Practice on Free Cooling in Data Centers

MASTER'S DEGREE IN THERMAL ENGINEERING

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Introduction

The aim of this analysis is to interact with Data Centers, specifically with CTTC's JFF2 Cluster. In particular, the thermal management strategy of the cluster has been investigated to understand how to interact with the cooling system to make it more efficient and reduce energy consumption.

This report addresses the setup and operational parameters required to enable various cooling modes in an air loop system designed for a data center. Using the data provided, which includes indoor and outdoor conditions recorded every five minutes over a single day, some conditions have been analyzed to understand the cooling system's responses. To visualize the setting of the cooling system, some images are presented, highlighting the two different operational modes, closed air loop and open air loop.

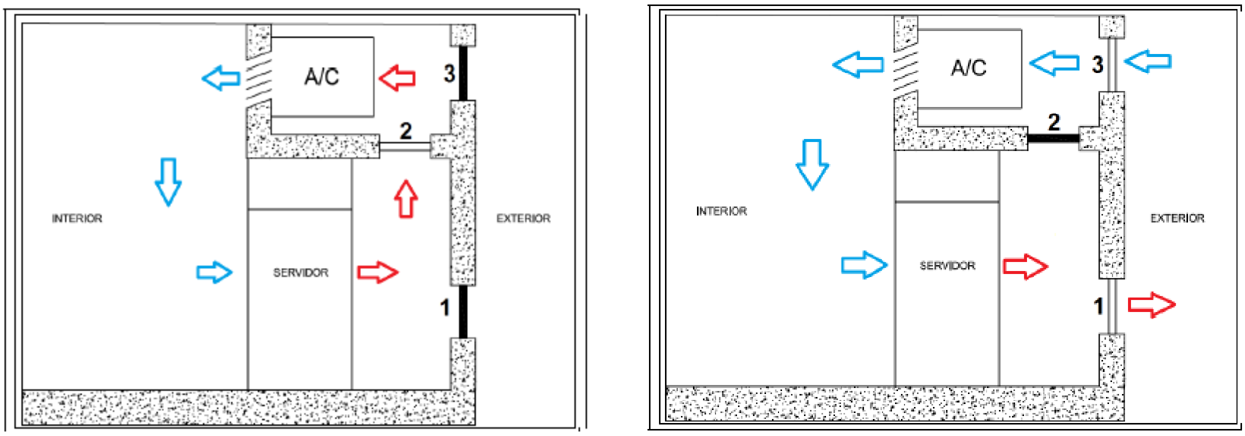

Figure 1. Section cluster room closed air loop cooling mode (sx). Section cluster room open air loop cooling mode (dx).

Table 1. Summary of operating modes.

	Closed Air Loop cooling	Open Air Loop cooling
Group 1	CLOSE	OPEN
Group 2	OPEN	CLOSE
Group 3	CLOSE	OPEN

When the external temperature is sufficiently low, the air-conditioning system operates in open air loop cooling mode, relying only on its ventilation system and using much less electricity. This open air loop cooling has been implemented without disconnecting the A/C units, allowing them to turn on if additional cooling is needed to maintain the inlet rack temperature. When external conditions support open air cooling, but extra cooling is temporarily required at the rack inlet, the A/C units activate in hybrid mode, an intermediate stage between full free cooling and conventional cooling. This can be seen in real-time data, where power consumption at the A/C units is recorded even as the exhaust fans run in open air loop mode.

Methodology

The provided data have been used to identify when the system switches between different cooling modes (open loop, closed loop, and potentially hybrid). To accomplish this, the dataset has been loaded into Python and then a logic has been implemented to determine when each cooling mode is active based on environmental conditions, temperature, humidity, and system thresholds. All the variables have been plotted over time (263 time intervals for a single day), to visualize conditions failing or meeting the criteria explained in the following table:

Table 2. Summary of conditions to access open air loop cooling mode.

