

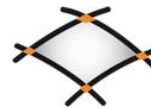
# OPTIMAL DESIGN OF THERMAL STORAGE TANKS FOR MULTI-ENERGY DISTRICT BOILERS

COFELY GDF-Suez / PROMES-CNRS Laboratory  
/ University of Perpignan Via Domitia

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4<sup>th</sup> International Symposium on INVERSE PROBLEMS, DESIGN AND  
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A4867SG, Session 5, Optimal design and Global Optimization,  
June 27, Thursday, 17:00-17:20



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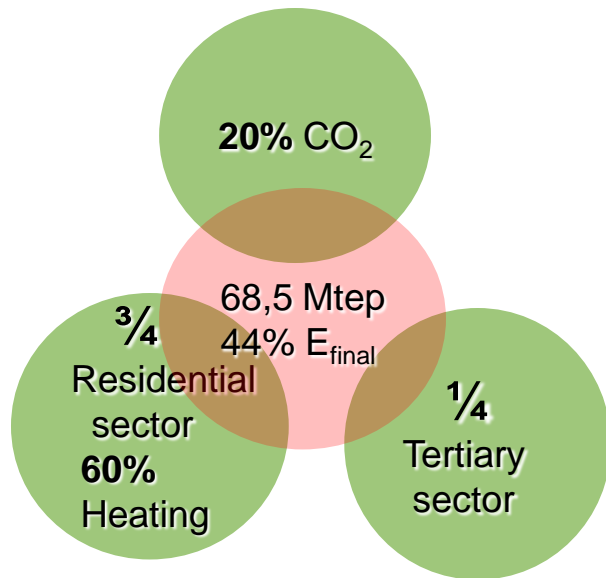
# ***Presentation outline***

1. Context of the project
2. Multi-energy district boiler
3. Design (sizing) strategy
4. Management strategy
5. Energy and economic evaluation
6. Case study
7. Conclusion and outlooks

# Context of the project

- 2010: final residential energy consumption accounted for **27%** of total energy consumption in the EU-27.
- 1990 – 2010: final residential gas consumption increased by **52%**.

## FRANCE



Heating plays  
an important role in energy  
efficiency programs

### Heating using biomass energy

- Biomass is cheaper than fossil fuels commonly used for heating
- Biomass can reduce CO<sub>2</sub> emissions

# Context of the project

Individual heating

Each house has its own heating system:

- Individual gas boiler
- Heat pump
- Electric heating



District heating

Centralized heat system for residential and commercial heating requirements



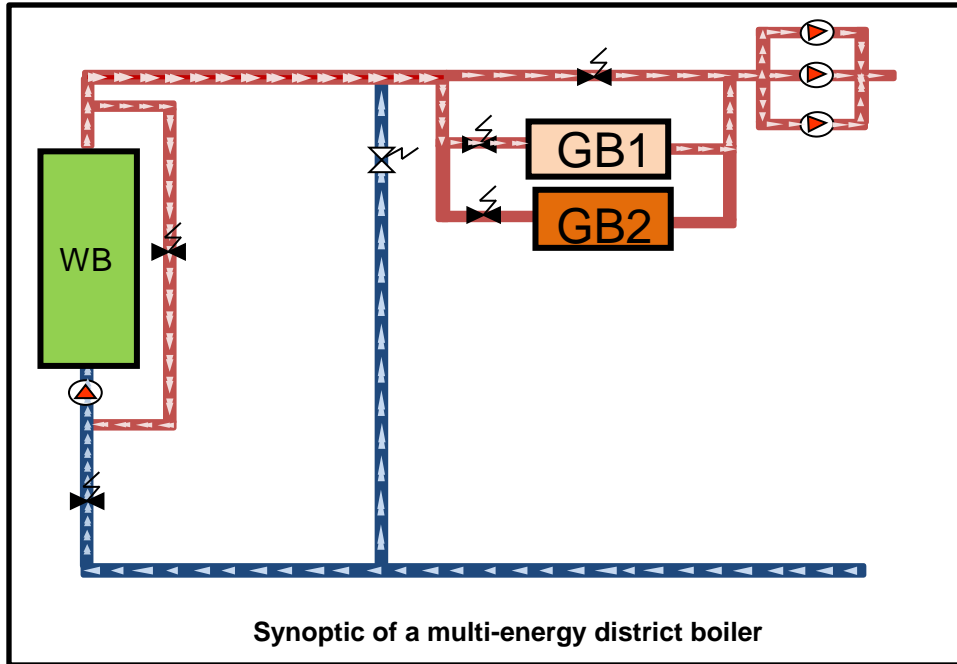
Manage?  
Size?  
Optimize?

