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Infrastructure de recherche : retours d'expérience sur les actions de performance énergétique du centre de nanosciences et de nanotechnologies (C2N)

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Infrastructure de recherche : retours d'expérience sur les actions de performance énergétique du Centre de nanosciences et de nanotechnologies (C2N).

Research Infrastructures : feedback on energy performance initiatives at the Nanosciences and nanotechnologies center (C2N).

www.c2n.universite-paris-saclay.fr

Unité mixte de recherche

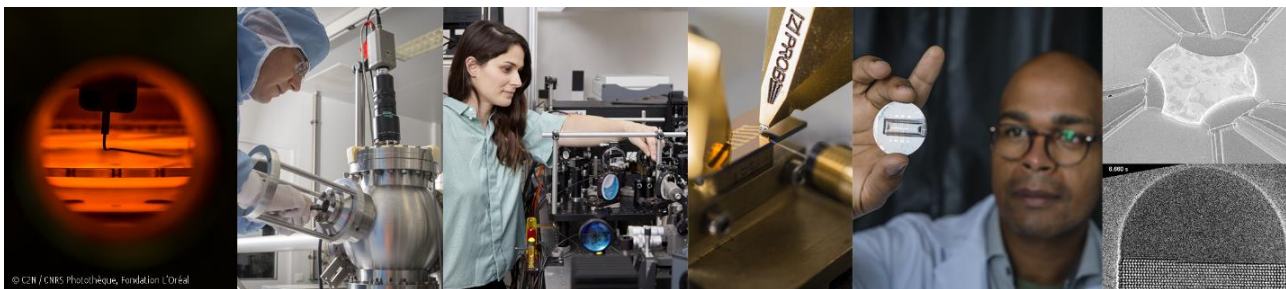


Sophie BOUCHOULE, Aristide LEMAÎTRE, C2N, CNRS.

- Chercheurs au C2N, Dpts Photonique / Matériaux - *Researchers in the Photonics / Materials Dpts.*
- Référents développement durable C2N – *'Sustainable development' contacts at C2N.*

Oral presentation given by S. Bouchoule at the annual conference of GDR Labos 1point5. Thursday, Nov. 07, 2024 - 10:40 am.

<https://l1p5-2024.sciencesconf.org/>



- **Motivations – C2N positioning in the CNRS global greenhouse gas emissions balance ('BEGES' in French)**
- **C2N energy consumption : impact of HVAC**
- **Technical background about HVAC**
- **C2N strategy (2022-2024) : 3 axes, some examples**
 - ✓ Crucial importance of sensing , measuring, and data analysis.
 - ✓ Axis 1 : **spend just (only)** the energy that is really needed.
 - ✓ Axis 2 : **recover waste** heat and energy whenever it is possible
 - ✓ Axis 3 : **decarbonate** the energy you need as most as possible.

- **Perspectives at C2N, and experience feedback**
 - ✓ Next C2N actions on HVAC systems in 2024 => 2025.
 - ✓ Experience feedback – practical conclusion to be drawn.

C2N – located in ‘plateau de Saclay research cluster’



120
CHERCHEURS ET
ENSEIGNANTS-CHERCHEURS



4
DÉPARTEMENTS DE
RECHERCHE



1
CENTRALE DE TECHNOLOGIE

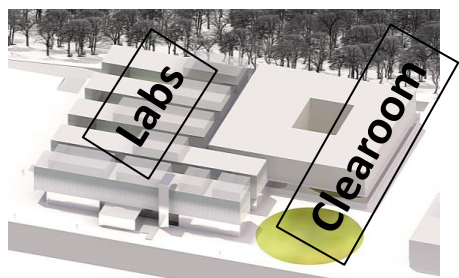
410
PERSONNES

200
PHDs &
POST-DOC FELLOWS

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Photos: Sergio Grazia



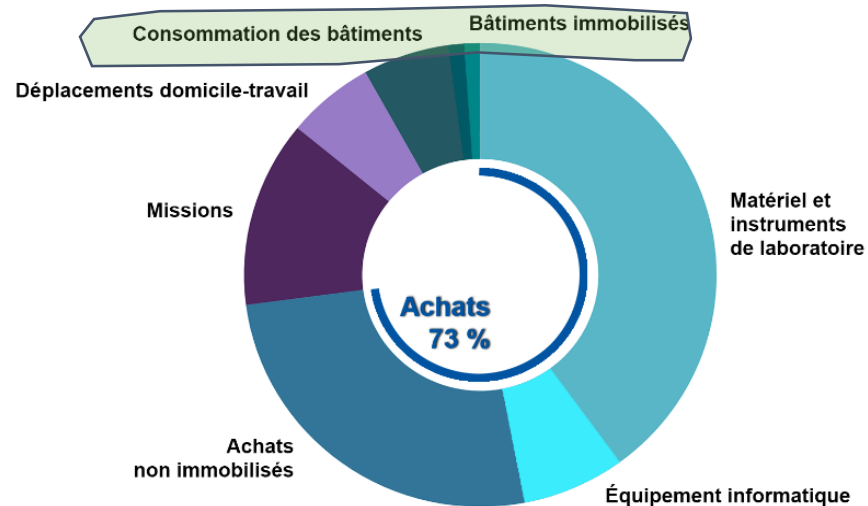
PHOTONICS
MATERIALS
NANOELECTRONICS
MICROSYSTEMS &
MICROBIOFLUIDICS

MICRO-
NANOTECHNOLOGY
- 4 Platforms
- part of RENATECH



CNRS ‘BEGES’ BALANCE- NATIONAL ANALYSIS (2019 data)

© CNRS - Source : BEGES 2022 sur les données 2019
Bâtiments gérés par le CNRS



1. Purchases (sci. instruments & informatics)

2. Travels & mobility (plane : 90%)

3. Energy for buildings (GAS/ELEC : 90%)



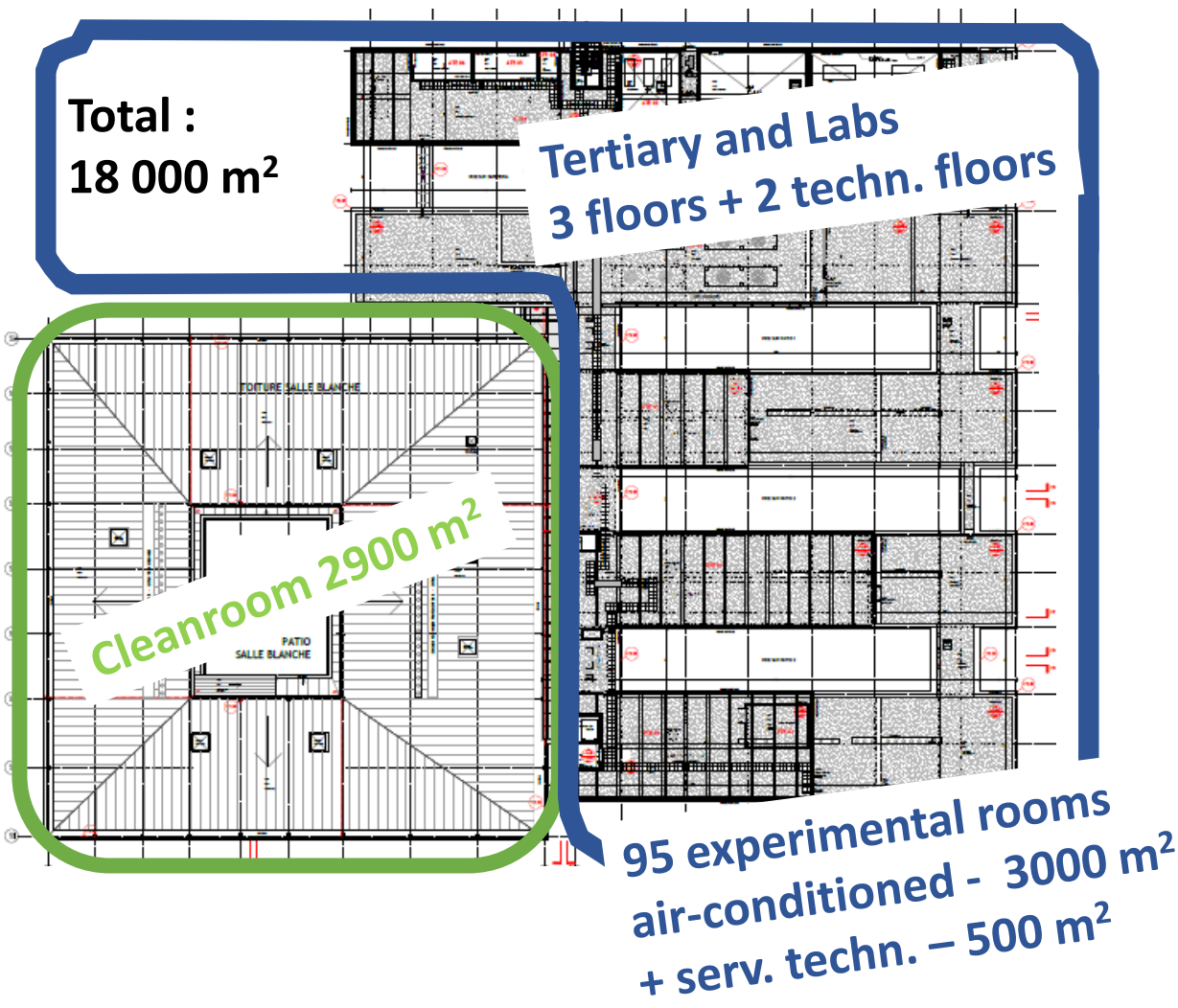
14 t. CO₂-e /year /person (2019)

