Renovating a house in **Morangis**

APPENDIX - Detailed report: dynamic thermal simulation

VELUX - LIVING PLACES - RENOVATION

ARTELIA / 16/04/2025 / 10820835

CONTENTS

PREAMBLE

1.1. ACTIVE HOUSE LABEL

The Active House label is a voluntary sustainable construction standard that aims to balance **comfort**, **energy** and **environmental impact** in buildings.

Active House requires buildings to provide a pleasant and stable indoor environment all year round, minimising the risk of overheating in summer and optimising the indoor temperature in winter, while limiting energy consumption.

It does not set rigid temperature thresholds: it considers that comfort also depends on the behaviour of users. Priority is given to a naturally comfortable building, without excessive dependence on active heating or air-conditioning systems.

1.2. SUBJECT OF THE STUDY

The simulation presented in this document should enable thermal comfort to be assessed in accordance with standard EN 16798-1 (adaptive method for buildings without air conditioning).

Adaptive comfort ranges:
When there is no mechanical air-conditioning, the standard uses an adaptive approach: it accepts that the inside temperature follows the outside temperature slightly.
For example: if it's very hot outside, the occupant will naturally accept a higher indoor temperature.

The comfort levels defined by the standard will be assessed.

1.3. THERMAL COMFORT STUDY METHODOLOGY

This study was carried out using *Design Builder* version 7.3.0.

Hygrothermal comfort depends on several parameters such as air temperature, radiant temperature, air velocity, level of clothing, degree of physical activity, etc. Several models exist to quantify the level of comfort as a function of these parameters.

The model chosen for this study is one of the most widely used, the Fanger model, and consists of determining a PMV (Predicted Mean Vote) value corresponding to a PPD (Predicted Percentage of Dissatisfied) value. The PMV represents the average result of an occupant vote in the thermal environment under consideration, with 0 corresponding to "neither too hot nor too cold", -3 to much too cold and +3 to much too hot. The PPD, directly linked to the PMV, represents the percentage of occupants likely to declare themselves dissatisfied with the thermal environment in question.

The study is therefore divided into the following stages:

- 3D modelling, allocation of materials (walls, joinery and glazing) and input of masks in DesignBuilder
- Entering thermal loads
- Entering usage scenarios (occupancy, lighting, etc.)
- Annual simulation and analysis of hygrothermal comfort

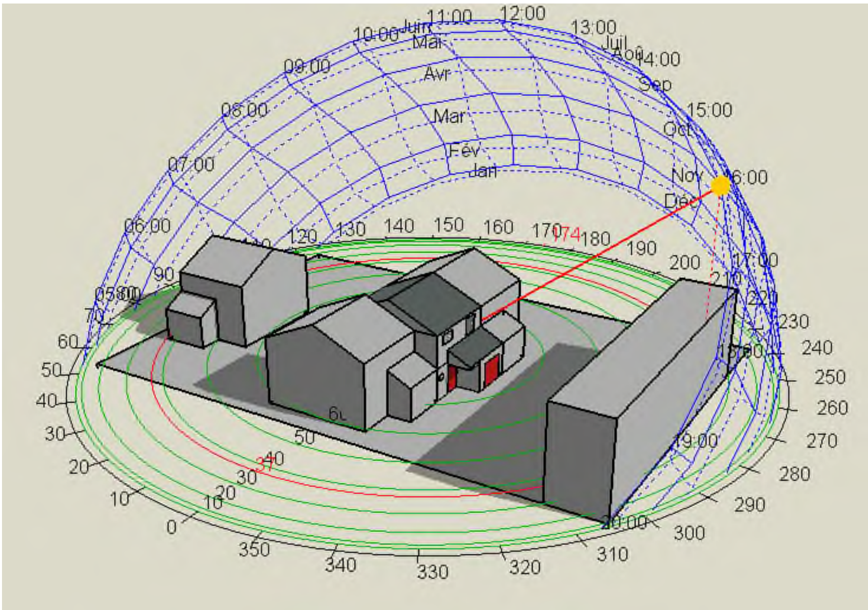


Fig. 1. *3D modelling of the project and its immediate environment*

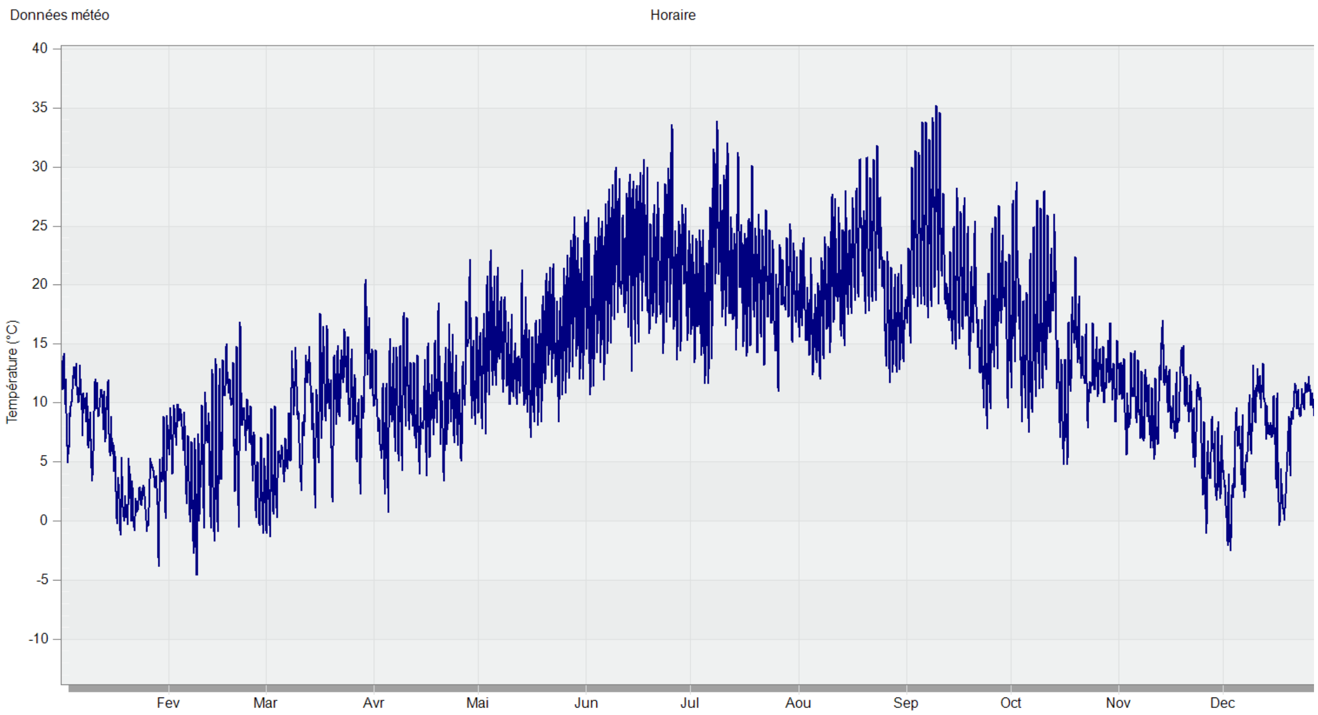
The simulations were carried out in several representative areas according to their type and sensitivity to solar radiation.

