

## An IAQ and thermal comfort coach prototype to improve comfort and energy consumption thanks to adequate management of natural ventilation:

Genesis, development and first feedback results

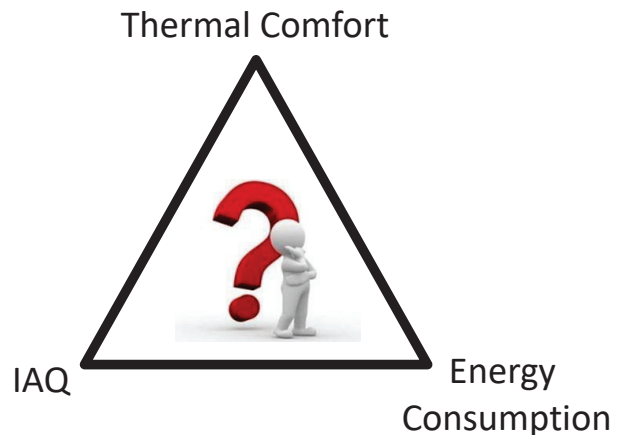


**Arnaud JAY**, Pierre BERNAUD, Franck ALESSI  
CEA, liten – Campus INES  
FRANCE



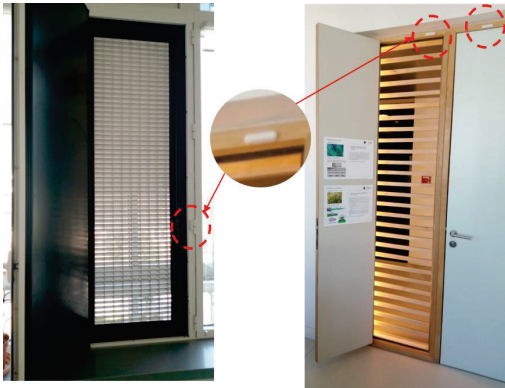
### CONTEXT

- Natural ventilation through open Windows allows to exchange easily 5 - 10 ACH for free
- But might bring some additional energy consumption or incomfort if open at inappropriate time



## Wind'ose genesis :

### Monitoring of our Naturally ventilated Office Building in Summer period



Monitoring of Windows /Doors opening

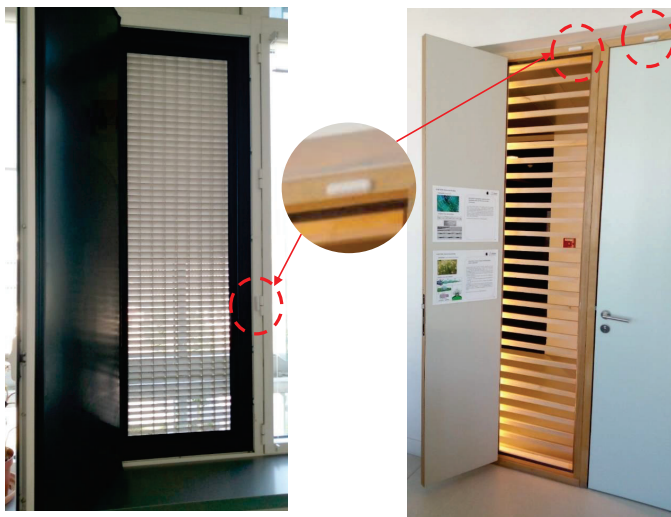
Interface to collect User feedback



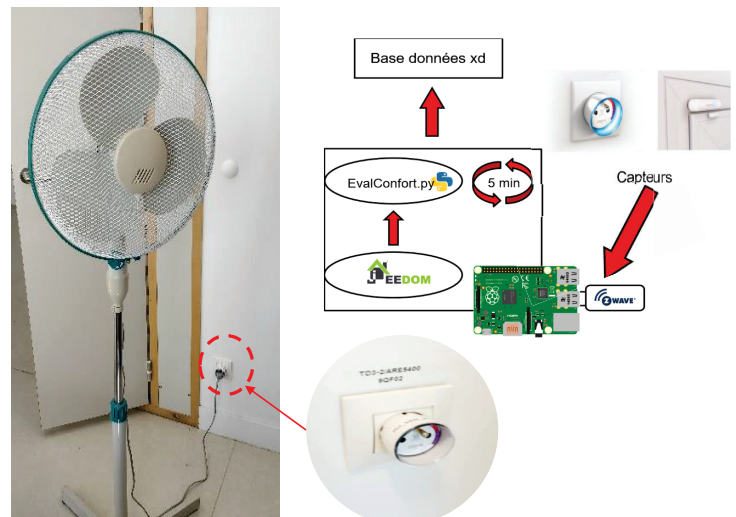
Exploring window opening behaviour for optimal cooling and thermal comfort

INIVE Webinar – 26 March 2024

## OPENINGS STATUS AND FAN MONITORING



Contact sensors on all openings on 2nd floor of west wing.



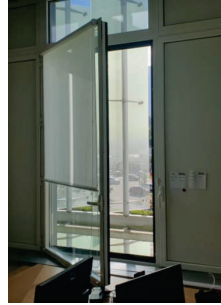
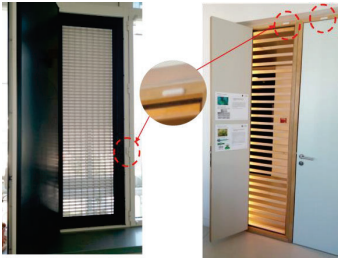
Power meters for fans .  
+ Z-wave repeator



Exploring window opening behaviour for optimal cooling and thermal comfort

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## Initial behavior campaigns: First results (1/2)

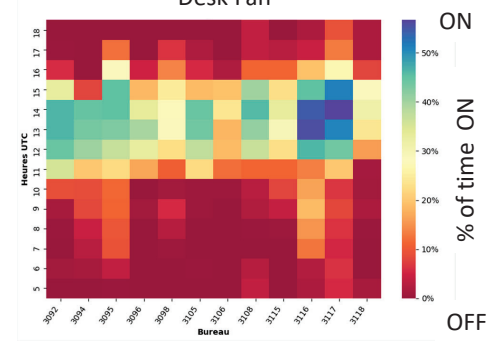
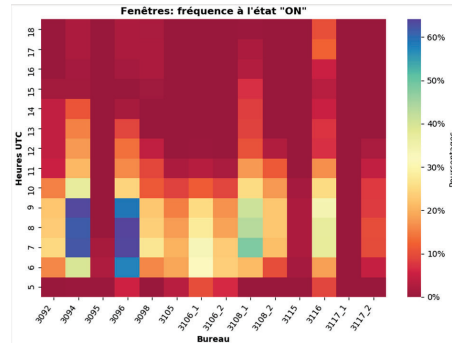
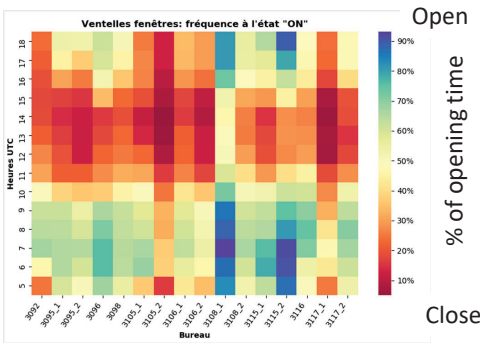


Window louvers to Outdoor and corridor

Windows to outdoor



Desk Fan



Exploring window opening behaviour for optimal cooling and thermal comfort

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## Initial behavior campaigns: First results (2/2)

### Clothing

Évaluation du Confort des Occupants

**VETURE**

Manche: 1-tête manche, manches courtes, manches longues

Manche: 2-tête manche, manches longues, pull

Bas (longueur): court, mi-long, long

Bas (taille): taille ajusté, taille étroit

Foot: pieds nus, sandales (ou pieds nus), chaussures avec chaussures, chaussures avec chaussures, chaussures avec chaussures

### Thermal Comfort : sensation, preference, satisfaction, acceptation

CONFORT THERMIQUE

Comment vous sentez-vous maintenant, avez-vous ?

Tête/froid, Froid, Légèrement froid, Légèrement chaud, Chaud, Très chaud

Souhaiteriez-vous avoir ?

Plus froid, Pas de changement, Plus chaud

Êtes-vous maintenant satisfait de cette ambiance thermique ?

Insatisfait, Satisfait, Satisfait, Satisfait

Trouvez-vous cette ambiance thermique acceptable ?

Inacceptable, Tout juste acceptable, Tout juste acceptable, Acceptable

### Potential annoyance

NUISANCES

Sonore

Vibrante

Visuelle

Électromagnétique

Électromagnétique

### Office Status : Windows, fans, ...

ÉTAT PIÈCE

Ouverts / Fenêtres: fermés, ouverts

Stores / Protections solaires: fermés, ouverts

Plafond: fermés, ouverts

### Global Comfort

CONFORT AÉRAULIQUE

Concernant les mouvements d'air, comment les jugez-vous ?

Insatisfait, Satisfait, Satisfait, Satisfait

**Air movement acceptability and preference**

BILAN

Trouvez-vous cet environnement confortable ?