20 000 persons (C2N < 2%)

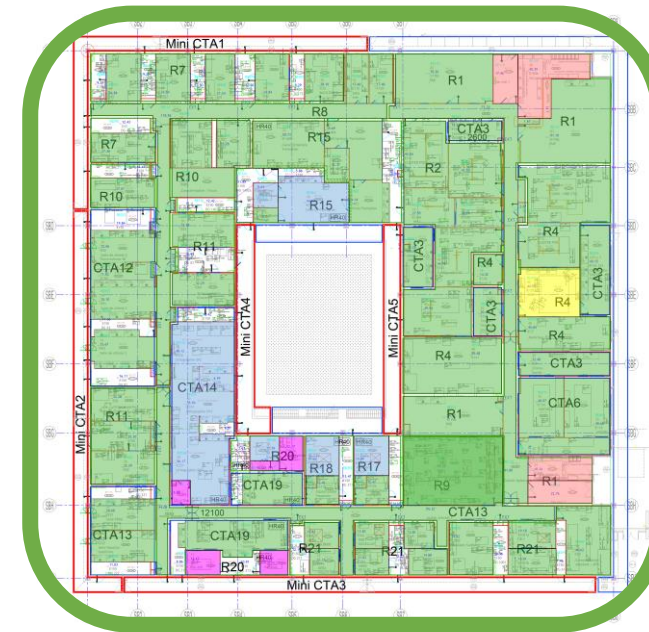
Buildings : 300 GWh (C2N ~ 4,5%)

NEW CNRS 2022 data : <https://www.cnrs.fr/fr/actualite/le-cnrs-calcule-son-deuxieme-bilan-carbone>

Building ~completed in 2018 – conception 2015-2016



- **Cleanroom** : class ISO 5 à 8
Control : P, T°C (20°C ± 1°C), RH (50% ± 10% or 40 % ± 5%)



Dust control
 7/7 -24/24
Overpressure :

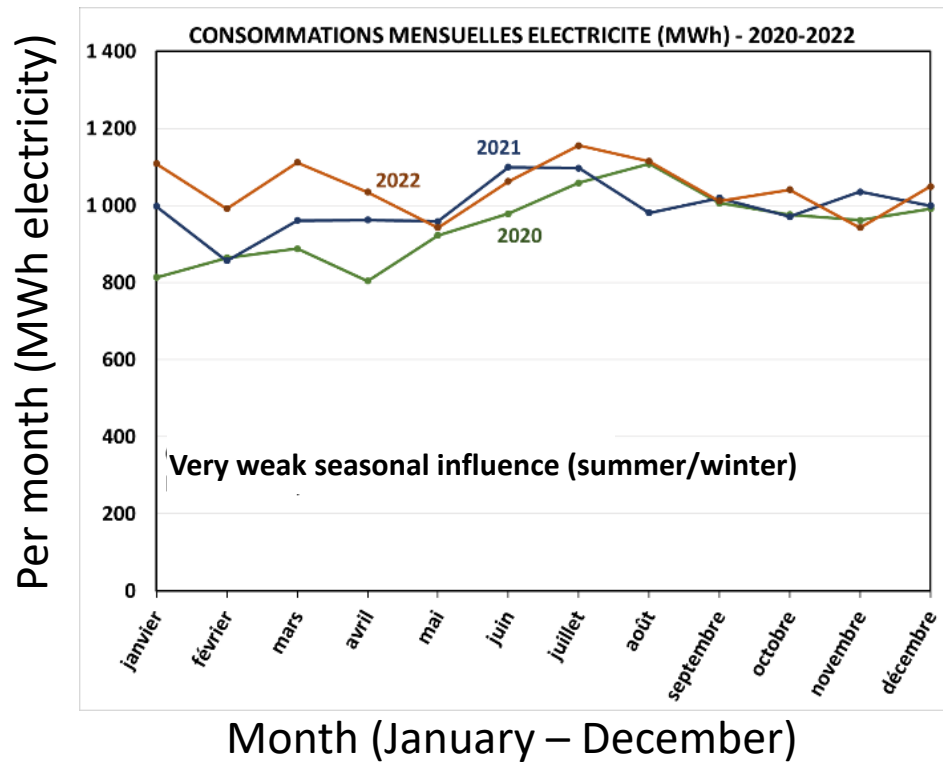
LEGENDE	
	-15 Pa
	+10 Pa
	+15 Pa
	+20 Pa
	+30 Pa

- **Air-conditioned experimental rooms (Labs) :**
Control : overpressure
 T°C (21°C ± 1°C), RH (50% ± 10)
- **Refreshed technical serv. attached to Labs :**
Control : T < 26°C

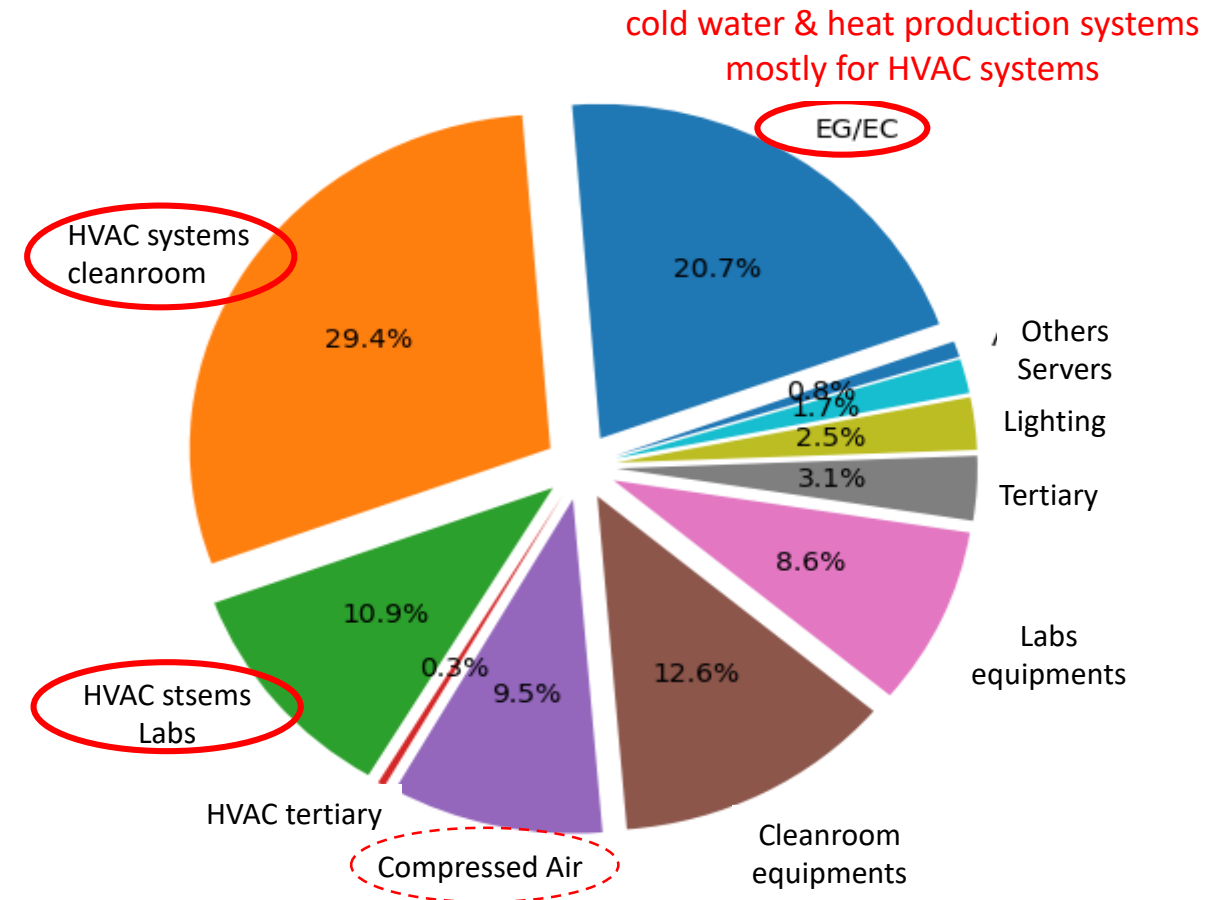
➤ Energy consumption – global data: electricity, gas