**OptiEnR research project: Optimization of a multi-energy district boiler**

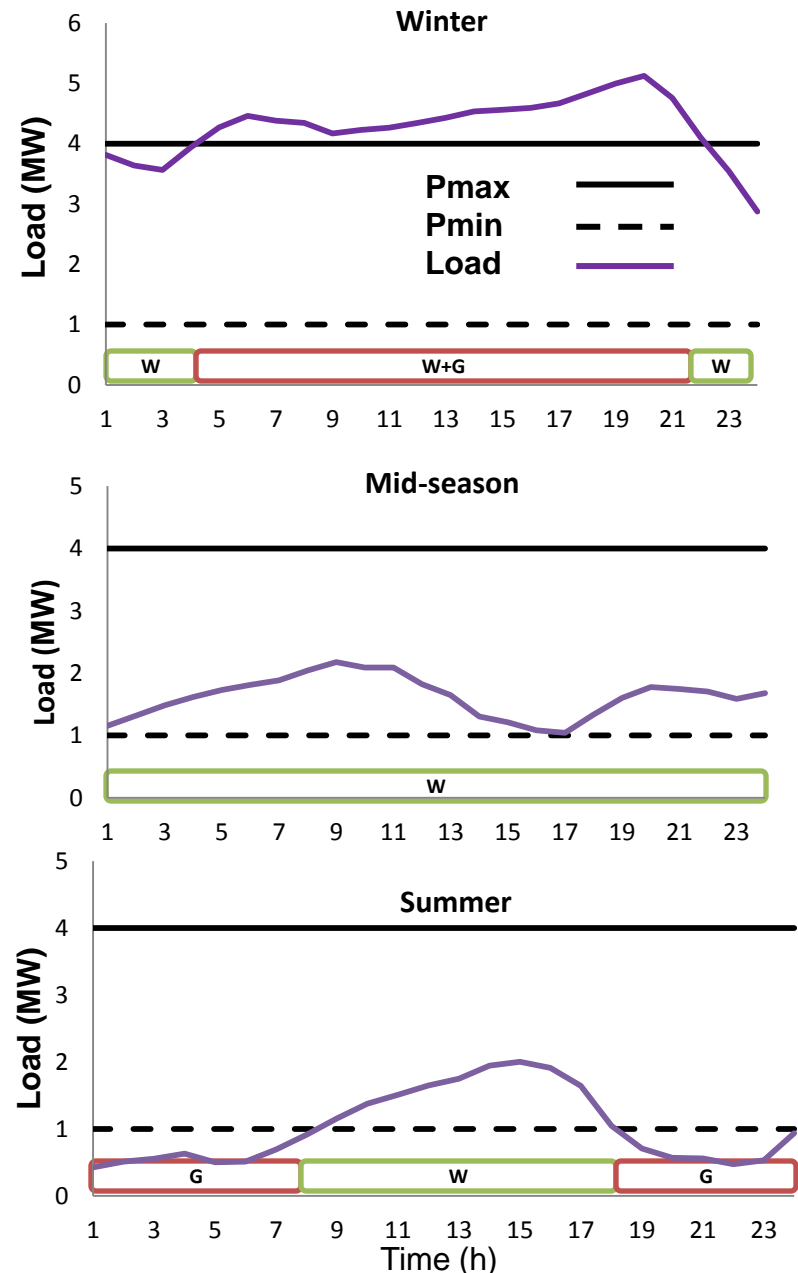
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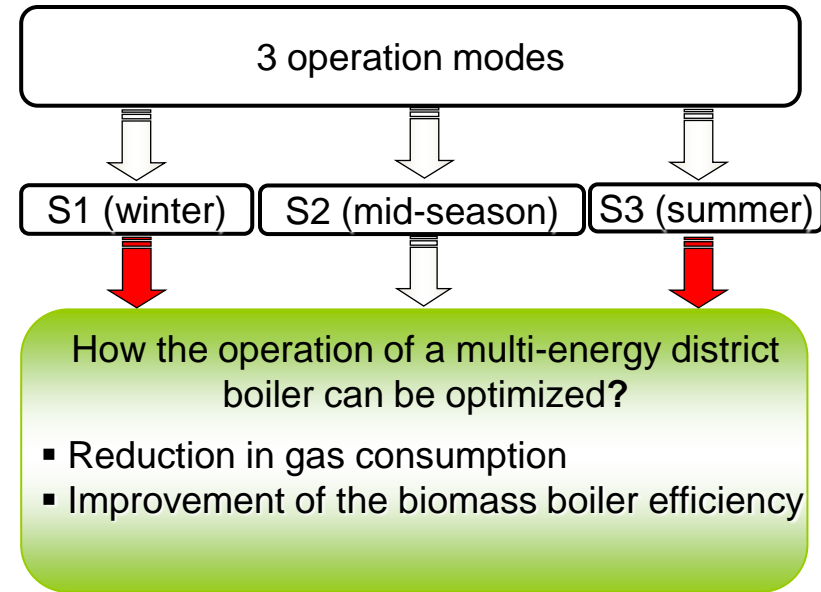
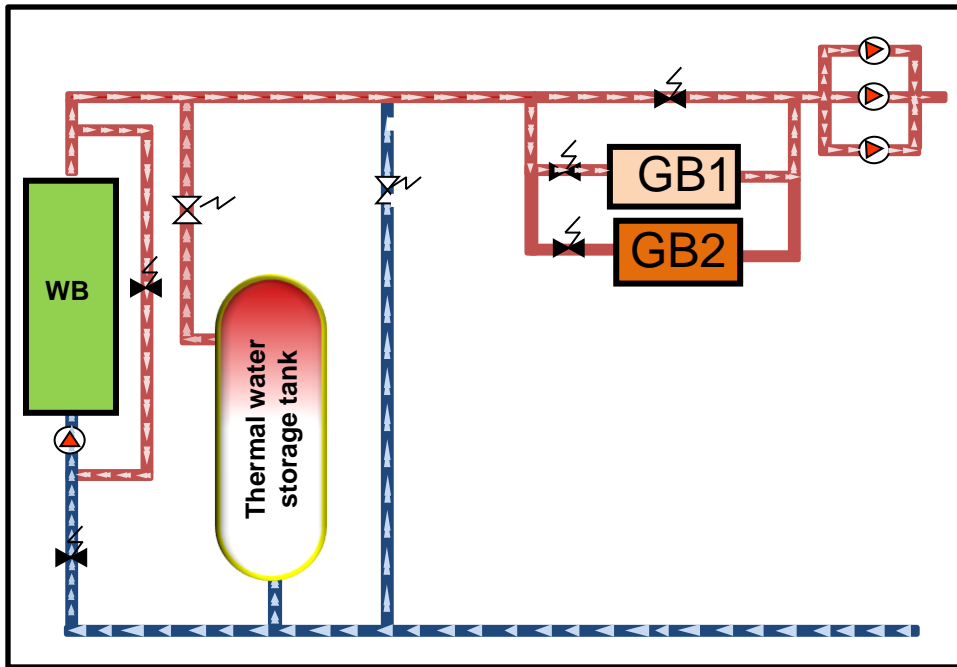
# Multi-energy district boiler



- Biomass boiler (WB)  
→  $[P_{\min}; P_{\max}] = [1; 4] \text{ MW}$
- Auxiliary gas boiler 1 (GB1)  
→  $\text{Load} > P_{\max}$  or  $\text{Load} < P_{\min}$
- Auxiliary gas boiler 2 (GB2)  
→ Maintenance / malfunction
- The whole system  
→ Variability in demand profiles



