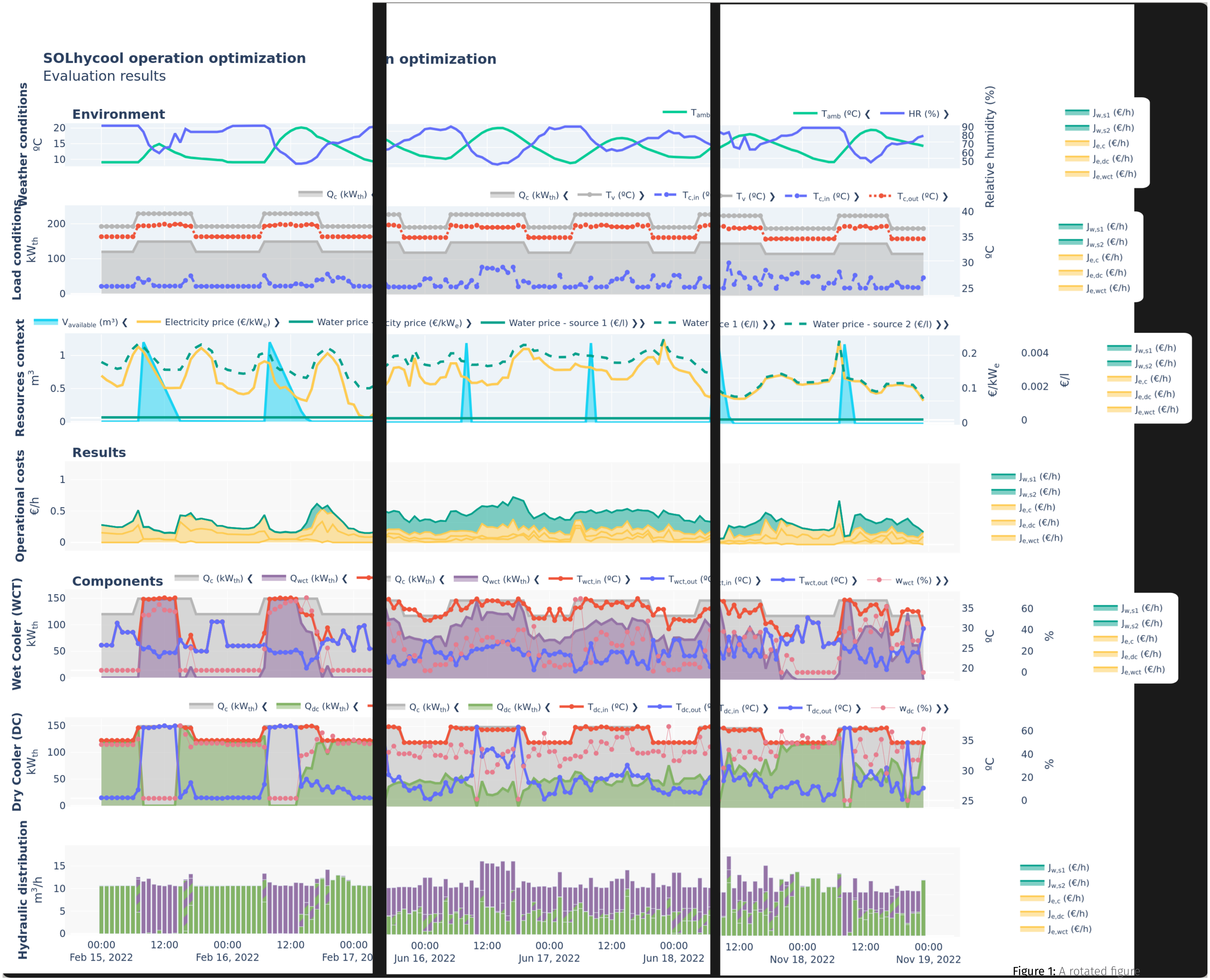

Figure 1: A rotated figure

Model 0.1: Test

$$
\begin{aligned}
T_{cc,out},\, C_e,\, C_w,\, T_{c,out} = \text{combined cooler model}&(q_c, R_p, R_s, \omega_{dc}, \omega_{wct}, T_{amb}, HR_i, T_v, \dot{m}_v) \\
T_{cc,in} &= T_{c,out} \\
T_{dc,in} &= T_{cc,in} \\
q_{dc} &= q_c \cdot (1 - R_p) \\
q_{wct,p} &= q_c \cdot R_p \\
q_{wct,s} &= q_{dc} \cdot R_s \\
T_{dc,out},\, C_{e,dc} &= \text{dc model}(q_{dc},\, \omega_{\text{dc}},\, T_{\text{amb}},\, T_{dc,in}) \\
q_{wct},\, T_{wct,in} &= \text{mixer model}(q_{wct,p},\, T_{Tcc,in},\, q_{wct,s},\, T_{dc,out}) \\
T_{wct,out},\, C_{e,wct},\, C_{w,wct} &= \text{wct model}(q_{wct},\, \omega_{wct},\, T_{amb},\, HR,\, T_{wct,in}) \\
T_{c,in},\, T_{c,out} &= \text{condenser model}(q_c,\, \dot{m}_v,\, T_v) \\
q_{cc},\, T_{cc,out} &= \text{mixer model}(q_{wct},\, T_{wct,out},\, q_{dc},\, T_{dc,out}) \\
C_e &= C_{e,dc} + C_{e,wct} + C_{e,c} \\
C_w &= C_{w,wct}
\end{aligned}
$$

As can be seen in Model 0.1, the counter is working.

Problem .1: Test

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

$$\min_{\mathbf{x},\,\mathbf{e};\theta} \quad J = f(\mathbf{x}, \mathbf{e}; \theta) = f(x)$$

with:

- Model name model

$$out_1,\, out_2 = f(in_1,\, in_2,\, \dots,\, in_N)$$

- Decision variables

$$\mathbf{x} = [x_1,\, x_2]$$

- Environment variables

$$\mathbf{e} = [e_1,\, e_2,\, \dots,\, e_3]$$

- Fixed parameters

$$\theta = [\theta_1 = X,\, \theta_2 = Y]$$

subject to:

- Box-bounds
    - $x_1 \in [\underline{x}_1, \overline{x}_1]$

- $x_2 \in [\underline{x}_2, \overline{x}_2]$
- Constraints
  - $|out_X - out_Y| \leq \epsilon_1$
  - $out_X \leq out_Z - \Delta Z$

As can be seen in Problem .1, the counter is working.

TL;DR

test test

Problem: Test

$$\min_{\mathbf{x},\mathbf{e};\theta} \quad J = f(\mathbf{x}, \mathbf{e}; \theta) = f(x)$$

with:

- Model name model

$$out_1,\ out_2 = f(in_1,\ in_2,\ \ldots,\ in_N)$$

- Decision variables

$$\mathbf{x} = [x_1,\ x_2]$$

- Environment variables

$$\mathbf{e} = [e_1,\ e_2,\ \ldots,\ e_3]$$

- Fixed parameters

$$\theta = [\theta_1 = X,\ \theta_2 = Y]$$

subject to:

- Box-bounds
  - $x_1 \in [\underline{x}_1, \overline{x}_1]$
  - $x_2 \in [\underline{x}_2, \overline{x}_2]$
- Constraints
  - $|out_X - out_Y| \leq \epsilon_1$
  - $out_X \leq out_Z - \Delta Z$

The kaobook class

PhD Thesis

Towards optimal resource management in solar thermal applications: desalination and CSP

Juan Miguel Serrano Rodríguez

June 5, 2025

University of Almería

The kaobook class

Disclaimer
You can edit this page to suit your needs. For instance, here we have a no copyright statement, a colophon and some other information. This page is based on the corresponding page of Ken Arroyo Ohori's thesis, with minimal changes.

Colophon
This document was typeset with the help of KOMA-Script and LaTeX using the kaobook class.
The source code of this book is available at:
https://github.com/fmarotta/kaobook
(You are welcome to contribute!)

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The harmony of the world is made manifest in Form and Number, and the heart and soul and all the poetry of Natural Philosophy are embodied in the concept of mathematical beauty.

– D'Arcy Wentworth Thompson

Acknowledgements

Test test test

Federico Marotta

Summary

I am of the opinion that every LaTeX geek, at least once during his life, feels the need to create his or her own class: this is what happened to me and here is the result, which, however, should be seen as a work still in progress. Actually, this class is not completely original, but it is a blend of all the best ideas that I have found in a number of guides, tutorials, blogs and tex.stackexchange.com posts. In particular, the main ideas come from two sources:

- Ken Arroyo Ohori's Doctoral Thesis, which served, with the author's permission, as a backbone for the implementation of this class;
- The Tufte-Latex Class, which was a model for the style.

The first chapter of this book is introductory and covers the most essential features of the class. Next, there is a bunch of chapters devoted to all the commands and environments that you may use in writing a book; in particular, it will be explained how to add notes, figures and tables, and references. The second part deals with the page layout and design, as well as additional features like coloured boxes and theorem environments.

I started writing this class as an experiment, and as such it should be regarded. Since it has always been intended for my personal use, it may not be perfect but I find it quite satisfactory for the use I want to make of it. I share this work in the hope that someone might find here the inspiration for writing his or her own class.

Resumen

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Introduction

1 Context and motivation

asdad

2 Thermal desalination overview

Desalination is increasingly recognized as a key strategy to address global freshwater scarcity, driven by the combined pressures of climate change and population growth. Regions already facing drought and water stress, such as parts of Spain, are expected to see growing dependence on desalinated water to meet rising demand. While desalination technologies—particularly membrane-based systems like Reverse Osmosis (RO)—have seen rapid expansion, the energy intensity of the process remains a major challenge. To mitigate this, efforts have focused on improving energy efficiency and integrating renewable energy sources such as solar or geothermal heat. In particular, thermal desalination technologies like Multi-Effect Distillation (MED) are gaining renewed interest due to their compatibility with low-exergy heat sources (*e.g.* waste heat) and the ability to treat high-salinity brines. These thermal processes also align better with circular economy approaches, allowing the concentration of brine and the recovery of valuable minerals such as lithium or magnesium, an emerging field known as brine mining.

3 CSP overview

In the pursuit of eliminating reliance on fossil fuels sources for energy generation and replacing them by renewable sources, Concentrated Solar Power (CSP) has proven to be a reliable contributor. In particular, in providing much needed energy storage, dispatchability and ensuring grid stability.

CSP plants use mirrors to concentrate the sun's energy to finally drive a turbine that generates electricity. This technology currently represents a minor part of renewable energy generation in Europe. Only approximately 5 GW are installed globally (of which 2.3 GW in Europe are concentrated in Spain). However, the potential for growth is significant given the capability of CSP to provide renewable electricity when needed thanks to in-built energy storage continuing the production even in the absence of sunlight, unlike other renewable technologies that are dependent on the availability of the energy source. Of increasing importance is also their potential application in improving the manageability of the grid, replacing fossil fuel alternatives. Their dispatchability enables plants to respond to peaks in demand, and provide ancillary services to the grid. According to the International Energy Agency forecasts, CSP has a huge potential in the long term, ranging from the 986 TWh by 2030 up to 4186 TWh by 2050 [1], which means that CSP will account for 11% of the electricity generated worldwide and for 4% in the case of Europe.

[1]: IEA (2014), *Energy Technology Perspectives*

3.1 Water use

The cooling of the power block in this technology plays a crucial role in its feasibility. The cheapest and most efficiency cooling technology is evaporative cooling, and that is why most plants, specially in Spain where built using this alternative (XX % [2]), however, the high-radiation areas in which they are located are usually regions with rapidly-degrading water availability due to climate change, so water has become a scarce resource. Nowadays most likely those plants would have been built with dry cooling technologies, significantly increasing the cost (up to 8% during periods of high ambient temperatures when energy demand and prices peak [**<empty citation>**]).

[2]: Thonig et al. (2023), *CSP.Guru 2023-07-01*

<empty citation>

4 Cooling overview

CSP plants are, in general, located in arid areas, where sun irradiance is high but water is scarce. The efficiency of these plants is highly dependent on the temperature at which the steam is condensed. To date, the conventional systems used to remove excess heat from CSP plants are either wet (water-cooled) or dry (air-cooled). The lowest attainable condensing temperature is achieved in wet cooling systems that depend on the wet-bulb temperature, allowing CSP plants to achieve higher efficiencies. However, this efficiency increase is at the expense of a high cost: excessive water use. Dry cooling systems eliminate the water use but they lead to lower plant efficiencies when the ambient air temperature is high. Those hot periods are often the periods of peak system demand and higher electricity sale price. The combination of the advantages of each of them into an innovative cooling system is thus of great interest. There are different types of innovative cooling systems: those that integrate the dry and wet cooling systems into the same cooling device, which are called hybrid cooling systems [3–5] and those that combine separate dry and wet cooling systems, which are called combined cooling systems. In the case of hybrid cooling systems, the dry section are composed of compact heat exchangers included in a wet cooling tower [3]. This kind of cooling systems can be considered as an efficient cooling solution for CSP plants [6] due to the energy conservation and water and greenhouse gas emissions savings. In the case of combined cooling systems, different configurations can be found. The most commonly proposed in the literature is the one that considers an Air-Cooled Condenser (ACC) in parallel with a Wet Cooling Tower (WCT), as can be seen in [7, 8]. In this kind of configuration, the exhaust steam from the turbine is condensed either through the ACC or through a Surface Condenser (SC) coupled with the WCT. Another configuration, recently proposed in [9] is a wet cooling tower and a Dry Cooler (DC) (type Air-Cooled Heat Exchanger (ACHE)) sharing a surface condenser. In this case, the exhaust steam from the turbine is condensed through the surface condenser and the heated cooling water is cooled either through the WCT or through the dry cooler. This kind of combined cooling systems are proposed as the most suitable option for a flexible operation as a function of the ambient conditions, since they allow to select the best operation strategies to achieve an optimum water and electricity consumption compromise [10]. In addition, if the optimization is combined with energy demand forecasting as described in [11], the expected results can be even better.

[3]: Rezaei et al. (2010), "Reducing Water Consumption of an Industrial Plant Cooling Unit Using Hybrid Cooling Tower"

[4]: Asvapoositkul et al. (2014), "Comparative Evaluation of Hybrid (Dry/Wet) Cooling Tower Performance"

[5]: Hu et al. (2018), "Thermodynamic Characteristics of Thermal Power Plant with Hybrid (Dry/Wet) Cooling System"

[6]: El Marazgioui et al. (2022), "Impact of Cooling Tower Technology on Performance and Cost-Effectiveness of CSP Plants"

[7]: Barigozzi et al. (2011), "Wet and Dry Cooling Systems Optimization Applied to a Modern Waste-to-Energy Cogeneration Heat and Power Plant"

[8]: Barigozzi et al. (2014), "Performance Prediction and Optimization of a Waste-to-Energy Cogeneration Plant with Combined Wet and Dry Cooling System"

[9]: Palenzuela et al. (2022), "Experimental Assessment of a Pilot Scale Hybrid Cooling System for Water Consumption Reduction in CSP Plants"

[10]: Asfand et al. (2020), "Thermodynamic Performance and Water Consumption of Hybrid Cooling System Configurations for Concentrated Solar Power Plants"

[11]: Wazirali et al. (2023), "State-of-the-Art Review on Energy and Load Forecasting in Microgrids Using Artificial Neural Networks, Machine Learning, and Deep Learning Techniques"

Modelling overview 5

5.1 Performance metrics

To evaluate the quality of the models fit to the experimental data, four performance metrics were evaluated: coefficient of determination (R^2), RMSE, Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE). These metrics are described below.

Coefficient of determination. R^2 measures the proportion of the variance in the predicted variable that can be attributed to the independent variable(s), in this case the considered system inputs. Values close to one indicate a better prediction accuracy. It is calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2},$$

where y_i is the measured or observed value for the output variable, in the $i - th$ observation, $\hat{y}_i$ is the estimated value of the same variable and n is the total number of observations. Finally, $\bar{y}$ is the mean value of the experimental values.

Root Mean Square Error. RMSE is a statistical measure of the difference between the values predicted by a model and the observed values. It is calculated as the square root of the mean of the squared differences between the predicted and observed values and it has its units.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

Mean Absolute Error. It represents the average absolute difference between predicted and actual values.

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

Mean Absolute Percentage Error. As the MAE, it calculates the difference between the predicted and the actual values, but in this case it does so in relative terms:

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_i}{y_i}\right| \times 100\%$$

5.2 First principle modelling

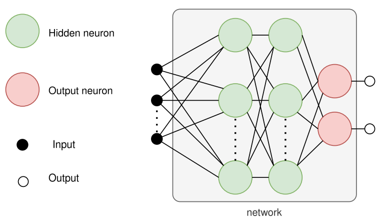
5.3 Data-driven modelling

Machine learning algorithms are unique in their ability to obtain models and extract patterns from data, without being explicitly programmed to do so. They are more effective with large volumes of data but can also be applied to build steady state regression models with less information of a process.

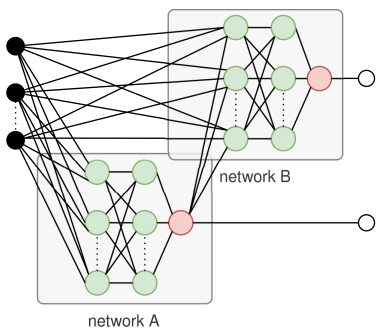
5.3.1 Gaussian Process Regression

5.3.2 Artificial Neural networks

Artificial Neural Networks (ANNs), as the name suggests, have a behavior similar to biological neurons. Their structure is formed by a succession of layers, each one composed by nodes (or neurons) and they receive as input the output of the previous layer. This process is subsequently repeated until the final layer which has a number of neurons equal to the number of outputs.



(a) MIMO configuration



(b) Cascade configuration

Figure 5.1: ANN model configurations

There are important aspects to be considered in the ANN model design, such as the model configuration, the network architecture and the network topology. They are discussed below.

Model configuration. If the model has more than one output, several configurations are available for the implementation of the model as shown in Figure 11.2. The first one is a Multiple Inputs Multiple Outputs (MIMO) configuration, where a single network receives all the inputs and directly produces all predicted outputs. The second one is a cascade structure. This cascading approach involves training a network (*network A* in Figure 11.2 (b)) to predict one output using the available inputs. Subsequently, these inputs, along with the output from the first-output-predicting network, are fed into a second network (*network B* in Figure 11.2 (b)) that is in charge of forecasting the second output. This procedure can be repeated as many times as desired. A potential advantage of this configuration is that it may reduce the experimental data requirements to obtain satisfactory results. A third option is the combination of both configurations, where some networks may predict several outputs, while others are fed some of these outputs as subsequently use them as inputs.

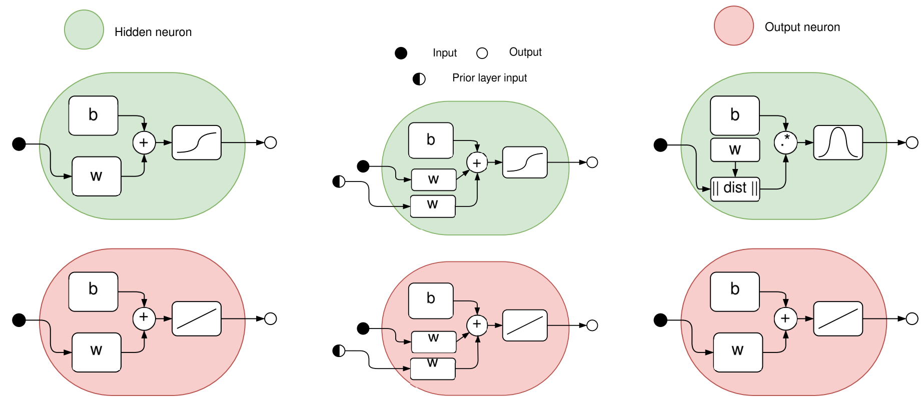
Network architectures. Three network architectures have been implemented and tested:

1. Feed Forward (FF) network - Figure 5.2 (a). This is the base network architecture, where different layers are added sequentially and the flow of information is unidirectional. The transfer function adopted in the hidden layers is the differentiable *Log-Sigmoid*[1], whereas the one employed in the output layer is a linear one with no saturations.
2. Cascade-forward (CF) network - Figure 5.2 (b). It is a variation on the feedforward network since it adds direct connections from the input and hidden layers to the output layer.
3. Radial Basis Function (RBF) network - Figure 5.2 (c). The transfer functions used in the first layer of the RBF network are different, they are local Gaussian like functions. Also, instead of multiplying by the weights, the distance between inputs and weights is computed and the bias is multiplied instead of added [12].

1: Defined as $logsig(x) = 1/(1+e^{-x})$, mapping any real input to a value between 0 and 1.

[12]: Hagan et al. (2014), *Neural Network Design*

Network topology. Two-layer networks (one hidden and one output layer) can learn almost any input-output relationship, including non-linear ones. Adding more layers can improve the learning for more complex problems. However, increasing the number of layers or neurons per layer increases the training computational requirements, requires more data for a satisfactory model and can lead to overfitting. Therefore, the process is usually started with two layers and then the number of layers is increased if they do not perform satisfactorily [12]. In this study, for the feedforward and cascade-forward architectures, one and two hidden layers have been tested with the following configurations: 5, 10, 20, 5-5, 5-10, 10-5, 10-10. For the case of the RBF, it only has one hidden layer and



(a) Feedforward (b) Cascade-forward (c) Radial-basis

Figure 5.2: Considered ANN architectures

neurons are added sequentially during the training process up to a maximum which is set to 120 neurons.

Training process. The next important aspect to consider is the training process. For the FF and CF networks many Gradient- or Jacobian-based algorithms can be utilized. In this case, the Levenberg-Marquardt backpropagation algorithm [13] has been used. It is a fast algorithm, ideal for multilayer networks with up to a few hundred weights and biases enabling efficient training. The training in this case is done in batches since sequential training is slower and does not produce better results. All data have been normalized applying the z-score normalization method. The criteria established for deciding when to stop the training is the following one: when the performance on the validation set increases (worsens) or when the gradient is below a minimum (1×10^{-7}) for a number of iterations or epochs, or when a maximum number of 1000 epochs is reached. The number of iterations to wait, often refereed as patience, is set to 6. Finally, the selected network parameters will be those of the best epoch.

[13]: Beale et al. (2010), "Neural Network Toolbox"

For each network architecture, the training process was repeated a total of ten times (this is the recommended practice if the computational requirements allow it, since it guarantees reaching a global optimum with a high degree of confidence [14]). The optimal architecture and training was selected according to a performance function, which in this case has been the Mean Squared Error (MSE) with the values normalized.

[14]: Hamm et al. (2007), "Comparison of Stochastic Global Optimization Methods to Estimate Neural Network Weights"

In the case of the RBF network, the chosen training method consists in two stages which treats the two layers of the RBF network separately. The first layer weights and biases are tuned based on the orthogonal least squares method [12], while for the second layer are computed in one step using a linear least-squares algorithm. During training, neurons are added to the first layer (in increments of 20) trying to minimize the MSE to some goal, which in this case is set depending on the case study: 10 for the MIMO configuration and 0 (°C^2) and 20 (l^2/h^2) for temperature and water lost networks, respectively, for the cascade configuration. Finally, a parameter called spread is used to set the first layer biases. Larger values of this parameter promote a smoother approximation of the training data (more generalization), conversely, lower values provide a more exact fit to the training data. Values from 0.1 to 30 have been tested for this parameter.