GAS (2020 -21) : 6.5 GWh/year (hot water)

ELECTRICITY (2020-21) : 12 GWh/year (the rest)



Annual Electricity consumption - repartition (2022)



55% of our electricity consumption for HVAC systems

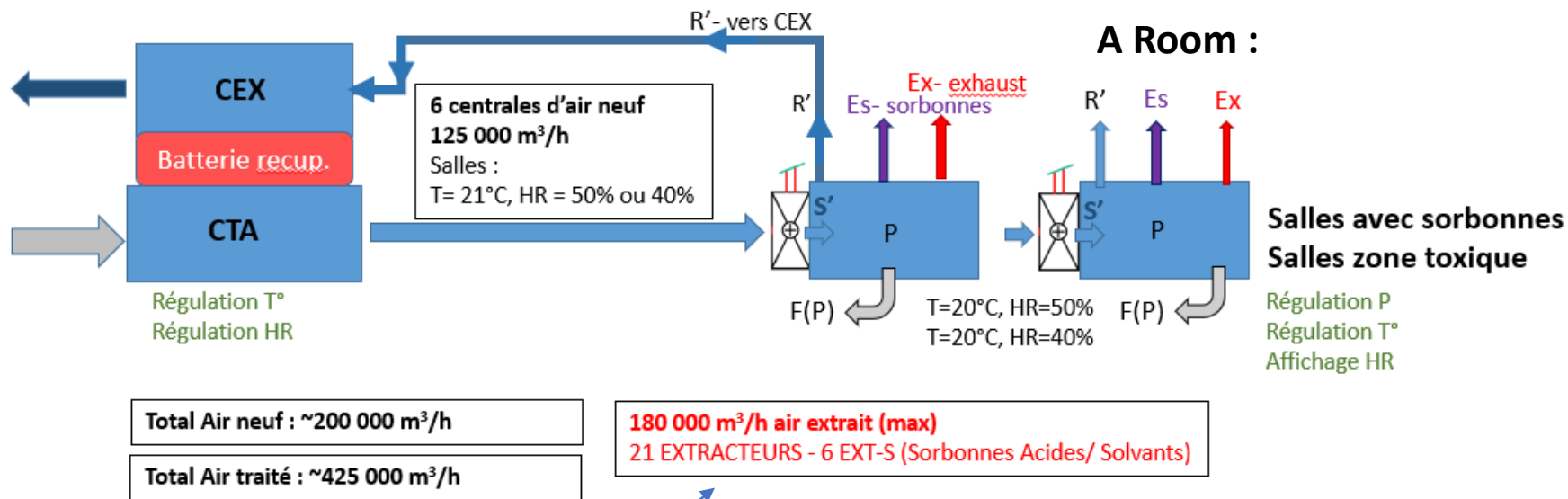
42 % (± 3 %) for cleanroom HVAC, incl.

- ~12 % for cold water production
- ~30% : the rest (vans, humidifiers, circulation pumps, automation, etc.)

- Some technical background is required, if you aim at controlling your HVAC systems.
- Our 'Bible' (UCL – Belgium) : <https://energieplus-lesite.be/>
To learn & understand almost everything !
- HVAC systems principles may vary – this is the C2N case :



1/ Air-conditioning with 100 % Fresh Air :



C2N data – only for cleanroom HVAC.

THE EQUATION for a room:

Fresh air flow-rate (AN) :

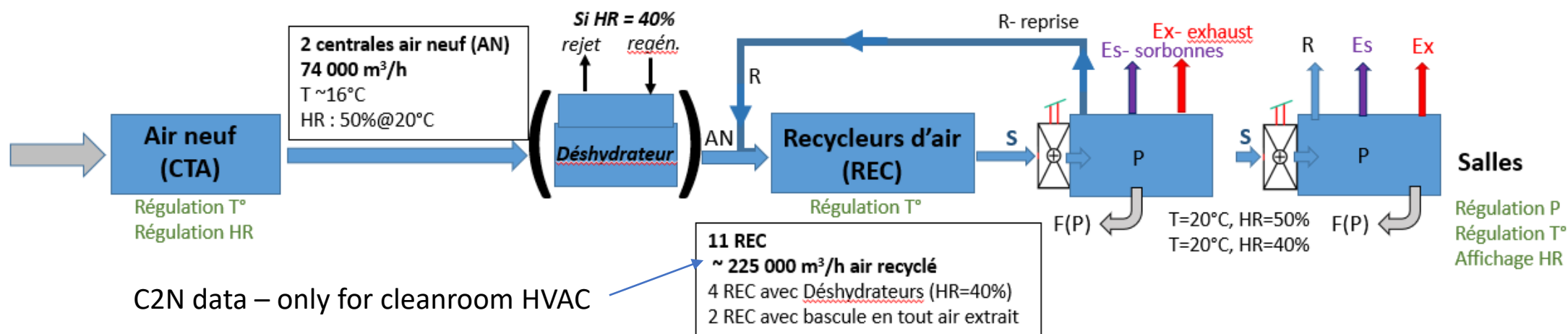
$$AN = S' = R' + Es + Ex + F(P)$$

- S' = AN : blown-in (fresh) air.
- R' : air extracted back
- Ex : other specific extractions
- Es : hoods extraction (if any)
- P : differential (over)pressure.
- F(P) : air leakage.
- F(P) = 0 if P=0, F(P) ↗ if P ↗

➤ HVAC systems principles may vary – this is the C2N case :

2/ Air-conditioning with Air Recycling:

- In some cleanroom areas + in all the Labs at C2N.



C2N data – only for cleanroom HVAC

THE EQUATION for a room:

$$(1) \quad S = R + Ex + Es + F(P)$$

$$(2) \quad S = AN + R$$

$$\Rightarrow AN = \underbrace{Ex + Es + F(P)}_{\text{air loss (to the outside)}}$$

air loss
(to the outside)

S : blown-in air into the room

R : air extracted back to the recycler from the room

Ex : other specific extractions - directly to the outside

Es : hoods extraction (if any) - directly to the outside

F(P) : air leakage

P : differential (over)pressure.

F(P) = 0 if P=0, F(P) ↗ if P ↗

➤ HVAC systems principles may vary – this is the C2N case :

3/ Conditions that fix the minimum flow-rate of fresh air (AN) or blown-in air (S, S')



$$AN \geq E_s + E_x + F(P)$$

Few ~ 1000' m³/h in our cleanroom – P=+15 Pa
Can be large if you have hoods ! (Es ↗ - réglemented).

$$AN \geq AN_{tech}$$

No clear regulations – technical servitudes, etc.. – 1-4 vol/h ...

$$AN \geq AN_{mini}$$

Sanitary rules®ulations – 25 m³/h/person



$$S \geq S_{therm}$$

Calculated, depending on air T°C at inlet/outlet to compensate for the room internal heat sources
few 100's to 1000's m³/h in labs and cleanroom



$$S \geq S_{ISO} \text{ (cleanroom)}$$

Dust control – *theoretical* ISO class – **15 vol/h 200 vol/h ! (ISO8 – ISO4)**

4/ Where is energy spent ?

