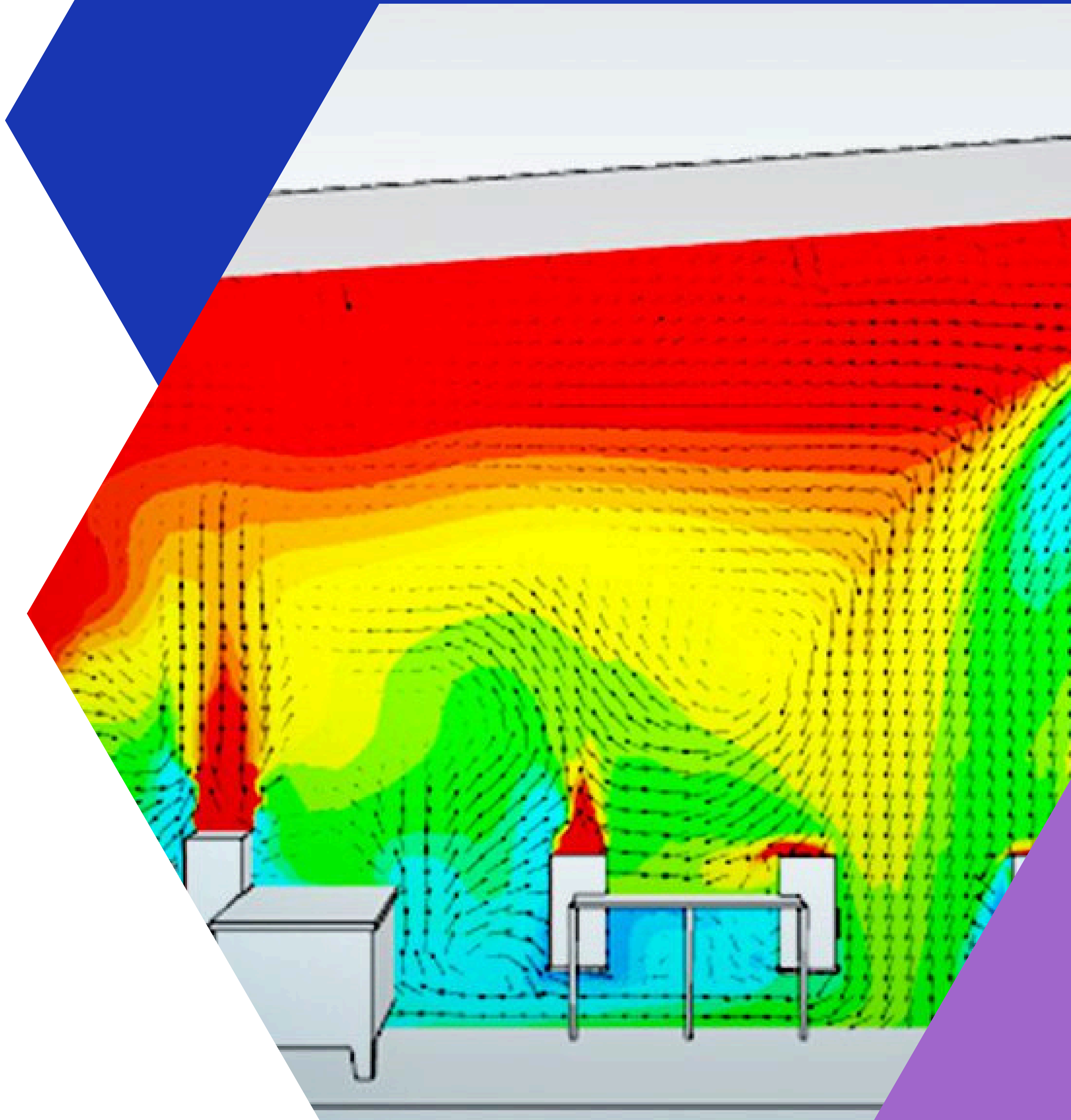
AC PLACEMENT OPTIMIZATION WITH CFD AND NN

Thomas IDIER

Goto Lab.



Introduction

Goal

The goal is to have access to the best **placement of Air Conditioner** in a **bedroom in University House Aobayama**

To know the best configuration, you need to do a **lot of CFD simulations**, so it takes a lot of time, the goal is to **train a NN model on a small database**, then use this model to **find the best placement**

To access the best configuration, I can **directly have access** to the **PMV** index though the CFD simulations

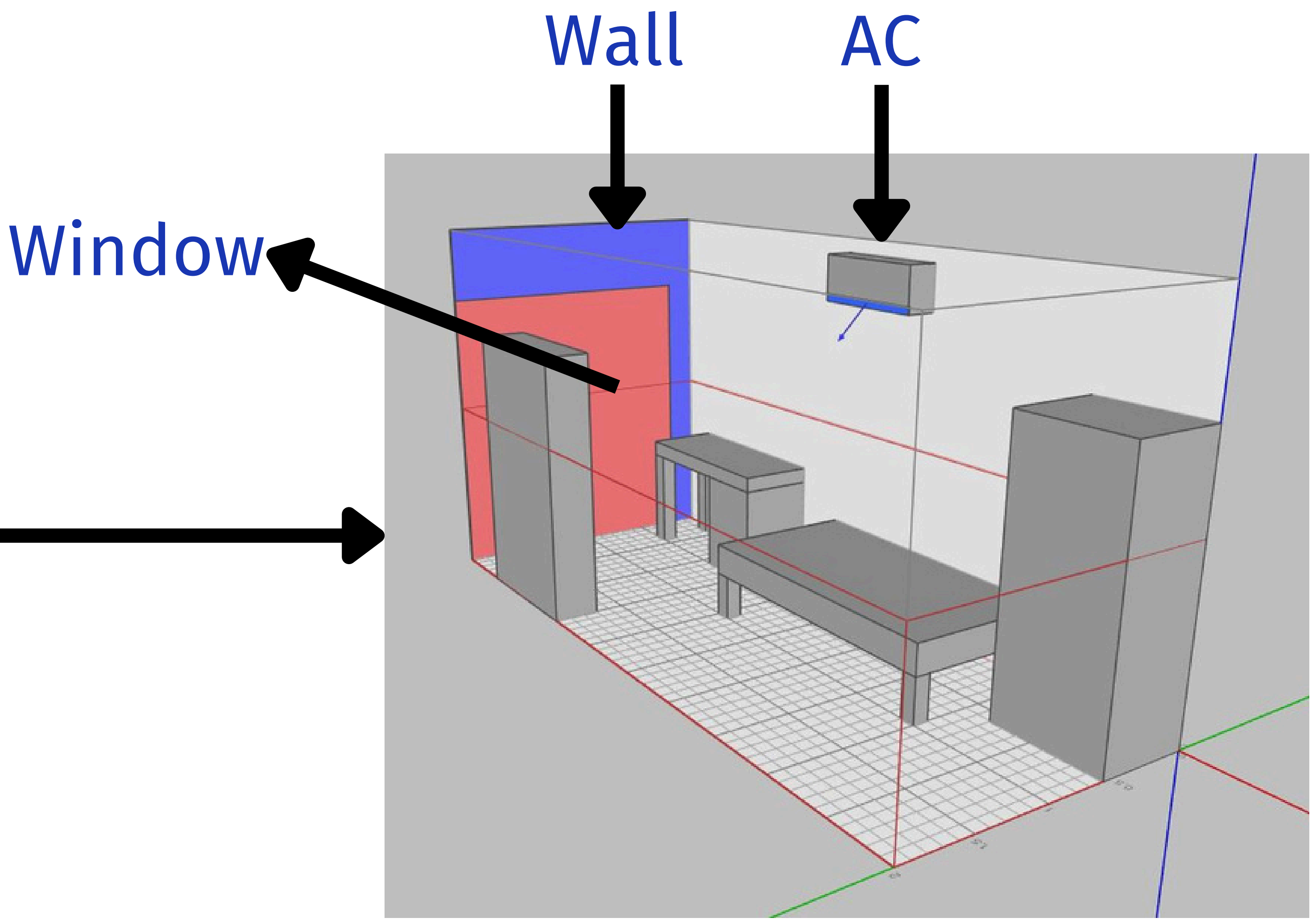
Hypothesis

- Man **studying** during the **evening**
- Man **sitting** on the bed or on the chair

- **Steady state**
- **Heat transmission** across glass **window** and **wall** connected to the outside only
- **No transmitted solar heat** (evening, no sun, drape during the day)
- **No heat transmission through wall, floor and celling** (not connected to outside)

01 CFD database establishment

Modelization



Modelization in Flowdesigner of my bedroom

Window and Wall

Heat Transfer Coefficient

$$h_{0summer} = 22.7W/(m2^{\circ}C)$$
$$h_{0winter} = 34W/(m2^{\circ}C)$$
$$h_i = 8.29W/(m2 \cdot {}^{\circ}C)$$

Areas

Wall

$$A_{wall} = 2.5 * 2 - 1.8 * 2.0 = 1.4m2$$

Different Area of the door glass

$$A_{window} = 1.8 * 2.0 = 3.6m2$$
$$A_{glazing} = 2 * 1.72 * 0.94 = 3.23m2$$
$$A_{frame} = 3.60 - 3.23 = 0.37m2$$

Edge of glass : 6.5 cm wide band around the perimeter of the glazing

$$A_{center} = 2 * (1.72 - 0.13) * (0.94 - 0.13) = 2.58m2$$
$$A_{edge} = A_{glazing} - A_{center} = 0.65m2$$

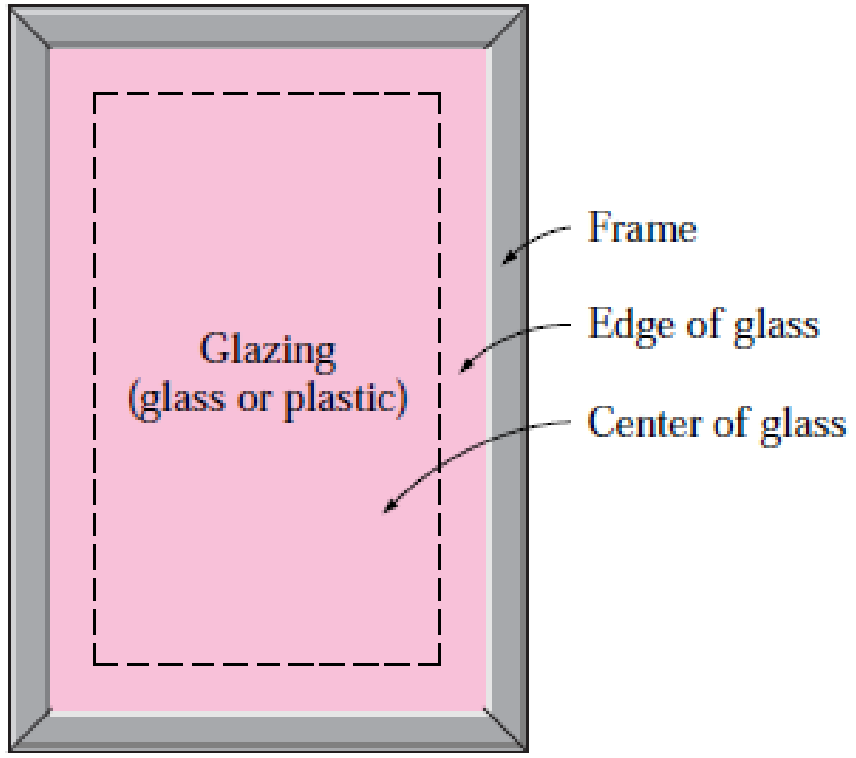


FIGURE 41
The three regions of a window considered in heat transfer analysis.