Non acceptable, Inacceptable, Tout juste acceptable, Tout juste acceptable, Acceptable

Merci de valider vos choix en cliquant sur ce bouton

des questions, des remarques : [evalin@ines.fr](mailto:evalin@ines.fr)

	Number of answers for each user							Total
	2017	2018	2019	2020	2021	2022	2023	
<b>Nb users</b>	23	29	13	16	10	4	8	51
<b>Total</b>	2232	17479	2490	3192	585	236	701	26915
User23	181	1393	176	508		135		2393
User26	51	1058	530					1639
User3	209	390	348	247			124	1318
User51	161	991	0					1152
User48	138	491	207	207				1043
User10	107	408	139	205	106		63	1028
User40	208	333	113	66	81	57	106	964
User44	52	187	457	253				949
...	...	...	...	...	...	...	...	...
User17			5	33				38
User47	30							30
User31		26						26
User20	18							18
User19					8			8

51 different users

7 summers campaign

	Number of air temperature measured							Total
	2017	2018	2019	2020	2021	2022	2023	
<b>Nb pers</b>	23	29	13	16	9	4	8	50
<b>Total</b>	12193	174058	61521	38804	6088	2958	7807	303429
User27	342	26385	30619					57346
User41	1349	20993	5216	585	624	669	1722	31158
User24	1161	16902	2300	4935		1327		26625
...	...	...	...	...	...	...	...	...
User36								115
User20					112			112
User47	100							100
User46					23			23

Automatic air temperature acquisition



Exploring window opening behaviour for optimal cooling and thermal comfort

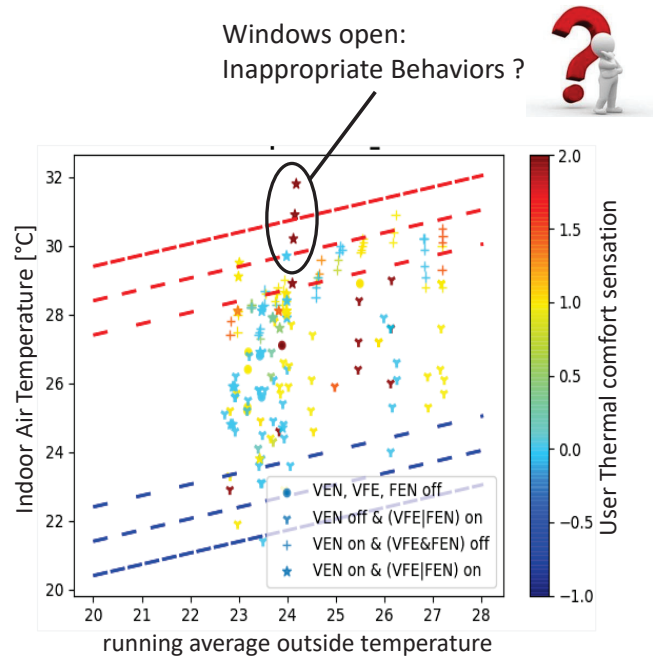
INIVE Webinar – 26 March 2024

## Initial behavior campaigns: First results (2/2)

The interface is divided into several sections:

- Clothing:** Includes sections for 'VETURE' (Sleeves, Length, Collar, Cuffs, Pockets) and 'NUISANCES' (Smell, Noise, Vibration, Pressure).
- Thermal Comfort:** 'CONFORT THERMIQUE' section with questions about current and desired thermal comfort, and 'CONFORT AERAIQUE' section about air movement acceptability.
- Office Status:** 'ETAT PIECE' section for 'Ouvrants / Fenêtres' (Open/Closed) and 'Stores / Protections solaires' (Shades/Blinds).
- Global Comfort:** 'BILAN' section for overall environmental satisfaction.
- Comments:** 'COMMENTAIRES LIBRES' section for free text input.

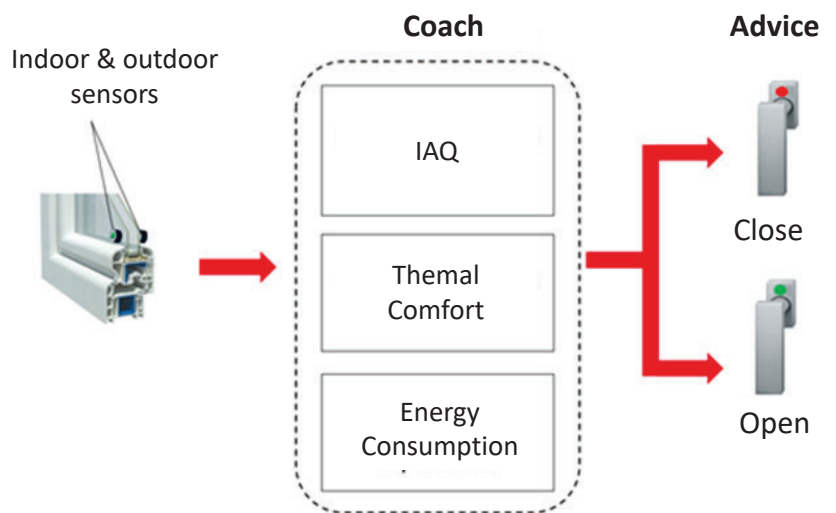
Interface to gather user feedback



User Comfort on Adaptive comfort chart

## WIND'OSE OBJECTIVE

- Coaching tool developed to help occupants to know whether it is a good option to open or close their windows.
- Coach objective is to consider the three components:
  - thermal comfort,
  - indoor air quality (IAQ)
  - energy consumption



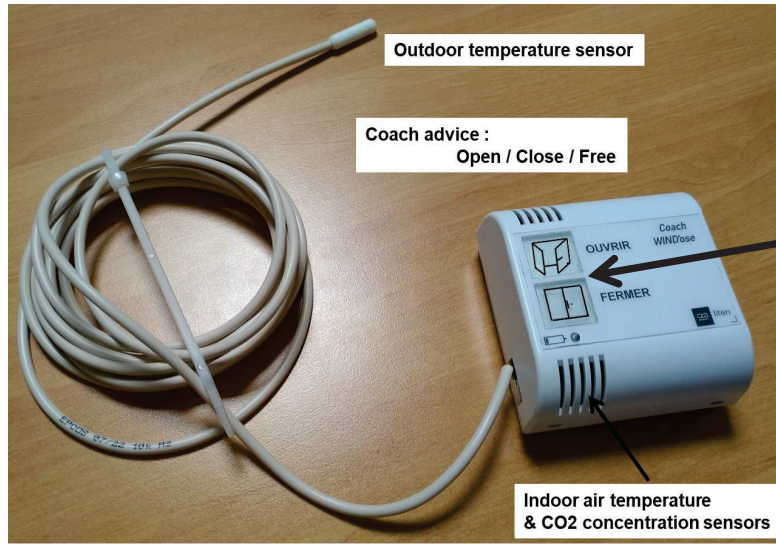
→ Based on Patent EP3971490 on "Method and system for advising on the opportunity of activating a door in order to improve the thermal comfort and/or the quality of the air"



