DISTRICT COOLING DISTRIBUTION NETWORK OPTIMIZER

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INTRODUCTION

District Cooling, technological challenges & INDIGO project

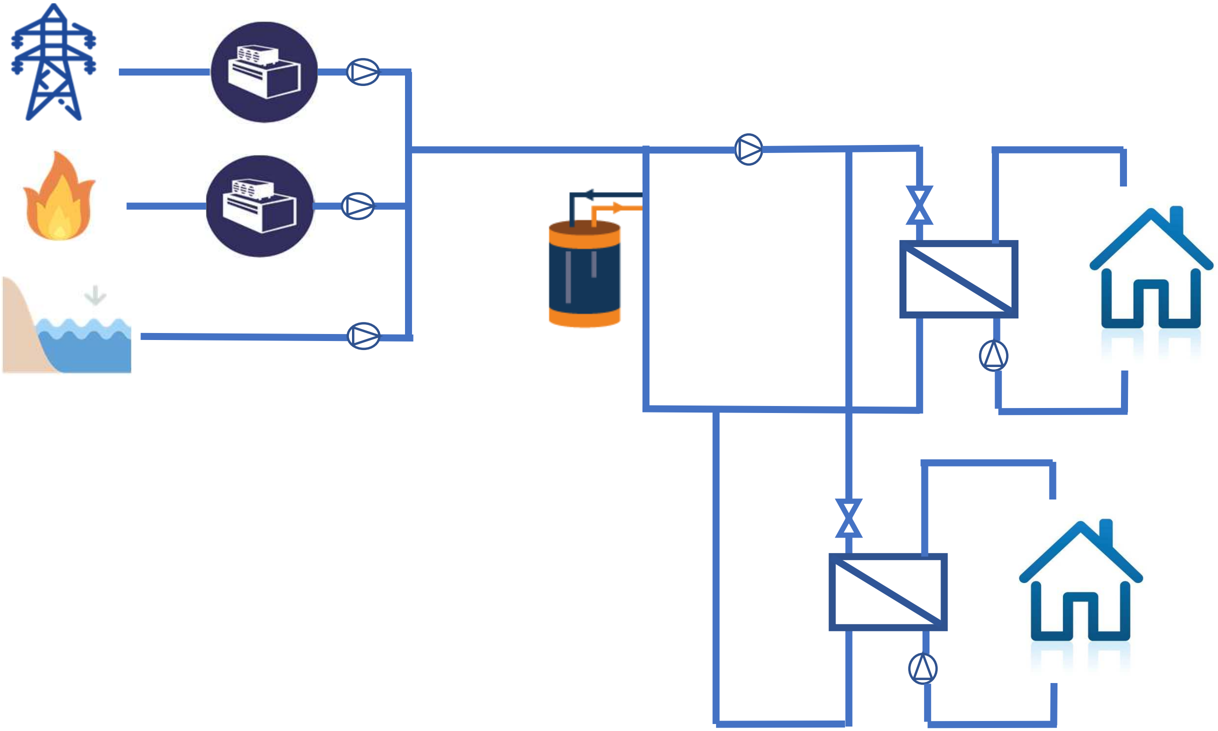
DISTRICT COOLING

COOLING DEMAND INCREASE

- **Buildings** account for **35% of final energy use** and **38% of emissions**
- Energy use for **space cooling** has increased faster than any other end use in buildings
- It is expected to keep rising in the following years

District cooling systems are one of the most promising options to cope with this demand increase:

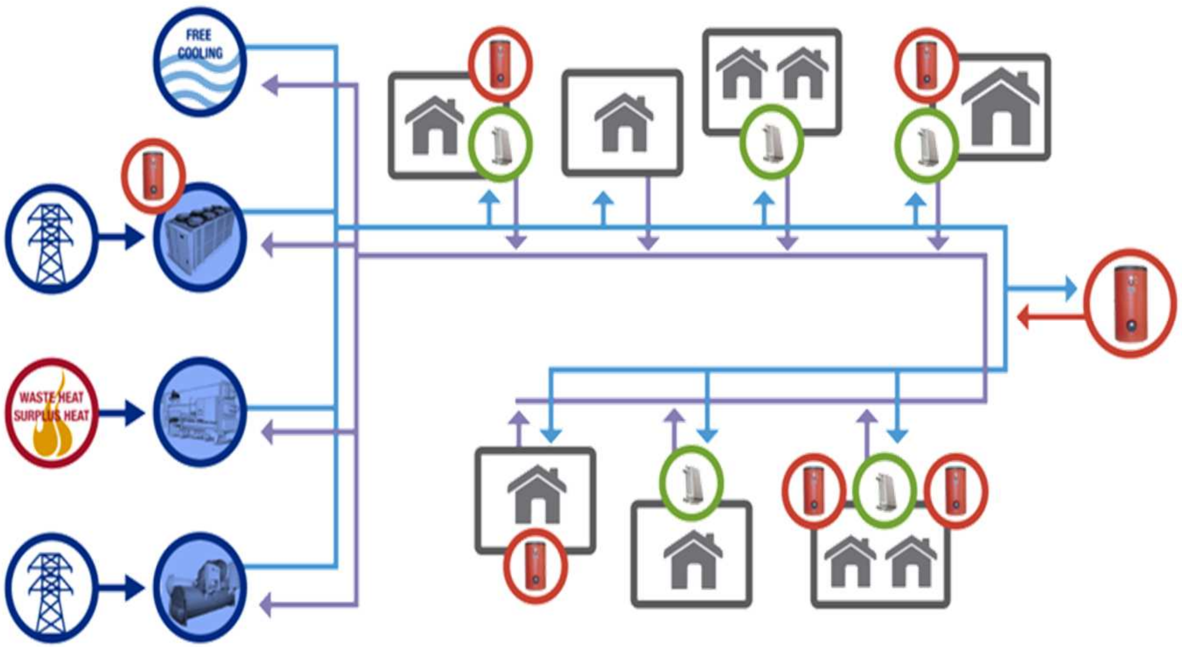
- **more efficient** than stand-alone on-site air conditioning systems
- drive the **integration of renewable sources**
- **reduce CO_2 emissions**



TECHNICAL CHALLENGES OF DC SYSTEMS

Non-manageable sources (waste heat, free cooling, Renewable sources)

Consumers with very different consumption profile and very variable



Units and systems with very different dynamics

Current conventional control methods very dependant on the plant operator know-how

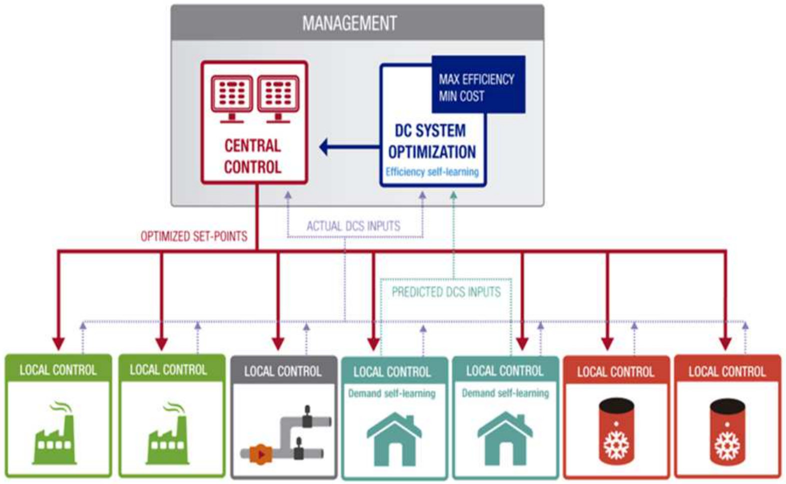
H2020 INDIGO PROJECT

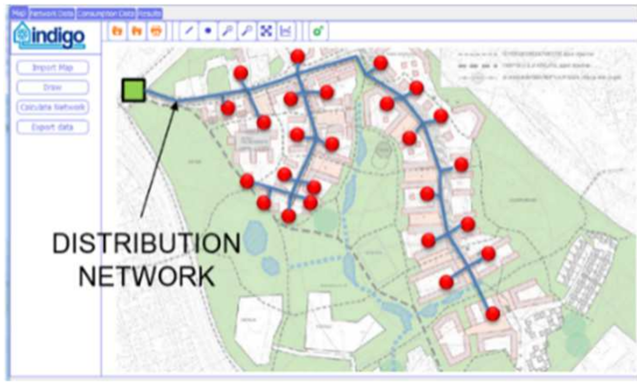
Objectives of the project:

- To **increase DC systems efficiency** contributing to a reduction over 45% of the primary energy consumption
- To **validate in a real District Cooling (DHC) installation** and to use this case-study as an exploitation demonstrator

New generation of Intelligent Efficient District Cooling Systems

Development of **an innovative and optimized DC system management strategy** to optimally schedule the energy supply to maximize the efficiency of the system or minimize the operation cost





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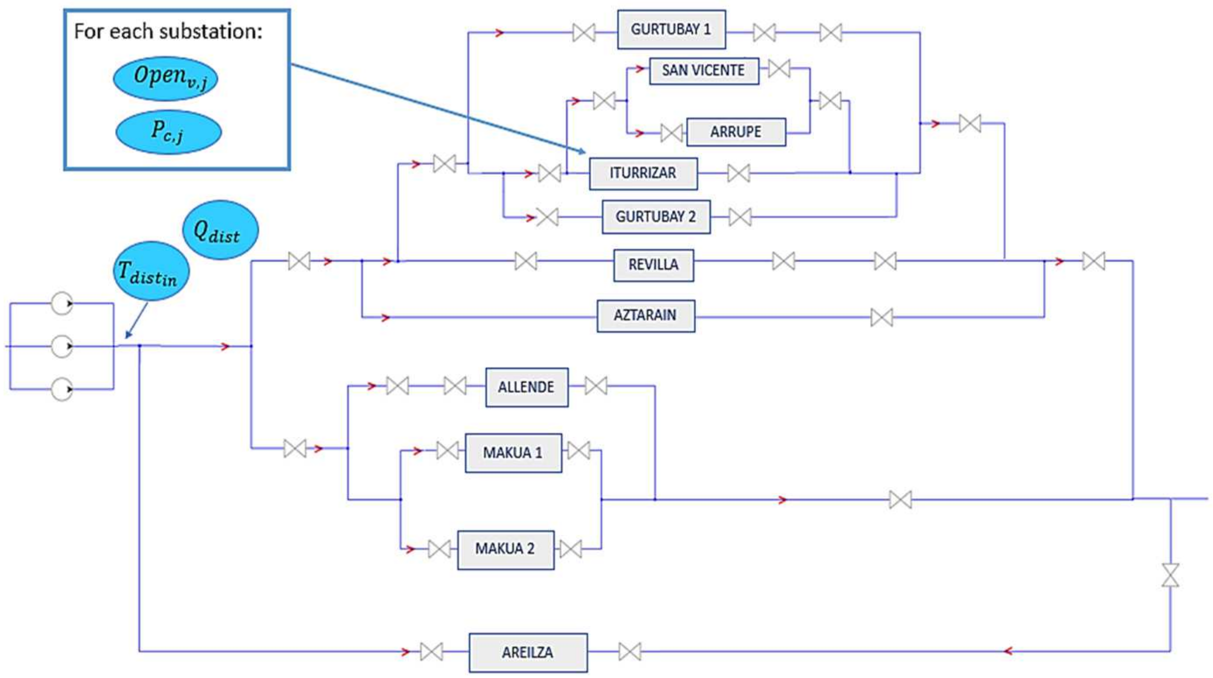
DISTRIBUTION NETWORK OPTIMIZER

DISTRIBUTION NETWORK OPTIMIZER

Develop a **control strategy** for the distribution network consisting of an **optimizer** that uses a reliable model of the network to decide how to actuate.

The optimizer calculates the optimal supply conditions to:

- Cover the cooling demand of the buildings
- Minimize the hydraulic and thermal losses of the network
- Maximize the temperature difference between the supply and return temperature of the network



