



GreenDays 2026

10-11 mars 2026 Sophia (France)

Optimisation énergétique des centres de données :

la modélisation thermique de GPU et CPU par Deep Learning
pour un refroidissement optimal.

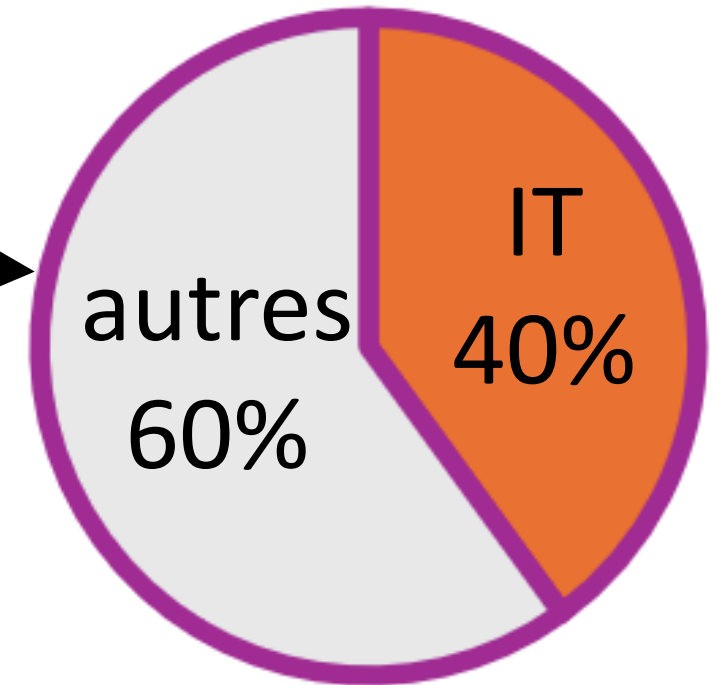
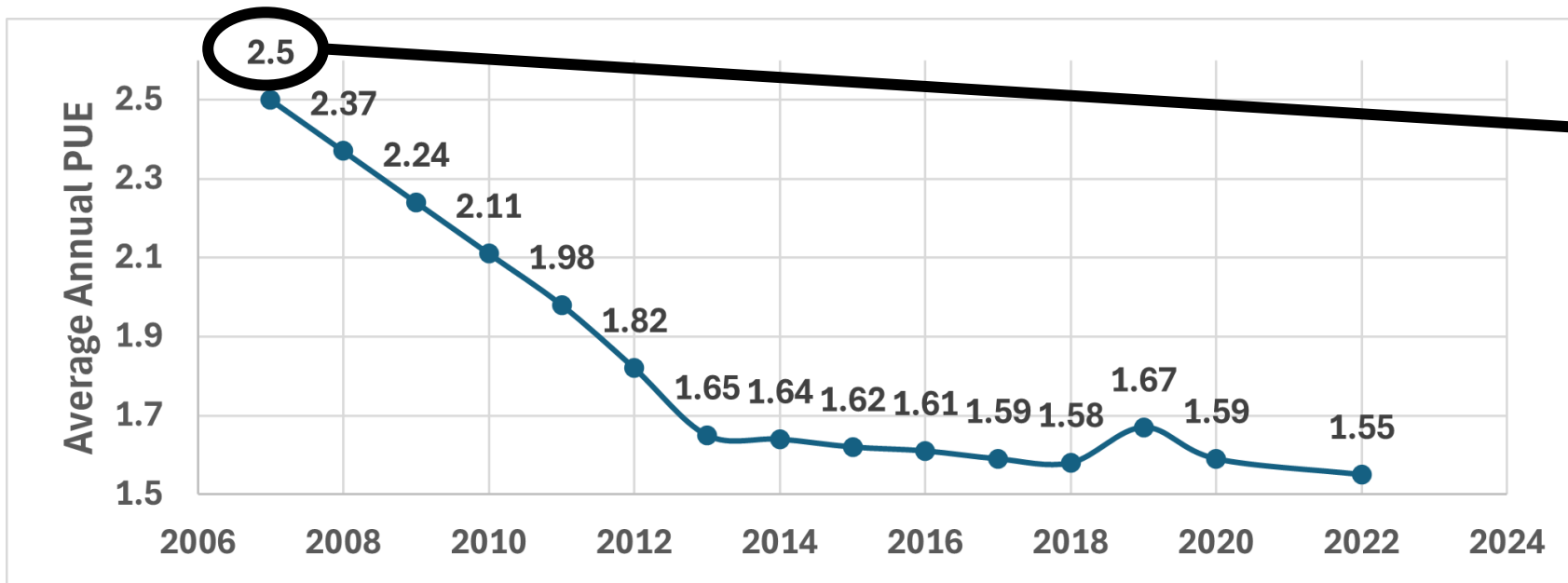


- I. État de l'art des centres de données;**
- II. Pistes d'amélioration;**
- III. Nos contributions;**
 - a) Notre banc de test;**
 - b) Méthodologie de prédiction;**
 - c) Résultat.**

I. État de l'art des centres de données

$$PUE = \frac{E_{\text{total}}}{E_{\text{IT}}} = \int_{t=0}^T \frac{P_{\text{total}}(t)dt}{P_{\text{IT}}(t)dt}$$

PUE : Power Unit Efficiency
IT : Information Technology

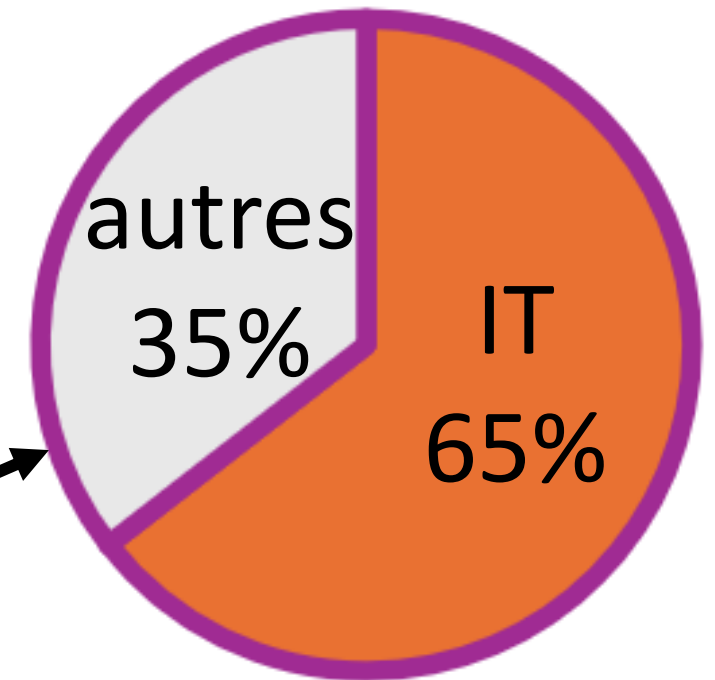
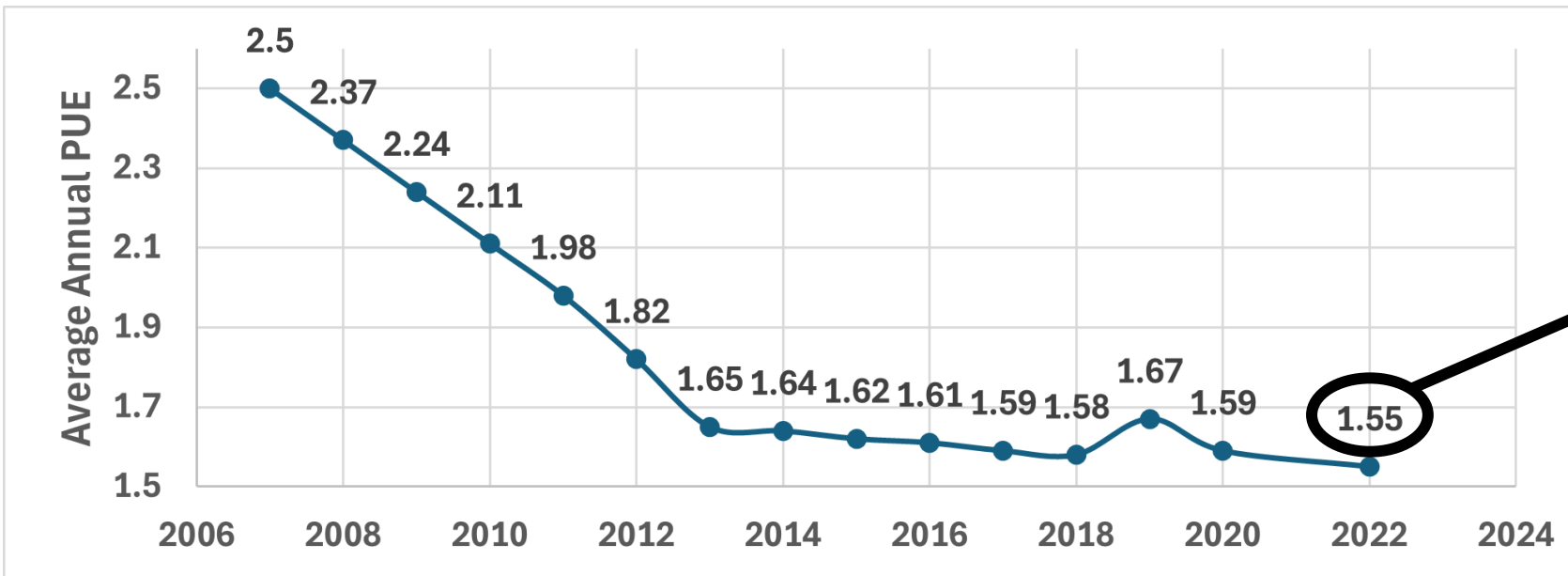


[1] "Global trends, performance metrics, and energy reduction measures in datacom facilities," Renewable and Sustainable Energy Reviews, Mar. 2023.

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[1] "Global trends, performance metrics, and energy reduction measures in datacom facilities," Renewable and Sustainable Energy Reviews, Mar. 2023.