- ✓ In the motors for the fans (air flow)
- ✓ In the motors for the circulation pumps (cold water, hot water flow)
- ✓ In the production & consumption of frigories for **air dehumidification**
- ✓ In the production of vaporized water (in air) for **air humidification**
- ✓ In air T°C control (cool or heat)
- ✓ Electricity
- ✓ Electricity
- ✓ **Electricity**
- ✓ **Electricity at C2N.**
- ✓ **Gas, electricity**

➤ HVAC systems principles may vary – this is the C2N case :

4/ Where do you spend energy ? → In fresh-air conditioning

Starting from the outside air

- ✓ Bring it to the **set T°C** => bring enthalpy.
- ✓ Add/remove **water vapor in it** (humidification/dehumidification) => bring enthalpy. **Strong part.**
- ✓ **Important value** = specific enthalpy (H_s , kJ/kg_{Air}) brought to air.
- ✓ or difference between H_s of outside air, and H_s setting value inside.

When external air enthalpy = setting value

- ✓ Minimum energy consumption : 'neutral point' of the building.

When H_s of external air is too low (dry air)

- ✓ Main energy consumption = air humidification

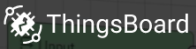
When H_s of external air is too high (humid air)

- ✓ Main energy consumption = air dehumidification
- ✓ **WINTER** : cold, dry air → too low enthalpy → humidification.
- ✓ **SUMMER** : hot, humid air → too high enthalpy → dehumidification.

➤ Crucial importance of sensing , measuring, and data analysis.

- ✓ **C2N asset** : many fluids & others sensors already installed, or ~ easy to be installed.
- ✓ The existing HVAC automation network makes the data available.

- ✓ Some sensors already present in 2018, others installed by us.

- ✓ All consumption data and histories presented, are taken from a database managed by Thingsboard Community Edition software.
Open Source IoT 
- ✓ **Deployed by A. LEMAITRE at C2N over the course of 2021-2022 :**
 - integrated solution periodically interrogating PLCs and other sensors or meters (BACnet and Modbus protocols)
 - storing data in an SQL database.
 - featuring a graphical user interface with easily configurable dashboards.
 - **Our database stores (over > 1 year) around three thousand measuring points every ten minutes.**

- ✓ **Without data, you are blind.**
- ✓ **W/o time spent to analyze the data, you do not understand, what happens.**

➤ **Axis 1 : spend just (only) the energy that is really needed.**

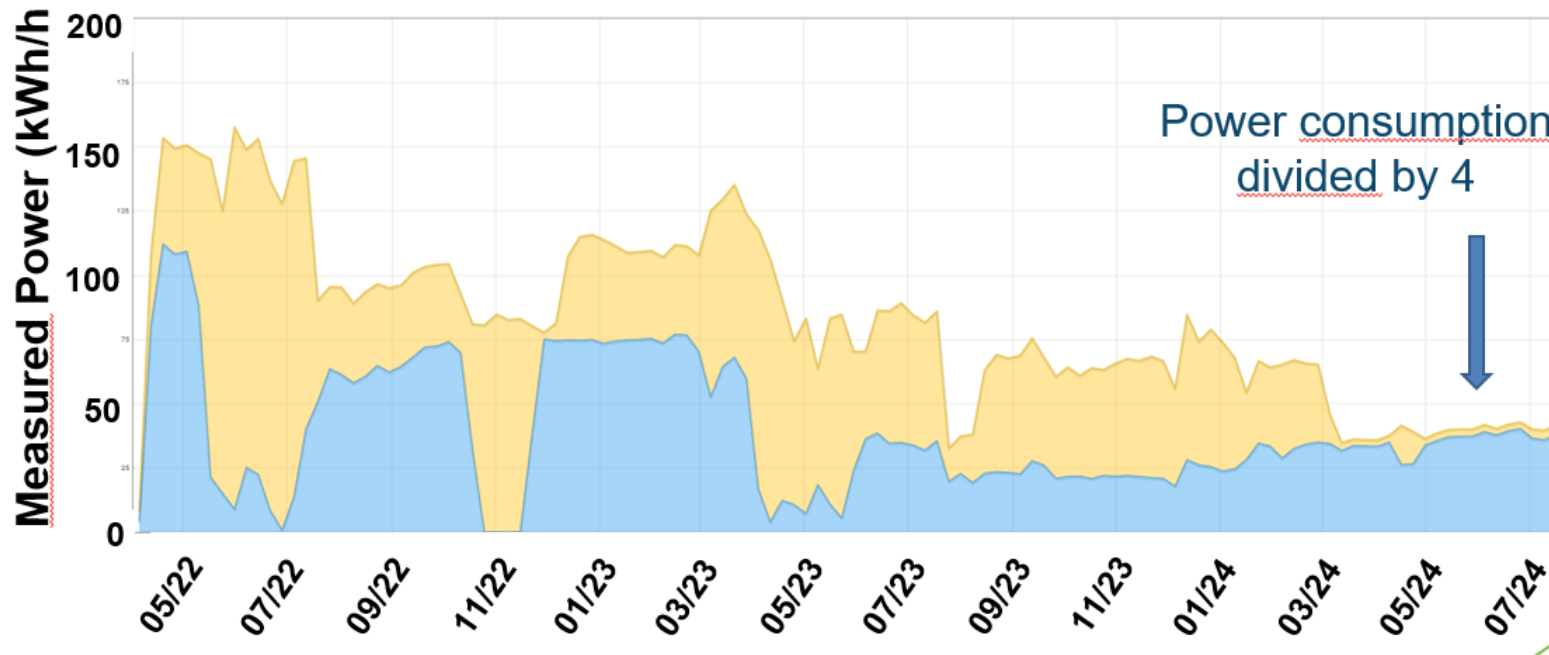
- Control the specific extraction and leakage flowrates. Do not maintain an extraction 'ON' if not required.
- Calculate S_{therm} in your lab. Confront to experience. Adapt your model.
 - ✓ Gain in calories (hot water - **Gas**)
 - ✓ Gain in frigories (cold water – **Electricity**)
 - ✓ Gain in the motors power (**Electricity**)
- Check if the fresh air (AN) flowrate is not oversized. Recalculate it.
- **In 2023, we have started to adapt the fresh air AN flowrate (AN), and total inlet flowrate (S), in the 95 exp. rooms**
 - ✓ Total fresh air flowrate typically reduced by a **factor of 2** (*sometimes limited by oversized equipment*)
 - ✓ The S flowrate per lab, typically divided by a **factor of 1.5 to 2**
 - ✓ 15 labs done.
 - ✓ **Gain – electrical power of the vans' motors : 60 kW => 30 kW in total (-0.26 GWh/year)**
 - ✓ **Expected gain - production of hot/cold water : under analysis ...**

TO BE CONTINUED....

Financial investment : ~0 €
time consuming.

➤ **Axis 1 : spend just (only) the energy that is really needed.**

- Check the efficiency of the operational mode of your most highly-consuming systems.
- At C2N : compressed air production.
- Compressed air needs to be **DRY enough**.
- Systems producing compressed air, always include a **DRYER**.
- This DRYER, generally **uses the compressed air that you have just produced**.
- If drying cycles are badly programmed → important energy waste.



- **DRYERS** have been programmed sequentially.
- **The DRYING cycle** is controlled by a humidity measurement
- **Expected gain : up to 1 GWh/year !**

TO BE CONFIRMED in 2024...

Financial investment : ~24 k€
time consuming.

