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Faculty of TECHNOLOGY

THESIS

-

Presented for the obtaining of a Master's degree

In: Civil Engineering

Specialty: Structure

By: NEDJLAA OUADAH & AYA ALIANE

Master's Thesis:

Technical Study of a Reinforced Concrete Building with Thermal Analysis of Utility Systems

Publicly defended on 14 / 06 /2026, In front of a jury composed of:

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بسم الله الرحمن الرحيم

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Dedication

(وَآخِرُ دَعْوَاهُمْ أَنِ الْحَمْدُ لِلَّهِ رَبِّ الْعَالَمِينَ)

سورة يونس – 10 –

It wasn’t a short journey, and that wasn’t the point, and the path wasn’t strewn with easy steps, but I did it

Here I am, having reached the end of my university journey after much toil and hardship, and after five years spent in pursuit of my dreams and knowledge—a journey filled with hopes and the struggles of striving—so yesterday marked the dawn of a new day.

I dedicate this work first and foremost to myself, and then to everyone who has worked alongside me to bring this journey to fruition.

May you remain a source of support for all time.

To those of whom Allah, the Most High, has said:

”وَاخْفِضْ لَهُمَا جَنَاحَ الذُّلِّ مِنَ الرَّحْمَةِ وَقُل رَّبِّ ارْحَمْهُمَا كَمَا رَبَّيَانِي صَغِيرًا”

To the one for whom God has placed Paradise at her feet, who embraced me with all her heart and soul, and who was the light that illuminated my days, the source of my strength and success (my dearest mother)

To the one whose brow was marked by sweat, who taught me that success comes only through patience and determination (My dear father)

To the one who embraced my dreams and supported me without limit, yesterday’s hardships have become today’s pleasant memories. Praise be to God who has granted us what we love with those we love.

To my steadfast support and the security of my days, to those who strengthened my resolve; they were the springs from which I drew sustenance for the best and purest of my days (My sister and brother)

Whoever said, ‘She is mine, I’ll have her,’ and ‘She is mine, I’ll take her even if she resists’—I’ve brought her here

Praise be to God, by whose grace good deeds are accomplished, and praise be to God.

Thank you, with love and gratitude, for the beginning and the end .

Aya Aliane

Dedication

قال الله تعالى:« وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ» «سورة التوبة، الآية 105» .

These nineteen years were not easy days; rather, they were bornof long-standing patience. She took her steps with determination when circumstances let me down, and with hope when the path grew narrow. This success is a testament to myself, and the culmination of a silent struggle, written with patience and determination before being sealed by the journey's end. Praise be to God, who made the beginnings easy and brought us to the end.

To those whose prayers were the light that dispelled the darkness of my days, to the two hearts that never grew weary of caring for me and never once withheld their generosity from me.

To the one whose name is inseparable from mine, to the one whose brow is marked by sweat—you were the beginning of every beautiful thing I have experienced; to the one who taught me values and principles, and that success comes only through patience and determination. To the light that illuminated my path, (To My Dear Faher)

To the one who made heaven lie at her feet, to the one whose prayers always surrounded me with goodness, you were the voice of hope that dispelled my fears; your words of support and encouragement made my dreams a reality. You are my source of strength and my constant inspiration (To My Dear Mother)

To my steadfast companion and the security of my days, to those who strengthened my resolve and became the springs from which I drew sustenance for the best of my days and their beauty, (To My Dear Sblings)

To those who believed in me and supported me in every step I took, to those who were my companions on the journey and in every situation, you have always been the support that propels me forward.

Today I stand with my certificate in hand and your faces in my heart, for you were my primary motivation. And to all my loved ones and the kind-hearted souls who supported me on this journey with encouragement and kind words during times of hardship and crisis, I dedicate my graduation to you all

Nedjlaa Oaudah

Abstract

This study examines a four-storey reinforced concrete building intended for residential use, located in the city of Tlemcen and classified as being in a seismic zone III. The design was carried out in accordance with the Algerian seismic regulations RPA2024. To achieve this, we must carry out a detailed analysis to understand the building, taking into account the various factors affecting this structure in terms of the loads it is subjected to and other factors. In Algeria, buildings are characterised by low energy efficiency, making them a major consumer of energy, particularly as the housing sector is not subject to strict regulations in this area. To determine the amount of heat loss and gain, as well as the annual heating requirements of the dwelling, we used the 'CYBE' calculation programme. This programme provides a description of the dwelling and its fittings, estimates energy consumption, and verifies the dwelling's compliance with DTR C3.2 and DTR C3.4 standards. The factors taken into account included: heating, cooling, wall composition and orientation, windows, local climate, and insulation. The software also provides advice and solutions for reducing energy consumption, alongside recommendations for improving energy efficiency, enhancing the building's performance, and ensuring thermal comfort within the home.

Keywords: Building, Reinforced concrete, thermal insulation, RPA2024

ملخص

يتناول هذا العمل دراسة مبنى من الخرسانة المسلحة (4طوابق) مخصص للاستخدام السكني، يقع في مدينة تلمسان ويصنف ضمن منطقة زلزالية (للمنطقة III) تم إجراء التصميم وفقًا للوائح الزلزالية الجزائرية RPA2024 ولتحقيق ذلك، يتعين علينا القيام بعمل دقيق يؤدي إلى فهم البناء مع مراعاة التأثيرات المختلفة التي تؤثر على هذا الهيكل فيما يتعلق بالأحمال التي يتعرض لها وغيرها في الجزائر، تتسم المباني بانخفاض كفاءتها في استهلاك الطاقة، مما يجعلها مستهلكًا رئيسيًا للطاقة، لا سيما مع عدم خضوع قطاع الإسكان لأنظمة صارمة في هذا المجال. ولتحديد كمية فقدان الحرارة واكتسابها، بالإضافة إلى احتياجات التدفئة السنوية للمسكن، استخدمنا برنامج "CYBE" الحسابي. يوفر هذا البرنامج وصفًا للمسكن وتجهيزاته، ويُقدّر استهلاك الطاقة، ويتحقق من امتثال المسكن لمعايير DTR C3.2 و DTR C3.4. وشملت العوامل التي تمّ أخذها في الاعتبار: التدفئة، والتبريد، وتكوين الجدران واتجاهها، والنوافذ، والمناخ المحلي، والعزل. كما يُقدّم البرنامج نصائح وحلولًا لخفض استهلاك الطاقة، إلى جانب توصيات لتحسين كفاءة استهلاك الطاقة، وتعزيز أداء المبنى، وضمان الراحة الحرارية داخل المنزل.

Resumè

Cet ouvrage porte sur l'étude d'un bâtiment en béton armé (4 étages) à usage résidentiel, situé dans la ville de Tlemcen et classé en zone sismique (zone III). La conception a été réalisée conformément à la réglementation sismique algérienne RPA2024. Pour ce faire, il nous a fallu mener un travail minutieux permettant de bien comprendre la construction, en tenant compte des différents facteurs qui influent sur cette structure, notamment les charges auxquelles elle est soumise. En Algérie, les bâtiments se caractérisent par une faible efficacité énergétique, ce qui en fait de grands consommateurs d'énergie, d'autant plus que le secteur du logement n'est pas soumis à des réglementations strictes en la matière. Afin de déterminer les pertes et les gains thermiques, ainsi que les besoins annuels en chauffage du logement, nous avons utilisé le logiciel de calcul « CYBE ». Ce logiciel fournit une description du logement et de ses équipements, estime la consommation d'énergie et vérifie la conformité du logement aux normes DTR C3.2 et DTR C3.4. Les facteurs pris en compte comprenaient : le chauffage, le refroidissement, la composition et l'orientation des murs, les fenêtres, le climat local et l'isolation. Le logiciel propose également des conseils et des solutions pour réduire la consommation d'énergie, ainsi que des recommandations pour améliorer l'efficacité énergétique, renforcer la performance du bâtiment et garantir le confort thermique à l'intérieur de la maison.

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LIST OF SYMBOL

G: *Continuous operation*

Q: *Operational use*

E: *Accidental operation*

$\boldsymbol{\sigma_{bc}}$: Allowable stress in concrete

$\boldsymbol{\sigma_{st}}$: *Allowable stress in concrete*

$\boldsymbol{A'}$: *Cross-sectional area of compressed steel and cross-sectional area of steel at ultimate elastic limit, respectively.*

At: *Cross-section of a transverse reinforcement bar.*

A : *Zone acceleration coefficient.*

α: *Neutral fibre coefficient.*

B: *Area of a concrete cross-section*

Br: *Reduced section.*

B, b: *Width (m).*

Ct: *Coefficient depending on the bracing system and the type of infill*

Cu: *Soil cohesion (kN/m²).*

D_s: *Slab diameter.*

D_a: *Average dynamic amplification factor*

ELS: *Serviceability limit state.*

ULS: *Ultimate limit state.*

E: *Longitudinal modulus of elasticity, earthquak*

f_{bu}: *Compressive stress in concrete at the elastic limit (EL): Elastic limit*

f_{cj} : *Characteristic compressive strength at 'j' days, expressed in MPa.*

f_{tj} : *Characteristic tensile strength at 'j' days, expressed in MPa*

h_t *: Total height of the foundation slab (m).*

h_N *: Height measured in metres from the base of the structure to the top floor.*

σ_b *: Compressive stress in concrete.*

σ_s *: Compressive stress in steel*

u *: Poison coefficient*

σ_s*: Normal stress.*

γ_W *: Density of water (t/m³).*

γ_b *: Safety factor.*

γ_s *:. Safety factor*

Φ *: Internal friction angle of the soil*

σ_{adm} *: Permissible stress at the foundation (bar)*

τ *: Limit shear strength as specified by the BAEL (MPa).*

τ_u*: Shear strength (MPa).*

Ψ *: Weighting factor based on the nature and duration of the*

operational load.

μ_u *: The ultimate moment, in a nutshell.*

λ_i *: Instantaneous coefficient. The stability of the structure depends on the strength of the various*

GENERAL INTRODUCTION

Civil engineering is one of the oldest and most extensive branches of engineering. It plans, designs, builds and operates the essential infrastructure of modern societies. A fundamental pillar of urban and economic development, it ensures the construction of roads, buildings, dams, bridges and water supply networks, thereby contributing to improved quality of life and urban development. Drawing on the principles of physics and mathematics to create sustainable structures, it plays a fundamental role in this context. Reinforced concrete buildings hold a prominent place in engineering projects, both in Algeria and worldwide. Among the most common types of construction in Algeria, they are valued for their durability and ability to meet safety requirements. However, developments in the construction sector, combined with climate change, have made it essential to pay particular attention to the thermal aspects of buildings. The study of the thermal performance of reinforced concrete buildings is of great importance, particularly given Algeria's diverse climate. This study aims to analyse a specific reinforced concrete building by identifying its type and purpose, while focusing on the thermal aspects that influence its performance. It also highlights the main engineering challenges associated with the design and construction of this type of building. It aims to provide a comprehensive second analysis of a reinforced concrete building, combining structural analysis and thermal evaluation of utility systems. It is based on a scientific methodology founded on theoretical analysis and the use of specialised engineering software. The study also highlights the civil engineer's responsibility in making appropriate design decisions, whether in terms of material selection, determining element thicknesses, or coordinating with different engineering disciplines to ensure that the project complies with the technical and regulatory standards applicable in Algeria. This work is limited to the analysis of a specific reinforced concrete building in terms of engineering characteristics and functional use, without generalising the results to all types of buildings. The methodology used is based on the use of structural calculation software to verify the structural behaviour of the building, as well as thermal modelling and simulation software to assess its energy performance. The results relating to utility systems are compared with the regulations and national standards in force in Algeria.This master'thesis is structured into three chapters. The first chapter presents surveys existing studies on reinforced concrete buildings, thermal performance, and utility systems. The second chapte delves into the structural engineering aspect, including the analysis of the building's reinforced concrete frame, and verification of its strength, stability,and compliance with Algerian standars.the third chapter,It explains how the systems work and how they are integrated into a reinforced concrete structure. Finally, a general conclusion provides a synthesis of the results, confirming that the designed concrete structure meets Algerian seismic standards (RPA) while significantly improving energy efficiency through thermal insulation. These findings advocate for a shift toward sustainable, climate-responsive design in Algeria. Ultimately, the study emphasizes the future integration of innovative insulation materials and renewable energy technologies to move buildings toward total energy self-sufficiency.

Chapter 1:

Project Overview

1.1. Introduction:

Structural engineering is the cornerstone of infrastructure development and urban communities, as it primarily aims to design structures characterised by safety, sustainability and cost-effectiveness. With the accelerating pace of urban growth, it has become essential to enhance technical studies of reinforced concrete buildings, as this is the most common and strongest material for bearing various structural loads. This project aims to conduct an in-depth technical study of a reinforced concrete building, starting with a structural inspection of the fundamental elements to ensure the stability of the structure under both static and dynamic loads, and extending to an examination of the utility systems that ensure the building's optimal functional performance. The combination of structural analysis and the assessment of utility systems embody a modern approach aimed at achieving a balance between structural rigidity and operational comfort, in accordance with applicable engineering standards and codes.

1.2. Presentation of the Structure:

This project consists of studying a residential construction for a Programme of 200 promotional housing units, this project will be located in the wilaya of Tlemcen, in the commune of Abou Tachfin 'Bréa':

- To the north, a two-storey school complex
- To the south, three-storey residential buildings
- To the west, EPE STARR
- To the east, a 12-metre-wide dual carriageway

<u>DRC Map:</u>

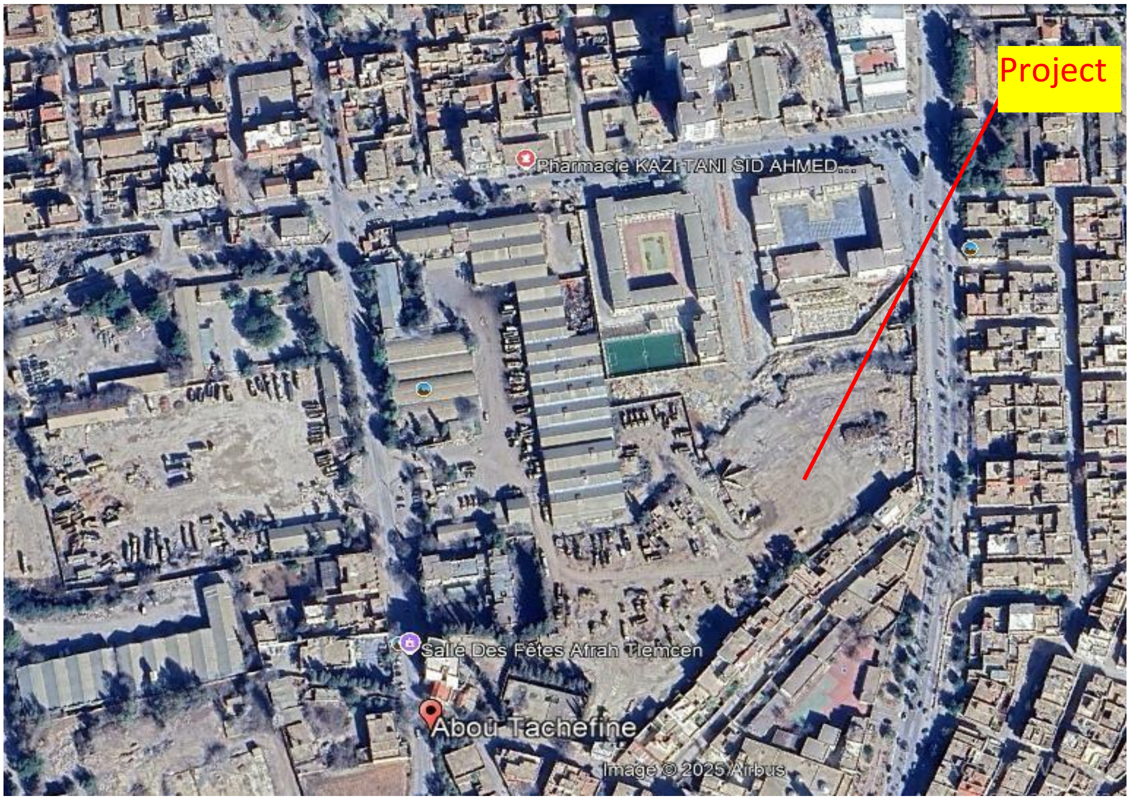


Figure 1.1 : *plan of the project at Tlemcen Municipality, Tlemcen Province (Google Maps,2025)*

The project is located at Abou-Techfine of municipality Tlemcen, which can be also sitauted at Zone (III) as mentioned and clarified in the new standar RPA2024.

1.2.1. Geometric Characteristics of the project:

The site area is: 20,173 m² with 12 blocks of 513 m²:

- Total height of the building ………………………….………… 15.30m
- Floor height ……………………………………...…….3.06m
- Building shape ………………………………………. rectangular
- Total width …………………………….…………… …19.00 m
- Total length ……………………………………………27.00m

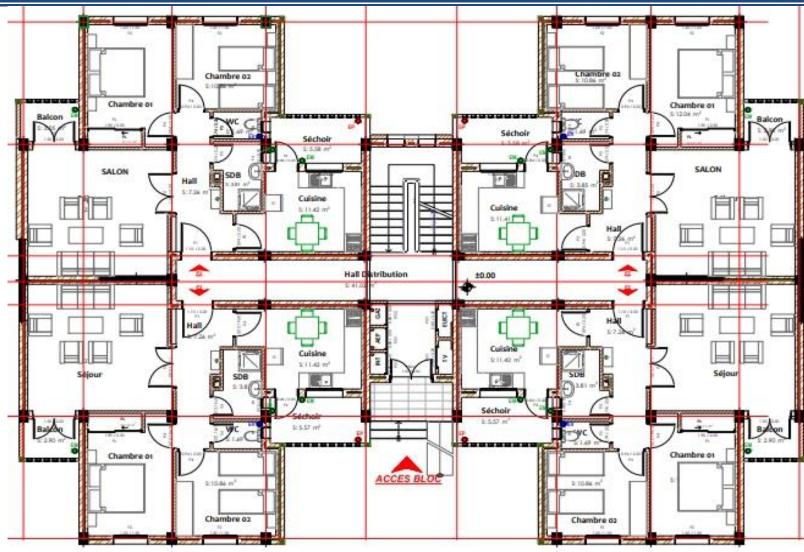


Figure 1.2 :*Architectural floor plan of the building, designed by office,2025)*

1.2.2. Description of the Structure:

Table 1.1*: Characteristics of block*

ROOMS APARTMENT AREA	
ROOMS	*CALCULATED AREA*
BEDROOM 1	*12,04 m^2*
BEDROOM 2	*10,86m^2*
KITCHEN	*11,42 m^2*
HALL	*7,26 m^2*
PL	*1,14 m^2*
BATHROOM	*3,81 m^2*
LIVING ROOM	*23,53 m^2*
WC	*1,69m^2*
LIVING Area	*71,75 m^2*
BALCONY	*2,90 m^2*
Drying Room	*5,57 m^2*
UNSABLE AREA	*80,22 m^2*

1.2.3. Regulations:

A- Framework:

- Main structure: column and beam system

- Secondary structure:

-Hollow core floors

-Reinforced concrete stairs.

-Concrete parapet

B-Infill:

- Interior separation walls are made of (10, 15) cm hollow bricks.

-External partitions made of 30 cm hollow bricks

- Calculation rules used:

The calculations are based on the following regulations:

• Algerian seismic regulations RPA2024; DTR-BC.2.48, BAEL).

• Permanent loads and operating loads (DTR-BC.2.2)

1.2.4. Service Status:

Service Limit States (SLS) refer to states of the structure that cause limited damage, or situations beyond which the serviceability criteria specified for the structure (or a component of the structure) are no longer met: Functioning of structures or structural components, comfort of individuals, construction characteristics.They relate to the usual criteria for use - cracks, deformations, vibrations, durability - associated with standard operating conditions for the structure.Exceeding these limits may cause damage to the structure, preventing it from fulfilling its purpose, but without leading to its complete destruction.The calculation criteria are based on permitted restrictions or deformations,The checks are based on restrictions on usage constraints, crack limit thresholds (which depend on exposure categories) and deformation limit thresholds (deflection).

The crack opening restriction is achieved by: establishing a minimum percentage of reinforcement and restricting the spacing between them and their diameters.

1.2.5. Concrete:

Concrete is the most commonly used building material worldwide. It is a composite material formed by combining various components in specific proportions to create, over time, a mass comparable to that of rock. In the civil engineering sector, concrete is the most frequently used construction material. It is mainly composed of natural aggregates (sand, gravel), standardised materials (synthetic cement), additives and water.

a) **Concrete mix design** :

The weight of the liant used to make a metre cube of concrete determines the *Concrete mix* design. The concrete is given 350 kg of cement per m3 in order to conduct this study. This dosage is intended to provide the anticipated resistance guarantees and to provide effective armature protection. The following proportions are found in one cubic metre of concrete:

• 350 kg/m3 of cement (CPA 325)

• Sable grossier 0<Dg<5mm → 400 L

•Gravier15<Dg<25mm → 800L

• Waste water 175 L The resulting béton has a volume mass that ranges from 2200 kg/m3 to 2400 kg/m3.

b) Mechanical Strength of Concrete:

a. Characteristic resistance in compression fcj

The concrete is distinguished by its good resistance to compression, which is determined to "j" day based on the resistance to 28 days using the following formulas:

• For resistances between fc28≤40 MPa.

$$\begin{cases} f_{cj} = \dfrac{j}{4.76 + 0.83j} f_{c28} \\ f_{cj} = 1.1 f_{c28} \end{cases} \qquad \text{si} \quad j \leq 60 \text{ jours}$$

• For resistances between fc28≥40 MPa.

$$\begin{cases} f_{cj} = \dfrac{j}{1.40 + 0.95j} f_{c28} \\ f_{cj} = f_{c28} \qquad\qquad\qquad\qquad \text{si} \quad j \le 28 \text{ jours} \end{cases}$$

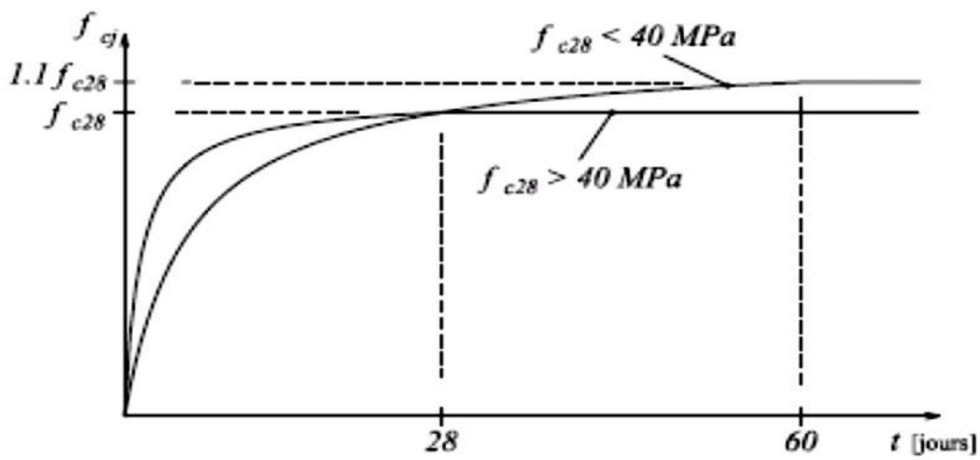


Figure1. 3: *Evaluation of the resistance f cj based on the concrete mass (Adapted from RPA 2024).*

c) **Resistance to the traction ftj:**

Two distinct operating modes are used to measure the resistance to traction directly using an axial traction essai:

• Flexion of non-armed prismatic debris.

• Diameter splitting of a cylindrical test piece (Brazilian test) .

The characteristic resistance to the concrete traction after j days, or ftj, is traditionally defined by the following relations:

$f_{tj}=0.6+0.06f_{cj}$ si $f_{c28} \le 60$Mpa $f_{tj}=0.275$ f_{cj} si $f_{c28}>60$Mpa

For:

ft j = 28 days; fc28 = 25 MPa; ft28 = 2.1 MPa

d) **The longitudinal deformation module of the concrete (BAEL91.Art A.2.1. 21)**

Under typical application constraints of less than 24 hours, it is assumed that the instantaneous longitudinal deformation module of the concrete (Eij) is equal to the number of (j) days:

$E_{ij} = 11000 \sqrt[3]{(f_{cj}}$ Thus, Eij = 32164,2 MPa

The final deformations of the concrete deformation module (Evj) that correspond to charges applied for extended periods of time (often more than 24 hours) include withdrawal and fluid flow:

Evj = 3700√(−cj) 3, therefore Evj = 10819 MPa

c. Fish Module: (Art A-2.1.3 BAEL91)

[3] = 0.2 For the purpose of justifying ULS

[3] = 0 For the purpose of justifying the SLS

e. Limite constraint

e. Ultimate limit state

• The final compression constraint

The following parabole-rectangle diagram is used for the S.L.U.

calculation:

$$f_{bu} = \frac{0.85 f_{c28}}{\theta \gamma_b}$$

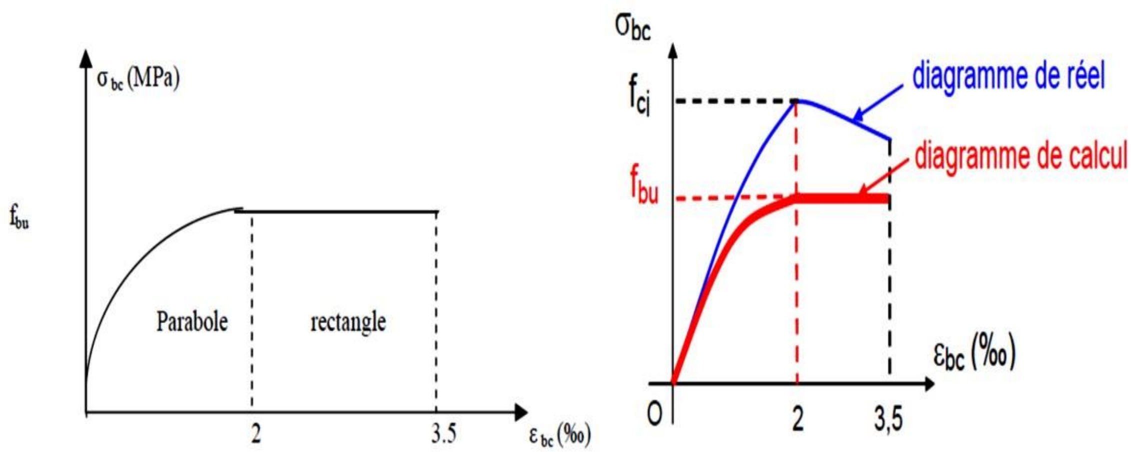


Figure.1.4: *Diagram of the béton's ultimate constraints under compression. (Adapted from RPA 2024.)*

γb: Decrease coefficient:

• In transitory or lasting conditions, γb = 1.5.

• In accidental instances, γb = 1,15.

θ: Depending on how long the charges are applied.

• θ = 1: when the likelihood of applying the charges in question is greater than 24 hours.

• θ = 0.9: when this duration falls between one and twenty-four hours.

• θ = 0.85: when it is less than one hour.

In our case, θ = 1.

For γb=1,5, ρbu = 14,17 MPa;

for γb=1,15, đbu = 18,48 MPa.

• The final cisaillement constraint

The final cisaillement constraint is limited by:

$$\tau_{adm} \leq \tau$$

For a mildly annoying fissuration

τ_{adm}= min (0,2 $\frac{f_{cj}}{\gamma_b}$; 5MPa)

For judiciable fissuration or well-judiciable fissuration

τ_{adm} = min (0,15 $\frac{f_{cj}}{\gamma_b}$; 4MPa)

Since fc28=25 MPa

1.3. Steel :

The alloy known as "steel" is made up of a small percentage of carbon and iron, and the steel used to make armored steel are:

• 0.15 to 0.25 percent of carbon.

• Mi-dure and dure for 0.25–0.40% carbon.

The following nuances of ciers are used in practice:

• Natural steel (feE 215, feE 235)

• High grip steel (feE 400, feE 500)

• Treillis soudés de maille (150 x 150) mm2 with Ø = 3.5 mm (T.S.L feE500)

• The steel longitudinal elasticity module is measured at Es=200,000 MPa.