[12]: Hagan et al. (2014), *Neural Network Design*

5.3.3 Random Forest

5.3.4 Gradient Boosting

5.4 Hybrid modelling

5.5 Data-driven from first-principles models. Sample generation

One important advantage that first-principles models have over data-driven is their scalability, that is, the ability to adapt a model developed and validated in a pilot-scale system, to a large scale one. This is true for many systems as long as the system configuration remains the same. This allows to study and analyze pilot scale plants and extrapolate the results to industrial sized plants. In addition, these type of model are also capable of predicting the behaviour of the modelled systems in conditions that have not been tested (*e.g.* different operating or environmental conditions), although the reliability of the model could be lower if these conditions move away from those experimentally used for some parameter calibration.

On the contrary, data-driven models are very specific to the system and operating ranges they are trained for. That is why training/calibrating a data-driven model with data from a first-principles model is a common practice to obtain a model that can be used in a larger range of operating conditions...

The process of generating samples from a first-principles model to train a data-driven model is called sample generation. It consists of running the first-principles model for a set of input parameters, which can be selected randomly or following a specific distribution, and then using the outputs of the first-principles model as the training data for the data-driven model.

The first step is to define the input parameters and their ranges. This can be done by selecting the most relevant parameters for the system and determining their ranges based on the system's operating conditions. The next step is to generate a set of input parameters, which can be done using different methods such as Latin Hypercube Sampling, Monte Carlo Sampling, Sobol Sampling, or simply grid sampling. These methods allow to generate a set of input parameters that cover the entire range of the input parameters and ensure that the generated samples are representative of the system's behaviour. Once the input parameters are defined, the first-principles model is run for each set of input parameters, and the outputs of the model are recorded. Finally, the recorded outputs are used to train the data-driven model.

6 Sensitivity analysis

It involves systematically assessing how variations in input parameters impact the model's outputs. In this case, the Sobol method [15], which is a variance-based approach, has been used. This method decomposes the total variance of the model output into contributions from individual input parameters and their interactions. By quantifying the relative importance of each parameter, Sobol analysis facilitates the identification of influential factors, enabling a more nuanced understanding of complex systems characterized by numerous interacting variables.

[15]: Nossent et al. (2011), "Sobol'sensitivity Analysis of a Complex Environmental Model"

The analysis results are different sensitivities indices such as total sensitivity indices (total-order), first-order sensitivity indices (first-order), and interaction sensitivity indices (second-order). First-order measures the direct effect of an input variable on the output, excluding interaction effects with other variables, while the second-order measures specifically this interaction effects. Finally, total-order indices account for the total effect of an input variable, including both direct and interaction effects.

6.1 Sensitivity analysis as a model analysis tool

Sobol sensitivity analysis provides a quantitative basis for assessing the consistency and validity of results when different approaches to model a system are compared. ANNs models with similar sensitivity analysis outcomes to those of the physical model, are likely to capture the essential features of the system, offering a means to verify their credibility and ensuring that the proposed solutions align with the underlying physical principles. Therefore, Sobol sensitivity analysis emerges as a powerful tool not only for understanding the system input-outputs relationships, but also as a way to validate and compare various modelling approaches. The sensitivity analysis has been performed using *SAlib*, an open source sensitivity analysis tool for the *Python* programming language [16, 17].

[16]: Herman et al. (2017), "SALib: An Open-Source Python Library for Sensitivity Analysis"

[17]: Iwanaga et al. (2022), "Toward SALib 2.0: Advancing the Accessibility and Interpretability of Global Sensitivity Analyses"

6.2 Sensitivity analysis as a measurement influence quantification tool

Sensitivity analysis can also be used to quantify the influence of measurement...

7 Control overview

asdad

7.1 PID controllers

7.2 Hierarchical control

8 Optimization overview

A general expression to define an optimization problem is:

$$\min_{\mathbf{x},\,\mathbf{e};\theta} \quad J = f(\mathbf{x}, \mathbf{e}; \theta) \quad \text{s.t.} \quad g_i(\mathbf{x}) \leq 0, \quad i = 1, \dots, m \tag{8.1}$$

where $\mathbf{x}$ is the vector of decision variables, $f(\mathbf{x})$ is the objective function to be minimized, and $g_i(\mathbf{x})$ are the constraints of the problem. The objective function is a scalar function that maps the decision variables to a real number, representing the cost or performance of the system. The constraints are functions that restrict the feasible region of the problem, defining the set of values that the decision variables can take. The optimization problem is to find the values of the decision variables that minimize the objective function while satisfying the constraints.

Regarding the constraints, they can be categorized in two types depending whether they can be evaluated before evaluating the objective function or not.:

- **Bounds**. These are constraints that limit the range of the decision variables, such as
$$x_i \in [l_i, u_i], \quad i = 1, \dots, n$$
where l_i and u_i are the lower and upper bounds of the decision variable x_i, respectively[1].
- **Constraints**. These are constraints that restrict the feasible region of the problem, such as
$$g_i(\mathbf{x}) \leq 0, \quad i = 1, \dots, m$$
where $g_i(\mathbf{x})$ are the constraint functions that depend on the decision variables $\mathbf{x}$, and m is the number of constraints. They can only be known after evaluating the objective function.

1: Also known as box-bounds

8.1 NLP problems

Non-Linear Programming (NLP)

8.2 MINLP problems

Mixed Integer Non-Linear Programming (MINLP)

8.3 Multi-objective optimization

8.4 Optimization algorithms

9 Research plan

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9.1 Hypothesis

9.2 Objectives

10 Contributions

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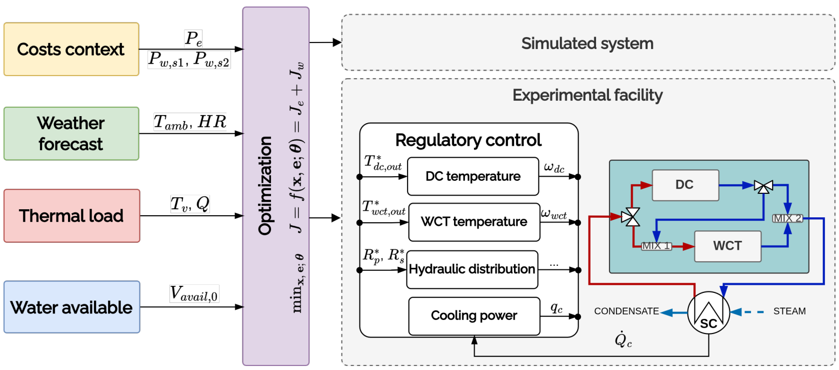
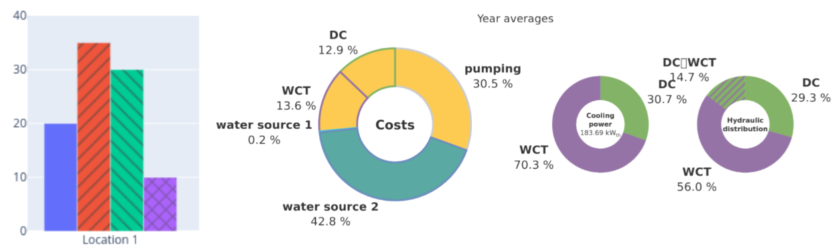
Optimal water and electricity management in a combined cooling system

TL;DR

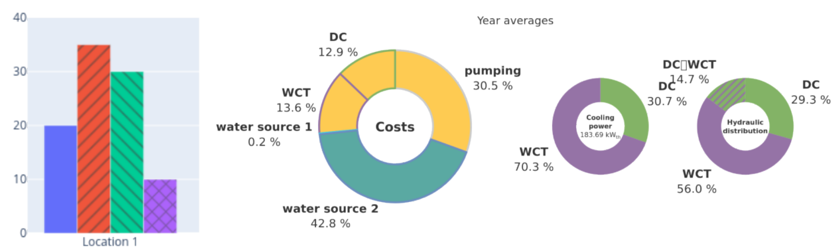
In the pursuit of extending the use and feasibility of solar thermal applications, two case studies are analyzed in annual simulations where the cooling solution makes use of a novel combined cooling system (CCS). To obtain these results, a model of the CCS has been developed based on the same configuration as the PSA pilot plant and different optimization strategies based on evolutionary algorithms were implemented to adapt the system operation to the changing conditions. They both were experimentally validated in the pilot plant. The CSP case study yields … while the MED case as can be seen in …

In pie chart, rename pumping to recirculation





(a) CSP case study results



(b) MED case study results

Figure 10.1: Results for the two case studies analyzed in this part. The first bar plot compares the specific cost of the different cooling alternatives. Lower is better. The second pie chart shows the breakdown of the costs, and the third and fourth pie charts show the cooling power distribution between DC and WCT and the hydraulic distribution, respectively.

Introduction

The cooling of the power block in this technology plays a crucial role in its feasibility. The cheapest and most efficiency cooling technology is evaporative cooling, and that is why most plants, specially in Spain where built using this alternative (XX % CSP data), however, the high-radiation areas in which they are located are usually regions with rapidly-degrading water availability due to climate change, so water has become a scarce resource. Nowadays most likely those plants would have been built with dry cooling technologies, significantly increasing the cost (up to 8% during periods of high ambient temperatures when energy demand and prices peak). At Plataforma Solar de Almería, we would like to explore a third alternative; a combined cooling system that integrates both technologies in a flexible hydraulic configuration. This alternative enables the adaptation of the operation based on the changing conditions, if optimization strategies are integrated.

On this part we analyze Andasol I, a 50 MW CSP plant with 8 hours of thermal storage located in Guadix (Spain), a region filled with renewable-power generation (PV and wind), thus representing the perfect scenario for what a renewable grid looks like. This plant was built in the 2000s and uses a WCT. The cooling system was replaced by the proposed CCS and yearly simulation results of the reduced-scale plant making use of the proposed combined cooling alternative yield...

To obtain these results, a physical model of the CCS has been developed based on the same configuration as the one located at Plataforma Solar de Almería facilities [2]. The model has been validated with experimental data and a static-optimization based on evolutionary algorithms [ref1,ref2] strategy has been implemented in order to adapt the system operation to the changing conditions. For the simulation environment two water sources are available, a cheaper source of water from reservoirs dependent on precipitation data and a significantly more expensive one from regenerated water. The next step is to scale the models in order to evaluate the full-scale system, and to include evaluations for the other two cooling alternatives (DC-only and WCT-only) in order to compare and draw a conclusion on which alternative is the most competitive on the given context.

Derived scientific contributions

Modelling of a combined cooling system 11

Decripción del modelo completo, cómo se integran los componentes, y después se describe cada component.

TL;DR

This chapter describes modelling of the different components of a combined cooling system, mainly a WCT and a DC. Different alternatives are presented, including the generation of samples for data-driven models trained using data from a physical model. Models are also developed for the other components of the system and finally it is shown how they are integrated into a complete system model.

Introduction

In order to study the potential advantages of making use of a combined cooling system, it is first necessary to develop the modelling of its components. Since the objective is performance prediction, this chapter focuses on the steady state modelling of the combined cooler main components, *i.e.* the WCT and the DC. More specifically, the aim is to compare two modelling strategies: that based on physical equations (Section 5.2) and that based on black box models (Section 5.3) such as ANNs, in order to see which one is more suitable for its integration in the optimization of the complete process.

This chapter presents a comparison between the two modelling approaches, at steady state and with a focus on optimization applications, in terms of predictive capabilities, experimental and instrumentation requirements, execution time, implementation and scalability. A sensitivity analysis is performed to further analyze and compare each case study. It also presents and evaluates all relevant aspects of interest in the development of such models, specifically for ANNs, model configuration, architecture and topology are discussed.

Other system components are also described in Section 11.3 (Other components) and finally their integration is discussed in Section 11.4 (Complete system).

11.1 Wet cooler

In the case of the models based on physical equations, the analysis of wet cooling towers has its origin in [18], in which the theory for their performance evaluation was developed. Merkel proposed a model based on several assumptions to simplify the heat and mass transfer equations to a simple hand calculation. However, these assumptions mean that Merkel's method does not reliably represent the physics of the heat and mass transfer process in a cooling tower. This was already stated by Bourillot [19] who concluded that the Merkel method is simple to use and can correctly predict cold water temperature when an appropriate value of the coefficient of evaporation is used. However, it is insufficient for the estimation of the characteristics of the warm air leaving the fill and for the calculation of changes in the water flow rate due to evaporation. Jaber and Webb [20] developed the equations necessary to apply the effectiveness-NTU[1] method directly to counterflow or crossflow cooling towers. This approach is particularly useful in the latter case and simpler compared to

[18]: Merkel (1925), "Verdunstungskühlung"

[19]: Bourillot (1983), "Hypotheses of Calculation of the Water Flow Rate Evaporated in a Wet Cooling Tower"

[20]: Jaber et al. (1989), "Design of Cooling Towers by the Effectiveness-NTU Method"

1: The effectiveness-NTU method estimates how well a heat exchanger transfers heat by comparing the actual heat transfer to the maximum possible, using a parameter, Number of Transfer Units (NTU), that reflects its size and flow characteristics.

a more conventional numerical procedure. Notice that the effectiveness-NTU method is based on the same simplifying assumptions as the Merkel method. On the other hand, Poppe and Rögener [21] developed the Poppe method. They derived the governing equations for heat and mass transfer in a wet cooling tower and did not make any simplifying assumptions as in the Merkel theory, which makes it a very precise model. As a matter of fact, predictions from the Poppe formulation have resulted in values of evaporated water flow rate that are in good agreement with full scale cooling tower test results [22]. This model has already been used for the evaluation of the thermal performance of solar power plants using different condensation systems (wet, dry and hybrid system), as can be found in Cutillas et al. [23].

[21]: Poppe et al. (1991), "Berechnung von Rückkühlwerken"

[22]: Kloppers et al. (2005), "A Critical Investigation into the Heat and Mass Transfer Analysis of Counterflow Wet-Cooling Towers"

[23]: Cutillas et al. (2021), "Energetic, Exergetic and Environmental (3E) Analyses of Different Cooling Technologies (Wet, Dry and Hybrid) in a CSP Thermal Power Plant"

In the case of black box models, numerous authors in the literature have designed ANN models for WCT with different objectives, such as performance prediction, simulation and optimization. One of the first works in this area is the one described in [24] where an ANN model was developed to predict the performance of a forced-counter flow cooling tower at lab scale. In this case, the input variables were the dry bulb temperature, the relative humidity of the air stream entering the tower, the temperature of the water entering the tower, the air volume flow rate and the cooling water mass flow rate. The outputs of this model were the heat rejection rate at the tower, the mass flow rate of water evaporated, the temperature of the cooling water at the tower outlet, the dry bulb temperature and the relative humidity of the air at the outlet of the tower. The results obtained with a 5-5-5[2] ANN demonstrated that wet cooling towers at lab-scale can be modelled using ANNs with a high degree of accuracy. There are also ANN models for Natural Draft Counter-flow Wet Cooling Towers (NDWCT) at lab-scale, such as the one proposed by [25]. In this case, the authors used a 4-8-6 ANN structure and considered some additional variables, such as air gravity, wind velocity, heat transfer coefficients and efficiency as outputs. All these works can be useful to validate the model development methodology but may fail predicting the performance of WCT at larger scale. In this sense, special attention deserves the study carried out by [26] where an 8-14-2 ANN model was proposed to predict the performance (the cooling number and the evaporative loss proportion) of NDWCTs at commercial scale. The model is based on 638 sets of field experimental data collected from 36 diverse NDWCTs used in power plants. It is a very challenging work since it covers samples from a wide range of tower sizes and capacities being the Mean Relative Error (MRE) below 5 %.

[24]: Hosoz et al. (2007), "Performance Prediction of a Cooling Tower Using Artificial Neural Network"

2: The notation n_1-...-n_l represents the architecture of the ANN model, where l is the number of layers and n_i are the nodes in each one of the layers.

[25]: Gao et al. (2013), "Artificial Neural Network Model Research on Effects of Cross-Wind to Performance Parameters of Wet Cooling Tower Based on Level Froude Number"

[26]: Song et al. (2021), "A Novel Approach for Energy Efficiency Prediction of Various Natural Draft Wet Cooling Towers Using ANN"

From the literature review, it can be stated that there are works based on Poppe and ANN models that evaluate the main output variables of WCTs. Nevertheless, to the author knowledge, there are no studies focused on the comparison between both modelling strategies. Also lacking is a comprehensive analysis of the different aspects that affect the models development and performance.

The static models presented in this section have been developed to predict two main outputs, the water temperature at the outlet of the WCT, $T_{w,o}$, and the water consumed due to evaporation losses, $\dot{m}_{w,lost}$. The inputs variables required by both modelling approaches, Poppe model and ANN models, are: the cooling water flow rate ($\dot{m}_w$), the water temperature at the inlet of the WCT ($T_{w,i}$), the ambient temperature (T_∞), the ambient relative humidity (ϕ_∞) and the frequency percentage of the fan (f_{fan}) (or its equivalence in air mass flow rate[3], $\dot{m}_a$).

3: ANN uses as input f_{fan} whereas Poppe's model uses $\dot{m}_a$.

11.1.1 Poppe model

The well-known Merkel number is accepted as the performance coefficient of a wet cooling tower [27]. This dimensionless number is defined in Equation 11.1, and it measures the degree of difficulty of the mass transfer processes occurring in the exchange area of a wet cooling tower.

[27]: Navarro et al. (2022), "Critical Evaluation of the Thermal Performance Analysis of a New Cooling Tower Prototype"

$$Me = \frac{h_D a_v V}{\dot{m}_w}, \tag{11.1}$$

where h_D is the mass transfer coefficient, a_V is the surface area of exchange per unit of volume and V is the volume of the transfer region.

The Merkel number can be calculated using the Merkel and Poppe theories for the performance evaluation of cooling towers. On the one hand, the Merkel theory [18] relies on several critical assumptions, such as the Lewis factor (Le) being equal to 1, the air exiting the tower being saturated with water vapour and it neglects the reduction of water flow rate by evaporation in the energy balance. On the other hand, the Poppe theory [21], which is the one used in this work, do not consider simplifying assumptions, thus being the one most usually preferred. In this theory, the authors derived the governing equations for heat and mass transfer in the transfer region of the wet cooling tower (control volume shown in Figure 11.1) assuming a one dimensional problem. In this figure, the red and green dashed lines indicate the fill and air-side control volumes, respectively.

[18]: Merkel (1925), "Verdunstungskühlung"

[21]: Poppe et al. (1991), "Berechnung von Rückkühlwerken"

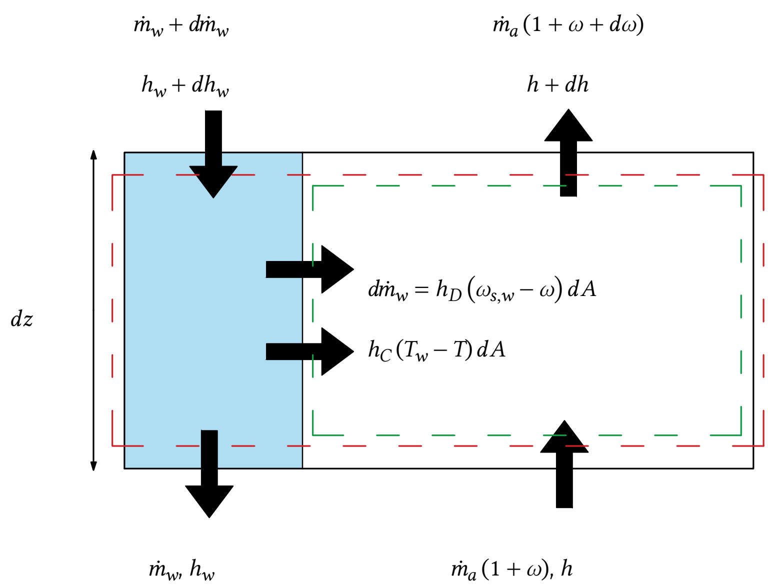


Figure 11.1: Control volume in the exchange area of a wet cooling tower arrangement.

Following the detailed derivation process and simplification of the previously-mentioned governing equations described in [27], the major following equations for the heat and mass transfer obtained, according to the Poppe theory, are:

$$\frac{d\omega}{dT_w} = \frac{c_{p_w} \frac{\dot{m}_w}{\dot{m}_a} (\omega_{s,w} - \omega)}{(h_{s,w} - h) + (\mathrm{Le} - 1)\left[(h_{s,w} - h) - (\omega_{s,w} - \omega) h_v\right] - (\omega_{s,w} - \omega) h_w} \tag{11.2}$$

$$\frac{dh}{dT_w} = c_{p_w} \frac{\dot{m}_w}{\dot{m}_a} \left[1 + \frac{(\omega_{s,w} - \omega) c_{p_w} T_w}{(h_{s,w} - h) + (\mathrm{Le} - 1)\left[(h_{s,w} - h) - (\omega_{s,w} - \omega) h_v\right] - (\omega_{s,w} - \omega) h_w}\right] \tag{11.3}$$

$$\frac{d\mathrm{Me}}{dT_w} = \frac{c_{p_w}}{(h_{s,w} - h) + (\mathrm{Le} - 1)\left[(h_{s,w} - h) - (\omega_{s,w} - \omega) h_v\right] - (\omega_{s,w} - \omega) h_w}, \tag{11.4}$$

where the quantity referred to as Me in Eq. 11.4, is the Merkel number calculated according to the Poppe theory. The above described governing equations can be solved by the fourth order Runge-Kutta method to provide the evolution of the air humidity ratio, air enthalpy and Merkel number inside the transfer area

[27]: Navarro et al. (2022), "Critical Evaluation of the Thermal Performance Analysis of a New Cooling Tower Prototype"

of the cooling tower (fill). Once these profiles are known, the amount of water lost due evaporation can be calculated as per Eq. Equation 11.6. Refer to [27] for additional information concerning the calculation procedure.

$$Me = \frac{h_D a_v V}{\dot{m}_w}, \tag{11.5}$$

$$\dot{m}_{w,lost} = \dot{m}_a(\omega_{a,o} - \omega_{a,i}) \tag{11.6}$$

[28]: Ashrae (2004), "HVAC Systems and Equipment"

It is important to mention that the Merkel number varies with the operation conditions and its value can be obtained using a correlation with the water-to-air mass flow ratio as an independent variable. One of the proposed correlations in ASHRAE [28] is:

$$\mathrm{Me} = c\,(\dot{m}_w/\dot{m}_a)^{-n} \tag{11.7}$$

4: See Section 14.1.1 (Wet cooler model alternatives comparison and validation)

where the constants c and n can be obtained from the fitting of experimental data[4].

11.1.2 Samples generation for first-principles to data-driven models

Aquí describir los rangos en los que se han movido las variables de entrada y el criterio para elegir esas variable de entrada para construir la combinatoria de valores de entrada.

Finally, all valid thermodynamic and operational combinations are merged into a comprehensive sample set, enabling detailed system evaluations across a realistic and constrained input space.