2. GENERAL MODELLING ASSUMPTIONS

2.1. WEATHER DATA - DRY AIR TEMPERATURE

The STD was produced using the Paris Orly meteorological file (Year 2021).

The hourly temperature distribution of this weather file is as follows



3. INTERNAL CONTRIBUTIONS AND OPERATING SCENARIO

For each zone with a specific use, a "Template" is created, grouping together all the following assumptions and their operation during the day: occupancy density, set/reduced temperature for heating and air conditioning, fresh air flow and extraction, lighting power and associated management, internal heat input linked to equipment.

	Room	Living room	Kitchen
Occupation	0.02 Per/m² (per square metre)	0.02 Per/m² (per square metre)	0.02 Per/m² (per square metre)
Metabolism	130 W/person	130 W/person	130 W/person
Lighting	2 W/m	2 W/m	2 W/m
Internal contributions	2 W/m	90 W/m² for	

4. FANGER STUDY HYPOTHESES

4.1. SETPOINT TEMPERATURES

On busy working days, the heating set-point temperature is of 20°C.

4.2. ACTIVITY

Metabolism

An individual's level of activity is measured in "met" and is equal to 58.2 W/m² of body surface area in an inactive seated position (an adult person has an average body surface area of 1.8 m² for men and 1.6 m2 for women). Metabolic heat is released mainly in the form of sensible heat, with the remainder in the form of latent heat and radiation.

The change in the body's metabolism as a function of activity results in an increase or decrease in the amount of heat to be dissipated. The more physical the activity, the more heat needs to be expelled. The heat exchanged is quantified by heat flow (met).

In our case, the occupants will have a "sedentary activity" type metabolism, which can be considered to be around 1.2 met (72 W/m²).

Activity			**Men**	**Woman**
	met	**W/m² (W/m²)**	**W**	**W**
Lying down	0,8	48	86	77
Seated rest	1	60	108	96
Sedentary activity (office, home, school, laboratory)	1,2	72	130	115
Standing light activity (purchasing, light industry)	1,6	96	173	154
Average standing activity (sales, work, housework, machine work)	2	120	216	192
Flat walking <2km/h	2	120	216	192
Flat walking <3km/h	2,4	144	259	230
Flat walking <4km/h	2,8	168	302	269
Flat walking <5km/h	3,4	204	367	326
Sustained physical work	3,8	228	410	364

4.3. CLOTHING

The thermal resistance of clothing plays an important role in an individual's heat balance. From the point of view of the thermal comfort of the human body, clothing is the equivalent of the thermal insulation of a house. We quantify the level of clothing with a thermal resistance (clo).

Level of clothing		Thermal resistance [clo]
Nude	-	0,0
Swimming costumes	-	0,1
Tropical wear	Shorts, open-necked short-sleeved shirt, light socks and sandals	0,3
Summer clothing	Light trousers, open-necked short-sleeved shirt, light socks and shoes	0,5
Light clothing	Long-sleeved cotton work shirt, work trousers, wool socks and shoes	0,7
Indoor winter clothing	Long-sleeved shirt, trousers, long-sleeved jumper, thick socks and shoes	1,0

4.4. AIR SPEED

Quantifying hygrothermal comfort also requires knowledge of air velocity.

> In winter, in accordance with the system sizing, the study will be carried out with **0.15 m/s** in winter and summer.

4.5. ANALYSIS METHODOLOGY

4.5.1. Winter period and mid-season

During this period, the temperature is set at 20°C, and the occupant's comfort is maintained by adjusting the level of clothing, chosen according to the outside temperature (1.1°C to 0.7°C). The occupant can remove or add a layer of clothing to maintain comfort (+/- 0.1 clo in winter and +/- 0.2 in mid-season).

4.5.2. Summer period

For this period, a minimum clo of 0.5 is set.

5. THERMAL COMFORT CRITERIA IN ACTIVE HOUSE

5.1. TEMPERATURE VARIATIONS

The aim is to limit sudden variations in temperature inside:

- Avoid overheating in summer by using bioclimatic design (shading, natural ventilation, thermal inertia).
- Reduce heat loss in winter by ensuring optimum insulation and airtightness.
- The recommended temperature ranges are described below

For rooms/spaces in buildings without mechanical air conditioning and with adequate natural ventilation (cross-ventilation or stack ventilation), **the maximum indoor operating temperatures are:**

1. $T_{i,o} < 0.33 \times T_{rm} + 20.8$ °C
2. $T_{i,o} < 0.33 \times T_{rm} + 21.8$ °C
3. $T_{i,o} < 0.33 \times T_{rm} + 22.8$ °C
4. $T_{i,o} < 0.33 \times T_{rm} + 23.8$ °C

(Trm is the mean sliding outdoor temperature, as defined in paragraph 3.12 "Mean sliding outdoor temperature" of standard EN 16798-1).