Conditions for Open Air Loop mode	
1	7ºC < Tenv < 40ºC
2	-3ºC < Tdew env < 22ºC
3	15% < RH% env <80%
4	-3ºC < Tdew room < 22ºC
5	15% < RH% room < 80%
6	Troom > Tdew env
7	Tout rack > Tenv (only to keep)

Conditions 1 to 6 are required to enter open air loop cooling mode, while conditions 1 to 7 are necessary to remain in this mode. Condition 7 specifically aims to prevent unnecessary activation of hybrid mode. This detailed approach is essential to prevent condensation within the data center, which could cause significant hardware issues. Moreover, to minimize instability, mode changes are delayed as follows:

- When transitioning from open to closed cooling mode, the system must remain in closed air loop cooling mode for at least 60 minutes.
- To switch to open air loop cooling mode, conditions 1 to 6 must be met continuously for at least 10 minutes.
- To exit open air loop cooling mode, none of conditions 1 to 7 should be met for a minimum of 5 minutes.

Results Analysis

The most relevant data are presented in graphical form as functions of time. To better visualize the change of the cooling mode, all graphs have been realized with a continuous line except for the interval where the cooling mode is switched from open air loop to closed air loop, represented by a dotted line instead. This condition occurred just once during the analyzed day.

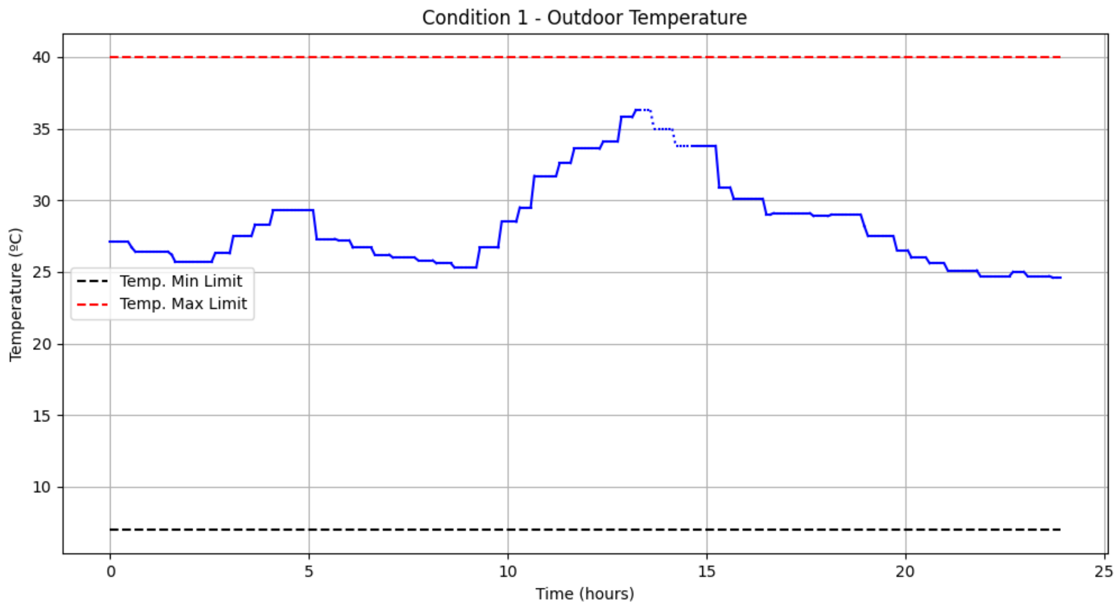

Figure 2. Condition 1 – Outdoor temperature evolution during the day.

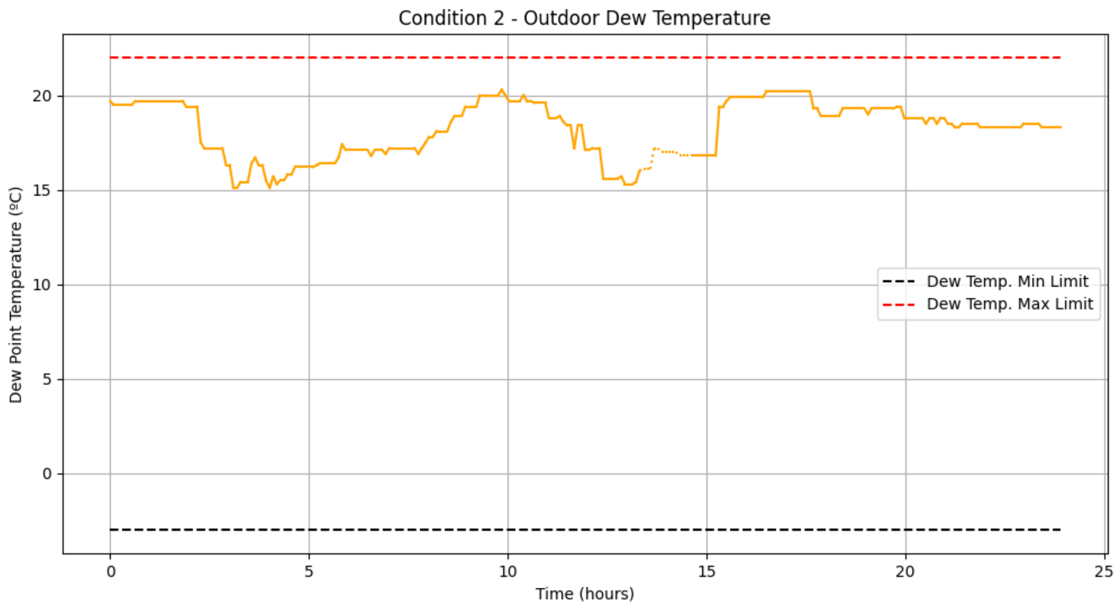

Figure 3. Condition 2 – Outdoor dew temperature evolution during the day.

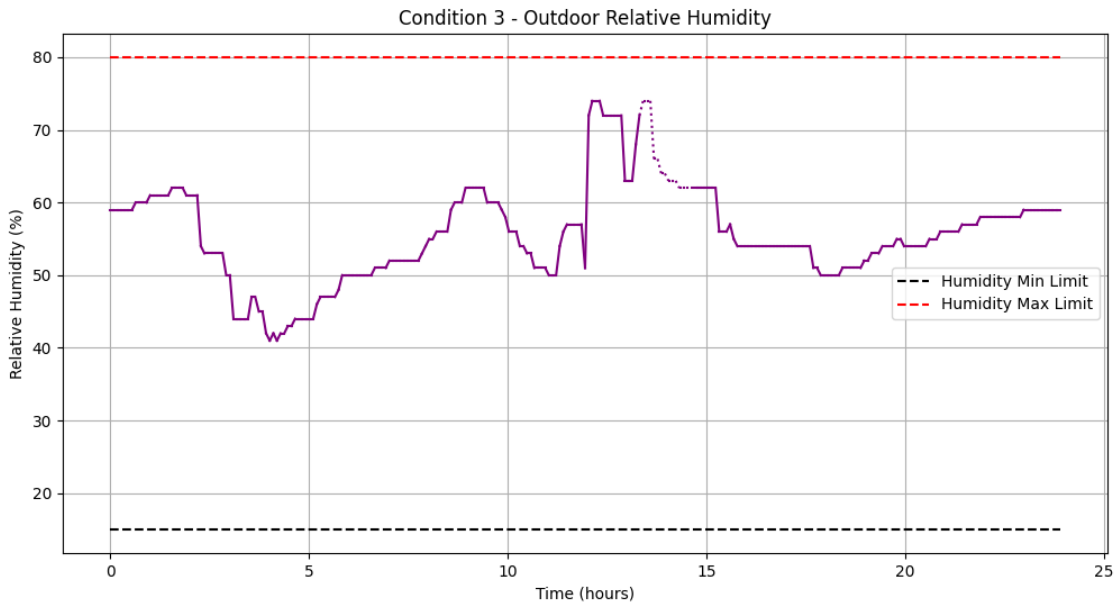

Figure 4. Condition 3 – Outdoor relative humidity evolution during the day.