11.1.3 Model interface

Model 11.1: Wet cooling tower

$$T_{wct,out},\, C_{w,wct} = \text{wct model}(q_{wct},\, \omega_{wct},\, T_{amb},\, HR,\, T_{wct,in})$$

11.2 Dry cooler

11.2.1 Samples generation for first-principles to data-driven models

In this work, sample generation is carried out using a structured grid-search approach to ensure comprehensive coverage of the input space. First, the most relevant input variables for the system are identified, and ranges are specified based on expected operating conditions. Then, the input space is discretized using a fixed number of resolution steps for each variable, as defined in Table .... Instead of generating values for the inlet temperature input variable, values are generated for the temperature difference with the dry-bulb temperature, therefore, a 2D grid is constructed using combinations of ambient temperature (Tamb) and the difference between inlet and ambient temperature (deltaTamb-Tin), with infeasible combinations filtered based on physical constraints. For each valid temperature pair (Tamb, Tdcin), additional independent variables (qdc, wdc) are combined via a Cartesian product, resulting in a full multidimensional grid of plausible operating points. This systematic procedure ensures a dense and uniform sampling across all relevant input dimensions

11.2.2 Model interface

Model 11.2: Dry cooler

$$T_{dc,out} = \text{dc model}(q_{dc}, \omega_{\text{dc}}, T_{\text{amb}}, T_{dc,in})$$

11.3 Other components

11.3.1 Electrical consumption

Electrical consumption is modelled with polynomial regressions of order 3 from experimental data:

Model 11.3: Electrical consumption

$$C_e = \text{electrical consumption model}(x)$$
$$C_e = p_1 \cdot x^3 + p_2 \cdot x^2 + p_3 \cdot x + p_4$$

p_i are the coefficients of the polynomial regression. They need to be calibrated for each component.

where C_e is the electrical consumption and x is the input variable (*e.g.* the recirculated cooling water flow rate, the dry cooler fan speed, etc.).

11.3.2 Surface condenser

The surface condenser is a heat exchanger that condenses steam into water, assuming that all the vapor that enters the condenser (at saturated conditions), leaves it as saturated liquid, it can be modelled by applying the first law of thermodynamics, which states that the heat lost by the steam (*released*) is equal to the heat gained by the cooling water (*absorbed*), and equal to the heat transferred by the condenser heat transfer surfaces (*transferred*).

Model 11.4: Surface condenser

$$T_{c,in}, T_{c,out} = \text{condenser model}(\dot{m}_c, T_v, \dot{m}_v)$$
$$LMTD = \frac{T_{c,out} - T_{c,in}}{\ln\left(\frac{T_v - T_{c,in}}{T_v - T_{c,out}}\right)}$$
$$\dot{Q}_{released} = \dot{m}_v \cdot (h_{sat.vap} - h_{sat.liq})$$
$$\dot{Q}_{absorbed} = \dot{m}_c \cdot c_p(T_{c,out} - T_{c,in})$$
$$\dot{Q}_{transferred} = U \cdot A \cdot LMTD$$
$$U = \ldots$$

The condenser area (A) is a constant parameter

where $T_{c,in}$ and $T_{c,out}$ are the cooling water inlet and outlet temperatures, respectively, $\dot{m}_c$ the cooling water mass flow rate, T_v vapour temperature and $\dot{m}_v$ its mass flow rate and $h_{sat,vap}$ and $h_{sat,liq}$ are the specific enthalpies of the steam at the inlet and outlet of the condenser, respectively. $\dot{Q}$ represents the heat transfer rate *i.e.* the thermal power.

11.3.3 Mixers

The mixers outlet flow ($q_{mix,out,i}$) and temperature ($T_{mix,out,i}$) can be determined with a simple mass and energy balances from its inlets streams ($q_{mix,in}$, $T_{mix,in}$):

Model 11.5: Mixer model

$$q_{mix,out}, T_{mix,out} = \text{mixer model}(q_{mix,in,1}, T_{mix,in,1}, q_{mix,in,2}, T_{mix,in,2}) \tag{11.8}$$

$$q_{mix,out} = q_{mix,in,1} + q_{mix,in,2} \tag{11.9}$$

$$T_{mix,out} = T_{mix,in,1} \cdot \frac{c_p(T_{mix,in,1})}{c_p(T_{out,i})} \frac{q_{mix,in,1}}{q_{mix,out,i}} + T_{mix,in,2} \cdot \frac{c_p(T_{mix,in,2})}{c_p(T_{out,i})} \frac{q_{mix,in,2}}{q_{mix,out,i}} \tag{11.10}$$

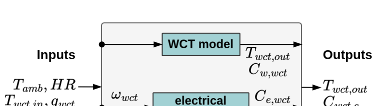
The audacious users might feel tempted to edit some of these packages. I'd be immensely happy if they sent me examples of what they have been able to do!

where $c_p(\cdot)$ is the specific heat, which can be assumed to be the same for the mixing temperature differences of this type of system.

11.4 Complete system

The complete model of the combined cooling system is based on the integration of the models of the WCT and the DC with the surface condenser and the mixers, and defined in Model 11.6 (Complete system).[5]

5: The cooling water recirculation electrical consumption is associated with the condenser here but not all consumption can be attributed to the condenser, the hydraulic circuit and specially the dry cooler will also offer a significant circulation resistance



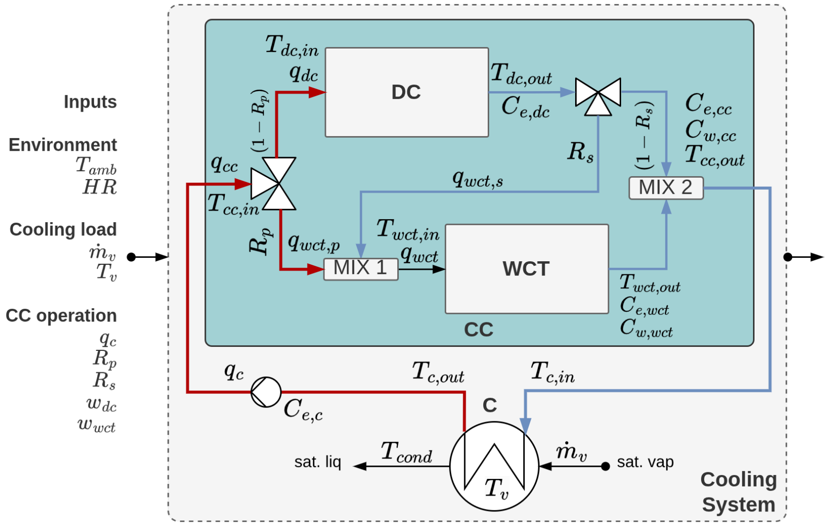


Figure 11.3: Complete model diagram of the combined cooling system

Model 11.6: Combined cooler

$T_{cc,out}, C_e, C_w, T_{c,out}$ = combined cooling system model$(q_c, R_p, R_s, \omega_{dc}, \omega_{wct}, T_{amb}, HR_i, T_v, \dot{m}_v)$

$$T_{cc,in} = T_{c,out}$$
$$T_{dc,in} = T_{cc,in}$$
$$q_{dc} = q_c \cdot (1 - R_p)$$
$$q_{wct,p} = q_c \cdot R_p$$
$$q_{wct,s} = q_{dc} \cdot R_s$$
$$T_{dc,out}, C_{e,dc} = \text{dc model}(q_{dc}, \omega_{\text{dc}}, T_{\text{amb}}, T_{dc,in})$$
$$q_{wct}, T_{wct,in} = \text{mixer model}(q_{wct,p}, T_{Tcc,in}, q_{wct,s}, T_{dc,out})$$
$$T_{wct,out}, C_{e,wct}, C_{w,wct} = \text{wct model}(q_{wct}, \omega_{wct}, T_{amb}, HR, T_{wct,in})$$
$$T_{c,in}, T_{c,out} = \text{condenser model}(q_c, \dot{m}_v, T_v)$$
$$q_{cc}, T_{cc,out} = \text{mixer model}(q_{wct}, T_{wct,out}, q_{dc}, T_{dc,out})$$
$$C_{e,c} = \text{electrical consumption}(q_c)$$
$$C_{e,dc} = \text{electrical consumption}(q_{dc})$$
$$C_{e,wct} = \text{electrical consumption}(q_{wct})$$
$$C_e = C_{e,dc} + C_{e,wct} + C_{e,c}$$
$$C_w = C_{w,wct}$$

Finally, the complete model diagram with all its variables can be seen in Figure 11.3.

Optimization of a combined cooling system 12

TL;DR

This chapter describes optimization problems for a combined cooling system, a DC and a WCT as well as different optimization strategies propositions to solve them. The objective is to minimize the daily cost of operation made up by the electricity and water costs, while ensuring the cooling demand is met. They key challenge is to manage the available water resource, since there is a limited amount of cheap rainwater available and any excess water required must be purchased at a significantly higher cost. From the alternatives, this can only be effectively achieved by the shrinking horizon optimization strategy applied to the combined cooler for which an implementation methodology is proposed.

12.1 Environment definition

The environment for the optimization problems described in this section includes the following components and is visualized in Figure 12.1:

Costs context The cooling system has mainly two associated operational costs: electricity and water use. For the electricity the sale price of electricity is used since whatever is consumed by the cooling system, it's electricity that cannot be sold to the market in the case of a CSP plant, and it is a electricity that needs to be purchased in the case of an MED plant. As for the water, ... This module provides values for the price of electricity (P_e) and the prices of water from source 1 ($P_{w,s1}$) and source 2 ($P_{w,s2}$).

Weather forecast The only two weather variables that have an impact on the cooling system are the ambient temperature (T_{amb}) and the relative humidity (HR) since they set the dry and wet bulb temperatures, and the psycrometric properties ...

Thermal load

Water resource availability Two sources of water are available, one of them, the cheaper one coming from a dam is limited in volume. The cheaper source (s_1) is prioritized until it is depleted, then the alternative source (s_2) is used:

$$C_{w,s1,i} = \frac{\min(V_{avail,i}, C_{w,i} \cdot T_s)}{T_s} \tag{12.1}$$

$$C_{w,s2,i} = C_{w,i} - C_{w,s1,i} \tag{12.2}$$

$$V_{avail,i} = V_{avail,i-1} - C_{w,s1,i} \cdot T_s \tag{12.3}$$

where i represents the step, at every step the amount used from each source is estimated and the dam-water left is updated accordingly.

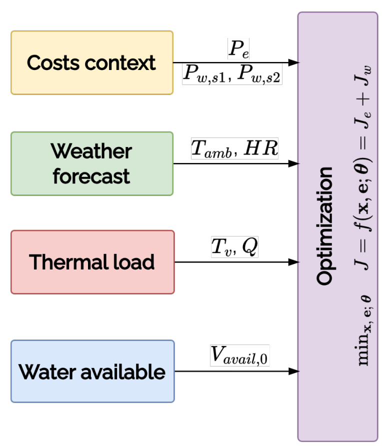


Figure 12.1: Block diagram of the environment components

12.2 Static optimization

As a first approach, the optimization problems evaluated are static. They are defined in a particular time given an environment, and decisions do not take into account prior decisions, neither consider the effect on future state.

Reminder: Optimization problem definition

The general optimization function is defined as:[a]

$$\min_{\mathbf{x},\mathbf{e};\theta} \quad J = f(\mathbf{x},\mathbf{e};\theta) \quad \text{s.t.} \quad g_i(\mathbf{x}) \le 0, \quad i = 1,\dots,m$$

where x is the decision vector, e represents the environment, and θ contains the fixed parameters.

[a] See Section **??** (**??**)

Every time a problem is evaluated, it will start with some initial volume ($V_{avail,0}$) for the particular step, and this volume needs to be updated before evaluating the next step. This yields that in order to evaluate several consecutive steps, they must do so sequentially.

12.2.1 Dry cooler

In the first case study, only the dry cooler is involved, and so all terms related to the wet cooler are set to zero and every water resource related term can be ignored as can be seen in Figure 12.2. The components are defined as follows:

See Section **??** (**??**) for a detailed description of the dry cooler and condenser model.

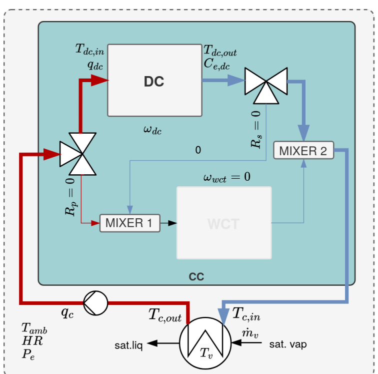


Figure 12.2: Diagram of the dry cooler only cooling problem

Problem: DC - static

$$\min_{\mathbf{x},\mathbf{e};\theta} \quad J = f(\mathbf{x},\mathbf{e};\theta) = C_e \cdot P_e$$

with:

$$T_{dc,out},\, C_e,\, T_{c,out} = f(q_c,\, \omega_{\text{dc}},\, T_{\text{amb}},\, T_v,\, \dot{m}_v)$$

- Decision variables

$$x = [q_c,\, \omega_{\text{dc}}]$$

- Environment variables

$$e = [T_{\text{amb}},\, P_e,\, T_v,\, \dot{m}_v]$$

- Fixed parameters

$$\theta = [R_p = 0,\; R_s = 0,\; \omega_{\text{wct}} = 0]$$

subject to:

- Box-bounds
  - $w_{dc} \in [\underline{w}_{dc}, \overline{w}_{dc}]$
  - $q_c \in [\underline{q}_c, \overline{q}_c]$
- Constraints
  - $|T_{\text{dc,out}} - T_{\text{c,in}}| \le \epsilon_1$
  - $T_{\text{c,out}} \le T_v - \Delta T_{\text{c-v,min}}$
  - $|Q_{\text{dc}} - Q_{\text{c,released}}| \le \epsilon_2$

12.2.2 Wet cooler

See Section 11.1 (Wet cooler) for a detailed description of the wet cooler and condenser model.

Problem: WCT - static

$$\min_{\mathbf{x},\mathbf{e};\theta} \quad J = f(\mathbf{x},\mathbf{e};\theta) = J_e + J_w$$

with:

$$\begin{aligned} J_e &= C_e \cdot P_e \\ J_w &= C_{w,s1} \cdot P_{w,s1} + C_{w,s2} \cdot P_{w,s2} \\ C_{w,s1} &= \min\left((V_{avail}, C_w \cdot T_s)/T_s\right) \\ C_{w,s2} &= C_w - C_{w,s1} \\ T_{wct,out},\ C_e,\ C_w,\ T_{c,out} &= f(q_c, \omega_{wct}, T_{amb}, HR, T_v, \dot{m}_v) \end{aligned}$$

- Decision variables

$$x = [q_c,\ \omega_{\text{wct}}]$$

- Environment variables

$$e = [T_{\text{amb}}, HR,\ P_e,\ P_{w,s1},\ P_{w,s2}, V_{avail},\ T_v,\ \dot{m}_v]$$

- Fixed parameters

$$\theta = [R_p = 1,\ R_s = 0,\ \omega_{\text{dc}} = 0]$$

subject to:

- Box-bounds
  - $w_{wct} \in [\underline{w}_{wct}, \overline{w}_{wct}]$
  - $q_c \in [\underline{q}_c, \overline{q}_c]$
- Constraints
  - $|T_{\text{wct,out}} - T_{\text{c,in}}| \leq \epsilon_1$
  - $T_{\text{c,out}} \leq T_v - \Delta T_{\text{c-v,min}}$
  - $|Q_{\text{wct}} - Q_{\text{c,released}}| \leq \epsilon_2$

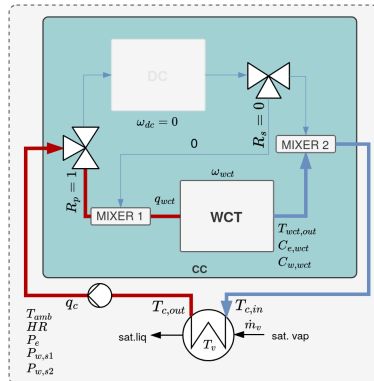


Figure 12.3: Diagram of the wet cooler only cooling problem

12.2.3 Combined cooler

Problem: CC - static

$$\min_{\mathbf{x},\mathbf{e};\theta} \quad J = f(\mathbf{x},\mathbf{e};\theta) = J_e + J_w$$

with:

$$\begin{aligned} J_e &= C_e \cdot P_e \\ J_w &= C_{w,s1} \cdot P_{w,s1} + C_{w,s2} \cdot P_{w,s2} \\ C_{w,s1} &= \frac{\min(V_{avail}, C_w \cdot T_s)}{T_s} \\ C_{w,s2} &= C_w - C_{w,s1} \\ T_{cc,out},\ C_e,\ C_w,\ T_{c,out} &= f(q_c, R_p, R_s, \omega_{dc}, \omega_{wct}, T_{amb}, HR, T_v, \dot{m}_v) \end{aligned}$$

- Decision variables

$$x = [q_c, R_p, R_s, \omega_{\text{dc}}, \omega_{\text{wct}}]$$

- Environment variables

$$e = [T_{\text{amb}}, HR,\ P_e,\ P_{w,s1},\ P_{w,s2}, V_{avail},\ T_v,\ \dot{m}_v]$$

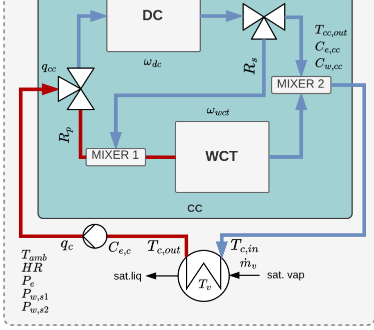
- Fixed parameters

$$\theta = [R_p = 1,\ R_s = 0,\ \omega_{\text{dc}} = 0]$$

subject to:

- Box-bounds

See Section 11.4 (Complete system) for a detailed description of the combined cooler and condenser model.



bined cooling system

Figure 12.4: Diagram of the combined cooler and condenser problem

- $w_{dc} \in [\underline{w}_{dc}, \overline{w}_{dc}]$
- $w_{wct} \in [\underline{w}_{wct}, \overline{w}_{wct}]$
- $q_c \in [\underline{q}_c, \overline{q}_c]$
- $R_p \in [0, 1]$
- $R_s \in [0, 1]$

▸ Constraints

- $|T_{\text{CC,out}} - T_{\text{C,in}}| \leq \epsilon_1$
- $T_{\text{C,out}} \leq T_v - \Delta T_{\text{C-v,min}}$
- $|Q_{\text{CC}} - Q_{\text{C,released}}| \leq \epsilon_2$

12.3 Shrinking horizon optimization

The problem structure is very similar to the static alternative, the main difference is that now the decision and environment vectors are composed not from the expected value for the optimization step, but an array of values from the current optimization step until the end of the prediction horizon (n_{steps}), this means that forecasts for each variable in the environment are needed, that is:

1. An operation plan of the thermal load (power block or MED operating conditions) needs to be defined.
2. An estimation of the costs context evolution. Water price is unlikely to change often,

$\forall i = 1 \dots n_{steps}$ is a notation to indicate that a condition must be held at every step i in the optimization horizon (n_{steps})

Problem: CC - horizon

$$\min_{\mathbf{x},\,\mathbf{e};\theta} \quad J = f(\mathbf{x}, \mathbf{e}; \theta) = \sum_{i=1}^{n_{steps}} (J_{e,i} + J_{w,i}) \cdot T_s$$

with:

$$
\begin{aligned}
& for\, i = 1 \dots n_{steps} : \\
& \quad J_{e,i} = C_{e,i} \cdot P_{e,i} \\
& \quad J_{w,i} = C_{w,s1,i} \cdot P_{w,s1,i} + C_{w,s2,i} \cdot P_{w,s2,i} \\
& \quad C_{w,s1,i} = \frac{\min(V_{avail,i}, C_{w,i} \cdot T_s)}{T_s} \\
& \quad C_{w,s2,i} = C_{w,i} - C_{w,s1,i} \\
& \quad V_{avail,i} = V_{avail,i-1} - C_{w,s1,i} \cdot T_s \\
& \quad T_{cc,out,i},\, C_{e,i},\, C_{w,i},\, T_{c,out,i} = f(q_{c,i}, R_{p,i}, R_{s,i}, \omega_{dc,i}, \omega_{wct,i}, T_{amb,i}, HR_i, T_{v,i}, \dot{m}_{v,i})
\end{aligned}
$$

▸ Decision variables

$$\mathbf{x} = [\mathbf{q_c}, \mathbf{R_p}, \mathbf{R_s}, \text{dc}, \text{wct}]$$

where $x = [x_{0,0},\, \dots\, x_{0,n_{steps}},\, \dots,\, x_{n_x,n_{steps}}]$

▸ Environment variables

$$\mathbf{e} = [\mathbf{T}_{\text{amb}}, \mathbf{HR}, \mathbf{P_e}, \mathbf{P_{w,s1}}, \mathbf{P_{w,s2}}, \mathbf{V_{avail,0}}, \mathbf{T_v}, \mathbf{\dot{m}_v}]$$

where $e = [e_{0,0},\, \dots\, e_{0,n_{steps}},\, \dots,\, e_{n_e,n_{steps}}]$

subject to:

▸ Box-bounds

- $\mathbf{w_{dc}} \in [\underline{w}_{dc}, \overline{w}_{dc}]$
- $\mathbf{w_{wct}} \in [\underline{w}_{wct}, \overline{w}_{wct}]$

- $\mathbf{q_c} \in [\underline{q}_c, \overline{q}_c]$
- $\mathbf{R_p} \in [0, 1]$
- $\mathbf{R_s} \in [0, 1]$

▸ Constraints, $\forall i = 1 \dots n_{steps}$:

- $|T_{\text{CC,out},i} - T_{\text{C,in},i}| \leq \epsilon_1$
- $T_{\text{C,out},i} \leq T_{v,i} - \Delta T_{\text{C-v,min}}$
- $|Q_{\text{CC},i} - Q_{\text{C,released},i}| \leq \epsilon_2$

12.3.1 A discussion on solving the optimization problem

Aquí comentar cómo no es factible resolver el problema directamente porque es muy difícil encontrar soluciones factibles debido a la estructura del problema.

Comentar número de elementos en el vector de decisión, crecimiento exponencial de la complejidad del problema con el número de pasos en el horizonte, etc..

12.3.2 Proposed solution: Decomposition-based multi-objective optimization with trajectory planning

We propose a two-level optimization strategy for a multi-stage decision problem[1]. At each stage of a prediction horizon, we independently solve a multi-objective optimization problem, yielding a Pareto front. We then formulate a global optimization problem to select a consistent path through the sequence of Pareto fronts, minimizing a cumulative objective (e.g., cost or distance), similar to a pathfinding or TSP-like problem over Pareto-optimal points.

1. Decompose a multi-stage problem into N stages.
2. Solve a multi-objective optimization problem at each stage independently to obtain a Pareto front.
3. Formulate a second-level problem to select a path through these Pareto fronts that minimizes a global objective, the cumulative operation cost[2].

1: Alternative wording: Pareto front chaining, multi-stage Pareto optimization, path planning on Pareto surfaces.

Reminder: Pareto front

When dealing with multiple objectives where no single solution is optimal, but improvements in one objective lead to trade-offs in others, we obtain a set of points that represent the best trade-offs between the objectives, known as a Pareto front[a]

[a] See Section 8.3 (Multi-objective optimization)

2: analogously to a Traveling Salesman Problem (TSP) on the Pareto surfaces

Solving the multi-objective optimization problems

Path selection subproblem

Problem nature description.

The path selection subproblem can be formulated as a graph traversal problem, where each node represents a point in the Pareto front of a stage, and edges represent the transition costs between these points. The goal is to find a path through the graph that minimizes the cumulative cost. This subproblem is a combinatorial optimization problem, in particular, a layered weighted directed graph.