# WIND'ose an e-fAIR prototype

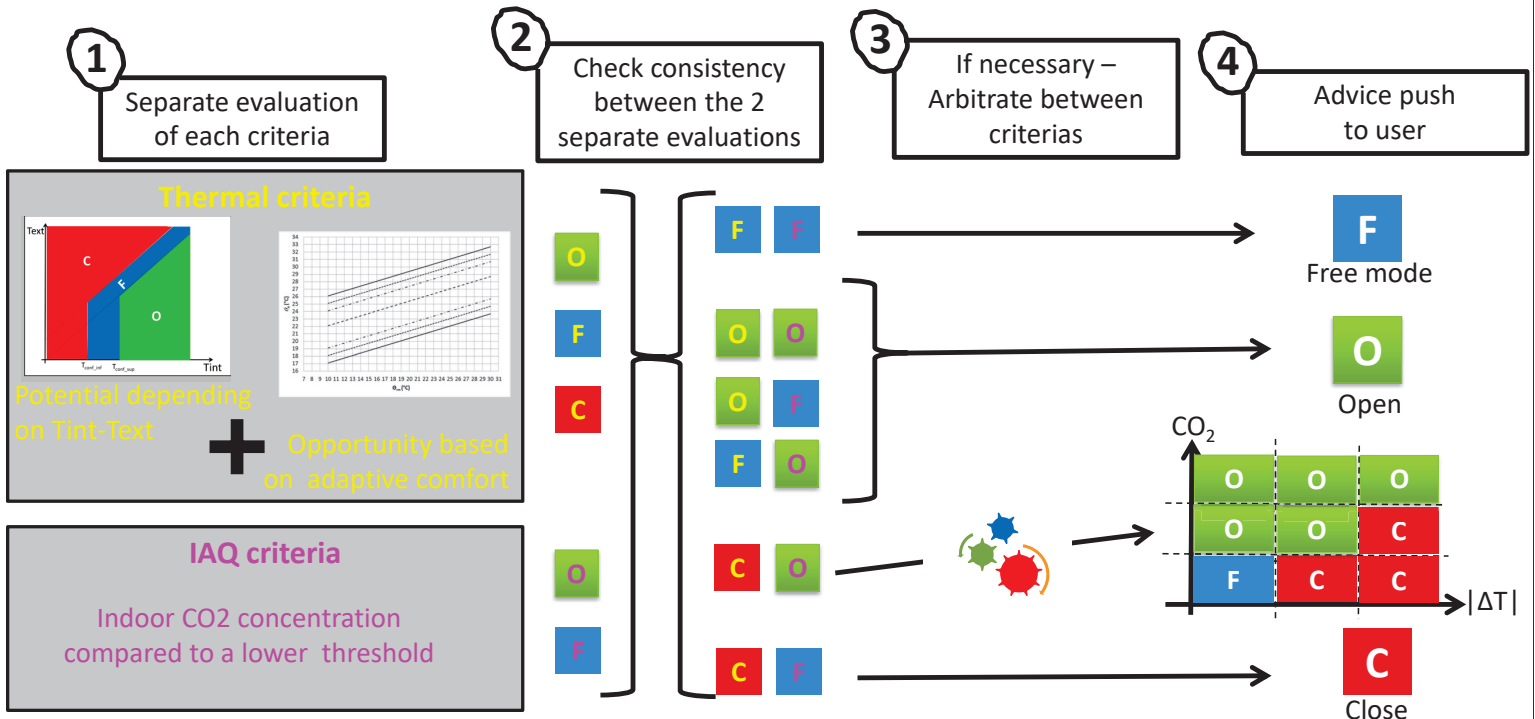
## SPECIFICATIONS AND PROTOTYPE V1

- 2 Indoor Sensors:
- Indoor air temperature
  - CO<sub>2</sub> concentration
- 1 Outdoor sensor
- Outdoor air temperature



Autonomous (Energy & embedded algorithm) and easy to set up

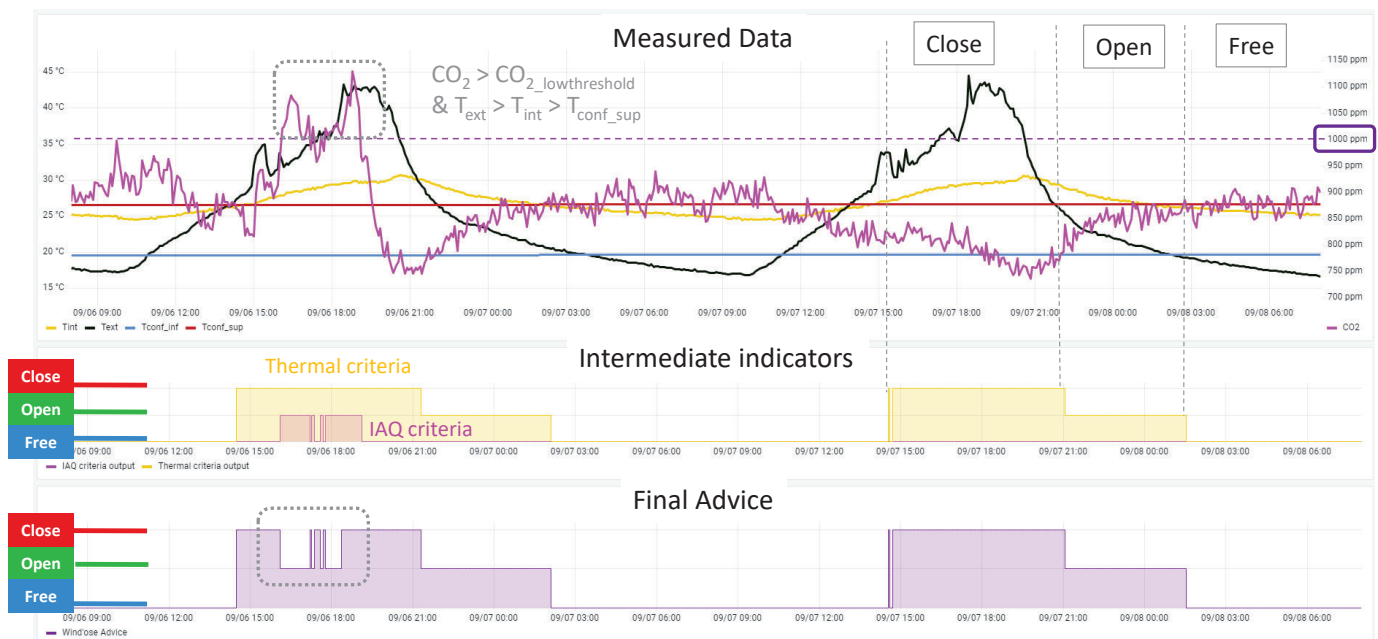
## WIND'OSE ALGORITHM



# EXPERIMENTAL CAMPAIGN SET UP ON A REAL BUILDING.



## FIRST RESULTS



## CONCLUSION AND PERSPECTIVE

- Wind'ose prototype answer our 1st requirements and specifications
- What's next:
  - Increase period and number of user feedback
  - Improve algorithm, and integrate specificity for
    - Mid-season
    - Winter
  - Enhance battery autonomy or integrate PV cells to get it fully autonomous.
  - Integrate other pollutants sensors.
  - Integrate shutter advice for solar control
  - ...



**Thank You for your attention**

**Next presentation :**

Coupling methodology of windows and ceiling fan occupant behaviour models  
with building energy models: a tropical case study

*Maxime Boulinguez & Maäréva Payet  
PIMENT Lab University of La Réunion  
Laboratoire d'Ecologie Urbaine Réunion, France*



**ines**  
INSTITUT NATIONAL  
DE L'ENERGIE SOLAIRE

**cea**





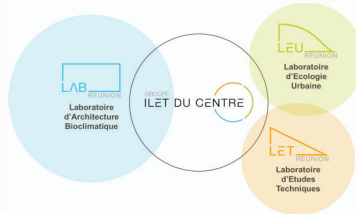
# Coupling methodology of windows and ceiling fan occupant behaviour models with building energy models

## A tropical case study

**Maareva PAYET**



PhD, head of the company's BEQ and R&D division  
LEU Réunion / associate researcher PIMENT, La Reunion University, France  
mp@leureunion.fr



**Maxime BOULINGUEZ**

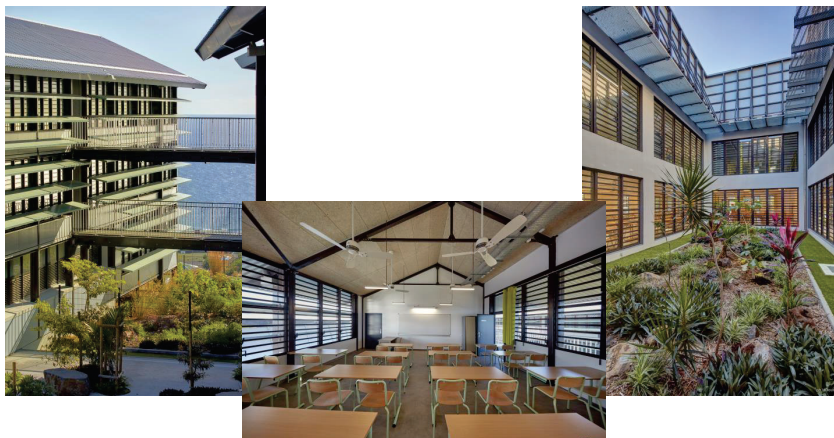


PhD student and co-head of R&D division  
LEU Réunion / PIMENT - La Reunion University, France  
maxime.boulinguez@univ-reunion.fr



## LEU REUNION, PART OF THE ILET DU CENTRE GROUP

### BIOCLIMATIC BUILDING DESIGN IN HOT AND HUMID TROPICAL CLIMATES



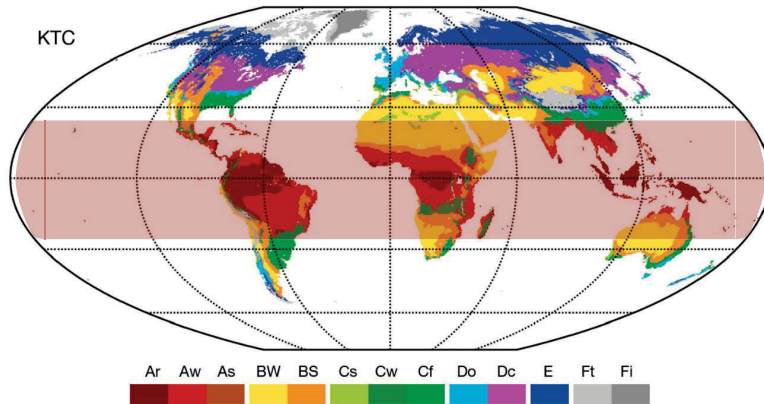
- **Solar protection**
- **Natural ventilation** to reduce the use of active and energy-consuming devices
- Solutions to couple **devices** when exclusive use of natural ventilation is not sufficient

Several ongoing research projects, including a **thesis on the comfort of mixed-mode buildings** and a **thesis defended in 2022 on occupant behaviours**



## DEFINITION OF HUMID TROPICAL CLIMATE

### FEATURES and ISSUES



According to Köppen-Trewartha

- Average monthly temperature > 18°C
- Rainfall threshold > 60mm over several months

The surface area of Aw subclass territories has increased since 1965-1994

(Belda et al. 2014)