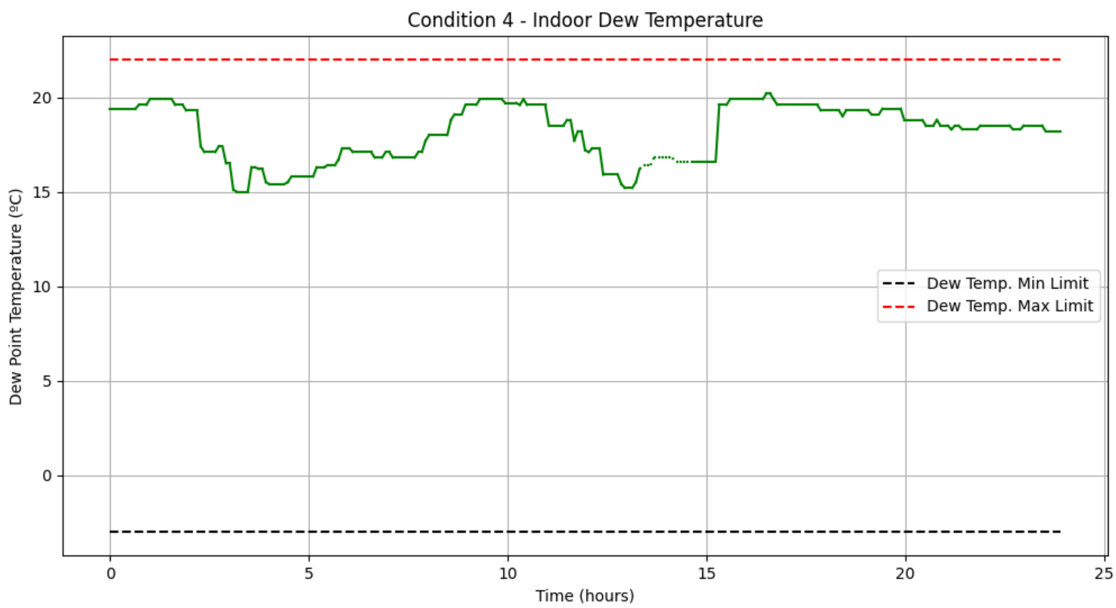

Figure 5. Condition 4 – Indoor dew temperature evolution during the day.

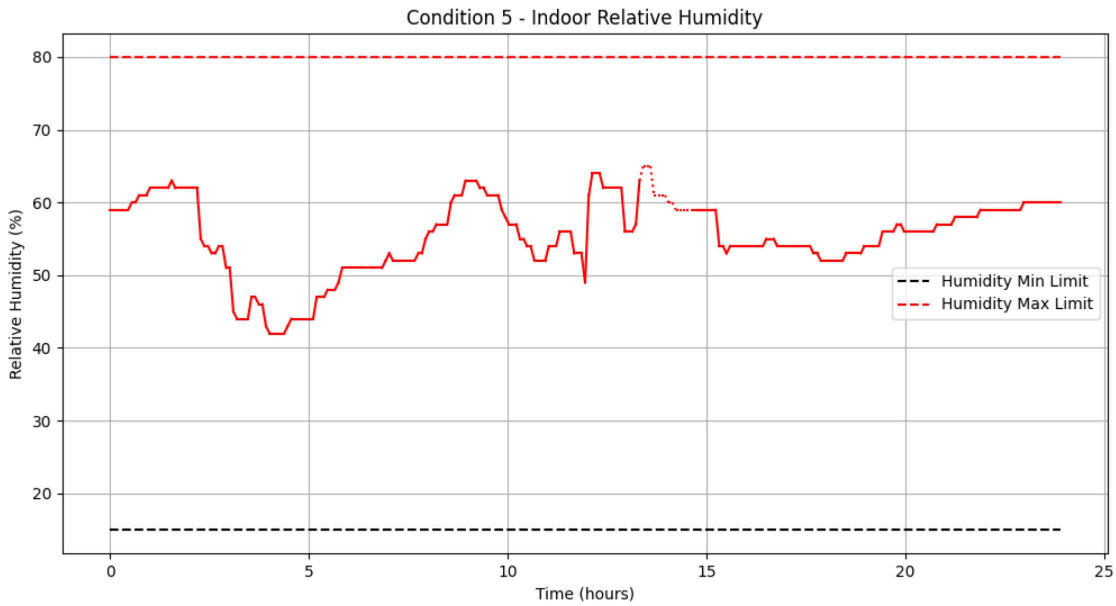

Figure 6. Condition 5 – Indoor relative humidity evolution during the day.

