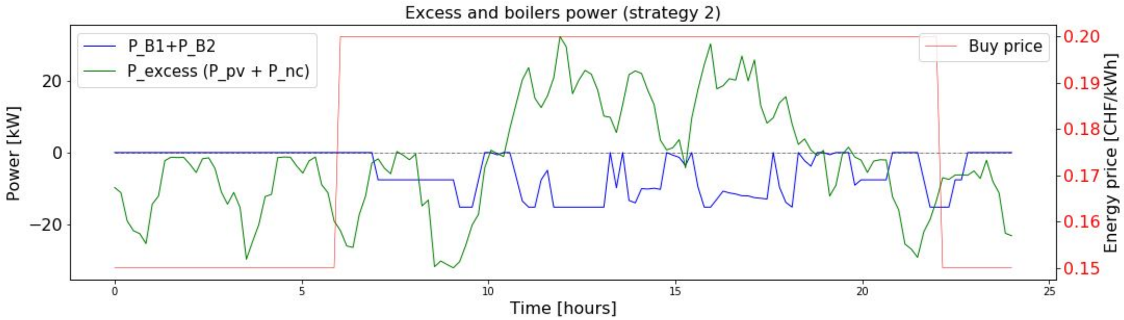


First results & Coming work

Comparing a basic rule based logic (Strategy 2) with a no-EMS strategy (baseline scenario):



Daily electricity bill: **37.62 CHF**



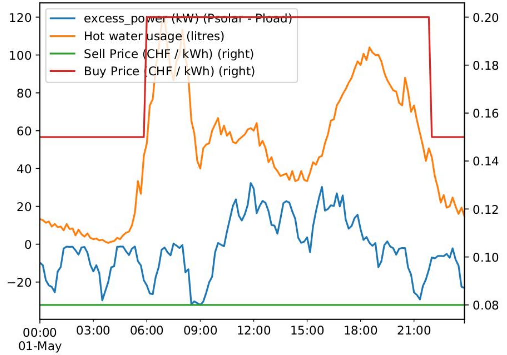
Daily electricity bill: **27.50 CHF**

Conclusion

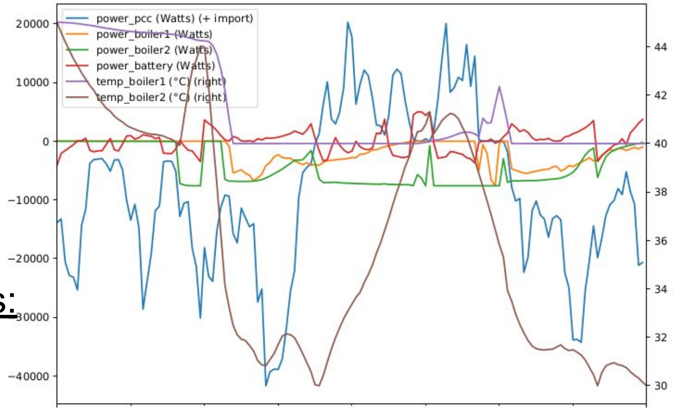
- Defined a **specific building scenario**, with its assumptions and models.
- Defined multiple **energy management strategies**.
- **Simulated** such building and the controller implementing the different control strategies.
- TO DO: Experiment with 7 control strategies, **analyze their cost-effectiveness**, and point their limitations.

MPC implementation

Disturbances:



Battery & boilers:



Boilers: