NN-based MPC for energy efficient HVAC systems for CERN accelerators

Nikolina Bunijevac
EN/CV/CL

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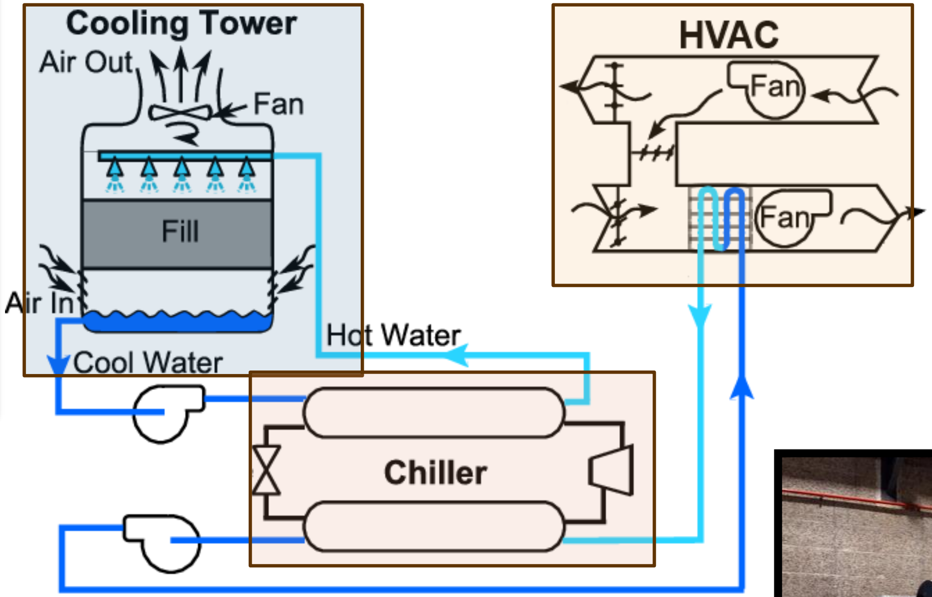
heating, ventilation, air conditioning

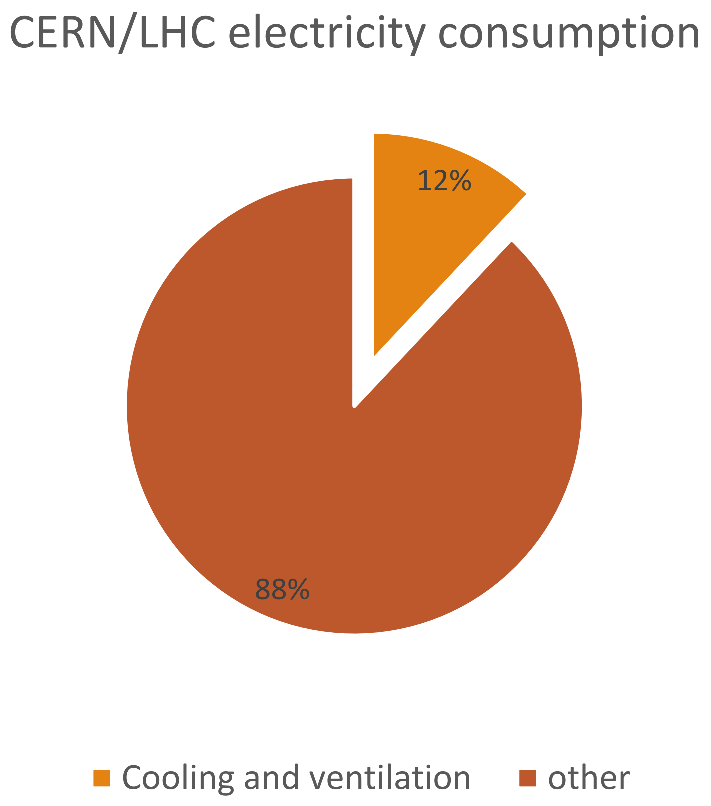


Cooling Tower
Air Out
Fan
Fill
Air In
Hot Water
Cool Water
HVAC
Fan
Fan
Chiller

NN-based MPC for energy efficient HVAC systems for CERN accelerators

Research motivation

Following global sustainability concerns, "pursuing actions and technologies aiming at ***energy savings and reuse****" is listed as one of the main objectives for 2021-2025 at the European Organization for Nuclear Research (CERN). This objective extends to the Cooling and Ventilation group.*

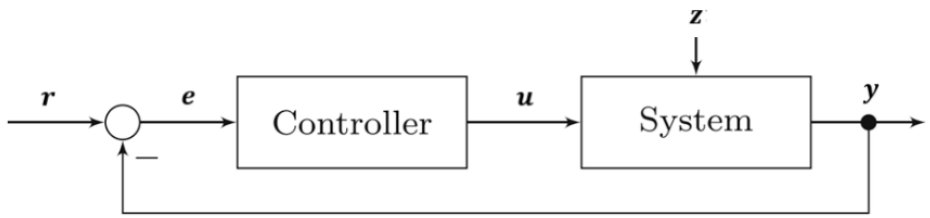


NN-based MPC for energy efficient HVAC systems for CERN accelerators

Controls optimization

Controls optimization

CLASSICAL FEEDBACK CONTROLLER



Controls optimization

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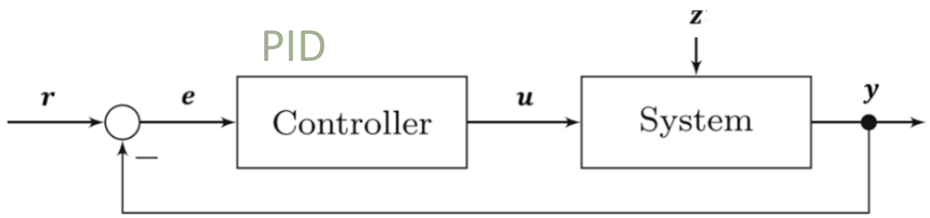

Controls optimization

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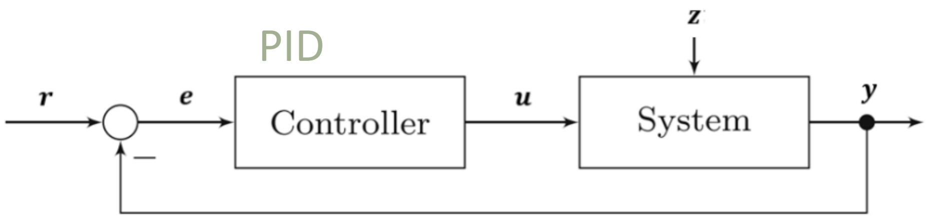
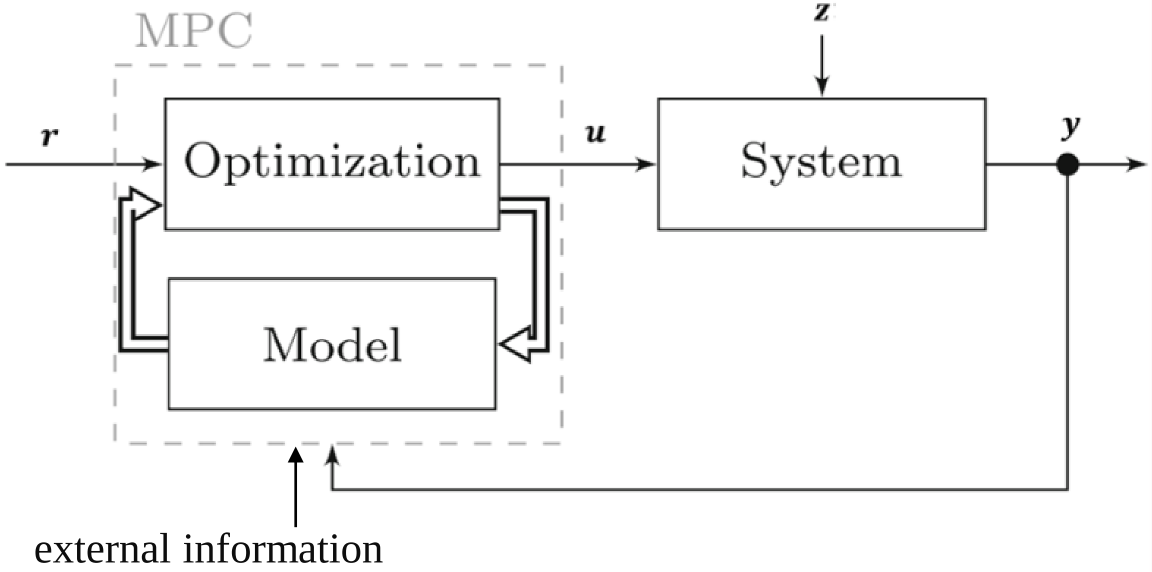
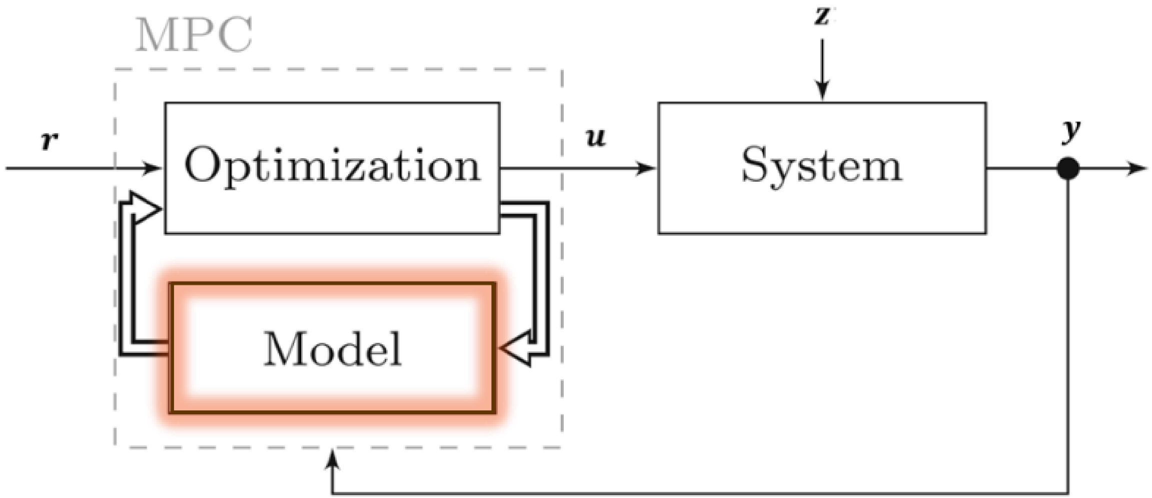


MODEL PREDICTIVE CONTROLLER



- prediction horizon

Modelling



System: Air Handling Unit (HVAC311)

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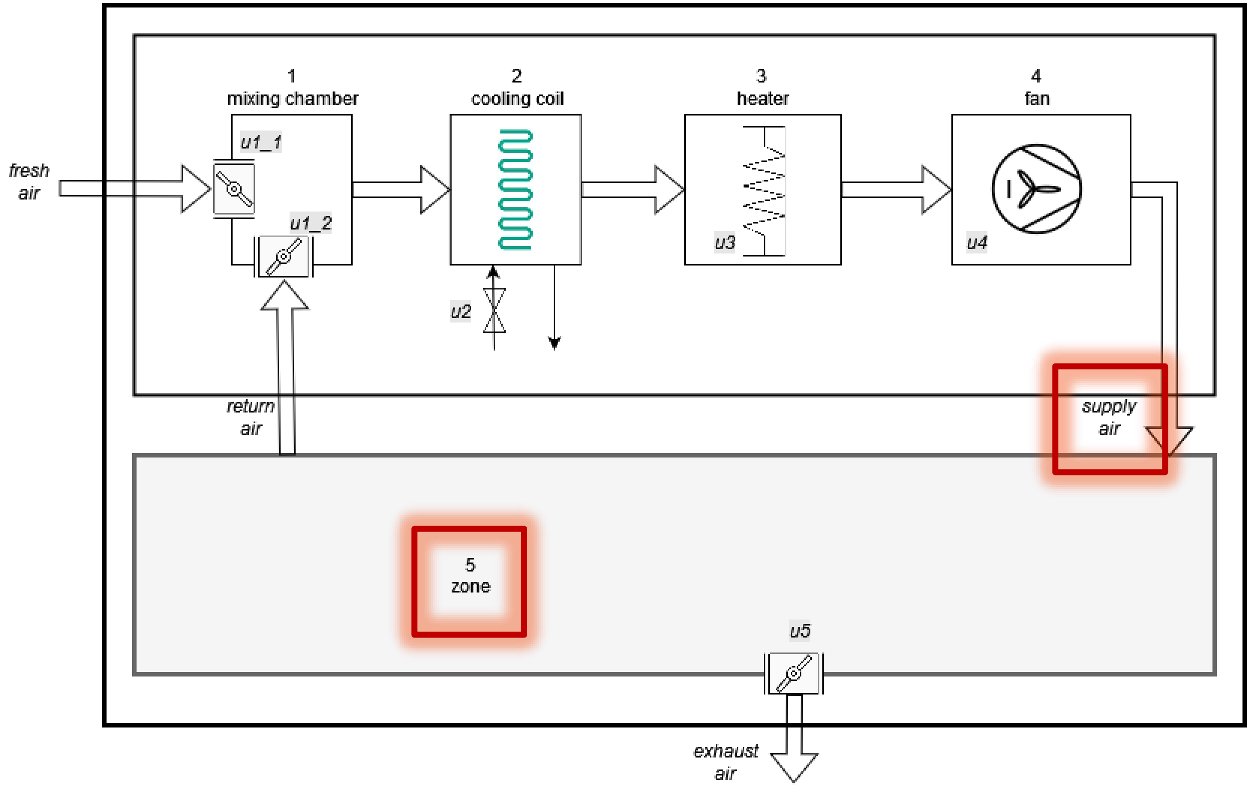
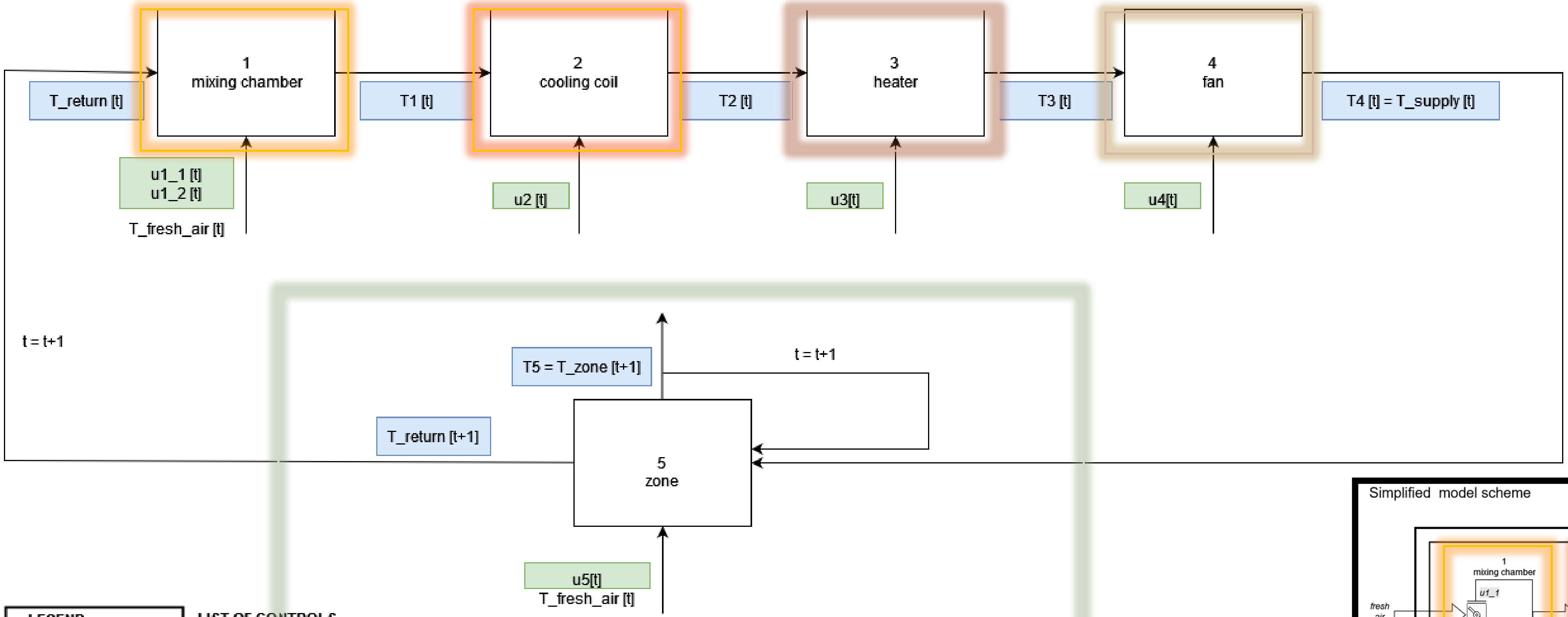
Simplified model scheme



Controlled variables

System diagram

Physics-informed approach



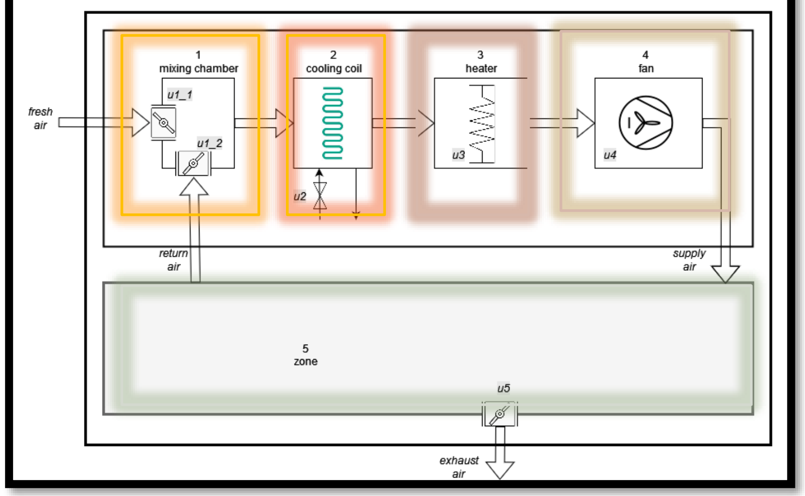
LEGEND

- input: controls
- input: measurements
- temperature values

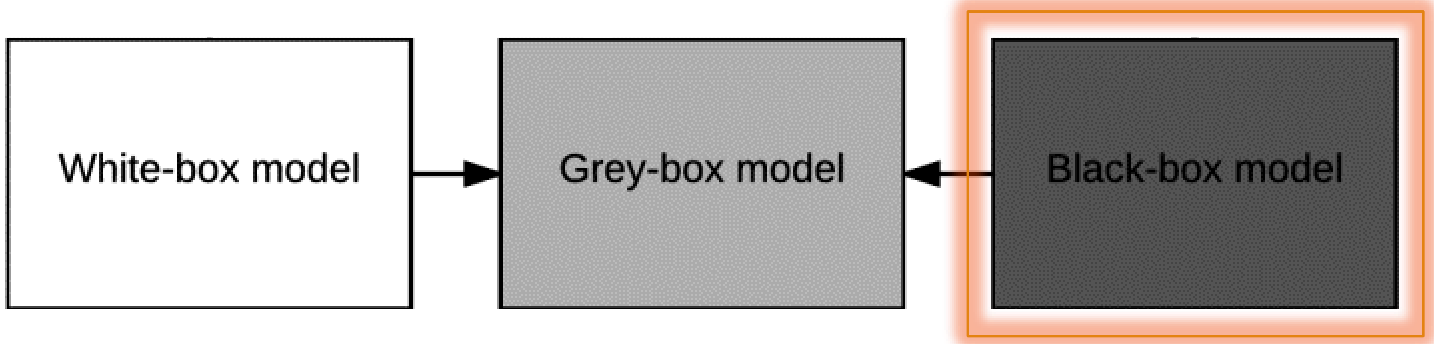
LIST OF CONTROLS

u1_1 damper_opening_return_air
u1_2 damper_opening_fresh_air
u2 cooling_coil_valve_opening
u3 electrical_heater
u4 fan_speed
u5 extraction fan speed

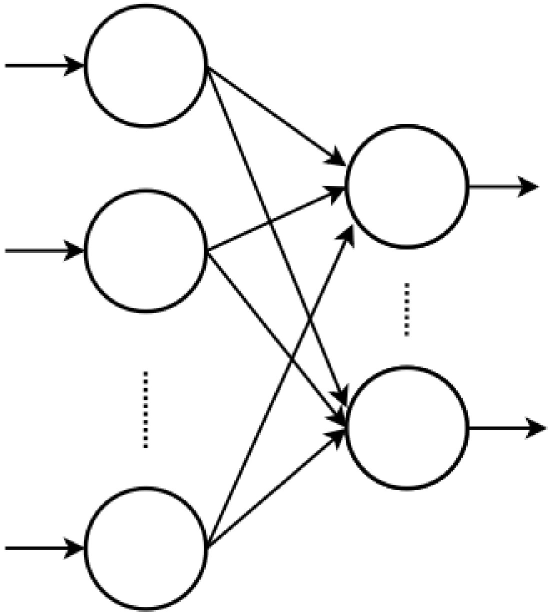
Simplified model scheme



Modelling: methodology



Modelling: methodology – **black-box**



FFNN

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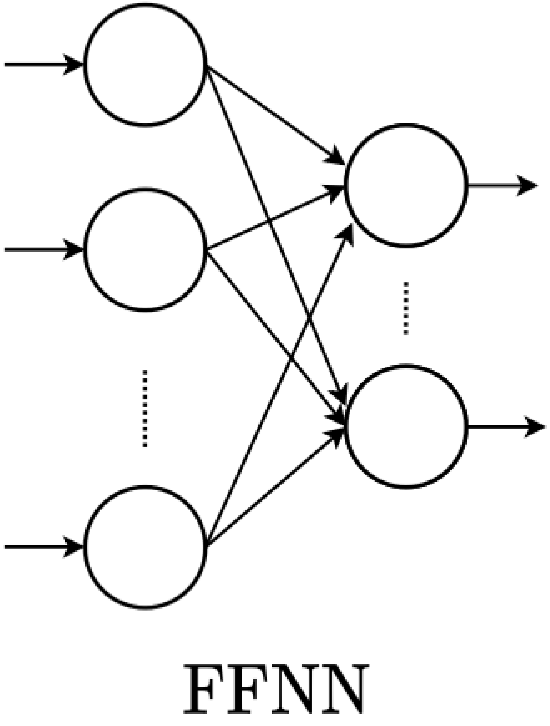

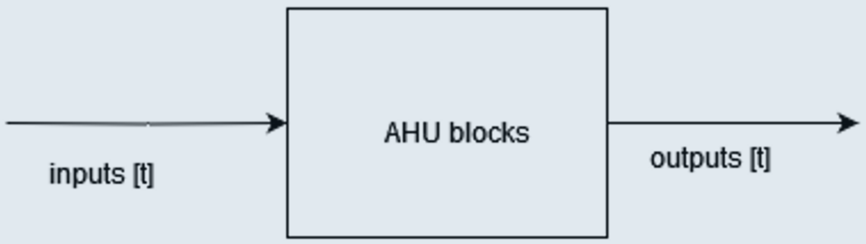

AHU blocks: steady-state

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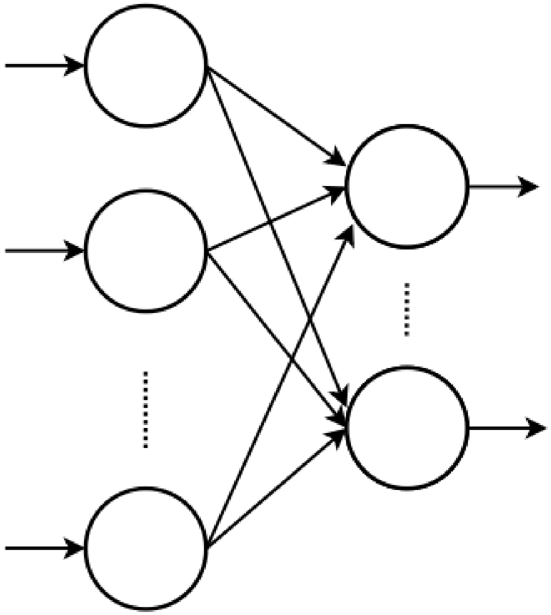

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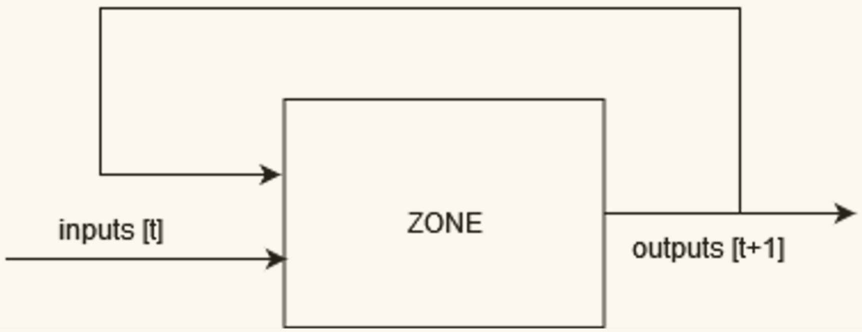
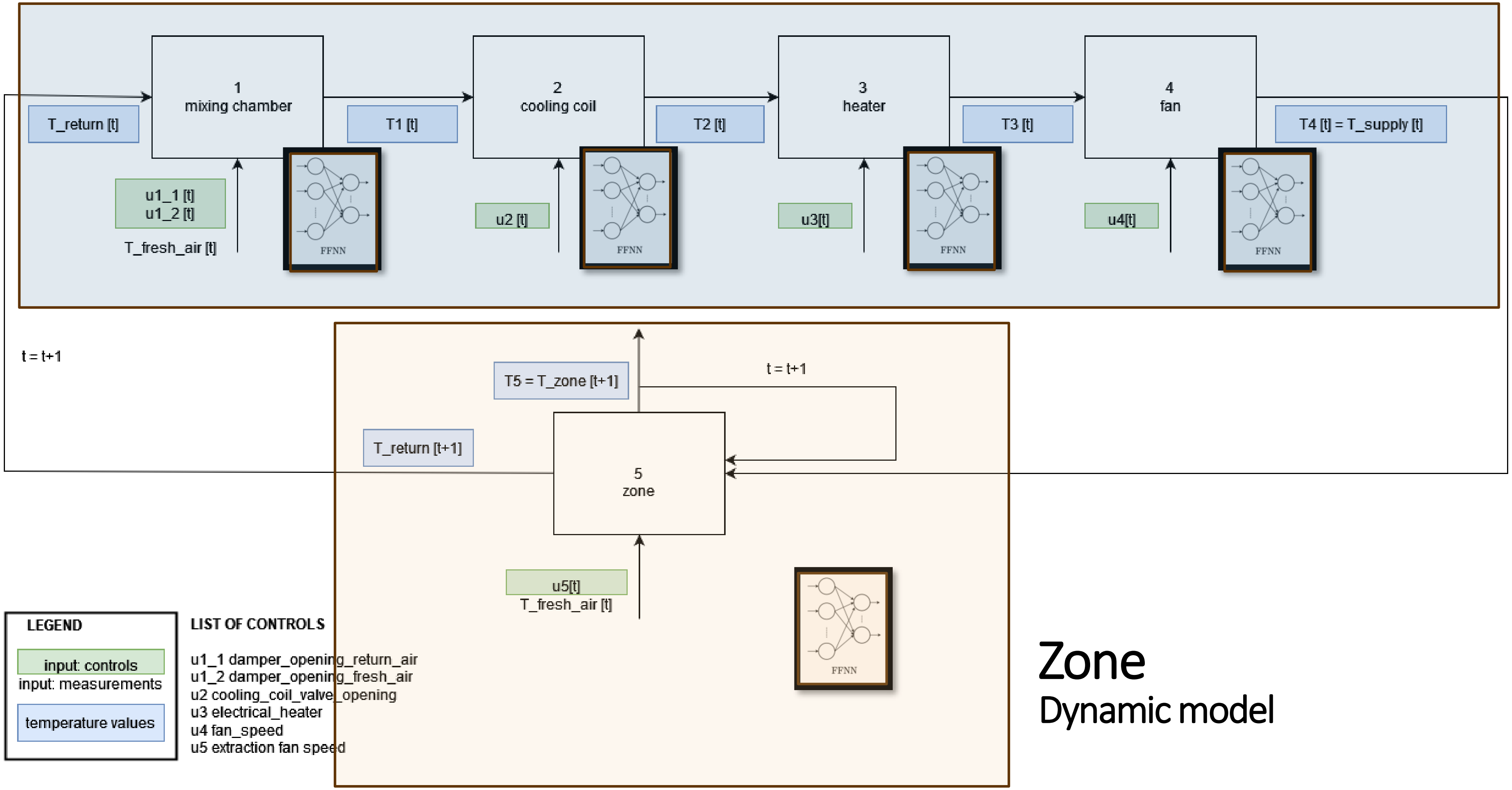


Zone: dynamic

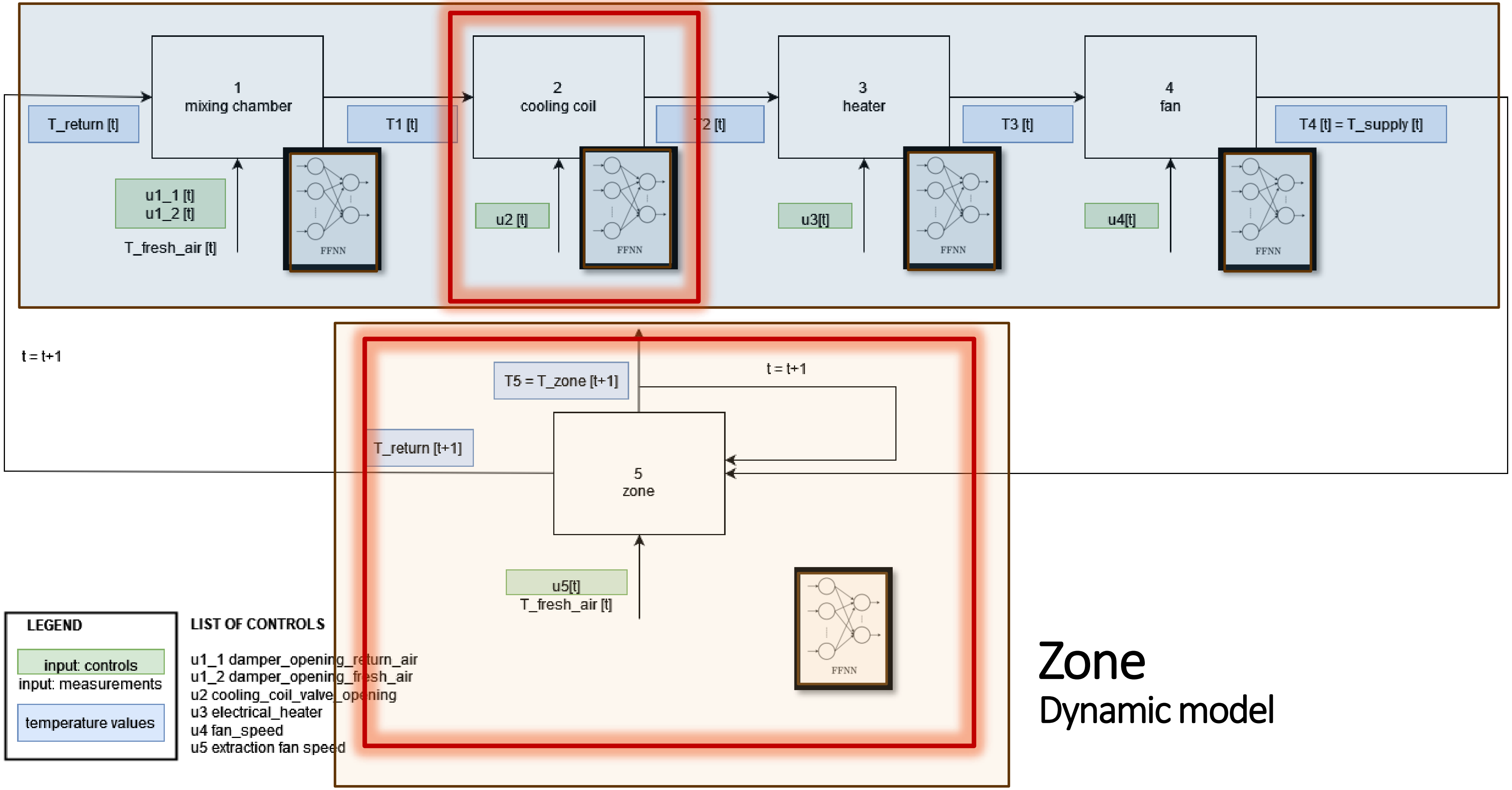
System diagram



AHU
Steady state models

Zone
Dynamic model

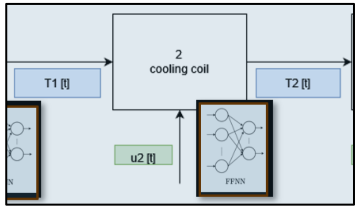
System diagram

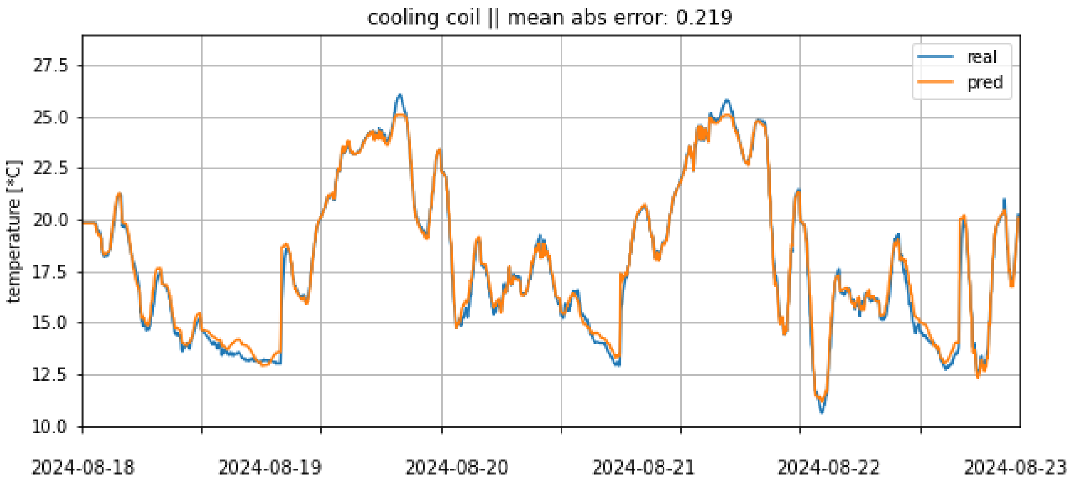


AHU
Steady state models

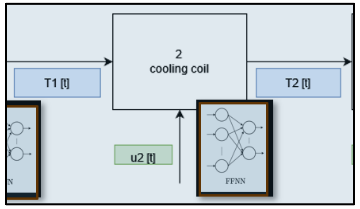
Zone
Dynamic model

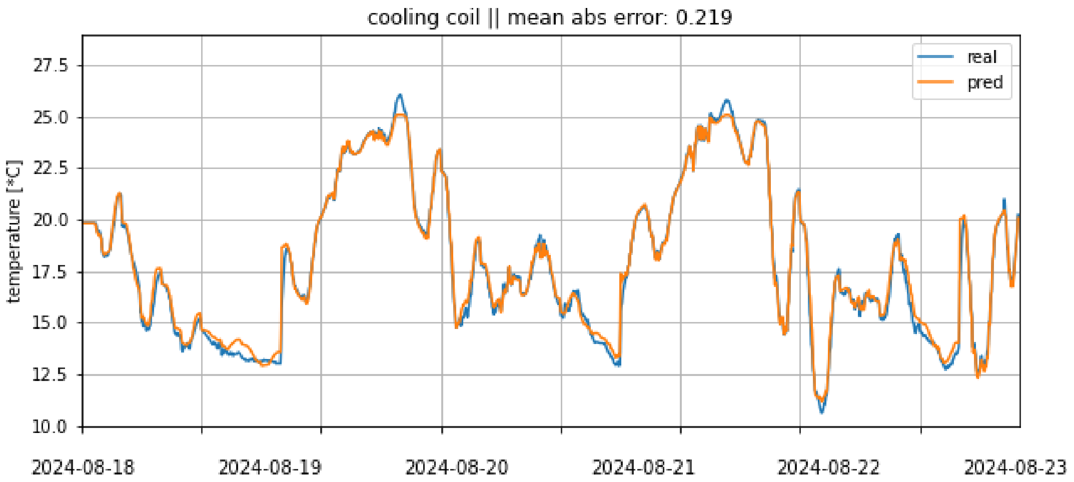
Example: cooling coil

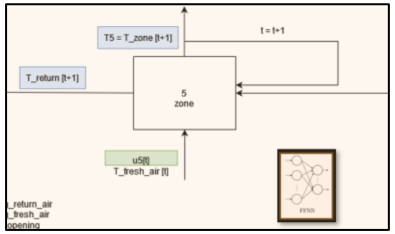


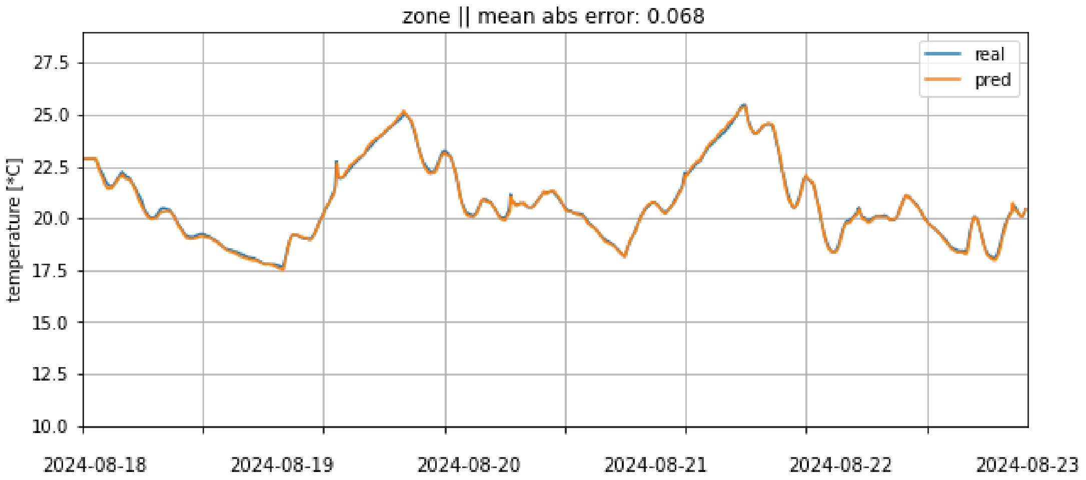


Example: cooling coil & zone

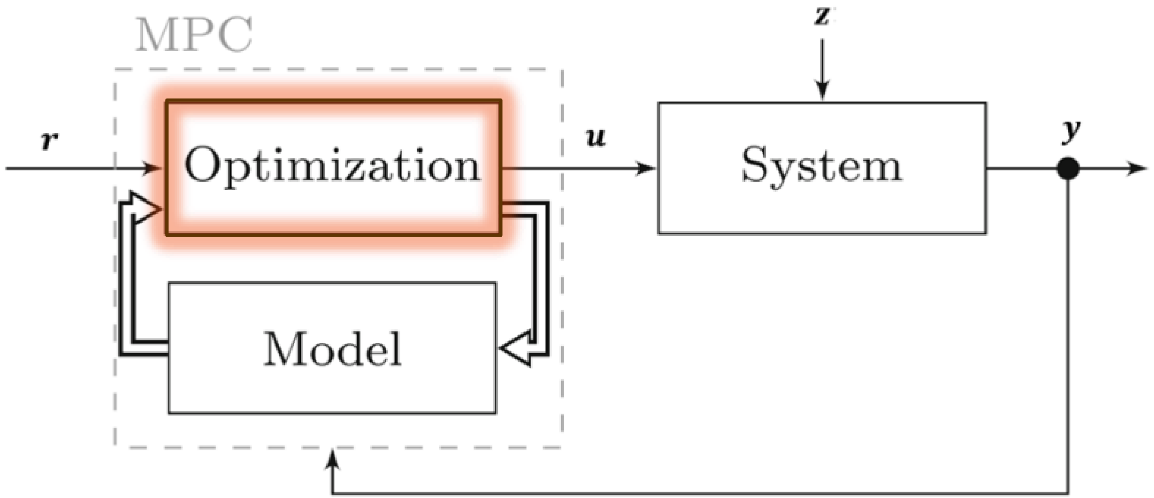








Optimization



Optimization

Optimization

$$J = \sum_{t \text{ in prediction horizon}} J[t]$$

- optimization function: estimation of electricity consumption for the prediction horizon + **penalty**

$$J[t] = \sum_{k=1}^{Nc} J^k(u^k[t], x^k[t])/J_{e\_max} + penalty$$

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embedded in variable coding

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penalty when violated

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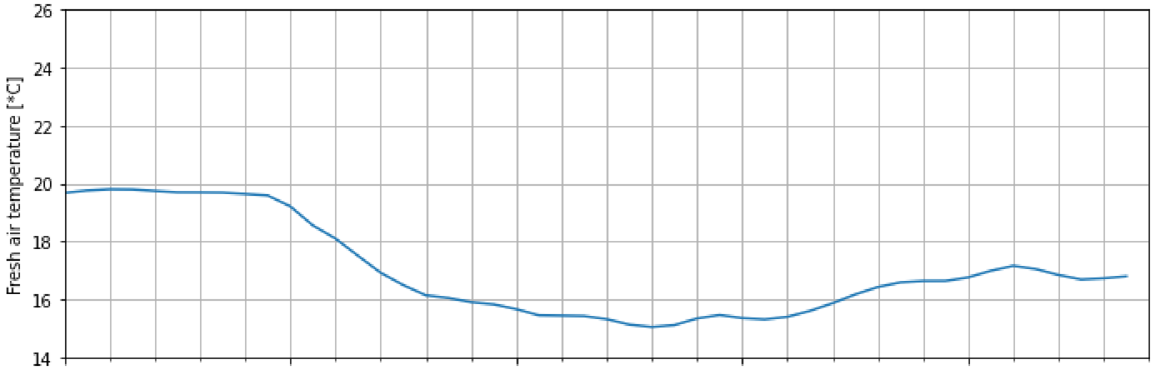
penalty when violated

- **genetic algorithm**
  binary

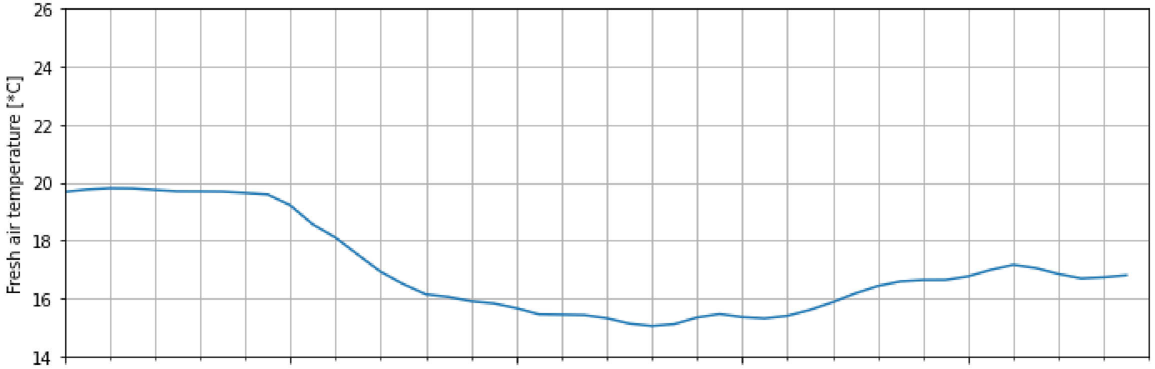
optimization technique based on evolutionary principles to find solutions to complex problems