50% of the population in the intertropical zone forecasted by 2050

(University of James Cook, Australia, 2014)

75% of the population in urban areas

(Rodrigues et al., 2019)

## MIXED MODE BUILDINGS

### DEFINITIONS

Passive cooling systems -> Openings

Low-energy cooling systems -> Ceiling Fans

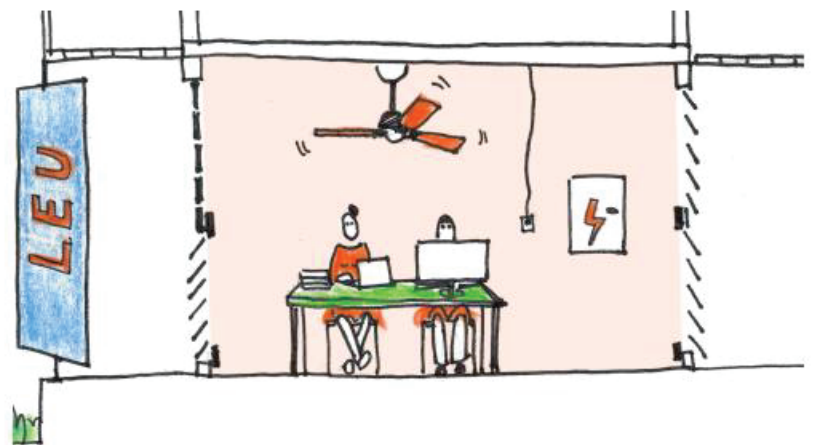
High-energy mechanical systems -> HVAC

Zoned Mixed Mode Building

(Brager, 2006)

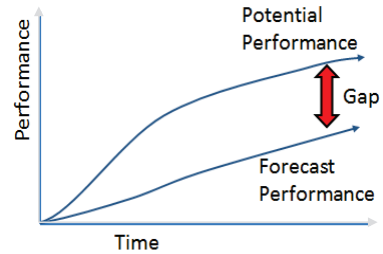
Different controls

(Raja, 2014)



## USER BEHAVIOUR IN MIXED MODE BUILDINGS

### RESEARCH QUESTIONS



How to assess user behaviour in mixed-mode buildings operating with ventilation ?

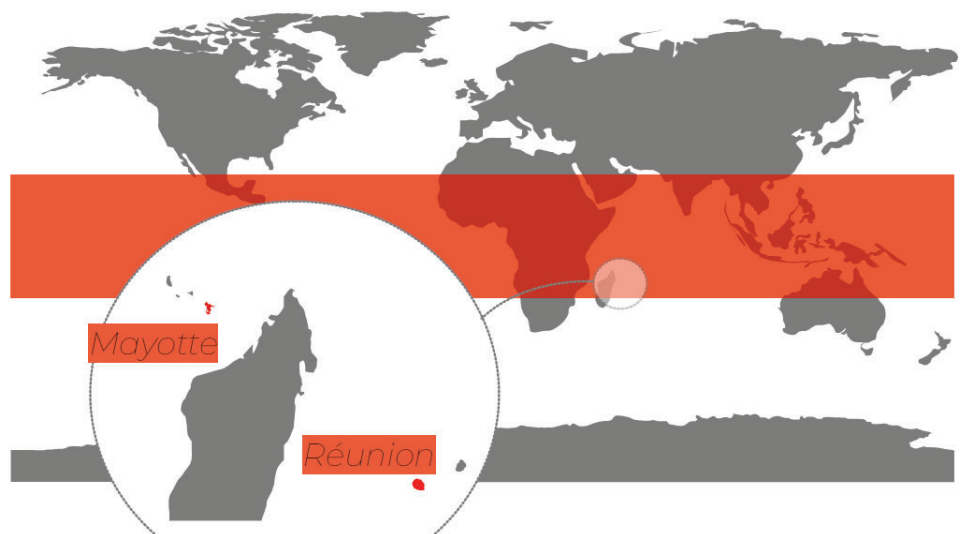
How to estimate the presence of users on openings and ceiling fans during the design phase ?

1- Model behaviours based on measured data

2- Integrate these behavioural models into a building model

## CASE STUDY IN REUNION ISLAND

### ILET DU CENTRE OFFICE BUILDING



## CASE STUDY IN REUNION ISLAND

### ILET DU CENTRE OFFICE BUILDING



310 m<sup>2</sup>

Two open plan floors (NV)

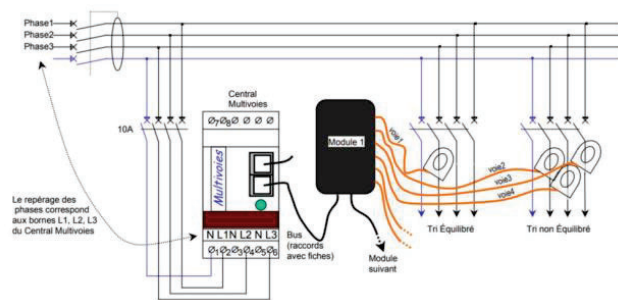
Singles offices (NV or AC)

Meeting rooms (AC)

IT room (AC)

## CASE STUDY IN REUNION ISLAND

### FIELD MEASUREMENTS



- 37 position sensors NODON (ENOCEAN)
- Irregular timestamp
- 2 states [0 ou 1]

- Energy meters OMEGAWATT
- 1 min timestamp
- Ceiling fan power [W] and offices plug [W]

## CASE STUDY IN REUNION ISLAND

### FIELD MEASUREMENTS



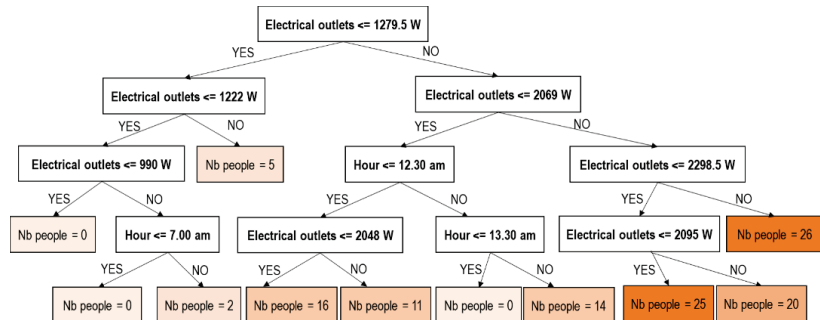
- 9 TESTO 174H temp/rh sensors
- Regular timestamp
- Air Temperature (+/- 0.5°C) et relative humidity (+/- 3 %HR)

- Meteorological station  
(Less than 1km far from site)

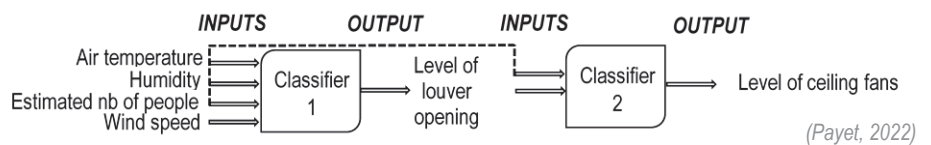
## OCCUPATION AND BEHAVIOURS MODELS

### CLASSIFICATION METHODS

Occupation model  
(Decision Tree)



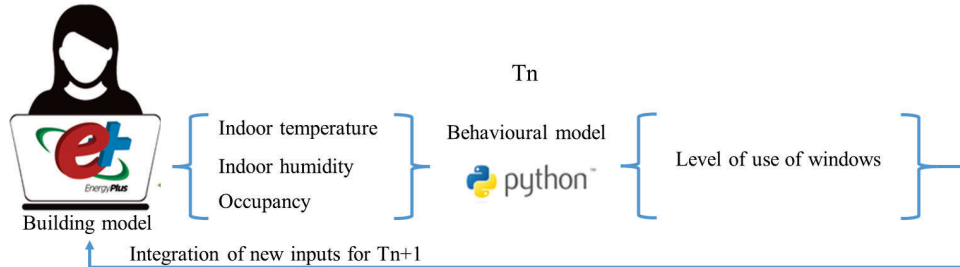
Ceiling fans and openings models  
(Random forest)





## IMPLEMENTING BEHAVIOURAL MODELS IN ENERGYPLUS

### PYTHON PLUGIN METHOD



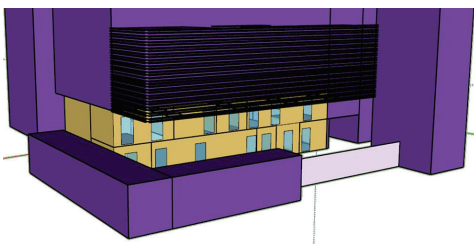
Method	Ease of implementation	Flexibility
Direct modelling	++++	+
Code customization	++	++
Customization of Core code	+	+++
Co-simulation	++	++++
Python plugin	+++	++++



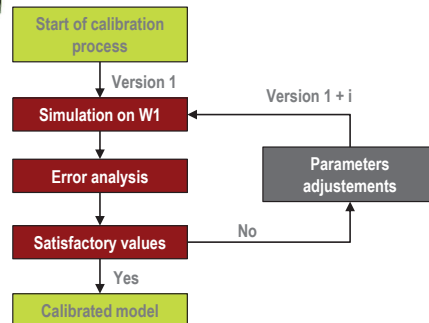
Coupling methodology of windows and ceiling fan occupant behaviour models with building energy models: a tropical case study