Heat Flow

Wall

$$U_{wall_{summer}} = \frac{1}{\frac{1}{h_i} + \frac{1}{h_{osummer}} + \frac{L}{\lambda_{concrete}}} = 4.25W/(m2 \cdot {}^{\circ}C)$$

$$\lambda = 1.4W/(m \cdot {}^{\circ}C)$$
$$L = 0.2m$$

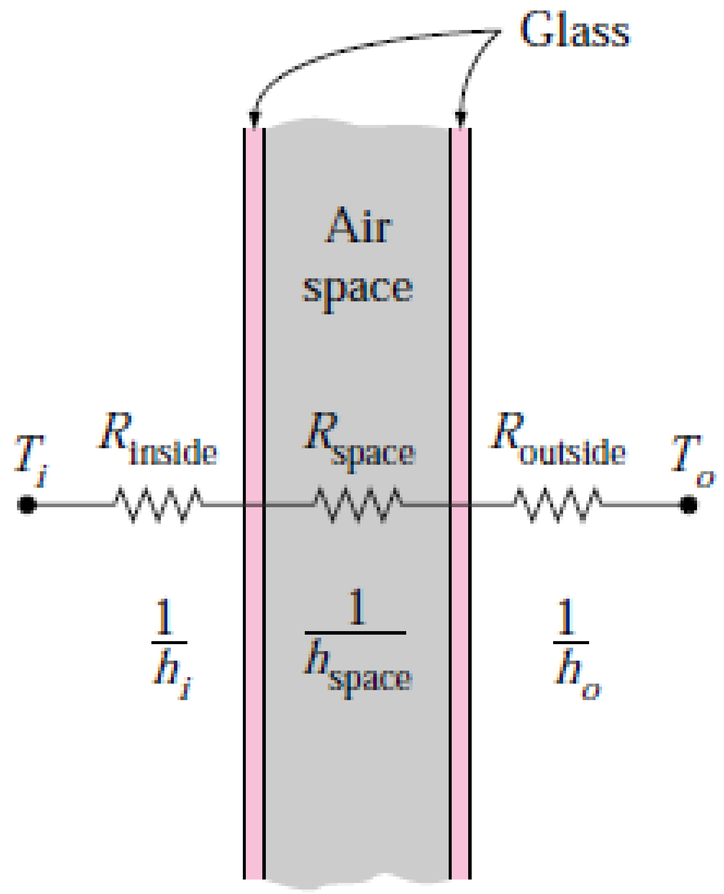
Double glazing

$$U_{center_{summer}} = \frac{1}{\frac{1}{h_i} + \frac{1}{h_{osummer}} + \frac{1}{h_{space}} + \frac{2*Lwindow}{\lambda_{window}}} = 3.51W/(m2 \cdot {}^{\circ}C)$$

$$h_{space_{summer}} = 8.8m2/{}^{\circ}C$$
$$L_{window} = 0.003m$$
$$\lambda_{window} = 0.92W/(m \cdot {}^{\circ}C)$$

Heat Flow Edge : **Metallic spacer**

$$U_{edge_{summer}} = 4W/(m2 \cdot {}^{\circ}C)$$



Heat Flow Frame : **Aluminium**

$$U_{frame} = 10.1W/(m2 \cdot {}^{\circ}C)$$

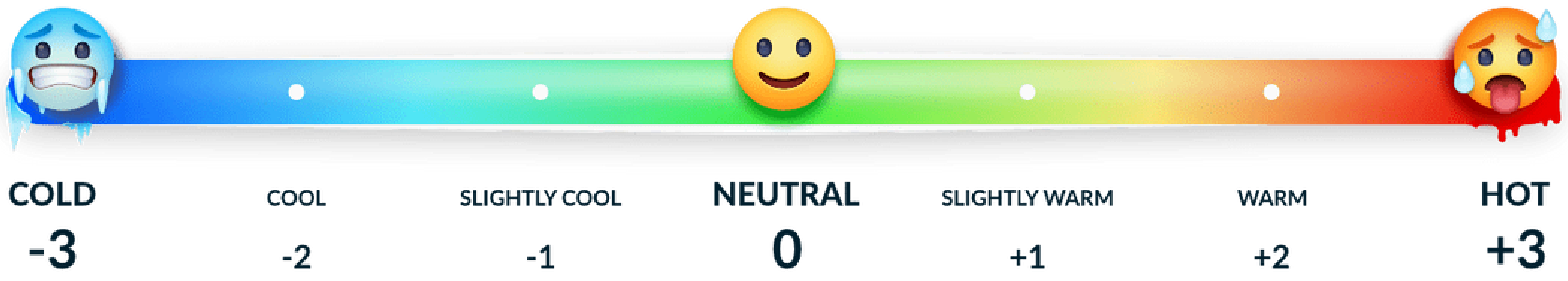
Window Heat flow

$$U_{window_{summer}} = \frac{1}{A_{window}} * (U_{center_{summer}} * A_{center} + U_{edge_{summer}} * A_{edge} + U_{frame} * A_{frame}) = 4.28W/(m2 \cdot ^{\circ}C)$$

PMV

PMV stands for **Predicted Mean Vote**, which is a **measure** used in **thermal comfort** studies to assess how a group of people feel about their thermal environment.

It's a way to quantify and **predict human comfort** or discomfort based on factors like temperature, humidity, air movement, and clothing insulation.



PMV Calculation : Clothing insulation

To calculate the PMV, you need to know the **clothing insulation**

Summer : 0.39 clo

23

Boxer shorts	88 g	0.45 mm	CO
Socks	44 g	0.93 mm	CO
T-shirt	158 g	0.64 mm	CO
Chino pants	422 g	0.70 mm	CO, ELA
Trainers/ sneakers	424 g	—	PES, RB

T-shirt not tucked in (over) chino pants.

Winter : 0.84 clo

16

Boxer shorts	88 g	0.45 mm	CO
Socks	44 g	0.93 mm	CO
T-shirt	158 g	0.64 mm	CO
Jeans (straight fit)	608 g	0.91 mm	CO, ELA
Thick hooded jacket (“Hoodie”)	830 g	4.65 mm	CO, PES
Shoes	812 g	—	LTH, RB

T-shirt tucked into jeans. Hood draped on back.

2021 **Updated Database of Clothing Thermal Insulation and Vapor Permeability Values of Western Ensembles for Use in ASHRAE Standard 55, ISO 7730, and ISO 9920**, James W. Smallcombe, PhD, Simon Hodder, PhD, Kalev Kuklane, PhD

PMV Calculation : Metabolic rate

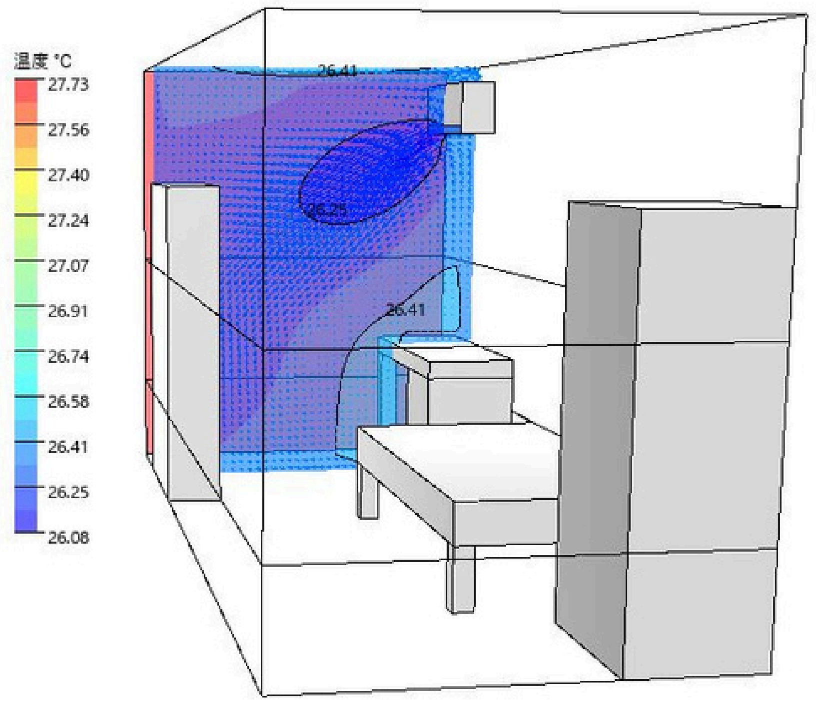
Table A.1 — Metabolic rates

Activity	Metabolic rates	
	W/m²	met
Reclining	46	0,8
Seated, relaxed	58	1,0
Sedentary activity (office, dwelling, school, laboratory)	70	1,2
Standing, light activity (shopping, laboratory, light industry)	93	1,6
Standing, medium activity (shop assistant, domestic work, machine work)	116	2,0
Walking on the level:		
2 km/h	110	1,9
3 km/h	140	2,4
4 km/h	165	2,8
5 km/h	200	3,4