Definición formal del problema

The transition cost is correlated to the current resource availability and will depend on the current state of the system, which is a function of the previous decisions.

Mencionar algoritmo seleccionado

The path optimization could be handled via dynamic programming, graph search (like Dijkstra or A*), or metaheuristics depending on the problem size. Metaheuristics: - Genetic Algorithms - Simulated Annealing - Ant Colony Optimization - Tabu Search - Particle Swarm Optimization

12.4 Limitations

Modelado de disponibilidad de agua en función de las precipitaciones. Esto es lo más complejo. Aunque haya mucha disponibilidad, puede ser que haya mucha demanda de agua (agricultura, etc), si hay poca disponibilidad puede que ni siquiera se permitiese su implementación. Si finalmente se ajusta el volumen máximo para que coincida con lo que consumiría el sistema húmedo exclusivamente, esto va a hacer que el húmedo no sea factible parte del año. Discutir.

Combined cooling pilot plant at Plataforma Solar de Almería 13

TL;DR

In this chapter a detailed description of the combined cooling pilot plant at PSA is provided including a Piping and Instrumentation Diagram (P&ID) diagram and the methodology followed to perform the experimentation and data-processing. Three experimental campaigns for the WCT with XX, XX and XX different operating points and one for the DC with XX operating points are processed and made openly available in public repositories.

Introduction

The combined cooling pilot plant at Plataforma Solar de Almería is a unique facility that integrates a wet cooling tower and a dry cooler in a flexible hydraulic configuration. It allows for the study and validation of different cooling strategies and the development of models.

...

This chapter describes the plant in Section 13.1 (Plant description) and the experimental campaigns carried out in Section 13.2 (Experimental campaigns).

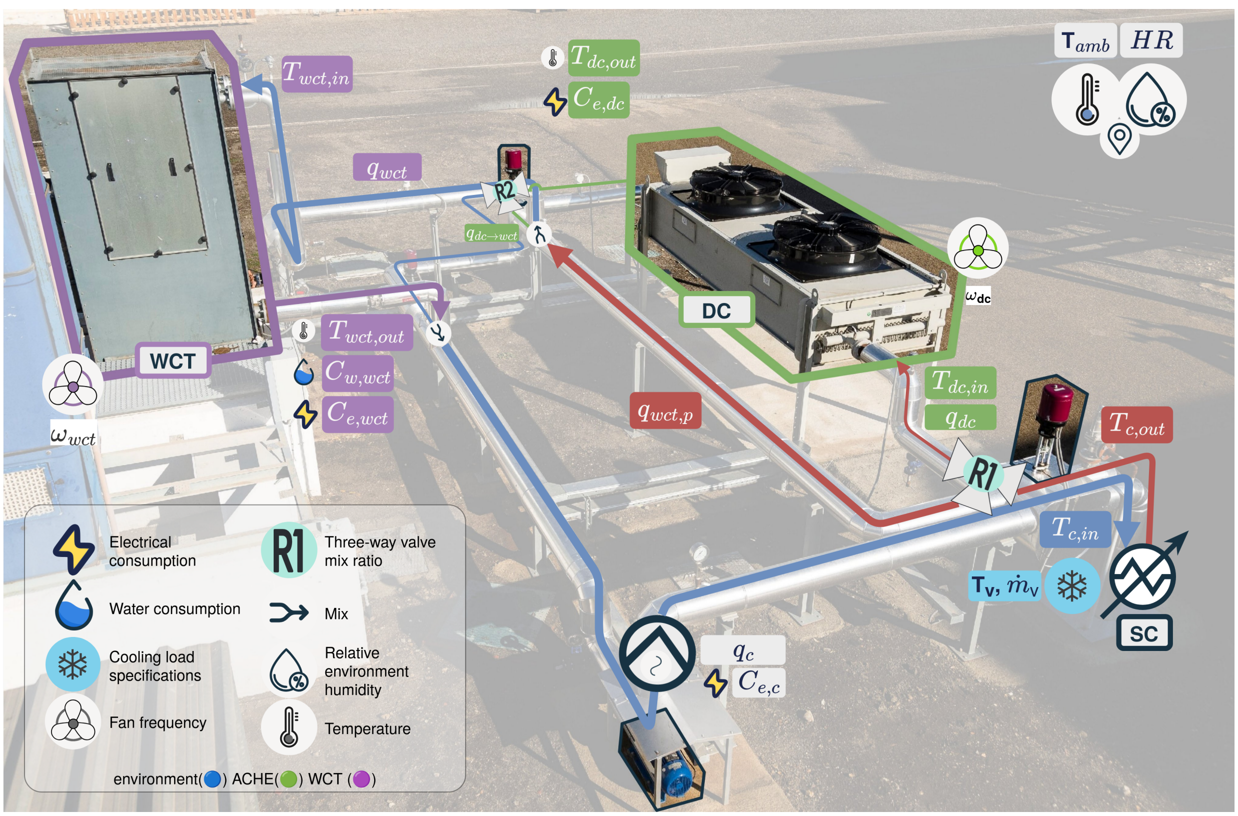


Figure 13.1: PSA combined cooling system facility

13.1 Plant description

The pilot plant of combined cooling systems located at PSA (see the layout in Figure 13.3) consists of three circuits: cooling, exchange and heating. In the cooling circuit (see a picture in Figure 13.2), water circulating inside the tube bundle of a Surface Condenser (SC) can be cooled through a Wet Cooling Tower and/or a Dry Cooling Tower (type Air Cooled Heat Exchanger, ACHE), both with a designed thermal power of 204 kW$_{th}$. In the exchange circuit, a saturated steam generator of 80 kW$_{th}$ (on the design point), generates steam at different pressures (in the range between 82 mbar and 200 mbar), which is in turn condensed in the surface condenser. In this way, the steam transfers its latent heat of condensation to the refrigeration water, that is heated. Finally, in the heating circuit, a solar field with a thermal power of 300 kW$_{th}$ at the design point, provides the energy required by the steam generator, in the form of hot water. It is a unique, very flexible, fully instrumented and versatile facility, able to operate in different operation modes: series and parallel mode, conventional dry-only mode (all water flow is cooled through the dry cooling tower) and wet-only mode (all water flow is cooled through the wet cooling tower). The instrumentation related to the WCT is described in Table Table 13.1. Note that the sensors measuring the air velocity and temperature and relative humidity at the outlet area of the wet cooling tower have not been installed in the plant. Portable sensors were used instead in some experiments, as described in Section ??.

Figure 13.2: Back view of the WCT.

In regards to operational aspects of the system, note that the cooling water and air flow rates at the experimental facility ($\dot{m}_w$, and air, $\dot{m}_a$, respectively), are modified with the *Pump 1* and the fan frequency percentage `SC-001`, respectively (see Figure 13.3).

Table 13.1: Characteristics of instrumentation ([a] value of the temperature in °C, [b] of reading, [c] full scale, [d] mean value).

Measured variable	Instrument	Range	Measurement uncertainty
Water temperature (`TT-001`, `TT-006`)	Pt100	0 - 100 °C	0.03 + 0.005·T^a
Cooling water flow rate (`FT-001`)	Vortex flow meter	9.8 - 25 m^3/h	± 0.65 % o.r.^{b}
Water flow rate (`FT-004`)	Paddle wheel flow meter	0.05 - 2 m^3/h	± 0.5 % of F.S^c + 2.5 % o.r
Ambient temperature	Pt1000	-40 - 60 °C	± 0.4 @20 °C
Relative humidity	Capacitive sensor	0 - 98%	± 3 % o.r @20 °C
Air velocity	Impeller anemometer	0.1-15 m s^{-1}	± 0.1 m s^{-1} + 1.5 % o.r
Outlet air temperature	Pt100	-20-70°C	±0.5°C
Outlet air humidity	Capacitive sensor	0-100%	± 2%

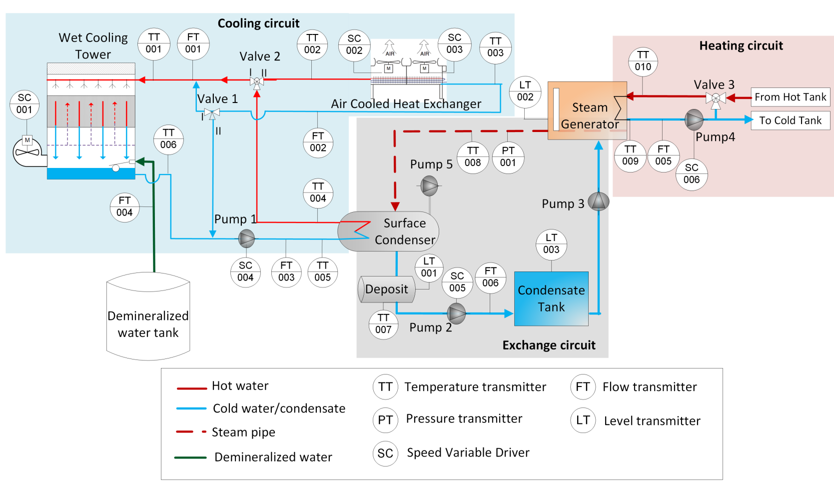


Figure 13.3: Layout of combined cooling systems pilot plant at PSA.

13.2 Experimental campaigns

With the aim of characterizing and developing models for this novel facility, over the years several experimental campaigns have been carried out. In particular, three different experimental campaigns have been performed to characterize the WCT specifically, while a campaign was also carried out to characterize the DC.

13.2.1 Experimental campaigns for the wet cooling tower

A total of 132 steady-state experimental points have been obtained. These data cover a large variety of ambient conditions (different seasons, days and nights) and thermal loads (from 27 kW to 207 kW). The objective of the experimental campaigns is to develop and validate two modelling strategies for the performance evaluation of the WCT[1].

1: See Section 11.1 (Wet cooler)

The normative framework followed to carry out the experiments, in order to ensure stable conditions, has been the standards `UNE 13741` [29] and the Spanish CTI [30]. These standards specify the test duration and the allowed variations of the most representative ambient and operating magnitudes (water flow rate, heat load, cooling tower range, wet-bulb and dry-bulb temperatures and wind velocity) during the tests. Although the duration of the test should not be less than one hour according to the standards, due to the low capacity of the WCT in the PSA pilot plant and the operational experience, the duration of the tests has been reduced to up to 30 minutes. Once stable conditions are maintained during the defined interval time, the average and deviations values of each measurement are calculated in order to check that they are within the allowable limits of the norm, which finally lead to a valid steady-state operating point.

[29]: UNE (2004), *Thermal Performance Acceptance Testing of Mechanical Draught Series Wet Cooling Towers*

[30]: CTI (2000), *Code Tower, Standard Specifications. Acceptance Test Code for Water Cooling Towers*

Figure 13.4 shows the main variables involved in one of the experiments performed at the pilot plant at constant air flow rate (f_{fan}=25 %). As can be observed, there are two time intervals in this case, in which the process is at stationary conditions according to the normative framework mentioned. In order to process the results of the experimental tests and identify valid time intervals, such as the ones shown in this example, a function has been implemented in the *MATLAB* environment. This function identifies whether the standard criteria is met and calculates the mean values of the required variables.

The data from the different experimental campaigns is available at [31, 32].

[31]: Palenzuela et al. (2024), *Steady-State Operation Dataset of an Experimental Wet Cooling Tower Pilot Plant Located at Plataforma Solar de Almería*

[32]: Serrano et al. (2024), "Wet Cooling Tower Performance Prediction in CSP Plants"

13.2.2 Experimental campaign 1 – Exp 1

This campaign was specifically designed for the calibration of the physical model. In total, 19 experimental tests were performed at the combined cooling pilot plant at PSA. The physical model focuses on the calculation of the Merkel number which, according to the literature ASHRAE [28], is not a constant value. Instead, it varies depending on the operating conditions (water-to-air mass flow ratio, $\dot{m}_w/\dot{m}_a$). Therefore, the experimental campaign has been designed to cover different water-to-air mass flow ratios. Both variables, the water and the air flow rates, were varied within the allowable range for plant operation. In the case of the water flow rate, it ranged from 8 m^3/h to 22 m^3/h, and in the case of the air mass flow rate, it was modified by changing the fan frequency from 12.5 Hz to 50 Hz (fan frequency percentage, f_{fan}, from 25 % to 100 %). The magnitudes required to experimentally determine the air mass flow rate (air velocity and air temperature and relative humidity) were measured at the outlet area of the cooling tower[2]. The outlet area was divided into 9 quadrants and the above

[28]: Ashrae (2004), "HVAC Systems and Equipment"

2: Using the sensors listed in Table 13.1

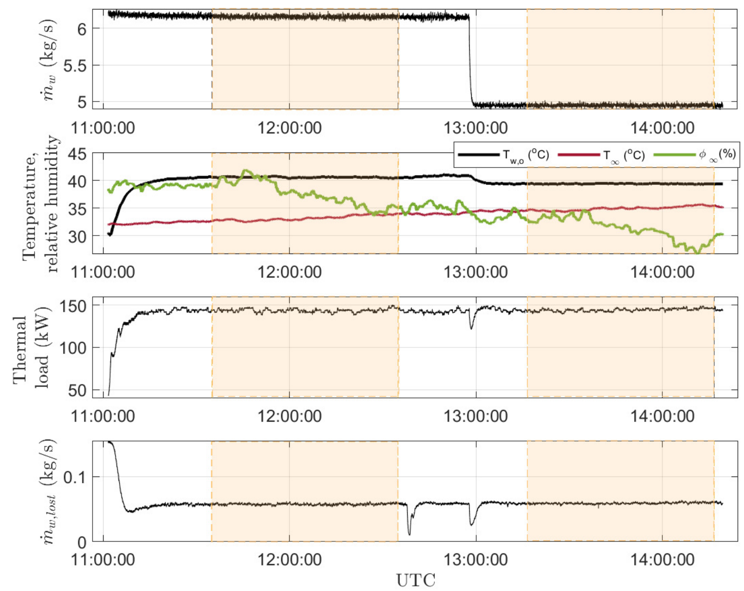


Figure 13.4: Example of one experiment at the pilot plant in July with two valid steady-state operating points.

mentioned magnitudes were registered at the center of each quadrant. The obtained values were averaged to determine the mean velocity, temperature and relative humidity used in the air mass flow rate calculation.

Following the same experimental procedure, air velocity, temperature and humidity maps were measured for 8 different f_{fan} levels (ranging from 30 % to 100 % in 10 % intervals)[3].

3: This enables to obtain the air mass flow rate at the outlet of the cooling tower, $\dot{m}_a$, using the permanent sensors installed in the facility

The range of air and water mass flow rates are 1.16-4.32 kg/s and 2.17-6.15 kg/s, respectively. Regarding the environmental conditions, these were quite similar for all tests in the campaign: high ambient temperatures (ranging between 32 °C and 41 °C), and low ambient relative humidities (between 13 % and 40 %) since the experiments were carried out during the summer season.

13.2.3 Experimental campaign 2 – Exp 2

The data required for data-driven models depends on several factors such as the complexity of the model and the error allowed or the diversity of the inputs. With the aim of obtaining a reliable model for the WCT, data collected over several years of operation of the combined cooling system have been used for tuning. They are a set of 115 stationary data covering the following operating ranges: ambient temperature, T_∞, [9-39] °C, ambient humidity, ϕ_∞, [10-87] %, inlet water temperature, $T_{w,i}$ [33-41] °C, cooling water flow rate, q_w, [6-23] m^3/h and fan frequency percentage, f_{fan} [21-94] %. The thermal load in these tests varies in the range of [27-178] kW_{th}. The number of steady-state data obtained is a reasonable value when compared to other similar data-driven models of counter-flow cooling towers, as in the case of [24], where 81 experimental points were collected for training and testing.[4]

4: Reminder, dataset is available at [31]

13.2.4 Experimental campaign 3 – Exp 3

With the aim of validating and comparing different modelling approaches, a dataset of 17 tests (different from the ones taken for experimental campaigns 1 and 2) has been compiled. This experimental campaign was designed using a design of experiments based on full factorial design with 4 factors and 2 levels (low and high), whose values are shown in Table 13.2.

An additional test at design operating conditions of the WCT ($T_{b,\infty}$=21 °C, $T_{w,i}$=40 °C, $\dot{m}_w$=6.9 kg/s and $T_{w,i} - T_{w,o}$=7 °C) has been also included in this test campaign, where $T_{b,\infty}$ is the ambient wet bulb temperature and $T_{w,o}$ the temperature of the water at the outlet of the WCT.

Table 13.2: Design of experiments for model comparison.

Variable	Low level	High level
T_b (°C)	≤ 10	≥ 15
$T_{w,i}$ (°C)	≤ 37	≥ 39
$\dot{m}_w$ (kg/s)	≤ 3.3	≥ 5
$T_{w,i} - T_{w,o}$ (°C)	≤ 7	≥ 8

13.2.5 Experimental campaigns for the dry cooler

14 Validation

To Do

After the chapter is complete, find and replace all mentions to RBF, ANN, RMSE and all other acronyms with the acronym with `\gls`.

14.1 Modelling

The two main components of the system (WCT and DC) are modelled with different approaches and compared in detail. Afterward, the integration of the selected modelling approach with the rest of the system components (Section 11.3) is validated in Section 14.1.5 (Complete system model validation).

14.1.1 Wet cooler model alternatives comparison and validation

As previously mentioned[1], three experimental campaigns have been performed, shown in Figure 14.1 as Exp 1, Exp 2, and Exp 3. Exp 1 corresponds to the Poppe model calibration campaign and it was designed for the calibration of the first principles model. The aims of such campaign was to fit a function (mapping) that relates the air mass flow rate at the outlet of the tower, $\dot{m}_a$, with the frequency of the fan, f_{fan}:

1: See Section 13.2.1 (Experimental campaigns for the wet cooling tower)

$$\dot{m}_a = -0.0014 f_{fan}^2 + 0.1743 f_{fan} - 0.7251. \tag{14.1}$$

and to calibrate a WCT performance coefficient: the Merkel number, Me. Figure 14.2 shows the variation of the Merkel number as a function of the water-to-air mass flow ratio ($\dot{m}_w/\dot{m}_a$) using data from Exp1. As can be seen, the Me decreases with $\dot{m}_w/\dot{m}_a$ values following a linear trend on log-log scale.

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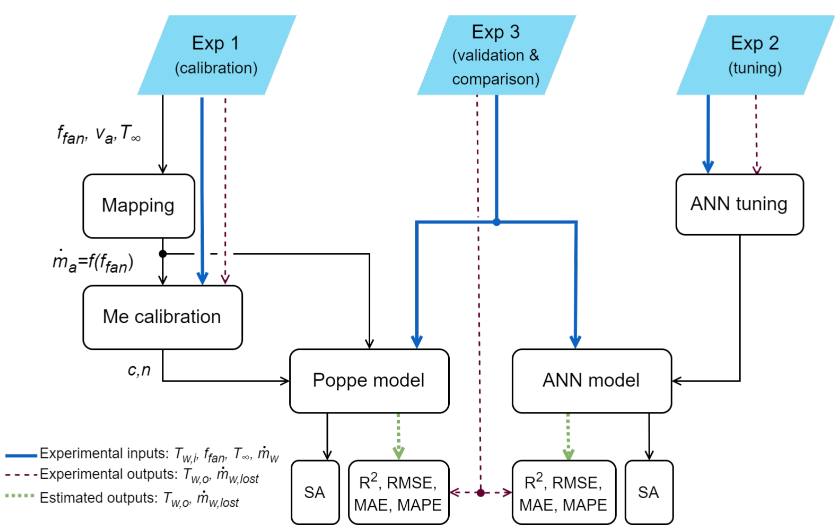


Figure 14.1: Calibration, tuning, validation and comparison procedure

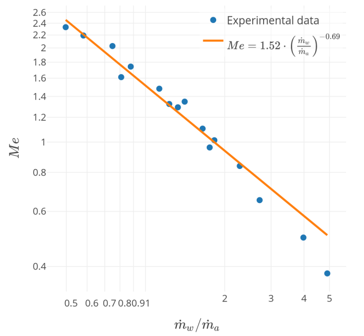


Figure 14.2: Experimental results for the Me number as a function of $\dot{m}_w/\dot{m}_a$.

Following the correlation for the Merkel number of a wet cooling tower described in Section 11.1.1, the parameters c and n obtained from the data fitting are 1.516 and 0.693, respectively.

Prediction capabilities

Tabla tocha añadiendo casos (GPR, DD from FP, RF, GB)

The results of each modelling alternative and its comparison can be visualized in Figure 14.3 and Table 14.1. The results of each modelling alternative and its comparison can be visualized Figure 14.3 shows the results obtained with the models using Exp 3. It shows the perfect fit together with the results obtained with Poppe's model, MIMO FF, cascade CF, and MIMO RBF. In Table 14.1, the performance of the studied modelling approaches are included for the different performance metrics[2]. T represents the performance metric value for the training / calibration dataset (Exp 1 or Exp 2 depending on the case), and V for the validation and comparison one (Exp 3). In all cases the model representing each alternative is in the best case scenario, *i.e.* maximum number of points available. On the other hand, `s.u.` indicates that the units of the column are the same as from the source variable.

2: Described in Section 5.1

Comparing both modelling approaches (see Figure 14.3), it can be outlined that both models provide a good prediction of the output variables, falling most of the discrepancies (errors) within the uncertainty range. Poppe's model provides a better prediction of the outlet temperature, obtaining an RMSE of 0.33 °C and an R^2 of 0.98. In comparison, the best ANN alternative (RBF MIMO) has a slight worse performance with an RMSE of 0.51 °C and $R^2 = 0.95$. In terms of water consumption, the physical model has a better prediction accuracy in terms of RMSE and R^2 (8.5 l/h and 0.97) compared to 11.24 l/h and 0.95 for the best ANN model (cascade CF). It can be stated that, although the results are better for the physical model (specially in the case of the outlet temperature prediction), both approaches produce valid results with high accuracy levels.

Experimental data requirements

In order to estimate the minimum number of tests required to obtain satisfactory results with both modelling strategies, an analysis was performed in which each modelling alternative was calibrated/tuned for different case studies with different amounts of available data, and then the performance metrics were

Table 14.1: Summary table of the prediction results obtained with the different modelling approaches studied.