➤ **Axis 1 : spend just (only) the energy that is really needed.**

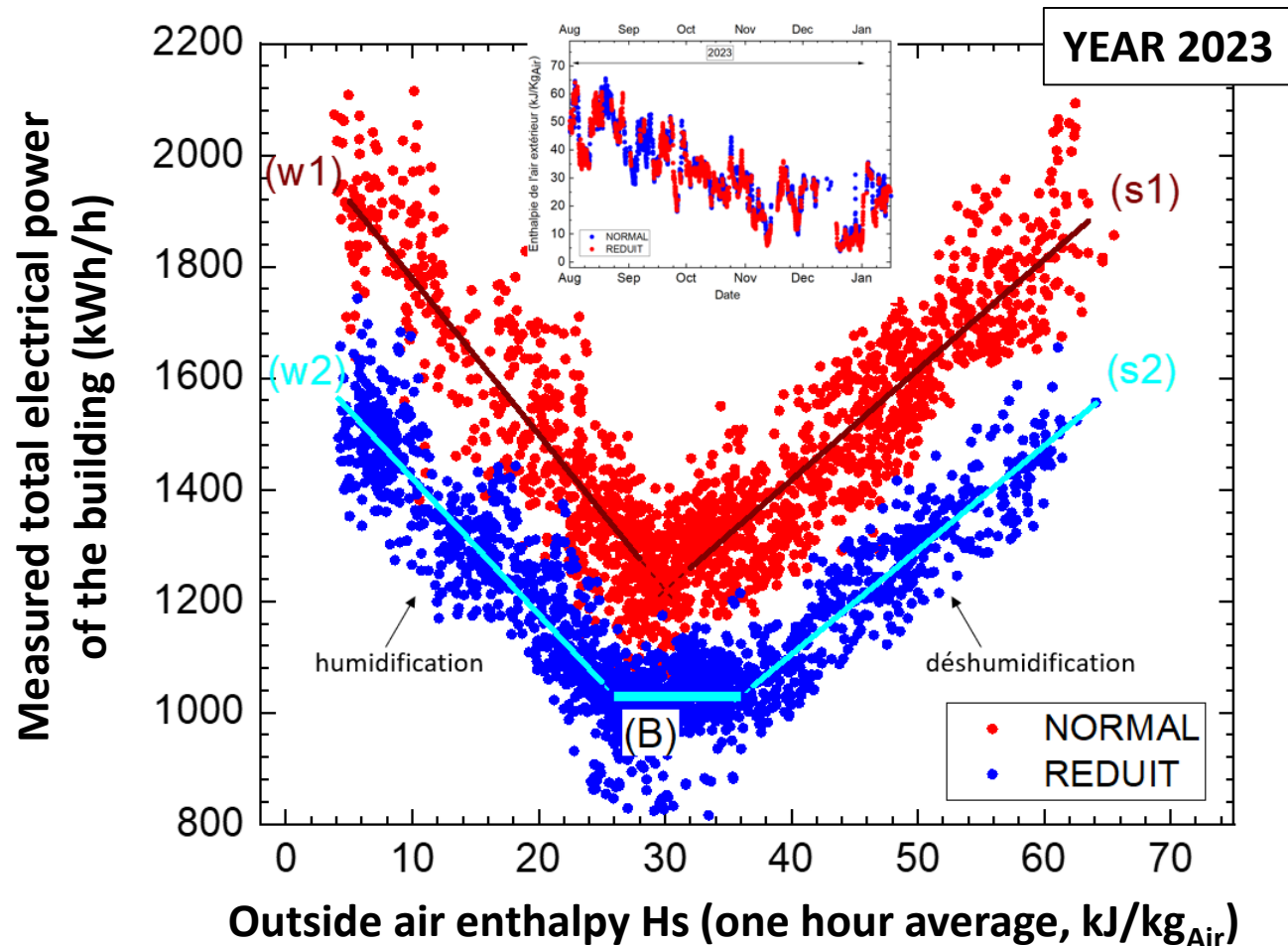
- **Implement a HVAC reduced or ‘degraded’ mode, when the building is un-occupied (nights + WE)**
 - Done in 2022 – with the HVAC constructor.
 - Implemented in some part of the cleanroom only.
 - **REDUCED HVAC mode at C2N means :**
 - ✓ **Reduce** the air flowrate (*S*), degrade the *theoretical ISO class*.
 - ✓ **Relax the tolerances** around the T°C and RH setting values.
 - ✓ In our case the overpressure setting value is kept constant.
 - ✓ The specific extraction flowrates are also unchanged.
- } → fresh-air flow rate (AN) cannot be changed a lot.

	NORMAL	REDUCED	Relative decrease	
TOTAL	Débit normal (m ³ /h)	Débit réduit (m ³ /h)	Réduction (%)	
Fresh Air (AN)				
<i>S</i> _{recycled}	Soufflage air neuf	198 000	164 000	17 %
	Soufflage air recyclé	225 000	154 000	31 %
Ex+Es	Extractions totales (max/min) :	178 000 / 79 000	79 000	-
Es only	Dont sorbonnes (max/min) :	85 500 / 36 700	36 700	-

some part of the cleanroom only

➤ **Axis 1 : spend just (only) the energy that is really needed.**

- **HVAC REDUCED mode, implemented in part of the cleanroom HVAC systems (2022).**



- **Motors (fans, pumps) ∇ -200 kW**
- **'Neutral point' power minimum (B) :**
enlarged in REDUCED Mode : $B \sim [26 - 36] \text{ kJ/kg}_{\text{Air}}$
- **« SUMMER »** - linear fit (s₁) et (s₂)
=> Power ∇ -23% to -18%
- **« WINTER »** - linear fit (w₁) et (w₂),
=> Power ∇ -22% to -19%

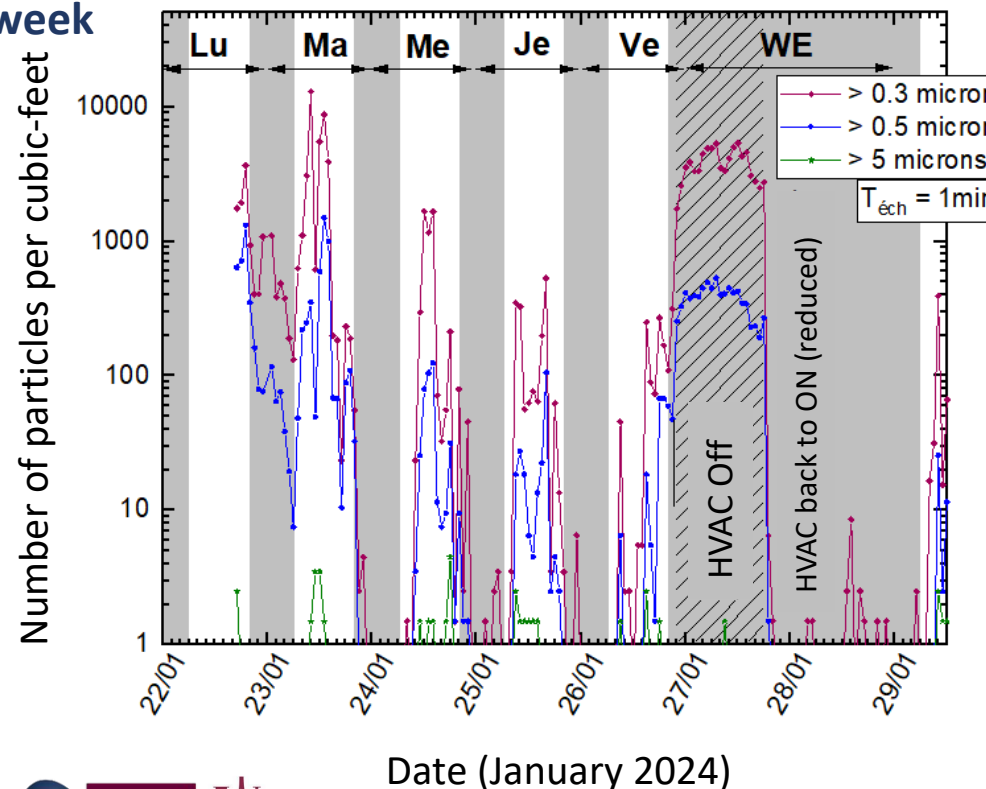
- **Average power decrease : -20.4 %**
(ponderation by the enthalpy statistics)
- **Annual energy savings :**
-12 % or ~1,4 GWh over one year

- **Weak variation of the slopes :**
=> (s₂) / (s₁) ~ -10% ; (w₂) / (w₁) ~ -16%
=> **fresh air flowrate relative decrease - limited.**