Table 2.1 2021 Thermal Guidelines for Air Cooling—
SI Version (I-P Version in Appendix B)

Equipment Environment Specifications for Air Cooling						
Class ^a	Product Operation ^{b,c}					Product Power Off ^{c,d}
	Dry-Bulb Temp. ^{e,g} , °C	Humidity Range, Noncond. ^{h,i,k,l,n}	Max. Dew Point ^k , °C	Max. Elev. ^{e,i,m} , m	Max. Rate of Change ^f , °C/h	Dry-Bulb Temp., °C, RH ^k , %
Recommended (suitable for Classes A1 to A4; explore data center metrics in this book for conditions outside this range.)						
A1 to A4	18 to 27	-9°C DP to 15°C DP and 70% rh ⁿ or 50% rh ⁿ				
Allowable						
A1	15 to 32	-12°C DP and 8% rh to 17°C DP and 80% rh ^k	17	3050	5/20	5 to 45 8 to 80 ^k
A2	10 to 35	-12°C DP and 8% rh to 21°C DP and 80% rh ^k	21	3050	5/20	5 to 45 8 to 80 ^k
A3	5 to 40	-12°C DP and 8% rh to 24°C DP and 85% rh ^k	24	3050	5/20	5 to 45 8 to 80 ^k
A4	5 to 45	-12°C DP and 8% rh to 24°C DP and 90% rh ^k	24	3050	5/20	5 to 45 8 to 80 ^k

* For potentially greater energy savings, refer to Appendix C for the process needed to account for multiple server metrics that impact overall TCO.

Source ASHRAE [2]

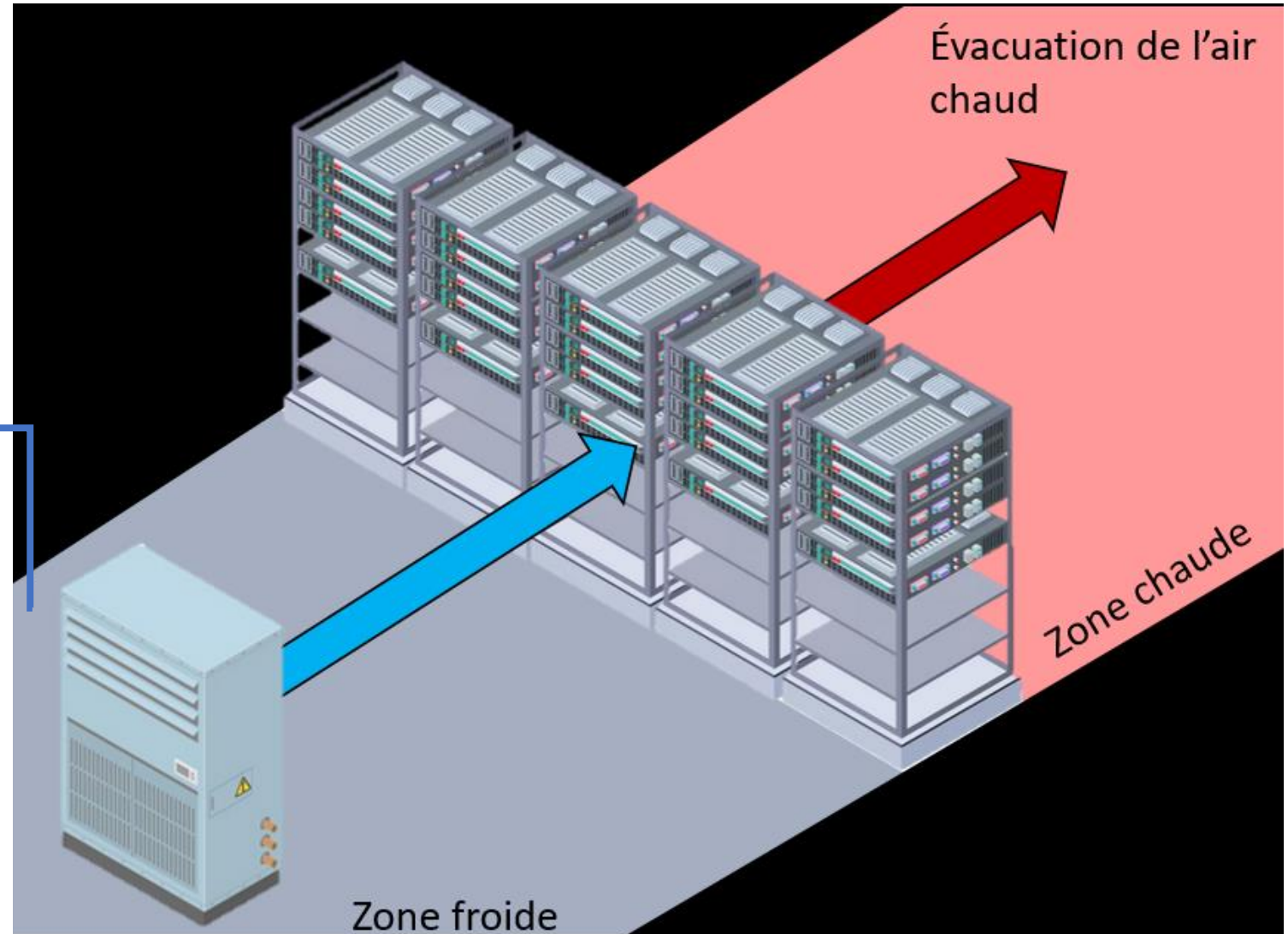
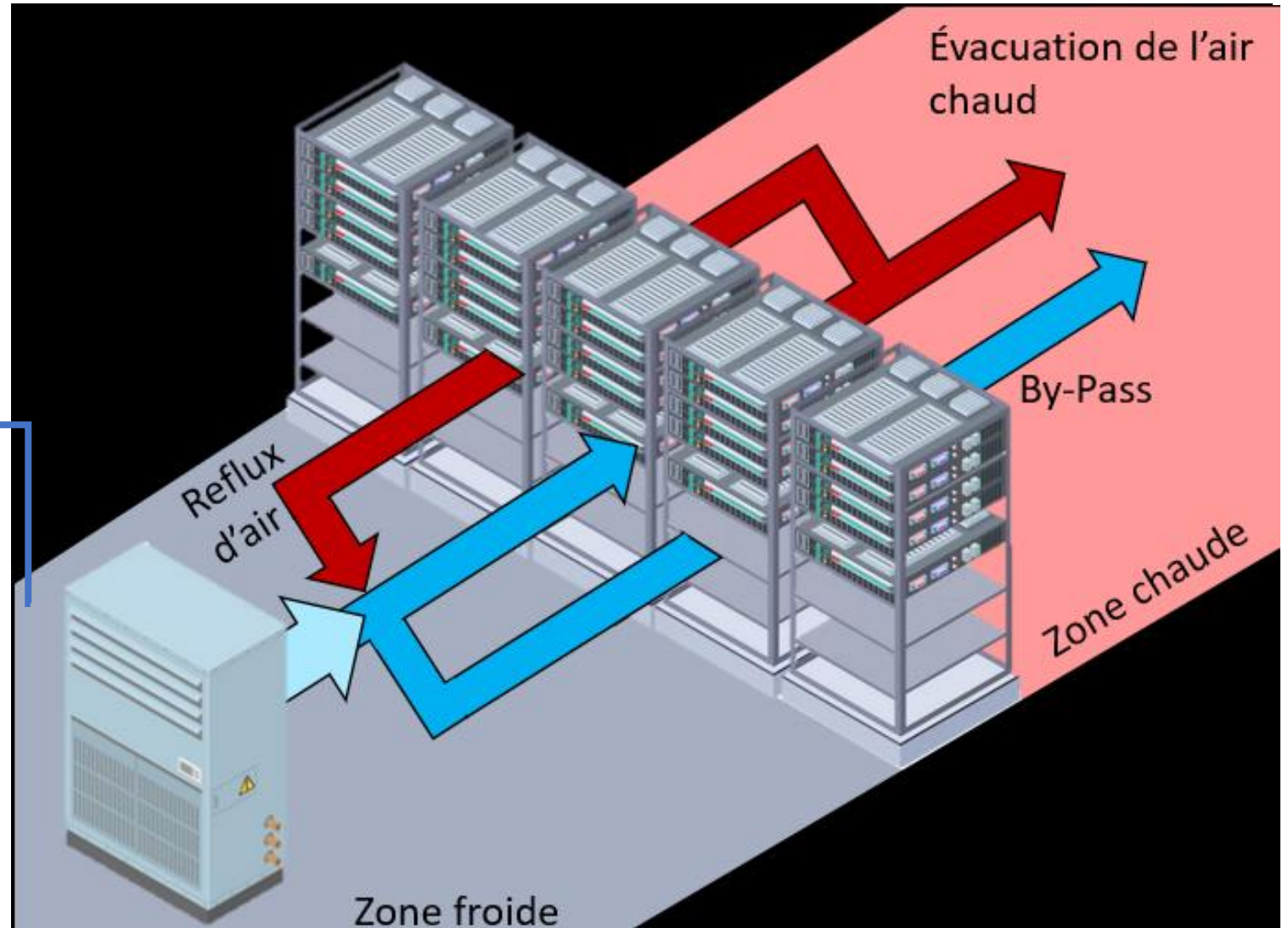


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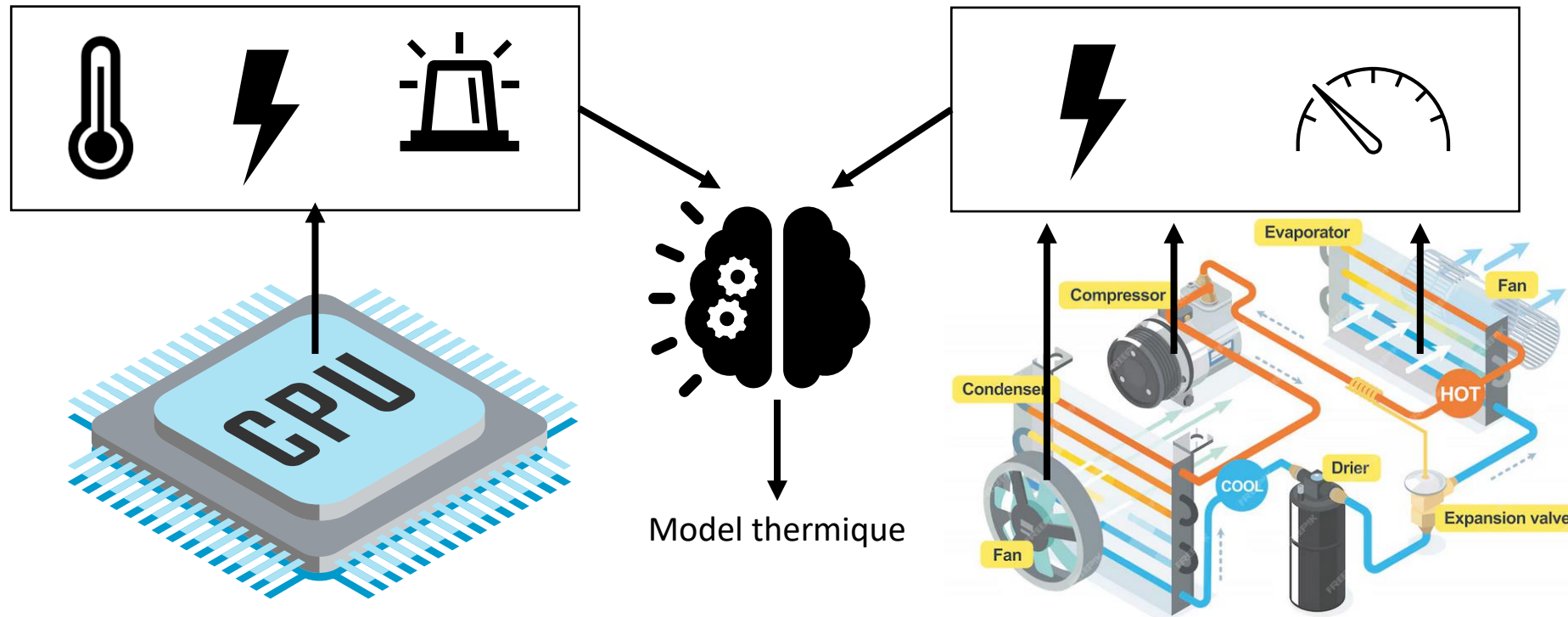
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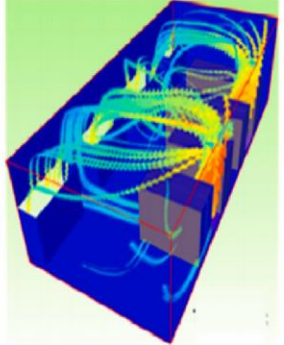
II. Pistes d'amélioration

Ne plus se baser uniquement sur les recommandations ASHRAE, mais contrôler la climatisation en fonction de la température des processeurs.