# Multi-energy district boiler



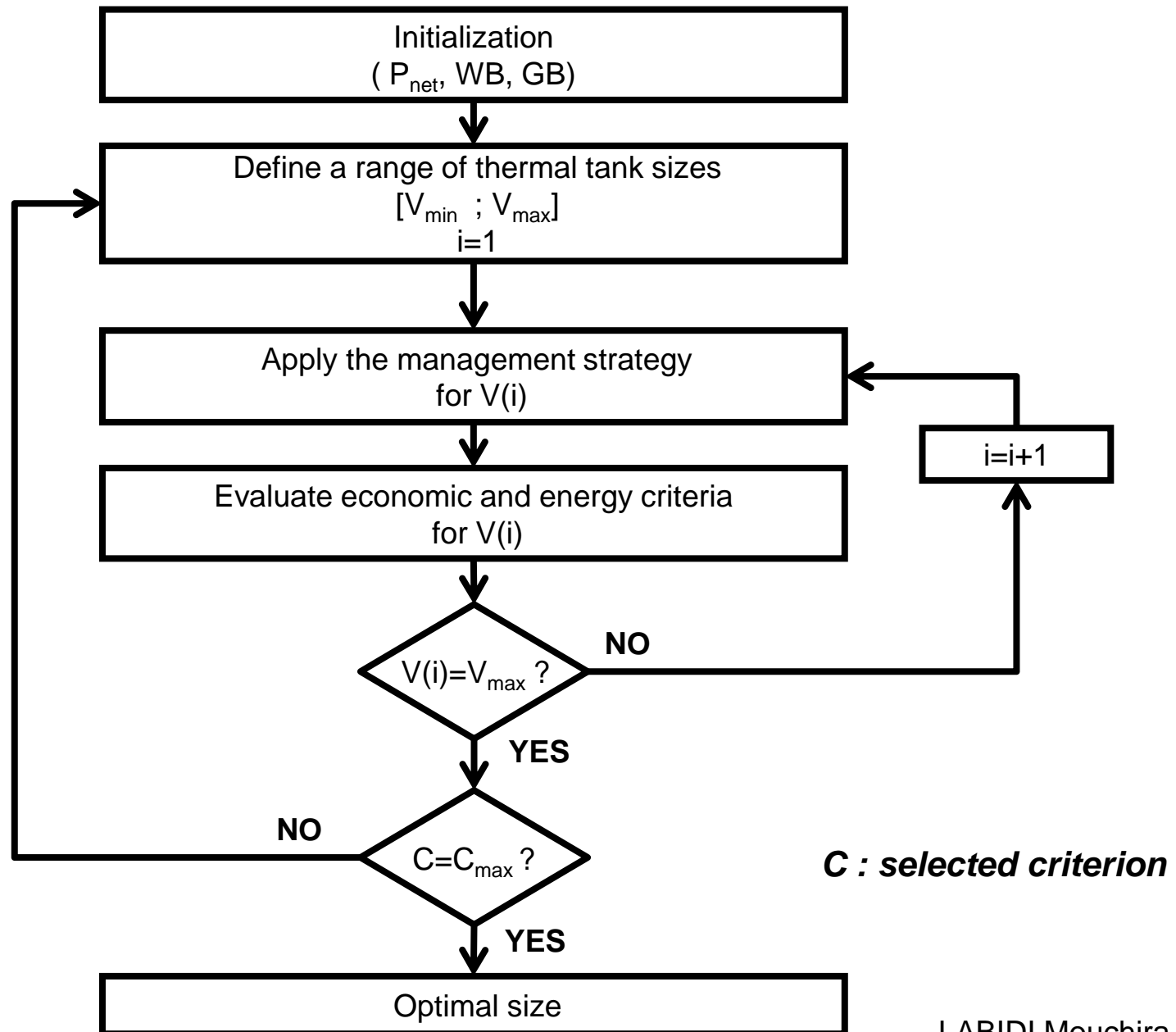
## Concept under development:

- How to size a thermal storage tank in a district boiler?
- How the whole system can be managed efficiently?

## Attractive technology:

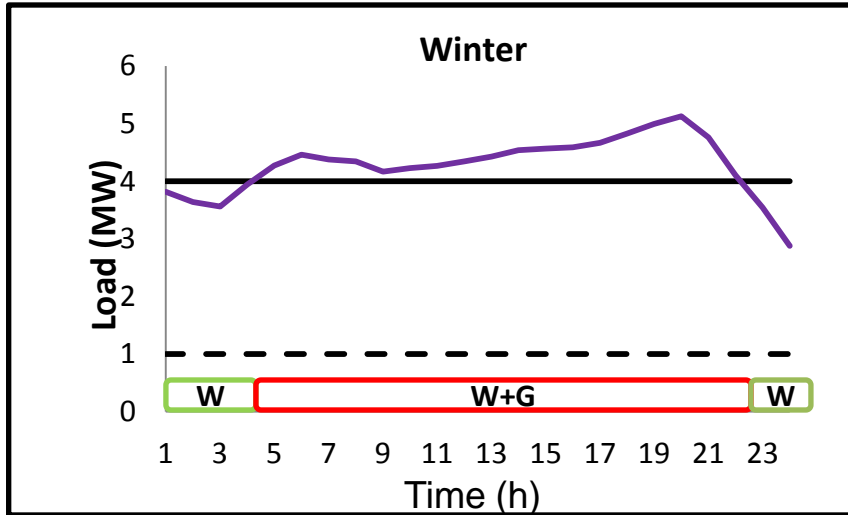
- Combined Heat and Power (CHP)
- Central Solar Heating Plants (CSHP)