The minimum indoor operating temperatures are:

1. $T_{i,o} > 21$°C
2. $T_{i,o} > 20$°C
3. $T_{i,o} > 19$°C
4. $T_{i,o} > 18$°C

The tolerance range increases as the comfort category decreases:

Category	Comfort level	Explanation
Category I	Very high	For sensitive areas (crèches, hospitals, retirement homes) where comfort must be excellent.
Category II	High	Comfort for the majority of occupants, in new and renovated buildings.
Category III	Acceptable	Acceptable level for existing buildings or certain more severe climatic conditions.
Category IV	Tolerated	Very wide level of comfort, used only in exceptional situations (technical limitations, high cost, difficult renovation).

6. PRE-WORKS SURVEY

6.1. SPECIFIC HYPOTHESIS

6.1.1. Envelope properties

Performance of opaque walls

The technical characteristics of the envelope used in the comfort study are given below:

Surface concerned	Composition	Thermal resistance (m^2.K/W)	Performance
Outside wall	Brick (22cm) Without added insulation	0.43	🔴
Low floor	Concrete structure without insulation	2.33	🔴
Attic	Wooden structure Weak 100 mm insulation over 10 years old	2.72	🔴

Performance of glazed facades

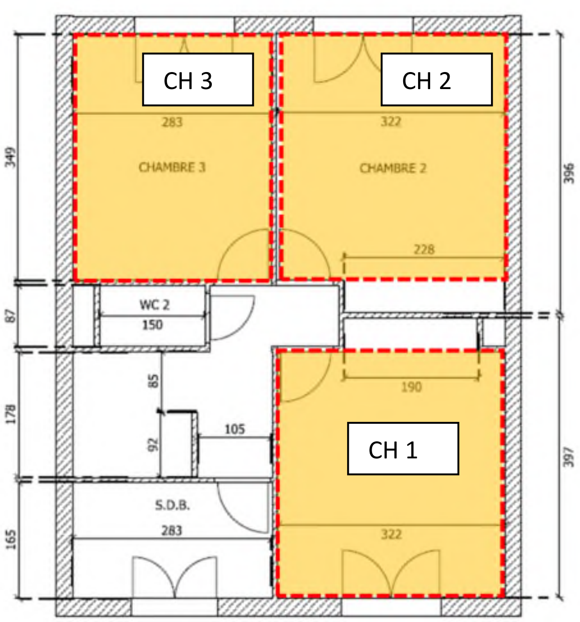
Surface concerned	Uw (W/m^2.k)	TLg	Fg	Sun protection	Visual	Performance
External joinery (Double glazing)	2,4	80	70	External blinds	/	🔴

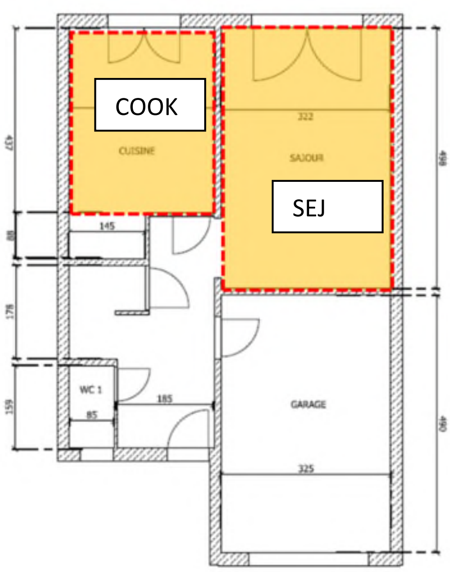
Infiltration

- Air permeability of the envelope at 4 Pa: 1.7 m3/h.m^2.

6.1.2. Identification of study areas

The study areas are identified below:



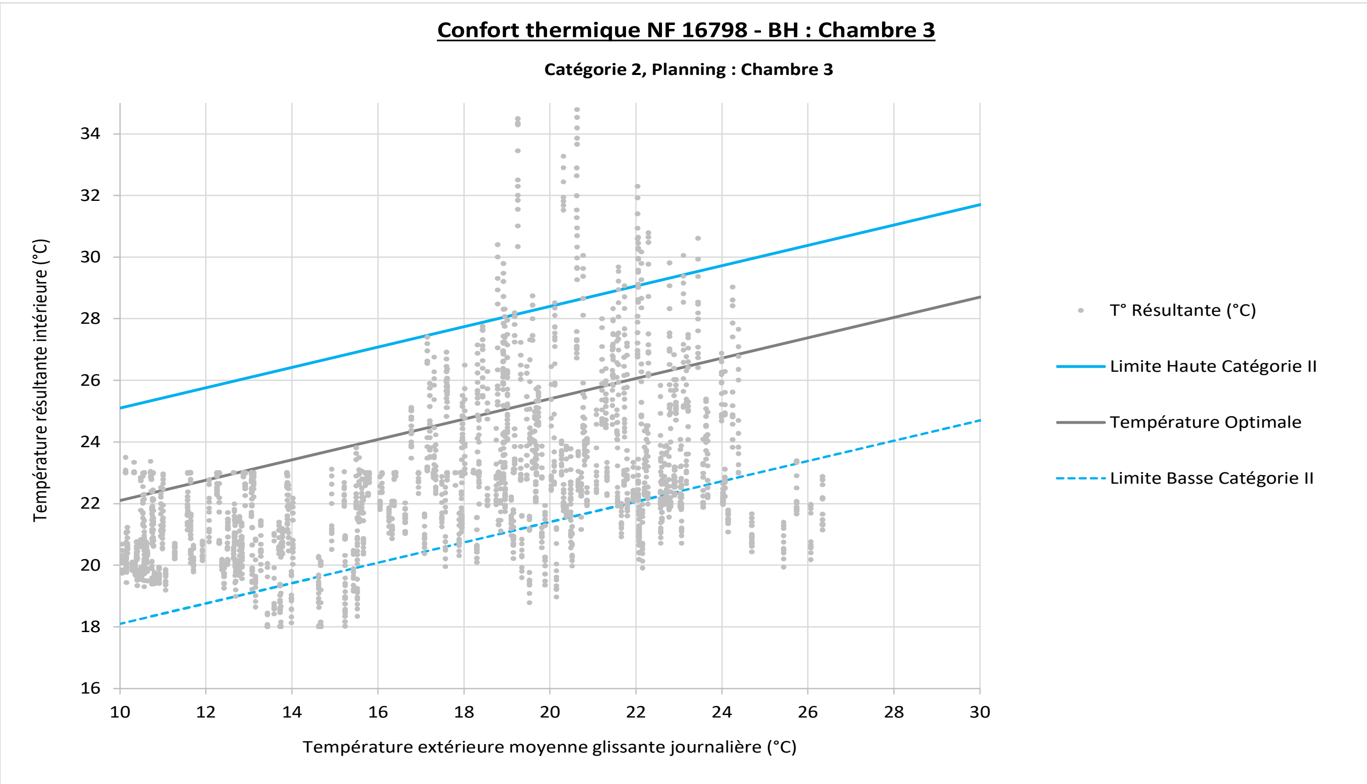


6.2. RESULTS OF THE BASELINE STUDY IN ACCORDANCE WITH STANDARD NF EN 16798-1

Representative area	Surface area (m²)	Reference category	Overrun (%)				Category Active House
			High limit	Low limit	High limit	Low limit	
Bedroom 1	12,0	2	71 h	407 h	3,1%	17,8%	4
Bedroom 2	13,0	2	65 h	549 h	2,6%	22,1%	4
Bedroom 3	11,0	2	68 h	323 h	3,3%	15,6%	4
Living room	18,0	2	62 h	44 h	2,5%	1,4%	4
Kitchen	12,0	2	19 h	9 h	2,9%	1,3%	4

6.3. GRAPHICAL REPRESENTATION OF RESULTS

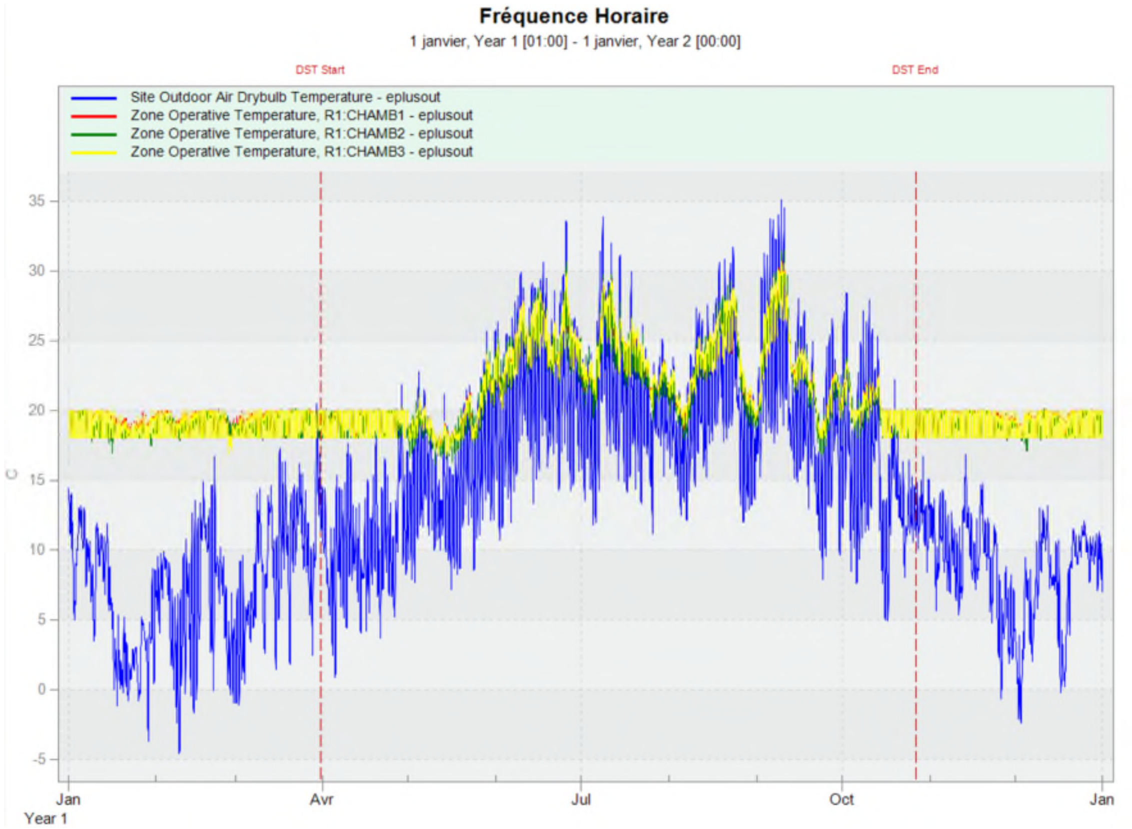
Example of temperature display on Bedroom 3:



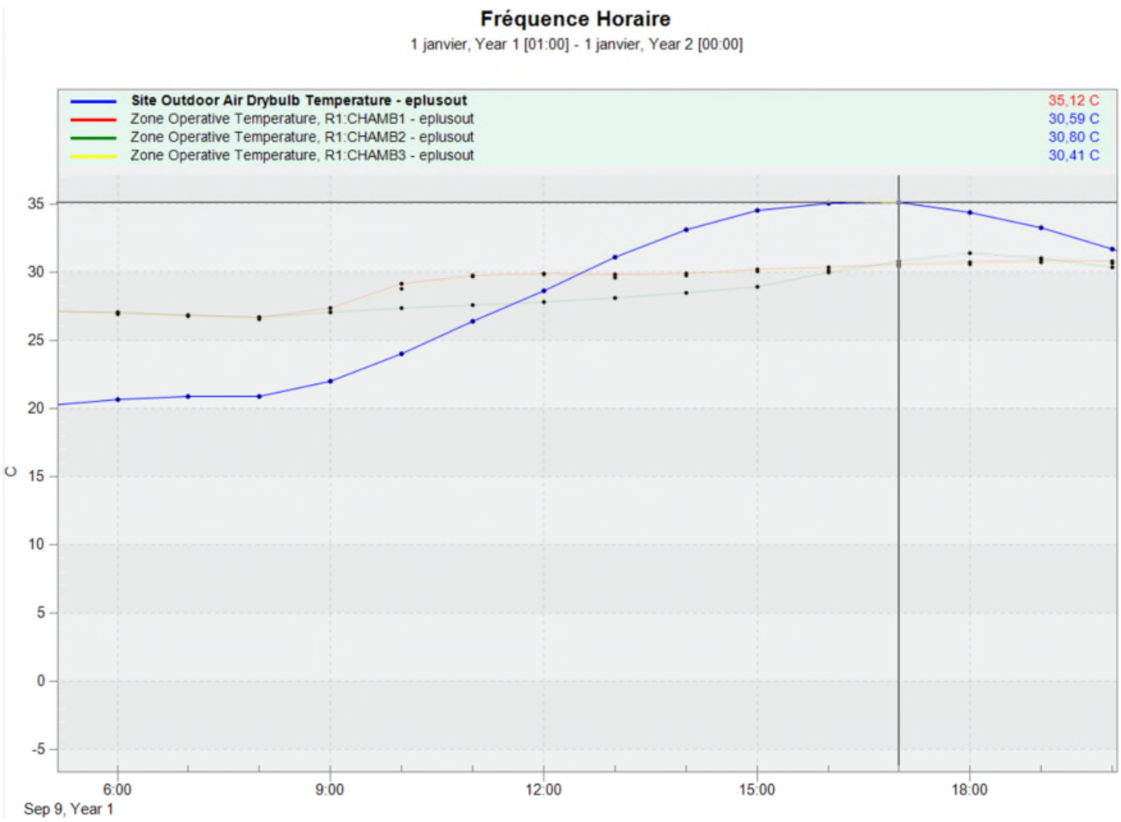
Reference lines :

- The grey curve represents the optimum indoor temperature expected according to the outdoor temperature.
- The solid blue curve represents the upper limit of comfort Category II.
- The dotted blue curve represents the low comfort limit for Category II.

Analysis of the operating temperatures shows that the required level of thermal comfort has not been achieved in order to comply with the Category II criteria defined in standard NF EN 16798-1. In fact, the variations observed exceed the recommended temperature thresholds, indicating a feeling of discomfort for a significant proportion of the occupancy time. This situation may be due to excessive internal gains, insufficient ventilation or unsuitable thermal inertia.



The graph above shows the operating temperature in the rooms as a function of the outside temperature over one year.



The graph above shows the spike in operating temperature during the hottest day. The temperature is more or less uniform across all the chambers, reaching 30°C when it's 35°C outside, with a difference of 5°C.

6.4. WAYS TO ACHIEVE THERMAL COMFORT

1. Insulation and waterproofing

    - Use of high-performance insulation systems.
    - Reducing infiltration of cold or hot air thanks to good airtightness.

2. Solar gain management

    - Optimising natural light while reducing excessive heat gain in summer.
    - Use of high-performance glazing (double or triple glazing) to reduce heat loss.

3. Ventilation and passive cooling

    - Integration of controlled mechanical ventilation (CMV) or natural ventilation systems to maintain a pleasant temperature while ensuring air quality.
    - Priority given to passive cooling techniques (through-ventilation, ground-coupled heat exchangers, etc.) before resorting to active air conditioning.

4. Intelligent control systems

    - Installation of sensors and automation to regulate the indoor temperature according to outdoor conditions.
    - Examples: motorised shutters, intelligent thermostat, sunlight-dependent blind management.

7. POST-CONSTRUCTION STUDIES

7.1. SPECIFIC HYPOTHESIS

7.1.1. Envelope properties

Performance of opaque walls

The technical characteristics of the envelope used in the comfort study are given below:

Surface concerned	Resistance Thermal ($m^2.K/W$)	Performance
Outside wall	4.5	
Low floor	3	
Attic	7.4	

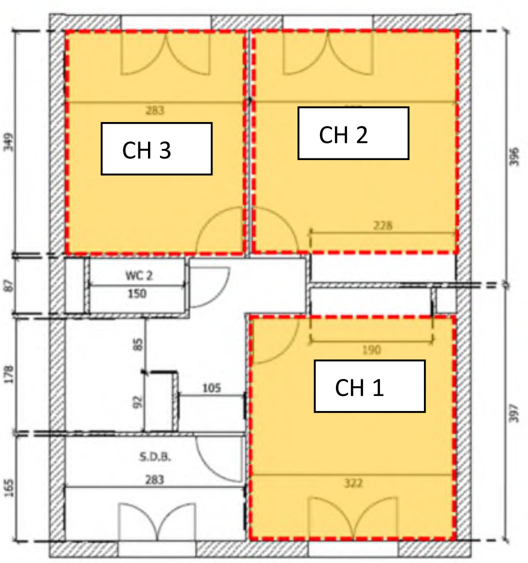
Performance of glazed facades

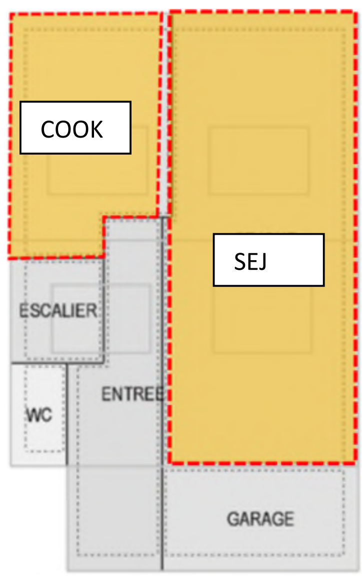
Surface concerned	Uw ($W/m^2.k$)	TLg	Fg	Sun protection	Performance
External joinery (Double glazing)	1,3	70	40	Store Ext	
Zenith openings (4 velux FFKF08)	1,3	63	30	Store Ext	