1.3.1. Type of Steel Used:

The following are the mechanical characteristics of several iron nuances:

• Elastic limit fy (MPa) in relation to the nominal size

• The traction resistance: fu = 360 MPa

• The elastic limit is fy = 235 MPa.

• The Young module: E = 210,000 MPa.

• The poisson coefficient is equal to 0.3.

• Cisaillement module: G = E/(2(1+ϑ)) = 81000 MPa

Tableau. 1. 2: Characteristics of Steel grades (Calculation rules for reinforced concrete at limit states

Type	*Steel grades*	*fe (Mpa)*	*Work*
Plain round bars	*FeE22* *FeE24*	*215* *235*	*Current employment.* *Lifting pins for manufactured parts*
Deformed bars Type 1 and Type 2 bars	*FeE40* *FeE50*	*400* *500*	*Common use*
HA wire mesh *Type 3 wires*	*FeTE40* *FeTE50*	*400* *500*	*used in the form of lattice or rights barriers*

Diagram of the constrained deformation calculation σs = f(ε◦) (Article A.2.2.2)

In calculations pertaining to limit states, a coefficient of security (γs) is introduced with the following values: γs = 1,15.

γs = 1,00 cases of accidental combinations.

We use older Fe E400 for our case.

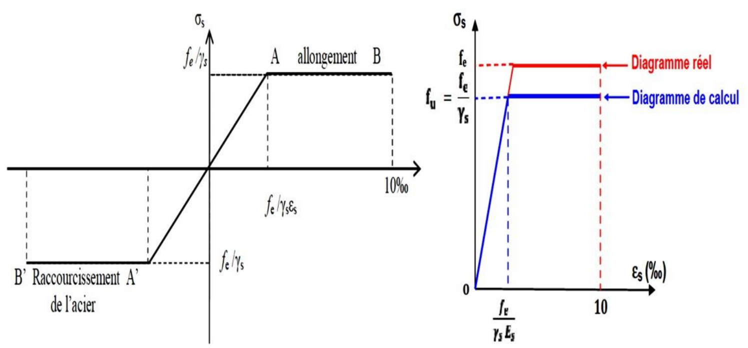


Figure.1.5: Stress-Strain Diagram for Steel (Règlement CBA 93 / Eurocode)

Actions refer to any physical influences or forces applied to a structure that cause internal stresses, strains, or deformations.

1.3.2. Loads:

A-permanent Loads (G):

Permanent loads have a constant or slightly varying intensity over time; they include:

➢ The structure's own weight.

➢ The weight of fixed structures, such as the equipment in industrial buildings and the caulking in sediments.

➢ The weight of earth pressures or liquid pressures. Deformations imposed on the structure.

B. Variable Loads:

These activities denoted by "Q" are those whose intensity varies frequently and significantly over time. They include:

➢ Operating loads;

➢ Climate-related "wind and snow" loads; and

➢ Loads applied during construction phase.

The effects of temperature.

C- Accidental actions:

➢ Earthquakes.

➢ Effect of ‘explosion’ shocks.

1.4. Internal Forces:

Requests are the efforts made at the charge point and on each portion of the structure by the operations that take place on it; they are expressed as forces:

Axial force (N)

▪ Shear force (V)

▪ Bending moment (M)

▪ Torsional moment (T)

1.5. Combinations of Calculations:

The following combinations of calculations are taken into consideration while determining solutions and deformations:

Durable situations:

°ULS: Ultimate limit states :

Correspond to the maximum value of the structure's load-bearing capacity, is:

- Static equilibrium (overturning of the building).
- Resistance of one of the structural materials (no failure).

$$1.35G + 1.5Q.$$

°SLS : Serviceability limit states *(1)*

These are the limits beyond which the normal operating conditions and durability of the structure or its components are no longer satisfied, is:

- Crack opening (limiting the tensile stress on the steel to limit crack opening
- Deformation of load-bearing elements (maximum deflection should not exceed the limit deflection).
- Compressive strength of concrete. The combination of actions at the serviceability limit state is:
- G + Q

°Accidental situations:

- $G + \psi Q + Ex + 0.3\ Ey$
- $G + \psi Q + Ex - 0.3\ Ey$
- $G + \psi Q - Ex + 0.3\ Ey$
- $G + \psi Q - Ex - 0.3\ Ey$
- $G + \psi Q + 0.3\ Ex + Ey$
- $G + \psi Q - 0.3\ Ex + Ey$
- $G + \psi Q + 0.3\ Ex - Ey$
- $G + \psi Q - 0.3\ Ex - Ey$

1.6. Regulation and Standards Used:

The project's study is developed in accordance with the conceptual and computational standards now in effect in Algeria, namely:

➢ The CBA93 (Code De Béton Armé).

➢ The 2024 revision of RPA 99 (Algerian Parasismique Regulation).

➢ Le BAEL 91 (Béton Armé aux Etats Limites).

➢ DTR-BC2.2 (Additional Charges and Surcharges Document Technique).

Assumptions:

- Sections that are straight and flat before deformation remain straight and flat after deformation.
- No relative slippage between concrete and steel.
- Tensioned concrete is disregarded in the calculations.

The selection of wall thickness and concrete type in the structural design is not only intended to ensure structural strength, but also constitutes the key factor in determining the thermal insulation of the building in accordance with the DTR regulations." "The structural framework transforms from a load-bearing support into a dynamic envelope that regulates heat exchange between the interior and exterior." Before constructing any building, it is essential to study heat transfer between the building and its surrounding environment to ensure the comfort of its occupants. Therefore, carrying out a detailed thermal analysis is of paramount importance. To combine these two factors (thermal performance and cost), it is necessary to optimise the fillings for various types of infilled walls. The calculation methods mentioned in (D.T.R.C3-2) are considered sufficient to find acceptable solutions.

1.7. Thermal Performance:

Thermal performance refers to the ability of a material, system or building to manage heat—that is, to absorb, store, transfer and lose thermal energy. It is a fundamental concept in fields such as construction, engineering, electronics and energy efficiency, the ability of a structure to keep interior temperatures tolerable while using the least amount of energy is known as thermal performance. Comfort, sustainability, and energy efficiency are all directly impacted by this crucial component of home design. The goal of thermal performance is to create a consistent and comfortable living environment all year round, regardless of the outside weather, not merely to keep a house warm in the winter and cool in the summer. (ISO 9869-1, 2014; Hens, 2017)

A home's ability to control its interior temperature is controlled by a number of elements, all of which have an impact on thermal performance. Here are a few of the essential components: Insulation: An essential component of thermal performance is insulation. It keeps heat inside the house in the winter and outside in the summer by acting as a barrier to heat flow. The demand for artificial heating and cooling can be greatly decreased with high-quality insulation in walls, roofs, and floors, resulting in reduced energy use and improved comfort. Size and Design of the Building (ISO 9869-1, 2014; Hens, 2017)

A building's thermal performance is also influenced by its size and design. In general, smaller dwellings use less energy for heating and cooling than larger ones. A home's ability to regulate its temperature can also be impacted by design features including the house's shape, ceiling height, and thermal mass. Thermal mass can be defined as a material's capacity to absorb, store, and release heat. *(ISO 9869-1, 2014; Hens, 2017)*

1.8. Type of Construction:

A home's thermal performance is greatly influenced by the materials and construction techniques employed in its construction. Heat is absorbed and stored by materials with high thermal mass, such as stone, brick, and concrete. Conversely, materials with little thermal mass are unable to absorb and retain heat. While some lightweight building materials might heat up and cool down more quickly, more insulation will be needed to provide the same degree of thermal comfort. When selecting materials for a thermally efficient housing, several aspects must be taken into account. (ISO 9869-1, 2014; Hens, 2017)

1.8.1. Comprehending Heat Transfer:

The fundamental concepts of heat transferConduction, convection, and radiationMust be understood in order to completely comprehend the ideaofthermal performance. Conduction: is the movement of heat through solid objects like roofs, floors, and walls. Heat conduction is reduced by good insulation, which helps to retain heat where it is needed. Convection: The movement of air that transfers heat. Energy efficiency and thermal comfort can be improved by controlling airflow in a house through efficient ventilation.

1.8.2. Radiation:

is the transfer of heat by electromagnetic waves, such sunlight coming in via windows Reducing unnecessary heat in the summer and maintaining warmth in the winter can be achieved by controlling solar gain with appropriate shading and window treatments.

- ***Figure1.6****: Installation of internal thermal insulation (Guide d'installation technique, Rockwool).*

1.8.3. In Summary :

For homes to be comfortable, sustainable, and energy-efficient, it is crucial to comprehend thermal performace and its importance in home design. Homeowners and builders can maximize a home's thermal performance by taking into account elements including insulation, building size, window orientation, and building materials. This raises the value of the property and promotes environmental sustainability in addition to energy savings and better comfort.

The Importance of Thermal Performance Evaluation:

At different phases of residential building and restoration, thermal performance evaluations—also known as energy ratings—are essential. By ensuring that homes satisfy minimal energy efficiency standards, these evaluations help reduce energy usage and improve living comfort. For compliance and the best possible home performance, it is essential to know when these evaluations are necessary. *(ISO 9869-1, 2014; Hens, 2017)*

1.8.4. New Residential Initiatives:

For new residential projects, thermal performance evaluations are required. The National Construction Code (NCC) mandates that all newly constructed dwellings adhere to certain energy efficiency requirements. Getting an energy rating through the Nationwide House Energy Rating Scheme (NatHERS) from an Accredited Assessor is the simplest approach to meet these standards. This evaluation guarantees that the building and design of the house include elements.

1.8.5. Significant Additions and Renovations:

Thermal performance evaluations are also necessary for major expansions and renovations to existing dwellings. An energy rating is required when a project includes significant modifications that could affect the home's thermal performance, such expanding the building, adding new rooms, or improving insulation. This category usually includes projects worth $50,000 or more. This maintains or enhances the home's overall thermal performance by guaranteeing that the renovated parts adhere to current energy efficiency standards. *(Semahi et al., 2019)*

1.8.6. Adherence to Regulations:

For regulatory compliance, thermal performance evaluations are crucial. These evaluations are mandated by building authorities and local councils as part of the development application procedure. For instance, new residences and renovations costing more than $50,000 in New South Wales must have a Building Sustainability Index (BASIX) accreditation. A NatHERS energy rating can satisfy the thermal performance requirements of the BASIX assessment. Obtaining the required building licenses and approvals requires adherence to certain regulations. (NSW Planning Portal, 2023).

1.9. Methods for Measuring Thermal Performance:

The process of determining a home's thermal performance is intricate and requires evaluating a number of variables. We'll examine the main techniques and resources utilized in these evaluations here.

1.9.1. Accredited Assessors Function:

Professionals with the necessary training and certification to undertake thermal performance evaluations using NatHERS software are known as accredited assessors. They are essential to guaranteeing the precision and dependability of energy ratings. The building's size, orientation, window glass, and insulation levels are just a few of the variables that assessors examine. They provide an energy rating that represents the anticipated thermal performance of the house by entering comprehensive data into the Nathers program. A complex collection of tools called Nather's software is intended to replicate the thermal behavior of a structure. Software examples include AccuRate Home, Hero, BERS Pro, and more. These programs model the energy performance of the house using comprehensive input data, such as local climate data and particular architectural features. The annual heating and cooling loads required to maintain comfortable interior temperatures are computed by the software. NatheRS software tools assist in identifying locations where thermal efficiency can be enhanced by delivering accurate energy ratings. This enables focused treatments that improve a home's overall functionality (NatHERS, 2023).

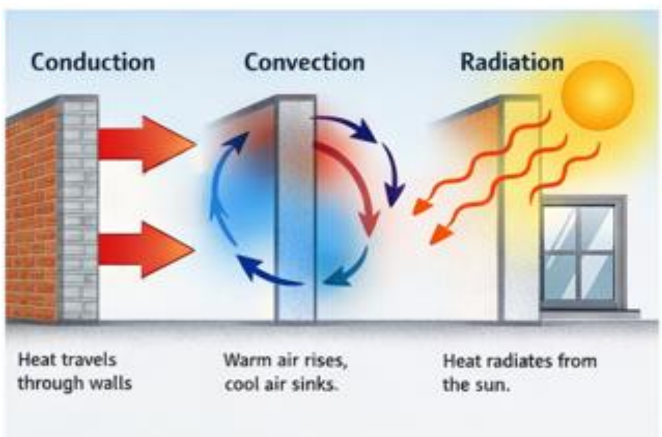


Figure.1.7: *Heat transfer modes (Conduction, Convection, Radiation) (U.S. Department of Energy (DOE))*

1.9.2. Utilization of Climate Data:

When evaluating thermal performance, climate data is essential. Home designs can be tailored to certain climatic circumstances with the use of accurate and localized climate information. Builders and architects may make sure that homes are better adapted to their locales, improving thermal efficiency and occupant comfort, by adding climate-specific data. *(Semahi et al., 2019*

Figure. 1 .8 : *Isolation en polystyrène expansé (EPS) (saint –Gobain)*

Figure.1.9: *Concrete and brick wall (U.S. Department of Energy (DOE), Office of Energy Efficiency & Renewable Energy)*

Thermal Imaging: An enhanced technique for locating locations of heat gain or loss inside a building is thermal imaging. Temperature fluctuations are captured by infrared cameras, which indicate insulation gaps, improperly sealed windows, and other thermal bridges. Thermal imaging enables targeted interventions that greatly enhance a home's thermal performance by visualizing these issue spots. Because it offers a clear road map for improving energy efficiency, this technology is particularly helpful for existing homes undergoing renovations. A summary: Thermal performance measurement is a complex process that uses a variety of techniques and instruments to guarantee that dwellings are both pleasant and energy-efficient. These methods, which range from energy ratings and NatHERS software to thermal imaging and climatic data, offer important insights into the thermal behavior of a structure. *(Semahi et al., 2019)*

1.10. Procedure for Obtaining an Energy Rating or Thermal Performance Assessment:

To make sure your house satisfies the National Construction Code's (NCC) energy efficiency standards, you must obtain a thermal performance assessment, generally referred to as an energy rating. Finding a certified assessor and comprehending the assessment results are just two of the crucial phases in this procedure. This thorough guide will assist you in successfully navigating this process.

Locating a Certified Evaluator: Locating an accredited assessor is the first step in receiving a thermal performance assessment. Professionally acknowledged energy assessors who are certified to use NatHERS (Nationwide House Energy Rating Scheme) software to perform energy ratings for homes are known as accredited assessors. Organizations like the House Energy Raters Association (HERA), the Building Designers Association Victoria (BDAV), and the Australian Building Sustainability Association (ABSA) provide these assessors with training and certification

Getting Ready for the Evaluation: The next stage is to get ready for the evaluation when you have located an accredited assessor. This entails obtaining the data and records required for the assessor to properly assess the thermal performance of your house. Important information you must supply is as follows: *Building plans:* are comprehensive architectural blueprints that include sections, elevations, and floor layouts. *Construction Details:* Details about the materials and techniques utilized, including glazing, window kinds, and insulation for the walls and roof.

place Information: Information about the location, such as orientation, shade from nearby buildings or trees, and any climate data unique to the place. (Semahi et al., 2019).

1.11. Recognizing The Evaluation Procedure:

There are multiple steps in the thermal performance evaluation process, each of which is intended to measure various facets of the energy efficiency of your house. Here's a summary of what to anticipate:

The assessor will go over your development designs and address any particular needs or worries you might have.

Data Collection: The building's design, building materials, insulation levels, window orientation, and other pertinent details will all be gathered by the assessor.

Energy Modeling: The assessor will estimate your home's thermal performance using Nathers software, accounting for occupancy patterns and local climate data.

Energy Rating Calculation: The software determines the home's overall energy efficiency by calculating an energy rating, which is First Consultation: given in stars (out of 10).

1.11.1. Analyzing The Findings:

This study offers suggestions for increasing energy efficiency together with comprehensive data on the thermal performance of your house. This is how the findings should be interpreted:

Star Rating : Higher energy efficiency is indicated by a higher star rating. The NCC usually requires a minimum rating of six stars (NatHERS, 2023).

Thermal Load: The report will describe the heating and cooling loads required to keep interior temperatures pleasant. Better thermal performance is indicated by lower loads.

Recommendations: The assessor could offer ideas for enhancing the energy efficiency of your house, like installing insulation, replacing windows, or maximizing shading.

1.12. The Advantages of Getting an Energy Rating:

Getting a thermal performance evaluation has a number of advantages, such as: Regulatory Compliance: Verifies that your house satisfies the NCC's energy efficiency standards. Energy Savings: Assists in figuring out how to cut back on energy use and utility costs.

Enhanced Comfort: By optimizing heating and cooling systems, indoor thermal comfort is improved. Environmental Impact: Promotes environmental sustainability and lessens the carbon impact of your house.

1.13. Role Of Climate Information:

When designing and assessing a home's thermal performance, climate data is crucial. Architects, builders, and homeowners may design energy-efficient, comfortable, and environmentally appropriate living spaces by having a thorough understanding of the local climate. The impact of climate data on thermal performance evaluations and home design will be briefly discussednthissection. (upadhyay,A.k.(2018)).

1.14. Enhancing Design Techniques:

To provide optimal thermal performance, different design solutions are needed for different climate zones. Utilizing climate data is essential in Australia, as climates vary from tropical in the north to moderate in the south. For instance, design elements that maximize solar gain in the winter and offer insulation to retain heat are advantageous for homes in colder areas. ventilation to reduce heat gain and encourage cooling.

Tropical Climates*:* The objective is to maximize cooling and minimize heat gain in tropical regions. Large, shaded verandas, high ceilings for improved air circulation, and the use of lightweight, rapidly cooling materials are a few examples of design techniques.

Temperate Climates*:* In temperate climates, a home's heating and cooling systems must be balanced. Strategic window placement to maximize solar gain in the winter and minimize it in the summer, as well as the use of materials with appropriate thermal mass to stabilize interior temperatures, are examples of design aspects.

Figure.1.10*: Thermal image of a house (Passivhaus Institut,2007)*

Arid Climates: In arid regions, the goal is to keep comfortable during chilly nights and minimize heat gain throughout the day. This could entail the use of shaded outdoor living areas, tiny windows, and thick walls with a high thermal mass. The term ‘thermal performance’ is generally related to how effectively something retains or prevents the diffusion of heat. This usually concerns the thermal conductivity of materials or assemblies of materials. Materials considered to have good thermal performance are generally good insulators, meaning they do not easily transmit heat. In contrast, materials with poor thermal performance tend to be better heat conductors, promoting rapid heat transfer, for example from a heated building to a cooler outdoor environment.During the summer, when outdoor temperatures can be considerably higher than indoors, a building with poor overall thermal performance will allow more heat to pass through, and will therefore be warmer inside compared to a building with good thermal performance.The thermal behaviour of a building's structure is also influenced by factors such as seasonal and temperature variations, diurnal variations (i.e., the difference between maximum and minimum temperatures over a 24-hour period), the level of solar gain and shade, incoming and outgoing thermal radiation, water and moisture absorption, air movement, infiltration, pressure differences, and so on.Thermal performance is now a crucial factor in building design. This is due to building standards that mandate fuel and electricity conservation and reduce carbon emissions by limiting the amount of heat that a building loses to the outside world. Thermal insulation in buildings acts as a barrier to reduce heat transfer inside and outside the building, both in summer and winter. (ISO 9869-1, 2014; Hens, 2017).

1.15. Thermal Insulation in Buildings Encompasses:

Thermal insulation in buildings encompasses the techniques and materials used to limit heat transfer between the interior and exterior of the building in order to maintain an ideal temperature inside the building in both summer and winter, while reducing energy consumption for heating and air conditioning.

1.15.1. How thermal insulation works:

Heat is transferred in three ways:

1) by conduction through walls, ceilings and floors;

2) by convection through the air

3) by radiation from the sun and hot surfaces.

1.15.2. Areas Of Application for Thermal Insulation:

external walls, roofs and windows

1.15.3. Materials Used for Thermal Insulation:

1) polystyrene (XPS/EPS)
2) rock wool, glass wool
3) cork

1.15.4. Importance Of Thermal Insulation:

Energy savings and cost reduction: It helps reduce the operating time of air conditioning and heating systems, thereby reducing electricity and fuel consumption.Thermal comfort: It helps maintain a moderate and stable indoor temperature, thereby improving quality of life.Building protection and extended lifespan: It protects walls and roofs from heat-induced expansion and contraction, reducing the risk of cracks and moisture.Protection of furniture and belongings: It protects the building from high temperatures that can damage furniture and appliances.Environmental protection: It helps reduce harmful carbon emissions associated with high energy consumption.Reduced air conditioner power consumption: It allows for the use of lower-powered, less expensive air conditioners. *(Al-Homoud,2004)*

1.16. Choosing The Right Thermal Insulation for Every Climate:

Choosing the right thermal insulation is vital for saving energy and achieving thermal comfort. Foam (such as polystyrene and polyurethane) is preferable in hot areas due to its high resistance to heat and moisture, while mineral or rock wool is recommended in cold areas due to its ability to retain heat. The choice of material depends on its low thermal conductivity, water absorption resistance, and compressive strength. The best types of thermal insulation are classified based on the nature of the climate:1. Areas with high temperatures (such as the Arabian Gulf region and desert areas): Polyurethane Foam (PU): This is the ideal choice for insulating roofs and walls, as it is lightweight and resistant to heat and moisture. This material comes in either sheet form or as a sprayable foam that can be used to fill gaps. Extruded polystyrene (XPS): Characterised by high compressive strength and excellent water absorption resistance, making it the ideal choice for roofs. Perlite boards: Natural fire-resistant materials used to insulate roofs and slopes.2. Cold weather areas (mountainous areas, places with harsh winters):

- Rock wool: Non-combustible inorganic material, excellent for insulating walls and ceilings, ensuring high efficiency in retaining internal heat.
- Glass wool: Used effectively to insulate suspended ceilings and lightweight walls.
- Cellulose: Used in low-temperature climates to insulate roofs with high efficiency.
- Temperate or hybrid climate:
- Expanded polystyrene (EPS - white foam): An economical and moderately efficient option for insulating walls and ceilings
- Cork: A natural material offering good insulation, often used for flooring and wall coverings.
- Key tips for choosing insulation:
- Thermal conductivity coefficient
- The lower this value, the more effective the material is at insulating.
- Vapour barrier: Essential in areas with high humidity to prevent moisture build-up inside walls, which can damage the insulation.

- Comprehensiveness: Thermal insulation must be combined with double-glazed windows and an effective ventilation system forbest performance*(Dong,Y;Kong,Mousavi,Rimanchi,B & Yap (2023))*

1.17. Comparisons Of Different HVAC Or Passive Cooling Strategies:

- Active cooling (mechanical air conditioning)
- Central air conditioning
- Concept: Cooling is generated in a central station (chiller) and then the cooled air is distributed through a system of air ducts to different locations.

1.17.1.Thermal performance:

- Ensures stable temperatures (22–26°C).
- Effective humidity control and thermal comfort (PMV close to zero).

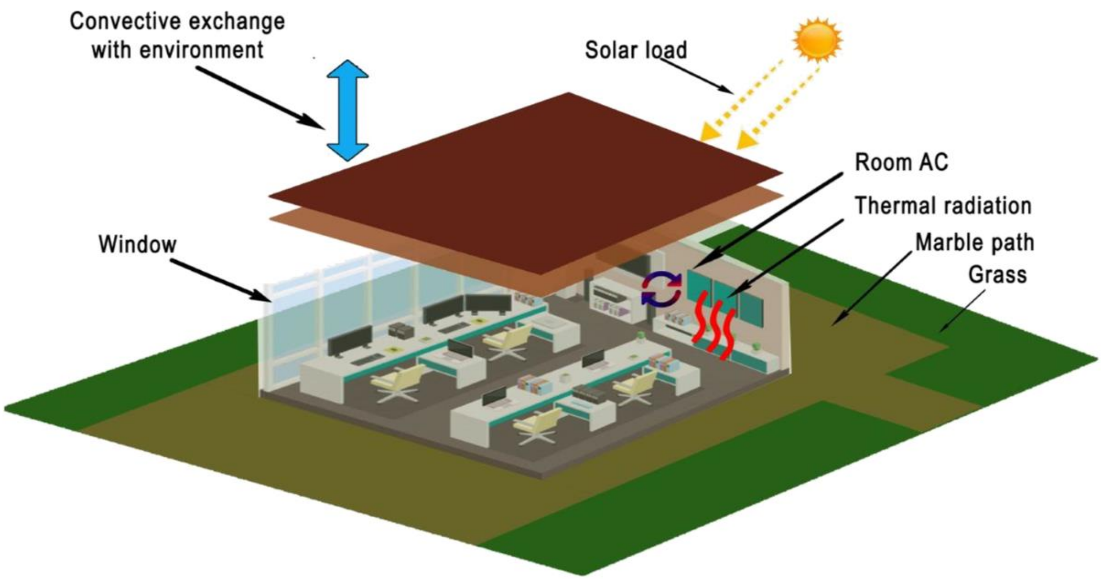


Figure. 1.11. Thermal performance of energy-efficient buildings for sustainable development (Indraganti ,2010)

- Energy use:
- Very high (huge cooling loads).
- Increases peak electricity demand in summer.
- Environmental impact :
- Indirect carbon dioxide emissions.

- Based on cooling fluids that may contain pollutants.

1.17.2. Structural Role:

- Requires technical spaces (machine rooms, air ducts).
- Affects architectural design

Split air conditioning system (Split - VRF)

- Principle: Independent units for each space containing an external compressor.

1.17.3. Thermal Performance:

- More precise individual control than central control.
- Reduction of unnecessary cooling.
- Energy use:
- Medium to high depending on use.
- More efficient than a traditional central system.
- Environmental impact:
- Lower energy consumption compared to centralised systems.
- This system is still in operation and relies on electrical energy.

Structural role:

- Easy to install.
- Limited impact on the concrete structure.

1.17.4. Artificial Ventilation:

Forced ventilation (VMC)

- Concept: Polluted air is extracted and fresh air is introduced by fans.
- Thermal performance:
- Does not provide direct cooling.
- Reduces thermal discomfort.

1.17.5.Energy use:

- Low to moderate.
- Effective when combined with a two-way heat exchanger.
- Environmental impact

- Improves indoor air quality (IAQ).
- Reduction of health burdens.
- Constructive role:
- Requires advance planning of air ducts.

- Compatible with heating systems.

1.17.6. Natural ventilation:

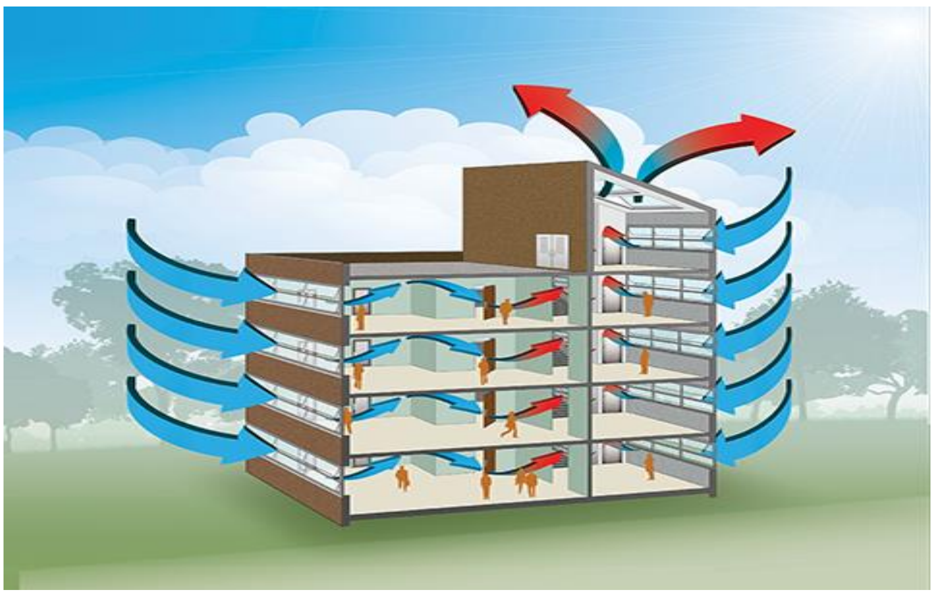


Figure1.12. Natural Ventilation: Bringing fresh air into commercial building (Adapted from cibse ,2005)

✓ Cross ventilation

- Principle: The pressure difference created by the wind pushes air to flow inside the building.
- Thermal performance:
- Reduction in internal temperatures of 3 to 5 degrees Celsius.
- Cool nights.