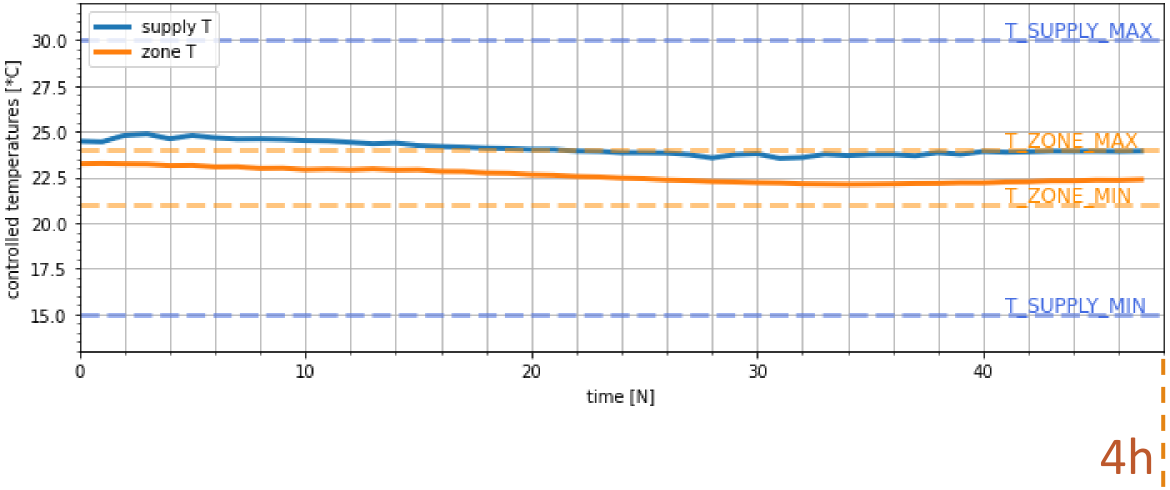
Example: MPC solution



4h

Example: MPC solution





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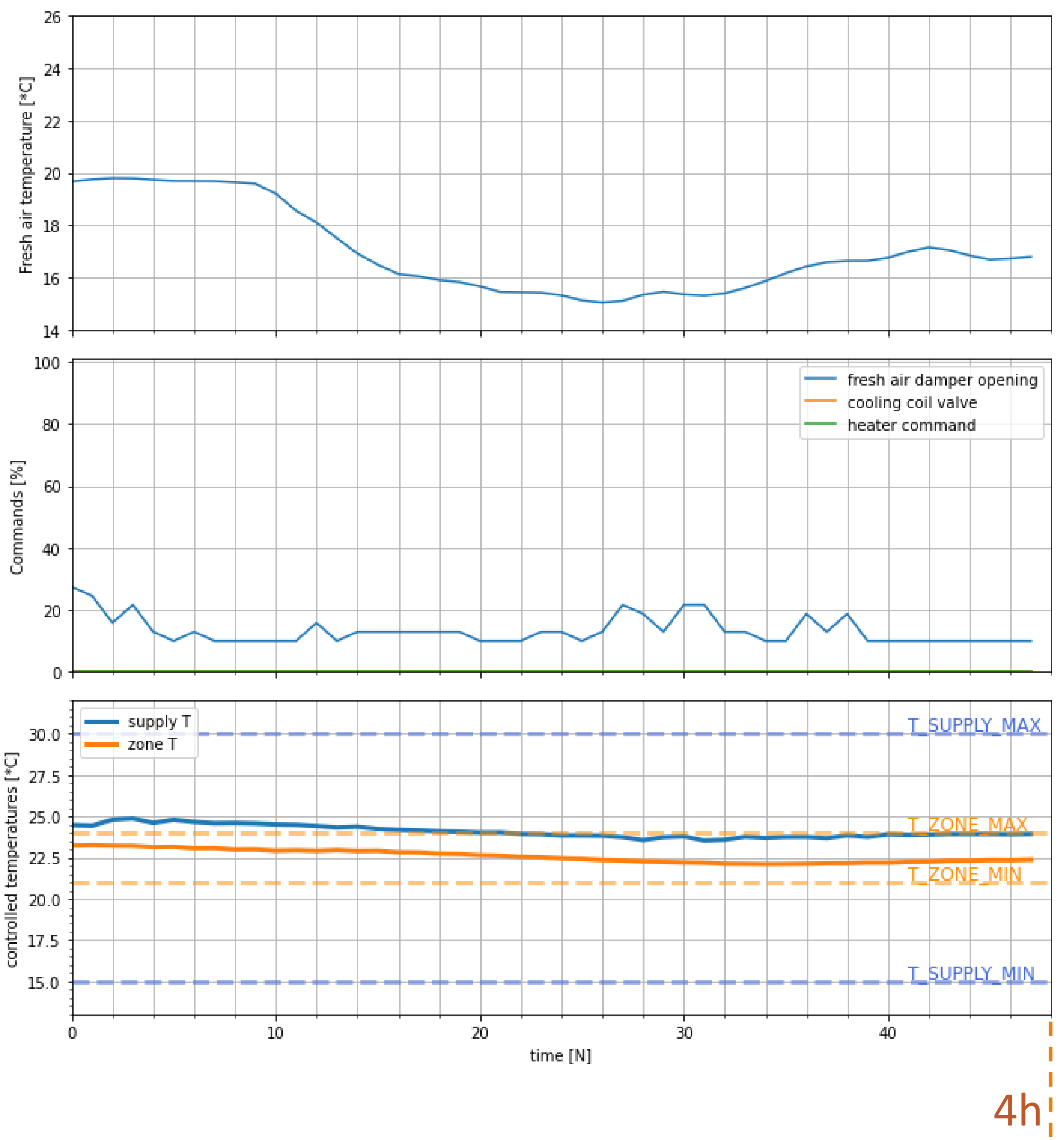
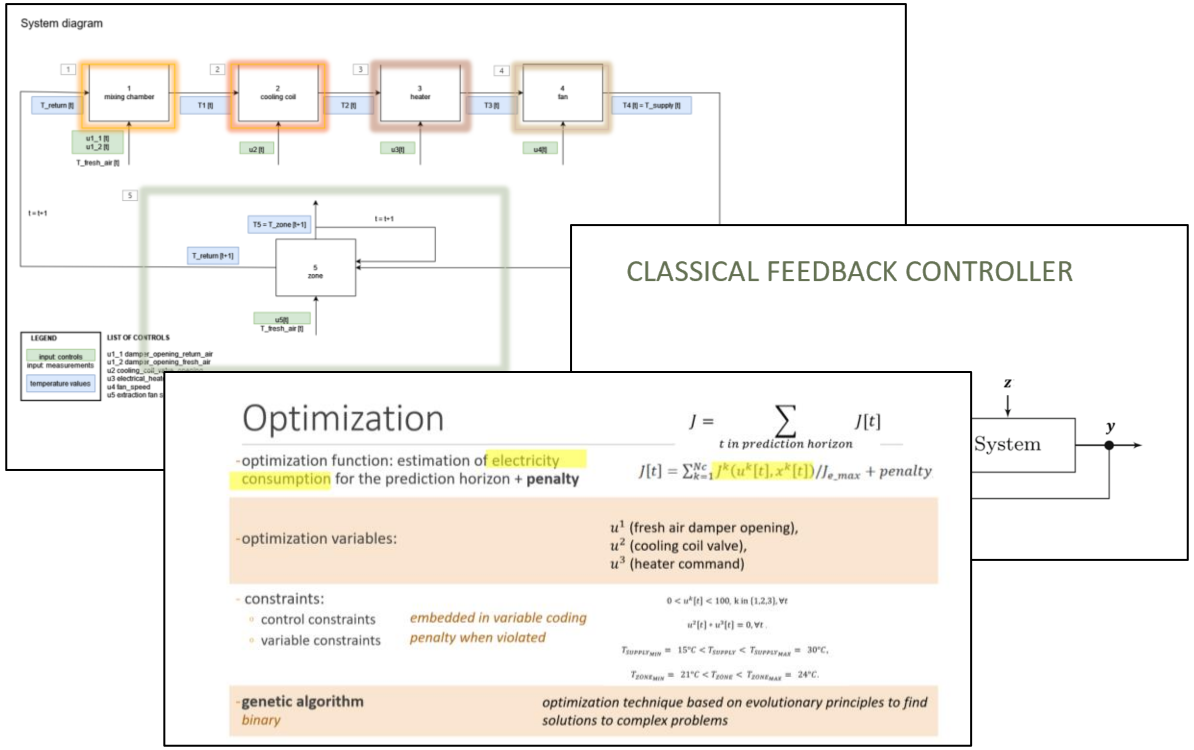


Next step

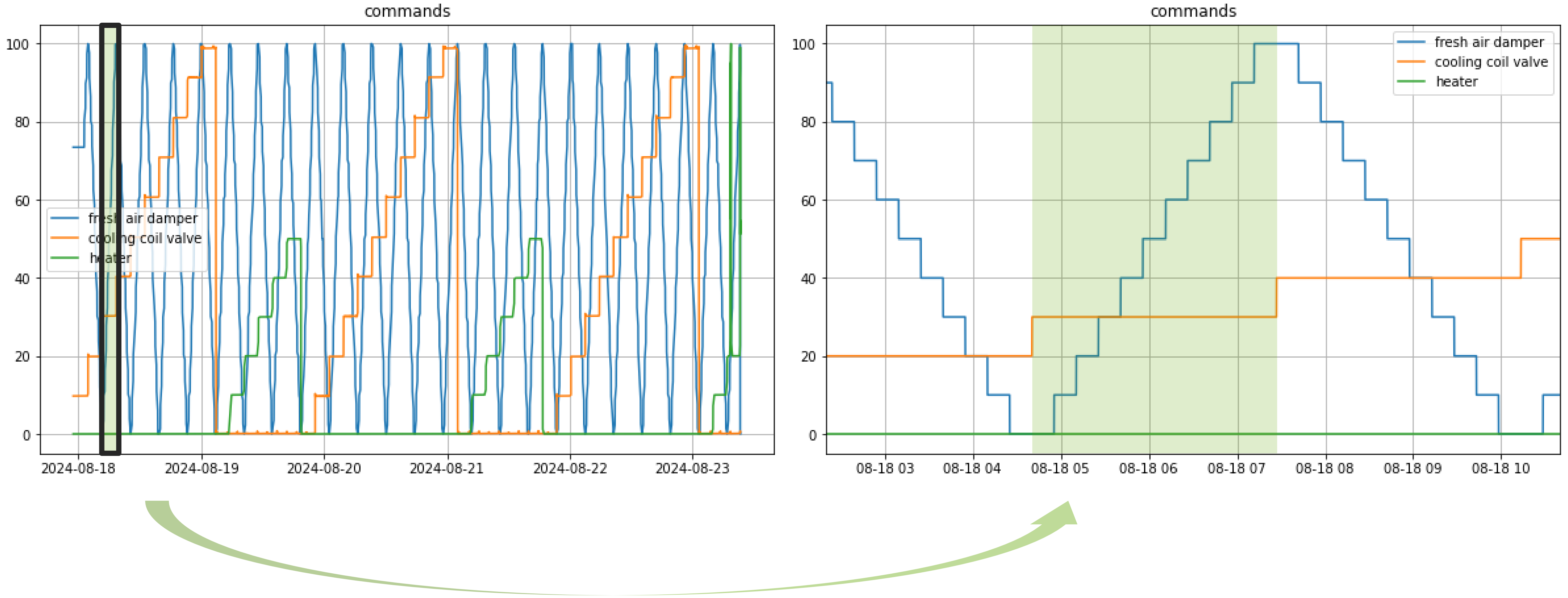
- thorough comparison between classical controls and MPC
- test zone on larger dataset
- If needed, MPC optimization upgrade for faster convergence