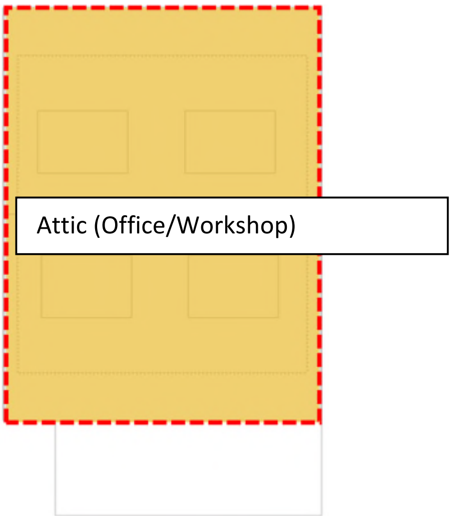
Infiltration

- Air permeability of the envelope at 4 Pa: 0.6 $m3/h.m^2$.

7.1.2. Identification of study areas







7.2. VARIANTS AND RESULTS

As part of the conversion of the attic space, a real challenge arose in terms of **visual** and **thermal comfort**, due to the creation of new living spaces on the roof. Aware of the direct impact that **overhead light** can have on the quality of the indoor environment (glare, overheating, light deficit depending on orientation), we carried out several **targeted simulations**.

These focused on **key parameters** such as **glazing ratio**, **size of openings**, **east/west orientations** and **solar protection mechanisms**.

The aim was to find the **best compromise** between a **good level of natural lighting** to maintain an acceptable level of lighting autonomy and **controlling solar gain** to avoid thermal discomfort. This fine-tuning work, carried out in parallel with the technical and architectural requirements, aims to guarantee a **lasting feeling of comfort** for the future occupants of the newly created attic space.

In this process of optimisation by variants, we paid particular attention to the notion of **summer comfort**, an essential aspect in spaces located under roofs such as attics. To do this, we used the **regulatory method of temperature overshoot**, as defined in the **RE 2020** and **HQE** thermal assessments.

This method consists of calculating, over the year, the **number of hours during which the indoor temperature exceeds certain comfort thresholds** for **26°C** (vigilance threshold) and **28°C** (marked discomfort threshold). These indicators can be used to assess the risk of **overheating in summer** and prolonged exposure of occupants to potentially uncomfortable or even problematic temperatures.

In addition, we also observed the **maximum indoor temperature reached on the hottest day of the year**, enabling us to judge the effectiveness of the thermal envelope (insulation, solar protection, inertia) and the ventilation strategy.

These analyses enabled us to test different **configurations of blackout, opening and natural ventilation**, resulting in a balanced solution that guarantees both **good lighting autonomy and controlled thermal comfort in summer.**

The table below shows all the variants tested as part of this project.

N°	Element	Base	Variant	T ≥ 26°C *(h/year)*	T ≥ 28°C *(h/year)*	Tint Max (°C)
A	BASE	- 4 velux windows FFKF08 - Manual ventilation (30% attic, R+1 and ground floor) - Manual shutter set at 400W/m².	-	412 (16%)	180 (6%)	31,12
1	Night ventilation	Manual ventilation (30% attic, R+1 and ground floor)	Self-opening attic (30%) + ground floor (3 cm) + manual 1st floor (30%)	387 (14%)	164 (6%)	30,5
2	Addition of attic floor mass	-	Fermacell floor panels	376 (13%)	150 (5%)	29
3	Adding roof weight	-	Plasterboard in attic ceilings	-	-	-
4	INT roof insulation	No ITI under the roof	Add 8 cm of wood wool	404 (14%)	164 (6%)	30
5	Blackout roof windows	Manual shutters set at 400W/m².	Automatic shutters closed to 80% (if interior T° > 25°C)	409 (15%)	175 (6%)	30,6
6	Facade insulation (ITE)	Polystyrene on blocks (140 mm)	Isover Isoconfort glass wool (160 mm)	407 (14%)	175 (6%)	31
B	PROPOSAL B	Set of variants 1 to 6 with roof glazing 4 velux FFKF08	2× FFKF06 West (1 motorised + 1 projection) + 2× MK06 East (1 motorised + 1 projection)	90 (3%)	0 (0%)	27,4
C	FINAL PROPOSAL	PROPOSAL B	Automatic opening + manual opening of living room bay from 7pm to 10pm + automatic shutters	90 (3%)	0 (0%)	27,4
D	**FINAL PROPOSAL adapted**	**FINAL PROPOSAL**	**Same scenario as above + 2019 weather file (warmer)**	**125 (4%)**	**0 (0%)**	**28,6**
D1	Blind variant 1	External shutters	West velux blind: external blind (Sws = 0.12 instead of 0.06)	151 (4%)	0 (0%)	28,8
D2	Blind variant 2	External shutters	Blackout **for all skylights**: external blinds (Sws = 0.12)	163 (4%)	0 (0%)	28,8
D3	Blind variant 3	External shutters	**East velux** blind: external blind (Sws = 0.12)	132 (4%)	0 (0%)	28,8

Comments on the variants carried out:

Variant 1: Night ventilation - Automatic opening of attic windows (30%) + ground floor (living room: 3 cm) + manual ground floor +1 (30%)
Automating attic ventilation provides **moderate savings**: -25 h at 26°C, -16 h at 28°C. Maximum temperature lowered to 30.5°C.

- An automatic system ensures that the windows open during these key hours (often between 10pm and 6am).
- In a manual system, it is rare for residents to open all the windows at night; the automatic systems work every day, without depending on the behaviour of users.

Variant 2: Fermacell panels on the floor
Slightly greater improvement than night-time ventilation: -36 h at 26°C, -30 h at 28°C. The maximum temperature drops significantly to 29°C. A good passive lever.

- Fermacell panels increase the building's **thermal inertia** by storing heat during the day, **delaying the rise in temperature** in the attic. This heat is then **released more slowly** at night, improving the efficiency of **night-time ventilation** and reducing heat peaks.