Predicted variable	Modelling alternative	Model config	Topology	Performance metric R^2 (-)		RMSE (s.u.)		MAE (s.u.)		MAPE (%)		Evaluation time (s)
				T	V	T	V	T	V	T	V	
$T_{o,w}$ (°C)	Poppe	-	-	-	0.98	-	0.33	-	0.27	-	0.87	6.288
	Feedforward ANN	MIMO	20-2	0.93	0.89	0.52	0.74	0.37	0.51	1.22	1.78	0.004
	Cascade-forward ANN	MIMO	10-5-2	0.93	0.90	0.50	0.70	0.35	0.47	1.15	1.65	0.004
	Radial basis ANN	MIMO	37-2	0.99	0.95	0.23	0.51	0.18	0.40	0.57	1.35	0.004
	Feedforward ANN	Cascade	10-10-1	0.94	0.89	0.46	0.72	0.32	0.49	1.05	1.71	0.007
	Cascade-forward ANN	Cascade	10-10-1	0.94	0.87	0.46	0.79	0.31	0.52	1.02	1.82	0.008
	Radial basis ANN	Cascade	92-1	0.99	0.69	0.23	1.22	0.08	0.92	0.25	3.20	0.008
$\dot{m}_{w,lost}$ (l/h)	Poppe	-	-	-	0.97	-	8.47	-	6.74	-	3.74	6.288
	Feedforward ANN	MIMO	20-2	0.95	0.90	11.75	16.27	9.47	14.53	7.74	8.44	0.004
	Cascade-forward ANN	MIMO	10-5-2	0.96	0.94	10.52	12.68	8.23	10.96	6.68	6.33	0.004
	Radial basis ANN	MIMO	37-2	0.99	0.93	4.88	13.86	3.67	10.93	2.94	6.76	0.004
	Feedforward ANN	Cascade	20-1	0.97	0.93	9.64	13.57	7.50	11.18	6.12	6.39	0.007
	Cascade-forward ANN	Cascade	10-10-1	0.97	0.95	8.52	11.24	6.18	9.15	4.92	5.21	0.008
	Radial basis ANN	Cascade	29-1	0.98	0.91	7.63	15.70	4.54	12.41	4.13	6.93	0.008

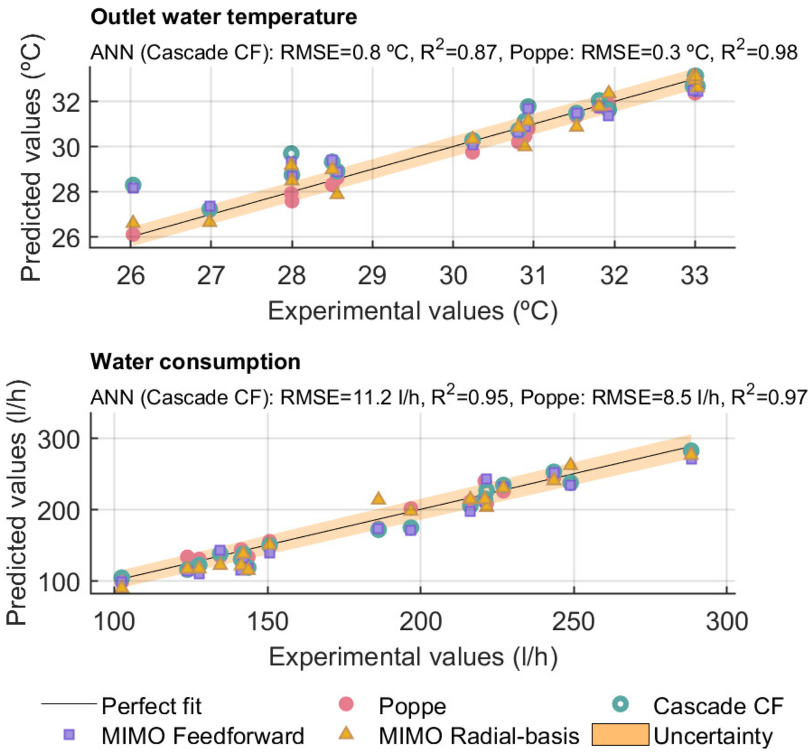


Figure 14.3: Model results obtained with Poppe and ANN models and data of Exp3

evaluated. In this way, trends in the predictive accuracy of the models as a function of the available data can be identified. When the variation becomes small, it can be stated that the model has converged and adding more information provides diminishing returns.

For the physical model, the number of tests from Exp 1, used to calibrate Me correlation, was varied from 2 up to 16 data points added sequentially. In the case of the ANN models, the available tuning data (Exp 2) was increased in steps of 10 %, starting from the availability of 10 % up to the entire data set (100 %).

In both cases, the criteria for selecting the data was not random, but it was done by applying physical knowledge. The water-to-air mass flow ratio, $\dot{m}_w/\dot{m}_a$, is a good indicator for selecting the operation points to be fed to the model. The trend observed in Figure 14.2 (decreasing Me for increasing $\dot{m}_w/\dot{m}_a$) has been extensively reported in the literature. This behavior is explained by the increase in the amount of water per unit of air that lead to a less effective cooling [33]. The situation corresponding to the minimum $\dot{m}_w/\dot{m}_a$ can be interpreted as the maximum air flow rate for a given water flow rate to be cooled. This results in the maximum driving force and, therefore, maximum Merkel number. As $\dot{m}_a$ decreases progressively, the driving force decreases for a given $\dot{m}_w$, and Me decreases accordingly. Based on this knowledge, the selection starts by choosing extreme points for the water-to-air mass flow ratio in the Me-$\dot{m}_a/\dot{m}_w$ relationship from the available data, which gives information of the system operating in its limits. Subsequently intermediate points are added, covering this way the whole operating range of the cooling system.

[33]: Ruiz et al. (2022), "Thermal Performance and Emissions Analysis of a New Cooling Tower Prototype"

The results of this study are presented in Figure 14.4, where the x-axis represents the number of available data points and the y-axis a model performance metric (RMSE) obtained when the model outputs are compared to data from Exp 3. From the results obtained, it can be clearly seen the advantage of the physical model in terms of data requirements, since with the minimal amount of points,

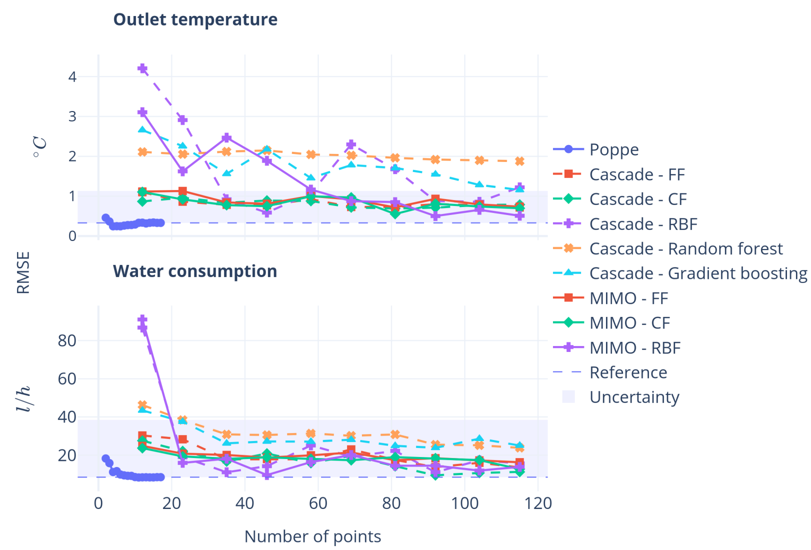


Figure 14.4: RMSE evolution as a function of the number of points used for calibration/-training of the Poppe's and data-driven approaches

good results are obtained, and by enlarging the available data points to 8-10, low variation in the RMSE evolution can be observed for both predicted variables. In the case of the ANN-based approaches, the results differ depending on the ANN alternative.

In terms of the outlet temperature, very good results (low error and variation) are obtained with the minimal dataset (10 % of available data, 12 data points) for feedforward and cascade-forward in any configuration (MIMO and cascade). If more data is added, RMSE is reduced from 1.1 up to 0.7 °C. Although the MIMO RBF outperforms the results of the other ANN alternatives, it does so only from 90 points onwards. For this case, the downward trend is much more noticeable but constant, which can not be stated for the cascade RBF, displaying an erratic evolution up to 70 points.

Similar conclusions can be drawn for the water consumption, except that in this case the two RBF configurations achieve satisfactory results much earlier, starting from 23 points.

Summarizing, both modelling approaches, Poppe's model and ANNs, produce satisfactory results since their predictions fall well within the range of uncertainty for all the case studies, although the obtained results, in terms of RMSE, favor the physical model. Therefore, while the ANN model benefits from as much data as possible, the Poppe model is already able to produce satisfactory results with just two properly selected points. These two points are easy to identify in advance because they are related to the maximum and minimum $\dot{m}_w/\dot{m}_a$ ratio of the wet cooling tower. In practice, to minimize the error prediction, around 5 points are often used. Out of the ANN alternatives, considering both output variables, if less than 70 data points are available, cascade-forward and feedforward alternatives with any configuration are the best option, producing satisfactory results with as low as 10 points. On the other hand, if enough data is available, MIMO RBF should be considered as a strong candidate, but not in the cascade configuration alternative.

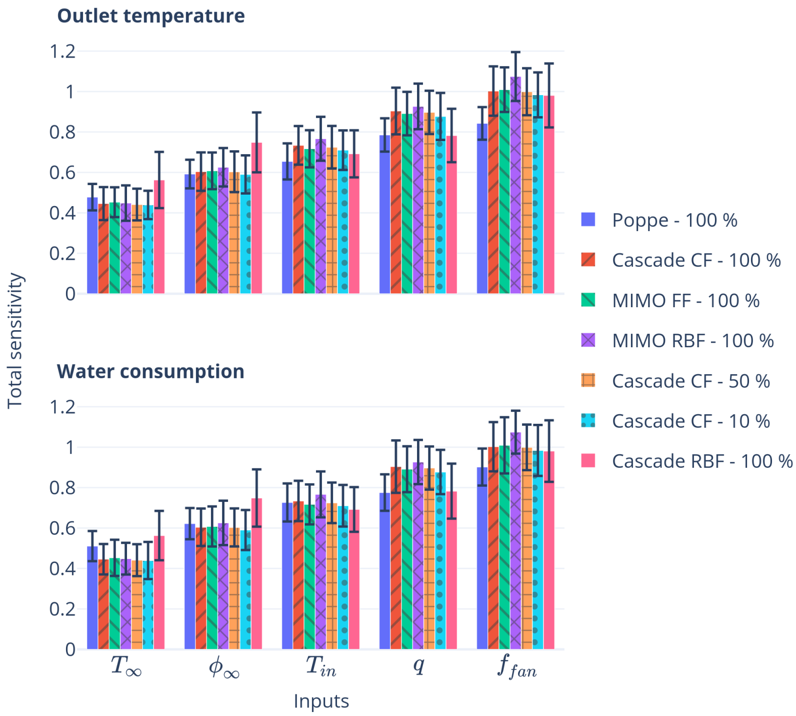


Figure 14.5: Sobol's sensitivity analysis result for different case studies

Sensitivity analysis

In Figure 14.5, only total-order sensitivity indices are represented in the y-axis for the two output variables (outlet temperature on the top and water consumption on the bottom). Its value ranges from 0 to 1, where 0 means the variable has no effect, and 1 means it has a significant effect on the output[3]. The x-axis represents the system's inputs and includes a bar for some of the obtained models with different calibration or training data points.

Comparing the results obtained for the different modelling approaches in Figure 14.5, it can be seen that very homogeneous results are obtained in all cases, except for the Cascade RBF case, which was the worst performing of all the alternatives. These results serve to confirm that, at least from a sensitivity analysis point of view, all valid approaches are similarly sensitive to variations in the same inputs, which is desirable since they are trying to predict the same physical system. In the case of Cascade RBF, a discrepancy can be observed; less relevant input variables (T_{amb} and ϕ_∞) are overestimated and overall higher uncertainties in sensitivity are observed.

It is also important to highlight that the observed results are in agreement with the underlying physics of the heat and mass transfer processes occurring in the exchange area of the tower. The frequency of the fan and the volumetric flow rate are directly related to $\dot{m}_a$ and $\dot{m}_w$, respectively, and they have a high influence on the heat transfer coefficients. These coefficients govern the evaporation processes, which impact the evaporation rate (water lost due evaporation) and the outlet water temperature. On the other hand, the ambient conditions and the inlet water temperature also affect the outputs, but less significantly, since the driving force for the evaporation is the difference between the inlet air enthalpy and the enthalpy of saturated air evaluated at water temperature.

Reminder: How to interpret Sensitivity Analysis (SA) results

The results are different sensitivity indices such as total sensitivity indices (total-order), first-order sensitivity indices (first-order), and interaction sensitivity indices (second-order). First-order measures the direct effect of an input variable on the output, excluding interaction effects with other variables, while the second-order measures specifically these interaction effects. Finally, total-order indices account for the total effect of an input variable, including both direct and interaction effects.[a]

[a] More in Chapter 6 (Sensitivity analysis)

3: values can go slightly above 1 due to computing errors. This is due to the Sobol sequence sample generator producing some unfeasible test samples that need to be discarded

14.1.2 Dry cooler model alternatives comparison and validation

Prediction capabilities

Tabla tocha añadiendo casos (GPR, DD from FP, RF, GB) La tabla debe incluir el tiempo de computación

Experimental data requirements

Sensitivity analysis

14.1.3 Main components modelling conclusions

This section presents a comparison between two modelling alternatives: data-driven and first-principles. It is applied to wet cooling towers and dry coolers when they are integrated into combined cooling systems, with the aim of optimizing this integration. The main conclusions obtained during the investigation and final recommendations can be summarized as follows:

Regarding the prediction of the output variables, in the case of the outlet water temperature, both models reported good results, with low errors falling within the uncertainty range of the experimental equipment. Nonetheless, the physical model performs better than the best ANN alternative (MIMO RBF): $R^2 = 0.98$ and RMSE= 0.33 °C compared to $R^2 = 0.95$ and RMSE= 0.51 °C, respectively.

For the predictions of water consumption, it was shown that the Poppe model accurately predicts this variable, with results of $R^2 = 0.97$ and RMSE= 8.47 l/h. The best ANN alternative (cascade CF) achieves close results with an $R^2 = 0.95$ and RMSE= 11.24 l/h.

However, the Poppe model reached such reliable prediction levels with a much lower number of tests, needing only 2. In comparison, the ANN alternatives need more data, at least 10 (with a good distribution over the operating range) for the FF and CF ANN models.

One of the main strengths of the Poppe model is its ability to predict the operation of the tower regardless of the conditions tested. This model is recommended to be used when it is necessary to scale up to larger systems, as long as the system design remains the same. In the case of the ANN model, it is only applicable to the same conditions and the same tower for which the model was developed.

The ANN model also has several strengths compared to the Poppe model. The most important one is the lower execution time. The ANN model is faster by orders of magnitude, it can be vectorized and its execution time is more constant regardless of the input conditions, in the order of milliseconds. Another advantage is that it can be developed and implemented without knowledge of the physical processes that take place in a wet cooling tower.

That is why in the end it was decided to make use of the best performing data-driven model, the Gaussian-Process Regression (GPR) calibrated using data from the first-principle models, where physical models can be adapted dynamically to the required scale, calibration data generated for the particular case study environment, and finally the data-driven model can be generated. This approach provides a way of having on-demand models that can be adapted to the particular case study, while still being fast and efficient in terms of computational resources.

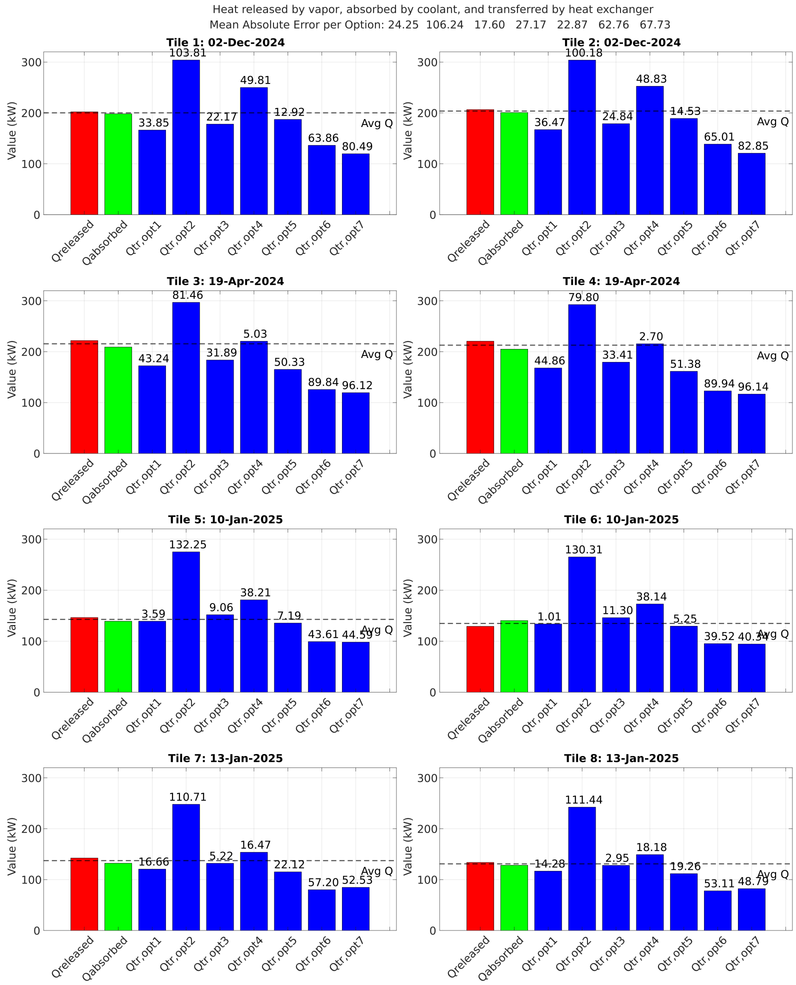


Figure 14.6: Heat transfer coefficient calibration results

14.1.4 Condenser model validation

For the surface condenser[4] a physical model is used, with the heat transfer coefficient as the only parameter to calibrate. Seven different alternative estimations of the heat transfer coefficient were calculated, using the data from the experimental campaign described in Section **??** (**??**). They are as follows:

4: See Section 11.3.2 (Surface condenser)

1. A
2. B
3. C
4. D
5. E
6. F

The results of the calibration are shown in Figure 14.6, where the y-axis shows the thermal power obtained and the x-axis holds different bars for the different heat transfer coefficient estimation methods, with bars also for the experimental heat released by the vapor and absorbed by the coolant. As can be seen in the figure. The shown results are for steady-state conditions with the condenser in an equilibrium state ($Q_{\text{released}} \approx Q_{\text{absorbed}}$), and with a large variation in the condenser conditions (120 to 200 kW, the whole operating range of the condenser). The results show that the heat transfer coefficient obtained with the method 3 is the one that best fits the experimental data, with a MAE of 17.6 kW and a maximum error of 33.41 kW (15%).

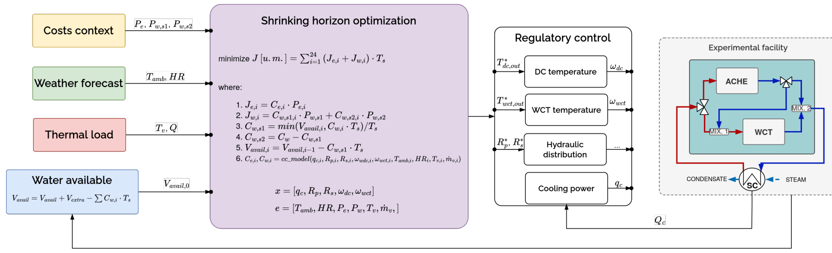


Figure 14.7: Proposed optimization strategy implementation. It is a hierarchical control strategy that combines a high-level optimization strategy with a low-level control strategy. The optimization strategy determines the optimal operation of the system, while the control strategy ensures that the system operates within the defined constraints and achieves the desired performance.

14.1.5 Complete system model validation

14.2 Control and optimization results

See Figure 14.7, for now, just see it, not much more to say about it.

Table 14.2: Box-bounds for the decision variables.

x	Units	lb	ub
q_c	m^3/h	5.22	24.15
R_p	–	0.00	1.00
R_s	–	0.00	1.00
ω_{dc}	%	11.00	99.18
ω_{wct}	%	21.00	93.42

14.2.1 Regular operation

14.2.2 Planned changes in operation

14.2.3 Unanticipated operational changes

15 Annual analysis: CSP and inland-MED

15.1 Environment definition

15.1.1 Water context

- Explicar método seguido para estimar el volumen disponible de agua para cada día - Explicar fuente alternativa. Agua regenerada

15.1.2 Costs context

- Contar cómo se han sacado los datos de REE usando su API mensualmente, y que de ahí se han unido en un dataset continuo. - Explicar el cálculo de la fuente de agua alternativa, cómo es un cálculo a partir del precio de la electricidad aplicando un factor.

15.2 ANDASOL-II CSP plant

Simulation data and parameters information:

Weather data Hourly weather data from Typical Meteorological Year (TPY) of Guadix (Spain) for the year . Data was obtained from ...

Thermal load Hourly thermal load data from the power block of ANDASOL-II CSP plant was generated using a plant model [<empty citation>] fed with the same weather data.

<empty citation>

Electricity price Spanish electricity market from 2022.

Maximum available water The maximum available water for ...