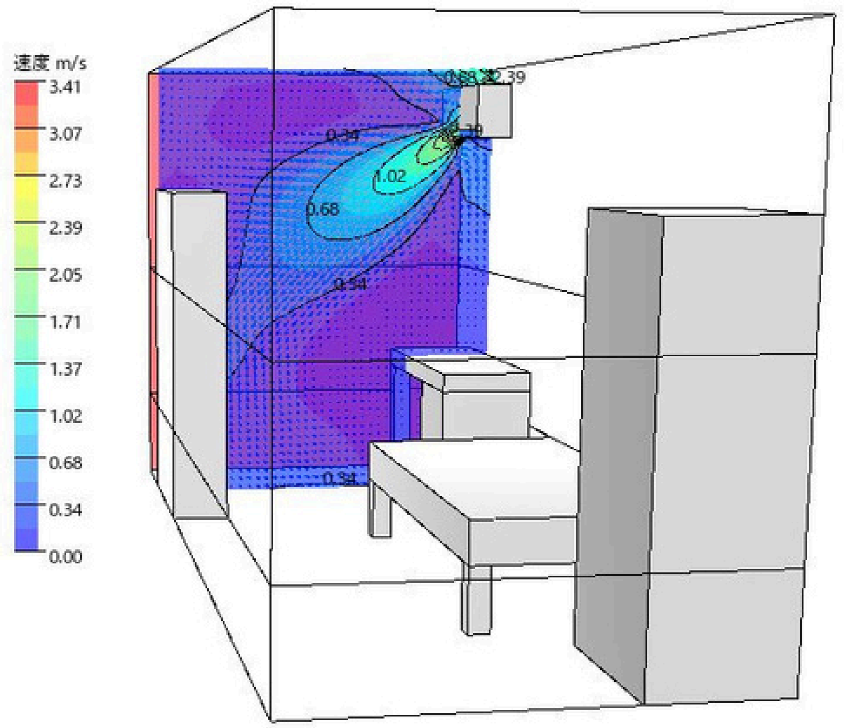
1.2 met

PMV Calculation

Temperature

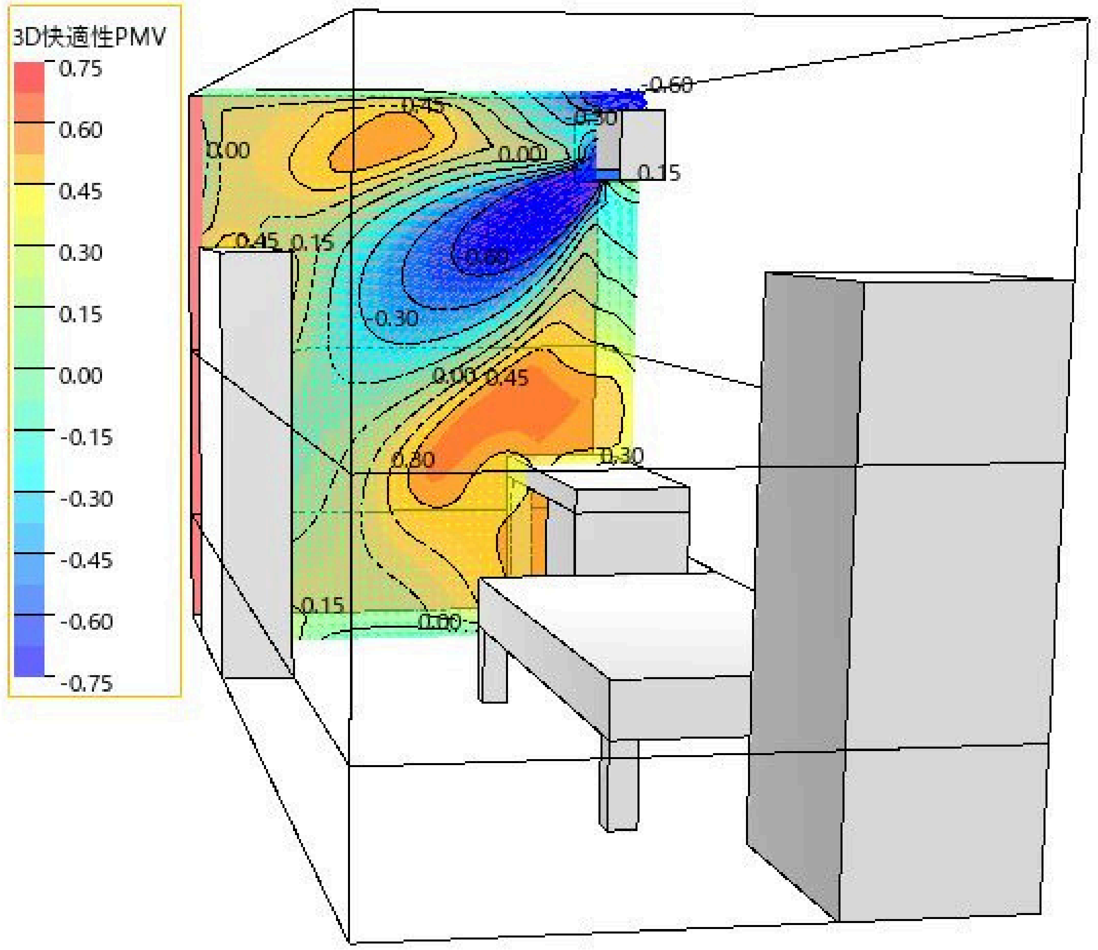


Velocity



ISO 7730 - 2005

$$PMV = \left[0{,}303 \cdot \exp(-0{,}036 \cdot M) + 0{,}028\right] \cdot \left\{ \begin{array}{l} (M-W) - 3{,}05 \cdot 10^{-3} \cdot \left[5\,733 - 6{,}99 \cdot (M-W) - p_a\right] - 0{,}42 \cdot \left[(M-W) - 58{,}15\right] \\ -1{,}7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_a) - 0{,}0014 \cdot M \cdot (34 - t_a) \\ -3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl}+273)^4 - (\bar{t}_r + 273)^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{array} \right\}$$



SAT Calculation

The **sol-air temperature** (SAT) is the **hypothetical outside air temperature** that, in the absence of solar radiation, would produce the same temperature distribution and heat transfer rate through a wall (or roof) as observed under the combined influence of **actual outdoor temperatures** and **incident solar radiation**.

$$SAT = T_{out} - \frac{\epsilon_{global}\phi_a R}{h_0}$$

ϕ_a form factor of the sky as seen from glass window : 0.5

R effective radiation to the sky from horizontal surface (Wm−2)

Power input in the AC

$$Q_{AC_{summer}} = (A_{wall} * U_{wall_{summer}} + A_{window} * U_{window_{summer}}) * (SAT - T_{in})$$

2009 **Comparison of theoretical and statistical models of air-conditioning-unit usage behaviour in a residential setting under Japanese climatic conditions**, Marcel Schweiker, Masanori Shukuya

When to use AC in Winter and Summer

Summer :

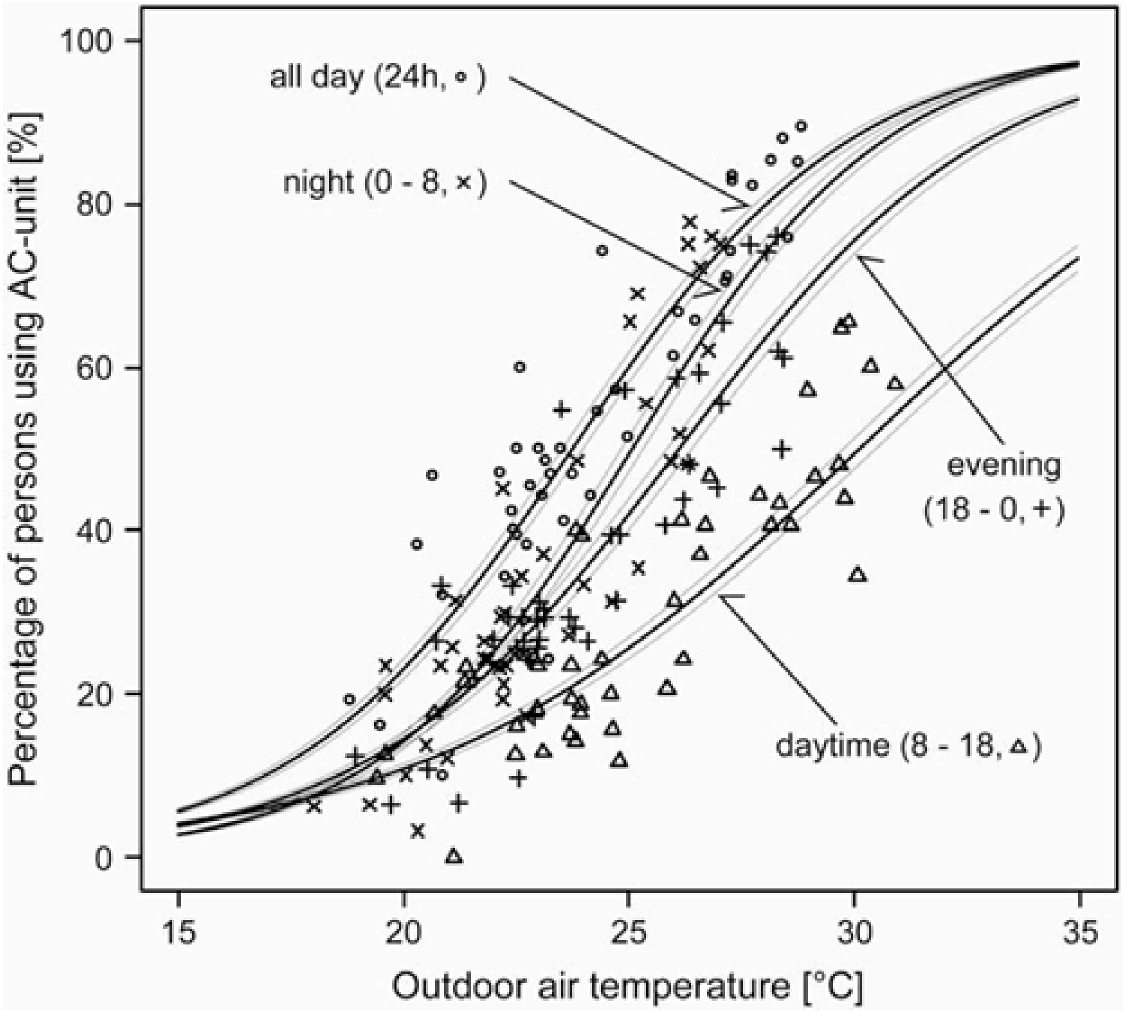


Fig. 4. Relationship between outdoor air temperature and percentage of persons using AC-units for the case of cooling in summertime. The outdoor air temperature is the value for respective period as shown inside the graph. The thin dotted lines along with the bold lines in between show the limits of the 5% confidence interval of the respective line.