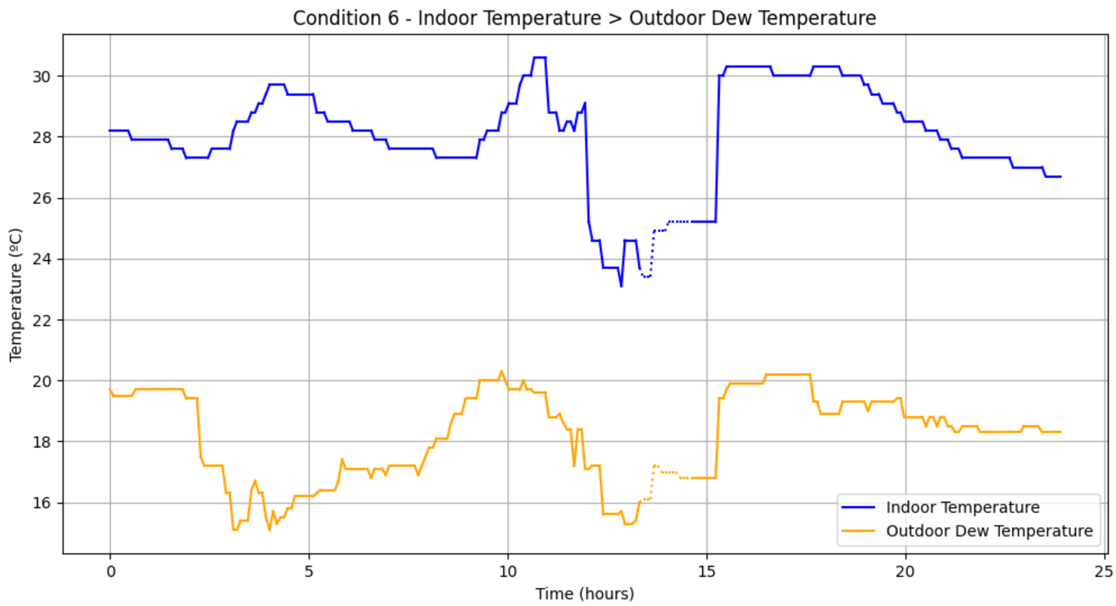

Figure 7. Condition 6 – Indoor temperature and outdoor dew temperature comparison.

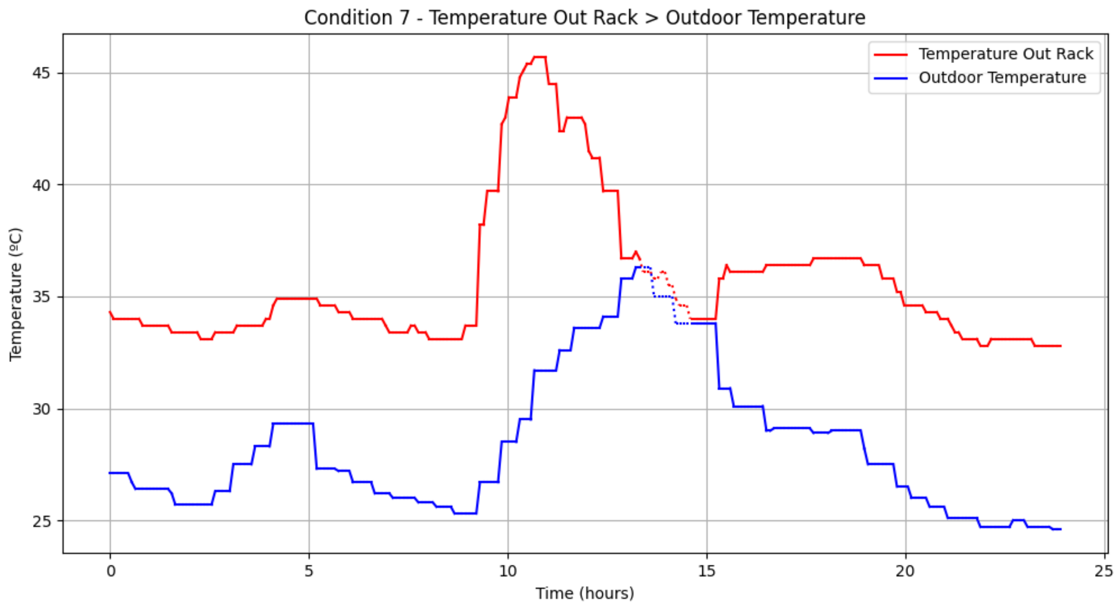

Figure 8. Condition 7 – Temperature out rack and outdoor temperature comparison.