➤ **Axis 1 : spend just (only) the energy that is really needed.**

- **What is the actual dust level in the REDUCED mode ?** (un-occupied cleanroom)
- Particle counter installed in one room where the air flowrate is decreased by 55% in REDUCED mode.
- The *theoretical* ISO class is degraded to ISO8 in REDUCED Mode
- Overpressure kept at a constant value : +15 Pa – excepted when the HVAC system is Off (P = 0 Pa)

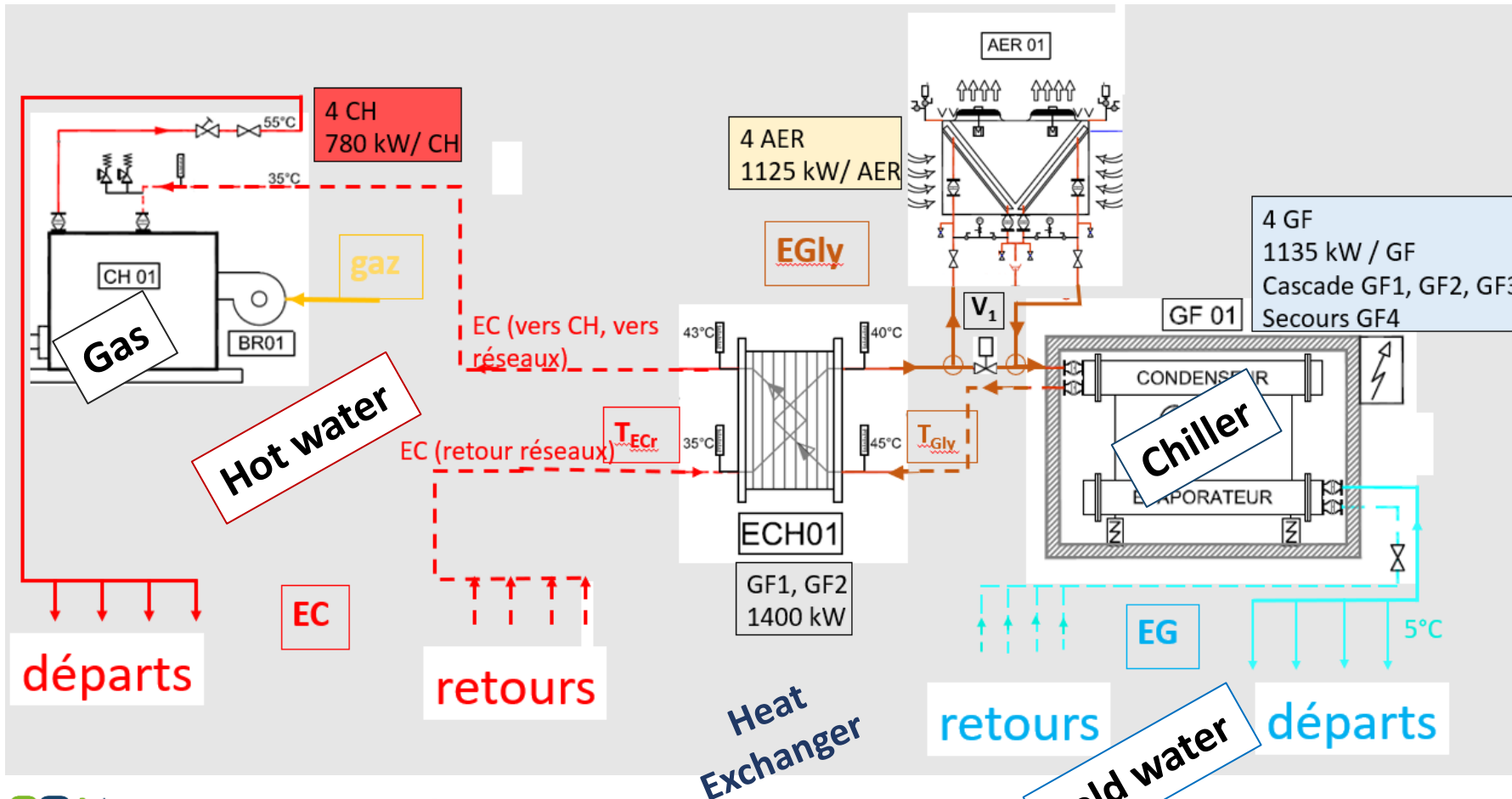
Over one week



- In REDUCED mode, the **actual** ISO class is kept much better than ISO8.
- Actually, even better class than in NORMAL mode (ISO7).
- This is true, if some overpressure is maintained.

➤ **Axis 2 : recover waste heat and energy**

- **Waste heat is produced when producing cold water** : use this heat to get hot water, instead of using gas.
- **A Heat Exchanger is needed**, between the chiller producing cold water, and the hot water network.
- **Check the efficiency of the Heat Exchanger.**

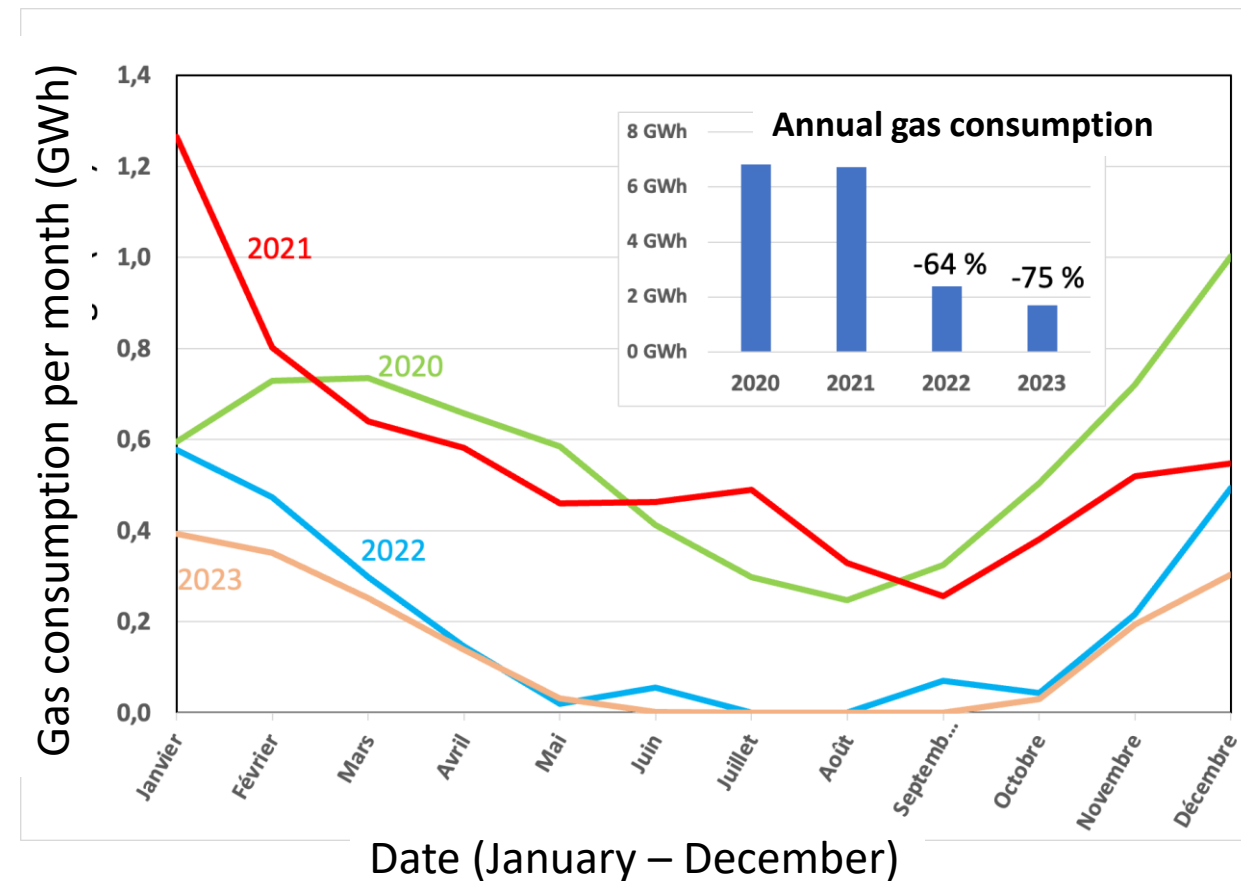


Heat Exchanger efficiency optimisation

- Flow rate EC << EGly.
- **Optimize $\Delta T_{ech} = T_{Gly} - T_{ECr}$**
- $T_{Gly} \Rightarrow 45^\circ\text{C}$ (by construction)
- **Optimize valve V_1**
- **Optimize T_{ECr}** (hot water network)
- Gas heater :
- **Heating law programming**
- T_{ext} dependency
- $T_{EC} = f(T_{ext}) \sim 40^\circ\text{C} - 55^\circ\text{C}$