Boîte « blanche »

CFD Method
Computational Fluid Dynamics Method

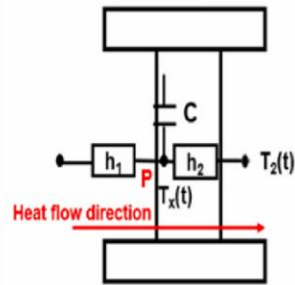


Paramétrage : -
Vitesse d'exécution : --
Sens physique : ++

Images tirées de [3]

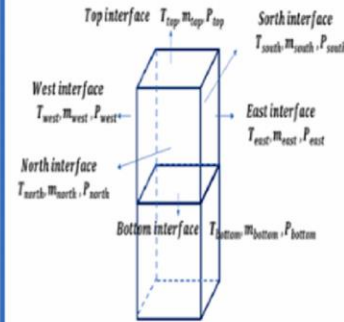
Boîte « grise »

Lumped Capacitance Method



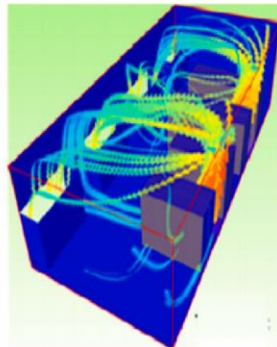
Paramétrage : +
Vitesse d'exécution : +
Sens physique : +

Zone Model Method



CFD Method

Computational Fluid Dynamics Method

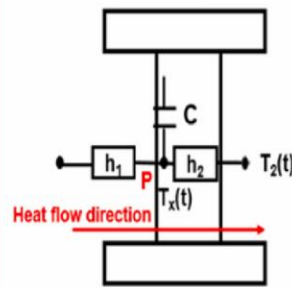


Paramétrage : -
Vitesse d'exécution : --
Sens physique : ++

Boîte « blanche »

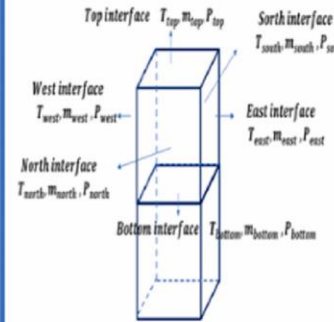
Boîte « grise »

Lumped Capacitance Method

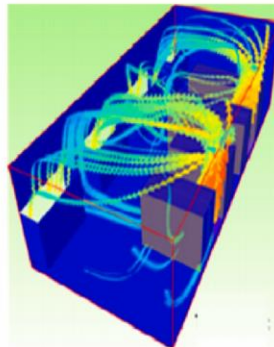


Paramétrage : +
 Vitesse d'exécution : +
 Sens physique : +

Zone Model Method

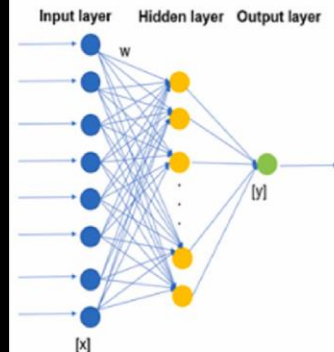


CFD Method Computational Fluid Dynamics Method



Paramétrage : -
 Vitesse d'exécution : --
 Sens physique : ++

Data-Driven Method



Paramétrage : ++
 Vitesse d'exécution : ++
 Sens physique : --

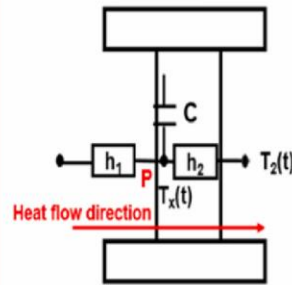
Boîte « blanche »

Boîte « noire »

Modèle	papers
Blanche	13
Grise	16
Noir	11

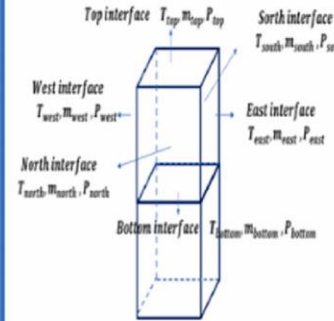
Boîte « grise »

Lumped Capacitance Method

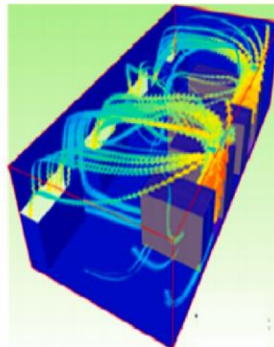


Paramétrage : +
 Vitesse d'exécution : +
 Sens physique : +

Zone Model Method

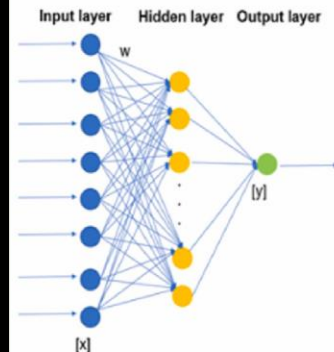


CFD Method Computational Fluid Dynamics Method



Paramétrage : -
 Vitesse d'exécution : --
 Sens physique : ++

Data-Driven Method



Paramétrage : ++
 Vitesse d'exécution : ++
 Sens physique : --

Boîte « blanche »

Boîte « noire »

III. Nos contributions

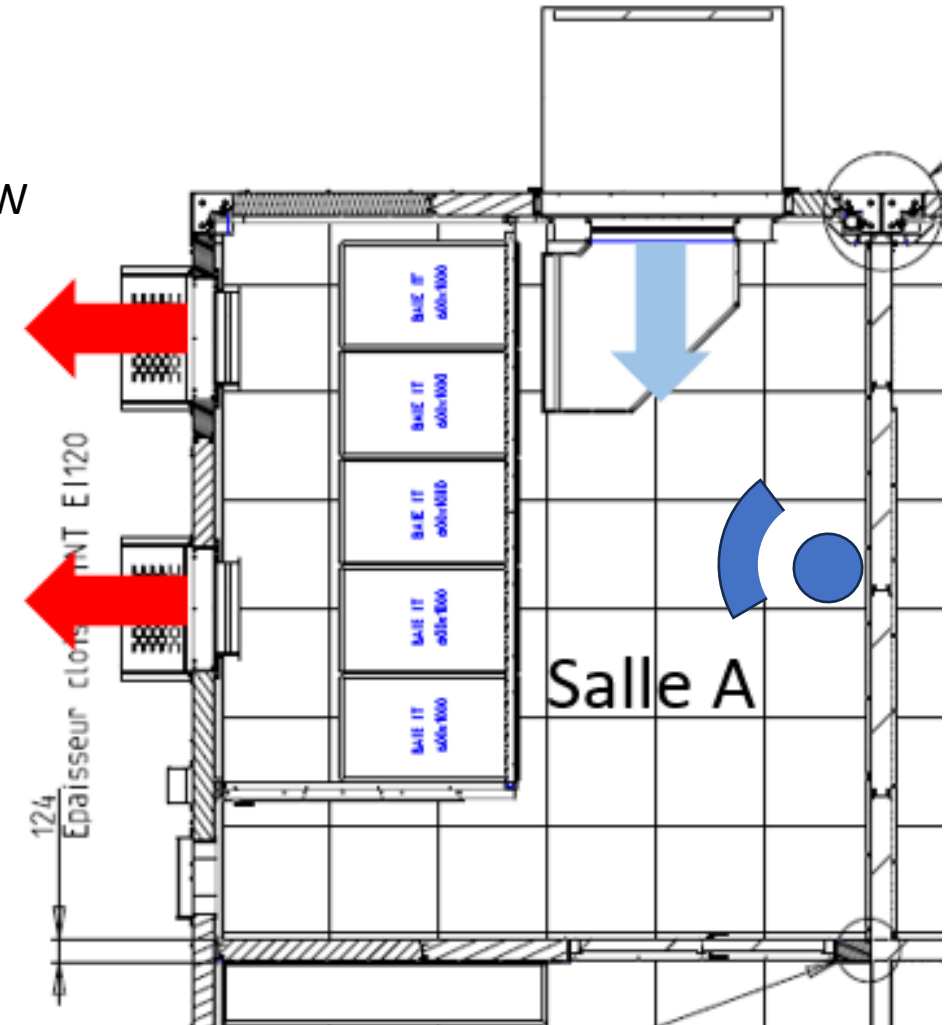
Nos contributions

a) Notre banc de test.



13 Serveurs Informatiques :
70 GPU
26 CPU

Consommation maximale de 20kW
Consommation passive de 5kW



Nos contributions

a) Notre banc de test.