In the figures above, the states "OPEN", represented by a continuous line, and "CLOSED", represented by a dotted line, are used to manage airflow:

- OPEN: This state is assigned when all predefined conditions are met, allowing the system to operate on open air loop mode. This indicates that temperature and humidity are within optimal ranges, with no risk of condensation or overheating.
- CLOSED: This state is activated when one or more conditions fall outside the desired ranges. In this mode, the system may reduce or stop the intake of external air, maintaining a more controlled internal environment to prevent issues.

The alternation between "OPEN" and "CLOSED" allows the system to adjust in real time, dynamically responding to environmental changes to ensure both efficiency and safety.

Figures 2 to 7 display the individual conditions and show how they interact to manage the cooling mode. Observing Figure 8 (Condition 7), we see an overlapping of the plots, which corresponds to a time frame from 13:20 to 13:35. During this period, hybrid mode is temporarily disabled.

From midnight onward, the system remains in open air loop mode, with the A/C minimally engaged, until 11:05. Between 11:05 and 13:25, the system operates in hybrid mode, as the A/C turns on to assist. Condition 7 is not satisfied between 13:30 and 14:35, which forces the system to switch to closed mode temporarily. For the rest of the day, the system reverts to open loop mode with minimal A/C usage.

To complete the analysis, the Power Usage Effectiveness (PUE) has been calculated according to its definition:

$$PUE = \frac{Total\ Energy}{IT\ Energy} = \frac{Power\ Computers + Power\ HVAC + Power\ Extractors}{Power\ Computers}$$

For a better visualization of the results, this value has also been plotted over time.

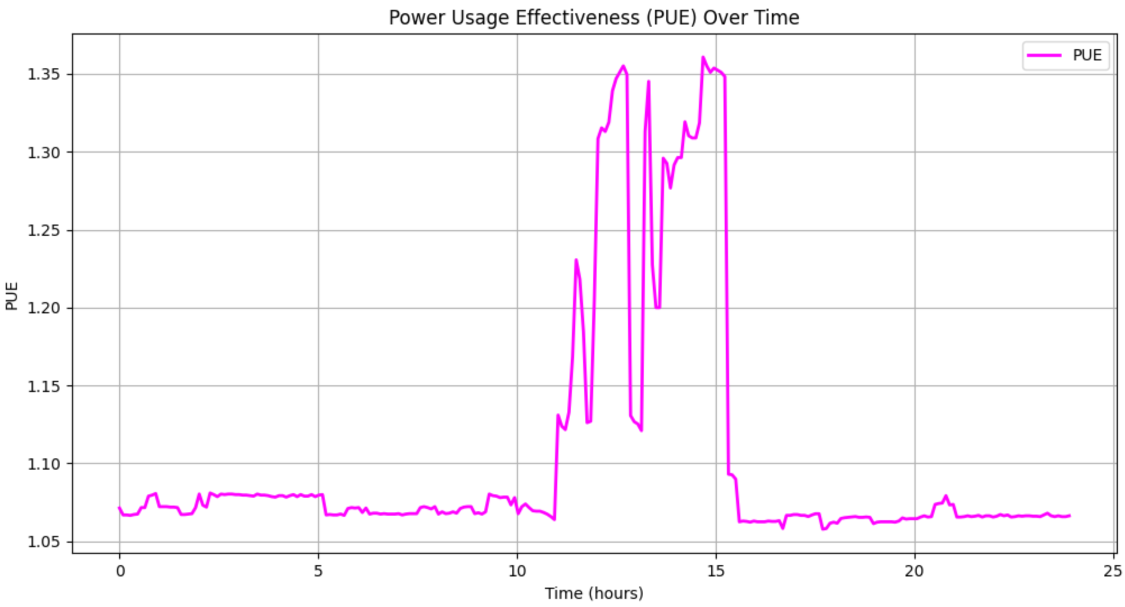

Figure 9. Power Usage Effectiveness (PUE) during the day.

Figure 9 illustrates the evolution of the Power Usage Effectiveness, highlighting instances when the system alternates between pure open, hybrid, and closed modes. The PUE calculation involves dividing the total energy consumed (including cooling and support systems) by the energy required only for the IT systems. The resulting values typically range from 1.06 (ideal) to 1.8 (industry average), and our observed values fall within this expected range, indicating a well-optimized system.