Winter :

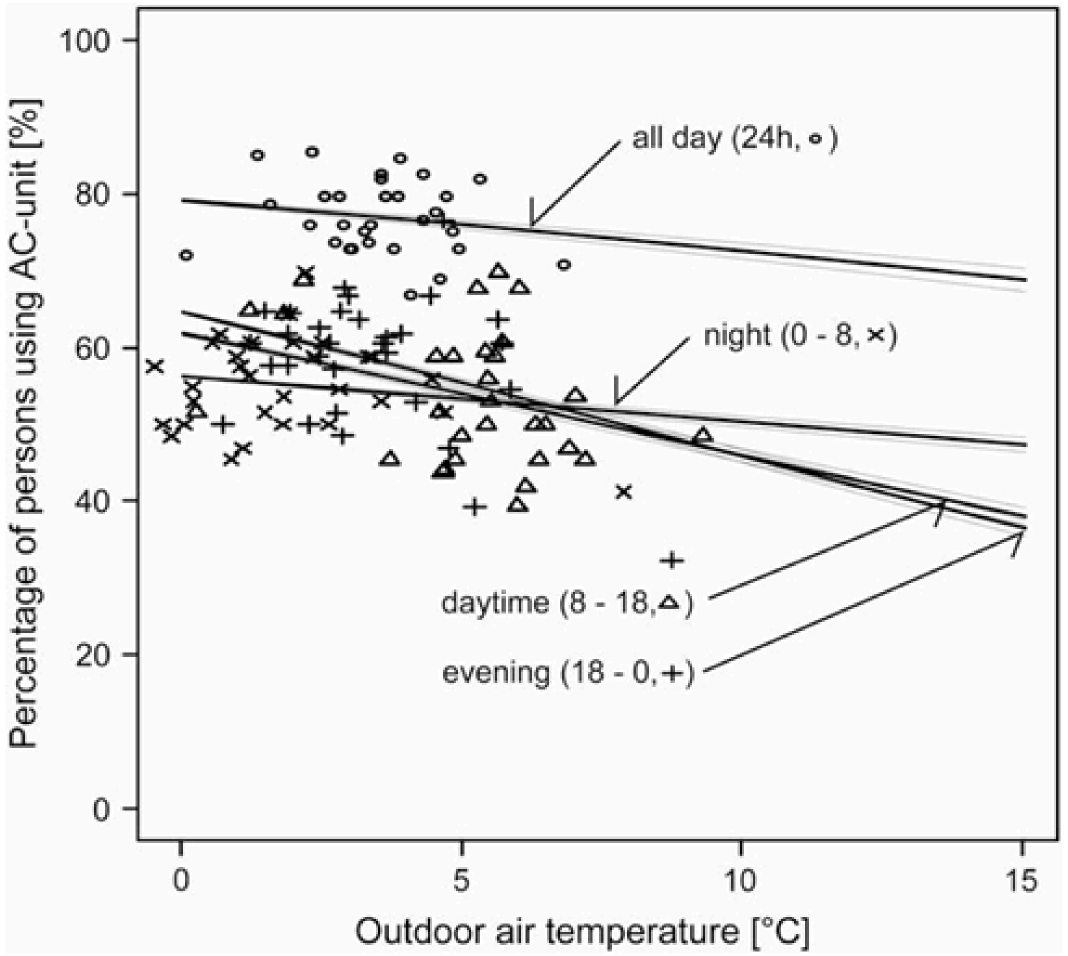


Fig. 5. Relationship between outdoor air temperature and percentage of persons using AC-units for the case of heating in wintertime. The thin dotted lines along with the bold lines in between show the limits of the 5% confidence interval of the respective line.

When **50% use AC in evening**:

Summer : **27 °C**

Winter : **8 °C**

02 Neural Network Training

Neural Network : Output PMV Field

Input Data :
- Yac
- SAT
- Qac

Output Data (for Z between 0 m and 1.2 m) :
- PMV Field

→

Neural Network in Summer

Neural Network in Winter

Database splitting

4 * 4 * 4 - 4 = 60 simulations

Yac = 1m

SAT	Qmin	Q2	Q3	Qmax
26,41		0	1	2
26,81	3	4	5	6
27,75	7	8	9	10
30,33	11	12	13	14

Yac = 2m

SAT	Qmin	Q2	Q3	Qmax
26,41		15	16	17
26,81	18	19	20	21
27,75	22	23	24	25
30,33	26	27	28	29

Yac = 3m

SAT	Qmin	Q2	Q3	Qmax
26,41		30	31	32
26,81	33	34	35	36
27,75	37	38	39	40
30,33	41	42	43	44

Yac = 4m

SAT	Qmin	Q2	Q3	Qmax
26,41		45	46	47
26,81	48	49	50	51
27,75	52	53	54	55
30,33	56	57	58	59

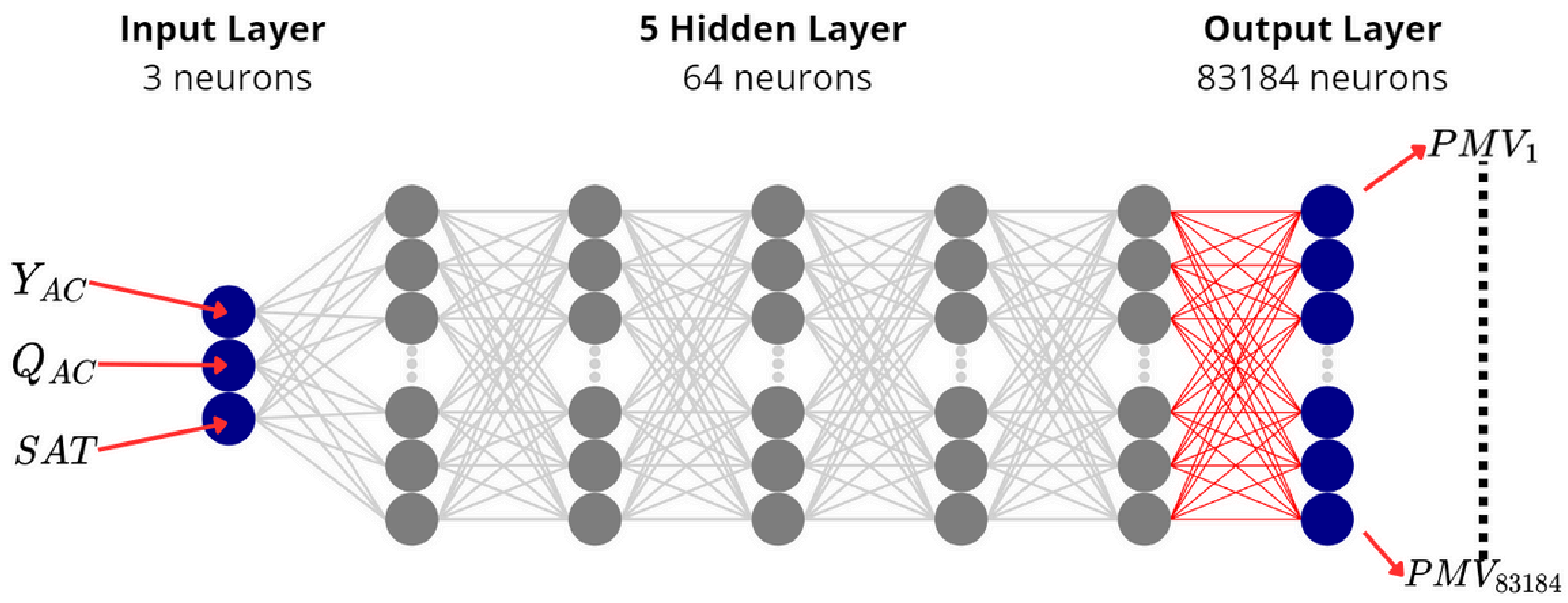
Training
Testing
Validation

NN training : 4 cases

- **Basic case : 83 184 blocks**
- **Normalization :** $$SAT_{\text{norm}} = \frac{SAT - \min(SAT)}{\max(SAT) - \min(SAT)}$$
- **Standardization :** $$SAT = \frac{SAT - \mu}{\sigma}$$
- **Dimension Reduction : 83 184 / 8 = 10 398 blocks**

Hyperparameters Optimization

Parameter	Values
neurons	64
optimizers	RMSprop
nb_hidden	5
epochs	5000
learning_rate	0.001
activation	relu