Variant 3: Plasterboard in attic ceiling
Significant improvement in summer comfort thanks to increased thermal inertia in the ceiling. The hours >26°C fall from 412 h (base) to 376 h, and those >28°C from 180 h to 150 h, a reduction of 36 h and 30 h respectively. The maximum temperature also fell from 31.1°C to 29°C, reflecting a significant reduction in heat peaks in the attic.

- **Plasterboard** increases the **thermal mass under the roof**, **slowing the transmission of heat** to the interior. This helps to **reduce temperature peaks** during the day.

Variant 4: Addition of ITI under roof 8 cm wood wool
This action limits the penetration of outside heat thanks to its good insulating and phase-shifting properties. It therefore delays the moment when the heat reaches the inside, reducing overheating during the day.

Variant 5: Automatic shutters closed at 80% (if indoor T° > 25°C)
Modest gain: -3 h at 26°C, -5 h at 28°C. But useful automation to guarantee activation. The maximum temperature drops slightly. Useful as a complement, but limited effect on its own.

- This action responds directly to the home's actual thermal requirements. This automatic management is more precise, reactive and constant, avoiding human oversights or delays, and makes it possible to reduce solar gain at the right moment, thus limiting overheating.

Variant 6: Facade insulation (ITE) Isover Isoconfort glass wool (160 mm)
Comfort is enhanced by higher thermal inertia. Very low density, 30 kg/m³ compared with 110 kg/m³ for glass wool (better capacity to store and release heat).

PROPOSAL B: Set of variants 1 to 6 with 2× FFKF06 West glazing (1 motorised + 1 projection) + 2× MK06 East glazing (1 motorised + 1 projection)

Only 90 hours > 26°C and no hours > 28°C. Maximum temperature reduced to 27.4°C. Very good combination of shading + orientation + effective ventilation.

PROPOSAL C: We add to PROPOSAL B the manual opening of the lounge bay between 7pm and 10pm when people are in the building. This may improve ventilation, but the effect is not measurable here.

PROPOSAL D: This is PROPOSAL C (final scenario) simulated with the **more scorching 2019 weather** file, more representative of hot spells: slight increase in the number of hours > 26°C (+35 h), but none > 28°C, and max temperature at 28.6°C.

Variant D1: Replacement of external shutters with external blinds (Sws = 0.12 instead of 0.06) to the west
Replacing the shutters with blinds improves natural light, but slightly reduces thermal comfort, especially on the west façade, which is very exposed at the end of the day.

Variant D2: Replacement of external shutters with external blinds (Sws = 0.12 instead of 0.06) on all velux windows
The thermal impact is accentuated, but only moderately, as the glazed area facing east is smaller than that facing west.

Variant D3: Replacement of external shutters with external blinds (Sws = 0.12 instead of 0.06) to the east only
The impact on comfort is marginal, as there are small glazed areas to the east, and the morning sun is still relatively low, and outside temperatures are cool.

Assumptions of proposal D (final):

- **Glazing type**: 2× FFKF06 West (1 motorised + 1 projection) + 2× MK06 East (1 motorised + 1 projection)

- **Night ventilation**: natural ventilation is activated when the outside temperature is lower than the inside temperature and the inside temperature is higher than 24°C.

  The openings in the attic will be opened automatically to 30% of the maximum opening area, representing 0.56 m². The windows on the ground floor (bedrooms) will open manually to 30% of the maximum opening area, representing 0.57 m². The living room window on the ground floor opens automatically by 3 cm, representing an opening area of 0.14 m², and manually by 50% between 7pm and 10pm when occupants are present, representing an opening area of approximately 2.4 m².

- **External solar protection**: These shutters are motorised and controlled by an indoor temperature sensor. When it detects that the indoor temperature exceeds a threshold of 25°C, it automatically triggers partial closure of the blinds to 80%.

  Closing 80% of the windows significantly reduces direct solar gains (those that penetrate through the glazing and overheat the interior). At the same time, it preserves natural light and maintains a certain amount of ventilation when the windows are open.

7.3. RESULTS OF THE FINAL SCENARIO

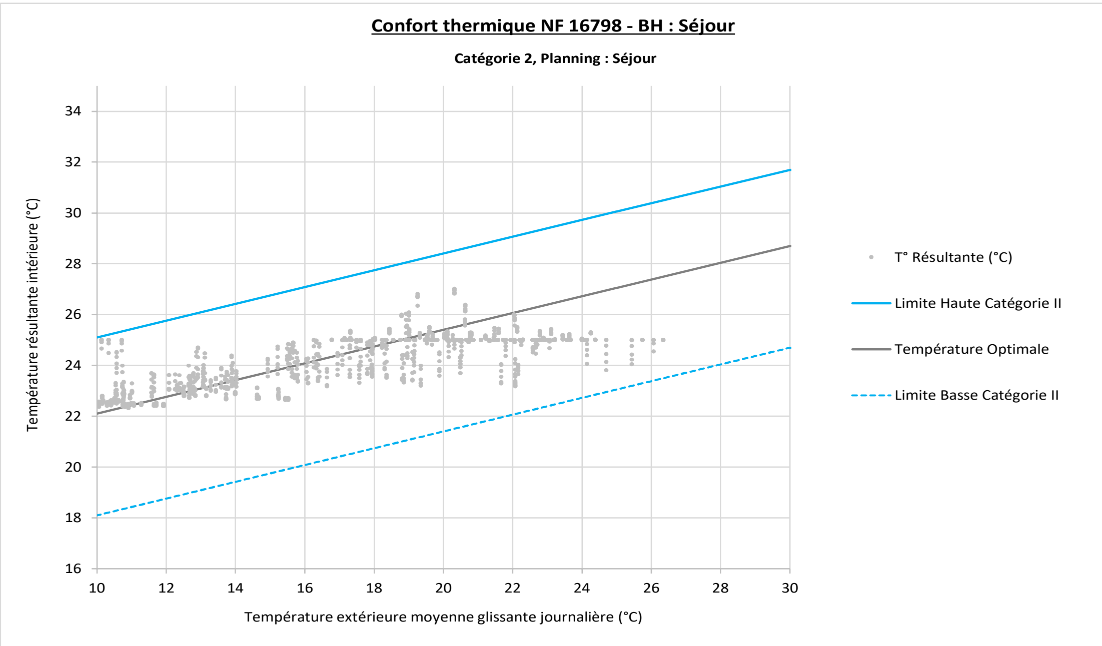
The results below are given for the scenario selected as a result of the various studies, i.e. proposal D described in the previous section.