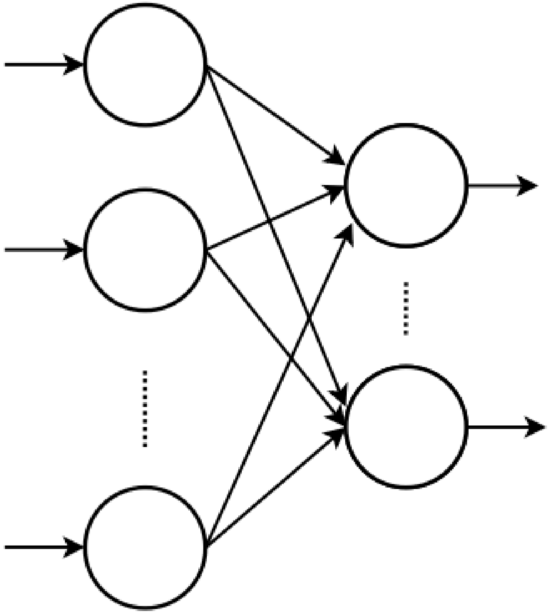
Discussion

Extra slides

MPC for HVAC
Modelling upgrade: dataset



Modelling: methodology – **black-box**



FFNN

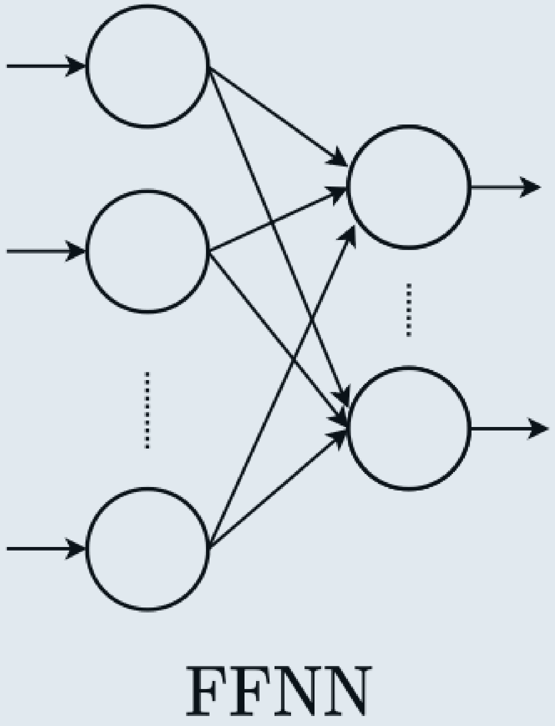
```python
class SimpleNN(nn.Module):
    def __init__(self, input_size, output_size,hidden_size1=5,hidden_size2=5):
        super(SimpleNN, self).__init__()

        self.fc1 = nn.Linear(input_size, hidden_size1)
        self.fc2 = nn.Linear(hidden_size1, hidden_size2)
        self.fc3= nn.Linear(hidden_size2, output_size)
```

	AHU (4 NNs)	ZONE (1 NN)
Number of parameters	~50 (61, 51, 51, 46)	182
Size of dataset (6:1 training:test)	2290	1565
Individual precision Mean abs error [*C]	~0.25 (0.39, 0.33, 0.09, 0.17)	0.17 (0.25, 0.09)

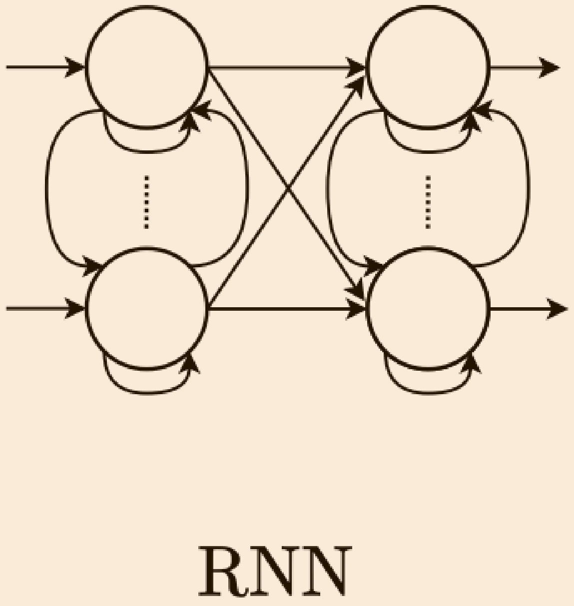
Modelling: methodology - update

AHU - fast

Zone - slow

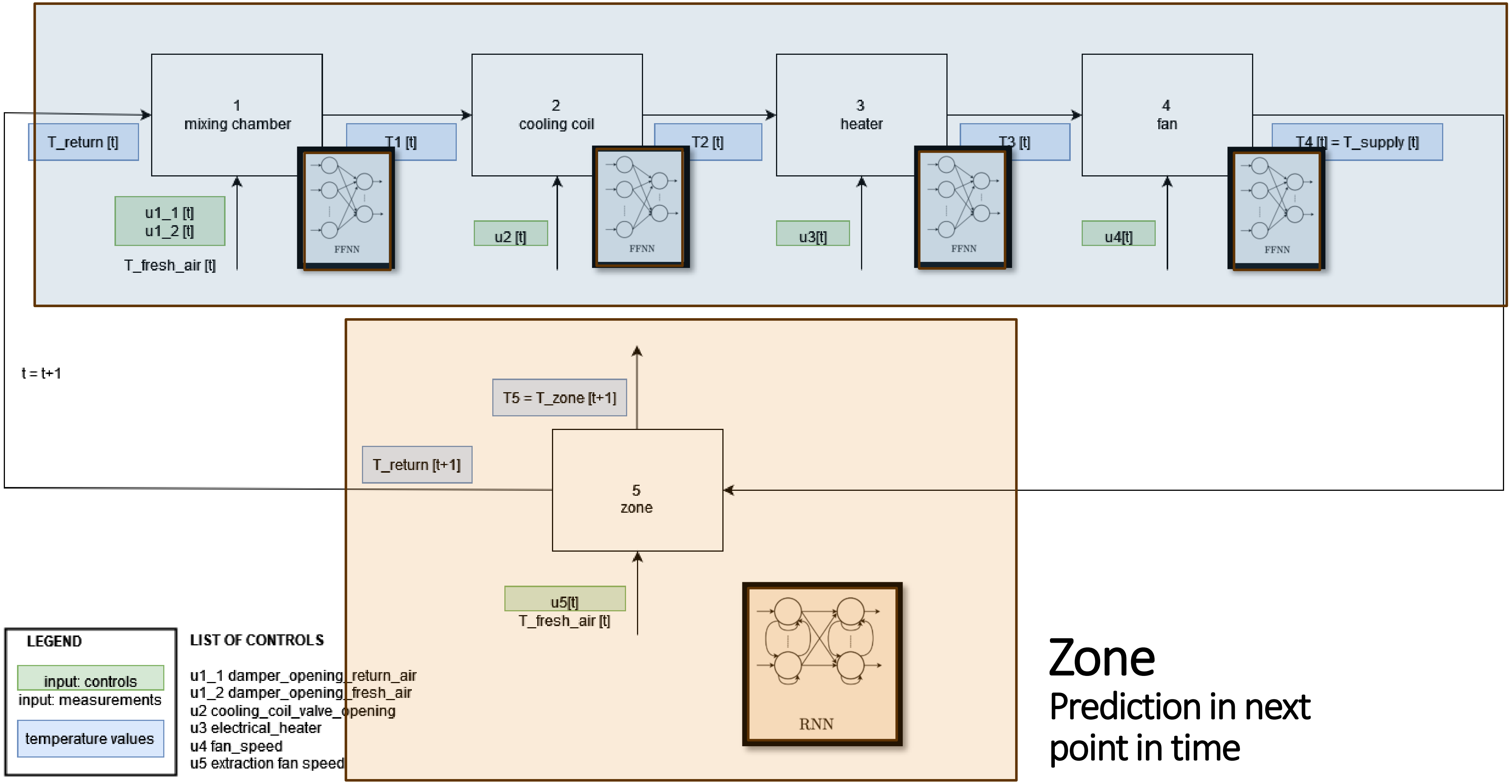


Steady state



Prediction in next point in time

System diagram



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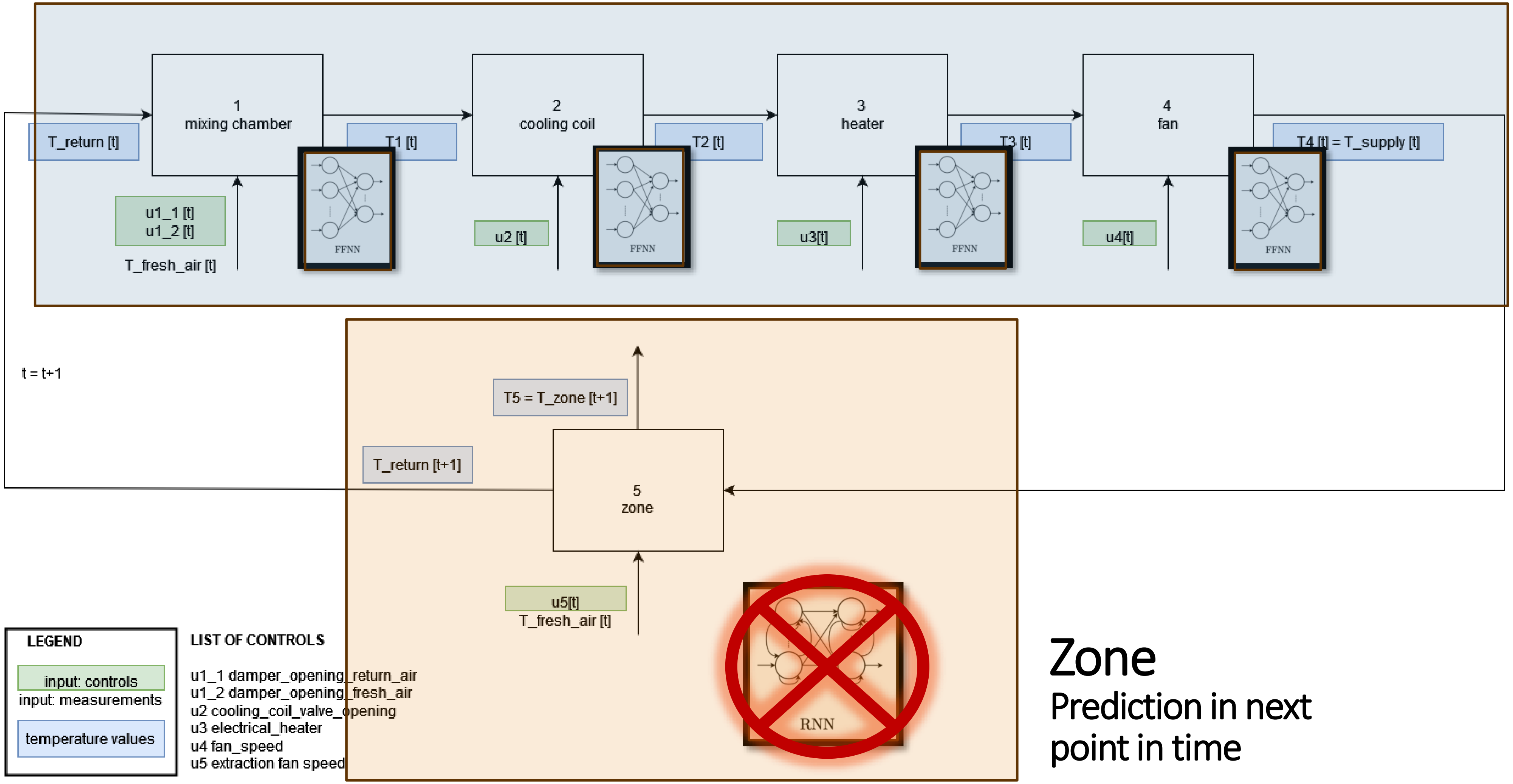