- ✓ Energy use:

- Environmental impact:
- 100% sustainable solution.
- Reduces reliance on air conditioning.

- ✓ Building role:

- The orientation of the building is important.
- The size and location of openings are decisive factors.

- ✓ Effect of smoke from the chimney

- Principle: Hot air rises and escapes through openings at the top.
- Thermal performance:
- Effective in multi-storey buildings.
- Enhances natural ventilation without the need for fans.
- Challenges:
- Difficult to control.
- Requires careful architectural planning.

- ✓ Passive cooling**:** Thermal insulation

- Principle: Reducing heat transfer through the outer shell.
- Thermal performance:
- Reduces thermal energy by up to 40%.
- Reduces the load on cooling systems.
- Construction role:
- Choosing the thickness and type of insulation is essential.
- Direct training for civil engineers.
- Thermal energy

- Concept: Storing heat in concrete elements and releasing it during the night.
- Thermal performance:

- Temperature stability.
- Activated with night ventilation.
- Climate adaptation:
- Excellent in dry and hot climates (Algeria).

✓ Shading

- Principle: Prevent solar radiation from entering the building before it reaches it.
- Thermal performance:
- Reduces solar load by 20 to 30%.. *(Al-Homoud,2004)*

In conclusion, this chapter examined the essential concepts relating to concrete and steel, the two main materials used in reinforced concrete construction. The presentation focused on the formulation of concrete mixes and their mechanical properties, including compressive strength, maximum stresses and longitudinal modulus of deformation, given their paramount importance in assessing the behaviour of structural elements under various loads.Steel has also been studied in terms of different types and mechanical characteristics, with particular emphasis on the stress-strain curve under extreme conditions, given its importance in understanding the behaviour of reinforcing bars in reinforced concrete. In addition, we discussed the forces acting on structures and the concepts of ultimate limit state (ULS) and serviceability limit state (SLS). We also presented an explanation of the design combinations used in design to ensure safety, durability and functionality. We also updated this chpter the opportunity to explore the theoretical foundations necessary for a sound understanding of thermal phenomena in buildings. We have examined the importance of thermal insulation, the properties of materials, energy gains and losses, as well as various forms of energy. An analysis of energy consumption, particularly in Tlemcen, shows that the residential sector accounts for a significant proportion of demand. This data will enable us to assess the energy performance of homes more effectively in future chapters and to make suggestions for improving it.

Chapter 2:

Structural Analysis of the Reinforced Concrete Building

2.1. Introduction:

The objective of pre-dimensioning is to establish the scale of the various elements. Structural components to absorb the forces associated with permanent loads and operational overloads. This phase constitutes the beginning and foundation of the argumentation relating to the strength, stability and durability of the project in the face of subsequent stresses: Vertical demands: These result from permanent loads and operational overloads applied to the floor, girders, beams and columns, which are ultimately redistributed to the ground through the foundations. Horizontal demands: These generally originate from seismic sources and are necessary for the bracing elements formed by the frames. The preliminary dimensioning of the basic load of the structure complies with the standards of regulations EC2, CBA 93 and RPA 2024.

2.2. Preliminary Dimensioning of the Floor:

The floor is a generally horizontal surface designed to divide two levels. It transmits the loads and overloads directly imposed on it to the load-bearing elements, while ensuring comfort functions such as acoustic and thermal insulation and waterproofing of the extreme levels. As part of our study of the building, two types of floors will be used:

- Hollow core floor.
- Solid slab floor.
- Hollow core floors.
- Hollow core floors consist of:
- Hollow cores (hourdis): these serve as infill and have no structural function.
- Beams: sturdy components of the floor
- Compression slab:

This is a reinforced concrete slab with a thickness ranging from 4 to 6 cm, Reduced dimensions. The thickness of the floors is determined primarily by the conditions of use rather than by strength criteria. The following should be checked to determine this thickness

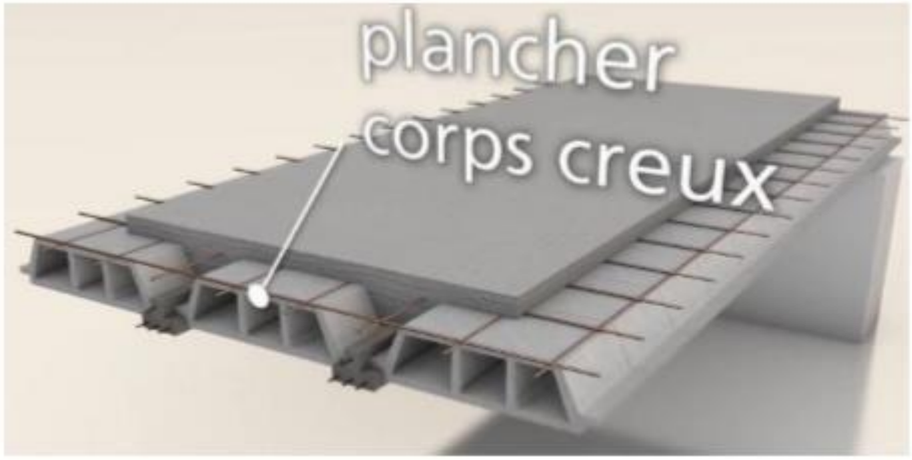


Figure 2.1: *The main components of a hollow core floor (***CBA 93*** (Reinforced Concrete Code)).

✓ Deflection resistance condition: CBA93 (section B.6.8.4.2.4)

The floor height is determined based on the stiffness condition specified in CBA93 as follows:

$$h \geq \frac{lmax}{22.5}$$

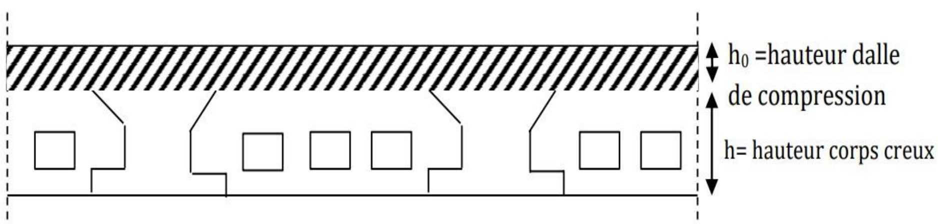


Figure 2.2: *Vertical section of a hollow floor (Based on CBA93)*

Lmax: Maximum length between support centres according to the arrangement of the beams used.

Lmax= min [Lx (max), Ly (max)]

ht : Total floor height.

b: Distance between beam centres.

2. 3. Preliminary Dimensioning:

The purpose of preliminary dimensioning is to define the dimensions of the various elements of the structure. These dimensions are chosen in accordance with the recommendations of RPA2024 and EC2. The results obtained are not definitive; they may be increased after verification in the dimensioning phase, Hollow core floors:

- ✓ According to the deflection condition in EC2 (art B.6.8, 424), the thickness of thefloor is determined using the following formula:

ht≥ $\frac{L}{22.5}$ $\longrightarrow$ ht≥ $\frac{3.5}{22.5}$ $\longrightarrow$ ht ≥ 0.15

(Maximum distance between supports)

Therefore, our choice is based on the availability of the material on the local market:

⇔ We opt for a floor with: ht=21cm (16+5)

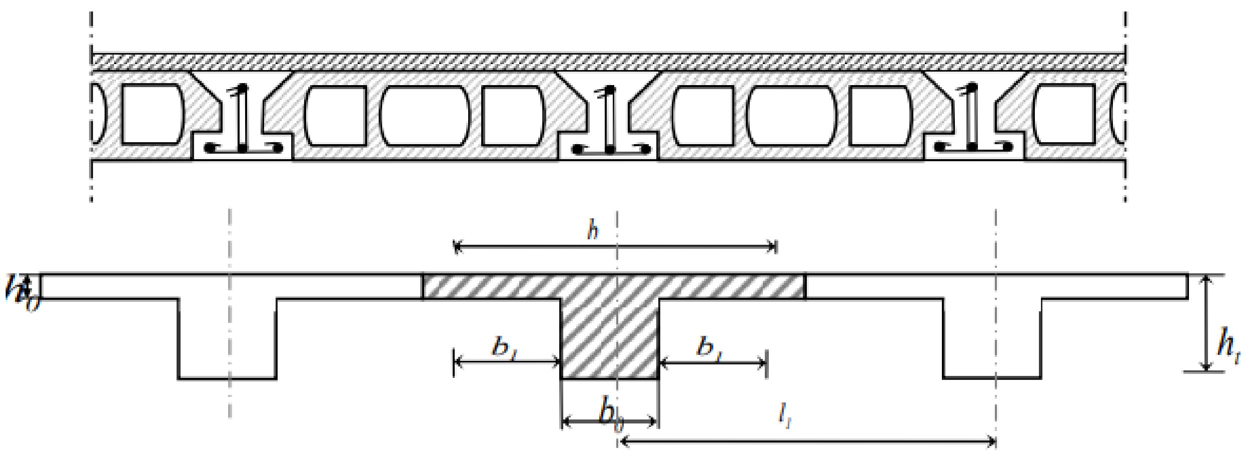


Figure 2.3: *Cross-section of a hollow core floor slab* (CBA93)

2.3.1. column:

Surface area of poles subject to greater stress:

S = (2.25 × 1.55) + (2.25 × 1.50) + (2.50 × 1.55)+(2.50×1.50) = 14,4875 m^2

S: Surface area supported by the most unfavourable post

$Nu = S \times Q \times n$ It is assumed that the uniformly distributed load is: $Q = 1t/m^2$.

n: The number of storeys/floors.

$Nu = 14{,}4875 \times 1 \times 5$

Nu =0,6444MN → Reduced concrete section

For a rectangular post: $Br = (a - 0.02)\ (a - 0.02)\ m^2$

❖ $$B_r \geq \frac{B \times Nu}{\frac{fcb}{0.9} + \frac{0.85 \times fc28}{100 \times \gamma s}}$$

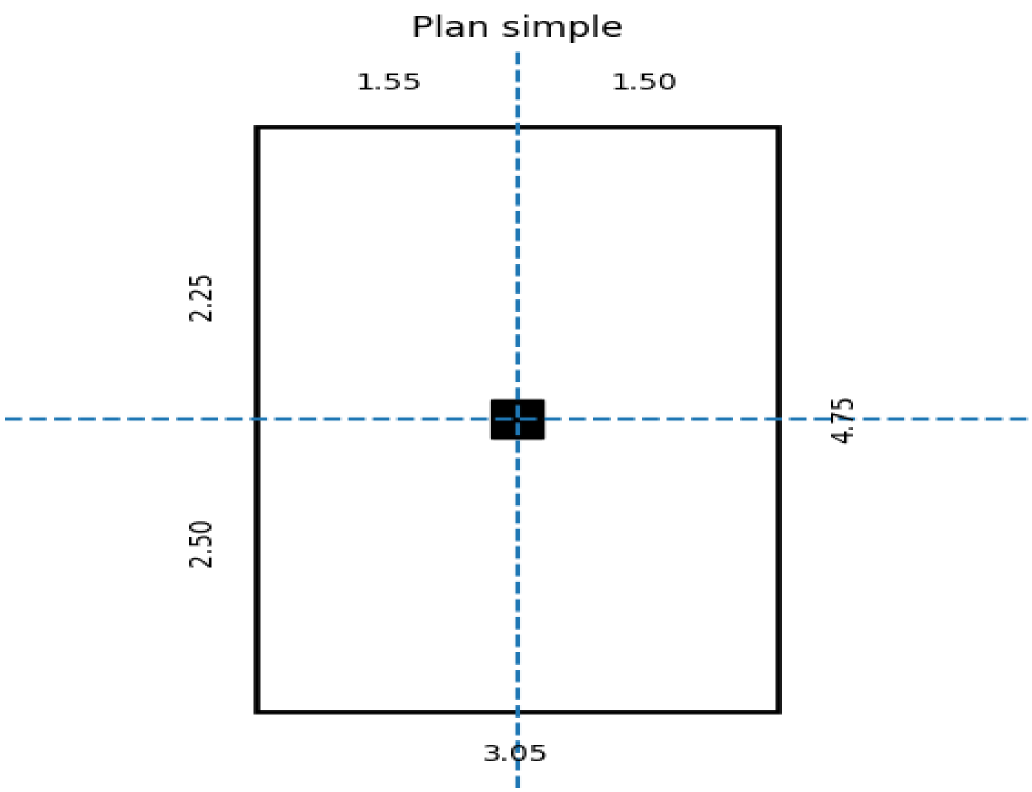


Figure2.4: Most stressed post (adapted outhor)

We take: $A/Br = 1\%$

With: $fe = 400MPa$; $fbc = 14.17MPa$; $\gamma s = 1.15$; $\gamma b = 1.5$; $fc28 = 25MPa$

β: Slenderness coefficient λ of the columns:

$\beta = 1 + 0.2\times(\frac{\lambda}{35})^2$ $\quad if\, \lambda < 50$

$\beta = 0.85\times(\lambda\ /100)$ $\quad if\, 50 < \lambda < 70$

- According to BAEL91 modified 99, it is preferable to take $\lambda = 35$.

$\beta = 1 + 0.2\ (35/35)2 = 1.2$.

fbc=$\frac{0.85\times25}{1.5}$ **= 14.16 Mpa**

Br$\geq \frac{\mathbf{1.2\times0.644}}{\mathbf{15.74+2.266}} \Rightarrow \boldsymbol{B_r \geq 0.0623\ m^2}$

More than : $Br = (a - 0.02)\ (a - 0.02) \geq 0.0623\ m^2$.

For : $a = b \rightarrow (a - 0.02)\ ^2 \geq 0.0623\ m^2\ a \geq 0.262m2$.

We take : $a = b = 0.40$

➢ According to RPA99 version 2024:

$B \geq Nu$ / (0.3 $\times fc28$)

$B = a^2 \geq 0.086\ m^2$.

$a = 0.293\ m$.

As a safety measure, the ground floor columns have a cross-section of:

(0.40 × 0.40) m^2.

According to RPA, for zone III.

⇒ Min (b1, h1)≥25cm (zone III)

B1=30cm and h1=35cm

Min (30,30)≥25cm; Min(b1,h1) ≥ he

$\frac{1}{4}\leq\frac{b1}{h1}\leq 4 \Rightarrow 0.25<\frac{30}{35}<4$ Conditions to check

$(a\text{-}2)^2>Br \Rightarrow \quad a>\sqrt{148.39}+2=12.18+2=14.18$cm

We take a=30 cm a=b=30cm. ⇒ therefore ($\mathbf{40x40}$)

2.3.2.Beams:

These are horizontal reinforced concrete support beams that transfer loads to the columns according to their location in the building. This is the laste one must be pre-dimensioned in accordance with deflection standards and verified using RPA2024, in accordance with the EC2. There are two types of beams in the structure as follow:

- **Main beam:**

$\frac{l}{15}\leq h\leq\frac{l}{10} \quad \Leftrightarrow \quad \frac{4.6}{15}\leq h\leq\frac{4.6}{10} \quad \Leftrightarrow 0.31 \leq h\leq 0.46$ CV

According to Algerian seismic standards RPA2024, h≥30; therefore:

We consider h=40 cm with $\boldsymbol{h}\leq 4.0$, so b ≥10.

-According to RPA 2024: b ≥ 20cm,

We take: b=35 (for reasons of feasibility of implementation)

2.3.3 Secondary beam:

The deflection condition according to EC2 is determined using the formula

$$\frac{l}{15}\leq h\leq\frac{l}{10} \quad \Leftrightarrow \frac{3.2}{15}\leq h\leq\frac{3.2}{10} \Leftrightarrow 0.21 \leq h\leq 0.32 \quad CV$$

- According to Algerian seismic regulations RPA2024: h≥30; therefore:

We take h=35cm with $\frac{h}{b} \leq 4.0$ therefore b≤ 8.750 .

⇔Pp(30x40)

-According to RPA 2024: b ≥ 20 cm⇔

We take: b = 30 cm (for reasons of feasibility of execution):

⇔Ps(30x35)

2.3.4 Preliminary Dimensioning of Beams: C.B.A.93

Beams are treated as T-sections. Their dimensions are as follows:

ht: Total floor height ⇒ ht = 21 cm

$L0$: Distance between two adjacent faces of two beams (65 − 12)

⇒ $L0$ = $53cm$

: the length of the largest span

⇒ L = 455 cm

$b0$: width of the rib

0.4×ht ≤ $b0$ ≤ 0.8×ht ⇒ 8. 4 ≤ b0 ≤ 16.8 ⇒ b0 = 12cm

h0: Thickness of the compression slab ⇒ h0 = 5 cm

: Width of the compression slab

⇒ b = 2. $b1$ + $b0$ $b1$ = min (0/ 2 ; L /2) ⇒ b1 = m (53/2 = 26.5mm; 45/5 10 = 45.5mm)

So we take $b1$ = 26.5 cm. b = 2. $b1$ + $b0$ = 2× 26.5 + 12 cm. ⇒ b = 65 cm. Let b = 65 cm

The preliminary dimensioning of the walls will be carried out in accordance with RPA 2024 (Article 7.7.1). Concrete walls serve to brace the building by absorbing horizontal forces (earthquakes and wind) and to absorb vertical forces, which they transmit to the foundations.

-According to RPA2024

Bracing elements satisfying the following condition:

lw ≥ max (he/3; 4bw; 1m)

where:

lw: length of the wall bw: the maximum thickness must comply with lw ≥ max (1.02; 0.80; 1m) → we take lw = 2m

bw ≥ max (15cm; he/20)

he=3.06m → 3.06/20 = 0.153 → therefore we take bw=20 cm

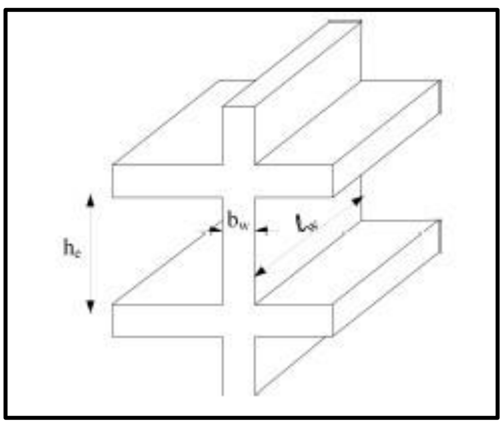


Figure 2.5: *Elevation sail cut (DTR BC 2-48)*

2.4 Load Descent:

2.4.1. Inaccessible terrace floor N+15.3m:

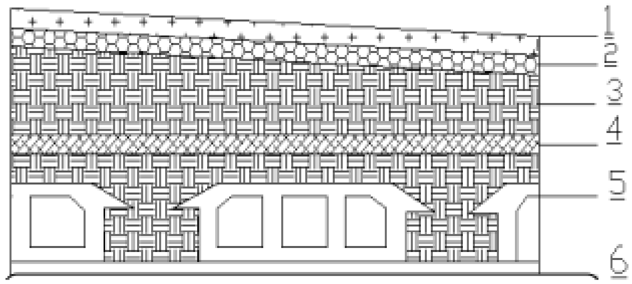


Figure 2.6: *Detail of an inaccessible terrace floor (DTR C3-4)*

Table 2.1*: Load reduction for inaccessible terraces:*

Designation of elements	*Thickness (cm)*	*Density (KN/m3)*	***poids*** *[**KN/m2**]*
Gravel	*5*	*17*	*0.85*
Multi-layer waterproofing	*2*	*0.6*	*0.12*
Slope shape	*10*	*22*	*2.20*
Thermal insulation	*4*	*4*	*0.16*
Hollow core	*21*	*14*	*2.94*
Plaster coating	*2*	*10*	*0.20*
		G	*6.47*
		Q	*1*

2.4.2. Floor Level N+6.48:

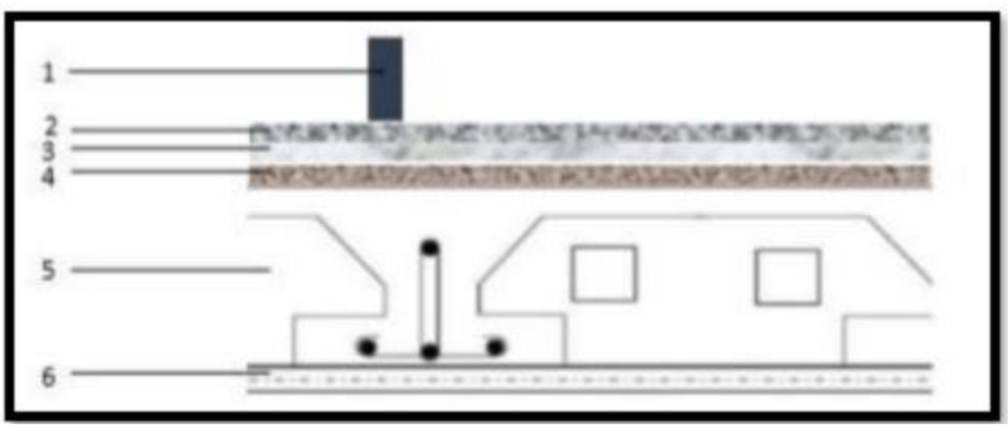


Figure 2.8: *Detail of the floor slab (DTR B.C.2.2)*

Table 2.2: *Current floor load descent*

Designation of elements	Thickness (cm)	Density (KN/m³)	Surface weight (KN/m²)
1. 15 cm partitions	10	10	1.00
2. Tiles	2	22	0.44
3. Laying mortar	2	20	0.40
4- Fine sand bed	3	18	0.54
5-Floor (hollow core)	21	14	2.94
6-Ceiling plaster	1.5	10	0.15
		G	5.47
		Q	1.5

2.4.3. Upper floor G/F N+3.06:

Table 2.3: *Load reduction from the upper floor of the ground floor*

Designation of elements	Thickness (cm)	poids [KN/m2]	Density (KN/m3)
Tiles	2	0.44	22
Laying mortar	2	0.4	20
Fine sand bed	3	0.54	18
Hollow core floor	21	2.94	14
Ceiling plaster (plaster coating)	10	0.9	10
10 cm hollow brick walls	1.5	0.15	90
G		5.37	
Q		1.5	

2.4.4. External Walll :

Table 2.4: Load reduction on external walls

30 cm hollow brick walls		30	2.60	8.66
	G		2.60	

2.4.5. Balcony:

1) Tiles.

2) Mortar.

3) Sand bed.

4) Solid slab.

5) Plaster coating.

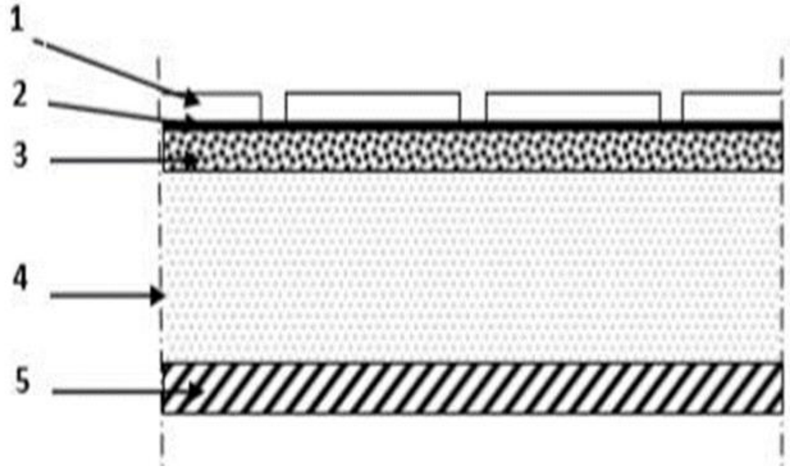


Figure 2.6: *Diagram of a balcony (*DTR B.C. 2-4)

Table 2.5: *Load descent from the balcony:*

G	***5.37***
Q	***3***

2.5. Preliminary dimensioning of beams:

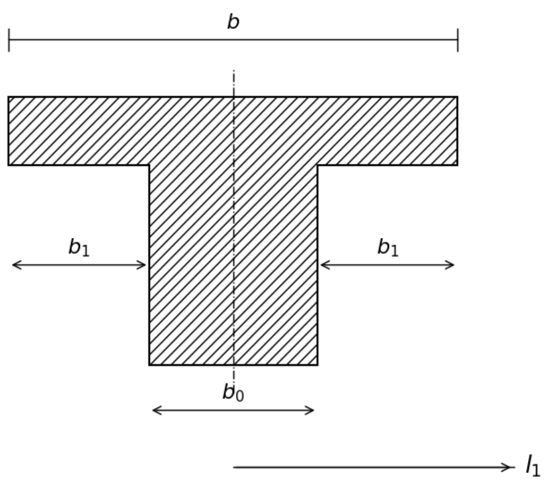


Figure 2.7*: Cross-section of a beam (author)*

ht = 21cm, $h0$ = 5 cm, $b0$= 12 cm

Several empirical methods are used to determine the bending moments and shear forces of beams:

- Three-moment method.
- Caquot method.
- Flat-rate method.

Software We Use:

In our case, we used ETABS software to determine these values. ETABS (Electrical Transient Analysis Programme) is sophisticated engineering software used for modelling, simulation, analysis and optimisation of electrical power systems. This integrated platform enables the design, analysis and operation of electrical networks in the industrial, commercial and utility sectors. The software enables engineers to perform various types of studies, such as load flow analysis, short-circuit analysis, transient stability analysis, arc flash analysis, protection coordination, and harmonic analysis. ETAP offers accurate modelling of electrical components such as generators, transformers, transmission lines, cables, circuit breakers and loads.

2.5.1. Modelling Phases:

Modelling using Autodesk Robot Structural Analysis 2014 software involves the Set up the model (units, grids, levels) ⎤ Establish the geometry of the model⎤ Set the analysis parameters (materials, sections, etc.) and assign them to the elements⎤ Specify the boundary conditions (supports and diaphragms). Establish the load scenarios (static and dynamic) and implement them on the components. ⎤ Specify the analysis choices (modal analysis options). Perform the analysis and make changes to the model if necessary. Use the analysis results (graphical representation, lists, export of results, etc.).

2.5.2. Assessment of Loads:

Table 2.7: Load descent from the balcony:

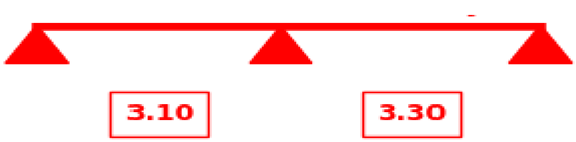
Level	G(KN/m²)	Q(KN/m²)	b(m)	Combinaison	
				ELU (KN/ml) qu=b×(1,35G+1,5Q)	ELU (KN/ml) qs=b×(G+Q)
Upper ground floor	5,37	1,5	0,65	6,17	4,47
terrace not accessible	6,47	1	0,65	6,65	4,86

Types of Beams:

Depending on the chosen beam layout, there are different types, which are shown below:

Type 01 :

Type 02 :



Type 03 :

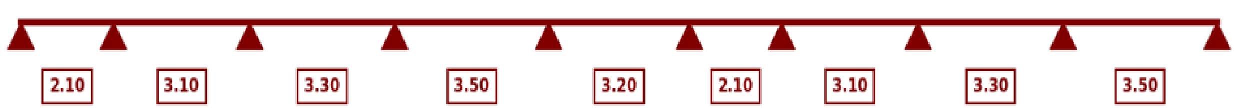


***Figure 2.7.**Multi-Span Continuous Beam Static Model (author)*

NOTE: Our project involves several types of beams, so it is common to choose a calculation method that is suited to the diversity of the beams. We have therefore chosen to calculate the reinforcement using the maximum moment at the span combined with the maximum moment at the supports for all the beams: b=65cm b0=12cm h=21cm h0=5cm d=0.9h=18.9cm fe=400 MPA.