Alternative water source factor

15.2.1 WCT

Anual muestreado cada 15 días. Versión interactiva sin muestrar

15.2.2 DC

15.2.3 CC

Static optimization

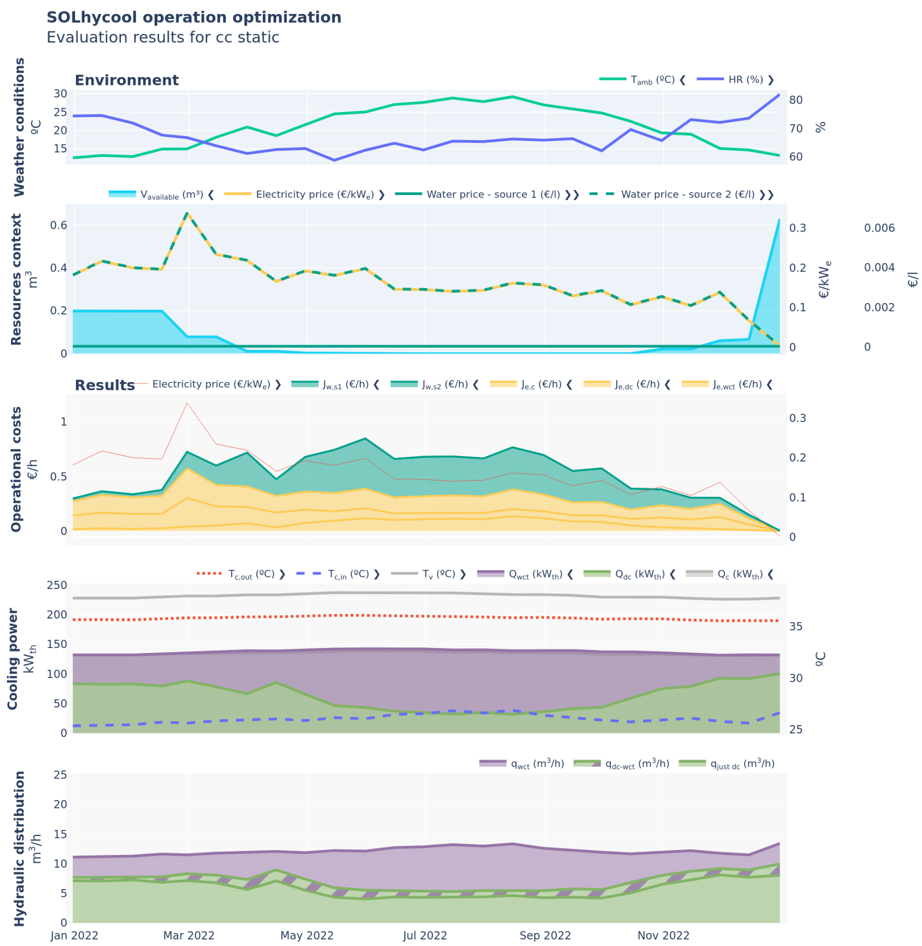


Figure 15.1: Annual simulation results for the CC system optimized with static optimization. Results are resampled every 15 days using their mean values. The original frequency results can be found in the interactive version:

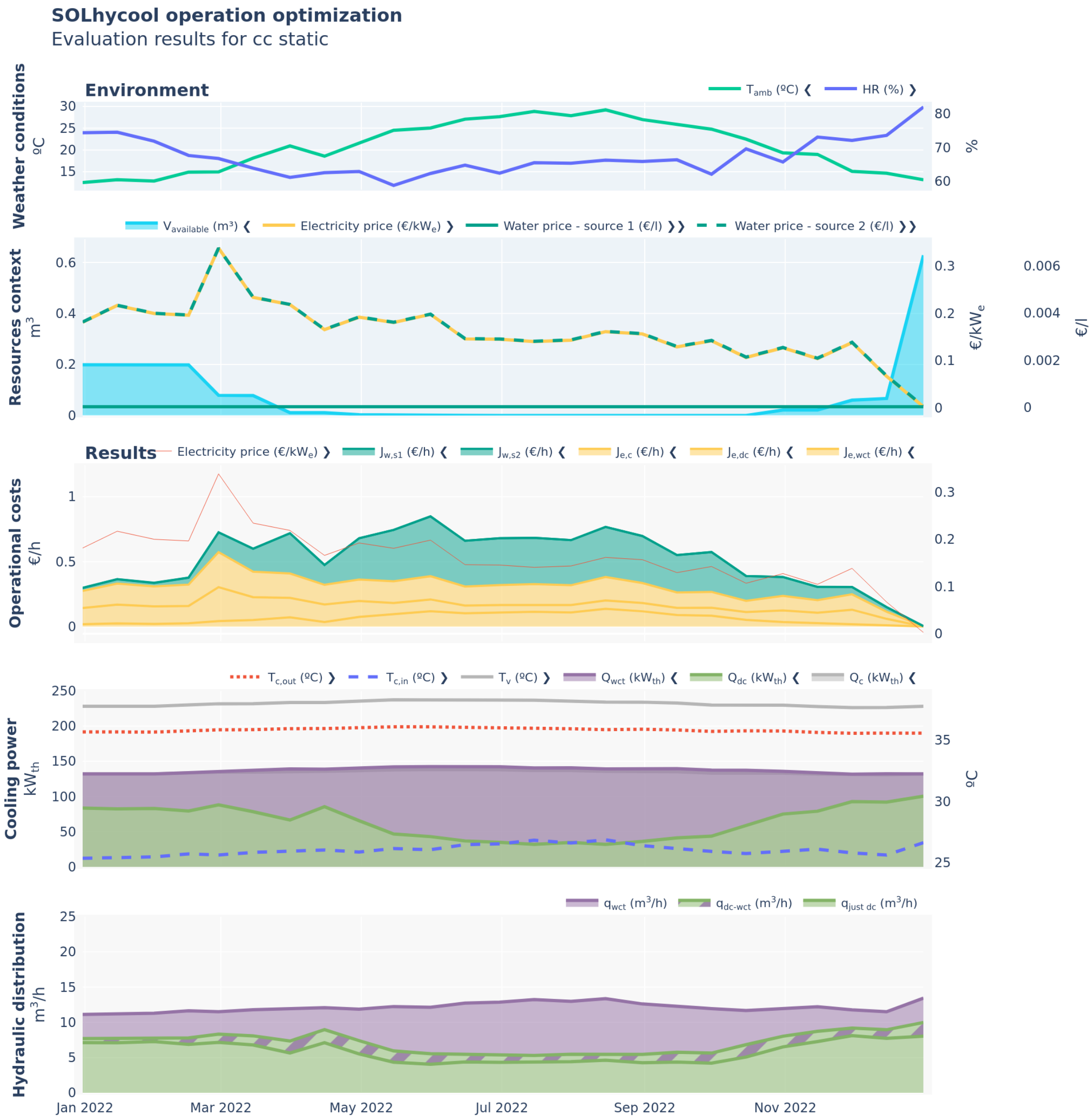
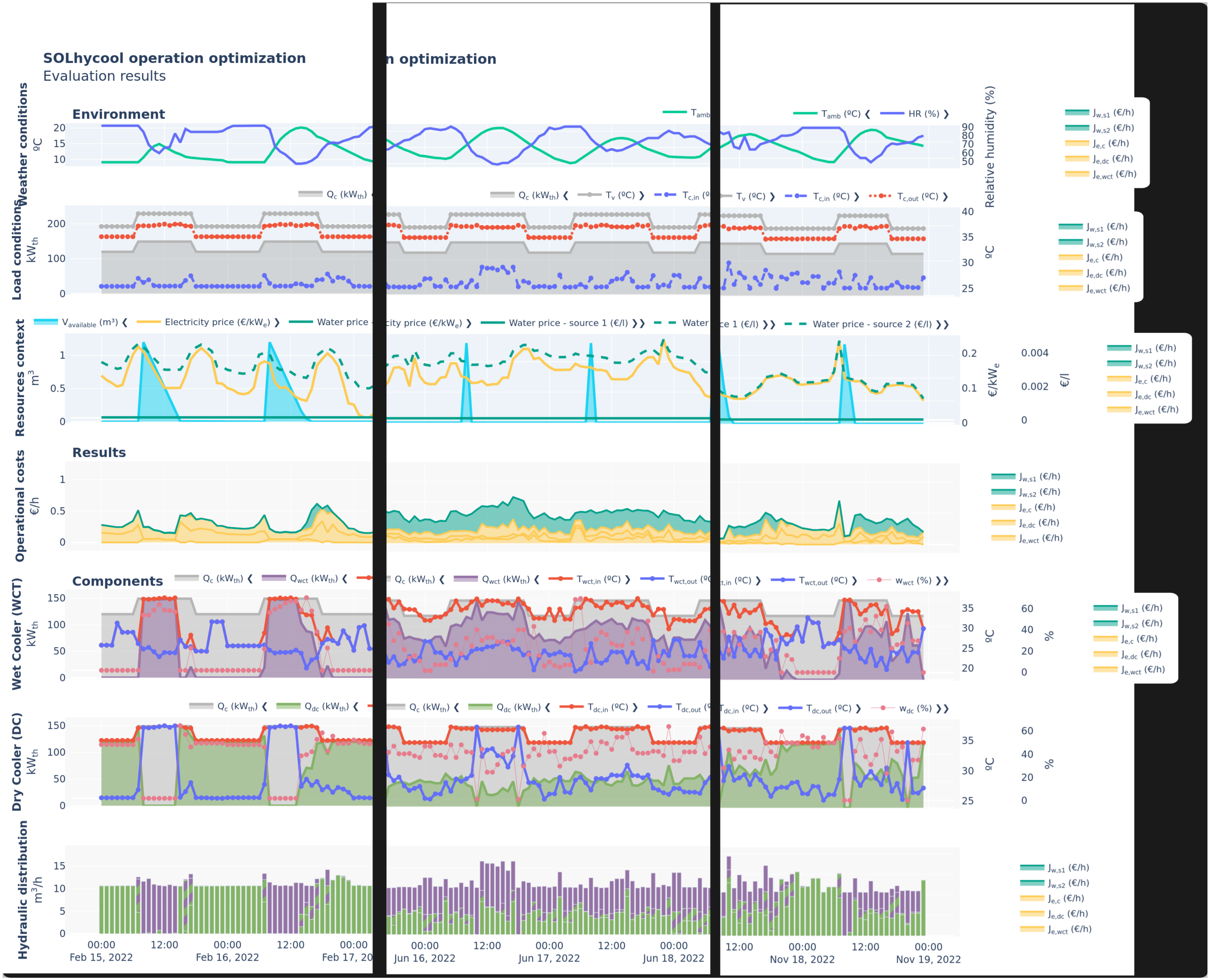
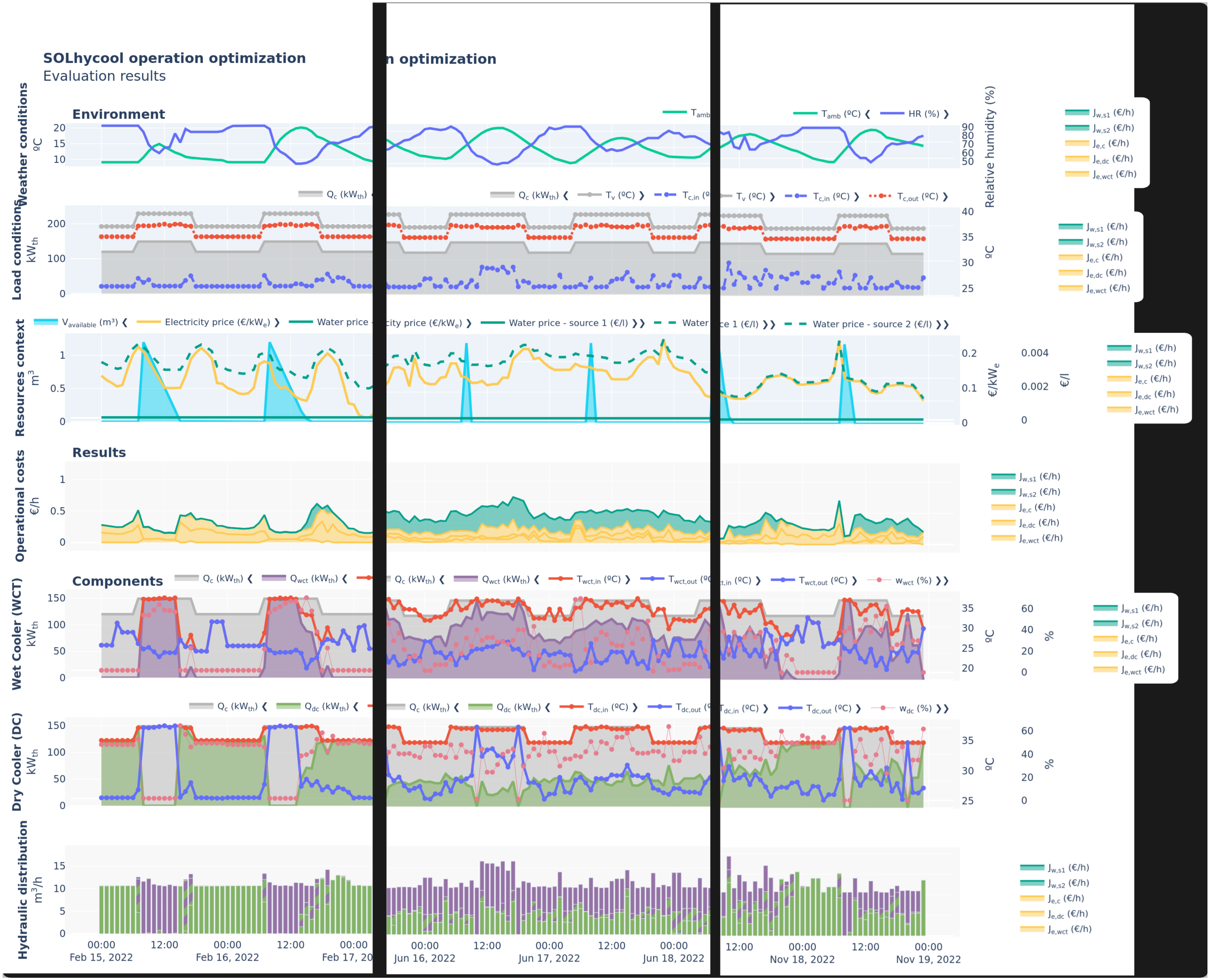


Figure 15.2: Annual simulation results for the CC system optimized with static optimization. Results are resampled every 15 days using their mean values. The original frequency results can be found in the interactive version:


SOLhycool operation optimization
Evaluation results
Environment
Weather conditions
Load conditions
Resources context
Results
Operational costs
Components
Wet Cooler (WCT)
Dry Cooler (DC)
Hydraulic distribution
Feb 15, 2022
Feb 16, 2022
Jun 16, 2022
Jun 17, 2022
Jun 18, 2022
Nov 18, 2022
Nov 19, 2022

Horizon optimization



SOLhycool operation optimization
Evaluation results
Environment
Weather conditions
ºC
Relative humidity (%)
Tamb (ºC)
HR (%)
Load conditions
kWth
Qc (kWth)
Tv (ºC)
Tc,in (ºC)
Tc,out (ºC)
Resources context
m3
Vavailable (m3)
Electricity price (€/kWe)
Water price - source 1 (€/l)
Water price - source 2 (€/l)
€/kWe
€/l
Results
Operational costs
€/h
Jw,s1 (€/h)
Jw,s2 (€/h)
Je,c (€/h)
Je,dc (€/h)
Je,wct (€/h)
Components
Wet Cooler (WCT)
kWth
Qwct (kWth)
Twct,in (ºC)
Twct,out (ºC)
wwct (%)
Dry Cooler (DC)
Qdc (kWth)
Tdc,in (ºC)
Tdc,out (ºC)
wdc (%)
Hydraulic distribution
m3/h
Feb 15, 2022
Feb 16, 2022
Jun 16, 2022
Jun 17, 2022
Jun 18, 2022
Nov 18, 2022
Nov 19, 2022

Comparison

15.3 MED plant

Conclusions and outlook

Conclusions

Outlook

MED

1. Configuraciones alternativas para procesos MED para aplicaciones de concentración de salmueras: geometría variable de efectos fuentes externas en efectos distintos al primero
2. Configuraciones alternativas para el proceso solar MED (almacenamiento con distintos puntos de carga y descarga, MED con distintos puntos de fuente externa, etc. Incluir diagrama de draw.io con las distintas configuraciones)
3. Configuraciones híbridas MED-MSF para aplicaciones de concentración de salmueras

Derived scientific contributions

1. Publicaciones en revista
2. Contribuciones a congreso
3. Coloquios doctorales
4. Colaboraciones en proyectos de investigación
5. Estancias de investigación
6. Repositorios de código
7. Repositorios de datos
8. Herramientas interactivas
9. Contribuciones a librerías de código abierto?

Template content

Introduction 16

16.1 The Main Ideas

Many modern printed textbooks have adopted a layout with prominent margins where small figures, tables, remarks and just about everything else can be displayed. Arguably, this layout helps to organise the discussion by separating the main text from the ancillary material, which at the same time is very close to the point in the text where it is referenced.

This document does not aim to be an apology of wide margins, for there are many better suited authors for this task; the purpose of all these words is just to fill the space so that the reader can see how a book written with the kaobook class looks like. Meanwhile, I shall also try to illustrate the features of the class.

The main ideas behind kaobook come from this blog post, and actually the name of the class is dedicated to the author of the post, Ken Arroyo Ohori, which has kindly allowed me to create a class based on his thesis. Therefore, if you want to know more reasons to prefer a 1.5-column layout for your books, be sure to read his blog post.

Another source of inspiration, as you may have noticed, is the Tufte-Latex Class. The fact that the design is similar is due to the fact that it is very difficult to improve something which is already so good. However, I like to think that this class is more flexible than Tufte-Latex. For instance, I have tried to use only standard packages and to implement as little as possible from scratch;[1] therefore, it should be pretty easy to customise anything, provided that you read the documentation of the package that provides that feature.

1: This also means that understanding and contributing to the class development is made easier. Indeed, many things still need to be improved, so if you are interested, check out the repository on github!

In this book I shall illustrate the main features of the class and provide information about how to use and change things. Let us get started.

16.2 What This Class Does

The kaobook class focuses more about the document structure than about the style. Indeed, it is a well-known LaTeX principle that structure and style should be separated as much as possible (see also Section Section 16.3 on the following page). This means that this class will only provide commands, environments and in general, the opportunity to do things, which the user may or may not use. Actually, some stylistic matters are embedded in the class, but the user is able to customise them with ease.

The main features are the following:

Page Layout The text width is reduced to improve readability and make space for the margins, where any sort of elements can be displayed.

Chapter Headings As opposed to Tufte-Latex, we provide a variety of chapter headings among which to choose; examples will be seen in later chapters.

Page Headers They span the whole page, margins included, and, in twoside mode, display alternatively the chapter and the section name.[2]

2: This is another departure from Tufte's design.

Matters The commands \frontmatter, \mainmatter and \backmatter have been redefined in order to have automatically wide margins in the main matter, and narrow margins in the front and back matters. However, the page style can be changed at any moment, even in the middle of the document.

Margin text We provide commands \sidenote and \marginnote to put text in the margins.[3]

Margin figs/tabs A couple of useful environments is marginfigure and margintable, which, not surprisingly, allow you to put figures and tables in the margins (*cfr.* Figure 16.1).

Margin toc Finally, since we have wide margins, why don't add a little table of contents in them? See \margintoc for that.

Hyperref hyperref is loaded and by default we try to add bookmarks in a sensible way; in particular, the bookmarks levels are automatically reset at \appendix and \backmatter. Moreover, we also provide a small package to ease the hyperreferencing of other parts of the text.

Bibliography We want the reader to be able to know what has been cited without having to go to the end of the document every time, so citations go in the margins as well as at the end, as in Tufte-Latex. Unlike that class, however, you are free to customise the citations as you wish.

Figure 16.1: The Mona Lisa.
https://commons.wikimedia.org/wiki/File:Mona_Lisa,_by_Leonardo_da_Vinci,_from_C2RMF_retouched.jpg

The order of the title pages, table of contents and preface can be easily changed, as in any LaTeX document. In addition, the class is based on KOMA-Script's scrbook, therefore it inherits all the goodies of that.

16.3 What This Class Does Not Do

As anticipated, further customisation of the book is left to the user. Indeed, every book may have sidenotes, margin figures and so on, but each book will have its own fonts, toc style, special environments and so on. For this reason, in addition to the class, we provide only sensible defaults, but if these features are not needed, they can be left out. These special packages are located in the style directory, which is organised as follows:

kao.sty This package contains the most important definitions of macros and specifications of page layout. It is the heart of the kaobook. Special features include: most commonly used LaTeX packages are already loaded; there is some flexibility to change the default layout; some fancy environments (with coloured boxes around them, floating, and/or with a counter) are predefined.

kaobiblio.sty Where commands to print citations in the margins are defined.[4] It is the kao- analog of biblatex.

4: See Chapter 20.

kaorefs.sty It contains some useful commands to manage labeling and referencing, again to ensure that the same elements are referenced always in a consistent way.

kaotheorems.sty For the style of mathematical environments, which can be optionally wrapped in a colourful mdframed environment, like in this document, or not.

The audacious users might feel tempted to edit some of these packages. I'd be immensely happy if they sent me examples of what they have been able to do!

In the rest of the book, I shall assume that the reader is not a novice in the use of LaTeX, and refer to the documentation of the packages used in this class for things that are already explained there. Moreover, I assume that the reader is willing to make minor edits to the provided packages for styles, environments and commands, if he or she does not like the default settings.

16.4 How to Use This Class

Either if you are using the template from latextemplates, or if you cloned the GitHub repository, there are infinite ways to use the `kaobook` class in practice, but we will discuss only two of them. The first is to find the `main.tex` file which I used to write this book, and edit it; this will probably involve a lot of text-deleting, copying-and-pasting, and rewriting. The second way is to start almost from scratch and use the `./examples/minimal_book/main.tex` file, which is a cleaned-up version of the `./examples/documentation/main.tex`; even if you choose the second way, you may find it useful to draw inspiration from the `./examples/documentation/main.tex` file.

To compile the document, assuming that its name is `main.tex`, you will have to run the following sequence of commands:

```
pdflatex main # Compile template
makeindex main.nlo -s nomencl.ist -o main.nls # Compile nomenclature
makeindex main # Compile index
biber main # Compile bibliography
makeglossaries main # Compile glossary
pdflatex main # Compile template again
pdflatex main # Compile template again
```

You may need to compile the template some more times in order for some errors to disappear. For any support requests, please ask a question on `tex.stackexchange.org` with the tag “kaobook”, open an issue on GitHub, or contact the author via e-mail.

Class Options, Commands and Environments

Class Options 17

In this chapter I will describe the most common options used, both the ones inherited from `scrbook` and the `kao`-specific ones. Options passed to the class modifies its default behaviour; beware though that some options may lead to unexpected results...

17.1 **KOMA** Options

The `kaobook` class is based on `scrbook`, therefore it understands all of the options you would normally pass to that class. If you have a lot of patience, you can read the KOMA-Script guide.[1] Actually, the reading of such guide is suggested as it is very instructive.

Every KOMA-Script option you pass to the class when you load it is automatically activated. In addition, in `kaobook` some options have modified default values. For instance, the font size is 9.5pt and the paragraphs are separated by space,[2] not marked by indentation.

1: The guide can be downloaded from `https://ctan.org/pkg/koma-script?lang=en`.

2: To be precise, they are separated by half a line worth of space: the `parskip` value is "half".

17.2 **kao** Options

In the future I plan to add more options to set the paragraph formatting (justified or ragged) and the position of the margins (inner or outer in twoside mode, left or right in oneside mode).[3]

3: As of now, paragraphs are justified, formatted with `\singlespacing` (from the `setspace` package) and `\frenchspacing`.

I take this opportunity to renew the call for help: everyone is encouraged to add features or reimplement existing ones, and to send me the results. You can find the GitHub repository at `https://github.com/fmarotta/kaobook`.

To Do

Implement the `justified` and `margin` options. To be consistent with the KOMA-Script style, they should accept a simple switch as a parameter, where the simple switch should be `true` or `false`, or one of the other standard values for simple switches supported by KOMA-Script. See the KOMA-Script documentation for further information.

The above box is an example of a `kaobox`, which will be discussed more thoroughly in Chapter 22 (Mathematics and Boxes) on page 101. Throughout the book I shall use these boxes to remarks what still needs to be done.

17.3 Other Things Worth Knowing

A bunch of packages are already loaded in the class because they are needed for the implementation. These include:

- etoolbox
- calc
- xifthen
- xkeyval
- xparse

- xstring

Many more packages are loaded, but they will be discussed in due time. Here, we will mention only one more set of packages, needed to change the paragraph formatting (recall that in the future there will be options to change this). In particular, the packages we load are:

- ragged2e
- setspace
- hyphenat
- microtype
- needspace
- xspace
- xcolor (with options `usenames,dvipsnames`)

Some of the above packages do not concern paragraph formatting, but we nevertheless grouped them with the others. By default, the main text is justified and formatted with singlespacing and frenchspacing; the margin text is the same, except that the font is a bit smaller.

As a last warning, please be aware that the `cleveref` package is not compatible with `kaobook`. You should use the commands discussed in Section 20.3 instead.

17.4 Document Structure

We provide optional arguments to the `\title` and `\author` commands so that you can insert short, plain text versions of this fields, which can be used, typically in the half-title or somewhere else in the front matter, through the commands `\@plaintitle` and `\@plainauthor`, respectively. The PDF properties `pdftitle` and `pdfauthor` are automatically set by hyperref to the plain values if present, otherwise to the normal values.[4]

There are defined two page layouts, `margin` and `wide`, and two page styles, `plain` and `fancy`. The layout basically concern the width of the margins, while the style refers to headers and footer; these issues will be discussed in Chapter 21 (Page Design) on page 95.[5]

The commands `\frontmatter`, `\mainmatter`, and `\backmatter` have been redefined in order to automatically change page layout and style for these sections of the book. The front matter uses the `margin` layout and the `plain` page style. In the mainmatter the margins are wide and the headings are fancy. In the appendix the style and the layout do not change; however we use `\bookmarksetup{startatroot}` so that the bookmarks of the chapters are on the root level (without this, they would be under the preceding part). In the backmatter the margins shrink again and we also reset the bookmarks root.