# Design (sizing) strategy

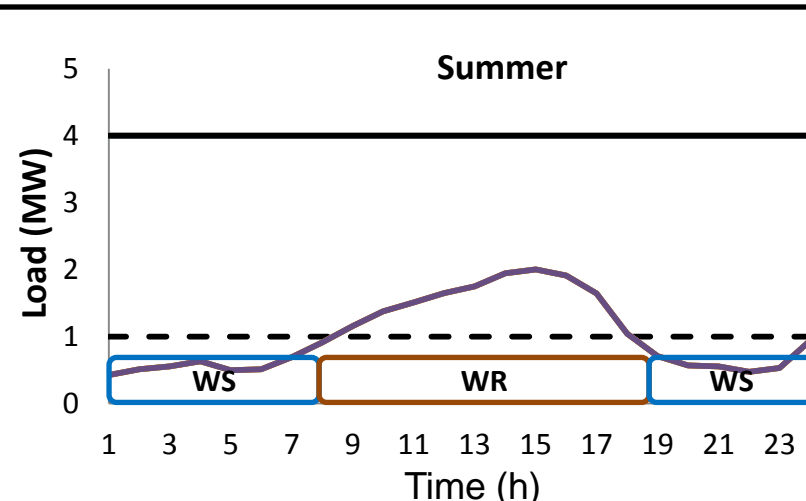
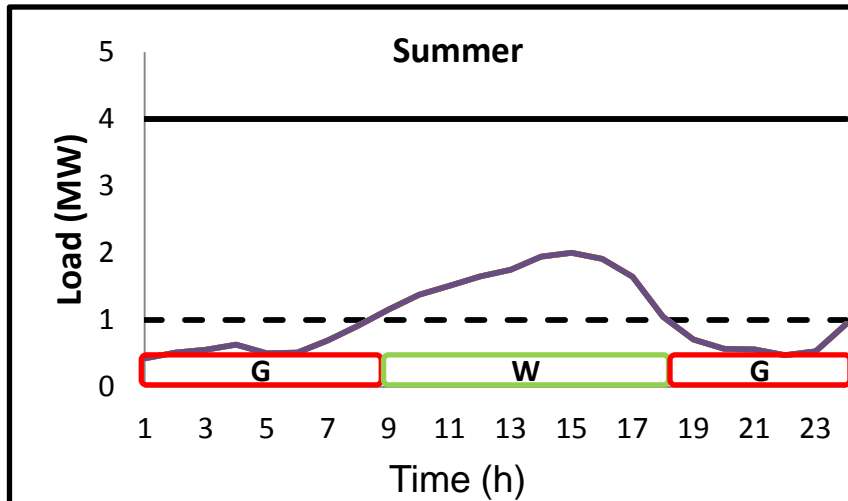
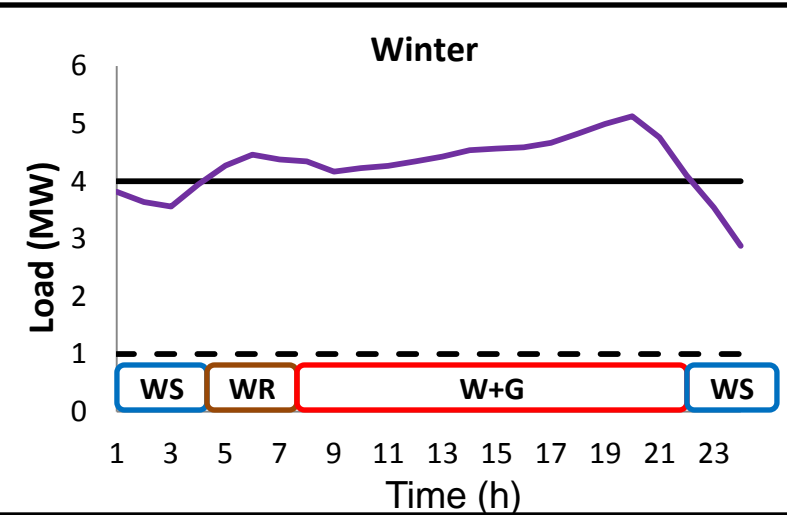


# Management strategy

Without thermal storage tank



With thermal storage tank

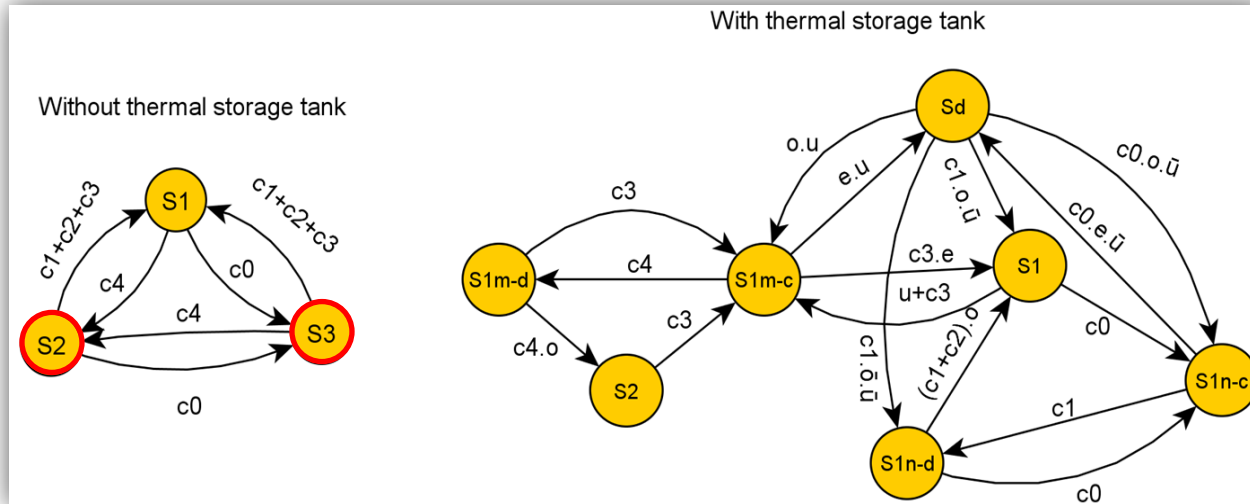


- W: Biomass boiler
- G: Gas boiler
- WS: Biomass boiler + Storing energy
- WR: Biomass boiler + Releasing energy

Pmax ———  
Pmin - - -  
Load ———



# Management strategy



State	Action	Transition	Condition
S1	Wood boiler	c0	$P_{net} < P_{min}$
S2	Wood boiler and gas boiler	c1	$P_{min} \leq P_{net} \leq th_1$
S3	Gas boiler	c2	$th_1 \leq P_{net} \leq th_2$
S1m-C	Wood boiler operating at maximum capacity and storing energy	c3	$th_2 \leq P_{net} \leq P_{max}$
S1m-d	Wood boiler operating at maximum capacity and releasing energy	c4	$P_{net} > P_{max}$
S1n-C	Wood boiler operating at minimum capacity and storing energy	o	$E_{cum} = 0$
S1n-C	Wood boiler operating at minimum capacity and releasing energy	e	$E_{cum} = E_{max}$
Sd	Releasing energy	u	Summer period