AHU
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Prediction in next point in time

Problems with RNN initialization

MPC for HVAC: Genetic algorithm: implementation

- prediction horizon: 2h (Ts = 15min → 8 points)

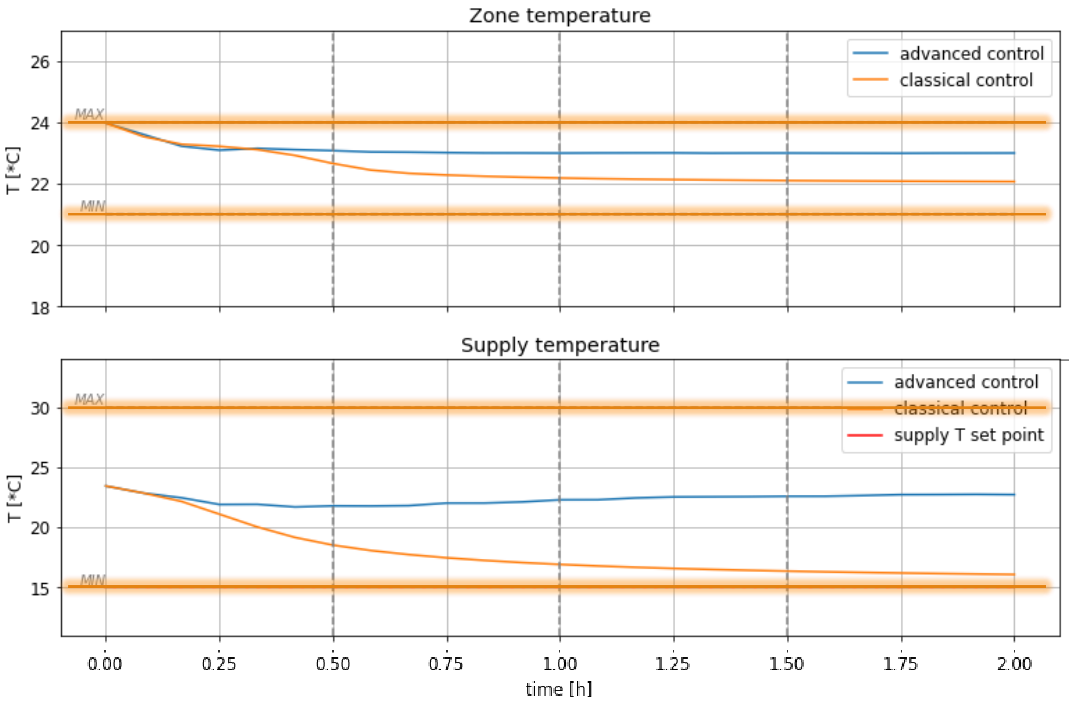
- optimization variable binary representation for 1 pt in time:

u^1					u^2/u^3					u^{23}	u^{off23}

- bits in total: 8*12 = 96 bits/optimization

- parameters:

POP_SIZE	60
NUM_GENERATIONS	3
CROSSOVER_PROB	0.5
MUTATION_PROB	0.4
TOURNAMENT_SIZE	3



- temperatures within limits

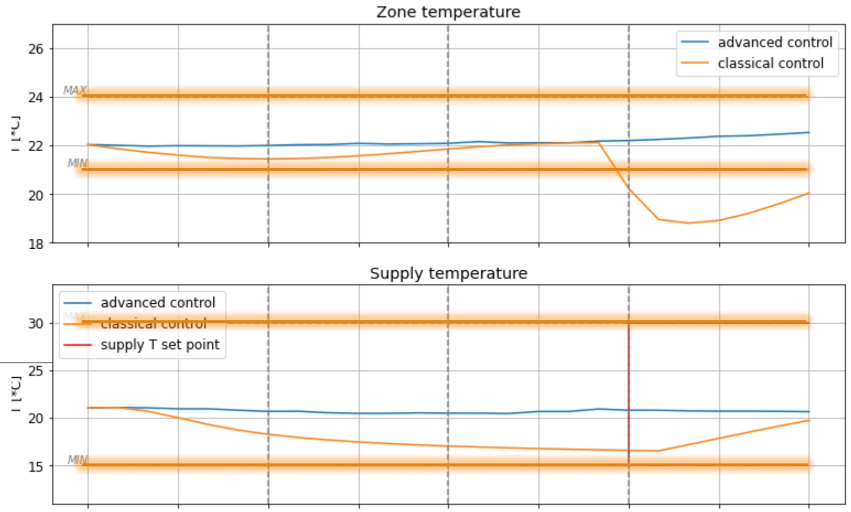
- advance controls: damper management

- PID: more active components

time [h]

MPC for HVAC Results

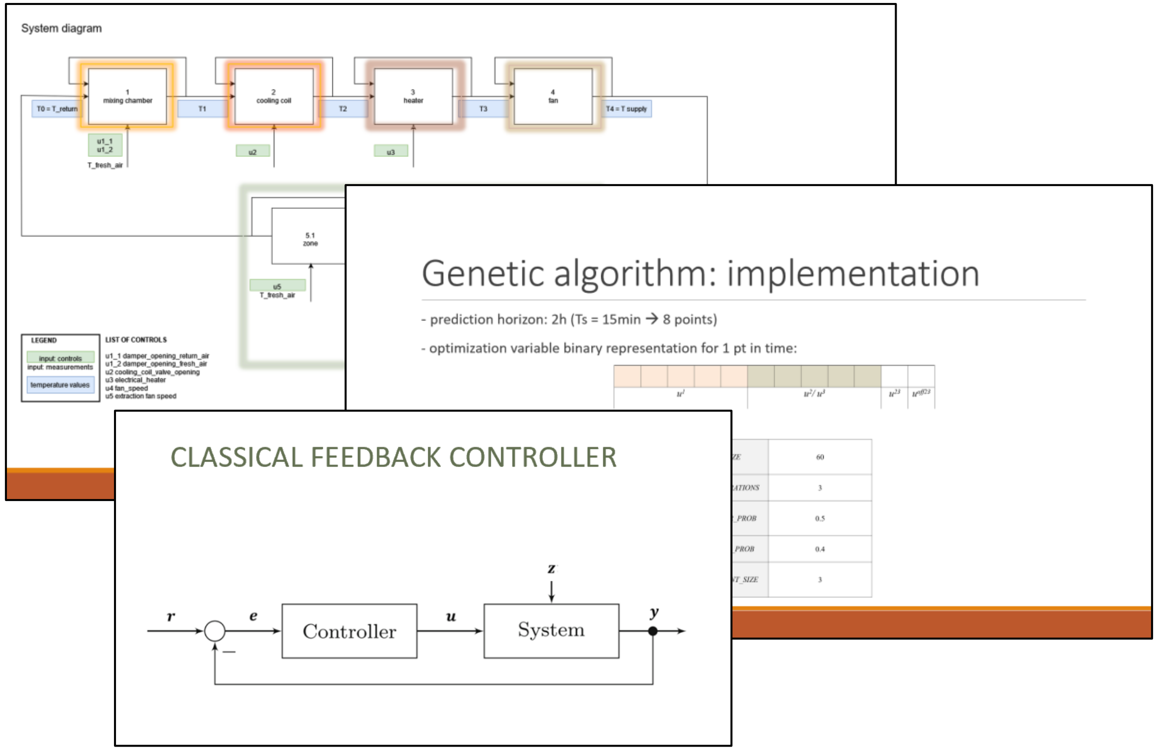
- constraints violated
- unusual system response
- unusual PID response



Conclusion

- promising results, but too optimistic (savings 77% comparing to 20% in literature)

- improvements:
  - improving model:
    - dataset, architecture, training
  - improving optimization algorithm:
    - faster execution → faster test comparison
  - tunning PID for fair comparison



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