## BUILDING ENERGY MODEL

### VALIDATION (based on indoor conditions)



Week simulated	Step	From	To	Season	Internal heat gains from users
W1	Calibration	20/12/2020	27/12/2020	Summer	No
W2	Validation	01/12/2020	08/12/2020	Summer	Yes
W3	Validation	06/07/2020	13/07/2020	Winter	Yes
W4	Validation	05/10/2020	12/10/2020	Mid-season	Yes



Validation results	Standards
NMBEh ≤ 5.3 %	NMBEh ≤ 10 %
CV(RMSE)h ≤ 6.6 %	CV(RMSE)h ≤ 30 %
MADh ≤ 2.8 °C	(Baba, 2022)
MBEh ≤ 1.2 °C	(Baba, 2022)

- ASHARE Guideline 14 (Measurement and Energy Demand)
- Int. Measurement & Verification protocol recommended by French Energy Agency ADEME
- Mean Bias Error & Mean Absolute Deviation

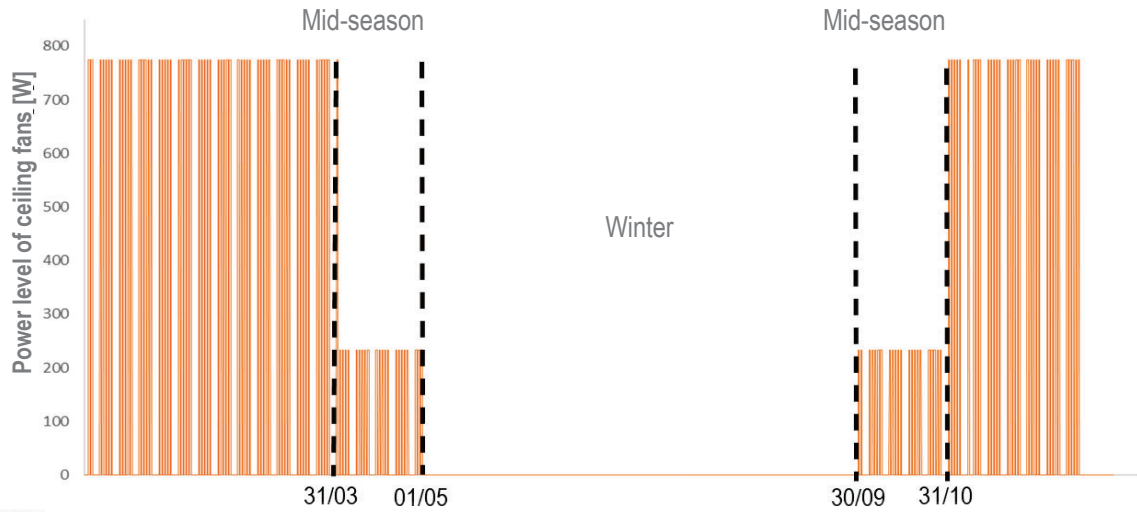


Coupling methodology of windows and ceiling fan occupant behaviour models with building energy models: a tropical case study



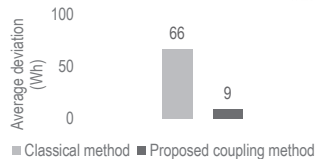
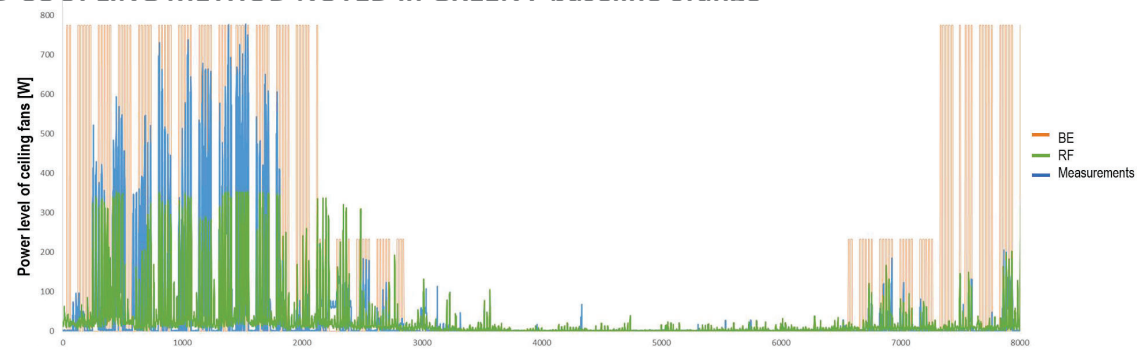
## CONVENTIONAL DESIGN OFFICE MODEL FOR CEILING FAN USE

### BASELINE METHOD



## COMPARISON WITH OUR RESULTS

### PROPOSED COUPLING METHOD NOTED in GREEN / baseline orange



Skill Score: assessing the value of a new model compared with a reference model

$$SS_{\text{Typical design office model / Coupling method proposed}} = 63\%$$

## TO CONCLUDE

### LIMITS OF THE PRESENT WORK

- Lack of generalisation capabilities
- Only NV + CF has been modeled so far (no AC+CF)
- Better estimate Ceiling Fans use but still need to improve related energy use for each predicted class

### PERSPECTIVES

- Extend field measurement studies to other building types and user categories to better teach models
- Add a level of complexity for mixed-mode cooled building with AC
- Investigate new way to estimate class energy use (seasonal class / monthly class, add model input parameter(s))

## Thank you for your attention

### Further readings:

Payet, Maareva, M. Boulinguez, M. David, P. Lauret, and F. Garde, 'Windows and ceiling fan occupant behaviour model coupling methodology with building energy models, a tropical case study', in *Ventilation, IEQ and health in sustainable buildings*, Copenhagen Denmark, 2023

M. Boulinguez, O. Marc, and J. Castaing-Lasvignottes, 'Development of a simplified model for evaluating refrigeration capacity and power consumption of air conditioning units based on heat exchanger entropic temperature definition', presented at the *International Congress of Refrigeration 2023, Paris, 2023*. doi: [10.18462/iir.icr.2023.0781](https://doi.org/10.18462/iir.icr.2023.0781)

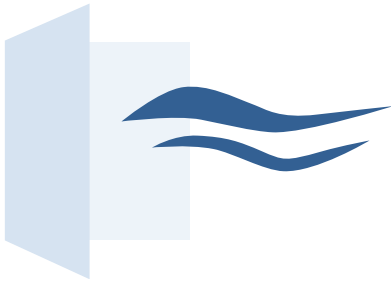
Payet, M., 2022. *Simulation du comportement des usagers dans les bâtiments tertiaires à faible consommation énergétique, en zone tropicale (phdthesis)*. University of la Reunion.

Payet, M., David, M., Lauret, P., Amayri, M., Ploix, S., Garde, F., 2022. *Modelling of occupant behaviour in non-residential mixed-mode buildings: The distinctive features of tropical climates*. *Energy and Buildings* 259, 111895. <https://doi.org/10.1016/j.enbuild.2022.111895>

# AIVC & Venticool webinar



## Observing and modeling window states in French dwellings monitored during a summer with heatwaves



Mathilde Hostein



26/03/2024

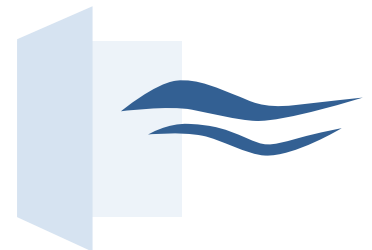
Supervisors: Bassam Moujalled, Marjory Musy & Mohamed El Mankibi



[mathilde.hostein@cerema.fr](mailto:mathilde.hostein@cerema.fr)

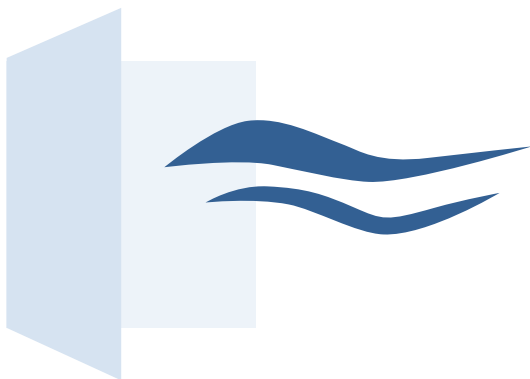
## Context

- **Occupant behaviour** → impact on indoor environment
- **Window use** → a key passive cooling strategy



## Presentation overview

- **Data collection:** field measurement campaign
- **Exploratory analysis:** link between in-situ measurement and surveys
- **Data-driven models:** window states prediction