# Energy and economic evaluation

## Parametric study:

Considering a wide range of thermal storage sizes

→ The optimal size can be chosen on the basis of the optimization of one or more criteria

▪ **Energy criterion:** wood coverage rate

$$C_{wood} = E_{wood} / (E_{wood} + E_{gas})$$

▪ **Economic criterion:** economic gain

$$G = (D_{op} - PBP) \times Ec$$

$E_{wood}$ : annual energy consumption from wood

$E_{gas}$ : annual energy consumption from gas

$D_{op}$ : operating period

$PBP$ : payback period

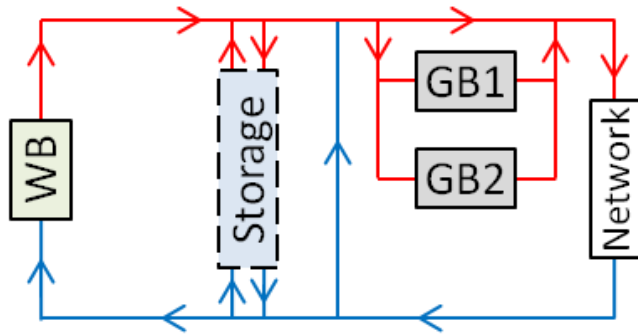
$Ec$ : annual economic gain

$C_{wood-c}$ : contractual wood coverage rate **(92%)**

## Optimization problem

$$\max_v (G) \text{ with } \begin{cases} V \in [V_{\min}; V_{\max}] \\ C_{wood}(V) \geq C_{wood-c} \end{cases}$$

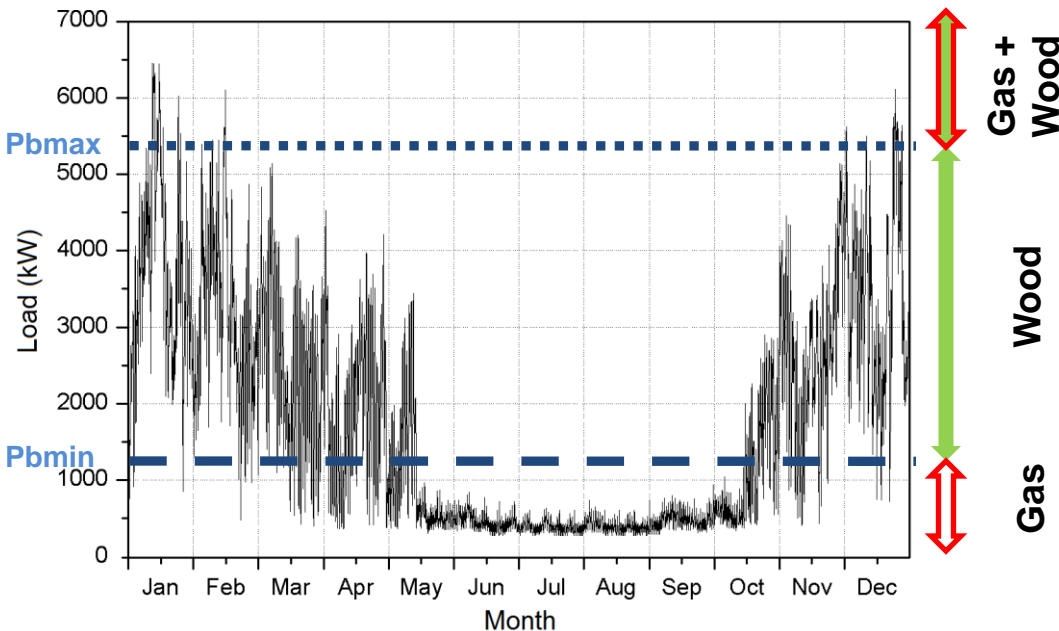
# Case study



Component	Characteristics
WB	[1350 ; 5400] kW
GB1	3500 kW
GB2	6500 kW
Storage	To be defined

▪ **Location:** Midi-Pyrénées, southwest of France

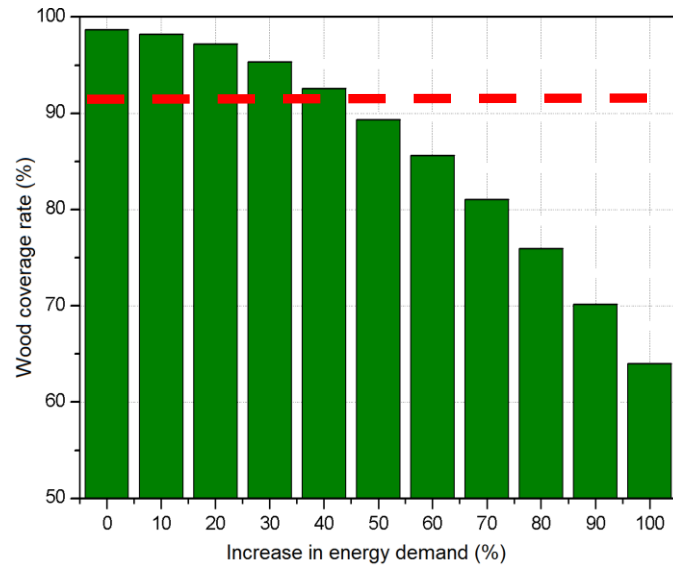
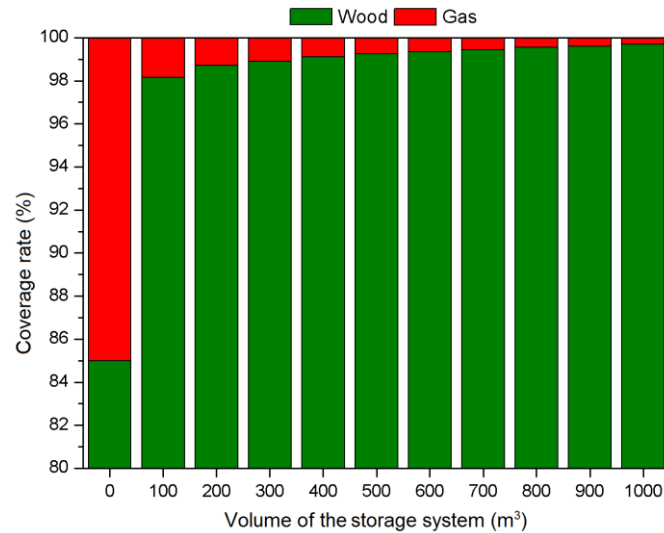
▪ **Climate:** temperatures can be high during summer and quite low during winter