Small/medium networks

- Static model
- Static optimizer

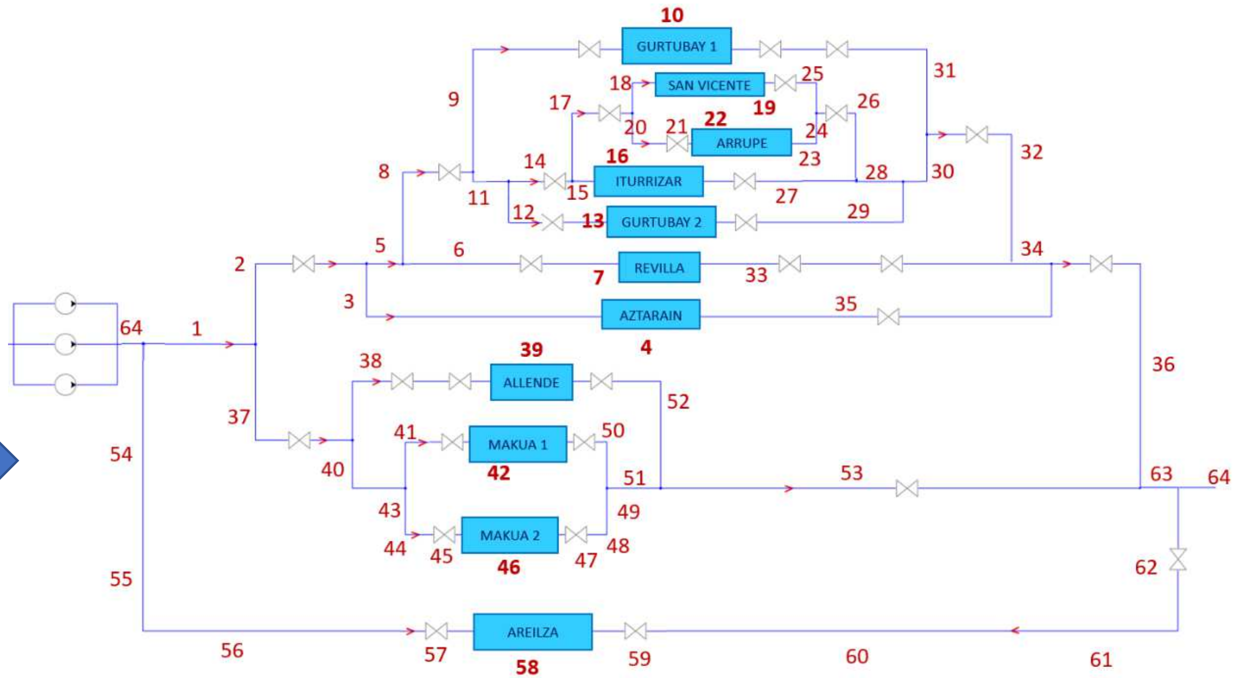
Large networks

- Dynamic model
  - Network inertia
  - Transport delays
- Model Predictive Control (MPC)