## Data collection

Field measurement campaign

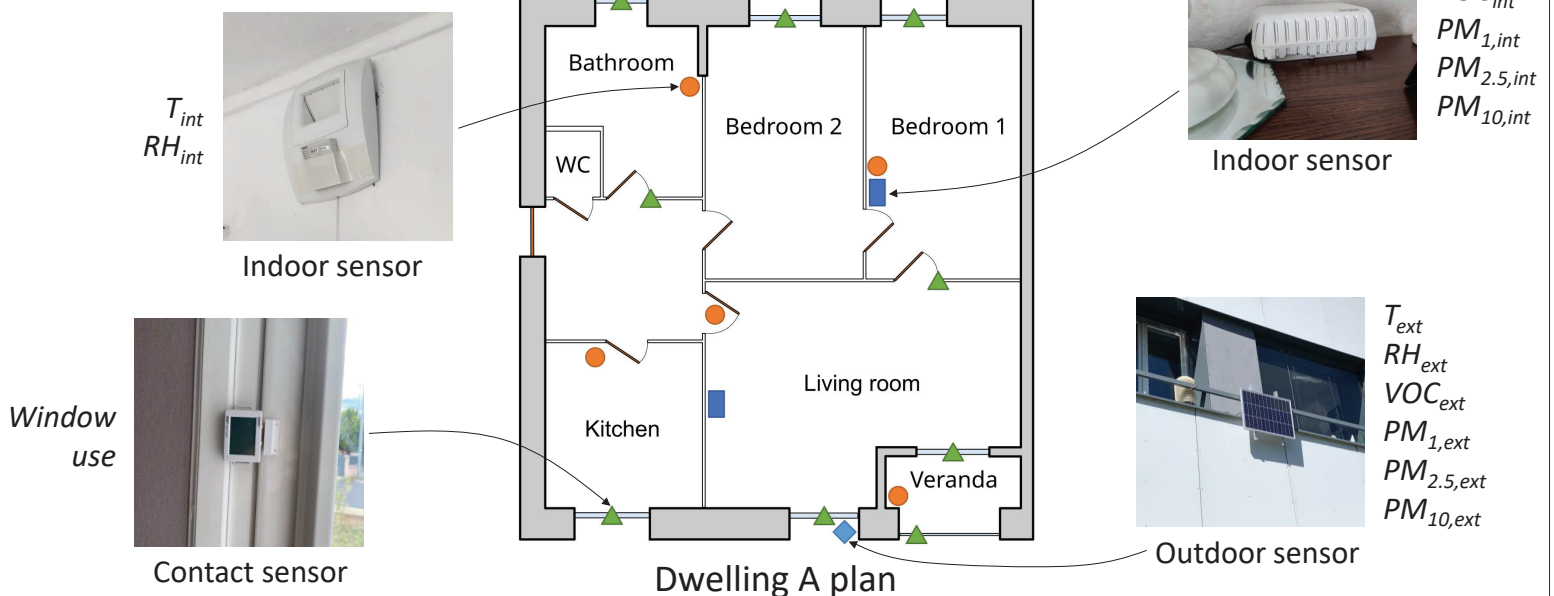
# Field measurement campaign

- CREATIV research project
  - Thermal comfort
  - Indoor air quality
  - Heatwave

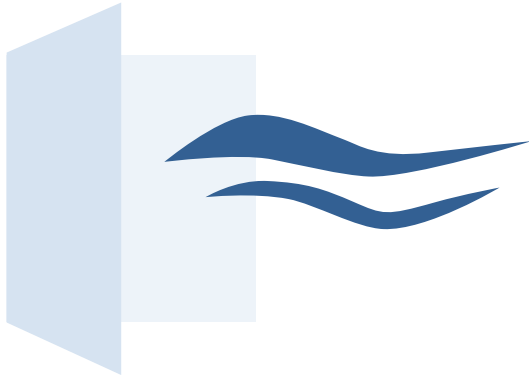


- 2 French cities
- 4 dwellings monitored
- June to September 2022
- Surveys :
  - Logbook
  - Thermal comfort surveys
  - General questionnaire
- Measurements