2.5.3. Calculation of Reinforcement :

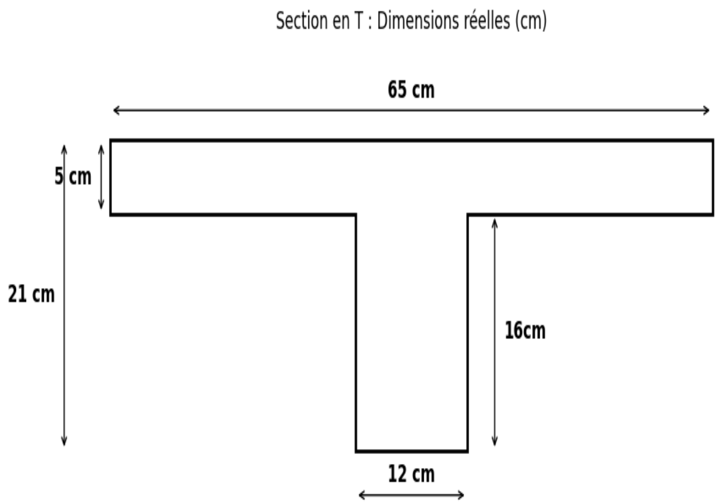


Figure 2.9: *Schematic diagram of a beam* Selected (*author)*

In span:

MUmax = 6.18 kN

Mu = 6.18 kN, Mu = 0.00618 MN.m

Mt = b.h0.fbc (d - h0 /2)

Fbc =$0.85 \times fc28/\gamma b$=0.85×25/1.5=14.17MPA

Therefore: Mt = 0.65 × 0.05 × 14.167 × (0.189-0.025) = 0.0755 MN.m

Mu = 0.00618 < Mt = 0.0755 therefore rectangular section

µu = d=0.9×0.21=0.189m

fbc=0.85×251.15

μu=0.006180.65×0.1892×14.17

μu=0.02

μu= 0.02 < μr =0.392 therefore simple reinforcement

Asc=0cm²

Z=d× (1-0.4α) ↔ z=0.189× (1-0.4×0.028) ↔ z=0.187m

$A_{ST}=\frac{Mu}{Z\times\sigma st}$

σSt= $\frac{fe}{\gamma s}$=347.826MPA

γs= 1.15

As $=\frac{0,00724}{0,187\times 347,826}$=1.113cm²

According to the section tables, we choose: 1 T12+1 T10=1.92 cm2 → Non-fragility condition

Ast≥ $0,23\times b\times d\times\frac{Ft28}{fe}$ =0,23×0,65×0,189× $\frac{2,1}{400}$ =1,48cm^2

Ast=1.92 cm^2>1,48cm^2 so condition check

• ELS:

In span:

We take ASt=2T12=2.26 cm² Mser = 4.47 kN, m=0.00447MN,m

X= 4,47 cm < h_0 = 5cm **so** AN in the table

I= b× $\frac{X^3}{3}$+n×Asc(x-d')^2+n× Ast (d-x)^2

$I=65\frac{4.47^3}{3}+15\times2.26\ (18{,}9-4{,}47)^2$

$I=0.9\times10^{-4}\ m^4$

Stress Calculation:

$\sigma bc=\frac{Ms\ \times x}{I}=2.22$ MPa

σbc (adm)=0.6×fc28=0.6×25=15MPa

σbc =0.42< σbc (adm)==15 condition verified

$\sigma st=\frac{n\times Ms\times(x-d')}{I}=107.50$ MPa

ft28=0.06×fc28+0.6=0.06×25+0.6=2.1MPa

σst0=min(266.67;201.63) σst0=201.63MPa

σst=107.50 < σst0=201.63 condition verified

Supports:

We take ASt=1T10+1T12= 1.92 cm²

Mser=5.25 kN,m=0.00525MN,m

X=11.25 cm < h0 =5cm therefore AN according to the table

$I= b\times \frac{X^3}{3}+n\times Asc(x-d')^2+n\times Ast\ (d-x)^2$

$I=3.25\times10^{-4}\ m^4$

Calculation of Stresses:

$$\sigma_{bc} = \frac{Ms \times x}{I} = \frac{5.25 \times 10^{-3} \times 0.1125}{3.25 \times 10^{-4}}$$

$$\sigma bc = 1.81\ Mpa$$

σbc (adm)=0.6×fc28=0.6×25=15MPa σbc =1.81 < σbc=15 condition verified

σst= 18.53 MPa

ft28=0.06×fc28+0.6=0.06×25+0.6=2.1 MPa

σst(adm) =min (266.67;201.63)

σst(adm)=201.63MPa σst=18.53 < σst(adm)=201.63 condition verified

Tangential Stress:

$\tau u = \frac{Tu}{b_{0\ \times d}}$

max=12.87 kN TU=12 .87×10^−3 TU = 0.56 MPA

bd 0.12×0.189

Justification of Concrete:

α =90°:

TL=min [0.15×fc28/γb, 4MPa] if cracking is detrimental or very detrimental

TL =min [0.15×25/1.5;4MPa]

TL =min [2.5;4MPa]

TL=2.5MPa

Tu=0.56 < TL=2.5 condition verified

Justification for Reinforcement:

$$St \leq \frac{At \times 0.9 \times \frac{fet}{\gamma s}(sin\alpha + COS\alpha)}{b(\tau_u - 0.3\ k\ ftj')}$$

ft28'= min (ft28;3,3MPA) avec ft28=2,1MPA ft28'= 2,1 MPA

K=1

Ø=Min (h/35 ; b_0/10 ; Ølmin)

Ø≤min (0,6 ;1,2 ;1)

Ø=0,6cm

Ø=6mm

At= 2Ø6=0.57cm²

Tu=1.3<TL=3.26 **c v**

$$St \leq \frac{0.57 \times 10^{-4} \times 0.9 \times \frac{235}{1.15}}{0.12(0.56 - 0.3 \times 2.1)}$$

St ≤ 1.25 m

STmin ≥ 7cm **on**

St=7cm

Stmax ≤ min (0,9d;40cm)

Stmax ≤ min (0,9×18,9;40)

Stmax ≤ min (17,01;40)

S_{tmax} ≤17,01cm ON STMAX=17cm

$\frac{At \times fe}{b}$ ≥max((Tu/2);0,4MPA)

$$\frac{513 \times 10^{-4} \times 235}{0.3 \times 0.07} \geq Max\ (0.284; 0.4)$$

0.63≥ max (0,28;0,4) CV

- **Réparation RPA (Zone III):**

S' ≤ (h/4;12ØLmin;30cm) et L=2h = 2×21= 42cm

S'≤(21/4;1×1,2;30)

S' ≤5,25cm S'=5cm

S ≤ h/2 ↔ S ≤ 21/2

S≤10,5cm

2.6. Analysis of Secondary Elements:

The structure comprises various elements that are divided into two categories: structural elements and non-structural elements. This chapter focuses exclusively on the analysis of non-structural components (various types of floors, staircases, parapets). This research is carried out using the following approach: examination of the loads on the components taken into account, calculation of the most severe stresses and definition of the required steel section.

2.6.1. Calculation of The Parapet:

The parapet is a structural component that surrounds the top of the building, designed to protect the joint between it and the sloping surface from rainwater infiltration. It is made of reinforced concrete. Under the effect of its own weight and a horizontal overload due to the handrail, it is considered to be a console integrated into the terrace floor. The most dangerous area is where it is embedded. For a strip measuring 1 linear metre, the calculation will be based on compound bending in the embedded section. The parapet is subject to weather conditions, so cracking can be harmful. In this context, the calculation will be carried out in accordance with ELU and ELS standards.

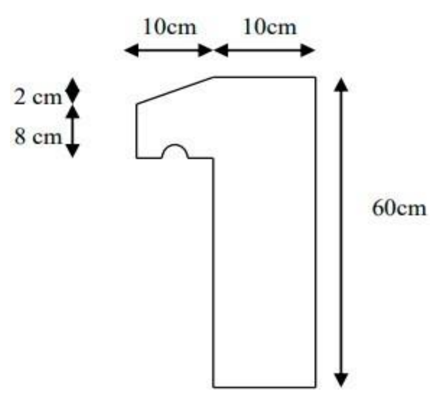


Figure 2.8*: Type of acroterio* ***(DTR B.C 2.2)***

2.6.2. Load Assessment:

Table 2.8: *Load descent from the balcony:*

Dead weight of the parapet:	G = 1.72 kN/ml
Live load (handrail) :	Q = 1.00 kN/ml

The Staircase:

Staircases, as structural elements, must be carefully designed to ensure safety, functionality and longevity. They must comply with current building standards and be suitable for their intended use and the available space.

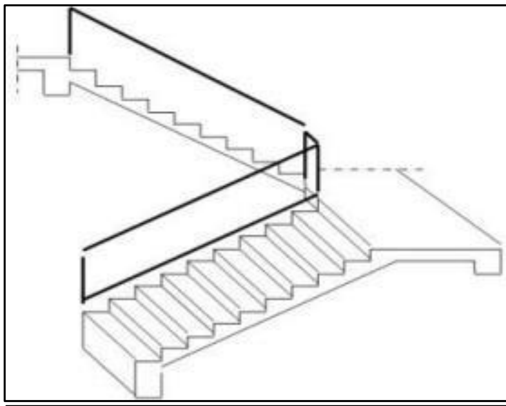


Figure 2.9: *Staircase diagram for Double-flight (DTR B.C 2.2)*

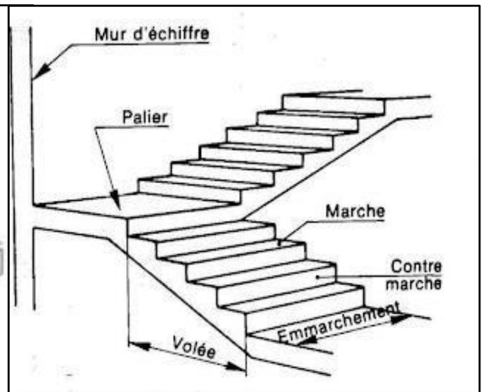


Figure 2.10Components of standard reinforced concrete stairase (DTR. B.C.2.2)

- **Stair Pre-Dimensioning**:

h: Riser height…………………………….17 cm

g: Step width. …………………………………30 cm

L: Length of the workbench…………………………….242 cm

l: Width of the workbench…………………………………… 120 cm

Lt: Total length of the landing (flight + landing) …

.3.92 cm Using Blondel's formula: $59cm \leq 2h\ g \leq 66\ cm$.

We find: 59 cm ≤ g 2h = 64 cm ≤ 66 cm ⇒ Condition verified

- **The inclination of the workbenches:**

$\alpha = tan{-1}\ (\frac{153}{240}) \Rightarrow \alpha = 32.51°$

- **Calculation of the workbench:**

$$\frac{l}{30} \leq e \leq \frac{l}{20}$$

$13,5 \leq e \leq 20,25$ ⇒ We take e = 15 cm

2.6.3. Evaluation of Loads and Overloads On Stairs:

Loads and overloads according to the DTR (B.C2.2):

a-Bearing:

Table 2.6: *Bearing loads and overloads*

Designation	$\boldsymbol{Ep}$ (m)	Densities(KN/m²)	weight(KN/m²)
Tiles (Granito)	0,02	22	0,44
Setting mortar	0,02	20	0,4
Self-weight of the landing	0,15	25	3,75
Sand layer	0,02	25	3,75
Plaster coating	0,02	10	0,2
		Total : G	**5.15**
		Total: Q	**2,5**

b-Bench:

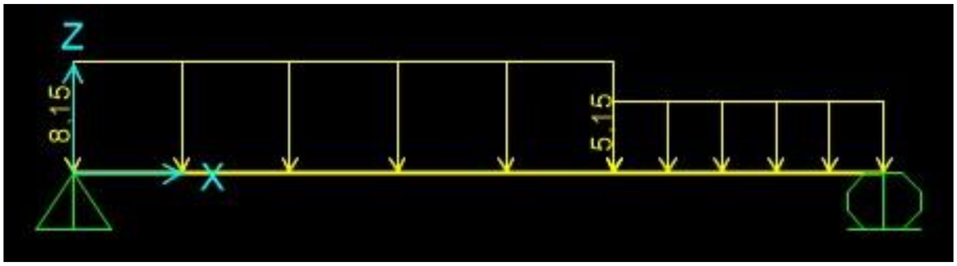


Figure 2.11: loads and overloads on the workbench and bearing ***(ETABS)***

Table 2.9*: Workbench loads and overloads .*

Designation	Ep (m)	Densities(KN/m²)	weight(KN/m²)
Tiles(Granito) on tread	0,02	22	0,44
Tiles(Granito) on riser	$0.02\times\frac{0.17}{0.3}$	22	0.25
horizontal bedding mortar	0,02	20	0,4
vertical bedding mortar	$0.02\times\frac{0.17}{0.3}$	20	0.23
Self-weight of the slab	0,15/cos∝	25	4.47
Weight of treads/riser	0,17/2	25	2.13
Plaster coating	0,02/cos ∝	10	0,23
		Total : G	8.15
		Total: Q	2,5

C - Combinations of actions:

- E.L.U = 1,35G + 1,5Q / ELS = G + Q

Table 2.10 : *Action combinations*

Combination of action	Bearing(KN/m)	The workbench(KN/m)
ELU	1,35x(5,15x1)+1,5(2,5x1)=**10.70**	1,35x(8.15x1)+1,5(2,5x1)=**14,75**
ELS	(5,15x1)+(2,5x1)=**7.65**	(8,15x1)+(2,5x1)= **10,65**

To the ULS :

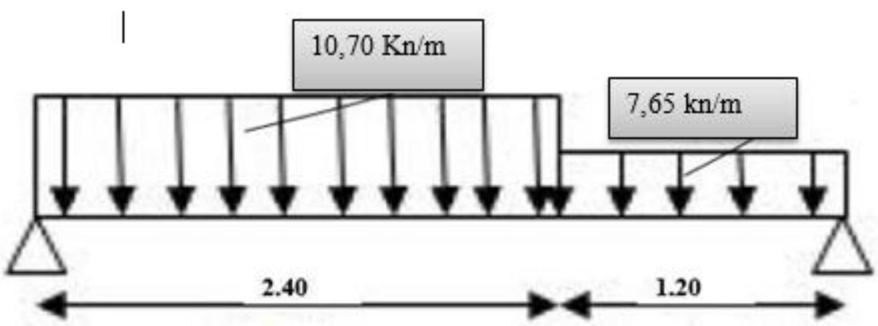


Figure 2.12*: Load combinations at (SLS)*

To the ELS:

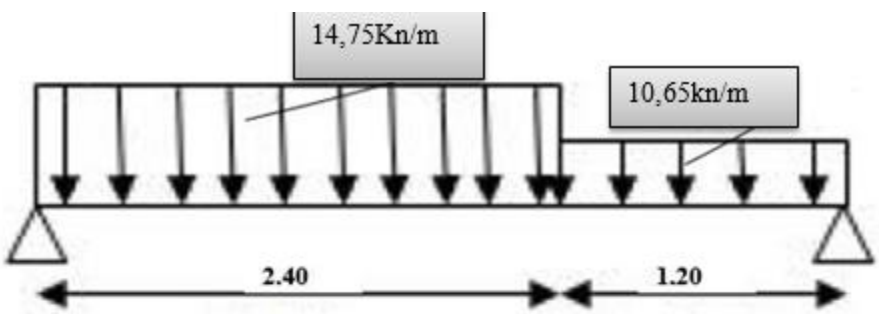


Figure 2.13*: Load combinations at (U.L.S)*

Modelling and verification with:

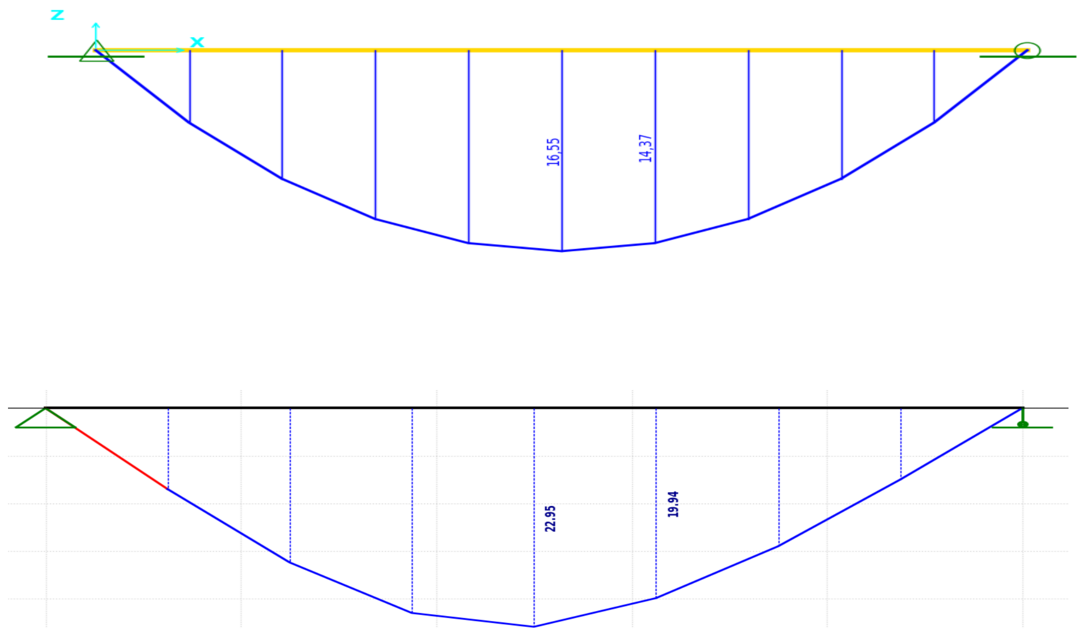


Figure2.14: *Moment diagram at ULS and SLS* ***(ETABS)***

2.6.4. Reinforcement calculation :

- In supports : Mappui = 0.5 .M0
- Moment in span : Mtravée=0.85.M0

$* \; b = 1ml \; / \; h = 0{,}15 / \; d = 0{,}135m \; / fc28 = 25 \; MPa \; / fe = 400 \; MPa \; / fbc = 14{,}1 M$pa

Tables2.11: *Summary of moments and shear stress for ULS and SLS*

	M_0(KN.m)	M_a(KN.m)	M_t(KN.m)	T(KN)
ELU	22.95	11.475	19.507	23.302
ELS	16.55	8.275	14.067	16.761

a) Longitudinal reinforcement:
b) (simple bending)
c) ELU: a-1) support:

$$\mu_u = \frac{Mu}{b \times d^2 \times fbc} \quad \mathbf{= 0,0444 \; \mathit{Mpa}}$$

$\mu_u = 0{,}0444 \leq \mu_R = 0.392$ → **yes** → single frame → **(Asc=0)**

$\alpha = 1{,}25\,(1 - \sqrt{1 - 2\mu_u}) \rightarrow \alpha = 1{,}25\,(1 - \sqrt{1 - 2 \times 0{,}0444}) = \mathbf{0{,}056}$

z = d (1 − 0,4) = 0,135(1 − 0,4 × 0,056) = **0,13** m.

$A_{ST}=\frac{Mu}{Z\times\sigma st}=\frac{\mathbf{0.011475}}{\mathbf{0.13\times347.87}}\Rightarrow Ast\geq$ **2.54 cm²**

$\boxed{\textbf{we take } 4T12=4.52cm^2}$

Amin=7.5≤ $Ast+Asc=7{,}92\leq Amax=60\rightarrow$ C V

a-2) span:

$\mu_u=\frac{Mu}{b\times d^2\times fbc}\quad = \mathbf{0,0755\ Mpa}$

μ_u = 0,0755≤ μ_R=0.392 → **Yes →single frame (Asc=0)**

α = 1,25 (1 − √1 − 2μ_u) → α = 1,25 (1 − √1 − 2 × 0,0755) = **0,098**

z = d (1 − 0,4α) = 0,135(1 − 0,4 × 0,098) = **0,13** m.

$\boldsymbol{A_{ST}=\frac{Mu}{Z\times\sigma st}}\quad = \mathbf{0.019083}\Rightarrow Ast\geq$ **4.31cm²** $\boxed{\textbf{we take : } 7T12=7.92cm^2}$

b) Distribution frames: (BAEL 94):

According to the BAEL91:

$A_r=\frac{A1}{4}$

Span: $A_r=\frac{7.92}{4}=1.98$→we take 3T12=3.39cm²

Support: $A_r=\frac{4.52}{4}=1.13$→we take 3T12=3.39cm²

<u>c) Spacing between reinforcements</u>: BAEL91 (art A.8.2, 4.2)

a-1 Longitudinal reinforcement: (pour b=1 m, h=15cm))

$St_{max}\leq$ min (3h, 33 cm) = min (45,33) → $\mathbf{St_{max}}$ **33 cm**

 $St = \frac{\mathbf{100}}{\mathbf{5}}$= **20cm** < St_{max} 33 cm= C V

We take St=20cm

a-2 Distribution fittings:

$St_{max} \leq$ min (4h, 45 cm) = min (45,33) → $\mathbf{St_{max}}$ **=33 cm**

Span: St = $\frac{100}{3}$=33 cm

support : St = $\frac{100}{3}$ =33 cm **cv**

ELS:

Span :

$$\mathbf{X}=\frac{\mathbf{15\times(4.52)}}{\mathbf{100}} \times (\sqrt{\mathbf{1}} +\mathbf{2}\times \frac{\mathbf{100\times13.5\times4.52}}{\mathbf{15\times4.52}} \mathbf{-1)}$$

X=3.65cm → x<h_0=5cm **: condition check → Therefore, the neutral axis lies within the table**

$$I= \frac{b\times x^3}{3}+n\times Ast \times(x-d')2+ n\times ASt\times (d-x)^2$$

$$I= \frac{100\times3.65^3}{3}+ 15\times4.53\times (13.5-3.65)^2 \rightarrow I=8199.029 \text{ cm}^4$$

***constraint verification**

$$\sigma_{bc} = \frac{Ms \times x}{I} = \frac{8.275 \times 10^{-3} \times 0.459}{13401.15 \times 10^{-8}}$$

$\boldsymbol{\sigma_{bc}}$ =2.83< $\overline{\sigma_{bc}}$ = 0.6fc28 = 15MPa = **Condition check *Shear verification:**

According to BAEL91 (Art. A.5.1.1): The tangential constraint must satisfy the following condition:

$\boldsymbol{\tau u}$= $\frac{\boldsymbol{TU}}{\boldsymbol{d\times b_0}}$< $\boldsymbol{\tau 1}$ = min (0.2.fc28/γ_b ; 5 MPa) ⇔ $\boldsymbol{\tau u}$= $\frac{\mathbf{18.5}}{\mathbf{100\times13.5}}$=**0.173 Mpa <$\boldsymbol{\tau}$l=3.33 Mpa⇔ Condition vérifier**

* Deflection check: According to BAEL (art B.6.5.6)

Condition	h/l>1/30	As/b.d>2/fe
Verification	0,0625>0,033	0,334>0,005
	CV	CV

d) Reinforcement Diagrams :

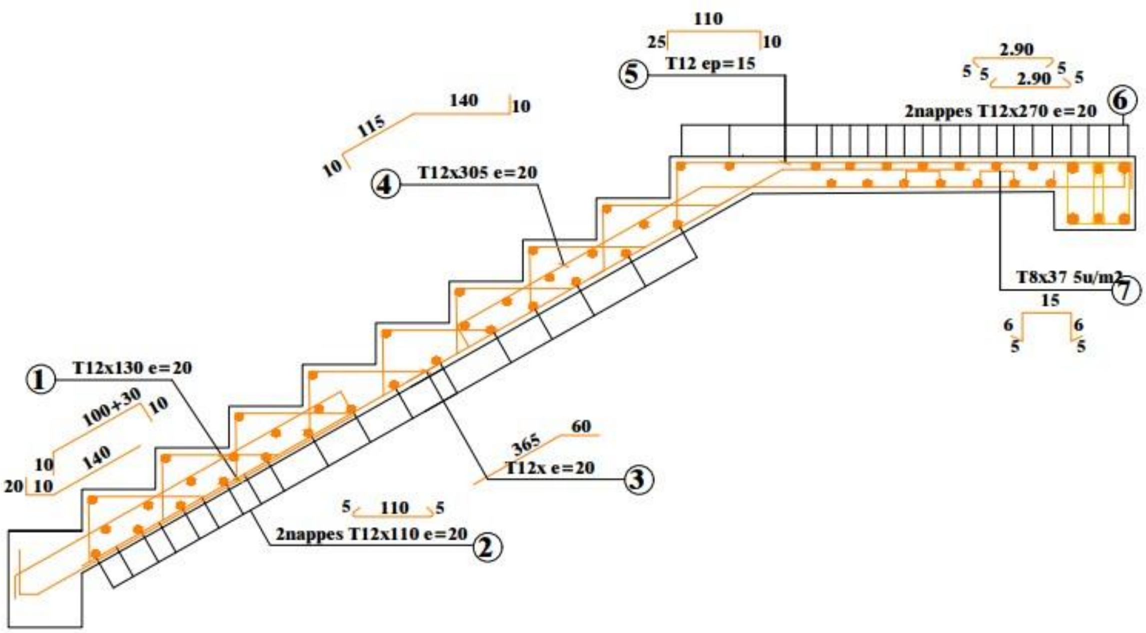


***Figure 2.14**: Staircase reinforcement diagrams(author)*

2.6.5. Study of the Landing Beam:

The landing beam is dimensioned using the BAEL equations, while its compliance is verified using the RPA 2024:

- ✓ According to BAEL91 Based on the deflection condition: The height h' of the landing beam must be:

$$\frac{l}{10} \leq h \leq \frac{l}{15} \leftrightarrow \frac{3,20}{15} \leq h \leq \frac{3,20}{10} \leftrightarrow 21,33 \leq h \leq 32$$

We Take h= 30 cm

*** Verification:**

$0,4.h \leq b \leq 0,8h \leftrightarrow 0,4\times40 \leq b \leq 0,8\times30 \leftrightarrow 12 \leq b \leq 24$ **We Take b=20 cm According to the RPA2024:**

$b \geq 25$ 20<25 CNV we take b=25cm **Load descent:**

P_P de the beam: $G_1=0,3\times0,35\times25=2,625$KN/m

Clean PP double-walled wall: $G_2=h\times Gparois=2,94\times2,97=8,73$KN/m

Net weight of the workbench and bearing

: G_3=($G_{Paillaisse}$×Lpaillaisse/2) +Gpalier×Lpailier

G_3== (8.15×2,42/2) +5,15×1,5=17,5862KN/m

G_p palière= 8,73+2,625+17,586=28,94KN/m

Q_p palière=Q×L=2,5×2,42= 6 KN/m

* q_u=1,35Gp+1,5Qp=1,35×28.94+1,5×6= 48.069 KN/m

* q_s=27,397+6= 34.94 7KN/m

ULS:

$$Mu=\frac{qu\times l^2}{8}=\frac{68\times 3.2^2}{8}= 61.528\ \text{KN.m}$$

$$Ms=\frac{qs\times l^2}{8}=\frac{34.94\times 3.2^2}{8}= 44.723\text{KN.m}$$

ULS : Span :

MU=61.528 KN MS= 44,72 KN fc28=25MPA b=30 cm h=30cm fe=400MPA

Cracking is detrimental

$$\mu_u= \frac{Mu}{b\times d^2\times fbc}$$

d=0,9×0,30=0,27m

$$f_{bc}=\frac{0.85\times 25}{1.15}$$

$$\mu u= \frac{61.528\times 10^{-3}}{0.3\times 0.27^2\times 14.16}=0{,}2<\mu r=0.392 \quad \text{so simple Frames}$$

$$\alpha=1{,}25(1-\sqrt{1-2\times \mu u})=0.281$$

z= d (1-0,4α) =0,27× (1-0,4×0,281) =0.239m

ASC=0cm² We take ASC 3T12= 3,39cm²

$$A_{ST}=\frac{Mu}{Z\times \sigma st}=\frac{61.528\times 10^{-3}}{0.239\times 347.826}$$

Ast= 7,40cm² we take AST 3T14+3T12=4,62+3,39= 8,01cm^2

σ_{St}= 347,826MPA

Amin= (0,5÷100) ×30×30=3,75cm^2

Amax= (4÷100) ×30×30=36cm²

Amin=5,25<8,01+3,39<Amax=36 = Condition check

* **ELS :** n=15 ASC=0 simple frames

$$x = n\frac{(A_{ST+A_{sc}})}{b}\left(\sqrt{1+\frac{2b(d\times A_{ST}+d'\times A_{SC})}{n(A_{ST}+A_{SC})^2}}-1\right)$$

$$x = 15\frac{(8.01)}{30}\left(\sqrt{1+\frac{2\times 30(27\times 8.01)}{15(8.01)^2}}-1\right)$$

$$x = 15.24 \text{ cm}$$

$I= \frac{b\times x^3}{3}+n\times Ast\times(x-d')2+ n\times ASt\times (d-x)^2$

I= $\frac{30\times12\text{^}3}{3}$+15×8,01× (27-15.24)^2 = 5,20**.**$10^{-4}m^4$

$\sigma_{bc} = \frac{Ms\times x}{I} = \frac{44.72\times10^{-3}\times0.152}{5.20\times10^{-4}}$=13,10 Mpa

$\underline{\sigma_{BC}}$=0,6×fc28=0,6×25=15MPA

σ_{BC}=13.10 <$\underline{\sigma_{BC}}$=15 = Condition check

σ_{st}=151.70 MPA

$\underline{\sigma_{st}}$(adm)=min($\frac{2}{3}fe; 110\sqrt{ŋ}ft28$)

f_{t28}=0,,06×fc28+0,6=0,06×25+0,6=2,1MPA

σ_{st0}=min($\frac{2}{3}$×400;110$\sqrt{1,6\times2,1}$)

$\underline{\sigma_{st}}$(adm)==min(266,67;201,63) $\underline{\sigma_{st}}$(adm)==201,63Mpa

σ_{st}=151.70 < $\underline{\sigma st}$(adm)==201,63 = Condition check

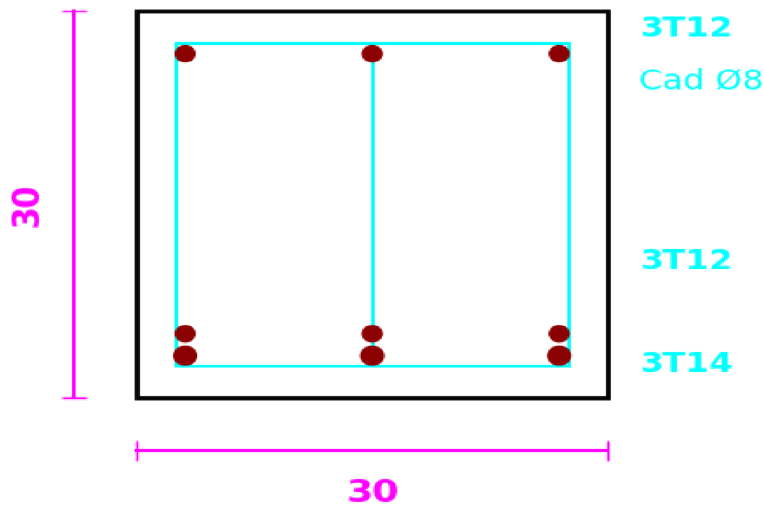


Figure 2.15: *reinforcement diagrams for the landing be*am (*author)*

2.7. Dynamic Study:

An earthquake is a sudden release of potential energy accumulated in rocks due to relative movements of different sections of the Earth's crust. When stresses exceed a certain level, a rupture in equilibrium occurs, generating seismic waves that spread in all directions and reach the Earth's surface. These ground movements cause structures to vibrate by displacing their supports, and are intensified to varying degrees within the structure. The amplification varies mainly according to the period of the structure and the type of soil. This requires us to conduct an in-depth study in order to try to highlight the dynamic behaviour of the structure and verify that it complies with the conditions and criteria for safety measures required by Algerian seismic standards RPA2024.