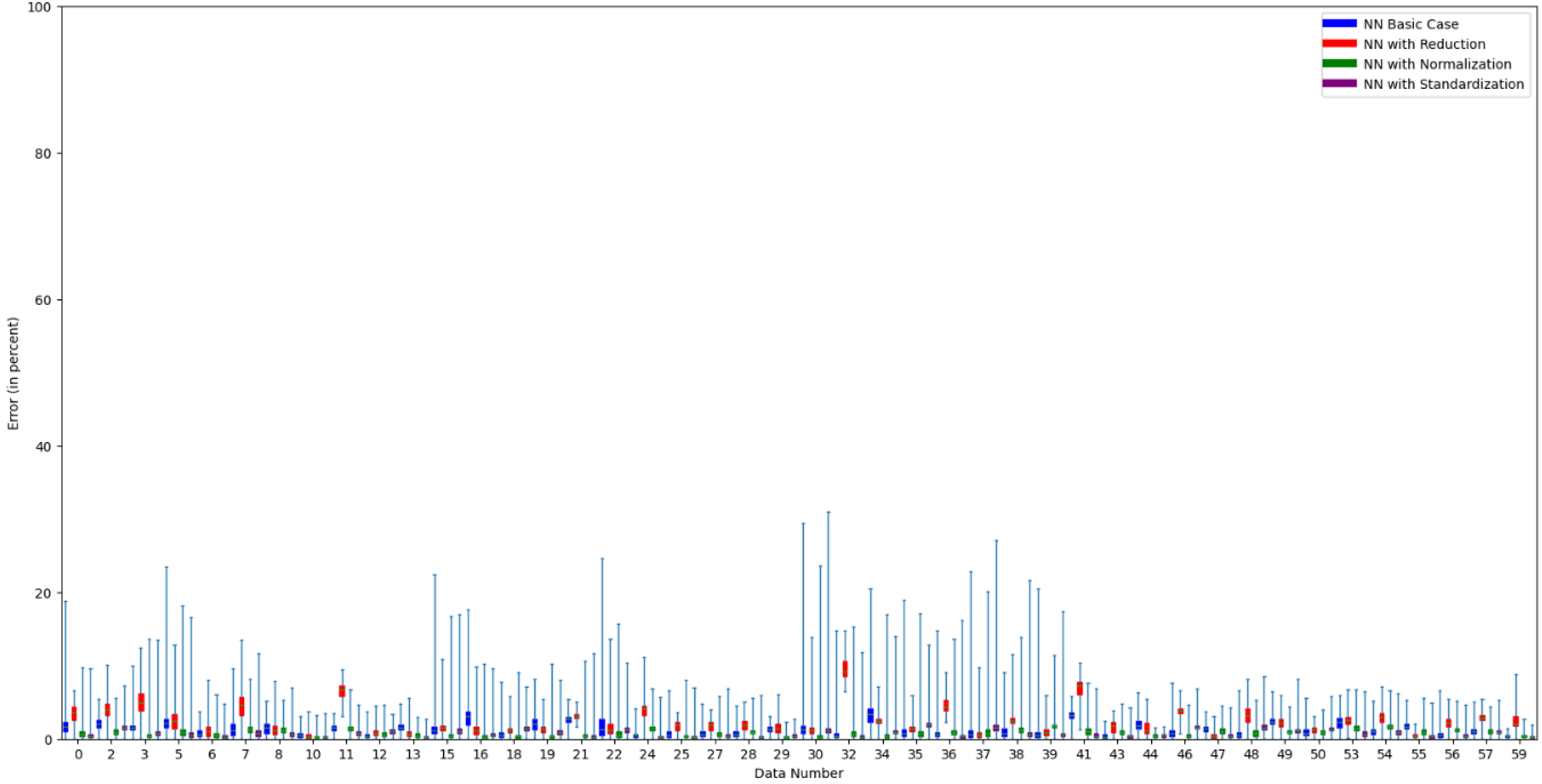


Error Quantification

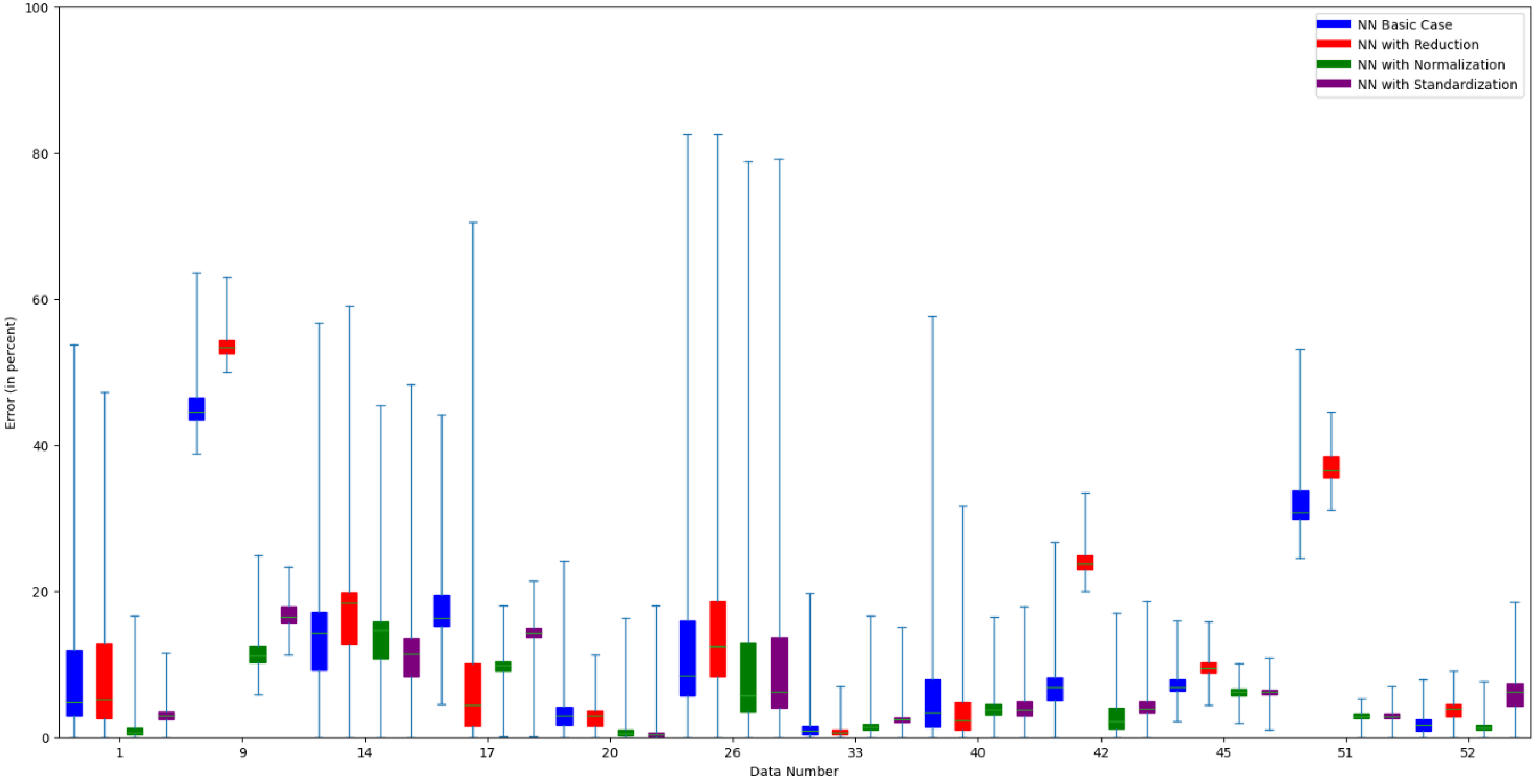
To quantify the **error** of a NN for each value of a block i, we calculate :

$$Err_i = \left| \frac{y_i^{CFD} - y_i^{NN}}{max\left(y_i^{CFD}\right) - min\left(y_i^{CFD}\right)} \right|$$

Result on the training dataset



Result on the testing dataset



Result on the testing dataset

Data Number	NN Basic Case	NN with Reduction	NN with Normalization	NN with Standardization
1	8.139490	9.048442	0.973443	3.026753
9	45.553799	53.700125	11.691819	16.889560
14	13.791781	16.913189	13.625349	11.434768
17	17.692813	8.137317	9.674165	14.228789
20	3.439430	2.732203	0.713181	0.437385
26	12.865245	15.449526	10.615810	11.013295
33	1.204221	0.779731	1.366374	2.393399
40	6.222906	3.881780	3.817003	4.160705
42	6.863333	24.147201	2.914599	4.293493
45	7.227992	9.490665	6.152362	6.171570
51	32.309253	37.029692	2.829195	2.877835
52	1.660562	3.602954	1.347347	5.912622
Mean	13.080902	15.409402	5.476721	6.903348

03 AC placement optimization

Conditions

The goal of the study is to find the **best position** of the AC, while **increasing the thermal comfort** and **minimizing the annual power consumption**

Criteria to quantify thermal comfort : Sum of PMV deviations

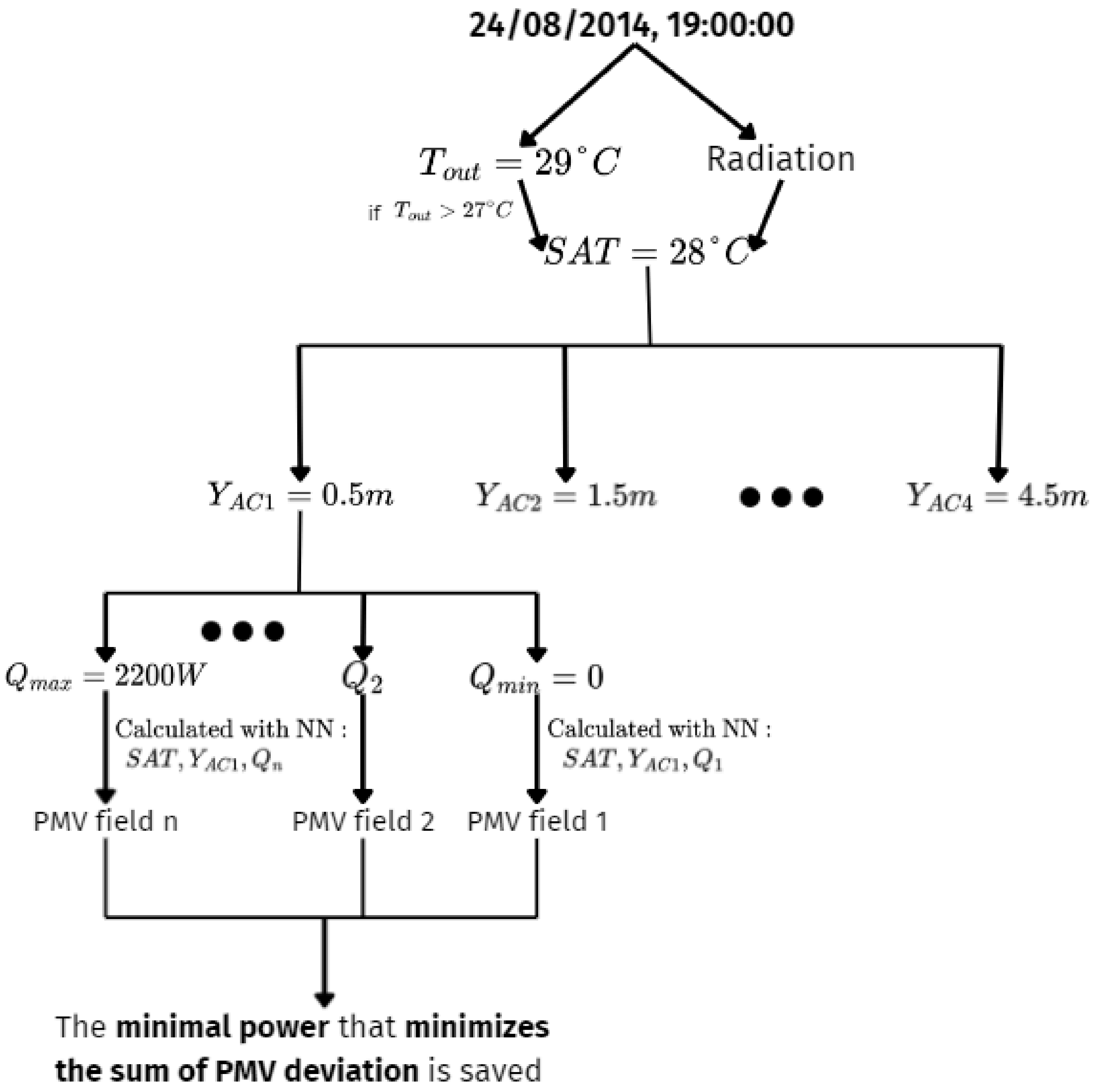
$$\Delta PMV_i = |PMV_i| - PMV_{range}$$