## Monitoring



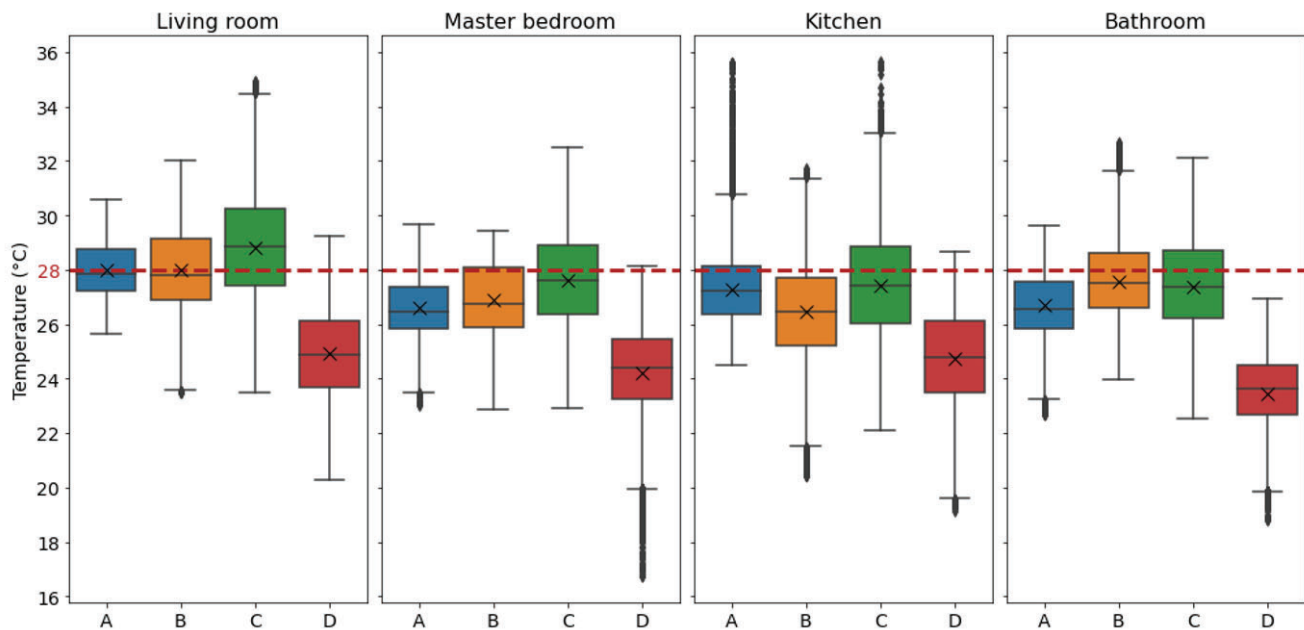




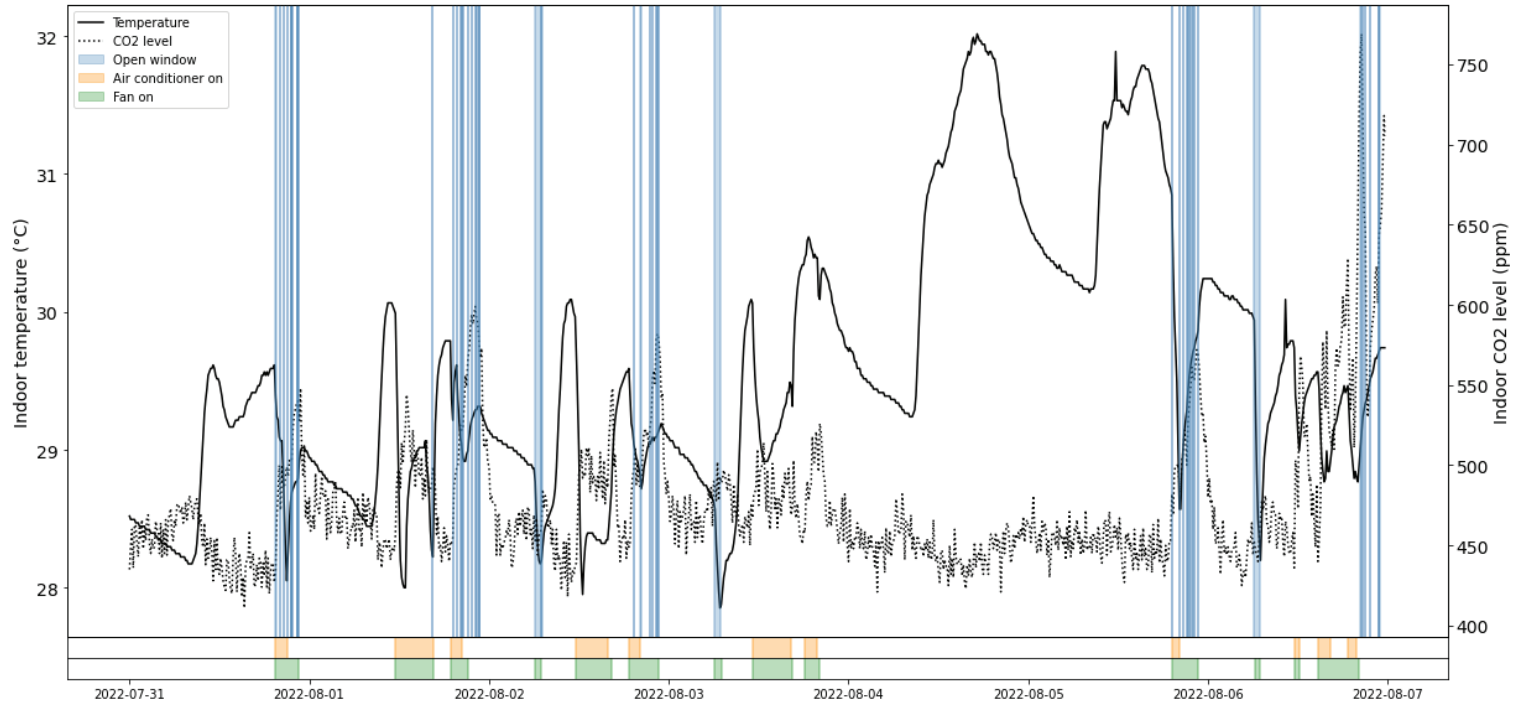
# Exploratory analysis

Link between in-situ measurement and surveys

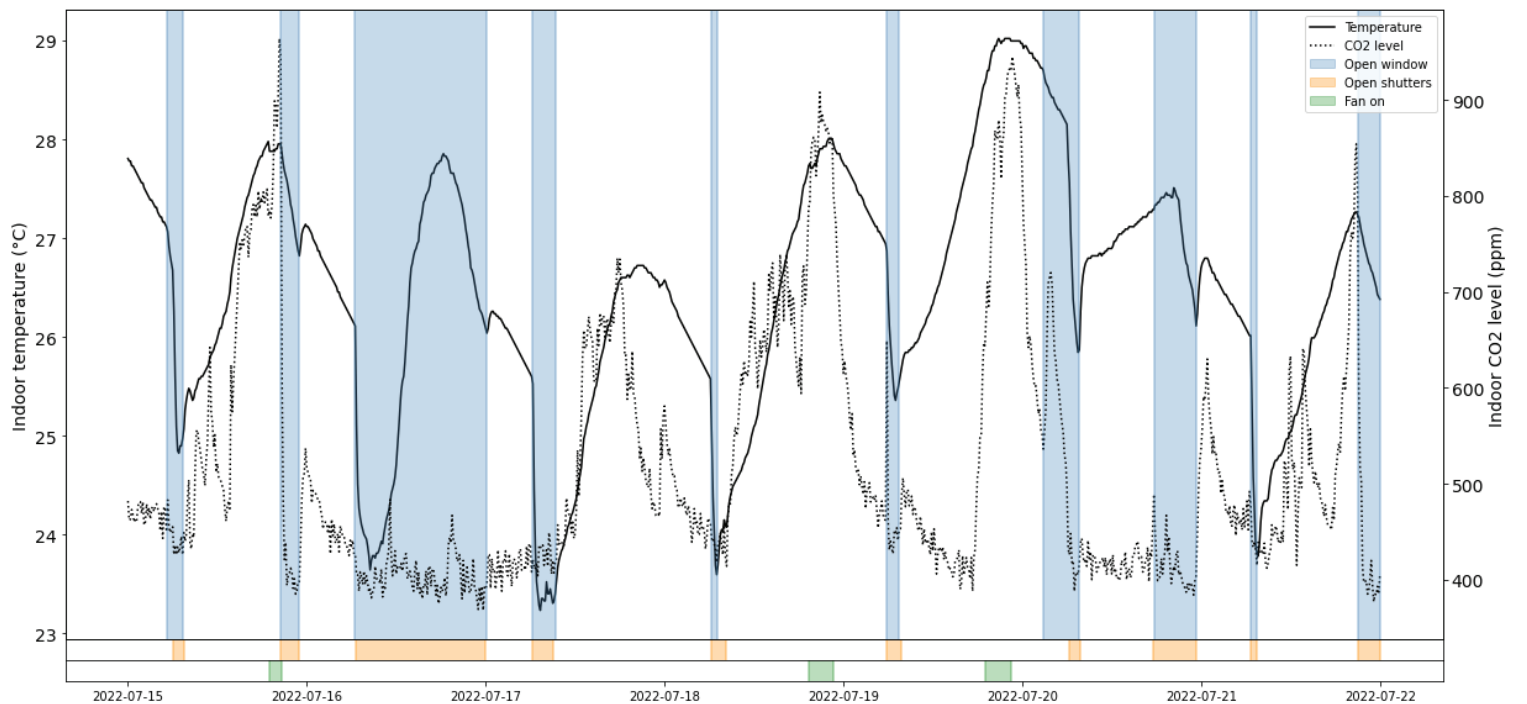
## Comparison of temperature by room in the different dwellings using boxplot diagrams with means displayed



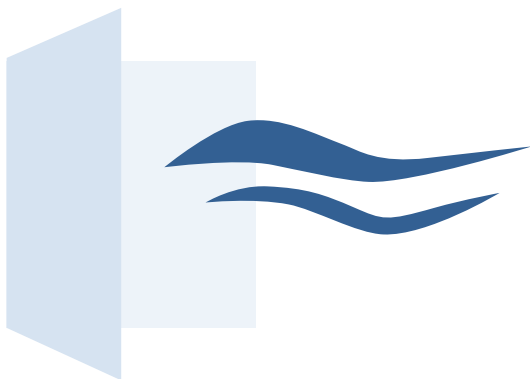
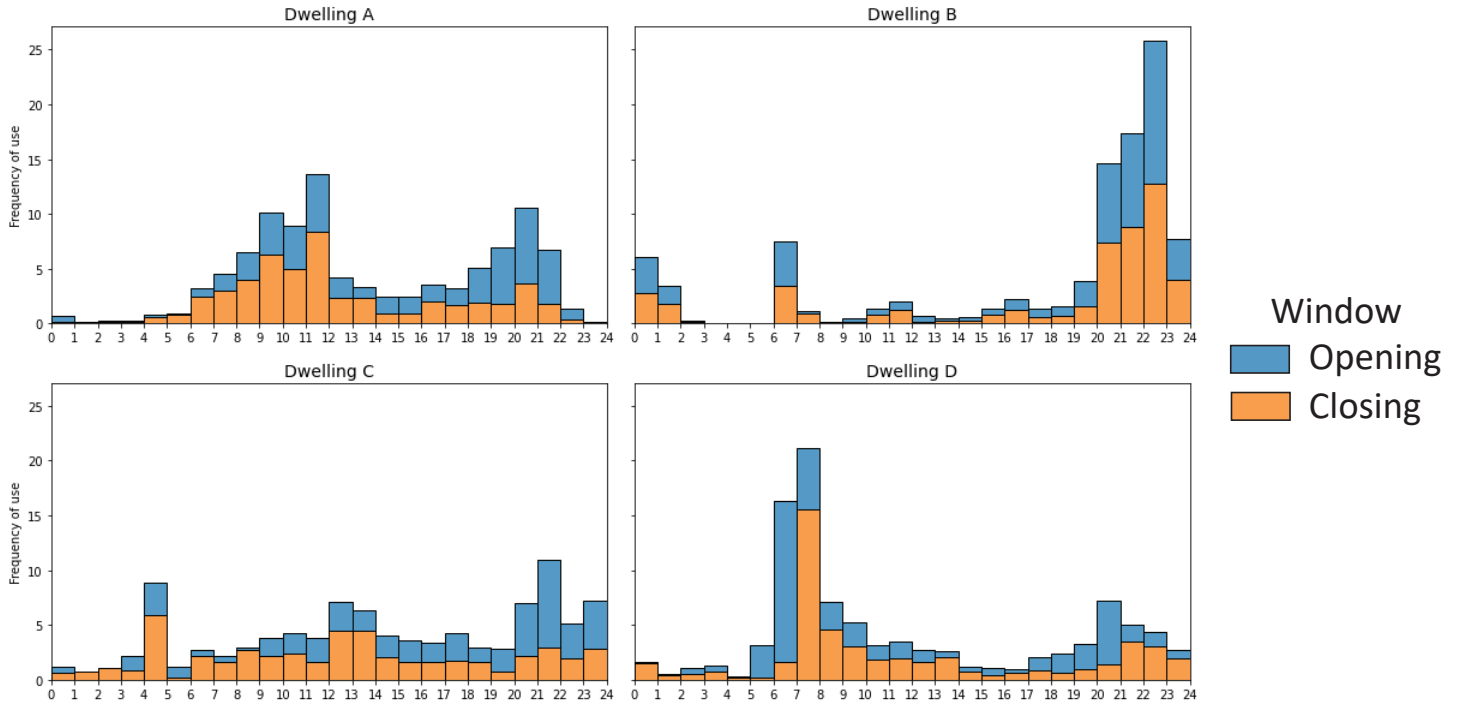
## Evolution of the indoor environment with adaptation actions in the living room of dwelling B during the 3<sup>rd</sup> heatwave



## Evolution of the indoor environment with adaptation actions in the living room of dwelling D during the 2<sup>nd</sup> heatwave