DISTRIBUTION NETWORK MODEL

Model of the distribution network of Basurto Hospital's DC

- 11 substations
- 64 pipes
- 2 km long



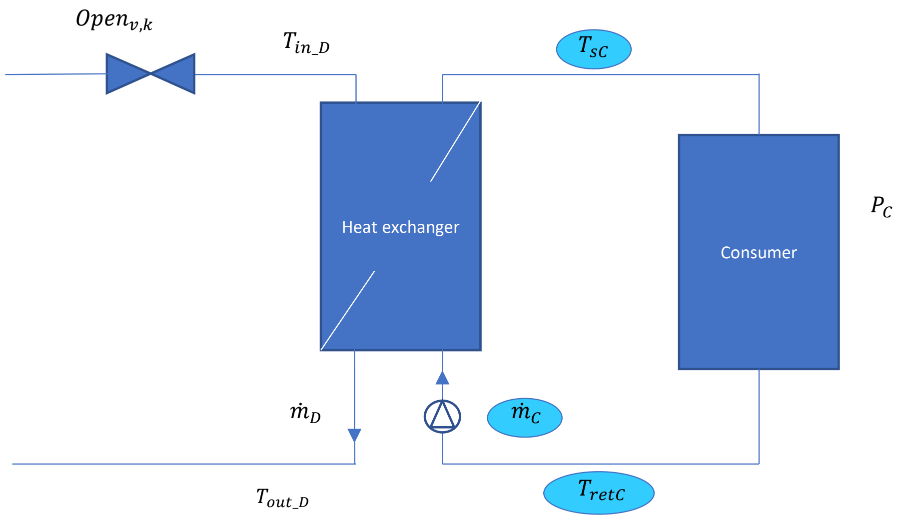
Physical model

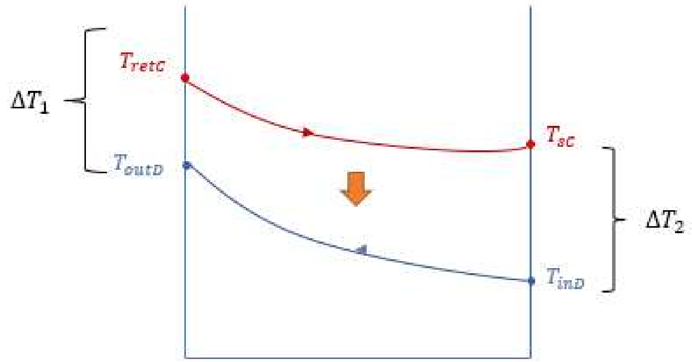
- Mass & Energy balances
- Primary and secondary hydraulic losses (control valves, balancing valves and auxiliary elements)
- Thermal losses

DISTRIBUTION NETWORK MODEL

Substations modelling

Logarithmic Mean Temperature Difference (LMTD)





All the **consumer-side** variables are handled:

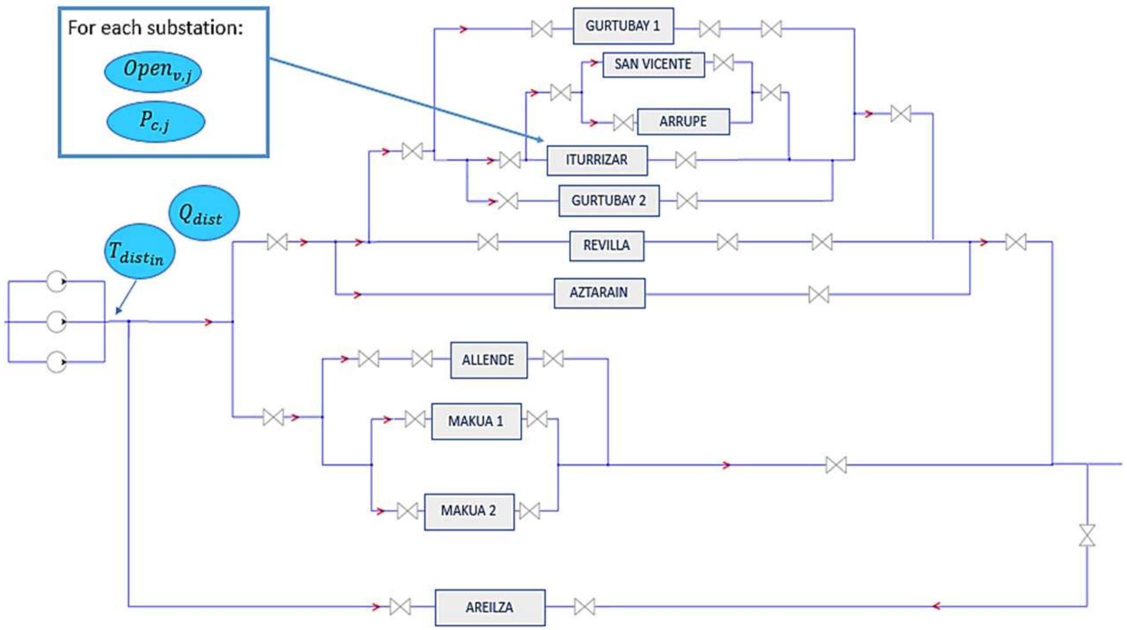
- Stablish operation restrictions → optimal supply temperature → AHU operation requierements
- Fixed and variable flow

OPTIMIZATION PROBLEM DEFINITION

Controlled operation → Optimization problem constraints

Optimal operation → Optimization problem cost function

Actuation variables:
- Supply temperature
- Supply mass flow rates
- Control valves opening
- Consumer-side variables



Inputs:
- Power demand

- Weather conditions

OPTIMIZATION PROBLEM DEFINITION

Optimizer development:
Non-linear optimization problem

MATLAB | CasADi | IPOPT solver

Cost function definition:

$$\mathbf{min} \rightarrow fun = \frac{\sum_{j=1}^{ns}\left(P_{dem,j} - P_{sup,j}\right)^2}{ErrP_{max}^2} + \alpha_1 \frac{\sum_{j=1}^{ns}\left(T_{sup,j}^{SP} - T_{sup,j}\right)^2}{ErrT_{max}^2} + \alpha_2 \cdot \frac{\left(P_{loss,hyd}^2 + P_{loss,th}^2\right)}{P_{loss,max}^2} - \alpha_3 \cdot \frac{\left(T_{dist,ret} - T_{dist,sup}\right)^2}{\Delta T_{max}^2}$$