4: We think that this is an important point so we remark it here. If you compile the document with pdflatex, the PDF metadata will be altered so that they match the plain title and author you have specified; if you did not specify them, the metadata will be set to the normal title and author.

5: For now, suffice it to say that pages with the `margin` layout have wide margins, while with the `wide` layout the margins are absent. In `plain` pages the headers and footer are suppressed, while in `fancy` pages there is a header.

18 Margin Stuff

Sidenotes are a distinctive feature of all 1.5-column-layout books. Indeed, having wide margins means that some material can be displayed there. We use margins for all kind of stuff: sidenotes, marginnotes, small tables of contents, citations, and, why not?, special boxes and environments.

18.1 Sidenotes

Sidenotes are like footnotes, except that they go in the margin, where they are more readable. To insert a sidenote, just use the command `\sidenote{Text of the note}`. You can specify a mark[O] with `\sidenote[mark]{Text}`, but you can also specify an offset, which moves the sidenote upwards or downwards, so that the full syntax is:

O: This sidenote has a special mark, a big O!

```
\sidenote[mark][offset]{Text}
```

If you use an offset, you always have to add the brackets for the mark, but they can be empty.[1]

1: If you want to know more about the usage of the `\sidenote` command, read the documentation of the `sidenotes` package.

In `kaobook` we copied a feature from the `snotez` package: the possibility to specify a multiple of `\baselineskip` as an offset. For example, if you want to enter a sidenote with the normal mark and move it upwards one line, type:

```
\sidenote[][*-1]{Text of the sidenote.}
```

As we said, sidenotes are handled through the `sidenotes` package, which in turn relies on the `marginnote` package.

18.2 Marginnotes

This command is very similar to the previous one. You can create a marginnote with `\marginnote[offset]{Text}`, where the offset argument can be left out, or it can be a multiple of `\baselineskip`, *e. g.*

```
\marginnote[-12pt]{Text} or \marginnote[*-3]{Text}
```

While the command for margin notes comes from the `marginnote` package, it has been redefined in order to change the position of the optional offset argument, which now precedes the text of the note, whereas in the original version it was at the end. We have also added the possibility to use a multiple of `\baselineskip` as offset. These things were made only to make everything more consistent, so that you have to remember less things!

To Do

A small thing that needs to be done is to renew the `\sidenote` command so that it takes only one optional argument, the offset. The special mark argument can go somewhere else. In other words, we want the syntax of `\sidenote` to resemble that of `\marginnote`.

We load the packages `marginnote`, `marginfix` and `placeins`. Since `sidenotes` uses `marginnote`, what we said for marginnotes is also valid for sidenotes. Side- and margin- notes are shifted slightly upwards (`\renewcommand{\marginnotevadjust}{3pt}`) in order to align them to the bottom of the line of text where the note is issued. Importantly, both sidenotes and marginnotes are defined as floating if the optional argument (*i. e.* the vertical offset) is left blank, but if the offset is specified they are not floating. Recall that floats cannot be nested, so in some rare cases you may encounter errors about lost floats; in those cases, remember that sidenotes and marginnotes are floats. To solve the problem, it may be possible to transform them into non-floating elements by specifying an offset of 0pt.

18.3 Footnotes

Even though they are not displayed in the margin, we will discuss about footnotes here, since sidenotes are mainly intended to be a replacement of them. Footnotes force the reader to constantly move from one area of the page to the other. Arguably, marginnotes solve this issue, so you should not use footnotes. Nevertheless, for completeness, we have left the standard command `\footnote`, just in case you want to put a footnote once in a while.*

18.4 Margintoc

Since we are talking about margins, we introduce here the `\margintoc` command, which allows one to put small table of contents in the margin. Like other commands we have discussed, `\margintoc` accepts a parameter for the vertical offset, like so: `\margintoc[offset]`.

The command can be used in any point of the document, but we think it makes sense to use it just at the beginning of chapters or parts. In this document I make use of a KOMA-Script feature and put it in the chapter preamble, with the following code:

The font used in the margintoc is the same as the one for the chapter entries in the main table of contents at the beginning of the document.

```
\setchapterpreamble[u]{\margintoc}
\chapter{Chapter title}
```

As the space in the margin is a valuable resource, there is the possibility to print a shorter version of the title in the margin toc. Thus, there are in total three possible versions for the title of a section (or subsection): the one for the main text, the one for the main table of contents, and the one for the margintoc. These versions can be specified at the same time when the section is created in the source TEXfile:

```
\section[alternative-title-for-toc]{title-as-written-in-text}[
    alternative-title-for-margintoc]
```

By default, the margintoc includes sections and subsections. If you only want to show sections, add

```
\setcounter{margintocdepth}{\sectiontocdepth}
```

somewhere in your preamble.

18.5 Marginlisting

On some occasions it may happen that you have a very short piece of code that doesn't look good in the body of the text because it breaks the flow of narration: for that occasions, you can use a `marginlisting`. The support for this feature is still limited, especially for the captions, but you can try the following code:

Listing 18.1: An example of a margin listing.

```
print("Hello World!")
```

```
\begin{marginlisting}
 \caption{My caption}
 \begin{lstlisting}[language=Python,style=kaolstplain]
 ... code ...
 \end{lstlisting}
\end{marginlisting}
```

* And this is how they look like. Notice that in the PDF file there is a back reference to the text; pretty cool, uh?

Since we are here, let me spend a few words about listsings. Thanks to contributions from Kazuhiko Sakaguchi, kaobook now supports both `listings` and `minted`. Just pass the option `listing=listings` or `listing=minted` when you load the `kaobook` class, and the appropriate pacakge will be loaded.

Not only textual stuff can be displayed in the margin, but also figures. Those will be the focus of the next chapter.

19 Figures and Tables

19.1 Normal Figures and Tables

Figures and tables can be inserted just like in any standard LaTeX document. The `graphicx` package is already loaded and configured in such a way that the figure width is equal to the textwidth and the height is adjusted in order to maintain the original aspect ratio. As you may have imagined, the captions will be positioned...well, in the margins. This is achieved with the help of the `floatrow` package.

Here is a picture of Mona Lisa (Figure 19.1), as an example. The captions are formatted as the margin- and the side-notes; If you want to change something about captions you can use the command `\captsetup` from the `caption` package. Remember that if you want to reference a figure, the label must come *after* the caption!

While the format of the caption is managed by `caption`, its position is handled by the `floatrow` package. Achieving this result has been quite hard, but now I am pretty satisfied. In two-side mode, the captions are printed in the correct margin.

Tables can be inserted just as easily as figures, as exemplified by the following code:

Listing 19.1: Caption of a listing.

```
\begin{table}
\begin{tabular}{ c c c c }
    \toprule
    col1 & col2 & col3 & col 4 \\
    \midrule
    \multirow{3}{4em}{Multiple row} & cell2 & cell3 & cell4\\ &
    cell5 & cell6 & cell7 \\ &
    cell8 & cell9 & cell10 \\
    \multirow{3}{4em}{Multiple row} & cell2 & cell3 & cell4 \\ &
    cell5 & cell6 & cell7 \\ &
    cell8 & cell9 & cell10 \\
    \bottomrule
```

The credits for the image above the chapter title go to: Bushra Feroz, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=68724647

```
\end{tabular}
\end{table}
```

which results in the useless Table Table 19.1.

Table 19.1: A useless table.

col1	col2	col3	col 4
Multiple row	cell2	cell3	cell4
	cell5	cell6	cell7
	cell8	cell9	cell10
Multiple row	cell2	cell3	cell4
	cell5	cell6	cell7
	cell8	cell9	cell10

I don't have much else to say, so I will just insert some blind text. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Figure 19.1: It's Mona Lisa again. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

19.2 Margin Figures and Tables

Marginfigures can be inserted with the environment `marginfigure`. In this case, the whole picture is confined to the margin and the caption is below it. Figure 16.1 is obtained with something like this:

Listing 19.2: Another caption.

```
\begin{marginfigure}
    \includegraphics{monalisa}
    \caption[The Mona Lisa]{The Mona Lisa.}
    \labfig{marginmonalisa}
\end{marginfigure}
```

There is also the `margintable` environment, of which Table 19.2 is an example. Notice how you can place the caption above the table by just placing the `\caption` command before beginning the `tabular` environment. Usually, figure captions are below, while table captions are above. This rule is also respected for normal figures and tables: the captions are always on the side, but for figure they are aligned to the bottom, while for tables to the top.

Table 19.2: Another useless table.

col1	col2	col3
Multiple row	cell2	cell3
	cell5	cell6
	cell8	cell9

Marginfigures and tables can be positioned with an optional offset command, like so:

```
\begin{marginfigure}[offset]
    \includegraphics{seaside}
\end{marginfigure}
```

Improve this part.

Offset ca be either a measure or a multiple of `\baselineskip`, much like with `\sidenote`, `\marginnote` and `\margintoc`. If you are wondering how I inserted this orange bubble, have a look at the `todo` package.

19.3 Wide Figures and Tables

With the environments `figure*` and `table*` you can insert figures which span the whole page width. For example, here are a wide figure and a wide table.

Figure 19.2: A wide seaside, and a wide caption. Credits: By Bushra Feroz, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=68724647

Table 19.3: A wide table with invented data about three people living in the UK. Note that wide figures and tables are centered and their caption also extends into the margin.

Name	Surname	Job	Salary	Age	Height	Country
Alice	Red	Writer	4.000 £	34	167 cm	England
Bob	White	Bartender	2.000 £	24	180 cm	Scotland
Drake	Green	Scientist	4.000 £	26	175 cm	Wales

It is the user's responsibility to adjust the width of the table, if necessary, until it is aesthetically pleasing. The previous table was obtained with the following code:

Listing 19.3: How to typeset a wide table

```
\begin{table*}[h!]
    \caption{A wide table with invented data about three people
    living in the UK. Note that wide figures and tables are
    centered and their caption also extends into the margin.}
    \begin{tabular}{p{2.0cm} p{2.0cm} p{2.0cm} p{2.0cm} p{2.0cm}
    p{2.0cm} p{1.5cm}}
        \toprule
        Name    & Surname   & Job       & Salary           & Age
      & Height    & Country \\
        \midrule
        Alice   & Red       & Writer    & 4.000 \pounds    & 34
      & 167 cm     & England \\
        Bob     & White     & Bartender & 2.000 \pounds    & 24
      & 180 cm     & Scotland \\
        Drake   & Green     & Scientist & 4.000 \pounds    & 26
      & 175 cm     & Wales \\
        \bottomrule
    \end{tabular}
\end{table*}
```

The `floatrow` package provides the "H" specifier to instruct LaTeXto position the figure (or table) in precisely the same position it occupies in the source code. However, this specifier does not work with wide figures or tables: you should use "h!" instead, like so: `\begin{figure*}[h!]`.

You may have noticed the full width image at the very beginning of this chapter: that, however, is set up in an entirely different way, which you'll read about in Chapter 21 on page 95.

kaobook also supports paginated tables (have a look at the `longtable` package). The `longtable`[1] environment behaves a bit differently from `table`, in that `longtable` encompasses both `table` and `tabular`, so that you can write, *e.g.*,

1: Interestingly, `longtable`s may require up to four rounds of compilation before they are typeset correctly.

Listing 19.4: Example of a longtable

```
\begin{longtable}{|l c c|}
    \hline
    One & Two & Three \\
    Left & Center & Center \\
    \hline
    \caption{Caption of the longtable.}
\end{longtable}
```

to obtain the following table:

One	Two	Three
Left	Center	Center

Table 19.4: Caption of the longtable.

The caption of a `longtable` is always positioned below the table, and it has the same width as the text (it doesn't extend into the margin). However, sometimes you may need a `longtable` that is so wide that it trespass into the margins; in those cases, you may want to also increase the width of the caption. To do so, you'll have to write two additional commands, one before and one after the `longtable`:

Listing 19.5: Increasing the width of the caption of a `longtable`.

```
\floatsetup[longtable]{margins=centering,LTcapwidth=table} % Add
    this line before the longtable to increase the caption width
\begin{longtable}{lp{8cm}p{5cm}p{2cm}}
...
\end{longtable}
\floatsetup[longtable]{margins=raggedright,LTcapwidth=\textwidth}
     % Add this line after the longtable to revert the previous
    change
```

Having seen figures and tables, it is now time to tackle hyperreferences.

References 20

20.1 Citations

To cite someone [Visscher2008, James2013] is very simple: just use the \sidecite command. It does not have an offset argument yet, but it probably will in the future. This command supports multiple entries, as you can see, and by default it prints the reference on the margin as well as adding it to the bibliography at the end of the document. Note that the citations have nothing to do with the text,[James2013] but they are completely random as they only serve the purpose to illustrate the feature.

Visscher2008, James2013

James2013

For this setup I wrote a separate package, kaobiblio, which you can find in the styles directory and include in your main tex file. This package accepts all the options that you can pass to biblatex, and actually it passes them to biblatex under the hood. Moreover, it also defines some commands, like \sidecite, and environments that can be used within a kao book.[1]

1: For this reason you should always use kaobiblio instead of biblatex, but the syntax and the options are exactly the same.

If you want to use bibtex instead of biblatex, pass the option backend=bibtex to kaobiblio. kaobiblio also supports two options that are not shared with biblatex: addspace and linkeverything, both of which are boolean options, meaning that they can take either "true" or "false" as a value. If you pass addspace=true when loading kaobiblio, a space will be automatically added before the citation marks. If you pass linkeverything=true, the author's name in the authoryear-* and authortitle-* styles will be a hyperlink like the year.[2]

2: The fact that the author name is not a hyperlink bothers more than one biblatex user. There are strong arguments *against* hyperlinking the author name, but in my personal opinion, linking the author's name does not result in any problems in most practical cases.

As you have seen, the \sidecite command will print a citation in the margin. However, this command would be useless without a way to customise the format of the citation, so the kaobook provides also the \formatmargincitation command. By "renewing" that command, you can choose which items will be printed in the margins. The best way to understand how it works is to see the actual definition of this command.

```
\newcommand{\formatmargincitation}[1]{%
    \parencite{#1}: \citeauthor*{#1} (\citeyear{#1}), \citetitle{#1}%
}
```

Thus, the \formatmargincitation accepts one parameter, which is the citation key, and prints the parencite followed by a colon, then the author, then the year (in brackets), and finally the title.[Battle2014] Now, suppose that you wish the margin citation to display the year and the author, followed by the title, and finally a fixed arbitrary string; you would add to your document:

Battle2014

```
\renewcommand{\formatmargincitation}[1]{%
    \citeyear{#1}, \citeauthor*{#1}: \citetitle{#1}; very interesting!%
}
```

The above code results in citations that look like the following.[Zou2005] Of course, changing the format is most useful when you also change the default bibliography style. For instance, if you want to use the "philosophy-modern" style for your bibliography, you might have something like this in the preamble:

Zou2005

```
\usepackage[style=philosophy-modern]{styles/kaobiblio}
\renewcommand{\formatmargincitation}[1]{%
    \sdcite{#1}%
}
\addbibresource{main.bib}
```

The commands like `\citeyear`, `\parencite` and `\sdcite` are just examples. A full reference of the available commands can be found in this cheatsheet, under the “Citations” section.

Finally, to compile a document containing citations, you need to use an external tool, which for this class is biber. You need to run the following (assuming that your tex file is called main.tex):

```
$ pdflatex main
$ biber main
$ pdflatex main
```

20.2 Glossaries and Indices

The `kaobook` class loads the packages `glossaries` and `imakeidx`, with which you can add glossaries and indices to your book. For instance, I previously defined some glossary entries and now I am going to use them, like this: computer. `glossaries` also allows you to use acronyms, like the following: this is the full version, Frame per Second (FPS), and this is the short one FPS. These entries will appear in the glossary in the backmatter.

Unless you use Overleaf or some other fancy IDE for LaTeX, you need to run an external command from your terminal in order to compile a document with a glossary. In particular, the commands required are:[3]

3: These are the commands you would run in a UNIX system, but see also Section 20.4 (A Final Note on Compilation); I have no idea about how it works in Windows.

```
$ pdflatex main
$ makeglossaries main
$ pdflatex main
```

Note that you need not run `makeglossaries` every time you compile your document, but only when you change the glossary entries.

To create an index, you need to insert the command `\index{subject}` whenever you are talking about “subject” in the text. For instance, at the start of this paragraph I would write `index{index}`, and an entry would be added to the Index in the backmatter. Check it out!

In theory, you would need to run an external command for the index as well, but luckily the package we suggested, `imakeidx`, can compile the index automatically.

A nomenclature is just a special kind of index; you can find one at the end of this book. To insert a nomenclature, we use the package `nomencl` and add the terms with the command `\nomenclature`. We put then a `\printnomenclature` where we want it to appear.

Also with this package we need to run an external command to compile the document, otherwise the nomenclature will not appear:

```
$ pdflatex main
$ makeindex main.nlo -s nomencl.ist -o main.nls
$ pdflatex main
```

These packages are all loaded in packages.sty, one of the files that come with this class. However, the configuration of the elements is best done in the main.tex file, since each book will have different entries and styles.

This brief section was by no means a complete reference on the subject, therefore you should consult the documentation of the above package to gain a full understanding of how they work.

Note that the `nomencl` package caused problems when the document was compiled, so, to make a long story short, I had to prevent `scrhack` to load the hack-file for `nomencl`. When compiling the document on Overleaf, however, this problem seem to vanish.

20.3 Hyperreferences

Together with this class we provide a handy package to help you referencing the same elements always in the same way, for consistency across the book. First, you can label each element with a specific command. For instance, should you want to label a chapter, you would put `\labch{chapter-title}` right after the `\chapter` directive. This is just a convenience, because `\labch` is actually just an alias to `\label{ch:chapter-title}`, so it spares you the writing of "ch:". We defined similar commands for many typically labeled elements, including:

- Page: `\labpage`
- Part: `\labpart`
- Chapter: `\labch`
- Section: `\labsec`
- Figure: `\labfig`
- Table: `\labtab`
- Definition: `\labdef`
- Assumption: `\labassum`
- Theorem: `\labthm`
- Proposition: `\labprop`
- Lemma: `\lablemma`
- Remark: `\labremark`
- Example: `\labexample`
- Exercise: `\labexercise`

Of course, we have similar commands for referencing those elements. However, since the style of the reference should depend on the context, we provide different commands to reference the same thing. For instance, in some occasions you may want to reference the chapter by name, but other times you want to reference it only by number. In general, there are four reference style, which we call plain, vario, name, and full.

The plain style references only by number. It is accessed, for chapters, with `\refch{chapter-title}` (for other elements, the syntax is analogous). Such a reference results in: Chapter 20.

The vario and name styles rest upon the `varioref` package. Their syntax is `\vrefch{chapter-title}` and `\nrefch{chapter-title}`, and they result in: Chapter 20 on page 89, for the vario style, and: Chapter 20 (References), for the name style. As you can see, the page is referenced in `varioref` style.

The full style references everything. You can use it with `\frefch{chapter-title}` and it looks like this: Chapter 20 (References) on page 89.

Of course, all the other elements have similar commands (*e.g.* for parts you would use `\vrefpart{part-title}` or something like that). However, not all elements implement all the four styles. The commands provided should be enough, but if you want to see what is available or to add the missing ones, have a look at the attached package.

In order to have access to all these features, the `kaorefs` should be loaded in the preamble of your document. It should be loaded last, or at least after `babel` (or `polyglossia`) and `plaintheorems` (or `mdftheorems`). Options can be passed to it like to any other package; in particular, it is possible to specify the language of the captions. For instance, if you specify "italian" as an option, instead of "Chapter" it will be printed "Capitolo", the Italian analog. If you know other languages, you are welcome to contribute the translations of these captions! Feel free to contact the author of the class for further details.

The `kaorefs` package also include `cleveref`, so it is possible to use `\cref` in addition to all the previously described referencing commands.

20.4 A Final Note on Compilation

Probably the easiest way to compile a latex document is with the `latexmk` script, as it can take care of everything, if properly configured, from the bibliography to the glossary. The command to issue, in general, is:

```
latexmk [latexmk_options] [filename ...]
```

`latexmk` can be extensively configured (see https://mg.readthedocs.io/latexmk.html). For convenience, I print here an example configuration that would cover all the steps described above.

```
# By default compile only the file called 'main.tex'
@default_files = ('main.tex');

# Compile the glossary and acronyms list (package 'glossaries')
add_cus_dep( 'acn', 'acr', 0, 'makeglossaries' );
add_cus_dep( 'glo', 'gls', 0, 'makeglossaries' );
$clean_ext .= " acr acn alg glo gls glg";
sub makeglossaries {
   my ($base_name, $path) = fileparse( $_[0] );
   pushd $path;
   my $return = system "makeglossaries", $base_name;
   popd;
   return $return;
}

# Compile the nomenclature (package 'nomencl')
add_cus_dep( 'nlo', 'nls', 0, 'makenlo2nls' );
sub makenlo2nls {
    system( "makeindex -s nomencl.ist -o \"$_[0].nls\" \"$_[0].
    nlo\"" );
}
```

However, if you'd rather not use an external package and want to do everything manually, here are some tips.[4]

4: As the author only uses Linux and compiles everything from the command line, he doesn't know how the compilation works in Windows or Mac. The tips, therefore, refer to the usage with Linux from the command line.

Compiling the examples in the kaobook repository

To compile the examples, and in particular the documentation, that are in the `examples` directory of the kaobook repository on GitHub, do as follows. **cd** into the root directory of the repository, and run `pdflatex -output-directory examples/documentation main.tex`. With this trick, you can compile the documentation using the class files pertaining to the repository (and not, say, those in your texmf tree). The "-output-directory" option works with the other LaTeX-related commands such as biber and makeglossaries.

A note of warning: sometimes LaTeX needs more than one run to get the correct position of each element; this is true in particular for the positioning of floating elements like figures, tables, and margin notes. Occasionally, LaTeX can need up to four re-runs, so If the alignment of margin elements looks odd, or if they bleed into the main text, try running pdflatex one more time.

Design and Additional Features

21 Page Design

21.1 Headings

So far, in this document I used two different styles for the chapter headings: one has the chapter name, a rule and, in the margin, the chapter number; the other has an image at the top of the page, and the chapter title is printed in a box (like for this chapter). There is one additional style, which I used only in the Chapter **??** (**??**); there, the chapter title is enclosed in two horizontal rules, and the chapter number (or letter, in the case of the appendix) is above it.[1]

1: To be honest, I do not think that mixing heading styles like this is a wise choice, but in this document I did it only to show you how they look.

Every book is unique, so it makes sense to have different styles from which to choose. Actually, it would be awesome if whenever a `kao`-user designs a new heading style, he or she added it to the three styles already present, so that it will be available for new users and new books.

The choice of the style is made simple by the `\setchapterstyle` command. It accepts one option, the name of the style, which can be: “plain”, “kao”, “bar”, or “lines”.[2] If instead you want the image style, you have to use the command `\setchapterimage`, which accepts the path to the image as argument; you can also provide an optional parameter in square brackets to specify the height of the image. `\setchapterimage` automatically sets the chapter style to “bar” for that chapter (and also for subsequent chapters).

2: Plain is the default LaTeX title style; the other ones are self explanatory.