if $\Delta PMV_i < 0$ then $\Delta PMV_i = 0$

For each PMV field, I can calculate :

$$\sum_{i=1}^{n} \Delta PMV_i$$

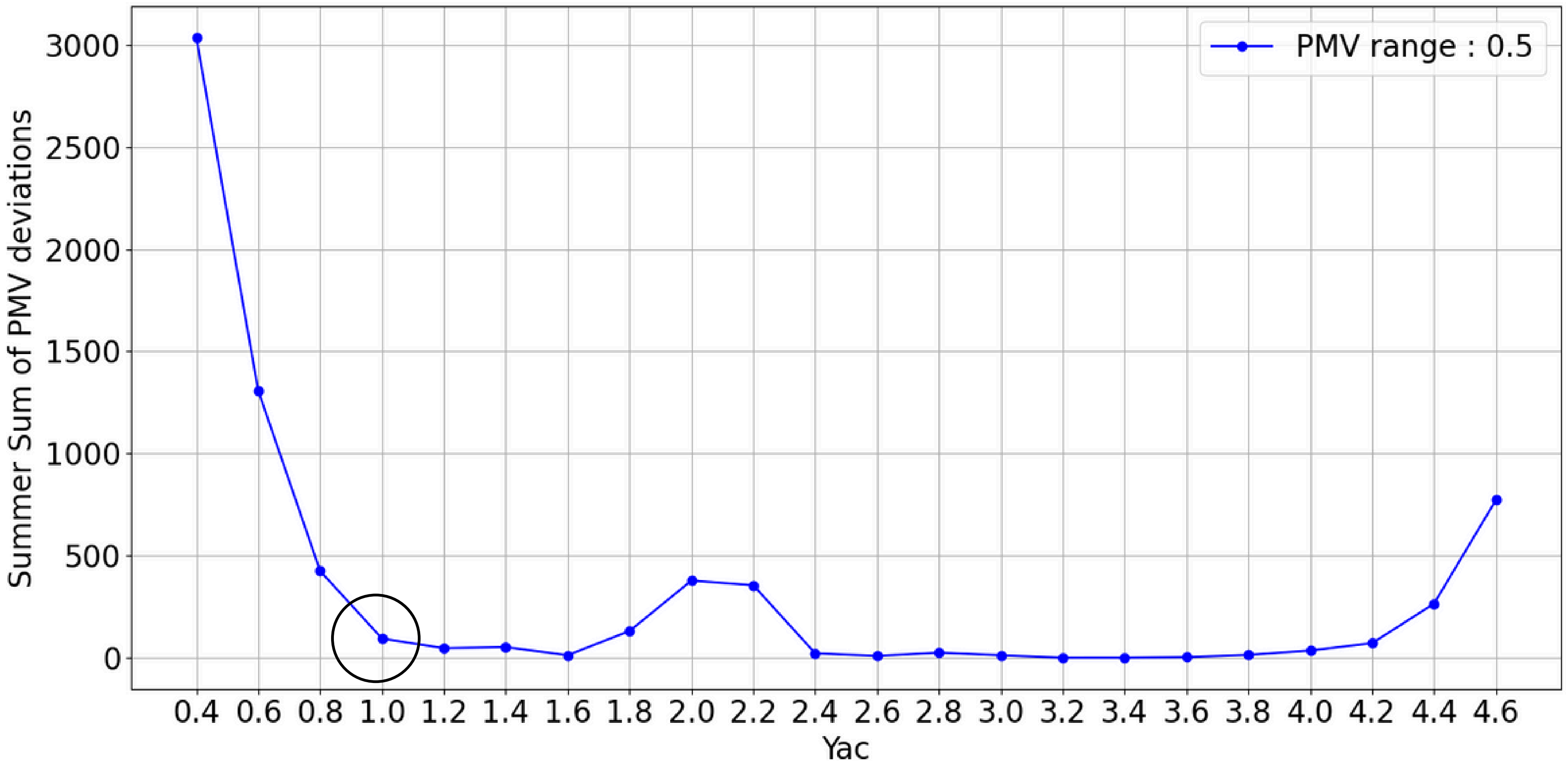
Methodology

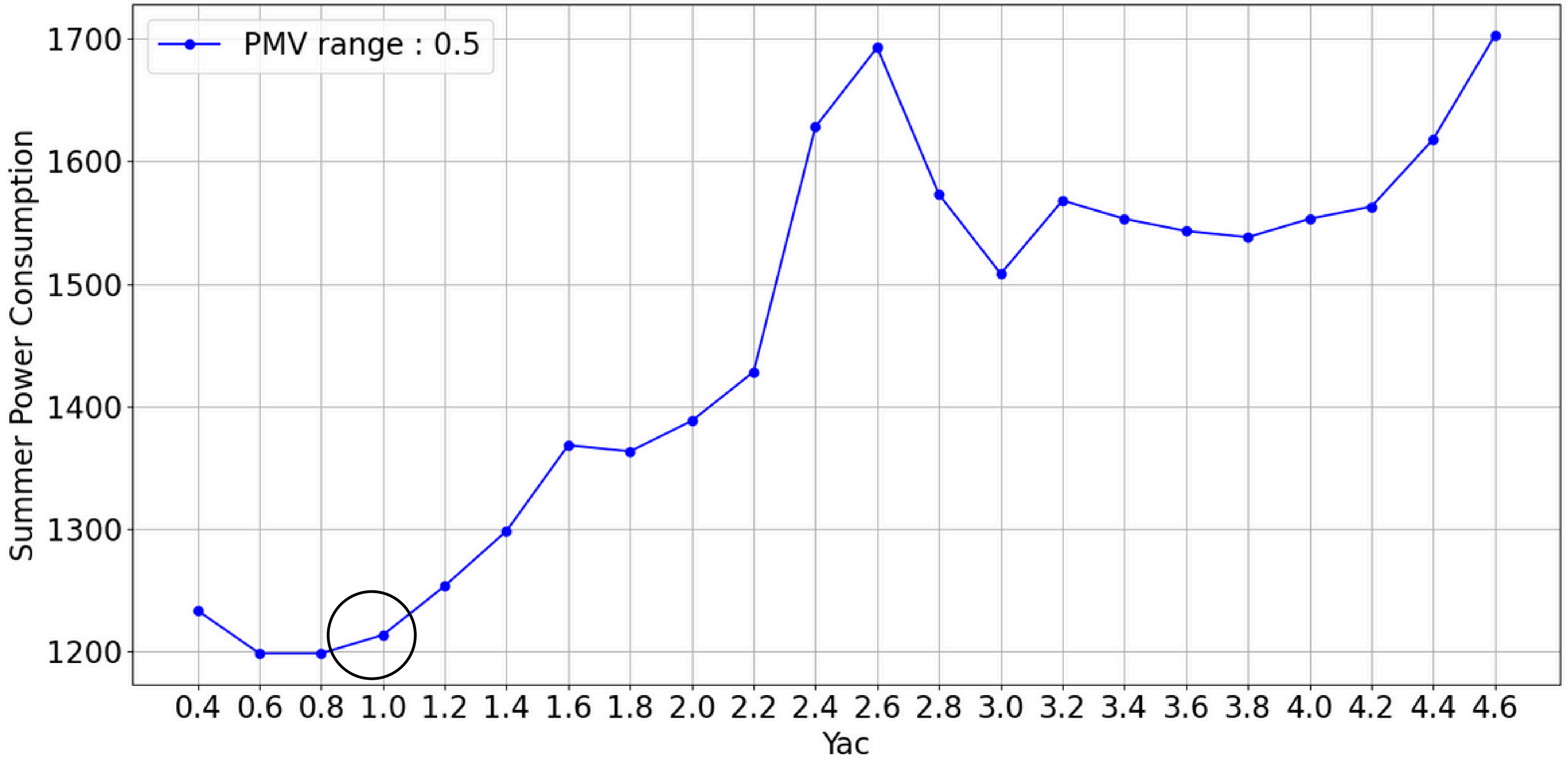


Summer Results

$$PMV_{range} = 0.5$$

Best position : **1 m**

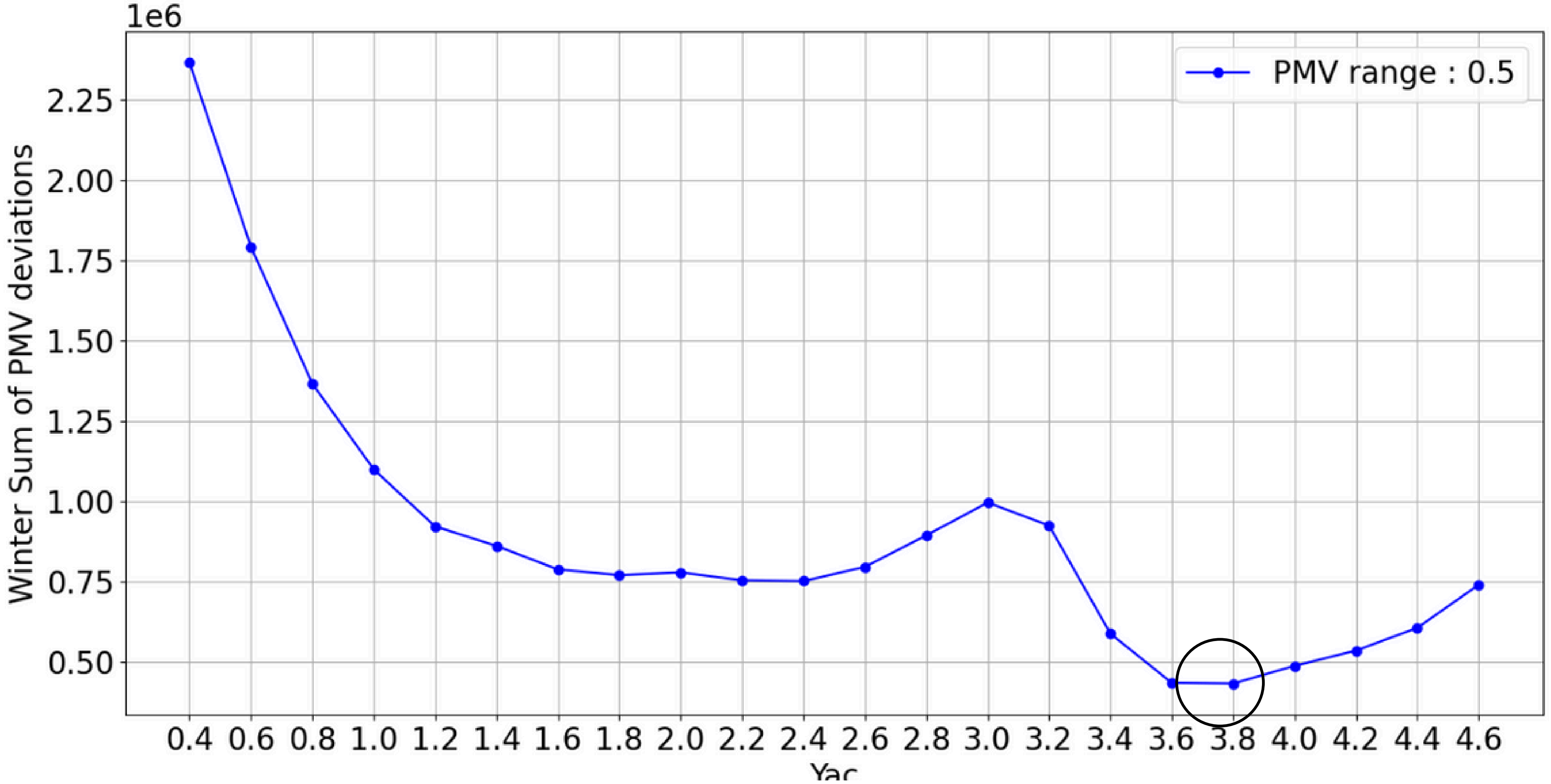


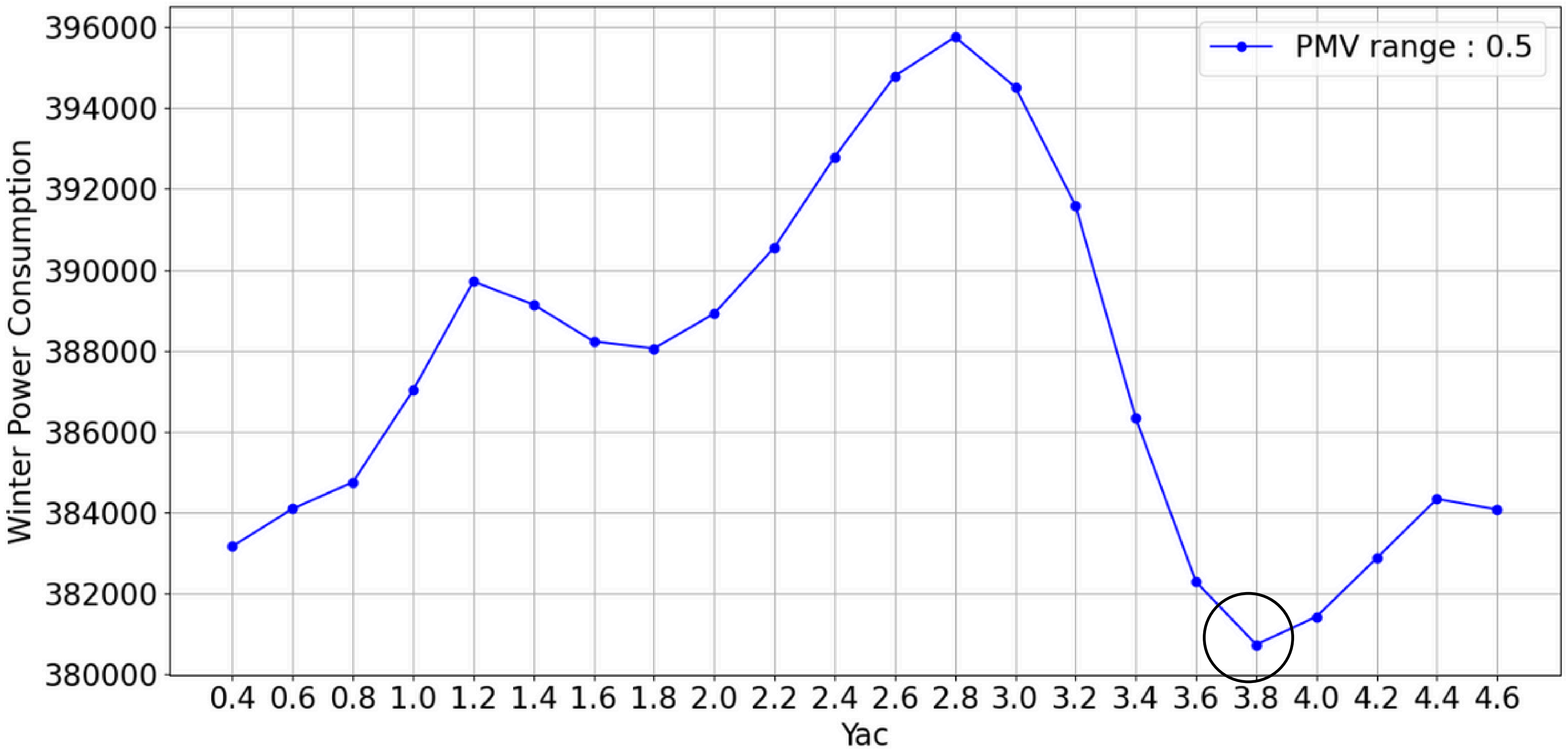


Winter Results

$$PMV_{range} = 0.5$$

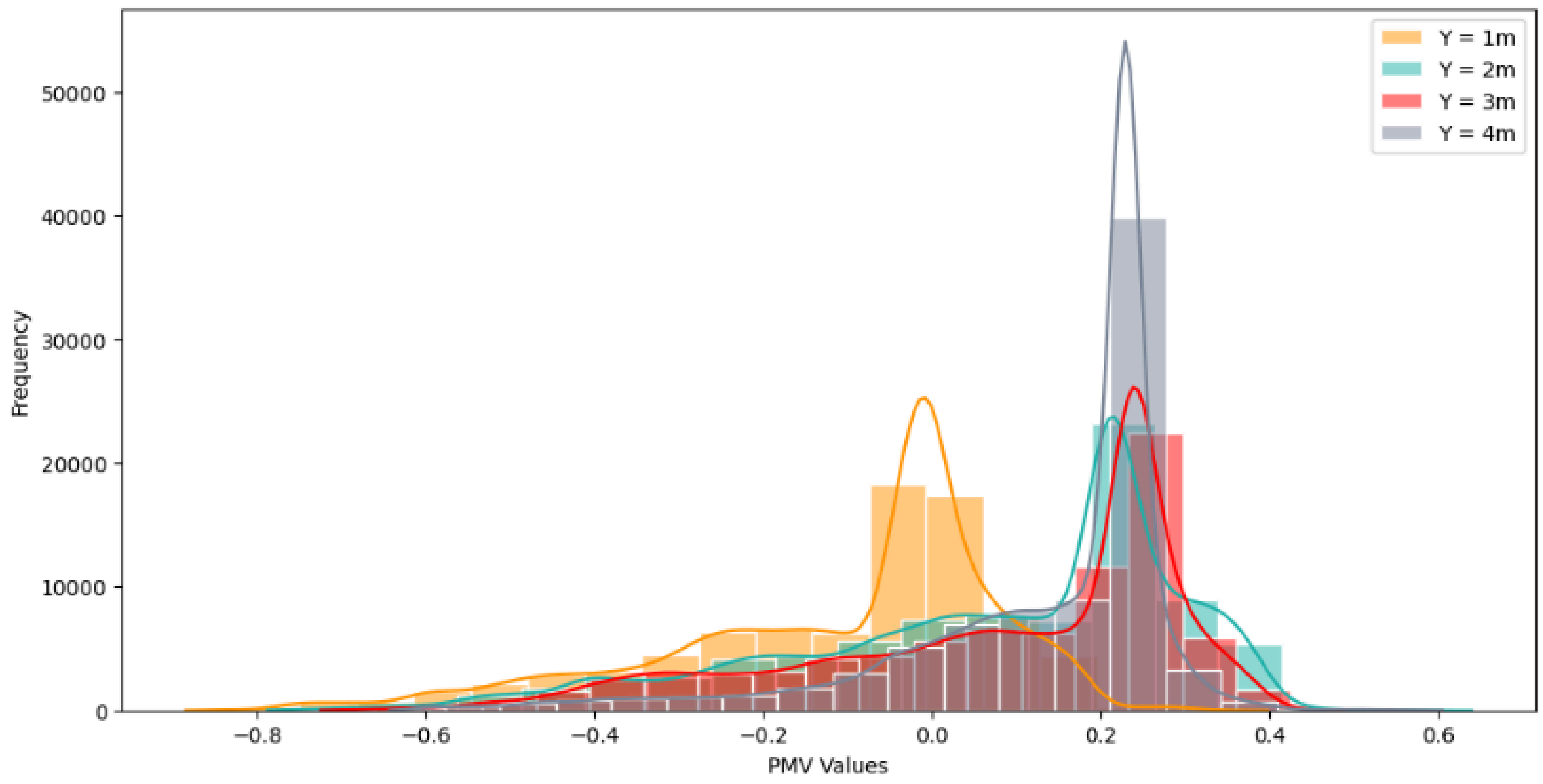
Best position : **3.8 m**





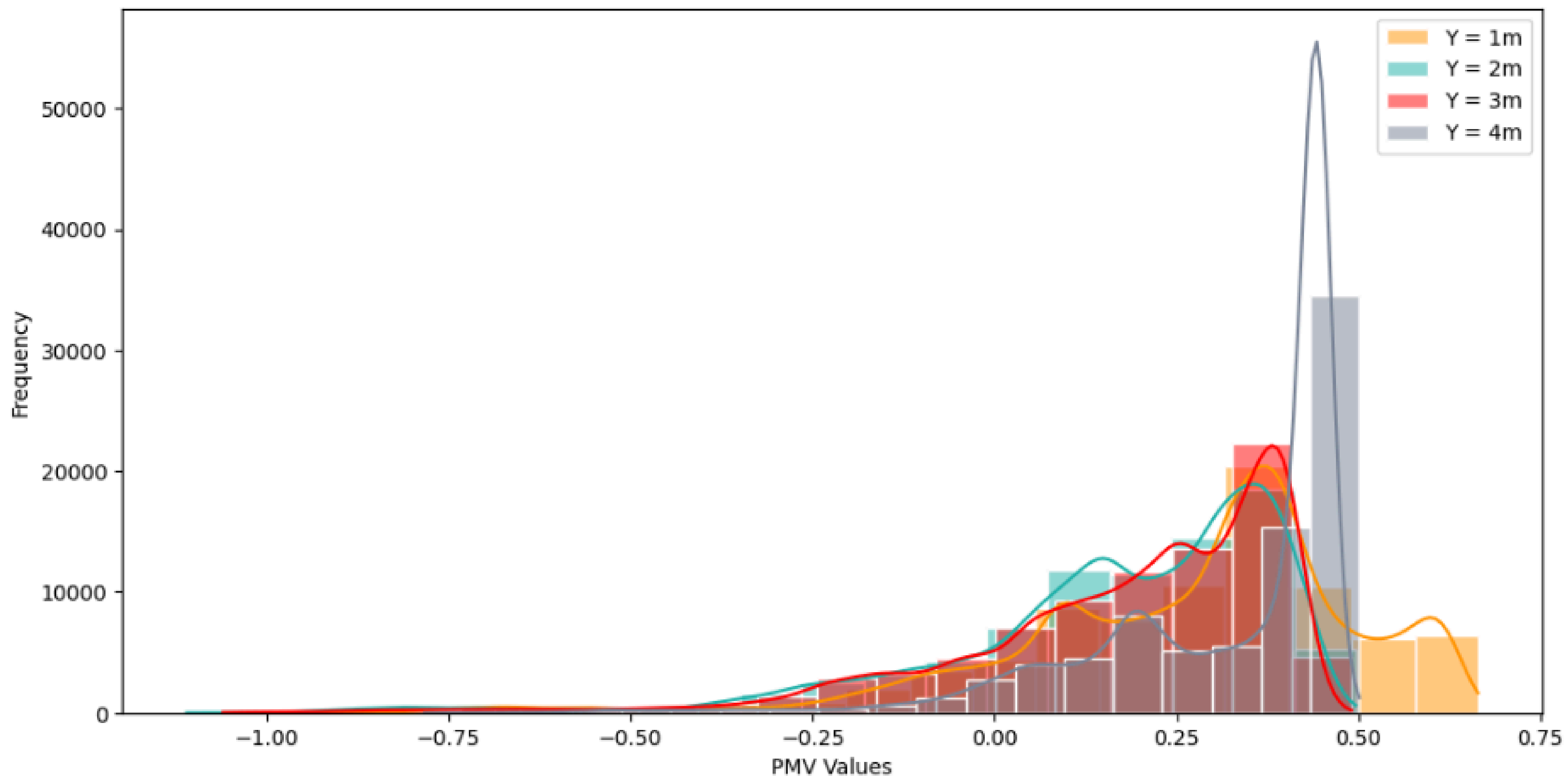
Analysis : Summer Results

In **Summer**, when the **AC is close to the window**, the **standard deviation** is the **lowest**, but the **cooling effect** is **worse** than when the AC is far from the window