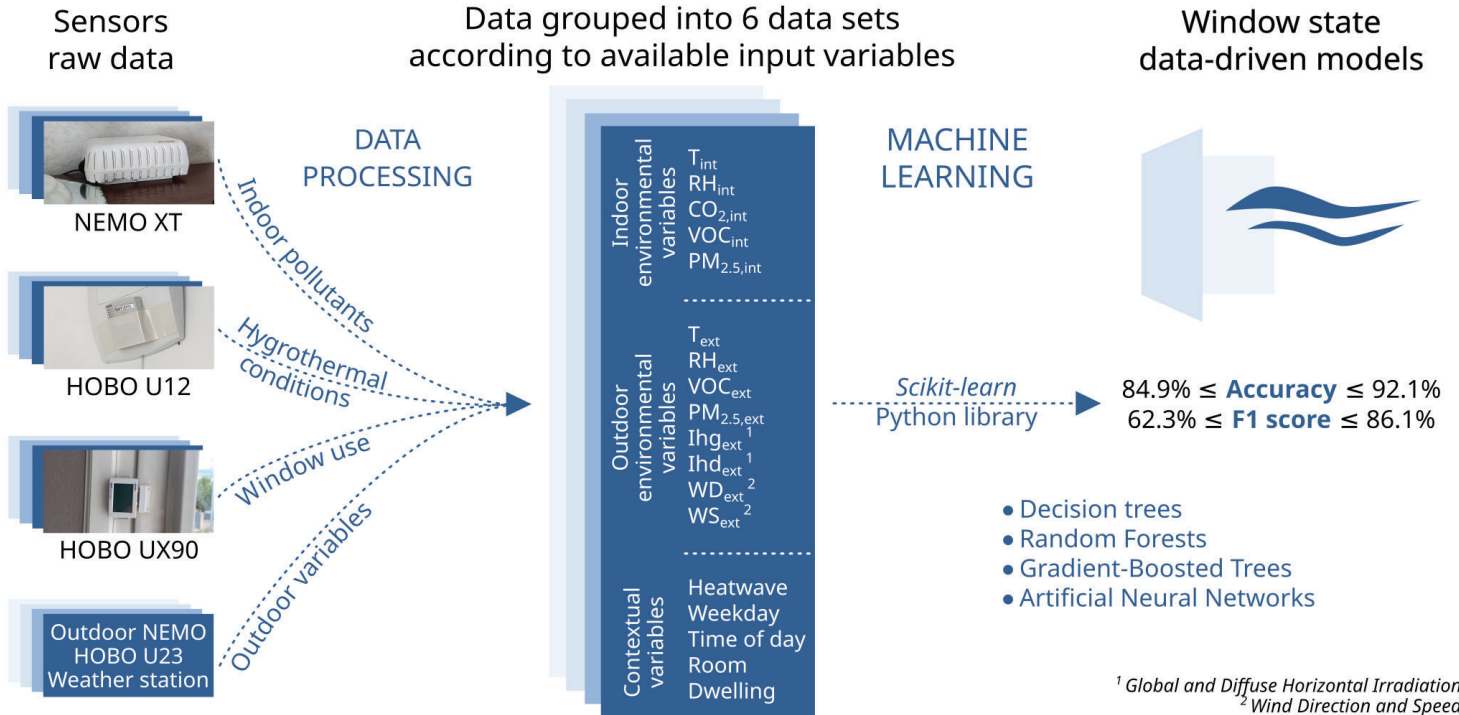
# Windows openings and closings according to the time of day



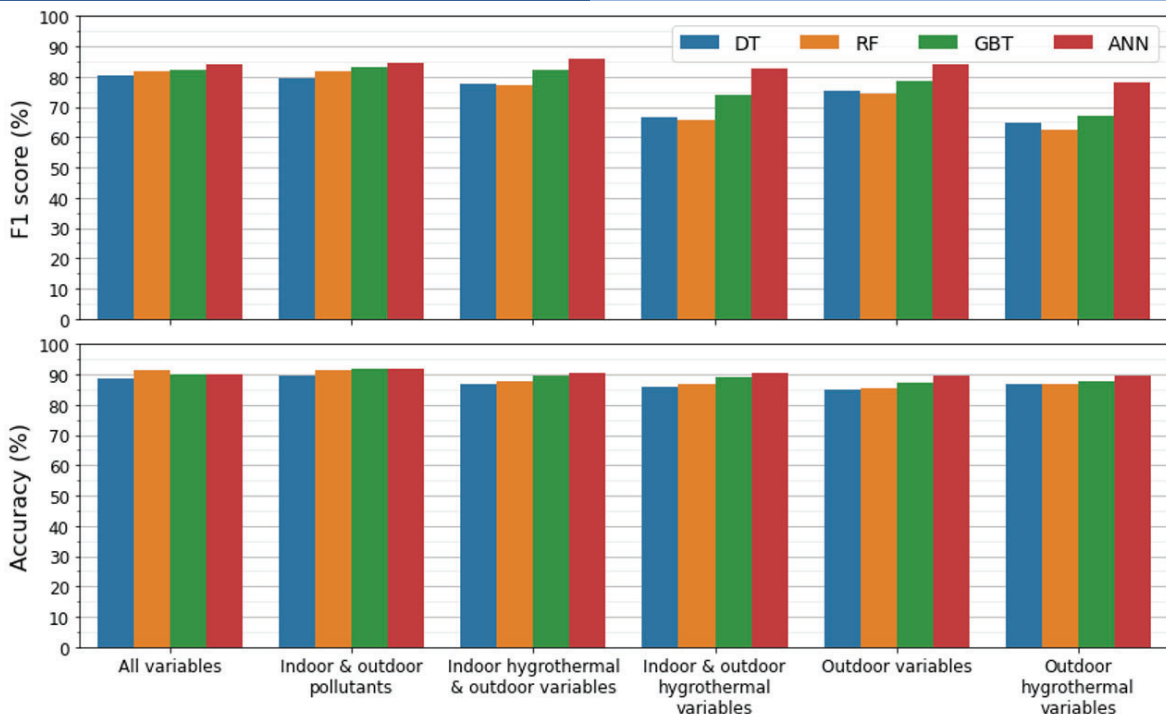
## Data-driven models

Window states prediction

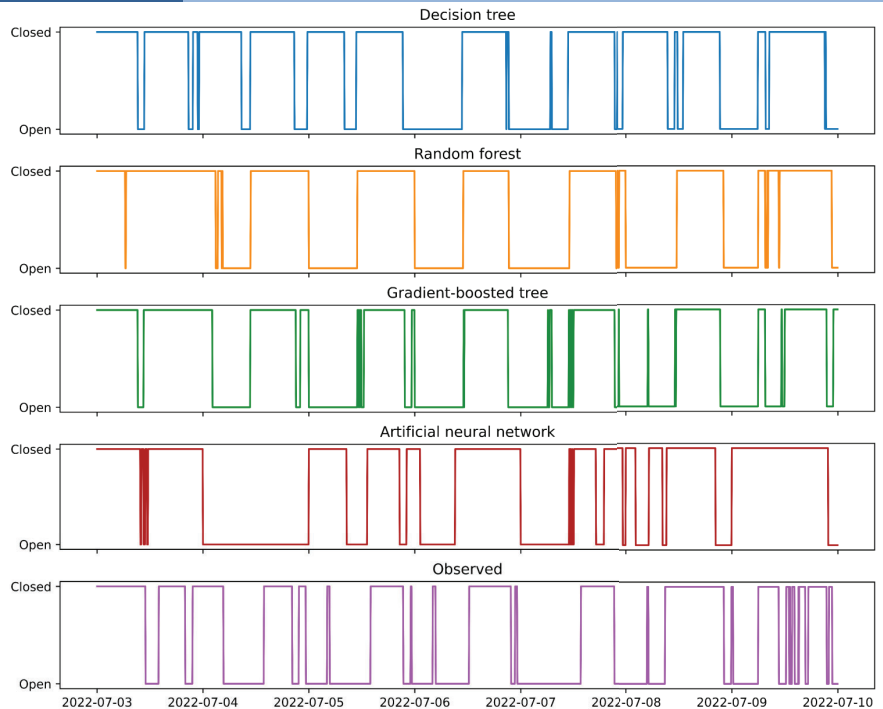
# Graphical abstract



# Metrics of the 4 data-driven models tested on the 6 dataframes with different input variables



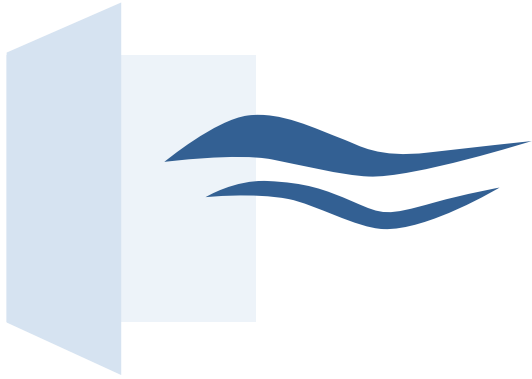
Window states observed and predicted by the four data-driven models in the master bedroom C with only the contextual and outdoor hygrothermal variables given as inputs



## Next steps

- Testing the models on an external dataset
  - another field measurement campaign last summer
  - same data collection methodology applied to a multi-family building in Nantes (France)
- Conducting semi-structured interviews with more households
  - to address additional drivers for window use
  - to consider in a more comprehensive way the adaptation actions that occupants implement in their homes to cope with heat





Thank you for your attention!  
Do you have any questions ?

Hostein M, Moujalled B, Musy M and El Mankibi M. 2023. "A study of indoor environment and window use in French dwellings monitored during a summer with heatwaves" in *43rd AIVC, 11th TightVent and 9th Venticool conference*. Copenhagen.