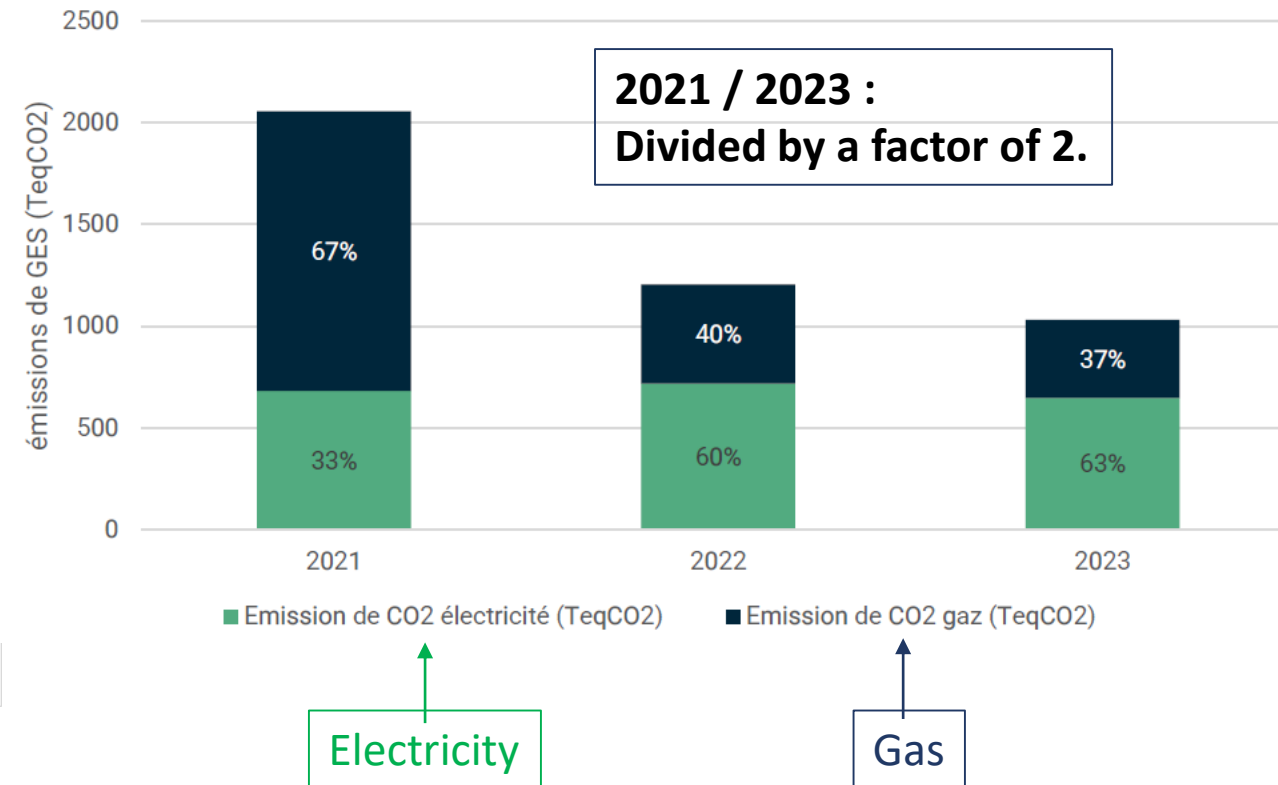
➤ Axis 2 : recover waste heat and energy

▪ Results



Gas no more needed from ~June to September
The heat exchanger does the job.

C2N building - Equivalent GreenHouse Gas emission :



➤ **Axis 2 : recover waste heat and energy**

- **Our conclusion : If cold and hot water is produced on-site, Heat exchanger is extremely powerful.**
- **At C2N : we consider extending this principle to other waste heat sources :**
 - **To air-conditioned air (at 21°C) extracted and rejected outside by specific extractors in the cleanroom**
 - **To a compressor in the Liquid-He recuperation system**

 - **To be further analysed ...**
 - **Installation costs...**

➤ **Axis 1 : spend just (only) the energy that is really needed.**

- In 2024, we have extended the REDUCED Mode to some HVAC systems producing fresh air for the Labs.

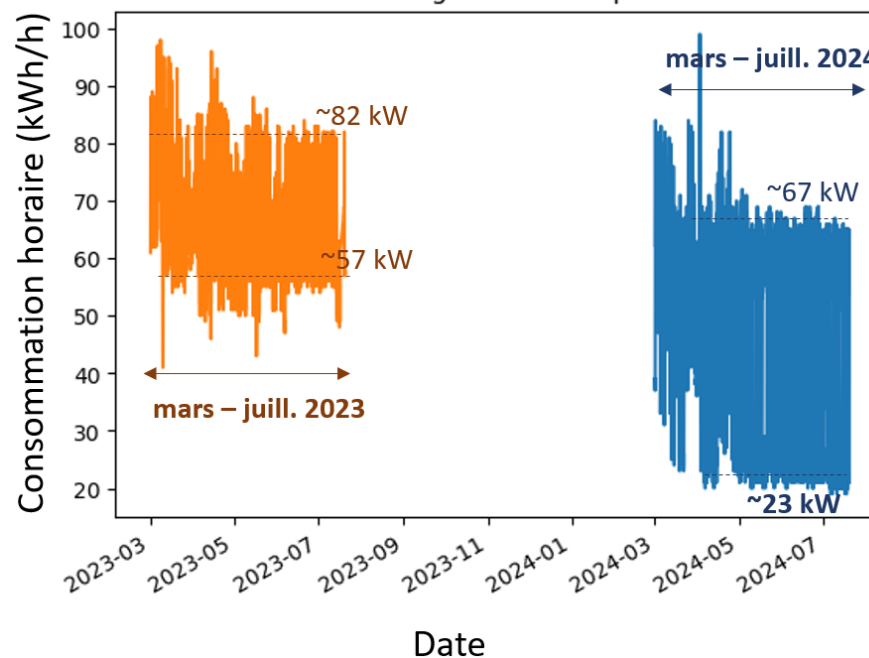
- ✓ Minimum investment
- ✓ Only programming and automation.
- ✓ No hardware change (regulators, motorization, etc.)

AAP CNRS Bas Carbone CNRS 2023

Financial cost : 20 k€ + Time

Estimated Energy savings : > 0,4 GWh/year ..