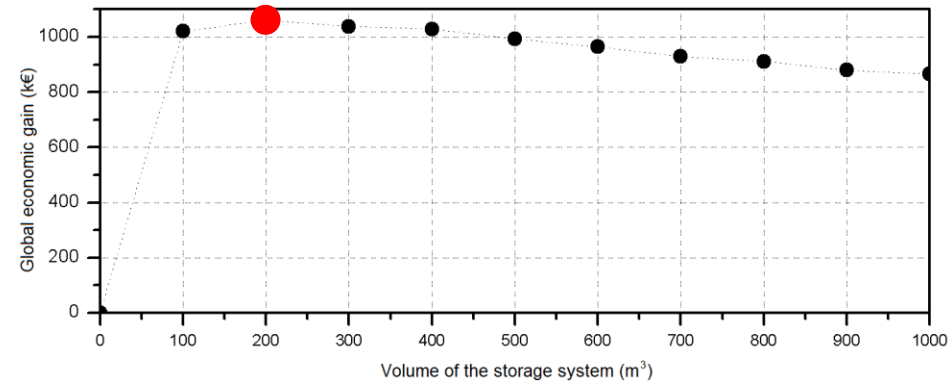
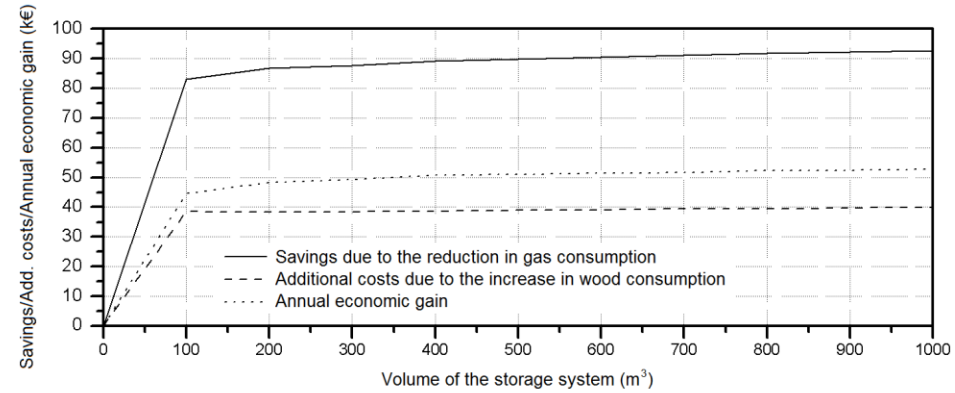
- Gas boiler is used during summer and winter (peak in demand)
- Wood boiler is used during winter and mid-season

# Case study

## Energy criteria



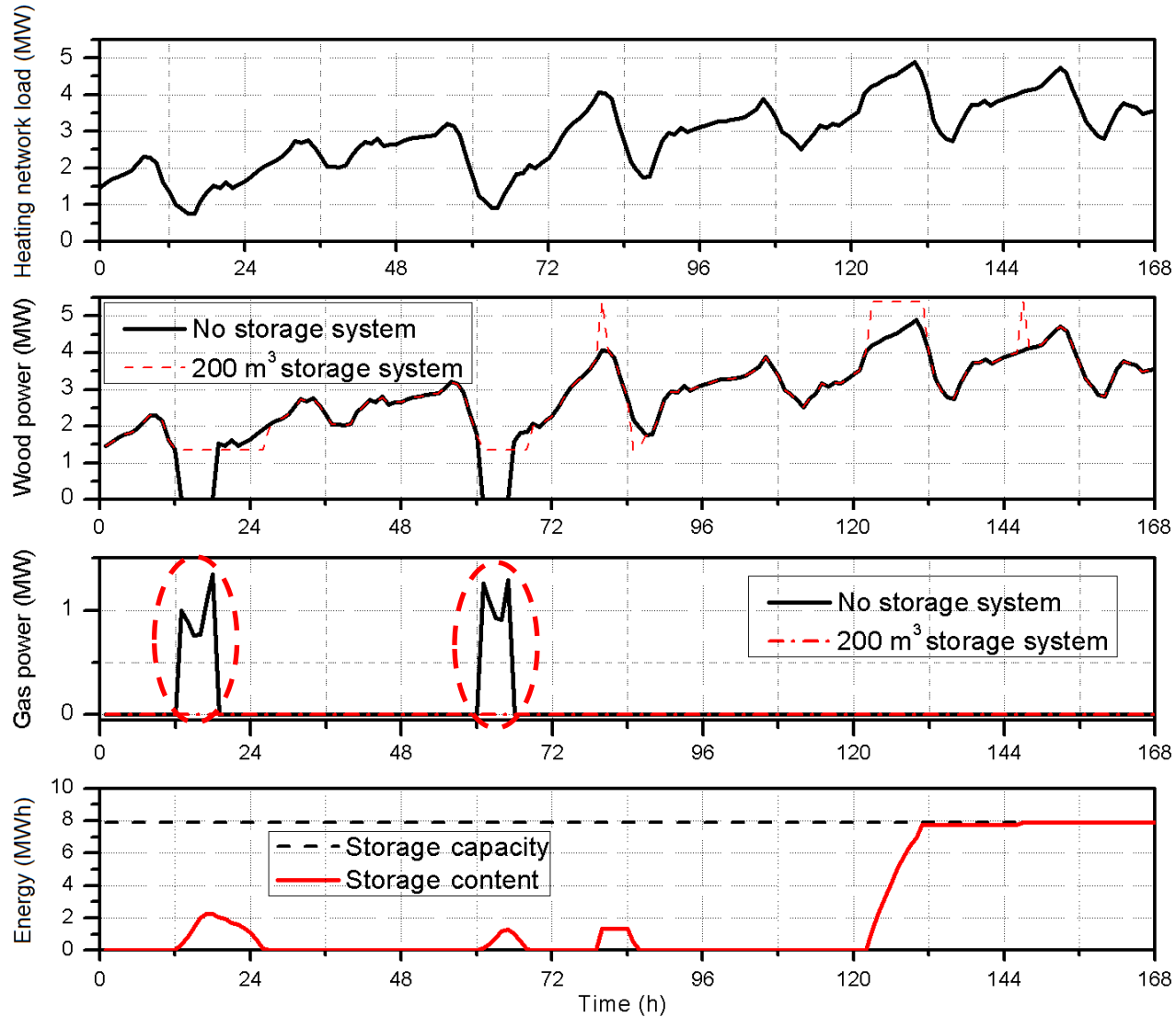
## Economic criteria



Configuration	$C_{wood}$	$Ec$	$G$ [25 years]	$PBP$
No storage system	85%	-	-	-
200 m³ storage system	98.7%	48.3 k€	1109.5 k€	2 years