2.7.1. Purpose of dynamic analysis:

The primary purpose of dynamic examination of a structure is to identify its intrinsic dynamic properties during vibratory movements. A study of this nature for our organisation, in its current form, is often very complex. This is why we use modelling techniques that sufficiently facilitate problem solving to make analysis possible.

2.7.2. Calculation Approach:

According to RPA 2024, seismic forces can be calculated using

- Spectral modal analysis method.

- Dynamic analysis method using accelerograms.

- Equivalent static method.

2.7.3. Equivalent Static Method:

In this method, RPA 2024 proposes replacing the actual dynamic forces generated by an earthquake with a system of fictitious static forces whose effects will be identical and considered to be applied separately in the two directions defined by the main axes of the structure.

2.7.4. Spectral Modal Analysis Method:

The spectral modal method is undoubtedly the most widely used method for seismic analysis of structures. In this method, for each vibration mode, the maximum effects generated in the structure by the seismic forces represented by a computational response spectrum are sought. These effects are then combined according to the most appropriate combination to obtain the total response of the structure.

2.7.5. Dynamic Analysis Method Using Accelerograms:

This method may be used on a case-by-case basis by qualified personnel, who have previously justified the choice of design earthquakes and behaviour laws used, as well as the method of interpolation of results and the safety criteria to be met.

2.7.6. Structural Modelling:

Studying the dynamic response of a structure (periods and natural modes) requires the selection of an appropriate dynamic model that reflects the nature of the actual system as accurately as possible. The model used to calculate the structure is an infinitely rigid vertical console fixed at its base (spit model), with masses concentrated at the centre of gravity of each level. ETABS software is used for modelling and analysing the structure, which simplifies the calculations sufficiently. The structural elements are modelled as follows:

▪ The portal elements (beams and columns) were modelled using two-node frame finite elements with six degrees of freedom (D.D.L) per node.

▪ The walls were modelled using four-node shell elements.

▪ The floors are simulated using rigid diaphragms.

▪ The slabs are modelled using slab elements that neglect membrane forces.

2.7.7. Arrangement of Walls:

The arrangement of sails must satisfy several conditions, which are listed below:

- The position of the sails must avoid torsional stresses in the structure.
- The sum of the effective modal mass must also reach 90% of the total mass of the structure in both directions.
- The number of sails arranged in the structure must ensure good rigidity while remaining economical.
- The final arrangement must also comply with Algerian earthquake regulations RPA2024.

In order to choose the right wall layout, an in-depth study of several variants was carried out (to take just one example). Below are those that are most suitable for our structure:

❖ **Wall Layout:**

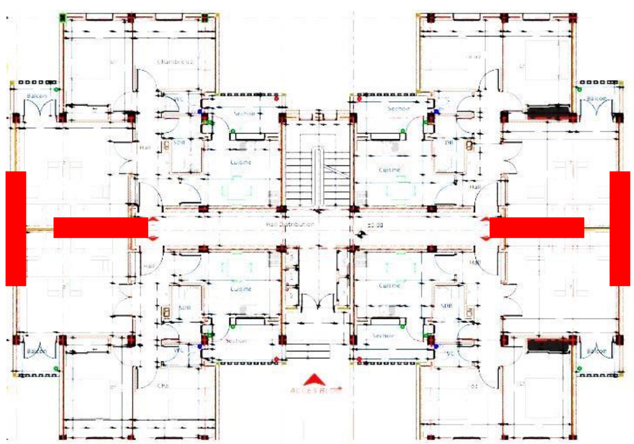


***Figure 2.16**: Wall layout(AUTOCAD)*

2.7.8. Choosing the calculation method:

When choosing the method to be used, it is essential to examine certain criteria related to the seismic standards currently in force in Algeria (RPA2024), which concern the regularity of the building's plan and elevation. We will use the equivalent static method to check compliance with RPA2024:

V Dynamic > 80% V Static

With:

Dynamic V: the resultant of seismic forces at the base.

Static V: the resultant of seismic forces calculated using the equivalent static method.

- **The Equivalent Static Method:**

According to section 4-2 of the RPA2024, the formula for determining the equivalent seismic force (V) applied to the base of the structure in the $\boldsymbol{x}$ and $\boldsymbol{y}$ directions is as follows:

$$\mathbf{V}=\boldsymbol{\lambda}\times\frac{\boldsymbol{S_{ad}}}{\boldsymbol{g}}\times\boldsymbol{T_0}\mathbf{0}\times\boldsymbol{w}$$

With:

- $\frac{Sad}{g}\times$T0: ordinate of the calculation spectrum for period T0
- T0: fundamental vibration period of the building λ: correction coefficient
- $0.85 : si\ T0 \leq (2.T2)\ et\ si\ le\ batiment\ a\ plus\ de\ 2\ n\ iveaux\ \lambda = (\ 1\ ,\ autrement\ )$
- W: total seismic weight of the building

The empirical formula to be used in each case is as follows:

Empirical T = CT $\times\ (hN)^{\frac{3}{4}}$

Where:

Empirical T: fundamental period (in s) hN: total height

Ct: coefficient, depending on the bracing system and type of infill, given in table (4.4 RPA2024).

Table 2.12: Values of the coefficient CT

Case	Bracing System	CT
1	Reinforced concrete space frames without masonry infill	0.075
2	Steel space frames without masonry infill	0.085
3	Reinforced concrete or steel frame frames with masonry infill	0.050
4	Other types of structures	0.050

Cas	Période à utiliser
$T_{calcul} < 1.3T_{empirique}$	$T_0 = T_{calcul}$
$T_{calcul} \geq 1.3T_{empirique}$	$T_0 = 1.3T_{empirique}$

Spart of the application of the developed equivalent static method (see § 4.2), the values of (T_0_, calculated using Rayleigh formulas or numerical methods, must not exceed the value estimated from the empirical formula by more than 30% (see Eqn. (4.4)).

The value to be used in the equivalent static method is then equal to: $T_{Max} = 1.3\ T_{empirique}$.

Table (2.10) provides the values of the period, (T_0), to be used in the formula for calculating the base shear (V).

Table 2.13: Calculation of the empirical fundamental period

C_T =	**0,050**
h_N =	**15,30**
$T_{empirique}$ =	**0,580**

❖ Verification of the structural numerical period (Tnumérique):

This is obtained from a numerical model (software modelling), and must be less than the empirical period (Texp).

The following must hold:

$T_{\text{numérique}} \leq T_{\text{exp}}$

Calculation of the total seismic force:

The total seismic force, V, applied to the base of the structure, must be calculated successively in two orthogonal horizontal directions, according to Eqn. (4.1) :

$$\frac{S_{ad}}{g}(T) = \begin{cases} A.I.S.[\frac{2}{3} + \frac{T}{T_1}.(2.5\frac{Q_F}{R} - \frac{2}{3})] & si : 0 \leq T < T_1 \\ A.I.S.[2.5\frac{Q_F}{R}] & si : T_1 \leq T < T_2 \\ A.I.S.[2.5\frac{Q_F}{R}].[\frac{T_2}{T}] & si : T_2 \leq T < T_3 \\ A.I.S.[2.5\frac{Q_F}{R}].[\frac{T_2.T_3}{T^2}] & si : T_3 \leq T < 4s \end{cases} \quad (3.15)$$

Table 2.14: Seismic Acceleration Coefficient (A) based on Seismicity Zones

Seismicity zone	***Seismicity level***	**A**
0	Very low	**0,00**
I	Low	**0,07**
II	Low to moderate	**0,10**
III	Moderate	**0,15**
IV	Moderate to high	**0,20**
V	High	**0,25**
VI	High	**0,30**

Classification of buildings according to their significance:

Significance Group: (Group 2)

Table 2.15: Importance Coefficient (I) by Building Category and Seismic Zone (RPA2024)

Importance Coefficient	Importance Coefficient			
	1A	1B	2	3
I	1,4	1,2	1	0,8

❖ Website category :

Category S_2 (stiff site): Very dense sand and/or gravel deposits or overconsolidated clay several tens of meters thick, characterized by a gradual increase in mechanical properties with depth and shear wave velocities (360m/s) < Vs_{30}≤ (800 m/s) .

Périodes T1,T2,T3 :

Table 2.16: *Soil Profile Site Coefficients (S) and Characteristic Periods (T1, T2)*

		S	T1	T2	T3
ZoneI + Zone II+ Zone III	S1	1	0,05	0,25	1,20
	S2	1,3	0,05	0,30	1,20
	S3	1,55	0,10	0,40	1,20
	S4	1,8	0,10	0,50	1,20
Zone V + Zone IV+ Zone VI	S1	1	0,10	0,40	2,00
	S2	1,2	0,10	0,50	2,00
	S3	1,3	0,15	0,60	2,00
	S4	1,35	0,15	0,70	2,00

In our case :

Table 2.17: Seismic Site Parameters for Zone III (High Seismicity)

Seismic zone	*Type ground*	*S*	*T1*	*T2*	*T3*
Zone III	*S2*	*1,30*	*0,05*	*0,30*	*1,20*

❖ Behavioural factor :

This takes account of non-linearity and depends on the bracing system; in our structure, we have a mixed bracing system, equivalent to walls with R = 4.5

Table 2.18: Behaviour Factor (R) Values Based on the Structural Bracing System

1	Frame system	5,5
2	Mixed bracing system, equivalent to a frame	5,5
3	Frame system or mixed system equivalent to a frame with rigid masonry infill	3,5
4	Mixed bracing system, equivalent to walls	4,5
5	Bracing system consisting of walls	4,5
6	Core-supported frame system or system with core effect	3
7	System operating as a vertical cantilever with predominantly distributed masses	3
8	Inverted pendulum system	2
9	System of large-dimensioned walls of lightly reinforced concrete	1,5

❖ Quality factor (Q):

The quality factor (Q) is determined by the formula:

: $\boldsymbol{Q}=\mathbf{1}+\Sigma\, \boldsymbol{pq}$

With:

P: Is the penalty to be applied depending on whether or not the quality criterion (q) is met.

Table 2.20: *Values of the Quality Factor Redundancy (Pq) (RPA2024)*

a	1	Regularity in plan view	0,05
	2	Regularity in elevation	0,20
	3	Minimum requirements regarding the number of storeys	0,00
	4	Minimum requirements regarding bay widths	0,10
b	1	Regularity in plan view	0,05
	2	Regularity in elevation	0,20
	3	Redundancy in plan view	0,05

CALCULATION OF THE CENTRE OF STIFFNESS:

- *Sail 1 :*

Ix=$\frac{2\times3^3}{12}$=0.45m4

Iy=$\frac{3\times0.2\text{^}3}{12}$ = 2.10-3m4

- *Sail 2 :*

Ix= $\frac{2\times0.2^3}{12}$ =1.33.10^{-3}m^4

$I_y = \frac{0.2\times2^3}{12} = 0.133 m4$

- *Post :*

$I_x = I_y = 0.4^4 / 12 = 2.13x10-3m4$

Centre of rigidity:

$X_{cr} = \sum I\times xi = 13.54$ m

$Y_{cr} = \frac{\sum I\times yi}{\sum I} = 9.4$ m

$\sum I$Weightings for category (b):

1/ consistency in layout:

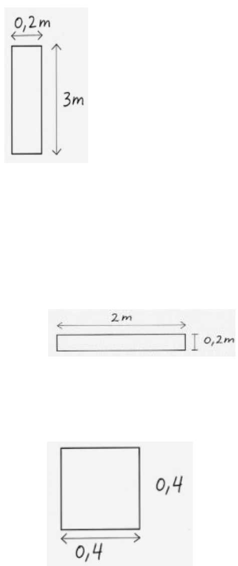


Figure2.18: *Technical Details and Seismic Design Parameters for the Structural Analysis. (AUTHOR)*

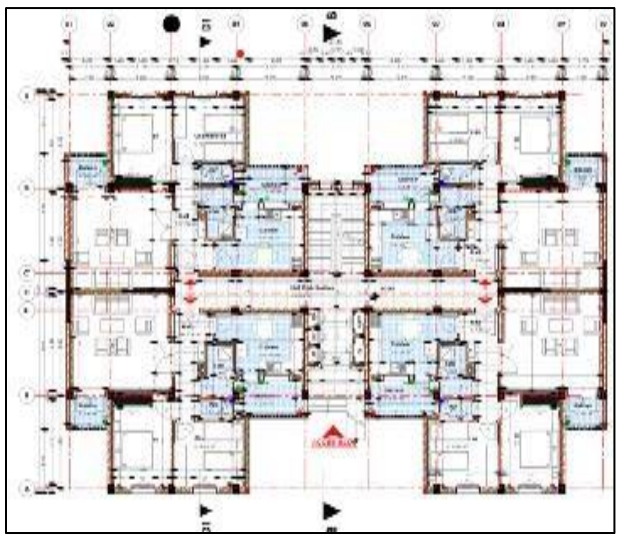


Figure2.17: *Standard Floor Plan of R+4 Residential Bulding(AUTOCAD)*

Table 2.21: Criteria for the regularity of the plan view (RPA2024)

Criteria	Observed	Not observed	Pq
A1. The building must have a substantially symmetrical configuration with respect to two orthogonal directions, both in terms of the distribution of stiffness and that of mass.	X		0
A2. On each storey and for each design direction, the distance between the centre of gravity of the masses and the centre of the stiffnesses must not exceed 15% of the building's dimension, measured perpendicular to the direction of the seismic action under consideration.	X		0
A3. The building's shape must be compact, with a floor length-to-width ratio of 4 or less (see figure 3.6). The sum of the dimensions of the building's recessed or projecting parts in a given direction must not exceed 25% of the building's total dimension in that direction,	27,5/19,4=1,41 < 4 X		0
A4. The floors must have sufficient rigidity relative to that of the vertical bracing to be considered non-deformable in their plane. In this context, the total area of floor openings must remain less than 15% of that of the floor	X		0

- $|X_{cm}-X_{cr}|$=0,06 m.
  - For the action according to Y, this distance is compared.

With 15% de Xtot=0.15x27.5=4.125m 0,06 m≪4,125 m → **OK**.

- $|Y_{cm}-Y_{cr}|$=0,07 m
  - For the action according to X, this distance is compared with **15% de** Ytot=0.15x19.4=2.91m 0,07 m≪2,91 m → **OK**.

2/ Consistency in Elevation:

Table 2.22: *Quality Factor Criteria for Vertical Regularity (Pq)*

Criteria	Observed	Not observed	Pq
B1. The bracing system must not include any discontinuous vertical load-bearing elements whose load is not transmitted directly to the foundation.	X		0
B2. Both the stiffness and the mass of the various storeys must remain constant or decrease gradually, without any sudden changes, from the base to the top of the building.	X		0
B3. The mass-to-stiffness ratio of two successive storeys must not vary by more than 25% in each design direction.	X		0
B4. In the case of stepped elevations, the variation in the building's plan dimensions between two successive storeys must not exceed 20% in both design directions and must only decrease with height. The largest lateral dimension of the building shall not exceed 1.5 times its smallest dimension. However, on the top floor, building elements such as laundry rooms, lift machine rooms, etc., may deviate from rules b3 and b4 and be calculated in accordance with the requirements for secondary elements.	X		0

3/Planar Redundancy :

Each storey must have at least four (4) rows of bracing frames in plan; these bracing frames must be arranged as symmetrically as possible, with the ratio between the maximum and minimum spacing not exceeding 1.5.

- ☐ Longitudinal direction:

$\frac{L\,max}{l\,min}=\frac{3.5}{2.1}=1.67>1.5$ → Criterion not met $=\mathbf{0,5}$

- ☐ Transverse direction :

$\frac{L\,max}{l\,min}=\frac{5}{4.5}=1.11<1.5$ → Critère observé $\boldsymbol{pq}=\mathbf{0}$

Qfx	1	+	0.05	=	1.05
Qfy	1	+	0	=	1

Summary table :

Table 2.23: *Summary of Seismic Design Parameters and Response Spectrum Inputs*

Seismicity zone	Zone III
A=	0,15
Importance group	2
I=	1
Soil type	S2
S=	1,3
Q=	Qx=1.05 ,Qy=1
R=	4,5
T1=	0,05
T2=	0,30
T3=	1,20

Total weight of the structure (W): The value of W comprises all permanent loads for residential buildings. It is equal to the sum of the weights Wi, calculated at each level (i): $\boldsymbol{W}=\Sigma \boldsymbol{W i}$

For: i = 1 to i = n $\boldsymbol{Wi}=\boldsymbol{WGi}+\boldsymbol{\beta}\times\boldsymbol{WQi}$

WGi : Weight due to permanent loads and any fixed equipment attached to the structure.

WQi : Charge d'exploitation.

β : Coefficient de pondération, fonction de la nature et de la durée de la charge d'exploitation, (β = 0.2) For a residential building.

$$F_i = \frac{(V - F_t).W_i.h_i}{\sum_{j=1}^{n} W_j.h_j}$$

où :

F_i: effort horizontal revenant au niveau i

h_i: niveau du plancher où s'exerce la force F_i

h_j: niveau du plancher quelconque

W_i, W_j: poids revenant aux planchers i et j, respectivement.

The structural weights were calculated using ETABS software and are summarised in the following table

Table 2.24: Vertical Distribution of Mass and Storey Heights

Level	Cumulated Height (m)	mass (tonnes)
DRC	3.06	611.971
1	6.12	609.162
2	9.18	609.162
3	12.24	609.162
4	15.3	518.344

The total weight of the structure: $\boldsymbol{W_T}= 2957.801\ (\boldsymbol{t}) \rightarrow \boldsymbol{W_T}= 29016.018\ (\boldsymbol{KN})$

❖ Calculation of the equivalent seismic force at the base (V):

Table 2.25: Shear Force Calculation

λ =	0.85	
$\frac{S_{ad}}{g}(T_0) =$	0.0678	0.646
Le poids de la structure (W) =	29016.018	
$V_{STx} = \boldsymbol{\lambda} . \frac{S_{ad}}{g}(T_0) . \boldsymbol{w}=$	1672.193 (kN)	
$V_{STy} = \boldsymbol{\lambda} . \frac{S_{ad}}{g}(T_0) . \boldsymbol{w}=$	1593.269 (kN)	
0,8X V_{STx}=	1337.754	
0,8X V_{STy}=	1274.615	

❖ Determination of the seismic force for each storey:

The total seismic force (V) must be distributed over the height of the structure in accordance with formula (4-7 of RPA2024):

$$V = F_t + \sum_{i=k}^{n} F_i$$

$Ft = \mathbf{0{,}07} \times \mathbf{T} \times \mathbf{V}\ si\ \boldsymbol{T} > \mathbf{0{,}7}\ \boldsymbol{s}$

$Ft = \mathbf{0\ si\ T} \leq \mathbf{0{,}7s}$

The distribution of seismic forces in both directions is shown in the following table:

Table 2.26: Calculation of Horizontal Force.

Level	$V_{x,y}$		Wi(kN)	Hi(m)	Wi.hi	∑Wj.hj	Fi_x	Fi_y	Vj_x	Vj_y
Ground floor	1672.193	1593.269	6003.435	3.06	18370.511	260746.014	117.812	112.251	1672.192	1593.266
1	1672.193	1593.269	5975.879	6.12	36572.379	260746.014	234.543	223.472	1554.38	1481.015
2	1672.193	1593.269	5975.879	9.18	54858.569	260746.014	351.814	335.209	1319.837	1257.543
3	1672.193	1593.269	5975.879	12.24	73144.759	260746.014	469.085	446.945	968.023	922.334
4	1672.193	1593.269	5084.954	15.3	77799.796	260746.014	498.938	475.389	498.938	475.389

❖ **<u>Period and mass contribution:</u>**

The sum of the effective modal mass must reach 90% of the total mass of the structure in both directions:

Table 2.27: Modal Participating Mass Ratios (ETABS)

Case	**Mode**	**Period**	**UX**	**UY**	**SumUX**	**SumUY**	**RZ**
		sec					
Modal	1	0,527441	0,79508	0,000007875	0,79508	0,000007875	0,0875
Modal	2	0,497388	0,000007899	0,76551	0,79509	0,76551	0,0229
Modal	3	0,453174	0,00338	7,419E-07	0,79847	0,76552	0,6502
Modal	4	0,163156	0,12451	4,822E-07	0,92298	0,76552	0,0099
Modal	5	0,146996	5,454E-07	0,1407	0,92298	0,90621	0,002
Modal	6	0,123682	0,00004988	1,533E-07	0,92303	0,90621	0,0821
Modal	7	0,096995	1,711E-08	0,00012	0,92303	0,90633	0,0036
Modal	8	0,096979	2,582E-07	0,000002996	0,92303	0,90633	0,0004
Modal	9	0,092273	0,000000463	0,00011	0,92303	0,90044	0,0309
Modal	10	0,092261	0,000004382	0,00001106	92,4%	0,90689	0,0013
Modal	11	0,085585	0,05043	3,241E-07	97,3%	0,90645	0,0001
Modal	12	0,077952	0,000000772	2,749E-10	97,3%	90,645%	0,0144

Safety checks:

1/ Checking the shear force at the base:

According to RPA2024:

$$\frac{V_{dynamique}}{V_{statique}} > 80\%$$

Table 2.27: Overall Reactions at the Base for Seismic Loads (Cases Ex and Ey) (ETABS)

OutputCase	CaseType Text	GlobalFX KN	GlobalFY KN	GlobalFZ KN	GlobalMX KN-m	GlobalMY KN-m	GlobalMZ KN-m	OutputCase
Ex	LinStatic	-1672,192	-1,694E-10	5,684E-13	2,54E-09	-23517,8197	17193,6712	Ex
Ey	LinStatic	-1,311E-10	-1593,266	1,1E-12	22407,8078	-1,975E-09	-23832,8594	Ey

$V_{X,}$ = 1672.192 KN > 0.8V_X = 1337.754 KN………………***CV***

$V_{y,}$ = 11593.266 KN > 0.8V_Y = 1274.615 KN………………***CV***

2/ Justification for the reduced normal force:

According to the RPA2024 regulations, in order to avoid or limit the risk of brittle failure under combined seismic loads, RPA2024 requires that the design compressive normal force be verified, which is limited by the following condition:

Column: $V = \frac{N}{B \times fc28} < 0.35$

wall : $V = \frac{N}{B \times fc28} < 0.4$

N :The maximum normal force applied to the columns under seismic loads.

B: The cross-section of the columns

B : La section transversale des poteaux

F_{c28} : 25 Mpa

Table 2.28: *Element Forces – Frames (ETABS)*

Frame	Station	OutputCase	CaseType	P	V2	V3	T	M2	M3	FrameElem	ElemStation
Text	M	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m	Text	m
9	0	G+0.2Q-EX-0.3EY	Combination	-1046,568	-16,829	-3,362	0,0579	-6,1682	-27,4721	212-1	0
9	1,53	G+0.2Q-EX-0.3EY	Combination	-1040,448	-16,829	-3,362	0,0579	-1,0246	-1,7245	212-1	1,53
9	0	G+0.2Q-EX+0.3EY	Combination	-1045,736	-16,807	4,47	0,0485	8,3811	-27,4362	212-1	0
9	1,53	G+0.2Q-EX+0.3EY	Commination	-1039,616	-16,807	4,47	0,0485	1,5414	-1,7217	212-1	1,53

N_{max} = 1046.568 KN

$V = \frac{1046\times10^{-3}\times568}{0{,}4\times0{,}4\times25} = 0.261 < 0.35$………………***CV***

N_{max} = 558.4 KN

$V = \frac{0.5584}{0{,}2\times3\times25} = 0.0372 < 0.4$………………***CV***

3/Verification of the behaviour coefficient R:

For a portal frame system braced by reinforced concrete walls, where ***R***=**4**.5, the following condition must be verified:

The sails → $Vvoile \leq 100\%$

Table 2.29: Basic shear force and shear forces in both directions (ETABS)

SectionCut Text	OutputCase	CaseType Text	P KN	V2 KN	V3 KN	T KN-m	M2 KN-m	M3 KN-m	GlobalX m	GlobalY m
SCUT1	Ex	LinStatic	0,246	961,422	-0,307	-972,7012	-0,7216	20671,399	13,6	9,5
SCUT1	Ey	LinStatic	-0,098	2,495	1090,122	1788,6853	4768,8368	36,8784	13,6	9,5

$\frac{961.422}{1090.122} = 88.19\% \leq 100\%$ ………………***CV***

La condition est vérifiée ; Donc on garde le coefficient de comportement ***R***=4.5

4/Check for deformation:

According to RPA2024: The relative lateral displacement of a storey in relation to its adjacent storeys must not exceed 0.75% of its height.
Where: δ(ek): Maximum horizontal displacement due to seismic forces at level (K).

$$\delta(k) = \frac{R}{Qf} \times \delta(ek)$$

R: Behaviour coefficient (R = 4.5).