État des Serveurs

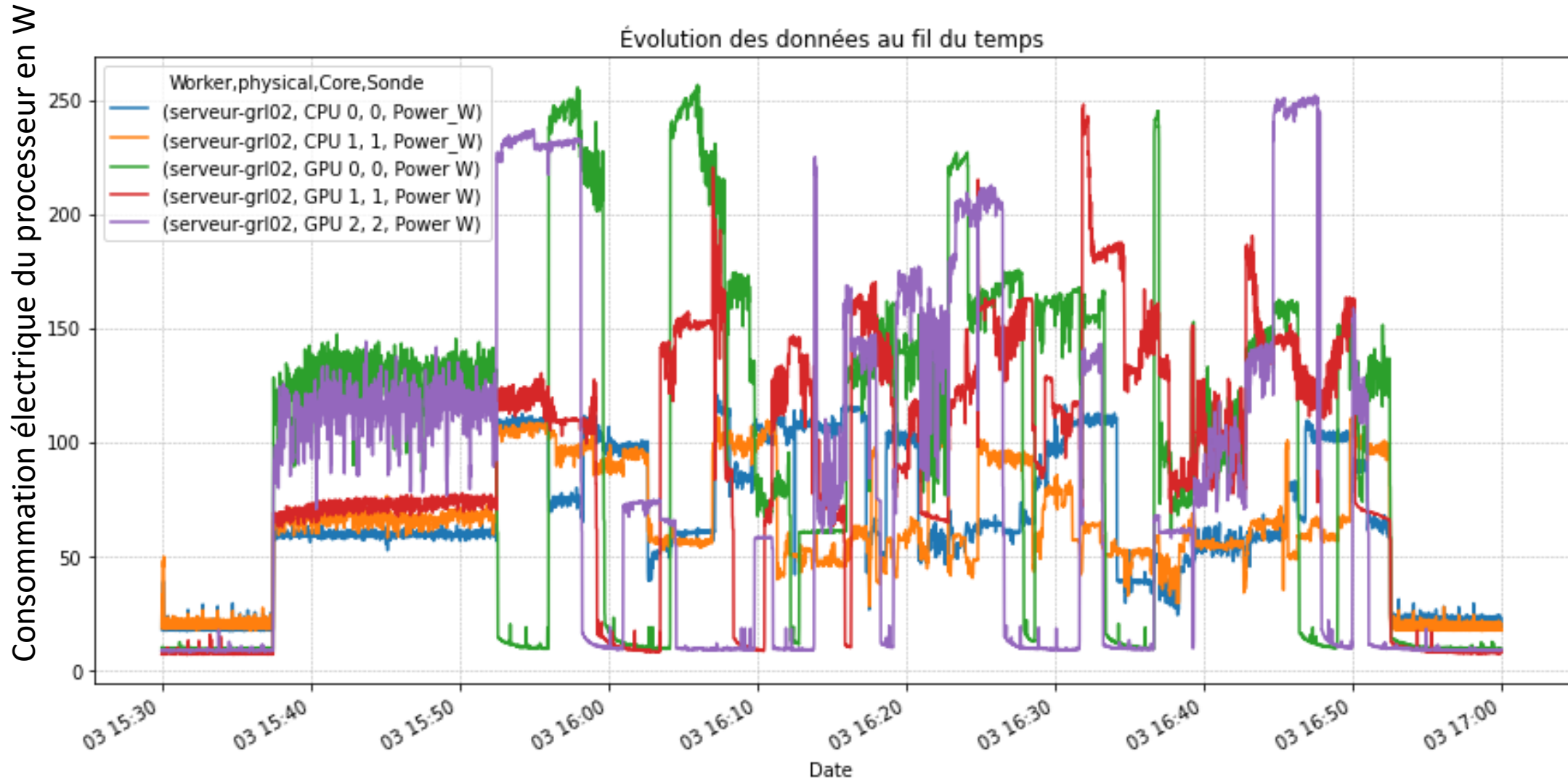
Température, usage et consommation du processeur.
Possibilité de stresser le processeur individuellement.

ID	CPU 1	CPU 2	GPU 1	GPU 2	GPU 3	GPU 4	GPU 5	GPU 6	GPU 7	GPU 8
serveur-grl00	Temp: 32°C Load: 4% Power: 30W	Temp: 33°C Load: 4% Power: 30W	Temp: 72°C Load: 36% Power: 105W	Temp: 69°C Load: 37% Power: 94W	Temp: 50°C Load: 37% Power: 91W	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A
serveur-grl02	Temp: 39°C Load: 22% Power: 65W	Temp: 39°C Load: 24% Power: 63W	Temp: 70°C Load: 39% Power: 138W	Temp: 81°C Load: 45% Power: 141W	Temp: 53°C Load: 37% Power: 105W	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A
serveur-grl06	Temp: 37°C Load: 24% Power: 64W	Temp: 33°C Load: 22% Power: 63W	Temp: 66°C Load: 37% Power: 118W	Temp: 83°C Load: 42% Power: 124W	Temp: 54°C Load: 38% Power: 100W	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A
serveur-grl11	Temp: 54°C Load: 28% Power: 71W	Temp: 50°C Load: 18% Power: 57W	Temp: 50°C Load: 33% Power: 92W	Temp: 47°C Load: 35% Power: 83W	Temp: 40°C Load: 32% Power: 78W	Temp: 51°C Load: 35% Power: 114W	Temp: 52°C Load: 34% Power: 85W	Temp: 40°C Load: 23% Power: 80W	Temp: 42°C Load: 32% Power: 79W	Temp: 48°C Load: 32% Power: 97W
serveur-grl08	Temp: 38°C Load: 20% Power: 62W	Temp: 44°C Load: 28% Power: 71W	Temp: 58°C Load: 33% Power: 88W	Temp: 60°C Load: 35% Power: 85W	Temp: 70°C Load: 38% Power: 96W	Temp: 61°C Load: 38% Power: 130W	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A
serveur-grl07	Temp: 32°C Load: 26% Power: 64W	Temp: 32°C Load: 29% Power: 64W	Temp: 56°C Load: 29% Power: 86W	Temp: 69°C Load: 39% Power: 131W	Temp: 74°C Load: 36% Power: 120W	Temp: 49°C Load: 36% Power: 91W	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A
serveur-grl05	Temp: 40°C Load: 21% Power: 66W	Temp: 39°C Load: 17% Power: 57W	Temp: 59°C Load: 34% Power: 86W	Temp: 64°C Load: 29% Power: 92W	Temp: 76°C Load: 37% Power: 108W	Temp: 53°C Load: 31% Power: 86W	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A	Temp: N/A Load: N/A Power: N/A
serveur-grl09	Temp: 52°C Load: 21% Power: 67W	Temp: 52°C Load: 25% Power: 59W	Temp: 50°C Load: 36% Power: 96W	Temp: 48°C Load: 37% Power: 87W	Temp: 50°C Load: 36% Power: 85W	Temp: 68°C Load: 37% Power: 119W	Temp: 49°C Load: 28% Power: 83W	Temp: 64°C Load: 40% Power: 126W	Temp: 44°C Load: 32% Power: 82W	Temp: N/A Load: N/A Power: N/A

Import Scenario ← Lancer un scénario

position	Capteurs	unité
CPU	Température	°C
	Puissance	W
	Utilisation	%
GPU	Température	°C
	Puissance	W
	Utilisation	%
Clim	Ventilation	%
	Température	°C
	Hygrométrie	%
	Conso eau	L/s

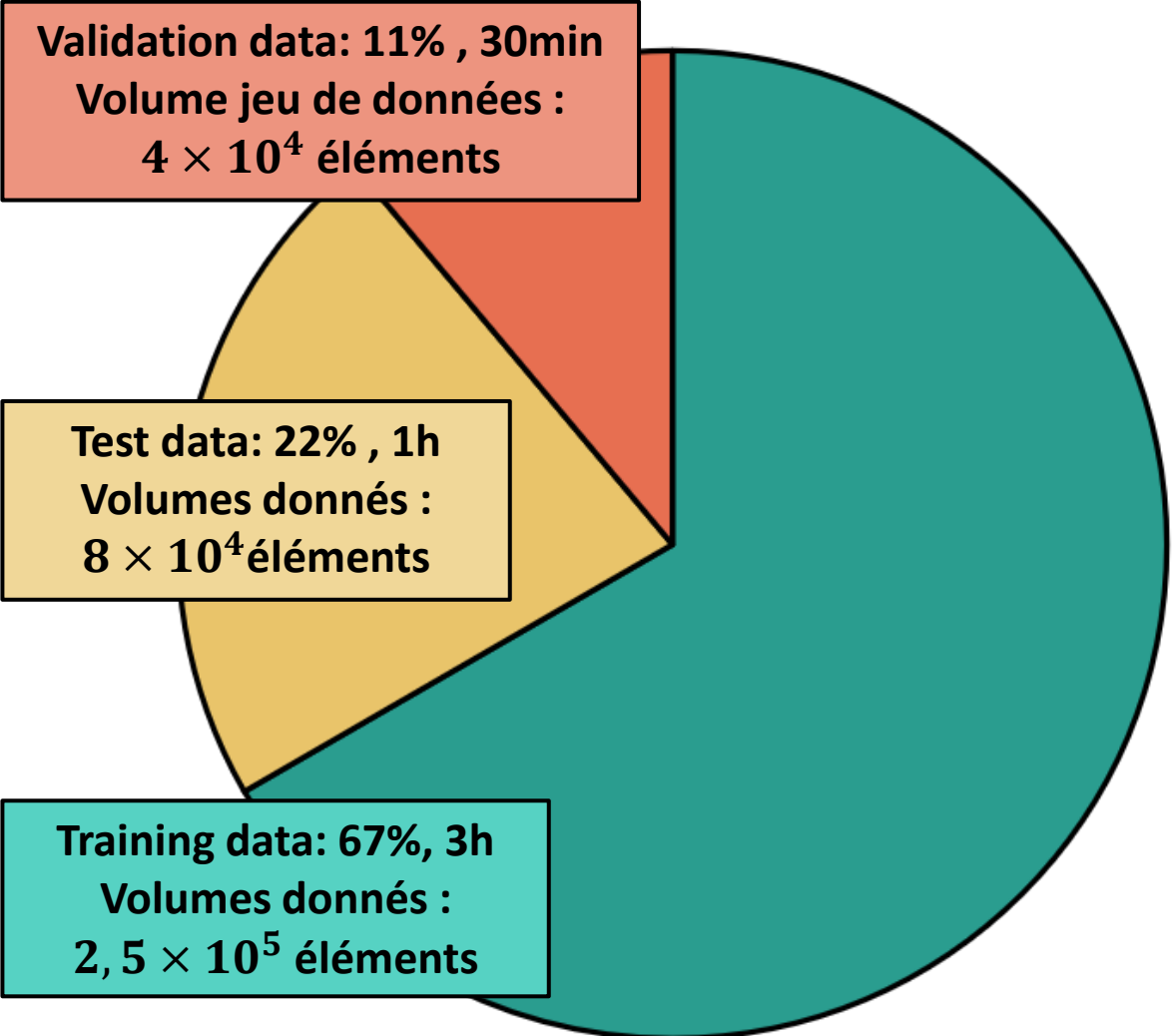
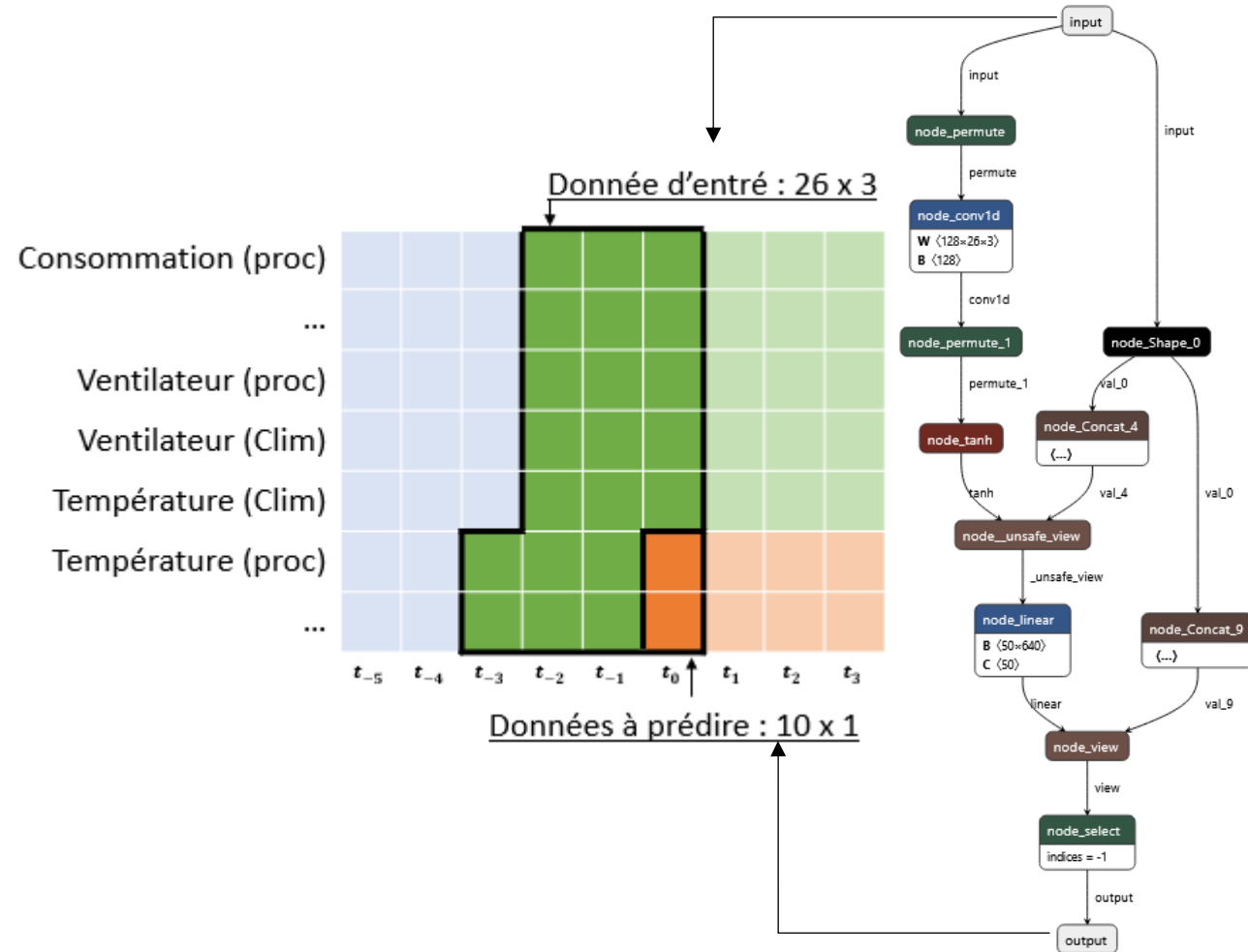
b) Méthodologie de prédiction.