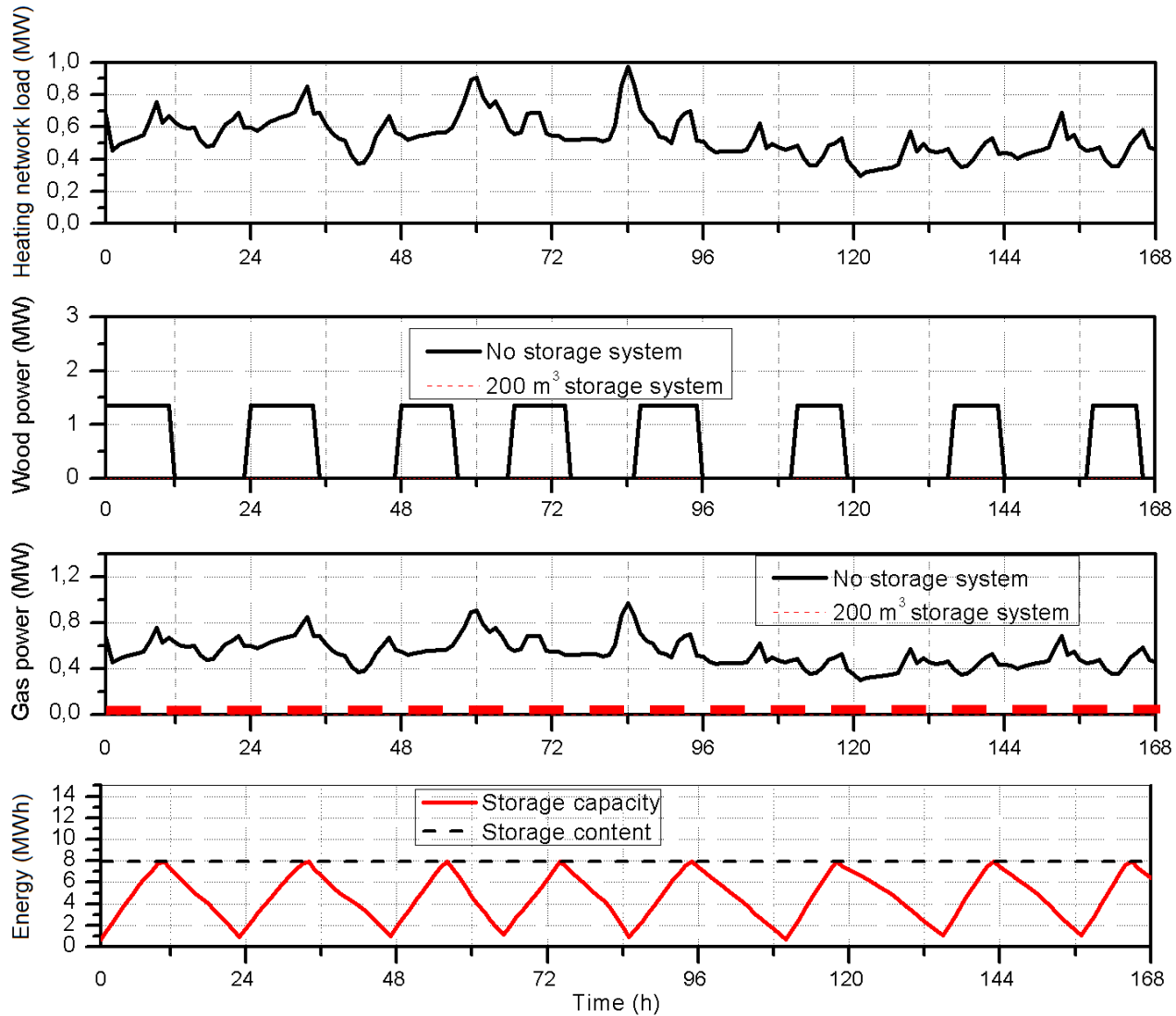
# Case study

## Plant operation during January



# Case study

## Plant operation during May



# Synthesis

Case study: synthesis	
Location	Midi-Pyrénées
Operating period (years)	25
Annual required energy (MWh)	16
Optimal size of the storage system (m <sup>3</sup> )	200
Wood coverage rate without storage system (%)	85
Wood coverage rate with storage system (%)	98.72
Price (k€)	98
Annual economic gain (k€)	48.3
Global economic gain (k€)	1109.5
Payback period (years)	2

- The contractual wood coverage rate is satisfied (92%)
  - Gas consumption is significantly reduced
  - Plant operation is improved

# Conclusions and Outlooks

- Useful design strategy → can be applied to any district boiler
- Strong relationship between the volume of the thermal storage tank and the characteristics of the district boiler (heat demand, boilers)

- Taking into account the biomass boiler dynamics
- Evaluate thermal losses in the thermal storage tank
- Develop a predictive control strategy