Analysis : Winter Results

In **Winter**, when the **AC is close to the window**, the **standard deviation** is the **lowest**, and the **heating effect** is **about the same** than when the AC is far from the window



Analysis : Physics explanation

When the **AC is far from the window** :

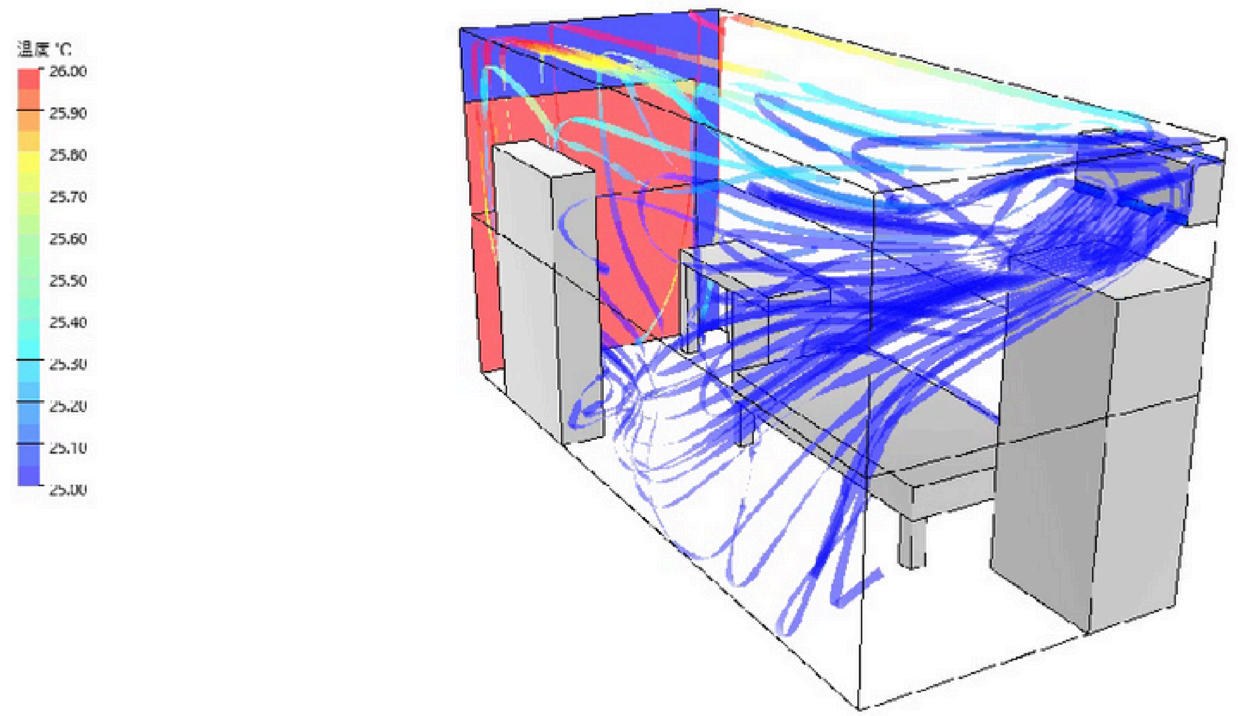
- **Low differential of temperature at the window**, so less heat gain, which needs **less power** to cool or heat the room
- **More differential of temperature inside the room**, so **high standard deviation**
- **Good airflow distribution**

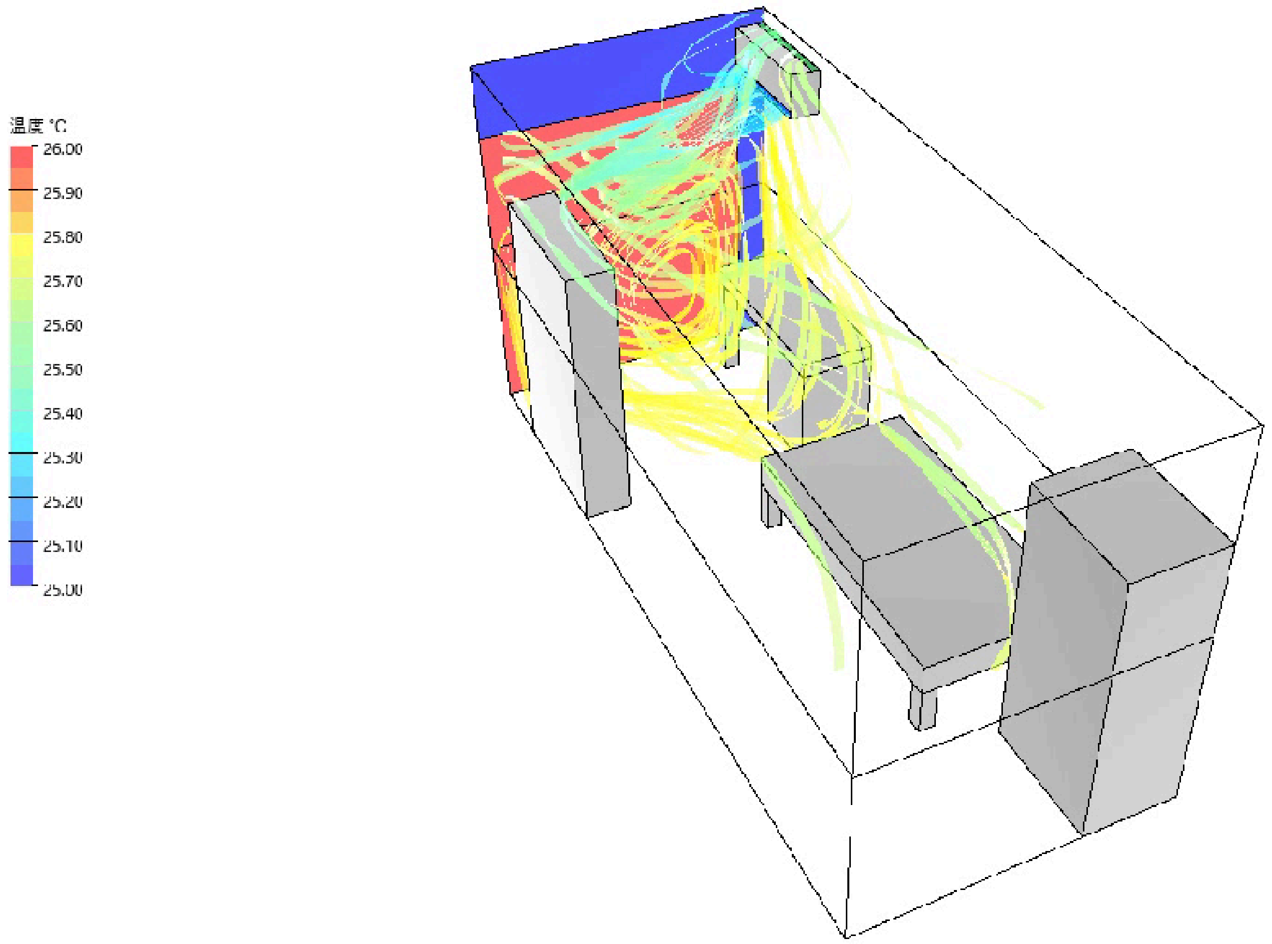
When the **AC is close to the window** :

- **High differential of temperature at the window**, so more heat gain, which needs **more power** to cool or heat the room
- **Less differential of temperature inside the room**, so **low standard deviation**
- **Bad airflow distribution**

Difference between summer and winter :

- In term of Power consumption, **summer is negligeable compared to winter**
- In **summer**, having a **good airflow** distribution (AC far from the window) is **beneficial** since it cools the room and it decreases the PMV. But in **winter**, it has the **opposite effect**, it decreases the PMV but we want the AC to heat the room, so the position close to the window is the best one in terms of PMV deviation and Power consumption





Thank you !