Minimize error in the supplied power

Minimize error in the supplied temperature

Minimize total hydraulic and thermal losses

Maximize temperature difference between the supply and return

Controlled operation

Optimal operation

$\alpha_1, \alpha_2, \alpha_3 \rightarrow$ weighting factors

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RESULTS

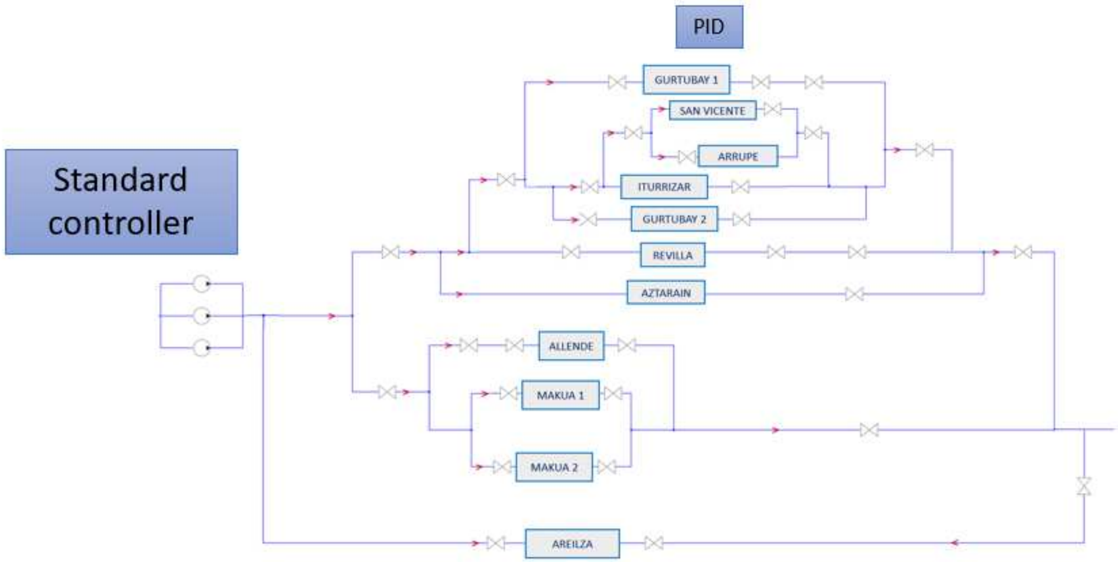
OPTIMIZER RESULTS

VIRTUAL SIMULATIONS: **BASELINE**

Standard controller

Replicate the operation in Basurto Hospital's DC

- Fixed supply temperature
- Return temperature control
- PID to control supply temperature in the substations



Virtual simulations

Both the optimizer and the standard controller simulated with the same network model

- Same boundary conditions (demand, weather conditions)
- Actuation time of 15 minutes

Simulation periods

- 31 randomly chosen days from August 2019 to July 2020 (at least 2 days from each month)
- The whole month of July 2020 – highest demand

KPI calculation

- *Controlled operation*: error in the supplied power and temperature
- *Optimal operation*: total hydraulic and thermal losses, and production plant electric consumption