Scénario construit à la suite d'une précédente étude [4]

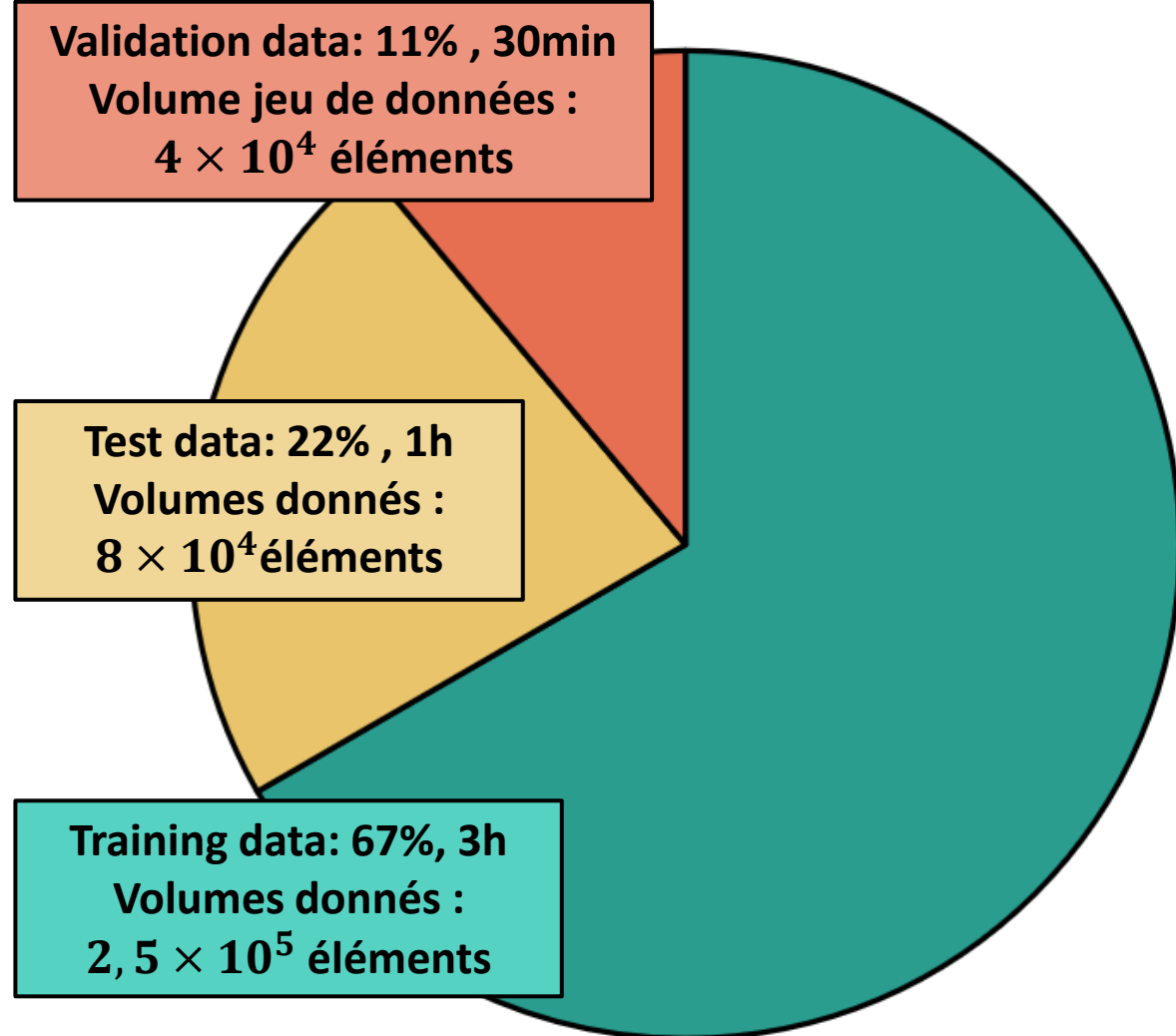
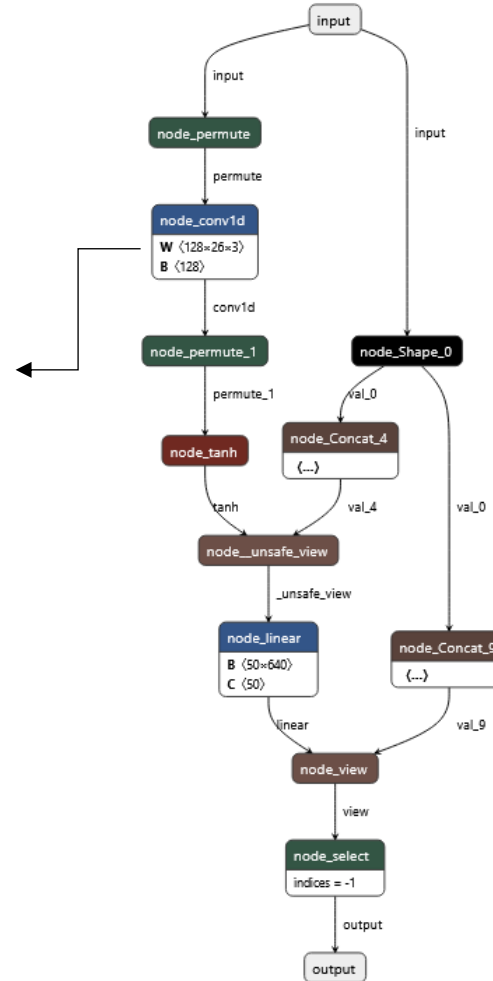
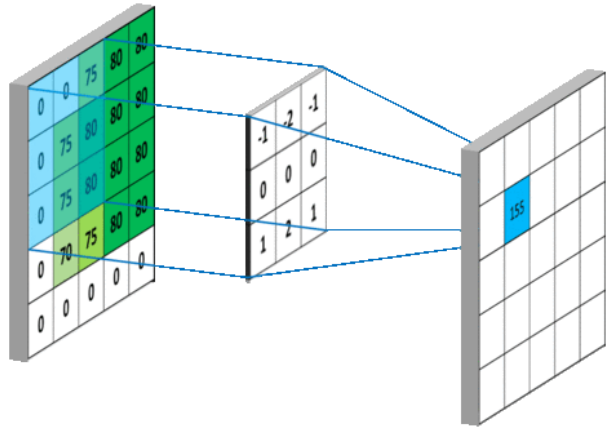
Nos contributions

b) Méthodologie de prédiction.