$\Delta(k)= \delta(k)- \delta(k-1)$ $\Delta(k)\leq 0.75\%(h_e)$ $\Delta(k)$:

The relative displacement of level (K) with respect to level $(K-1)$ he :

The height of each level. The results are summarised in the following

TABLE 2.30: Diaphragm Center Of Mass Displacements -X-X

Story	Output Case	UX δek (mm)	UX δek (m)	R	Q_f	$\delta_k = \frac{R}{Q_F}.\delta_{ek}$ δk (m)	δk_{-1} (m)	$\Delta_k = \delta_k - \delta_{k-1}$ Δ_k (m)	$V_A.\Delta_k$	h_k (m)	$\overline{\Delta_k}$ hk .0,0075	Verfication
Story5	EX	6,47	0,00647	4,5	1,05	0,02773	0,02361	0,00411	0,00206	3,06	0,02295	Condition verified
Story4	EX	5,51	0,00551	4,5	1,05	0,02361	0,01800	0,00561	0,00281	3,06	0,02295	Condition verified
Story3	EX	4,2	0,0042	4,5	1,05	0,01800	0,01114	0,00686	0,00343	3,06	0,02295	Condition verified
Story2	EX	2,6	0,0026	4,5	1,05	0,01114	0,00429	0,00686	0,00343	3,06	0,02295	Condition verified
Story1	EX	1	0,001	4,5	1,05	0,00429	0,00000	0,00429	0,00214	3,06	0,02295	Condition verified
												Condition verified

TABLE 2.31: Diaphragm Center Of Mass Displacements - Y-Y

Story	Output Case	UY δek (mm)	UY δek (m)	R	Q_f	$\delta_k = \frac{R}{Q_F}.\delta_{ek}$ δek (m)	δek_{-1} (m)	$\Delta_k = \delta_k - \delta_{k-1}$ Δ_k (m)	$V_A.\Delta_k$	h_k m	$\overline{\Delta_k}$ hk .0,0075	Verfication
Story5	EY	6,3	0,0063	4,5	1	0,02835	0,02318	0,00518	0,00259	3,06	0,02295	Condition verified
Story4	EY	5,15	0,00515	4,5	1	0,02318	0,01701	0,00617	0,00308	3,06	0,02295	Condition verified
Story3	EY	3,78	0,00378	4,5	1	0,01701	0,01008	0,00693	0,00347	3,06	0,02295	Condition verified
Story2	EY	2,24	0,00224	4,5	1	0,01008	0,00359	0,00649	0,00324	3,06	0,02295	Condition verified
Story1	EY	0,798	0,000798	4,5	1	0,00359	0,00000	0,00359	0,00180	3,06	0,02295	Condition verified

5/ Justification with regard to the P-Δ effect:

Second-order effects (or P-Δ effects) are effects caused by vertical loads following displacement. They can be neglected in the case of buildings if the following condition is satisfied at all levels

$$\theta(k)=\frac{k)\times\Delta(k}{(k)\times(h)}) \leq 0.10$$

P(k) : the weight of the structure and the associated operating loads above level k

P(k) = $\sum_{i=k}^{n}(WGi + \beta Wqi)$

V(k): shear force at the floor level "k".

$\Delta(k)$: the relative displacement of level k with respect to level k−1.

$h(k)$: height of floor k.

β : Weighting factor, (β = 0,2) For a residential building.

Si : 0.1 <Θk<0.2 The $P-\Delta$ effects can be taken into account approximately by amplifying the seismic effects calculated using a first-order elastic analysis by a factor of 1/(1− Θk).

If: Θ(k)> 0.2, the structure is potentially unstable and must be redesigned.

Table 2.32: *Verification of the P-delta effect for interstage (x-x direction)*

Sens X-X						
Levels	**h_k (m)**	**P_k (kn)**	**V_k (kn)**	**Δ_k (m)-x**	**θ**	**Observation**
Story5	3,06	084,954	498,9380	0,00411	0,01370	Condition verified
Story4	3,06	11 060,833	968,0230	0,00561	0,02096	Condition verified
Story3	3,06	17 036,712	1 319,8370	0,00686	0,02893	Condition verified
Story2	3,06	23 012,591	1 554,3800	0,00686	0,03318	Condition verified
Story1	3,06	29 016,026	1 672,1920	0,00429	0,02430	Condition verified

Table 2.33: *Verification of the P-delta effect for interstage (direction -y-y)*

Sens Y-Y						
Levels	h_k (m)	P_k (kn)	V_k (kn)	Δ_k (m)-x	θ	Observation
Story5	3,06	5 084,954	475,3890	0,00518	0,01809	Condition verified
Story4	3,06	11 060,833	922,3340	0,00617	0,02416	Condition verified
Story3	3,06	17 036,712	1 257,5430	0,00693	0,03068	Condition verified
Story2	3,06	23 012,591	1 481,0150	0,00649	0,03295	Condition verified
Story1	3,06	29 016,026	1 593,2660	0,00359	0,02137	Condition verified

Note: From the two tables, it can be seen that the condition $\theta(k) \leq 0.10$ is satisfied; therefore, the P_Δ effects can be neglected.

2.8. Analysis of Structural Elements:

Our structure is a three-dimensional assembly of columns, beams and walls, firmly connected and capable of absorbing all vertical and horizontal forces (self-supporting structure). When determining the reinforcement in accordance with the CBA93, BAEL91 and RPA2024 standards, the worst-case scenario is taken into account. We have used structural analysis software (ETABS), a computer tool that enables the determination of the various internal forces in each section of the structural elements for various design combinations. The beams will be subjected to a simple bending analysis. A composite bending analysis will be carried out for the columns and walls Cost structures:

- ✓ BAEL 91 Regulation: These are structures that take into account only fixed costs (G) and operating costs.

- 1.35G + 1.5Q at the E.L.U

- G + Q at the E.L.S

- ✓ RPA Regulation 2024:

These are combinations that take seismic loads into account.

- G+0.2Q ± 0.3Ex± Ey at the E.L.A

- G+0.2Q ± Ex± 0.3Ey

-G: fixed costs.

Q: unweighted operating costs.

: seismic action described by its horizontal components.

2.8.1. Column Analysis:

Columns are vertical elements that transfer the loads generated by the beams to the foundations. The calculation of column reinforcement is based on the axial force (N) and the bending moment (M).

- ✓ Stress results provided by ETABS:
- ✓ The table below summarises the results for internal forces and maximum moments based on the conditions previously provided by the ETABS software:

Table2.34: *Maximum accidental loads*

Floor	N max(KN)	Mcorres(KN)	M max(KN)	N corres(KN)	M min (KN)	Ncorees(KN)
Colomun	814.104	20.92	37.648	747.918	29.465	462.908

Table2.35: *Maximum loads at the ELU*

Floor	N max(KN)	M corres(KN)	M max(KN)	N corres(KN)	M min (KN)	N corees(KN)
Colomun	1124.127	4.790	9.51	1106.181	7.39	583.633

Table2.36: *Maximum loads at the ELS*

Floor	N max(KN)	M orres(KN)	M max(KN)	N orres(KN)	M min (KN)	N orees(KN)
Colomun	821.106	3.51	6.98	427.133	5.4	427.136

- **Reinforcement Calculation :**

- Longitudinal reinforcement:

According to RPA2024, longitudinal reinforcement must be straight, high-strength and free of hooks. The proportion located in seismic zone I is limited by:

A $_{min} = \frac{As}{b \times h} < 0.9\%$ zone III

A $_{max} = \frac{As}{b \times h} < 4\%$ current zone

A $_{max} = \frac{As}{b \times h} < 8\%$ Nodale zone

The minimum permitted diameter is 12 mm.

In Zone III, the minimum lap length is 50 L.

- **Calculation Of The Reinforcement:**

We will use a column on the ground floor as an example for our calculation, as it is subject to greater stress. The reinforcement is designed for combined bending, given that the column is subjected to an axial force N and a bending moment M.

b=0.4 m, h=0.40 m; µR=0.379 d=0.36 m, d'=0.04 m fc28=25 MPa; fe=400 MPa; fbc=14.1 6MPa ;=347,82 MPa. γS= 1,15 ; γb= 1,5

ELA:

N_U= 1.124 MN

M_U= 0,00479 $MN.m$

- **Calculation of Eccentricity:**

$e = \frac{Mu}{Nu} = \frac{0.00479}{1,124} = 4.26 \times 10^{-3}$ m

e= $4.26\times10^{-3} < \frac{h}{6} = 0.066$ m

$e_a = e+\frac{h}{2}-d' = = 0.164$ m

$M_a = N_u \times e_a = 1.124\times0.164 = 0.184$ m

Conditions check :

Nu $\times(d-d')-Ma$= 1.124×(0,36−0,04)−0,184= 0,176 → ***I***

(0.377-0.81× d' / d)b.d².f$_{bc}$ = (0.377- $\frac{0.04}{0.36}$ 0.81×)0.4×0.36²×17.71 = 0.263 → ***II***

In our case, the section is partially compressed with tension in the bottom reinforcement, as shown below:

I<***II*** →

$\mu\mu = Ma \,/\, b\times d^2\times fbc$= 0.250

μ_u= 0, 250 ≤ μ_R=0.379 (FeE 400) → **CV**

So ($\boldsymbol{A2}$=). The section is simply reinforced

$\alpha = 1.25 \times (1 - \sqrt{1 - 2\mu}\,)$ ⇒

α= 0,366 m

z = d (1 − 0,4α)= 0,36(1 − 0,4 × 0,366)=0,307 m.

$\sigma st = fe/\gamma s$ = 400/1.15=347,82 MPa.

$$A1 \geq \left(\frac{Ma^2}{Z} - NU\right) \times \frac{1}{\sigma st}$$

$$A1 \geq \left(\frac{0.184}{0.307} - 1.124\right) \times \frac{1}{347{,}82} = -15.08\ cm$$

The column reinforcement is negative, so we will use the minimum specified in RPA2024

The minimum cross-sectional area is 0.7% of the total cross-sectional area:

$Amin$=0.9%×b×h=14.4cm^2

$Aadopt\acute{e}e$ = 8T16=16.08cm² >$Amin$ →$\boldsymbol{CV}$

➢ The maximum cross-sectional area:

The maximum cross-sectional area is 4% in the main zone and 6% in the overlap zone.

$Amax$=4%×b×h=64 cm^2

$Amax$=8%×b×h=128 $cm2$

$Aadoptée$ = 15.14 <$Amax$ →$\boldsymbol{CV}$

According to BAEL91 rules:

➢ The minimum cross-sectional area:

$Amin$=0.2%×b×h= 3.2 $cm2$

$Aadoptée$ = 16.08 >A_{smin} →$\boldsymbol{CV}$

- **Condition of non-fragility :**

A_{min}=0,023×f_{c28}×b×d/f_e = 2.07 cm^2 A_s >A_{min} →$\boldsymbol{CV}$

Serviceability Limit State (SLS) verification:

Eccentricity calculation:

$e=\frac{Ms}{Ns}=\frac{3.51}{821.106}= 4.27\times10^{-3}$ m

❖ Position of the neutral axis:

$P=-3(e-\frac{h}{2})^2+\frac{6\,n\,A2}{b}(e-\frac{h}{2}+d')+\frac{6\,n\,A1}{b}(e-\frac{h}{2}+d)=-0.128$ m

$q=2(e-\frac{h}{2})^3+\frac{6\,n\,A2}{b}(e-\frac{h}{2}+d')^2-\frac{6\,n\,A1}{b}(e-\frac{h}{2}+d)^2=-0.015$ m

Si $e_1 = 0.5$

$e^1=\sqrt[3]{-P\,e1-q}= 0.407$m

$x=\frac{h}{2}+e_1-e = 0.6$ m

$S=\frac{b\times x^2}{2}+n\,A_2\,(x-d')-nA_1(d-x)=0.077\ m^2$

❖ Calculation of stress in concrete:

$\sigma_{bc} = \frac{Ns \times x}{s}$

$\sigma_{bc} = \frac{0.8211 \times 0.6}{0.077} = 6.39$ MPa

$\overline{\overline{\sigma_{bc}}} = 0.6 f_{c28} = 15 MPa$

$\sigma_{bc} \leq \overline{\overline{\sigma_{bc}}} \rightarrow$ **CV**

$\sigma st = \frac{n\ Ns(d-x)}{s} = \frac{15 \times 0,8211 \times (0,36-0,6)}{0,077} = 38,39$ MPA

$\sigma_{st} = 38.39\ MPa \leq \overline{\overline{\sigma_{st}}} = 201,63\ MPa \rightarrow$ CV

Transverse reinforcement:

❖ Specific verification under tangential stresses u :

Verification in accordance with RPA 2024:

$\tau bu \leq \overline{\overline{\tau bu}}$

Where: τbu = v/b× d

: Shear force in the section under consideration

: The width of the section under consideration

: The effective height

lf = 0.7 × L0 = 0.7 × 2.86 = 2.002 m

$\Lambda g = lf\ ou\ lf$: Geometric slenderness

$a\ b$

ρd=0.075 S:λ ≥5

ρd=0.04 S: λ ≤5

Table 2.37: *Specific verification under normal stresses*

Level	V(MN)	λg	ρ_d	**τbu**	**$\overline{\overline{\tau bu}}$**	Note
Road surfaces	0.02298	5.005	0.075	0..159	1.875	CV

Selection of transverse reinforcement :

According to RPA 2024, the transverse reinforcement for columns is calculated using the formula:

$$\frac{At}{t} \times \frac{\rho a \times vu}{h1 \times fe}$$

Where:

V: This is the maximum design shear force.

$h1$: Total height of the gross cross-section.

f: 400 MPa.

ρa : Correction factor that takes into account brittle failure under shear :

ρa=2.50 S: λg≥5

ρa=3.75 S: λg≤5 t: spacing of transverse reinforcement

Node area:

$$\begin{cases} t \leq Min(10.\phi_l; 12.5\text{ cm}) : \text{en zones I, II et III} \\ t \leq min(b_0/3, 10\text{cm}, 60\phi_l) : \text{en zones IV, V et VI} \end{cases}$$

→ t ≤ min(10×1.6 ;12.5) =12.5 cm

we take

t=0.10 cm

With Distribution L= 2 h = 80 cm

Current Zone:

$$\begin{cases} t' \leq 15\phi_l : \text{en zones I, II et III} \\ t' \leq Min(b_1/2; h_1/2; 10\phi_l) : \text{en zones IV, V et VI} \end{cases}$$

→ t’ ≤ 15x1.6=24 cm we

take t’=20 cm

Distribution according to RPA: (Zone III):

Nodal Zone: T' ≤ min(h/4, 12 ΦLmin, 30 cm) and L = 2h

Standard Zone: S ≤ h/2

• Verification of transverse reinforcement according to

RPA 2024:

The minimum amount of transverse reinforcement $At/t{\times}b$ in % is given as follows:

S : $\lambda g \geq 5 \rightarrow At\ /t{\times}b$=0.3%

S : $\lambda g \leq 5 \rightarrow At/t{\times}b$=0.8%

S :$3 \leq \lambda g \leq 5$ → Interpolation

Table2.38: *Transverse reinforcement in columns*

Level	h(cm)	Vu(MN)	l_f (cm)	λ_g (cm)	ρa	A_t (cm^2)	A_{tmin} (cm^2)	choix
RDC	40	0.02298	200.2	5.005	2.5	0.449	1.5	2T8

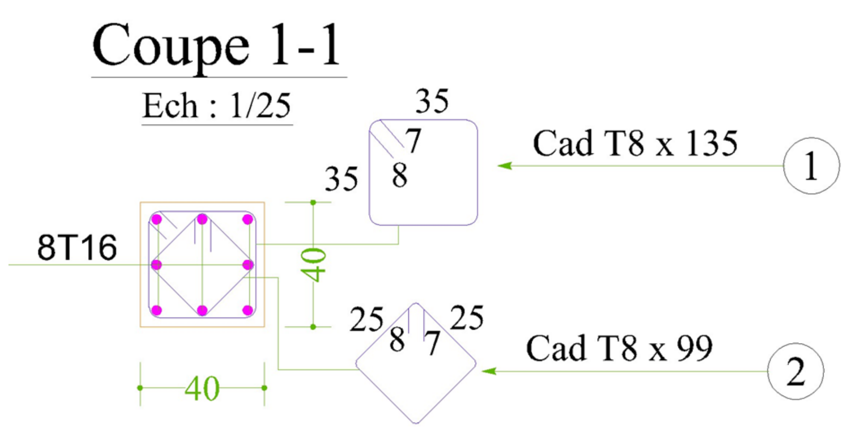


Figure.2.19: *Cross-Section Of a Reinforced Concrete Column (Personal work (based on design codes)*

2.8.2. Beam analysis:

The beams in question are subjected to bending moments and shear forces. For the sake of simplicity, normal forces will not be taken into account, and the analysis will therefore focus on simple bending. In accordance with the appendices on load combinations, we will consider the maximum moments at the spans and supports. We will determine the reinforcement cross-section according to the ELU, then carry out the required verification under the ELS. Load combinations:

➢ BAEL 91 Code:

These are combinations that take into account only permanent loads $\boldsymbol{G}$ and service loads $\boldsymbol{Q}$.

- $1.35G + 1.5Q$ at the U.L.E.
- $G + Q$ at the S.L.S.

RPA 2024 Regulations:

These are combinations that incorporate seismic loads E.

- $G+0.2Q \pm 0.3Ex \pm Ey$ at the ultimate limit state
- $G+0.2Q \pm Ex \pm 0.3Ey$

Where:

G : dead loads.

Q: unweighted service loads.

E: seismic action described by its horizontal components.

Maximum stresses in main and secondary beams:

Table2.39: *Maximum stresses in secondary beams*

	ELU		ELS		ELA		
Section	M(Support) $(KN.m)$	(Span) $(KN.m)$	M(Support) $(KN.m)$	M(Span) $(KN.m)$	M(Span)) $(KN.m)$	M(Span) $(KN.m)$	V
30*35	37.508	34.236	27.309	24.874	81.1602	43.474	68.169

Secondary beam reinforcement : Longitudinal reinforcement :

ELA :

• Span :

b=0,30 m, h=0,35m ; μR=0.379,=0,315 m, d'=0,035 ,
$fc28$=25MPa ;fe=400 MPa ;fbc=14,16 MPA ,σst=347,82
MPa. (γb = 1,5) ; (γs = 1,15).

$(_{\text{Span}})$ = 43.474 $KN.m$

$u_u = \frac{Mu\ max}{b \times d^{2\times} fbc}$= 0,103

μ_u= 0,103≤ μ_R=0.379 (FeE 400) → **CV**

Therefore, compression reinforcement is not required (Asc=0). The section is simply reinforced.

α = 1,25 (1 −√1−2μ_u) → α = 1,25 ×(1 − √1−2×0,103)=0,136

$Z = d$ (1 − 0,4)= 0,315×(1 − 0,4 × 0,103)=0,302 m

$\sigma st = fe/\gamma s$ = 400/1,15=347,82 MPa.

$Ast \geq \frac{MU}{z \times \sigma st}$ → $_{st}$≥ 0,043474/0,302×347,82 =4,13 cm^2

Ast =4.13 cm^2

$Amin$=0,5%×b×h=5.25 cm^2

We'll take :3T12+2T12=3.39+2.26=5.65 $\boldsymbol{cm}^2$

- Condition of non-fragility :

Ast≥0.23×b×d ft28/fe

Ast≥0.23×0,30×0,315×2.1/400

Ast≥1.14 cm² CV

• On your feet:

b=0,30 m, h=0,35m ; μ_R=0.379 d=0,315 m, d'=0,035 m

f_c28=25 MPa ;=400 MPa ; $_{bc}$=14,16MPA

σ_{st}=347,82 MPa. (γb = 1,5) ; (γs = 1,15)

(Support) = 81.1602 $KN.m$

μu $=\frac{Mu\ max}{b\times d^2\times fbc}$= 0,147≤ μ_R=0.379

(FeE 400) → **CV**

Therefore, compression reinforcement is not required (Asc=0). The section is simply reinforced.

α = 1,25 (1 −$\sqrt{1-2\mu u}$) → α = 1,25 (1 − $\sqrt{1-2\times 0{,}147}$)=0,199

Z = d (1 − 0,4)= 0,315×(1 − 0,4 × 0,199)=0.290 m

σst =$fe/\gamma s$ = 400/1,15=347,82 MPa.

$Ast\geq\frac{MU}{z\times\sigma st}$ → $A_{st}\geq$ $\frac{0{,}0811602}{0{,}290\times 347{,}82}$ =8.04cm^2

Ast =8.04 cm^2

We have: 3T12+3T14=9.55 $\boldsymbol{cm}^2$

- Non-fragility condition :

Ast≥0.23×b×d ×ft28/fe

Ast≥0.23×0,30×0,315×2.1/400

Ast≥1.14 cm² CV

➢ RPA2024 condition:

$Amin$=0.5%×b×h=5.25 cm^2

$Aadopt$é($trav$ée) =8.04 cm^2 >$As\ min$ →$\boldsymbol{CV}$

$Aadopt$é($appui$)=8.04 cm^2 >$As\ min$ →$\boldsymbol{CV}$

❖ SLS:

• Span:

$$X=n\times \frac{(Ast+Asc)}{b}\left(\sqrt{1+\frac{2b(d\times Ast+d'\times Asc)}{n(Ast+Asc)^2}}-1\right)$$

$$X=15\times \frac{(8.01)}{30}\left(\sqrt{1+\frac{2\times30\times(31.5\times8.01)}{15(8.01)^2}}-1\right)=12.37\ cm$$

$$I=\frac{b\times x^3}{3}+\times\ Ast\times(x-d')2+n\times ASt\times(d-x)^2$$

$$I=\frac{30\times12.37\text{^}3}{3}+15\times8.01\times(31.5-12.37)^2=6.28.10^{-4}m^4$$

- Maximum stress in steel:

$$\sigma_{bc}=\frac{nM_s\times(d-x)}{I}=\frac{15\times0.024874\times(0.315-0.1237)}{6.28\times10\text{^}-4}=113.655\ MPa$$

σ_{st}=113.655 $MPa \leq \overline{\overline{\sigma_{st}}}$=201,63 MPa → CV

• Support :

- Neutral axis position

$b \times x^2/2+(x-d') - nA_{St}(d-x)$ avec n=15

$\frac{30 \times x}{2} - 15 \times 8.04(31.5-x)$

$15x^2 - 120{,}6\ (31.5 - x) = 0$

$15x^2 + 120.6x - 3798.9 = 0$

$\sqrt{\Delta}$= 492.420

x = 12.394 cm

- Moment of inertia of the cross-section:

I=$b \times x^3/3+(x-d')2+ nASt(d-x)^2$

I=$\frac{30 \times 12.39^3}{3}$+ 15×8.04(31.5−12.39)^2

I=63062.316 cm4

- **Maximum stress in concrete :**

σ_{bc}=0.0273089 ×0.1239 = 5.365 Mpa

0.00063062316

$\overline{\overline{\sigma_{bc}}}$ = 0.6f_c28 =15MPa

$\sigma bc \leq \overline{\overline{\sigma bc}}$ → **CV.**

A-Maximum stress in steel :

σst = $= \frac{nM_s \times (d-x)}{I} = \frac{15 \times 0.024874 \times (0.315-0.1239)}{0.00063062316}$ =124.133 MPa

σst=124.133 $MPa \leq \overline{\overline{\sigma st}}$=201.63 MPa → CV

• Maximum section (RPA): (Art. 7.5.2.1 RPA 2024)

$Amax$=4%×b×h = 42 cm2 → the current area

$Amax$=6%×b×h = 63 cm^2 → the overlap area.

Transverse Reinforcement • Calculation of øt:

The diameter of the transverse reinforcement for the main beams is given by

$ø_t$=8 mm

• Spacing calculation: (in accordance with RPA V2024) ✓ the nodal zone

$St \leq \min(\frac{h}{4},; 12 \times ø l_{min};30cm) \rightarrow St \leq \min(\frac{35}{4},; 12\times1,2;30cm)$

St =8 cm. SI L=2h =0.70 m

The Nodal Zone:

$St' \leq \frac{h}{2}$

St'=15 cm

Shear verification:

$\tau u \leq \overline{\overline{\tau u}}$

Avec : $\tau_u = \frac{TU}{b \times d}$

$\tau_u = \min(0,2 \times Fc28/\gamma b;5MPa)$=min(3,33 ;$5MPa$)

$\tau_u = \frac{0.1569}{0.30 \times 0315}$ = 1.67 MPa

τ_u=1.67 $MPa \leq \overline{\overline{\tau_u}}$=3 ,33 MPa

Summary table of options:

Table2.40: *Reinforcement of secondary beams*

Secondary beams	Longitudinal reinforcement					Cross-bracing		
	A min (cm^2)	Span		Supports		ø(mm)	S(cm)	S'(cm)
		Acalculate	Choice	Acalculate	Choice			
	5.25	3.6	5.65	7	8.01	ø8	8	15

➢ Overlap length: According to RPA2024: The minimum overlap length is 50ø (in Zone III).

ø = 1.2 cm → L_r = 1.2 × 50 = 60

We adopt Lr=60 cm

ø=1.6 cm→Lr=1.6×50=80

Lr=80 cm

We adopt Lr=80 cm

➢ The anchorage length: According to (C.B.A.93)

Ls = fe ø

s'×4

Where: τs'= 0.6(Ψ)²× ftj with anchorage coefficient: Ψ = 1.5 Steel HA

Adhesion stress: $\tau s'$ = 0.6 × (1.5)² × 2.1 = 2.835 MPa Length of straight anchorage: Ls = fe ø

s'×4

a curve equal to: r = 5.5 × ø ($Acier\ HA$)

Where Ø: Rebar diameter.