7.3.1. Results of the study in accordance with standard NF EN 16798-1

Representative area	Surface area (m²)	Reference category	Overrun (%)				Category Active House
			High limit	Low limit	High limit	Low limit	
Bedroom 1	12,0	2	3 h	0 h	0,1%	0,0%	2
Bedroom 2	13,0	2	2 h	0 h	0,1%	0,0%	2
Bedroom 3	11,0	2	3 h	0 h	0,1%	0,0%	2
Living room	26	2	0 h	0 h	0,0%	0,0%	1
Kitchen	12,0	2	0 h	0 h	0,0%	0,0%	1
Attic	25	2	11 h	0 h	0,7%	0,0%	3

7.3.2. Graphical representation of results

Example: Living room



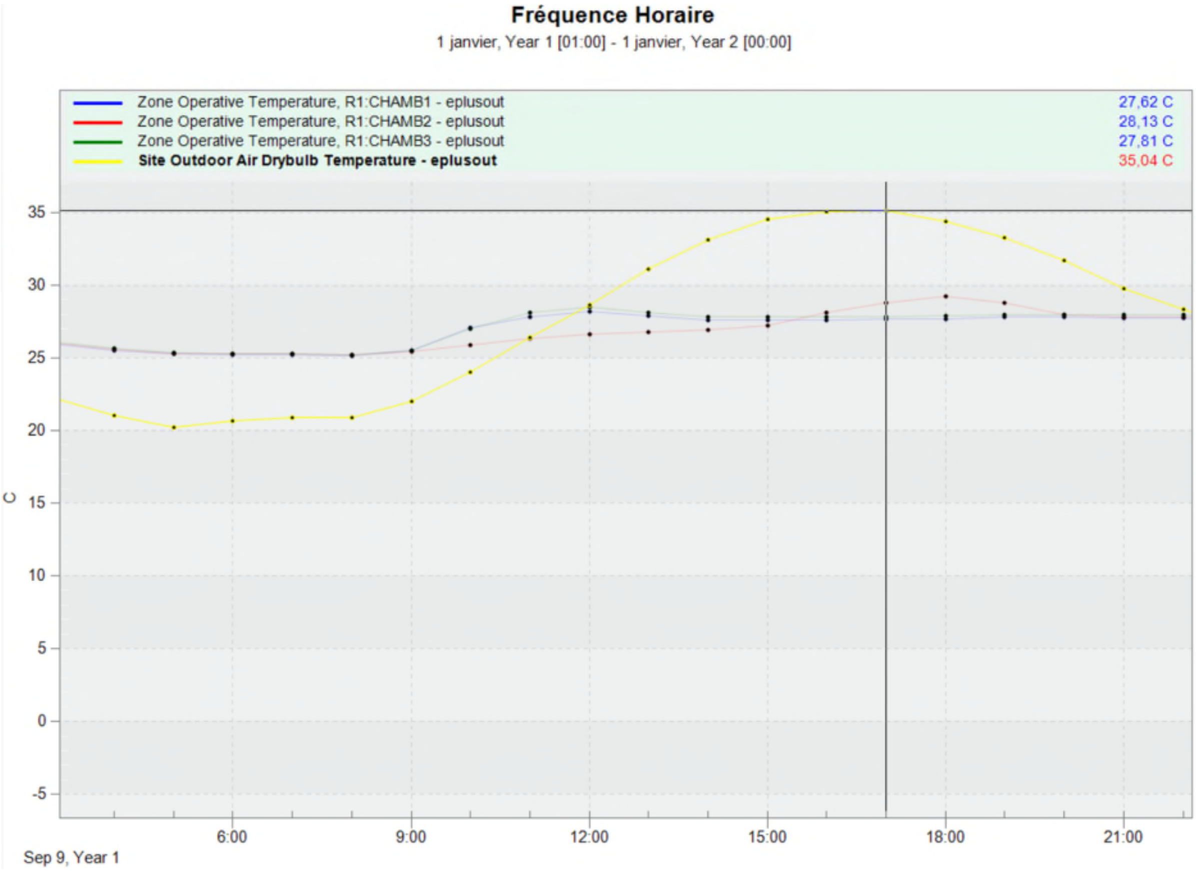
Reference lines :

- The grey curve represents the optimum indoor temperature expected according to the outdoor temperature.
- The solid blue curve represents the upper limit of comfort Category II.
- The dotted blue curve represents the low comfort limit for Category II.

On the simulations after major renovation of the house, thermal comfort has been considerably optimised and now meets the **Category II** criteria defined by **standard NF EN 16798-1**. Thanks to the improvements made, including reinforced insulation, better heating management and optimised ventilation, the indoor environment offers more stable and pleasant thermal conditions.

During **the majority of occupancy time**, temperatures vary between **20°C and 26°C**, guaranteeing thermal comfort in line with the requirements of the standard. These adjustments ensure optimum well-being for occupants by maintaining an even, regulated temperature.
What's more, the solutions put in place prevent overheating in summer, ensuring optimum comfort all year round.

The graph above shows the operating temperature in the chambers as a function of the outside temperature over one year.



The graph above shows the operating temperature in the attic as a function of the outside temperature on the hottest day of the year.

After the refurbishment work, perceived temperatures fell significantly, from **2°C to 2.5°C**, thereby limiting **overheating in summer**. The operating temperature in the bedrooms no longer exceeds 27.8°C, significantly improving thermal comfort for occupants.