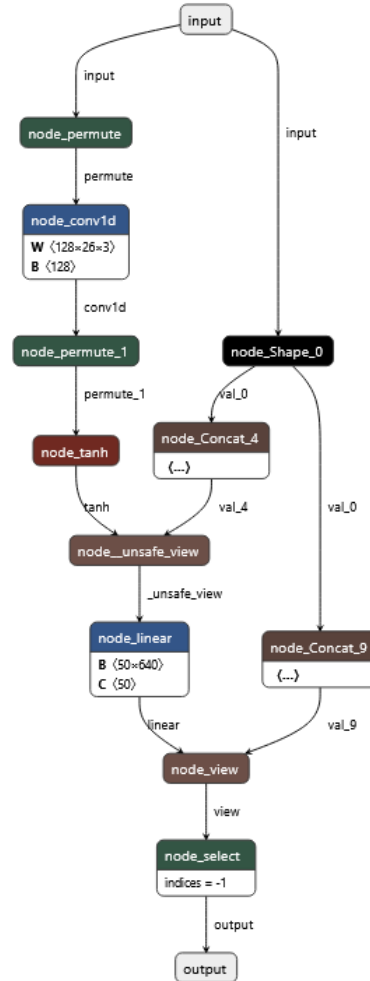
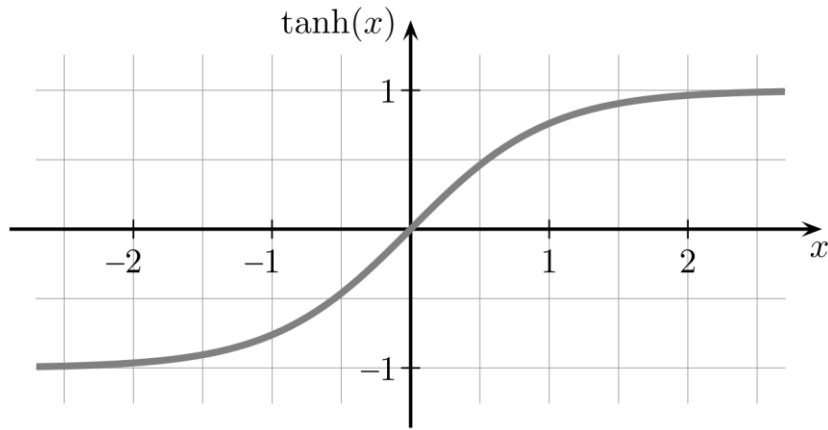
Nos contributions

b) Méthodologie de prédiction.



Nos contributions

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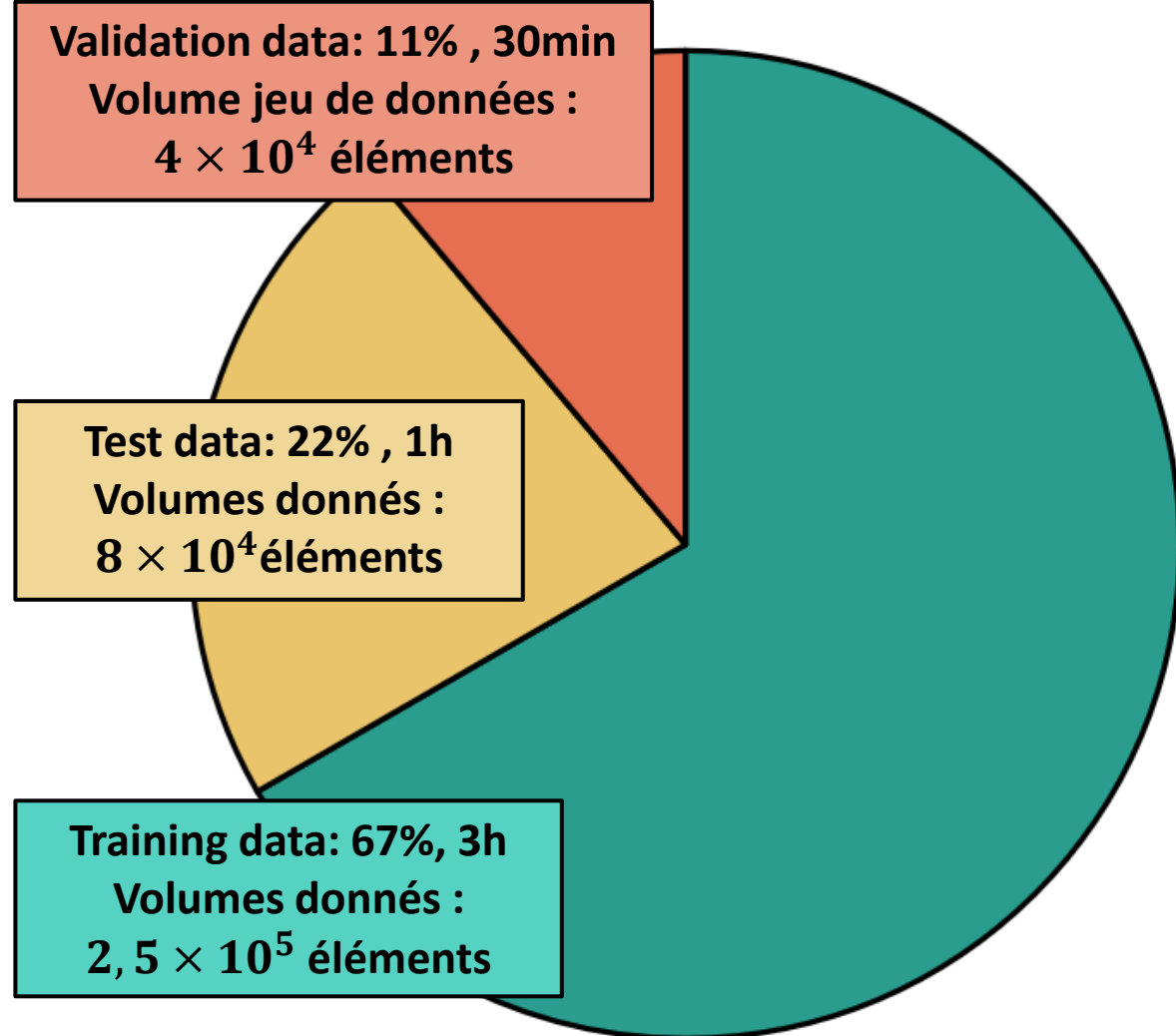
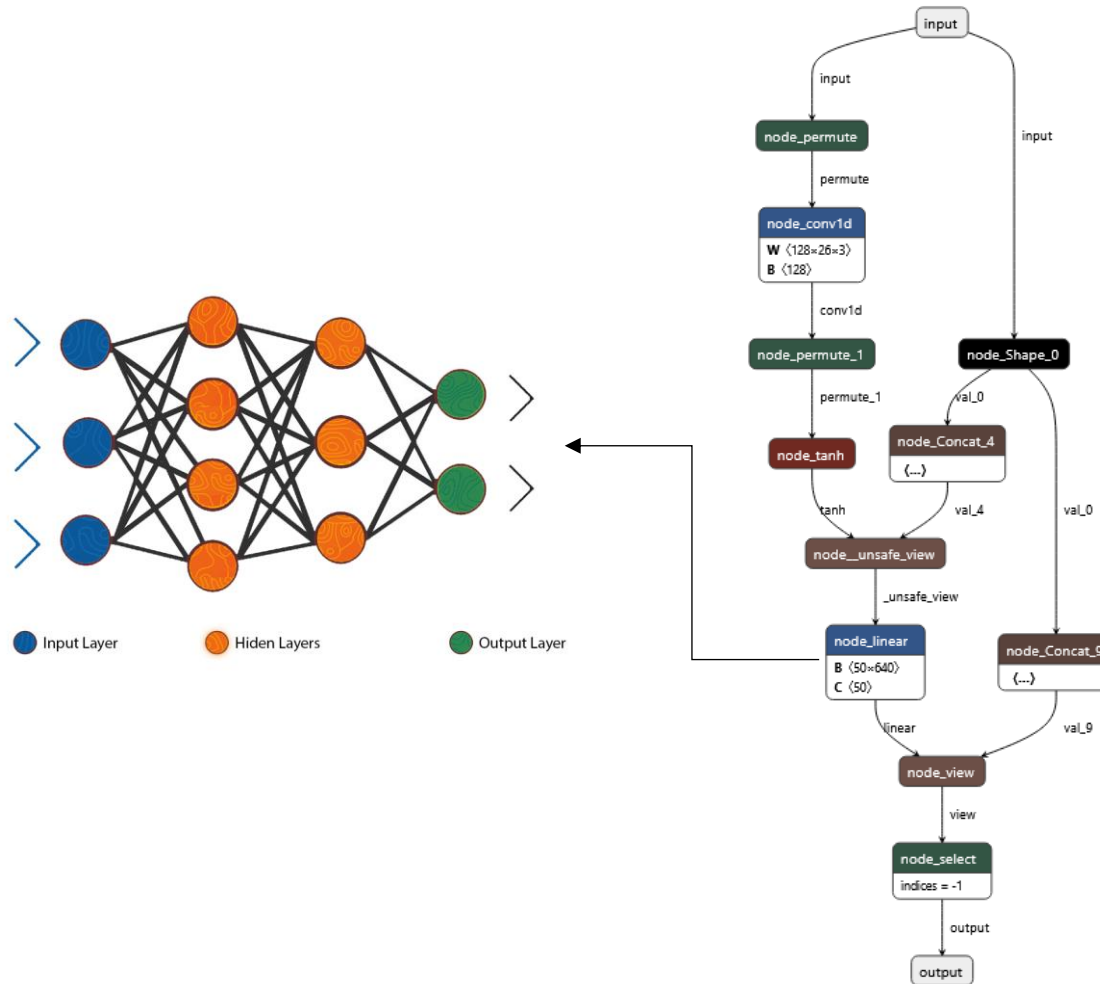
Validation data: 11% , 30min
Volume jeu de données :
 4×10^4 éléments