EXAMPLE : Motors (fans and pumps) – HVAC Labs



- **Electrical power**

Motors :

↳ – 70 000 kWh (over 4.5 months)

Motors + Humidifiers :

↳ – 100 000 kWh (over 4.5 months)

- **Building total consumption**

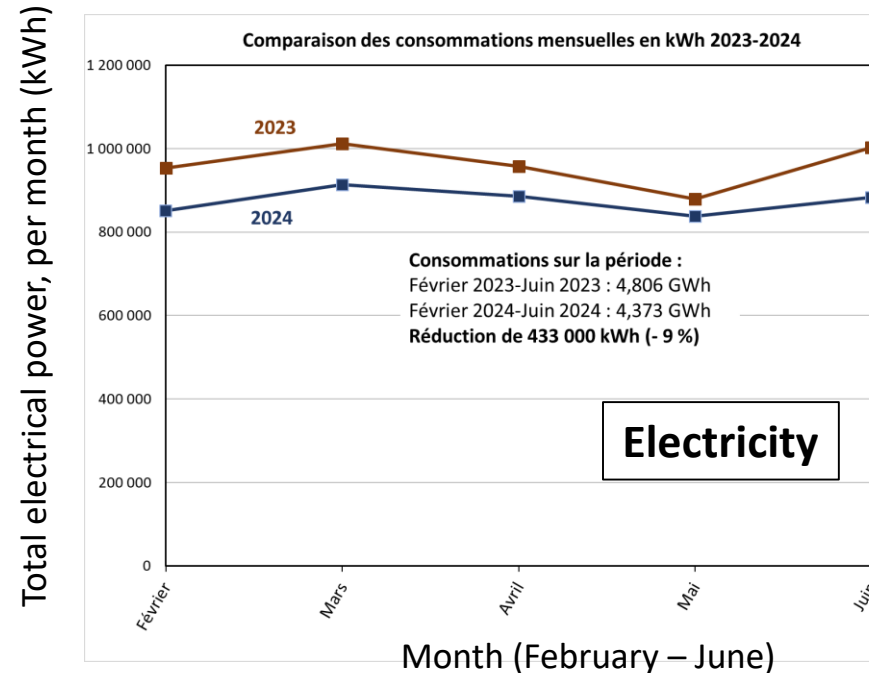
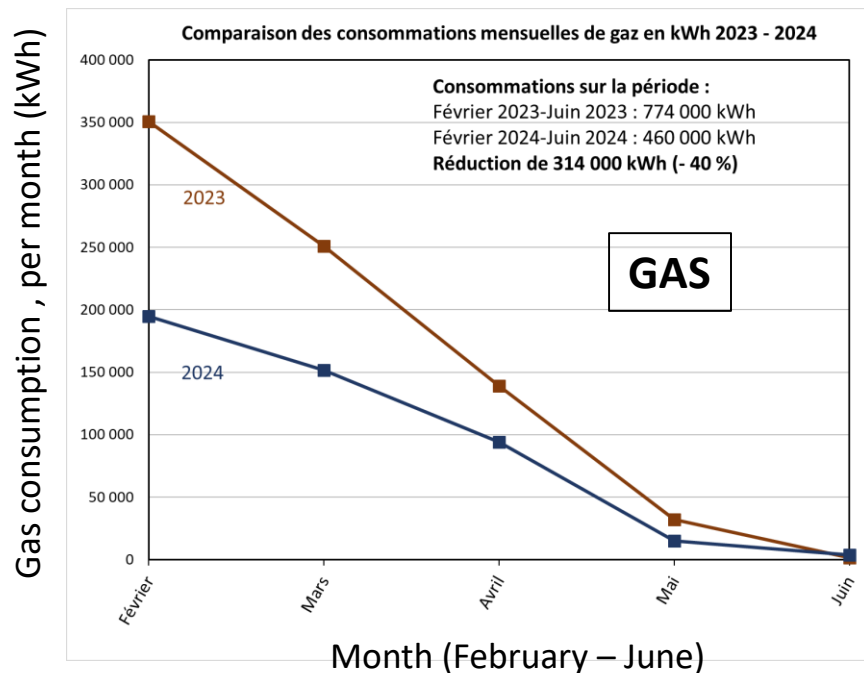
Electricity Feb.-June 2024

↳ – 400 000 kWh (vs 2023).

- **ROI : < one year.**

➤ **Axis 1 : spend just (only) the energy that is really needed.**

- **Total energy consumption - Status mid-2024, after the different 2024 actions :**



Electricity – energy savings:

- **9% decrease**
- **To be further analysed along 2024**
- **Our goal :**
 - < 10 GWh/year
 - 20% compared to 2020

➤ **Axis 1 : spend just (only) the energy that is really needed.**

- In 2025, we will continue to rationalize our air flowrates in the Labs
- we will install real-time particle counters in cleanroom for monitoring the dust level vs the flowrates....
- In 2025, we will extend the REDUCED Mode to other HVAC systems in cleanroom, and to all Labs.
 - ✓ More important investment
 - ✓ One-year work on the HVAC installation
 - ✓ **Supported by CNRS – DR04**
 - ✓ Capitalizing on the previous experience.
 - ✓ C2N people active in defining the program, supervising the work.

Financial cost : 400 k€ + Time.

Expected Energy savings : 1 GWh/year

Etat –Programme 348
TRANSITION ENVIRONNEMENTALE

➤ **Axis 2 : recover waste heat and energy**

- In 2024, an energy audit of C2N building was supported by CNRS-DR04.
- Heat exchangers are possible at some other locations.
- Modifications of the installations are needed, at this point (financial cost).

➤ **Axis 3 : decarbonate the energy still needed (as most as possible)**

- In 2024, we have evaluated (with IPVF colleagues) that ~ 500-700 kW of PV power is available on the C2N roofs
- In 2025, we will evaluate more precisely technically such an option - with the support of CNRS-DR04.

- The energy audit in 2024 concluded that **Gas consumption could be almost completely suppressed.**
- At the cost of important modifications
- and more electricity needed. But with a greenhouse gas emission net decrease.

- **Energy audit : represents a certain cost ... but bring ideas !**

- **Measuring is of crucial importance. You are blind otherwise.**
- **It is required to invest time, to acquire knowledge and expertise in the subject, and to be involved in the implementation of actions, and in the analysis of these actions.**
- *or to have plenty of funding ... but even so, it is needed to be active in the work supervision and results analysis.*
- **To be efficient, act collectively (gather the expertise of colleagues in data analysis, technical aspects, automation)**
- **Question the usual rules about air flowrates, pressure, extractions, generally fixed for dust control : is it *really* needed ?**
- **Start small. If successful, it will represent the first step towards more important modifications**
- **The first % of reduction may generally be easy to gain**
- **The last % of reduction will be the hardest...**
- **At this level :** thinking about *how to change our own work* to spend less energy, might become necessary...

➤ **MORE TO READ :**

www.cnrs.fr *Transition bas carbone : un plan ambitieux pour le CNRS ; Plan de transition du CNRS – la performance énergétique des bâtiments,*
<https://thingsboard.io/> Thingsboard CE, an open-source IoT platform.

R. Vallin, S. Bouchoule, et A. Lemaître, *Mise en place de modes Normaux et Réduits, gains énergétiques associés et développements futurs,* Journée technique de l'ASPEC – Contamin@Bordeaux, Bordeaux, 9 nov. 2023. <https://hal.science/hal-04620420v1/>

S. Bouchoule, A. Lemaître, *Etablissement de recherche - Actions de performance énergétique et retours d'expérience du Centre de nanosciences et de nanotechnologies,* Salles Propres n°143, pp 32-41, mars 2024. <https://hal.science/hal-04556913v2/>

This presentation : <https://hal.science/hal-04630156>

QUESTIONS ?

Alain CLÉMENT, Laoges THAO (SLI/C2N/CNRS) for their continuous support in the implementation of the actions.

Antoine CASELLES (SLI/C2N/CNRS) for his technical support and the link with the maintenance

Alain PÉAN (SI/C2N/CNRS) for his support with the servers, the database, and the supervision tool.

Sebastien SAUVAGE (C2N / Photonics Dpt) for having actively join us to rationalize the HVAC systems of the Labs.

Stephane COLLIN (C2N / Photonics Dpt) for his help in evaluating the Photovoltaic potential.

The C2N “HVAC labs team” (10 researchers & engineers) acting as local contact points when modifications are decided in the HVAC of the labs.

The C2N cleanroom engineers involved in the modifications proposed for the cleanroom :

Special thanks to **Abdelmounaim HAROURI** for his constant supervision of the actions on the hoods extraction in 2024

Denis BOLE, J.-P. MARCHESSEAU (STL/DR04/CNRS) for their support, and for the common strategy and common analysis of the actions.

The maintenance team (Dalkia) on site C2N, for their collaboration and for accepting to implement our ideas onto the HVAC systems.

R. VALLIN and V. ANTOINE (Equans, Axima) for fruitful discussions during the 1st implementation of the REDUCED mode, and waste heat recovering
R. Vallin supervised the implementation and exploitation of the REDUCED Mode in cleanroom in 2022. <https://www.ma-page.pro/site/richardvallin/>

A. TOUIT et J. NICOLLE (Equans, Carbon Shift) for the fruitful discussions during the energy audit of C2N building.