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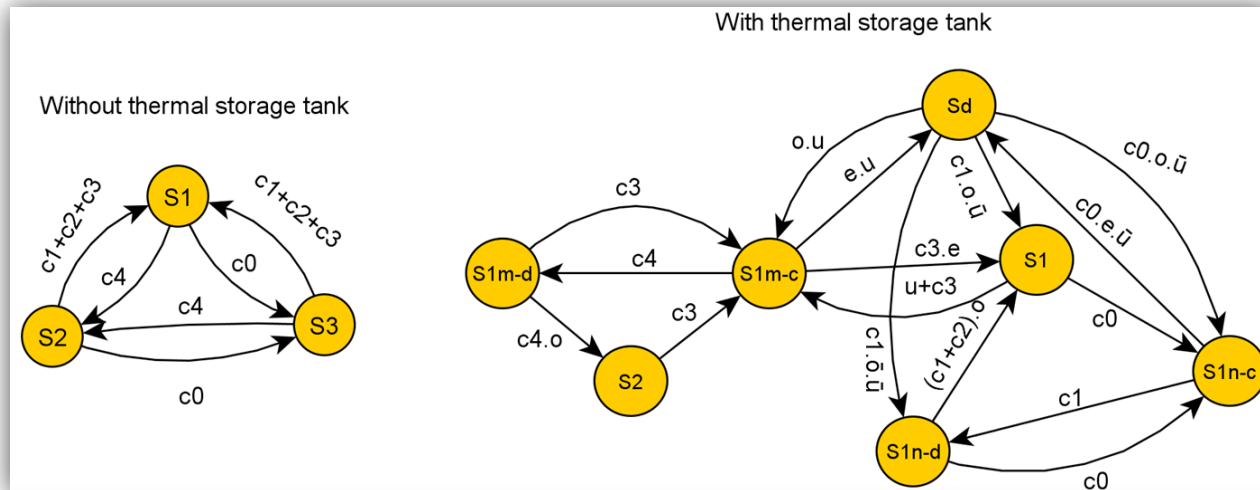
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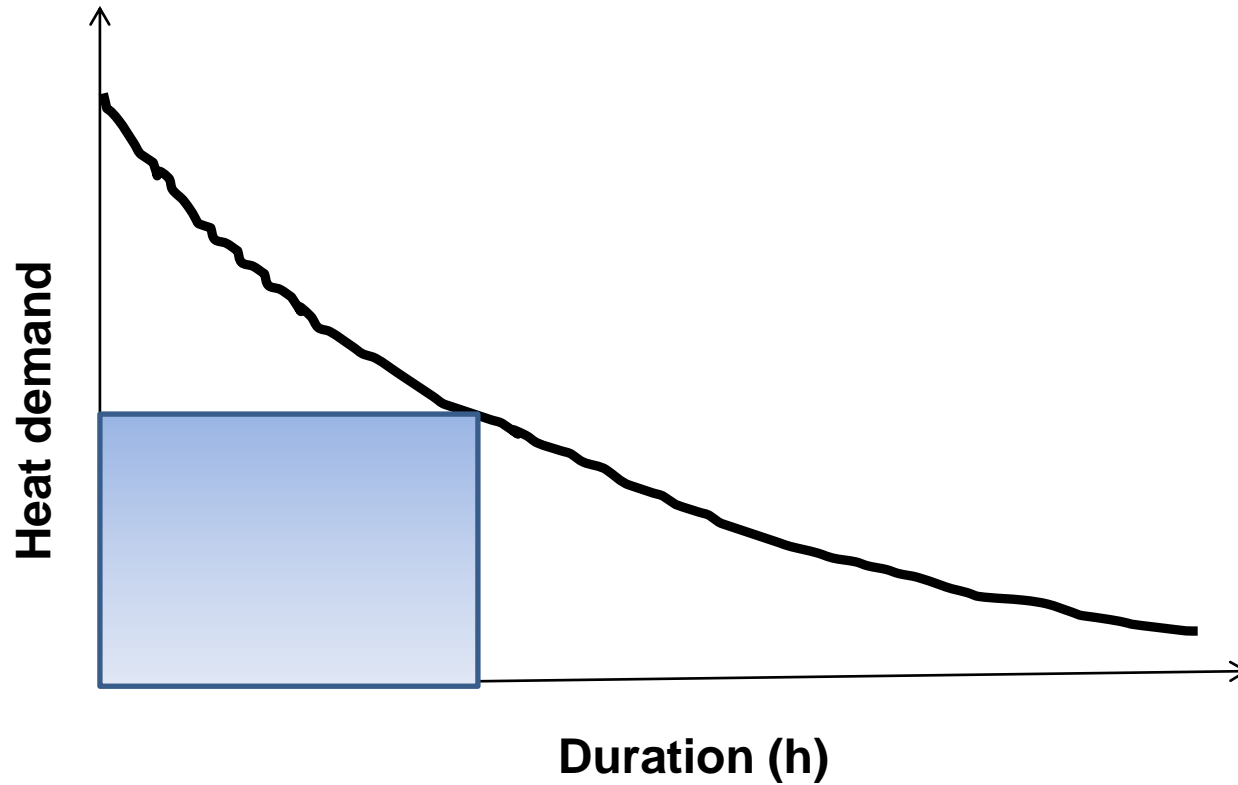
# Management strategy



State	Action	Transition	Condition
$S_1$	$P_{WB} = P_{res} \text{ \& } P_{GB} = 0 \text{ \& } TS = 0$	$c_0$	$P_{net} < P_{min}$
$S_2$	$P_{WB} = P_{WB}^{max} \text{ \& } P_{GB} = P_{res} - P_{WB}^{max} \text{ \& } TS = 0$	$c_1$	$P_{min} \leq P_{net} < th_1$
$S_3$	$P_{WB} = 0 \text{ \& } P_{GB} = P_{res} \text{ \& } TS = 0$	$c_2$	$th_1 \leq P_{net} < th_2$
$S_{1m-c}$	$P_{WB} = P_{WB}^{max} \text{ \& } TS = 1$	$c_3$	$th_2 \leq P_{net} \leq P_{max}$
$S_{1m-d}$	$P_{WB} = P_{WB}^{max} \text{ \& } TS = -1$	$c_4$	$P_{net} > P_{max}$
$S_{1n-c}$	$P_{WB} = P_{WB}^{min} \text{ \& } TS = 1$	$o$	$E_{cum} = 0$
$S_{1n-d}$	$P_{WB} = P_{WB}^{min} \text{ \& } TS = -1$	$e$	$E_{cum} = E_{max}$
$S_d$	$P_{WB} = 0 \text{ \& } TS = -1$	$u$	Summer period

Thermal storage tank → allows gas consumption to be reduced

Useful management strategy → can be applied to any district boiler



### **Biggest rectangle method**

The 8760 heat demand data are sorted in descending order and placed in a load-duration diagram, the biggest rectangle that can be inscribed in the load-duration curve is determined. The intersection of this rectangle with the vertical axis determines the maximal capacity of the boiler.