The anchorage length: L ≥ 2 + + ø/2

Where: $L2$= −(× 1)−(×) $L1$ =10ø

The curve's anchorage (θ = 90°) → (α = 1.87); (β = 2.19)

($L1$; $L2$): Straight lengths. (Fe = 400 MPa); ($f\ t28$ = 2.1 MPa)

Summary Table of *Reinforcement:*

Table2.42: *Reinforcement of secondary beams*

Level	**Section(cm^2)**	**Reinforcement longitudinal**		**Reinforcement transversal**		
		Support	**Span**	**ø*t*(mm)**	**S(cm)**	**S'(cm)**
		Ast chosen	*A*st chosen			
All	**30*35**	**3T12+2T12**	**3T12+3T14**	**ø8**	**8**	**15**

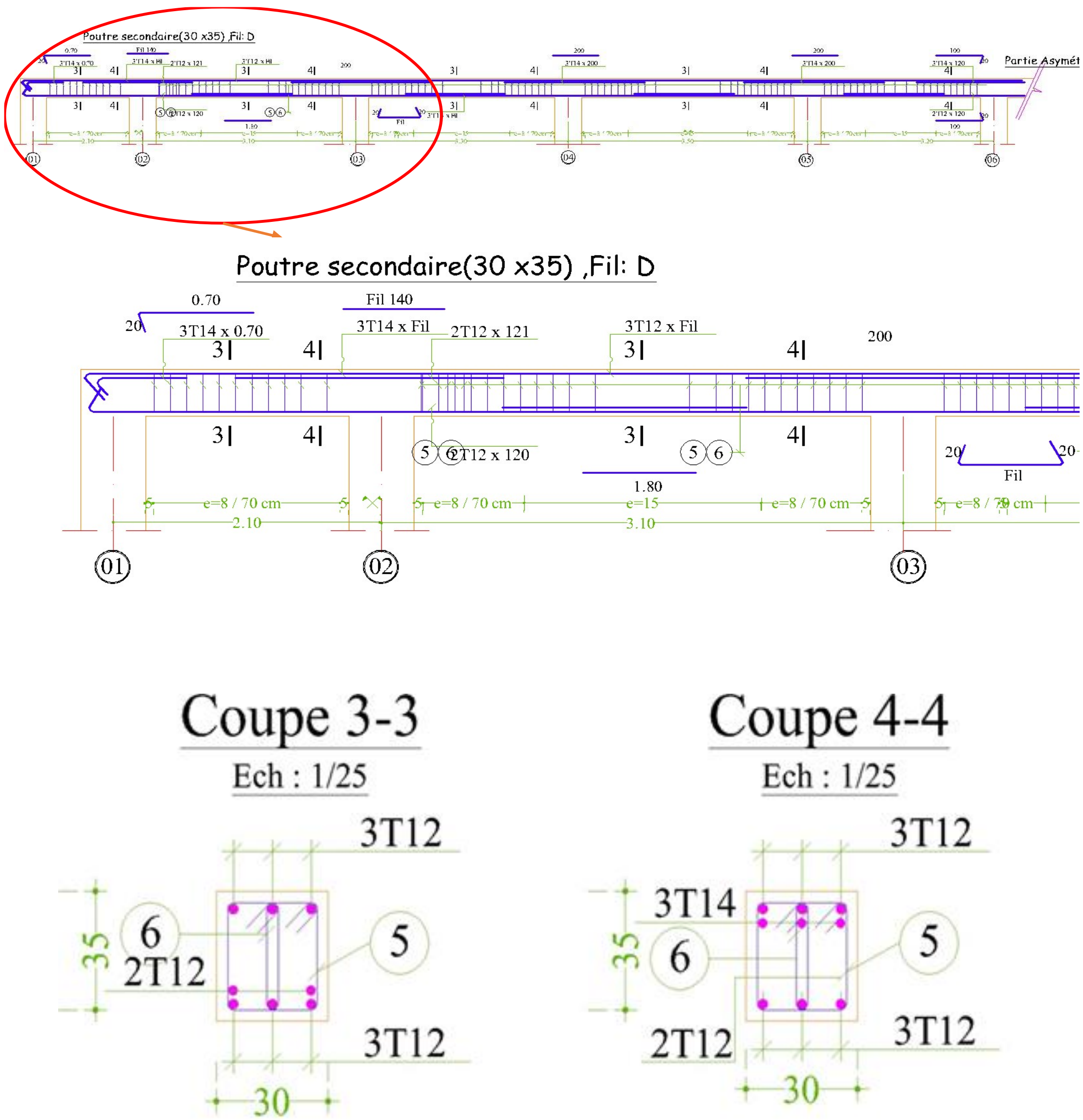


Figure.2.20: *Reinforcement Details Of The Secondary Beam (30.35) ((Personal work (based on Design Codes))*

2.8.3. Reinforcement Drawings for the Secondary Beam:

-Reinforcement calculation:

-Main beam reinforcement:

Tableau2.43: *Design Internal Forces for The Main Beam Under Different Limit States (ULS, SLS, ALS)*

	ELU			ELS			ELA		
Section	M support $(KN.m)$	M Span $(KN.m)$	V_u(kn)	M Span $(KN.$ m)	M support $(KN.m)$	V (KN)	M support $(KN.m)$	(Span) $(KN.m)$	V (KN)
(30 x 40)	-62.528	34.962	-95.314	-45.777	25.4822	69.451	**-108.996**	**66.501**	**157.9**

Longitudinal reinforcement:

❖ ULS:

• Support:

b = 0,30 m, h = 0,45 m ; μ_R=0.379

d = 0,405 m, d' = 0,045 m

$fc28$=25 MPa ;=400 MPa ;c=16,14 MPA

σ_{st}=347,82Pa ;(γb = 1,15) ; (γs = 1.5).

M_u $(travée)$ = 108.996 KN.m

$\mu_u=\frac{Mu\ max}{b\times d^{2\times} fbc}$

0, 156<μr =0.379   So, simple fittings

α=1,25 (1$-\sqrt{1-2\times uu}$)=0,213

z= d (1-0,4α) =0.340m

Ast= $\frac{Mu}{z\times\sigma st}$

Ast=8.014 $\boldsymbol{cm}^2$

Amin= (0,5÷100)×30×45=6,75cm^2

Ast= 6.75 cm² we take

Ast 3T16+3T12=6.03+3.39= 9.42 cm²

Amax= (4÷100) ×30×45=54 cm²

Amin=6.75<9.42+3,39=12.81<Amax=54 = Condition to check

ELS: Support

n=15 ASC=0 simple frames

$$x = n\frac{(A_{ST+A_{SC}})}{b}\left(\sqrt{1+\frac{2b(d \times A_{ST} + d' \times A_{SC})}{n(A_{ST}+A_{SC})^2}} - 1\right)$$

$$x = 15\frac{(9.42)}{30}\left(\sqrt{1+\frac{2 \times 30(40.5 \times 9.42)}{15(9.42)^2}} - 1\right) = 15.382 \text{ cm}$$

$I = \frac{b \times x^3}{3} + \times Ast \times (x - d')2 + n \times ASt \times (d-x)^2$

I=$\frac{30 \times 15.382^3}{3}$+15×9.42× (40.5-15.382)^2 = 1.26.10^{-3}m^4

-$\boldsymbol{\sigma}BC = \frac{Ms \times x}{I} = \frac{45.777 \times 10^{\wedge}-3 \times 0.15382}{1.26 \times 10^{\wedge}-3}$

- σBC =5.58 Mpa

$\underline{\sigma_{BC}}$=0,6×fc28=0,6×25=15MPA

σ_{BC}=5.58 <$\underline{\sigma_{BC}}$=15 condition vérifier

σ_{st}=136.884 MPA

$\underline{\sigma_{st}}$(adm)=min($\frac{2}{3}fe$; $110\sqrt{\eta}ft28$)

f_{t28}=0,,06×fc28+0,6=0,06×25+0,6=2,1MPA

σ_{st0}=min($\frac{2}{3}$ ×400;110$\sqrt{1{,}6 \times 2{,}1}$)

$\underline{\sigma_{st}}$(adm)==min(266,67;201,63)

$\underline{\sigma_{st}}$(adm)==201,63MPA

σ_{st}=136.884 < $\underline{\sigma st}$(adm)==201,63 Condition to check

• **Across the span :** b = 0,30 m, h = 0,45 m ; μ_R=0.379

d = 0,405 m, d' = 0,045 m

fc_{28}=25 MPa ;=400 MPa ;c=18,47 MPA

σ_{st}=400 MPa ;(γb = 1,15) ; (γs = 1.0).

M_u (travée) = 66.501 KN.m Cracking is harmful

d=0,9×0,45=0.405m

μ_u=0,0731<μr =0.379

α=1,25(1-$\sqrt{1-2\times \mu u}$)=0.0949

z= d (1-0,4α) =0.389m

ASC=0cm^2 we take ASC 3T12= 3,39cm^2

Ast=4.274 **cm²**

Amin= (0,5÷100)×30×45=6,75cm^2

Ast= 6.75 cm² WE take AST 3T14+3T12=4,62+3,39= 8,01 cm^2

Amax= (4÷100)×30×45=54 cm²

Amin=6.75<8,01+3,39<Amax=54 = c v

ELS:

n=15 ASC=0 simple frames

$$X=n\times\frac{(Ast+Asc)}{b}\left(\sqrt{1+\frac{2b(d\times Ast+d'\times Asc)}{n(Ast+Asc)^2}}-1\right)$$

$$X=15\times\frac{(8.01)}{30}\left(\sqrt{1+\frac{2\times30\times(40.5\times8.01)}{15(8.01)^2}}-1\right)=14.446\text{ cm}$$

$$I=\frac{b\times x^3}{3}+\times Ast\times(x-d')2+n\times ASt\times(d-x)^2$$

$$I=\frac{30\times14.446\hat{}3}{3}+15\times8.01\times(40.5-14.446)^2=1.12.10^{-3}m^4$$

-$\boldsymbol{\sigma}BC=MS.x=25.4822\times10\hat{}-3\times0.14446$

- σBC =3.286 Mpa

$\underline{\sigma_{BC}}$=0,6×fc28=0,6×25=15MPA

σ_{BC}=3.286 <$\underline{\sigma_{BC}}$=15 condition vérifier

σ_{st}=88.92 MPA

$\underline{\sigma_{st}}(adm)=\min(\frac{2}{3}fe;\,110\sqrt{ἠ}ft28)$

f_{t28}=0,,06×fc28+0,6=0,06×25+0,6=2,1MPA

$\sigma_{st0}=\min(\frac{2}{3}\times400;110\sqrt{1,6\times2,1})$

$\underline{\sigma_{st}}$(adm)=min(266,67;201,63)

$\underline{\sigma_{st}}$(adm)=201,63MPA

σ_{st}=88.92 < $\underline{\sigma st}$(adm)=201,63 **c v** b- Transverse reinforcement:

❖ Tangential stresses:

$\tau_u = \frac{TU}{b \times d}$

TU=157.9 kn

Justification for concrete:

α=90°

Tl=min [0.15×fc28/γb, 4 MPa] if cracking is detrimental or highly detrimental

T_l=min [0,15×25/1,15; 4MPA]

T_l=min [3.26;4MPA]

T_l=3.26MPA

Tu=1.3<TL=3.26 **c v**

$$\mathbf{St} \leq \frac{\boldsymbol{At \times 0.9 \times \frac{fet}{\gamma s}(sin\alpha + COS\alpha)}}{\boldsymbol{b(\tau_u - 0.3\ k\ ftj')}}$$

ft_{28}=min (ft_{28};3,3MPA) avec ft_{28}=2,1MPA K=1 for simple bending without a concrete joint

θt=Min (h/35;b_0/10; θ_{lmin}) ⇔ θt ≤min (1.29; 3; 1.2)

θt = 0.8 cm on prend θt =8mm

At= 2Ø8= 1.01 cm²

$$\mathbf{St} \leq \frac{\mathbf{1.01 \times 10^{-4} \times 0.9 \times \frac{235}{1.15}}}{\mathbf{0.3(1.3 - 0.3 \times 2.1)}}$$

St≤0.09 m

STmin≥7cm we take St=10cm

Stmax≤min(0,9d;40cm)

Stmax≤min(0,9×18,9;40)

Stmax≤min(17,01;40)

Stmax≤17,01cm we take stmax=17cm

$\frac{At \times fe}{b \times st} \geq$ max((Tu/2);0,4MPA)

$\frac{1.01 \times 10^{-4} \times 235}{0.3 \times 0.10} \geq$ max(0.65;0.4MPA)

0.79≥max(0.65;0.4) **c v**

0.791 ≥ 0,5 c v

❖ Frame spacing Repair in accordance with RPA (Zone III):

Nodal zone:

S'≤(h/4;12ØLmin;30cm) and L=2h = 2×21= 42cm

S'≤(21/4;12×1,2;30)

S' ≤5,25cm **we take S'= 5cm Current Zone**

S ≤ h/2 ↔ S≤21/2

S≤10,5cm **we take s=10cm,** with the first frame positioned 5 cm from the sill

➢ Overlap length: According to RPA2024: The minimum overlap length is 50ø (in zone III).

ø = 1.2 cm → L = 1.2 × 50 = 60

We therefore adopt L = 60 cm

ø=1,6 cm→L_r=1,6×50=80

L_r=80 cm

E ➢ Anchorage length: According to (C.B.A.93)

Ls = fe ø

s'×4

Where: τs'= 0.6(Ψ)²× ftj with anchorage coefficient: Ψ = 1.5 steel HA

Adhesion stress: $\tau s'$ = 0.6 × (1.5)² × 2.1 = 2.835 MPa Length of straight anchorage: Ls = fe ø

s'×4

a curve equal to: r = 5.5 × ø (steel HA)

Let L = 80 cm

Where Ø: Rebar diameter.

The embedment length: L ≥ 2 + + ø/2

Where: $L^2 = Ls-(\alpha \times L1)-(\beta \times r)$

$L1$ =10ø

The anchor point of the curve (θ = 90°) → (α = 1,87) ; (β = 2,19)

($L1$; $L2$) : Straight lengths

(Fe = 400 MPa) ; (f $t28$ = 2,1 MPa)

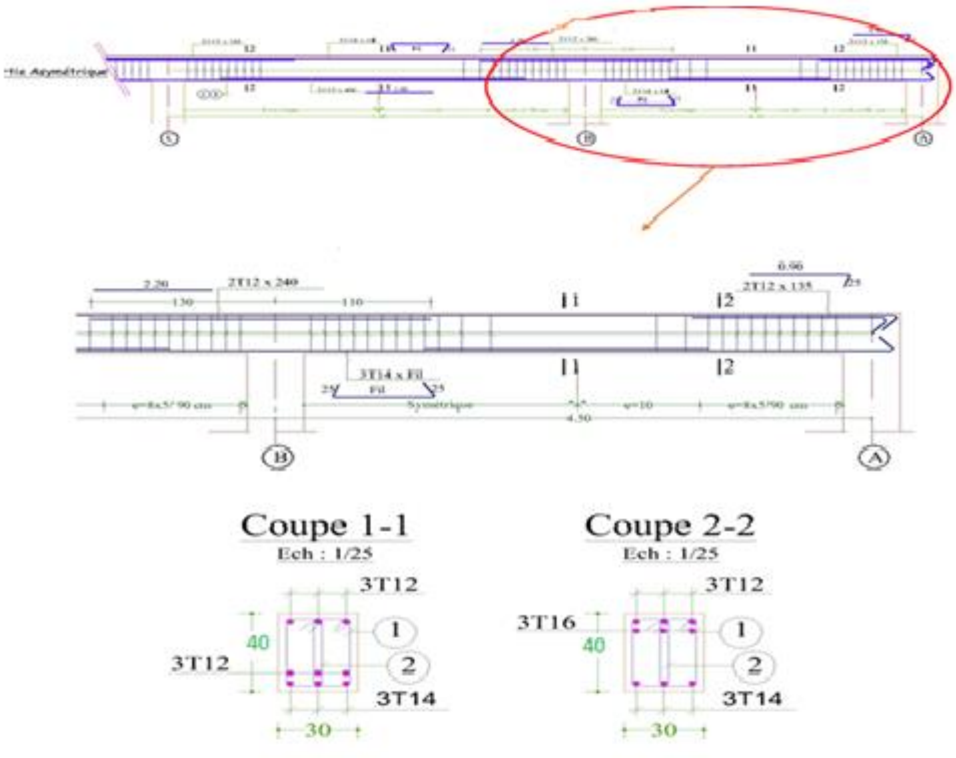


***Figure2.21**: Reinforcement Details Of The Pricipale Beam(30.40) ((Personal work (based on Design Codes))*

2.9. Analysis of Shear walls:

A shear wall is a structural element that ensures the stability of the structure against horizontal loads, primarily wind and seismic forces, and transfers vertical loads to the foundations. The walls will be assessed for composite bending due to the stresses acting upon them, with the bending moment and normal force being determined based on the combination of permanent, operational and seismic loads. The wall reinforcement will be carried out in accordance with the BAEL 91 code, whilst checks will be performed in accordance with the Algerian seismic code RPA 2024. In conjunction with this, the loads:

➢ BAEL 91 code:

These are combinations that consider only dead loads $\boldsymbol{G}$ and operational loads $\boldsymbol{Q}$.

- 1.35 G + 1.5Q at the Ultimate Limit State (ULS)

- G + Q at the Serviceability Limit State (SLS)

RPA 2024 Regulations:

These are combinations that take seismic loads E into account.

- G+0.2Q ± 0.3Ex± Ey at the UFL

- G+0.2Q ± Ex± 0.3Ey

Where:

: permanent loads.

: unweighted service loads.

: seismic action represented by its horizontal components

Vertical reinforcement:

The calculation will be carried out for vertical strips, the length of which is determined as follows:

lw ≥ max(he/3, 4bw, 1m) according to RPA 2024

lw: is the length of the wall. To determine the vertical reinforcement, the stress method will be used.

The calculation of piers (solid wall) is carried out for composite bending with shear force

b_w=0.2m ; l_w=2m ; $h_{trumeau}$=2.86m ; f_c28=25 MPa ;f_e=400 MPa ;f_{bc}=17.71 MPA ;σ_{st}=400 MPa. γ_S= 1 ; γ_b= 1,2 ; Nu=558.4KN ; Mu=1124.76KN.m ; V=315.37KN

e= $\frac{Mu}{Nu}$= $\frac{1124.76}{558.4}$= 2.01 m

G = 1 m

The centre of torsion lies outside the cross-section, so the cross-section is partially compressed

ea=e+(d-$Ltru$)

d=L-5-10/2=1.9 m

e_a=2.01+($1.9-\frac{2}{2}$) = 2.91 m

$M_a = N_u \times e_a$ = 0.5584×2.91 = 1.624 m

$\mu_\mu = \frac{Ma}{b \times d^2 \times fbc}$ = 0.127

μ_μ= 0, 127 ≤ μ_R=0.379 (FeE 400) → **CV**

so (**A_2=0).**

$\alpha = 1{,}25\ (1 - \sqrt{1 - 2\mu_\mu}\ )$

$\alpha = 1{,}25(1 - \sqrt{1 - 2 \times 0.127}\ ) = 0.170$

z = d (1 − 0,4)= 1.9(1 − 0,4 × 0,170)=1.77 m.

$\sigma st = fe/\gamma s$ = 400/1.15=347.826 MPa.

A1 ≥$\left(\frac{Ma^2}{Z} - Nu\right) \frac{1}{\sigma st}$

A1 ≥$\left(\frac{1.624}{1.77} - 0.5584\right) \times \frac{1}{347.826}$ =10.978 cm

adapted= 6T16=12.06cm²

• With Lrumeau = 200/10 = 20 cm

• Lc (current zone) = L - 20 × 2 = 160 cm For the current zone

Spacing:

$1.5bw = 30cm$ → S ≤ 25 cm → S = 20 cm

S ≤ min { 25 cm

• lc ≥ max(0.15lw;1.5bw) = 30 cm == CV

Lc = (2 × 10) + [n × 1.2 + (n – 1) × 20] n = 160 / 21.2 = 7.54

we take n = 8 bars

Therefore, the reinforcement adopted in the standard zone is 8 x 2 T12

(T12 is the regulatory minimum for longitudinal reinforcement)

• The thickness of the confined edge must satisfy the following condition:

=max (20, 2.80/20) = 20 cm ULS verification:

According to RPA 2024:

As ≥ 0.2% x Strumeau =Lt x bw=200 x 20=4000 cm²

As=4T20+2 x 8T12=30.62 cm²

Therefore, As = 30.62 ≥ 0.2 x Strumeau = 8 cm²

The choice is to check for ELS

Transverse reinforcement: According to RPA 2024:

$$\frac{Ah}{s} \geq \frac{V}{z.fe}$$

with:

• V: design shear force, V = 1.4Vu, calcul

• z: distance between the centres of gravity of the reinforcement at the two confined ends

$\overline{V}$=1.4 x 315.37=441.518 kN

z= hc-2c'= 2.86-2x10= 266 cm

At ≥ 0.25 bw.

So we set At = 2T10 = 1.57 cm² ²

$$As \leq \frac{At}{0.25\% \times Bw}$$

$$As \leq \frac{1.57 \times 10^{-4}}{0.25\% \times 0.20} = 0.314 \text{ m}$$

Verification according to RPA 2024:

• S ≤ 1.5bw=0.30 m

•S ≤ 25 cm

Therefore, we take S= 20 cm

Overlap: According to RPA 2024 / L=0.28 .Ø= 0.445 m =50 cm

Reinforcement layout for the wall:

- . Selection of foundation type:
- Checking the isolation pad

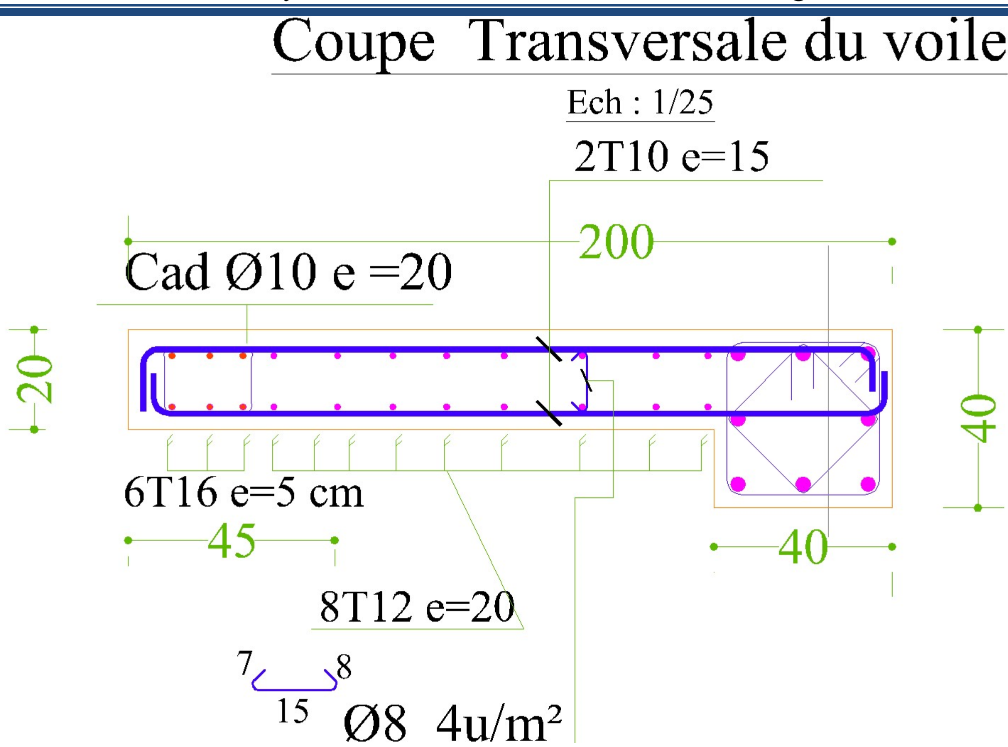


Figure2.22: *Reinforcement layout for walls (created using AutoCAD software)*

2.10. Foundation Study:

The infrastructure comprises components designed to ensure that loads and overloads from the superstructure are transferred to the ground. This transfer takes place either directly to the ground (shallow foundations: footings or raft foundations) or via other elements (as in the case of pile caps, for example). It is therefore a crucial aspect of the structure, ensuring its proper design and construction, and guaranteeing solid support and adequate load distribution.

- The various types of foundations.
- There are several types of foundations:

2.9.1. Shallow Reinforced Concrete Foundations:

Comprising isolated footings, cantilever footings and continuous footings, these structures transfer loads to a stable soil layer at a shallow depth ($D/B \leq 1.5$).

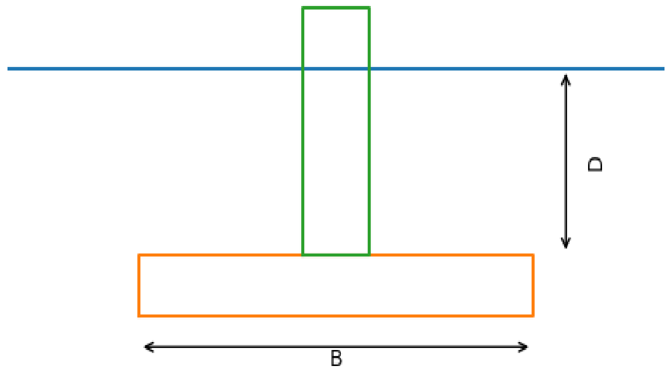


Figure 2.23: *Insulated sole (author)*

2.9.2. Deep and Semi-Deep Foundations:

These elements, comprising piles or strips that act as load-bearing diaphragm walls, behave in a similar way to cast-in-situ piles without casing. They transfer loads to a deep, load-bearing soil layer.

2.9.3. Reasons for Choosing the Type of Foundation:

The selection of the type of foundation depends on various factors, including:

- Soil properties.
- Nature of the structure.
- Load borne by the soil.
- Cost-effectiveness.

2.9.4. Design Calculations:

In accordance with the regulations, shallow foundations are designed based on the following load combinations:

- ❖ The dimensions of shallow foundations are determined based on the following load combinations, According to the BAEL:

- ✓ 1.35G+ 1.5Q
- ✓ G +Q

For foundations shared by multiple vertical elements (foundation beams, strip footings, raft foundations, etc.), the following load combination is used, according to the **RPA2024:**

- ✓ G+ψQ±1.4Ex
- ✓ G+ψQ±1.4Ey

- **G**: Dead load *(self-weight)*
- **Q**: Live load *(imposed load)*
- **ψ** : Combination factor
- **Ex, Ey**: Seismic force in the X and Y directions
- **1.4** : Seismic amplification factor

❖ All the results presented in the table were obtained from numerical modeling performed using ETABS software.

Table 2.44: Maximum Axial Design Loads (Normal Forces) at the Base

Normal Force (KN)	ULS	SLS
	2946,418	2742,711

This results according to combision ULS et SLS

❖ **Dimensioning of the Base:**

-for rectangular distribution:

$S_F \geq \frac{Ns}{\delta sol} = \frac{2742{,}711}{190}$=14,43 m^2

We have the total distance between aal the colomuns under the foundation is:

$$L = 19.40 + (0.5\ x\ 2) = 20.40\ m$$

So the width of the foundation can be obtained by:

$B = S_F/L = 14.43/20.40$ $so\ we\ can\ take\ B > 0.70\ m$ based on that results we can take the width of the foundation as B = 1.20 m

d$\geq \frac{B-b}{4}$

d≥ $\frac{1.20-0.4}{4} = 0.20\ m$ We Take **d= 0.30 m** → CV

H≥ $d + 0{,}05$ h≥ $0.35\ m$ $We\ \boldsymbol{Take}\ \ \boldsymbol{h = 35\ cm}$ → CV

❖ **Reinforcement of the Sole:**

$fe = 400MPa\ et\ \gamma s = 1.15$

✓ σst= $\frac{fe}{\gamma s} = \frac{400}{1{,}15} = 347\ MPa$

✓ $\overline{\sigma_{st}} = \min(\frac{2}{3}\ fe\ ; 110\sqrt{nft28}) = \min(266.66\ MPA\ ; 201{,}633\ Mpa)$

$$\rightarrow \overline{\sigma_{st}} = 201{,}633\ Mpa$$

❖ **A ULS:**

As=$\frac{Nu\ (B-b)}{8\times d\times \delta st} = \frac{2946{,}418(15-0.4)}{8\times 4\times 347} = 3{,}874\ m^2$ we Take 8T12 =6,03m^2

❖ **A SLS:**

As=$\frac{Ns\ (B-b)}{8\times d\times \cancel{\sigma st}} = \frac{2742{,}711(15-0.4)}{8\times 4\times 201{,}633} = 6{,}206\ m^2$ we Take 8T14=7,04m^2

- As=max (AsULS, AsSLS) = max (3,874 m^2; 6,206 m^2) = 6,206 m^2 **we Take 8T14**
- Ar =$\frac{AS}{4} \times B = \frac{7{,}04}{4} \times 15$ → Ar = 26,4 cm^2

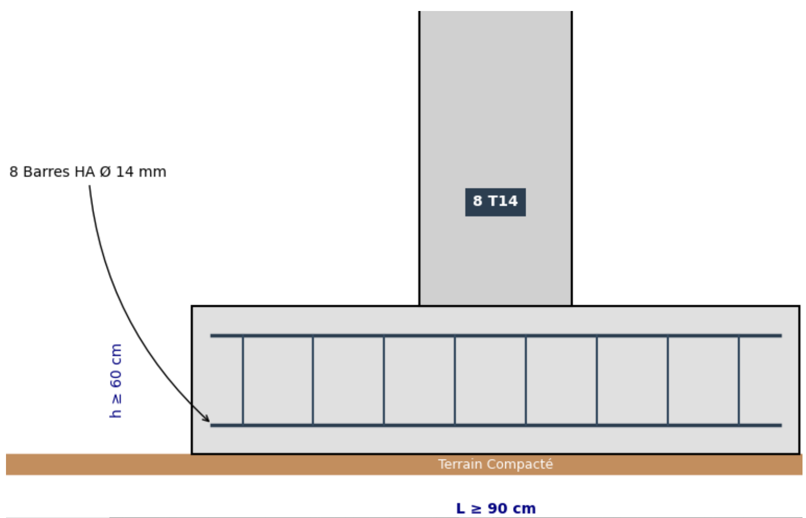


Figure 2.24: *Typical Reinforcement Diagram for a Shallow Foundation (author)*

The analysis of the infrastructure is a crucial stage in the design of a project. The choice of foundation is influenced by various factors relating to soil properties, as well as the structural dimensions. For our organisation, the chosen foundation is a strip footing.