Test data: 22% , 1h
Volumés donnés :
 8×10^4 éléments

Training data: 67% , 3h
Volumés donnés :
 $2,5 \times 10^5$ éléments

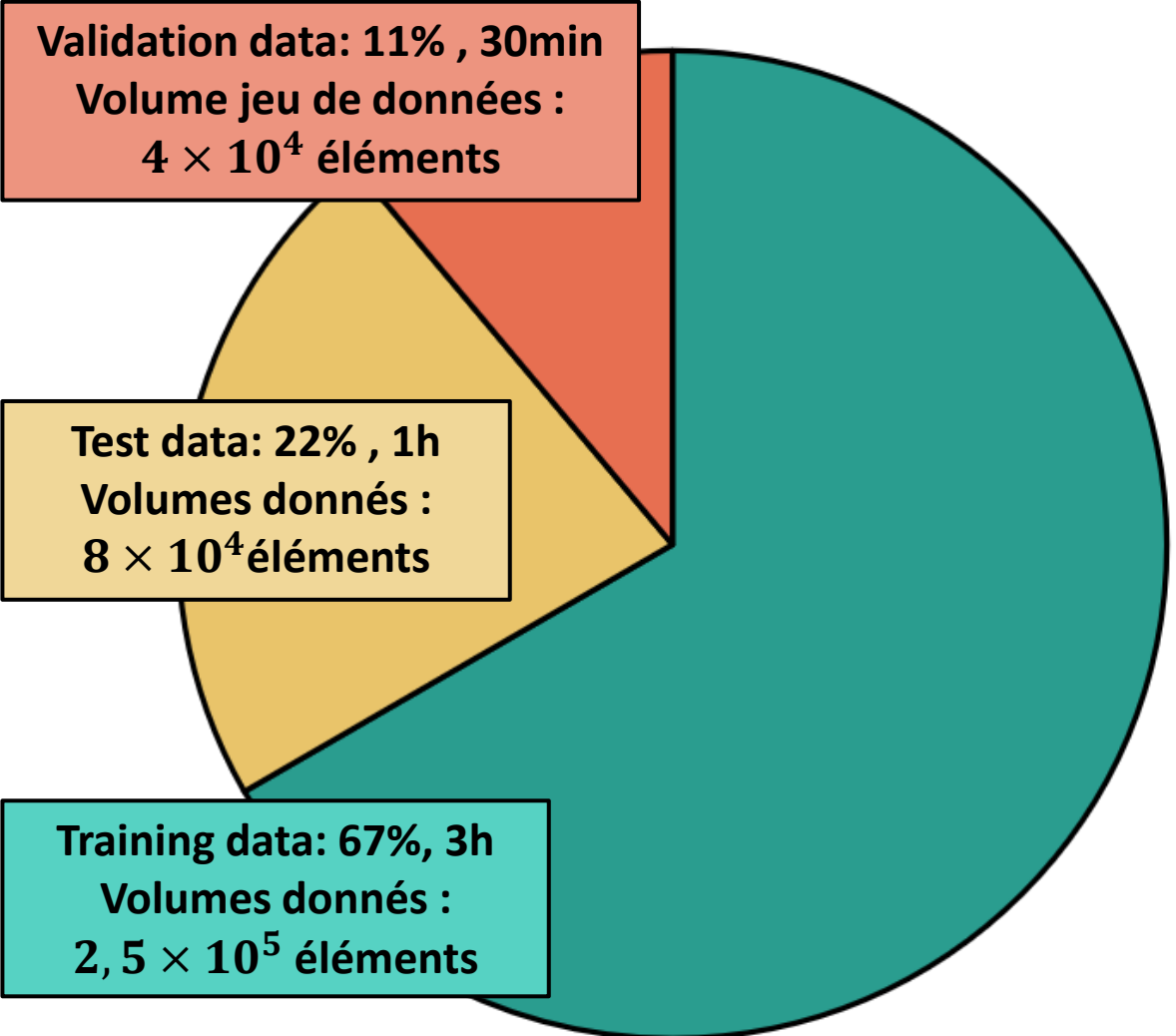
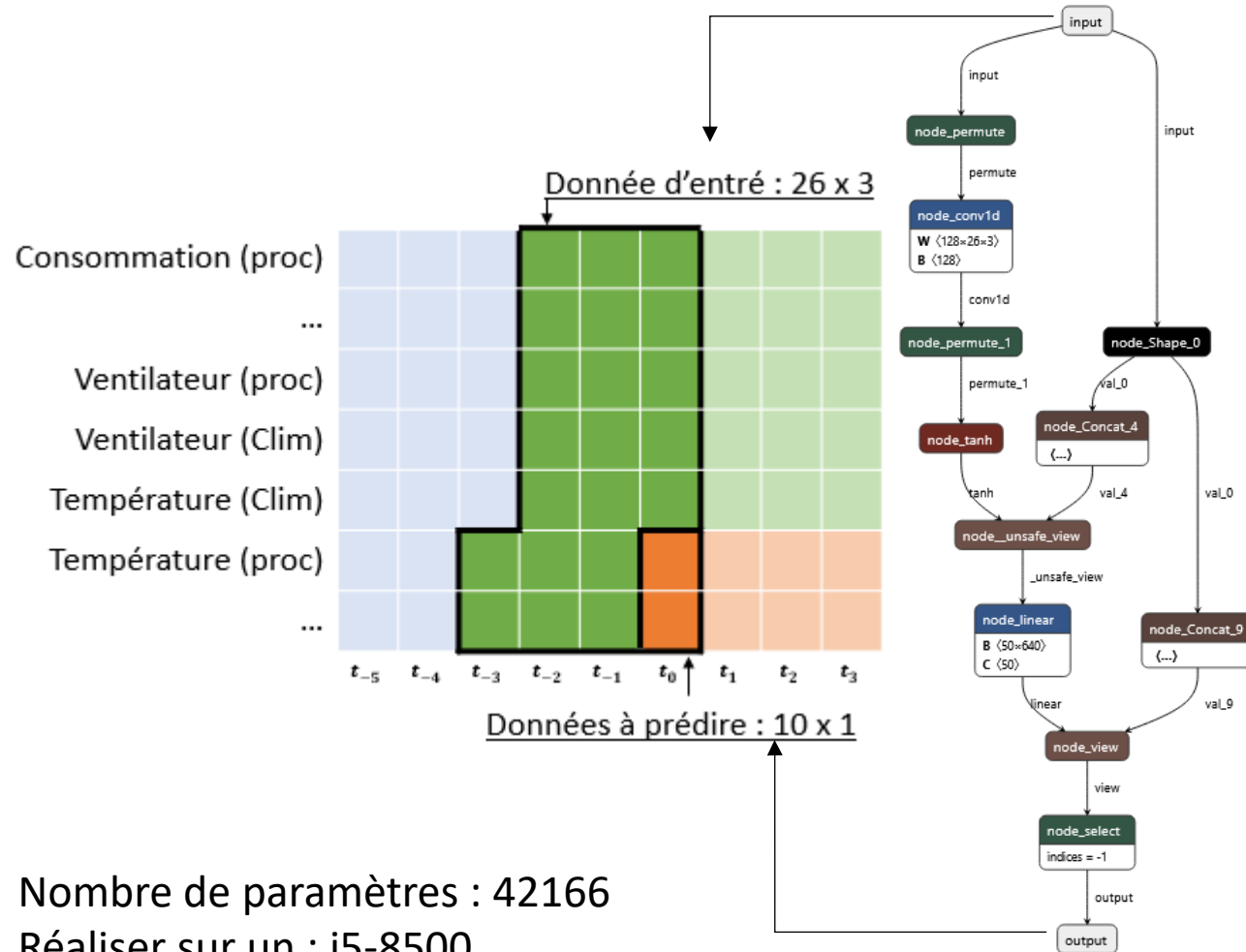
Nos contributions

b) Méthodologie de prédiction.



Nos contributions

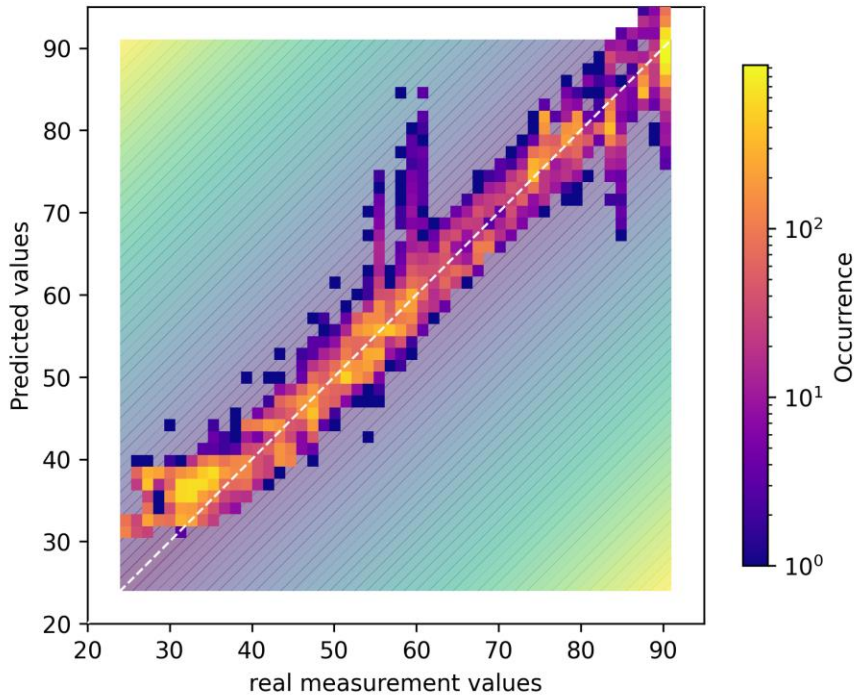
b) Méthodologie de prédiction.



Nombre de paramètres : 42166
Réaliser sur un : i5-8500
Entraînement \approx 10 minutes
Inférence \approx 5 secondes (pour 1h de prédiction)