Let us make some examples. In this book, I begin a normal chapter with the lines:

```
1 \setchapterstyle{kao}
2 \setchapterpreamble[u]{\margintoc}
3 \chapter{Title of the Chapter}
4 \labch{title}
```

In Line 1 I choose the style for the title to be “kao”. Then, I specify that I want the margin toc. The rest is ordinary administration in LaTeX, except that I use my own `\labch` to label the chapter. Actually, the `\setchapterpreamble` is a standard KOMA-Script one, so I invite you to read about it in the KOMA documentation. Once the chapter style is set, it holds until you change it.[3] Whenever I want to start a chapter with an image, I simply write:

3: The `\margintoc` has to be specified at every chapter. Perhaps in the future this may change; it all depends on how this feature will be welcomed by the users, so keep in touch with me if you have preferences!

```
\setchapterimage[7cm]{path/to/image.png} % Optionally specify the
     height
\setchapterpreamble[u]{\margintoc}
\chapter{Catchy Title} % No need to set a chapter style
\labch{catchy}
```

If you prefer, you can also specify the style at the beginning of the main document, and that style will hold until you change it again.

21.2 Headers & Footers

Headers and footers in KOMA-Script are handled by the `scrlayer-scrpage` package. There are two basic style: “scrheadings” and “plain.scrheadings”. The former is used for normal pages, whereas the latter is used in title pages (those where a new chapter starts, for instance) and, at least in this book, in the front matter. At any rate, the style can be changed with the `\pagestyle` command, *e.g.* `\pagestyle{plain.scrheadings}`.

In both styles, the footer is completely empty. In plain.scrheadings, also the header is absent (otherwise it wouldn’t be so plain…), but in the normal style the design is reminiscent of the “kao” style for chapter titles.

21.3 **`twoside`** mode

To Do

The `twoside` class option is still unstable and may lead to unexpected behaviours. Great strides have been done since the first version of `kaobook`, but some work still needs to be done. As always, any help will be greatly appreciated.

By passing the `twoside` option to the `kaobook`, the style of left and right pages will be different, similarly to a printed book. In digital books, having a symmetrical layout for left and right pages is less important, and you may be tempted to use the `twoside=false` option. However, keep in mind that in “oneside” mode the `\uppertitleback` and `\lowertitleback` commands are not available.[4] If you want to have the upper/lower titleback in a one-side document, just add manually the contents that you’d put using the upper/lower titleback commands.

4: Another useful thing to keep in mind is that, when `twoside=true`, an extra white page will be added to the frontmatter.

21.4 Table of Contents

Another important part of a book is the table of contents. By default, in `kaobook` there is an entry for everything: list of figures, list of tables, bibliographies, and even the table of contents itself. Not everybody might like this, so we will provide a description of the changes you need to do in order to enable or disable each of these entries. In the following Table 21.1, each item corresponds to a possible entry in the TOC, and its description is the command you need to provide to have such entry. These commands are specified in the attached style package,[5] so if you don’t want the entries, just comment the corresponding lines.

5: In the same file, you can also choose the titles of these entries.

Of course, some packages, like those for glossaries and indices, will try to add their own entries. In such cases, you have to follow the instructions specific to that package. Here, since we have talked about glossaries and notations in Chapter 20, we will briefly see how to configure them.

In a later section, we will see how you can define your own floating environment, and endow it with an entry in the TOC.

For the `glossaries` package, use the “toc” option when you load it: `\usepackage[toc]{glossaries}`. For `nomencl`, pass the “intoc” option at the moment of loading the package. Both `glossaries` and `nomencl` are loaded in the attached “packages” package.

Entry	Command to Activate
Table of Contents	`\setuptoc{toc}{totoc}`
List of Figs/Tabs	`\PassOptionsToClass{toc=listof}{\@baseclass}`
Bibliography	`\PassOptionsToClass{toc=bibliography}{\@baseclass}`

Table 21.1: Commands to add a particular entry to the table of contents.

Additional configuration of the table of contents can be performed through the packages `etoc`, which is loaded because it is needed for the margintocs, or the more traditional `tocbase`. Read the respective documentations if you want to be able to change the default TOC style.[6]

6: (And please, send me a copy of what you have done, I'm so curious!)

21.5 Paper Size

Recent versions of Kaobook support paper sizes different from the default A4. It is possible to pass the name of the paper as an option to the class, as we are accustomed for any other LaTeX class. For example, the class option `b5paper` would set the paper size to the B5 format.

We also support the paper sizes specified in this web page and some additional sizes requested by the users, with the option names specified in Table 21.2.

Table 21.2: Some non-standard paper sizes supported by kaobook.

Dimension	Option name
12.0cm x 19.0cm	smallpocketpaper
13.5cm x 21.5cm	pocketpaper
14.8cm x 21.0cm	a5paper
15.5cm x 22.0cm	juvenilepaper
17.0cm x 17.0cm	smallphotopaper
21.0cm x 15.0cm	appendixpaper
17.0cm x 22.0cm	cookpaper
19.0cm x 27.0cm	illustratedpaper
17.0cm x 17.0cm	photopaper
16.0cm x 24.0cm	f24paper

For instance, to use the "smallpocketpaper" add the correct description at the beginning of the documentclass instruction:

```
\documentclass[
        smallpocketpaper,
        fontsize=10pt,
        twoside=false,
        %open=any,
        secnumdepth=1,
]{kaobook}
```

Sometimes it is convenient to adopt a landscape view; `kaobook` provides two additional options, `a4paperlandscape` and `169paperlandscape`, which set the page in landscape mode with width-to-height ratios of, respectively, 1.414 and 16:9.

21.6 Page Layout

Besides the page style, you can also change the width of the content of a page. This is particularly useful for pages dedicated to part titles, where having the 1.5-column layout might be a little awkward, or for pages where you only put figures, where it is important to exploit all the available space.

In practice, there are two layouts: "wide" and "margin". The former suppresses the margins and allocates the full page for contents, while the latter is the layout used in most of the pages of this book, including this one. The wide layout is also used automatically in the front and back matters.

Sometimes it is desirable to increase the width for just one or a few paragraphs; the `widepar` environment does that: wrap your paragraphs in this environment, and they will occupy the full width of the page.

To change page layout, use the `\pagelayout` command. For example, when I start a new part, I write:

```
\pagelayout{wide}
\addpart{Title of the New Part}
\pagelayout{margin}
```

Beyond these two basic layouts, it is also possible to finely tune the page layout by redefining the `\marginlayout` command. This command is called internally by the higher-level `\pagelayout`, and it is responsible for setting the width of the margins and of the text. The default definition is:

```
\newcommand{\marginlayout}{%
    \newgeometry{
        top=27.4mm,             % height of the top margin
        bottom=27.4mm,          % height of the bottom margin
        inner=24.8mm,           % width of the inner margin
        textwidth=107mm,        % width of the text
        marginparsep=8.2mm,     % width between text and margin
        marginparwidth=49.4mm,  % width of the margin
    }%
}
```

so if you want to, say, decrease the width of the margin while increasing the width of the text, you could write in the preamble of your document something like:

```
\renewcommand{\marginlayout}{%
    \newgeometry{
        top=27.4mm,             % height of the top margin
        bottom=27.4mm,          % height of the bottom margin
        inner=24.8mm,           % width of the inner margin
        textwidth=117mm,        % width of the text
        marginparsep=8.2mm,     % width between text and margin
        marginparwidth=39.4mm,  % width of the margin
    }%
}
```

where the text width has been increased by 10mm and the margin width has been decreased by 10mm.

21.7 Numbers & Counters

In this short section we shall see how dispositions, sidenotes and figures are numbered in the `kaobook` class.

By default, dispositions are numbered up to the section in `kaobook` and up to the subsection in `kaohandt`. This can be changed by passing the option `secnumdepth` to`kaobook` or `kaohandt` (e.g. 1 corresponds to section and 2 corresponds to subsections).

The sidenotes counter is the same across all the document, but if you want it to reset at each chapter, just uncomment the line

`\counterwithin*{sidenote}{chapter}`

in the `styles/style.sty` package provided by this class.

Figure and Table numbering is also per-chapter; to change that, use something like:

`\renewcommand{\thefigure}{\arabic{section}.\arabic{figure}}`

21.8 White Space

One of the things that I find most hard in LaTeX is to finely tune the white space around objects. There are not fixed rules, each object needs its own adjustment. Here we shall see how some spaces are defined at the moment in this class.

Attention! This section may be incomplete.

Space around sidenotes and citations marks

There should be no space before or after sidenotes and citation marks, like so:

sidenote[7]sidenote
citation[**James2013**]citation

7: This paragraph can be used to diagnose any problems: if you see whitespace around sidenotes or citation marks, probably a % sign is missing somewhere in the definitions of the class macros.

Space around figures and tables

```
\renewcommand\FBaskip{.4\topskip}
\renewcommand\FBbskip{\FBaskip}
```

Space around captions

```
\captionsetup{
    aboveskip=6pt,
    belowskip=6pt
}
```

Space around displays (*e.g.* equations)

```
\setlength\abovedisplayskip{6pt plus 2pt minus 4pt}
\setlength\belowdisplayskip{6pt plus 2pt minus 4pt}
\abovedisplayskip 10\p@ \@plus2\p@ \@minus5\p@
\abovedisplayshortskip \z@ \@plus3\p@
\belowdisplayskip \abovedisplayskip
\belowdisplayshortskip 6\p@ \@plus3\p@ \@minus3\p@
```

22 Mathematics and Boxes

22.1 Theorems

Despite most people complain at the sight of a book full of equations, mathematics is an important part of many books. Here, we shall illustrate some of the possibilities. We believe that theorems, definitions, remarks and examples should be emphasised with a shaded background; however, the colour should not be to heavy on the eyes, so we have chosen a sort of light yellow.[1]

1: The boxes are all of the same colour here, because we did not want our document to look like Harlequin.

Definition 22.1.1 *Let (X, d) be a metric space. A subset $U \subset X$ is an open set if, for any $x \in U$ there exists $r > 0$ such that $B(x, r) \subset U$. We call the topology associated to d the set τ_d of all the open subsets of (X, d).*

Definition 22.1.1 is very important. I am not joking, but I have inserted this phrase only to show how to reference definitions. The following statement is repeated over and over in different environments.

Theorem 22.1.1 *A finite intersection of open sets of (X, d) is an open set of (X, d), i.e τ_d is closed under finite intersections. Any union of open sets of (X, d) is an open set of (X, d).*

Proposition 22.1.2 *A finite intersection of open sets of (X, d) is an open set of (X, d), i.e τ_d is closed under finite intersections. Any union of open sets of (X, d) is an open set of (X, d).*

Lemma 22.1.3 *A finite intersection[a] of open sets of (X, d) is an open set of (X, d), i.e τ_d is closed under finite intersections. Any union of open sets of (X, d) is an open set of (X, d).*

[a] I'm a footnote

You can even insert footnotes inside the theorem environments; they will be displayed at the bottom of the box.

You can safely ignore the content of the theorems...I assume that if you are interested in having theorems in your book, you already know something about the classical way to add them. These example should just showcase all the things you can do within this class.

Corollary 22.1.4 (Finite Intersection, Countable Union) *A finite intersection of open sets of (X, d) is an open set of (X, d), i.e τ_d is closed under finite intersections. Any union of open sets of (X, d) is an open set of (X, d).*

Proof. The proof is left to the reader as a trivial exercise. Hint: Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. □

Definition 22.1.2 *Let (X, d) be a metric space. A subset $U \subset X$ is an open set if, for any $x \in U$ there exists $r > 0$ such that $B(x, r) \subset U$. We call the topology associated to d the set τ_d of all the open subsets of (X, d).*

Here is a random equation, just because we can:

$$x = a_0 + \cfrac{1}{a_1 + \cfrac{1}{a_2 + \cfrac{1}{a_3 + \cfrac{1}{a_4}}}}$$

Example 22.1.1 Let (X, d) be a metric space. A subset $U \subset X$ is an open set if, for any $x \in U$ there exists $r > 0$ such that $B(x, r) \subset U$. We call the topology associated to d the set τ_d of all the open subsets of (X, d).

Remark 22.1.1 Let (X, d) be a metric space. A subset $U \subset X$ is an open set if, for any $x \in U$ there exists $r > 0$ such that $B(x, r) \subset U$. We call the topology associated to d the set τ_d of all the open subsets of (X, d).

As you may have noticed, definitions, example and remarks have independent counters; theorems, propositions, lemmas and corollaries share the same counter.

Remark 22.1.2 Here is how an integral looks like inline: $\int_a^b x^2 dx$, and here is the same integral displayed in its own paragraph:

$$\int_a^b x^2 dx$$

There is also an environment for exercises.

Exercise 22.1.1 Prove (or disprove) the Riemann hypothesis.

We provide one package for the theorem styles: kaotheorems.sty, to which you can pass the `framed` option you do want coloured boxes around theorems, like in this document.[2] You may want to edit this files according to your taste and the general style of the book. However, there is an option to customise the background colour of the boxes if you use the `framed` option: when you load this package, you can pass it the `background=mycolour` option (replace "mycolour" with the actual colour, for instance, "red!35!white"). This will change the colour of all the boxes, but it is also possible to override the default colour only for some elements. For instance, the `propositionbackground=mycolour` option will change the colour for propositions only. There are similar options for theorem, definition, lemma, corollary, remark, and example.

2: The styles without `framed` are not showed, but actually the only difference is that they don't have the yellow boxes.

22.2 Boxes & Custom Environments [3]

3: Notice that in the table of contents and in the header, the name of this section is "Boxes & Environments"; we achieved this with the optional argument of the `section` command.

Say you want to insert a special section, an optional content or just something you want to emphasise. We think that nothing works better than a box in these cases. We used `mdframed` to construct the ones shown below. You can create and modify such environments by editing the provided file kao.sty.

Title of the box

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

If you set up a counter, you can even create your own numbered environment.

Comment 22.2.1

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

22.3 Experiments

It is possible to wrap marginnotes inside boxes, too. Audacious readers are encouraged to try their own experiments and let me know the outcomes.

title of margin note

Margin note inside a kaobox.
(Actually, kaobox inside a marginnote!)

I believe that many other special things are possible with the kaobook class. During its development, I struggled to keep it as flexible as possible, so that new features could be added without too great an effort. Therefore, I hope that you can find the optimal way to express yourselves in writing a book, report or thesis with this class, and I am eager to see the outcomes of any experiment that you may try.

Bibliography

Here are the references in citation order.

[1] IEA. *Energy Technology Perspectives*. IEA. 2014. URL: https://www.iea.org/reports/energy-technology-perspectives-2014 (visited on 11/30/2023) (cited on page 7).

[2] Richard Thonig, Alina Gilmanova, and Johan Lilliestam. *CSP.Guru 2023-07-01*. Zenodo, July 1, 2023. (Visited on 05/31/2025) (cited on page 7).

[3] Ebrahim Rezaei, Sirous Shafiei, and Aydin Abdollahnezhad. "Reducing Water Consumption of an Industrial Plant Cooling Unit Using Hybrid Cooling Tower." In: *Energy Conversion and Management* 51.2 (Feb. 1, 2010), pp. 311–319. DOI: 10.1016/j.enconman.2009.09.027. (Visited on 03/10/2023) (cited on page 9).

[4] Wanchai Asvapoositkul and Mantheerapol Kuansathan. "Comparative Evaluation of Hybrid (Dry/Wet) Cooling Tower Performance." In: *Applied Thermal Engineering* 71.1 (Oct. 5, 2014), pp. 83–93. DOI: 10.1016/j.applthermaleng.2014.06.023. (Visited on 03/10/2023) (cited on page 9).

[5] Hemin Hu et al. "Thermodynamic Characteristics of Thermal Power Plant with Hybrid (Dry/Wet) Cooling System." In: *Energy* 147 (Mar. 15, 2018), pp. 729–741. DOI: 10.1016/j.energy.2018.01.074. (Visited on 03/10/2023) (cited on page 9).

[6] S. El Marazgioui and A. El Fadar. "Impact of Cooling Tower Technology on Performance and Cost-Effectiveness of CSP Plants." In: *Energy Conversion and Management* 258 (Apr. 15, 2022), p. 115448. DOI: 10.1016/j.enconman.2022.115448. (Visited on 03/29/2024) (cited on page 9).

[7] G. Barigozzi, A. Perdichizzi, and S. Ravelli. "Wet and Dry Cooling Systems Optimization Applied to a Modern Waste-to-Energy Cogeneration Heat and Power Plant." In: *Applied Energy* 88.4 (Apr. 1, 2011), pp. 1366–1376. DOI: 10.1016/j.apenergy.2010.09.023. (Visited on 03/10/2023) (cited on page 9).

[8] G. Barigozzi, A. Perdichizzi, and S. Ravelli. "Performance Prediction and Optimization of a Waste-to-Energy Cogeneration Plant with Combined Wet and Dry Cooling System." In: *Applied Energy* 115 (Feb. 15, 2014), pp. 65–74. DOI: 10.1016/j.apenergy.2013.11.024. (Visited on 03/10/2023) (cited on page 9).

[9] Patricia Palenzuela et al. "Experimental Assessment of a Pilot Scale Hybrid Cooling System for Water Consumption Reduction in CSP Plants." In: *Energy* 242 (Mar. 1, 2022), p. 122948. DOI: 10.1016/j.energy.2021.122948. (Visited on 03/10/2023) (cited on page 9).

[10] Faisal Asfand et al. "Thermodynamic Performance and Water Consumption of Hybrid Cooling System Configurations for Concentrated Solar Power Plants." In: *Sustainability* 12.11 (2020). DOI: 10.3390/su12114739 (cited on page 9).

[11] Raniyah Wazirali et al. "State-of-the-Art Review on Energy and Load Forecasting in Microgrids Using Artificial Neural Networks, Machine Learning, and Deep Learning Techniques." In: *Electric Power Systems Research* 225 (Dec. 1, 2023), p. 109792. DOI: 10.1016/j.epsr.2023.109792. (Visited on 03/31/2024) (cited on page 9).

[12] Martin T. Hagan et al. *Neural Network Design*. Martin Hagan, 2014. 800 pp. (cited on pages 12, 13).

[13] Mark Hudson Beale, Martin T Hagan, and Howard B Demuth. "Neural Network Toolbox." In: *User's Guide, MathWorks* 2 (2010), pp. 77–81 (cited on page 13).

[14] Lonnie Hamm, B. Wade Brorsen, and Martin T. Hagan. "Comparison of Stochastic Global Optimization Methods to Estimate Neural Network Weights." In: *Neural Processing Letters* 26.3 (Dec. 1, 2007), pp. 145–158. DOI: 10.1007/s11063-007-9048-7. (Visited on 03/16/2024) (cited on page 13).

[15] Jiri Nossent, Pieter Elsen, and Willy Bauwens. "Sobol'sensitivity Analysis of a Complex Environmental Model." In: *Environmental Modelling & Software* 26.12 (2011), pp. 1515–1525 (cited on page 15).

[16] Jon Herman and Will Usher. "SALib: An Open-Source Python Library for Sensitivity Analysis." In: *The Journal of Open Source Software* 2.9 (Jan. 2017). DOI: 10.21105/joss.00097 (cited on page 15).

[17] Takuya Iwanaga, William Usher, and Jonathan Herman. "Toward SALib 2.0: Advancing the Accessibility and Interpretability of Global Sensitivity Analyses." In: *Socio-Environmental Systems Modelling* 4 (May 2022), p. 18155. DOI: 10.18174/sesmo.18155 (cited on page 15).

[18] F. Merkel. "Verdunstungskühlung." In: *VDI Zeitschriff Deutscher Ingenieure, Berlin, Alemania* (1925), pp. 123–128 (cited on pages 29, 31).

[19] C Bourillot. “Hypotheses of Calculation of the Water Flow Rate Evaporated in a Wet Cooling Tower.” In: (Aug. 1983) (cited on page 29).

[20] H. Jaber and R. L. Webb. “Design of Cooling Towers by the Effectiveness-NTU Method.” In: *Journal of Heat Transfer* 111.4 (Nov. 1989), pp. 837–843. DOI: 10.1115/1.3250794 (cited on page 29).

[21] M. Poppe and H. Rögener. “Berechnung von Rückkühlwerken.” In: *VDI wärmeatlas* (1991), p. Mi 1 (cited on pages 30, 31).

[22] J.C. Kloppers and D.G. Kröger. “A Critical Investigation into the Heat and Mass Transfer Analysis of Counterflow Wet-Cooling Towers.” In: *International Journal of Heat and Mass Transfer* 48.3 (2005), pp. 765–777 (cited on page 30).

[23] C. G. Cutillas et al. “Energetic, Exergetic and Environmental (3E) Analyses of Different Cooling Technologies (Wet, Dry and Hybrid) in a CSP Thermal Power Plant.” In: *Case Studies in Thermal Engineering* 28 (Dec. 1, 2021), p. 101545. DOI: 10.1016/j.csite.2021.101545. (Visited on 03/27/2024) (cited on page 30).

[24] M. Hosoz, H. M. Ertunc, and H. Bulgurcu. “Performance Prediction of a Cooling Tower Using Artificial Neural Network.” In: *Energy Conversion and Management* 48.4 (Apr. 1, 2007), pp. 1349–1359. DOI: 10.1016/j.enconman.2006.06.024. (Visited on 03/08/2023) (cited on pages 30, 46).

[25] Ming Gao et al. “Artificial Neural Network Model Research on Effects of Cross-Wind to Performance Parameters of Wet Cooling Tower Based on Level Froude Number.” In: *Applied Thermal Engineering* 51.1 (Mar. 1, 2013), pp. 1226–1234. DOI: 10.1016/j.applthermaleng.2012.06.053. (Visited on 03/08/2023) (cited on page 30).

[26] Jialiang Song et al. “A Novel Approach for Energy Efficiency Prediction of Various Natural Draft Wet Cooling Towers Using ANN.” In: *Journal of Thermal Science* 30.3 (May 2021), pp. 859–868. DOI: 10.1007/s11630-020-1296-0. (Visited on 03/04/2023) (cited on page 30).

[27] P. Navarro et al. “Critical Evaluation of the Thermal Performance Analysis of a New Cooling Tower Prototype.” In: *Applied Thermal Engineering* 213 (2022), p. 118719. DOI: 10.1016/j.applthermaleng.2022.118719 (cited on pages 30–32).

[28] Ashrae. “HVAC Systems and Equipment.” In: *Chapter 36 Cooling Towers*. 2004 (cited on pages 32, 45).

[29] UNE. *Thermal Performance Acceptance Testing of Mechanical Draught Series Wet Cooling Towers*. manual. UNE. 2004 (cited on page 45).

[30] CTI. *Code Tower, Standard Specifications. Acceptance Test Code for Water Cooling Towers*. manual. Cooling Technology Institute. 2000 (cited on page 45).

[31] Patricia Palenzuela et al. *Steady-State Operation Dataset of an Experimental Wet Cooling Tower Pilot Plant Located at Plataforma Solar de Almería*. Zenodo, June 21, 2024. (Visited on 06/01/2025) (cited on pages 45, 46).

[32] Juan Miguel Serrano et al. “Wet Cooling Tower Performance Prediction in CSP Plants: A Comparison between Artificial Neural Networks and Poppe’s Model.” In: *Energy* (May 29, 2024), p. 131844. DOI: 10.1016/j.energy.2024.131844. (Visited on 05/30/2024) (cited on page 45).

[33] J. Ruiz et al. “Thermal Performance and Emissions Analysis of a New Cooling Tower Prototype.” In: *Applied Thermal Engineering* (2022), p. 118065. DOI: 10.1016/j.applthermaleng.2022.118065 (cited on page 51).

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