OPTIMIZER RESULTS

VIRTUAL SIMULATIONS: **RESULTS**

Total thermal demand in the simulation period: 195.9 MWh

CONTROLLED OPERATION

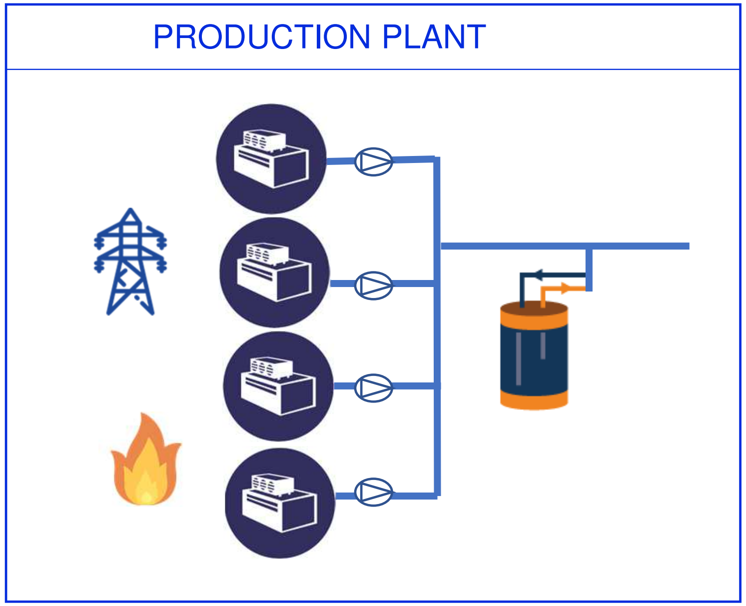
NRMS error	Optimizer	Baseline
Supply power	0.65%	0.7%
Consumer supply temperature	1.64%	3.45%

OPTIMAL OPERATION

	Optimizer	Baseline	Reduction
Total hydraulic losses	48.8 kWh	138.8 kWh	64.8%
Total thermal losses	68.8 kWh	91.8 kWh	25.1%
Total losses	117.6 kWh	230.6 kWh	49%

ELECTRIC CONSUMPTION: **BASELINE**

Electric consumption impact analysis
It is necessary to consider the production plant.



Production plant model

Use a simulation model of the production plant to calculate the **electric consumption of the production plant** with the optimizer and with the standard controller supply conditions.

- Electric vapour compression chillers
- Absorption chillers

Production plant model:
"**Virtual testbed for model predictive control developments in district cooling systems**"
Zabala et al
https://doi.org/10.1016/j.rser.2020.109920

OPTIMIZER RESULTS

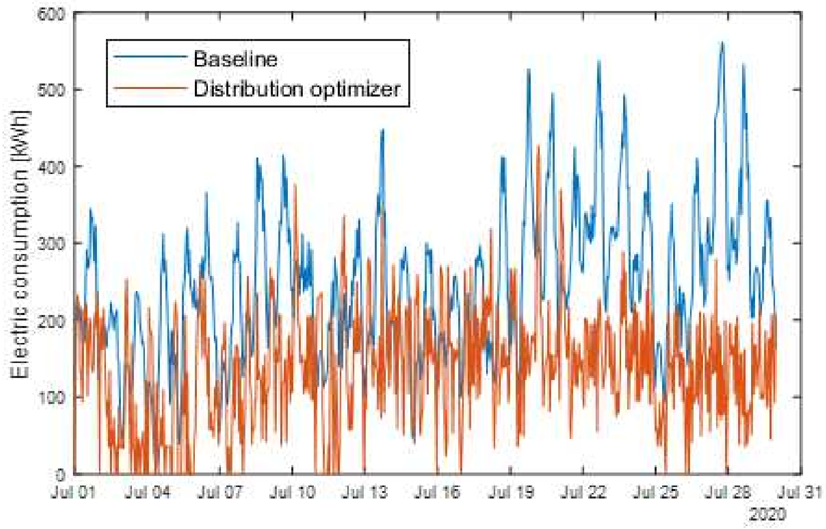
ELECTRIC CONSUMPTION: **RESULTS**

Electric consumption impact analysis

It is necessary to consider the production plant.

Baseline electric consumption in the reference period	170 MWh_e
Electric consumption with optimizer	94.92 MWh_e
Electric consumption reduction	75.08 MWh_e
Primary energy reduction	180.42 MWh
Percentage of energy savings with the optimizer	**44.16%**

Simulation period: month July 2020



Production plant electric consumption comparison with the optimizer and the standard controller

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CONCLUSIONS

CONCLUSIONS

DISTRIBUTION NETWORK OPTIMIZER

Improvement of the controlled operation:

- Better demand coverage
- Better compliance with operating restrictions

Hydraulic and thermal network losses reduction up to **50%** at virtual level

Reduction of the primary from the production plant electric consumption up to **44%** at virtual level

FUTURE RESEACH

Scale the solution to large network

- Consider the network dynamics and transportation delays
- Develop an MPC

#GrowthMakers

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