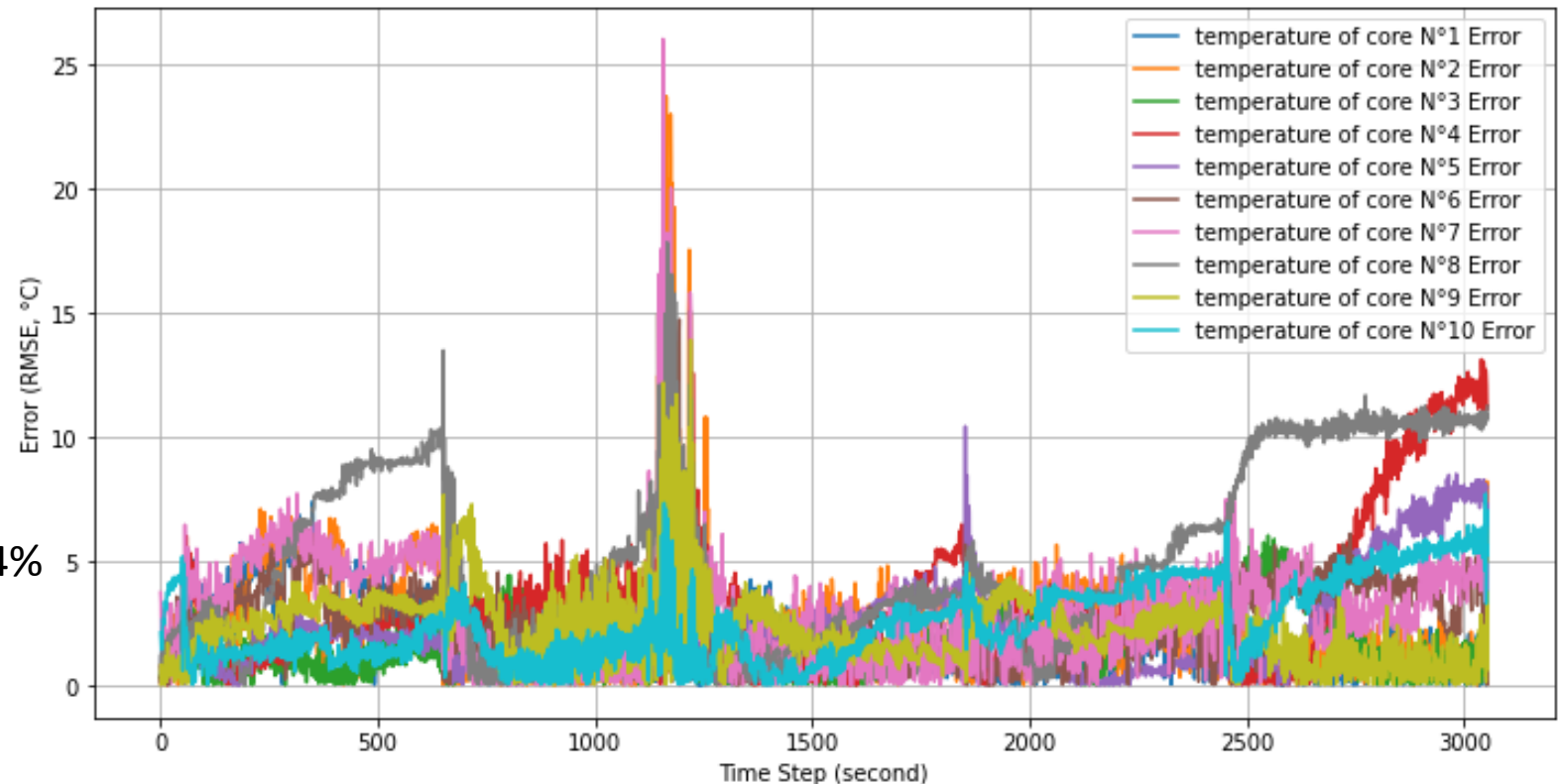
b) Résultat

Prediction VS real measurement



±5 °C pour une plage de températures de 50 °C à 110 °C.
±7 °C pour une plage de températures de 30 °C à 50 °C.
±10 °C pour une plage de températures de -10 °C à 30 °C.
[5] Intel

Error between Predicted and Valid Values



RMSE: 3.57°C

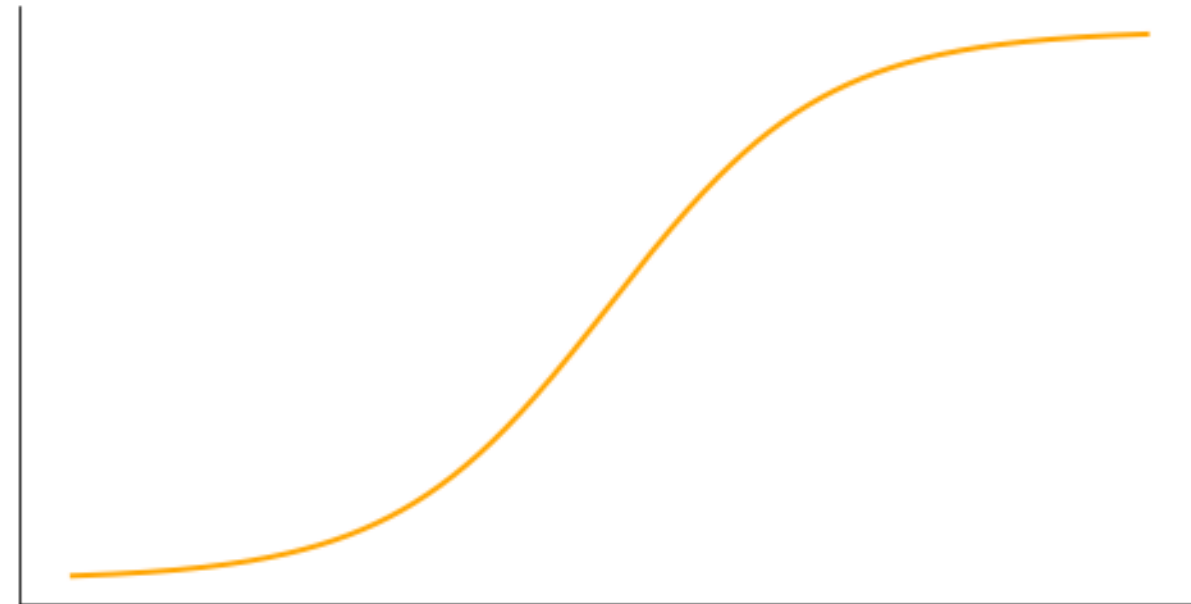
Erreur maximale: 26.02°C

Erreur inferieure à la précision de sondes: 94%

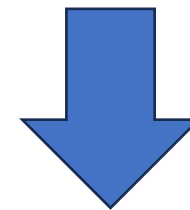
Conclusion

- Introduction à une problématique du refroidissement des centres de données.
- Description de notre banc de test et de l'outil RedGrape.
- Présentation d'une méthode précise de prédiction de température.

Déterministe

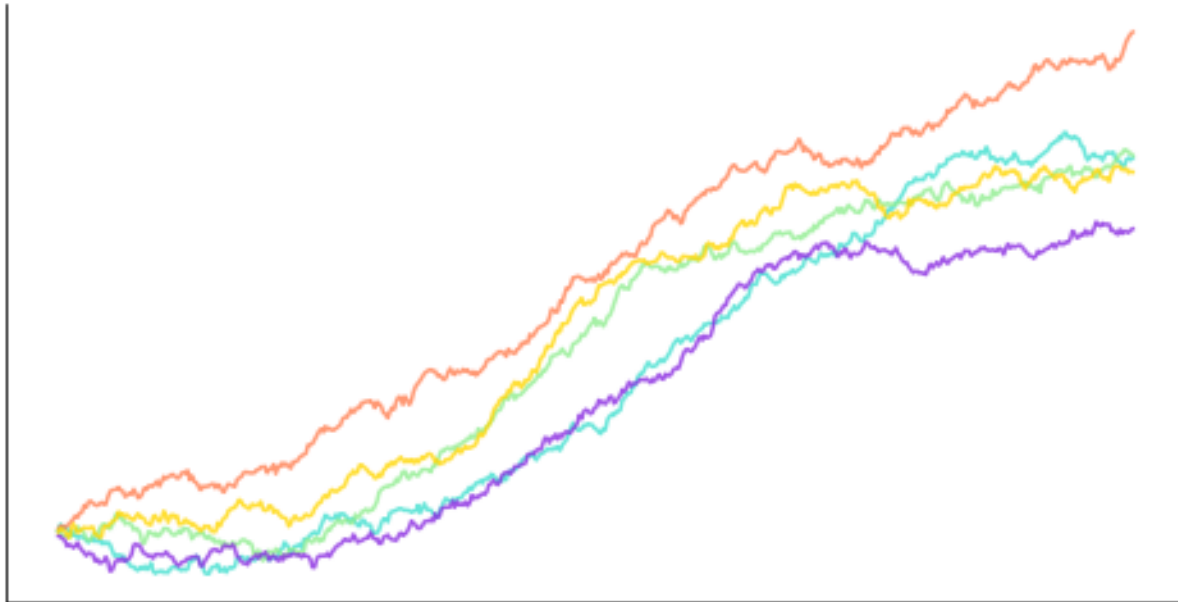


Consommation

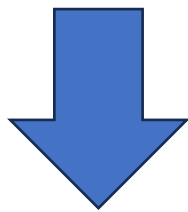


Température

Probabiliste

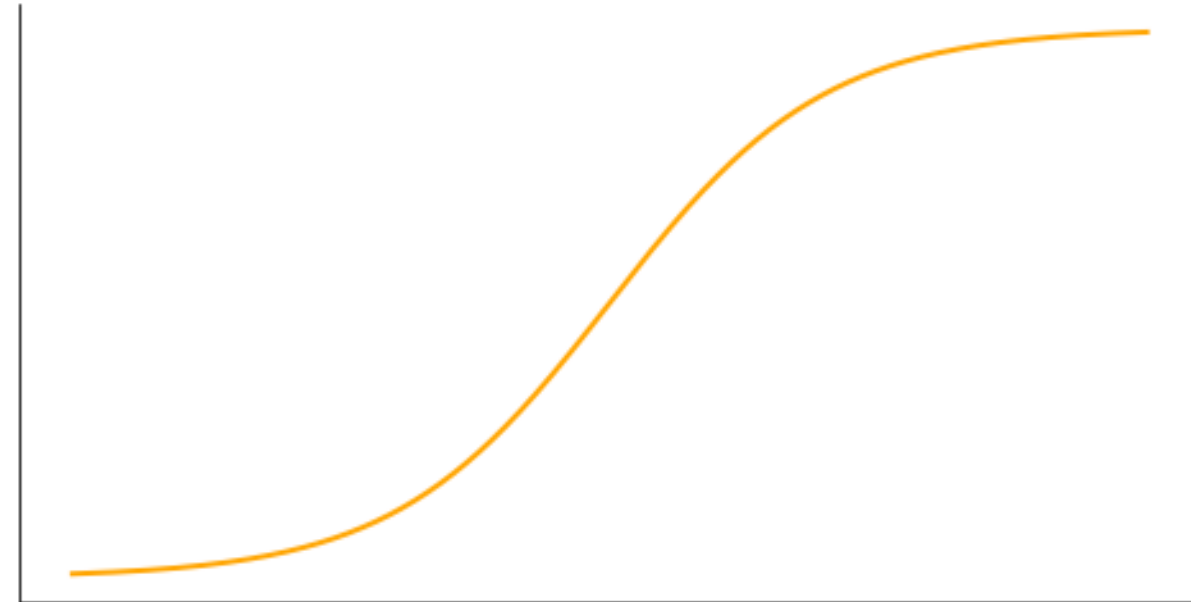


Usage

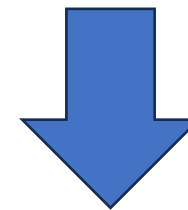


Consommation

Déterministe



Consommation



Température

- [1] “Global trends, performance metrics, and energy reduction measures in datacom facilities”, Amin Isazadeh, Davide Ziviani, David E. Claridge, Renewable and Sustainable Energy Reviews, Mar. 2023.
- [2] “2021 Equipment Thermal Guidelines for Data Processing Environments”, ASHRAE TC 9.9 Reference Card
- [3] “ Dynamic thermal environment management technologies for data center : A review” Y. Du, Z. Zhou, X. Yang, X. Yang, C. Wang, J. Liu et J. Yuan, Renewable and Sustainable Energy Reviews, nov. 2023.
- [4] How data impacts coupled GPUs temperature prediction : a preliminary study based on synthetic data. J. Beurrier, C. Josset, Y. Favennec et B. Parrein, 2026, 18th IEEE/ACM International Conference on Utility and Cloud Computing.
- [5] <https://edc.intel.com/content/www/us/en/design/products/platforms/processor-and-core-i3-n-series-datasheet-volume-1-of-2/thermal-sensor-accuracy-taccuracy>