In conclusion, this study of the four-storey building has highlighted the importance of preliminary sizing of structural elements and reinforcement in the design of a stable and robust structure. Preliminary sizing is an essential step that enables the appropriate dimensions of beams, columns and slabs to be estimated prior to detailed calculation, whilst ensuring the safety and cost-effectiveness of the project. The analysis of the loads applied to the building, whether permanent or operational, played a fundamental role in assessing the structure’s behaviour under various stresses. Furthermore, the dynamic analysis enabled the building’s response to seismic actions to be analysed in order to ensure its stability and compliance with regulatory requirements. Finally, the foundation study confirmed the importance of effective load transfer to the ground in order to ensure the durability and safety of the structure. Thus, this study as a whole has provided a comprehensive overview of the design of a reinforced concrete building and a better understanding of the various stages required to construct a reliable and high-performance structure.

Chapter 3:

Thermal Analysis of utility systems

3.1. Introduction:

Utility systems are an essential and integrated infrastructure that ensures the continuity of daily life and the progress of cities. Their role in civil engineering lies in being an integral part of the planning, design and implementation of infrastructure; civil engineers study and coordinate water, drainage and electricity networks with roads and buildings, whilst emphasising safety, efficiency and sustainability. They also help mitigate risks such as flooding and pollution, and improve the standard of living within cities, making utility systems a fundamental component of any successful urban project. Electricity is used to power water pumping stations and wastewater treatment plants, as water is essential for the population and for the efficiency of many industrial activities. At the same time, telecommunications systems rely on electricity to transmit data and connect people with organisations. Whilst the gas system contributes to energy supply, waste management and stormwater drainage systems help to preserve the environment and public health. This chapter focuses on the thermal analysis of building utility systems, including load calculation, simulation, and performance optimization.

3.2. Overview of Building Utility Systems:

Building services systems are essential components that ensure the proper functioning, comfort and safety of any building. These systems provide fundamental services such as heating, air conditioning, water supply, electricity and gas distribution. It is essential to plan their design and integration carefully to ensure energy efficiency, sustainability and user comfort.

3.2.1. HVAC Systems (Heating, Ventilation, and Air Conditioning):

HVAC systems are designed to maintain thermal comfort and indoor air quality within buildings. They control the temperature, humidity and air circulation inside the building. Heating systems are used during cold periods to provide warmth, whilst air-conditioning systemsare used to cool indoor spaces during hot weather. Ventilation ensures the renewal of indoor air and the removal of pollutants. The efficiency of HVAC systems directly influences energy consumption and occupant comfort. It is therefore crucial to design them correctly and carry ot a thermal analysis to optimise their performance.

3.2.2. Water Supply System:

The water supply network ensures the distribution of drinking water throughout the building for domestic and sanitary use. This includes storage tanks, pipes, pumps and control systems. A well-designed water system ensures adequate pressure and flow whilst minimising leaks and energy consumption. As water is a crucial resource, its proper management contributes to sustainability and overall well-being.

3.2.3. Electrical Systems:

Electrical systems provide the power required for lighting, the operation of equipment, and the functioning of other building systems such as air conditioning and water pumps. These systems include power distribution networks, cabling, protective devices and control systems. An efficient electrical design ensures safety, reliability and reduced energy consumption. It also plays a crucial role in supporting modern technologies and smart building systems.

3.2.4. Gas Supply System:

The gas supply system is used to provide energy for heating, cooking and, in some cases, industrial processes within the building. This includes pipes, valves, meters and safety devices. Proper design and installation of gas systems are essential to ensure safety and prevent hazards such as leaks or explosions. Gas systems also contribute to energy efficiency when used correctly.

3.3. Thermal Regulations and Design Specifications (DTR):

The design and calculation of building services systems are based on regulatory technical documents known as DTRs (Documents Techniques Réglementaires). These documents set out the requirements and standards for the proper design, installation and operation of various systems within buildings. The technical design documents used in the calculation of building services systems are:

- hermal Design Specification (DTR)
- Ventilation Design Specification (DTR)
- Plumbing Design Specification (DTR E8.1)
- Electrical Design Specification (DTR E10.1)
- Gas Design Specification (DTR C4)

3.4. Thermal Load Assessment:

Recently, Algeria has experienced climate changes in terms of temperature and rainfall, leading to a prolonged drought. Today, arid regions cover 59% of the country. Dry regions now account for 59% of the country. According to climate data and recent analyses relating to 2026, the Tlemcen region has recently experienced a period of drought or insufficient rainfall. However, this is not a ‘total and unrelenting drought’, but rather a phenomenon of climatic variation between dry and wet periods.

World Bank. (2022). *Climate Risk Country Profile: Algeria*. World Bank Group.

3.4.1. Climatic Data:

- Summer temperature: 30°C → 40°C.
- Winter temperature: 5°C → 15°C.
- Humidity: moderate to low.
- Strong solar radiation, particularly in summer.
- Winds vary depending on the mountainous terrain.

3.4.2. Impact on The Building :

- Significant increase in cooling load in summer
- Relatively lower cooling requirements in winter
- Walls and roof are exposed to strong solar radiation

The climate of Tlemcen is classified as a semi-arid Mediterranean climate according to the Köppen–Geiger classification (Kottek et al., 2006)

Climat et Voyages. (2023). *Climat : Tlemcen*

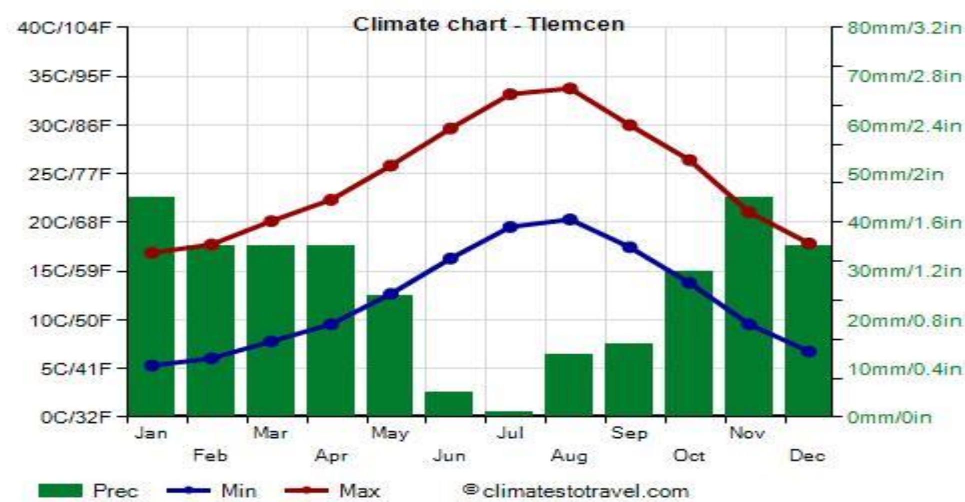


***Figure 3.1**: Climatic Conditions of Tlemcen Showing Temperature and Rainfall Distribution*

(Weather Atlas. (2023). *Climate and weather in Tlemcen*).

- Max (Maximum Temperature)
- Min (Minimum Temperature)
- Prec (Precipitation)

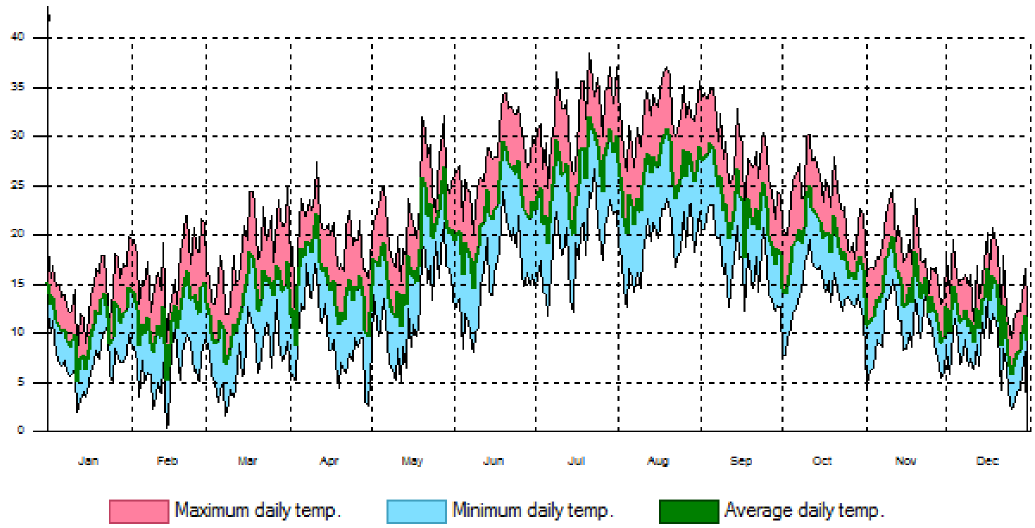


***Figure 3.2**: Annual Temperature Variations: Daily Maximum, Minimum and Average (CYPE,2017)*

3.5. Using Local Climate Data to Simulate Heat Gains And Losses:

Accurate integration of local climate variables with the building's physical characteristics is essential for correctly simulating heat gains and losses. To obtain reliable results, the simulation must take into account both static and dynamic thermal behaviour.

A- Essential Local Climate Parameters:

For an accurate simulation, you will need a weather data file (usually in. epw or. met format) containing the following elements: Dry-bulb temperature: Determines the conductive heat flow through walls, roofs and windows. Solar radiation (global, diffuse and direct): Essential for calculating solar heat gain coefficients (SHGC) and the influence of shadows. Relative Humidity: Crucial for calculating latent heat gains and assessing the risk of condensation. Wind Speed and Direction: Affect the convective heat transfer coefficient of external surfaces and natural ventilation rates'.

3.6.Heat Gains:

Heat gain is the total amount of thermal energy that enters the building and causes the indoor temperature to rise.

3.6.1. Solar gains through windows and glazing

- Through external surfaces such as walls and the roof.
- Transmission through the building envelope.
- Heat transfer through: Walls

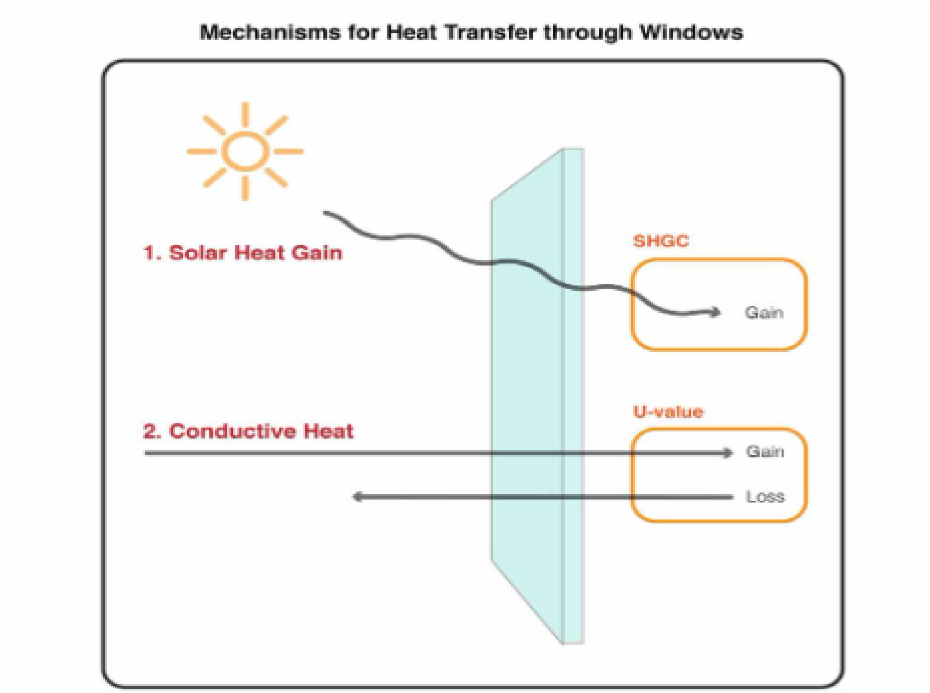


Figure 3.3: *Mechanisms of Heat Transfer (Conduction, Convection, and Radiation) ASHRAE (2021)*

3.6.2. Internal gains (internal sources)

- Heat emitted by occupants.
- Lighting.
- Electrical appliances.

3.6.3. Ventilation and infiltration

- Warm air from outside entering the space Air loss through openings.

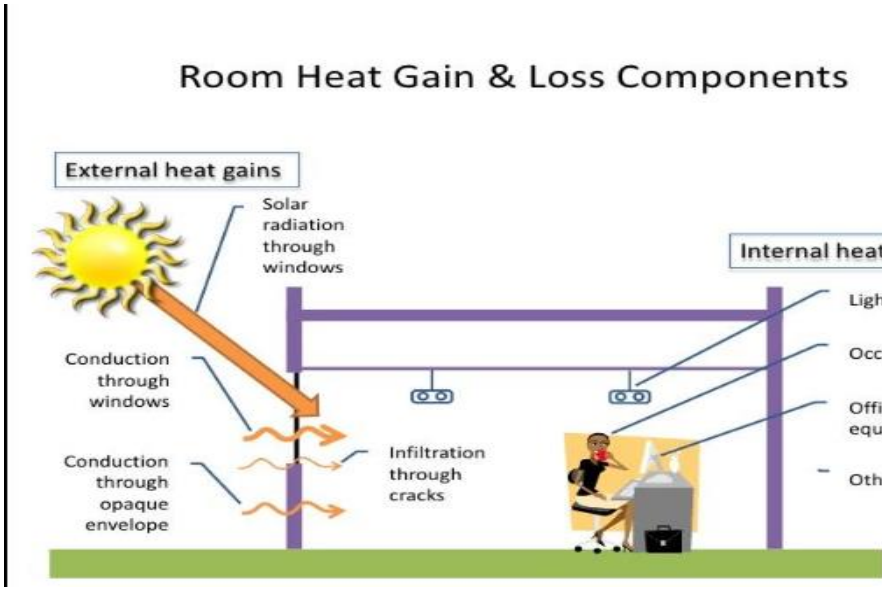


Figure 3.4: *Mechanism of room and losss(Ashrae)*

3.7. Heat Losses:

Heat loss refers to the loss of energy in homes. This refers to the dissipation of energy in the form of heat in poorly insulated houses and flats. You are being trained on data up to October 2023.Heat loss occurs when the indoor temperature exceeds the outdoor temperature, or vice versa.

-According to DTR C3-2, heat loss is defined as follows:

Heat loss refers to the amount of heat leaving a room, or a group of rooms, through heat transfer via the walls and air exchange, for a temperature difference of one degree between the inside and outside. It is expressed in watts.in watts per degree Celsius (W/°C).

A- Identifying Energy Losses:

Heat loss refers to the heat dissipation from a building, which escapes to the outside when the indoor temperature exceeds the outdoor temperature. This loss can occur through surfaces (walls, roofs, windows) and thermal bridges (areas of thermal discontinuity). through the use of insulation materials or air circulation (ventilation systems).Heat loss leads to excessive energy consumption for heating, reduced thermal comfort, and can compromise the building's structural integrity.

In a home, energy loss occurs through every wall. These critical elements include: the roof, walls, as well as windows and doors. (Zeghichi*, 2025)*

Figure 3.5.: *Heat loss rates in a residential building (*Zeghichi, 2025)

- ✓ The Roof:

The roof is the primary weak point in a home when it comes to insulation. Between 25% and 30% of heat loss occurs through the roof. This phenomenon can be attributed to several factors. The roof provides a large surface area where the interior andexterior meet. Furthermore, the roof is constantly exposed to the wind, and the heat generated inside the home tends to rise and concentrate under the roof.

- ✓ Walls:

Walls account for 20 to 25% of a home's heat loss. They are therefore the second-largest source of heat loss.

- ✓ Ventilation systems:

While essential for maintaining a healthy home, they create openings that allow heated air to escape... but also let in cold air from outside. Between 20 and 25% of heat loss occurs through air exchange, as well as through various leaks. *(Moufok, 2020)*

- ✓ Windows:

10 to 15% of heat loss in a poorly insulated home occurs through the windows. Some older homes have poorly insulated glass panes, including single-pane windows. This results in significant heat loss. Air leakage also occurs around doors, especially when the seals are damaged. (*Moufok, 2020)*

- ✓ Thermal bridges:

These are gaps between materials and the structural walls; they disrupt the insulating barrier and account for 5 to 10% of heat loss in homes. *(Zeghichi, 2025)*

- ✓ Lower levels:

When ground floors are not well insulated, the floor becomes a heat conductor. *(Zeghichi, 2025)*

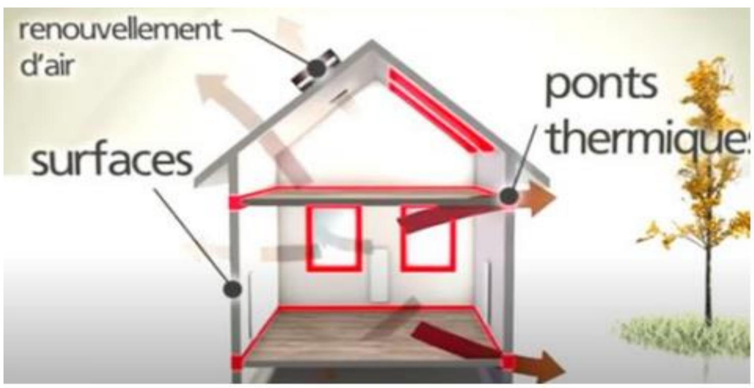


***Figure 3.6**: Heat Losses (Zeghichi, 2025)*

3.8. The Importance of Reducing Heat Loss:

When heat loss is significant, it becomes difficult to heat a room—and in many cases, the entire house—which requires a considerable amount of energy. fuel to reach a comfortabletemperature. In the worst-case scenario, a house loses 95% of the heat generated bythe heating system! Fortunately, insulation offers solutions to this problem of heat loss. *(Morel & Gnansounou, 2008)*

3.8.1. Heat losses resulting from hydronic heating systems in residential buildings with high insulation:

Many construction concepts relating to current and future high-efficiency buildings are based on highly insulated building envelopes, such as passive houses, zero-emission buildings, or nearly zero-energy buildings (nZEB). Thanks to the building's high insulation, we can simplify the heating distribution system and reduce the number of heating sources to just a few units. One possible solution is to rely on a hydronic heating system comprising a limited number of low-temperature radiators, such as one radiator per floor and another in the bathroom. This solution reduces heat loss from the pipes and lowers capital costs, but theoretically provides less thermal comfort compared to a full-cycle system. This thesis examines the thermal conditions inside the building using both systems. The case studies, which reflect the worst-case winter conditions as well as the most likely scenarios, help to provide a more realistic picture. The two systems are also evaluated in terms of their effectiveness. Pipe losses are treated as recoverable internal gains, and two variables are calculated for the distribution coefficient. (*Antoine, s.d)*

3.9. Simulation and Modelling:

CYPE is a comprehensive suite of software tools designed for the design, analysis and sizing of building structures made of reinforced concrete, steel and composite materials. It enables detailed modelling of various structural components such as columns, beams, slabs and foundations, whilst taking into account the various applied loads, including dead, live and seismic loads. CYPECAD, which is based on the finite element method, provides accurate structural analysis in accordance with current regulations and standards. It also offers sophisticated tools that automate the creation of working drawings, calculations and quantity take-offs, thereby streamlining the engineer's work whilst reducing the likelihood of errors. The inclusion of CYPE software in this research aims to ensure the optimal design of the analysed structure, whilst guaranteeing robust results that comply with technical and regulatory standards.

CYPETHERM EPlus is a specialised building energy simulation tool that enables engineers and designers to analyse thermal performance and energy consumption with exceptional accuracy. Key features of this software, in brief:

3.9.1. The internal engine (EnergyPlus):

The software relies primarily on the EnergyPlus engine, the most powerful and accurate engine developed by the US Department of Energy (DOE). This engine is capable of calculating:

Detailed heat transfer (radiation, conduction, convection). Energy consumption of heating, ventilation and air conditioning (HVAC) systems. Lighting and energy consumption in electrical appliances.

3.9.2. Working Environment (BIM):

The software is part of the CYPE system and is fully integrated into workflows using BIM (Building Information Modelling) technology. It is possible to import the building model in IFC format (from software such as Revit or ArchiCAD). Data synchronisation via the BIMserver.center platform. (8,760 hours). Gas emissions: calculation of carbon dioxide (CO2) emissions.

3.9.3. Building Modelling:

It is a comprehensive process for creating an accurate digital representation of buildings, which is not limited to external aspects alone, but extends to include physical, thermal and structural characteristics. With regard to residential projects (such as R+4 or R+5 buildings), modelling is divided into three main levels:

3.9.4. Geometric and Architectural Modelling

This stage represents the digital 'structure' of the project, where spatial dimensions are defined with extreme precision. Components: drawing walls, slabs, columns and windows. Zoning: allocating rooms and spaces according to their function (bedrooms, kitchen, corridors); this is a crucial step for moving on to the thermal simulation stage. Software used: Revit or ArchiCAD.

3.9.5. Defining physical and thermal properties here:

lines and shapes are transformed into tangible materials with specific physical behaviour: Defining layers: Specifying wall components in detail (e.g. 15 cm brick + 5 cm thermal insulation + 2 cm concrete). Thermal coefficients: Entering the thermal transmittance coefficient (\lambda) and calculating the total resistance (R). Operating conditions: Defining occupancy times, lighting, and the temperatures required for heating and cooling. Analytical modelling This is the level on which calculation software (such as CYPETHERM EPlus) relies to assess building performance: Structural analysis: Converting columns and beams into a computational mesh to study loads and earthquakes. Thermal simulation: converting the architectural model into 'thermal zones' to study heat flow and loss through the building envelope. To conclude this chapter, a detailed thermal analysis of the building was carried out, in full compliance with Algerian thermal standards (DTR Thermique) and utilising the advanced simulation capabilities of the CYPE software. The thermal load assessment highlighted the direct link between the characteristics of the building envelope and the efficiency of its technical services systems, particularly the heating, ventilation and air conditioning (HVAC) systems. The numerical simulation successfully identified the main areas of energy inefficiency and periods of peak demand. This enabled the suggestion of targeted improvement strategies, such as thermal insulation and solar gain control, to reduce energy consumption. Ultimately, to achieve energy efficiency in the Algerian context, it is essential to harmonise thermal performance with structural design and to bridge the gap between structural stability.

3.10. Description of materials and building elements:

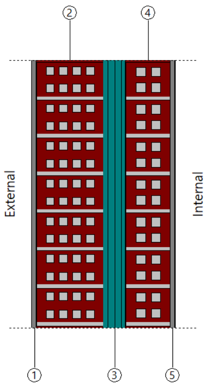
3. 10.1. Building Envelope

1) **Façades**

- **Opaque fraction of the façades**

Murs Ext	Total surface area 208.34 m²

Murs Ext



Layer list:

1 -	Mortar (dry density 1700)	1.00 cm
2 -	Terracotta (nominal density 2000)	15.00 cm
3 -	Polystyrène	5.00 cm
4 -	Terracotta (Nominal density 2000)	10.00 cm
5 -	Mortar (Dry density 1700)	1.00 cm

Properties — Thermal transmittance, U: 1.22 W/(m²·K)
Total thickness 32.00 cm

2) **Façade openings**

P1

P1

Properties — Thermal transmittance, U: 2.00 W/(m²·K)
Absorptance, α_S: 0.600 (colour intermediate)

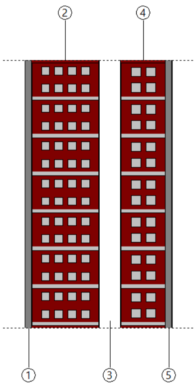
3.11. PARTITIONING SYSTEM

3.11.1 Internal vertical partitioning

❖ **Non-visible part of the internal vertical partitioning**

Cloisons 30 cm	Total surface area 208.71 m²

Cloisons 30 cm



Layer list:

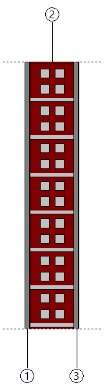
1 - Mortar (dry density 1700)	1.50 cm
2 - Terracotta (nominal density 2200)	15.00 cm
3 - Area	5.00 cm
4 - Terracotta (nominal density 2200)	10.00 cm
5 - Mortar (dry density 1700)	1.50 cm

Properties Thermal transmittance, U: 1.66 W/(m²·K)

Total thickness 33.00 cm

Cloisons	Total surface area 289.63 m²

Cloisons



Layer list:

1 - Mortar (dry density 1700)	1.00 cm
2 - Terracotta (nominal density 2000)	10.00 cm
3 - Mortar (dry density 1700)	1.00 cm

Properties Thermal transmittance, U: 2.46 W/(m²·K)

Total thickness 12.00 cm

3.11.1. Internal vertical openings

P3

P3

Properties Thermal transmittance, U: 2.00 W/(m²·K)

Absorptance, α_S: 0.600 (colour intermediate)

P4	
P4	
Properties	Thermal transmittance, U: 2.00 W/(m²·K)
	Absorptance, α_S: 0.400 (colour intermediate)

P5	
P5	
Properties	Thermal transmittance, U: 2.00 W/(m²·K)
	Absorptance, α_S: 0.600 (colour intermediate)

P2	
P2	
Properties	Thermal transmittance, U: 2.00 W/(m²·K)
	Absorptance, α_S: 0.600 (colour intermediate)

3.12.MATERIALS :

***Table 3.1**: Meterial Layer Specification and Propertize (CYPE2026)*

Layers					
Material	e	ρ	λ	RT	Cp
Mortar (Dry density 1700)	1.00	1700.00	1.000	0.01	1000.00
Terracotta (Nominal density 2000)	15.00	1950.00	0.790	0.19	1000.00
Polystyrene	5.00	1050.00	0.160	0.31	1300.00
Terracotta (Nominal density 2000)	10.00	1950.00	0.790	0.13	1000.00
Mortar (dry density 1700)	1.50	1700.00	1.000	0.02	1000.00
Terracotta (nominal density 2200)	15.00	2150.00	0.920	0.16	1000.00
Terracotta (nominal density 2200)	10.00	2150.00	0.920	0.11	1000.00

Used abbreviations			
e	*Thickness cm*	RT	*Thermal resistance (m²·K)/W*
ρ	*Density kg/m³*	Cp	*Specific heat J/(kg·K)*
λ	*Thermal conductivity W/(m·K)*		

3.12.1. ENERGY DEMAND CALCULATION SUMMARY

The table below summarises the results obtained for the calculation of the heating and cooling energy demand of each habitable zone, as well as the total energy demand of the building.

Habitable zones	S_u (m²)	D_{heat} (kWh/year)	(kWh/m²·year)	D_{cool} (kWh/year)	(kWh/m²·year)
Z	361.72	103349.39	285.72	0.00	0.00
	361.72	103349.39	285.72	0.00	0.00

Table 3.2 : ***Summarises the heating and cooling energy demand for each habitable zone (Z) and the total building energy demand (kWh/year and kWh/m²·year).(CYPE2026)***

where *:*

S_u: Net floor area of the habitable zone, m².

D_{heat}: Calculated value of the heating energy demand, kWh/m²·year.

D_{cool}: Calculated value of the cooling energy demand, kWh/m²·year.

3.13. MONTHLY RESULTS:

3.13.1. Annual energy balance of the building:

The following bar chart shows the energy balance of the building for each month, taking into account the energy lost or gained due to thermal transmission via opaque and light elements (Q_{op} and Q_w, respectively), the energy interchange due to ventilation and infiltrations (Q_{ve+inf}), the gain in heat due to occupancy (Q_{ocup}), lighting (Q_{light}) and internal equipment (Q_{equip}) as well as the necessary heating (Q_H) and cooling (Q_C) inputs.

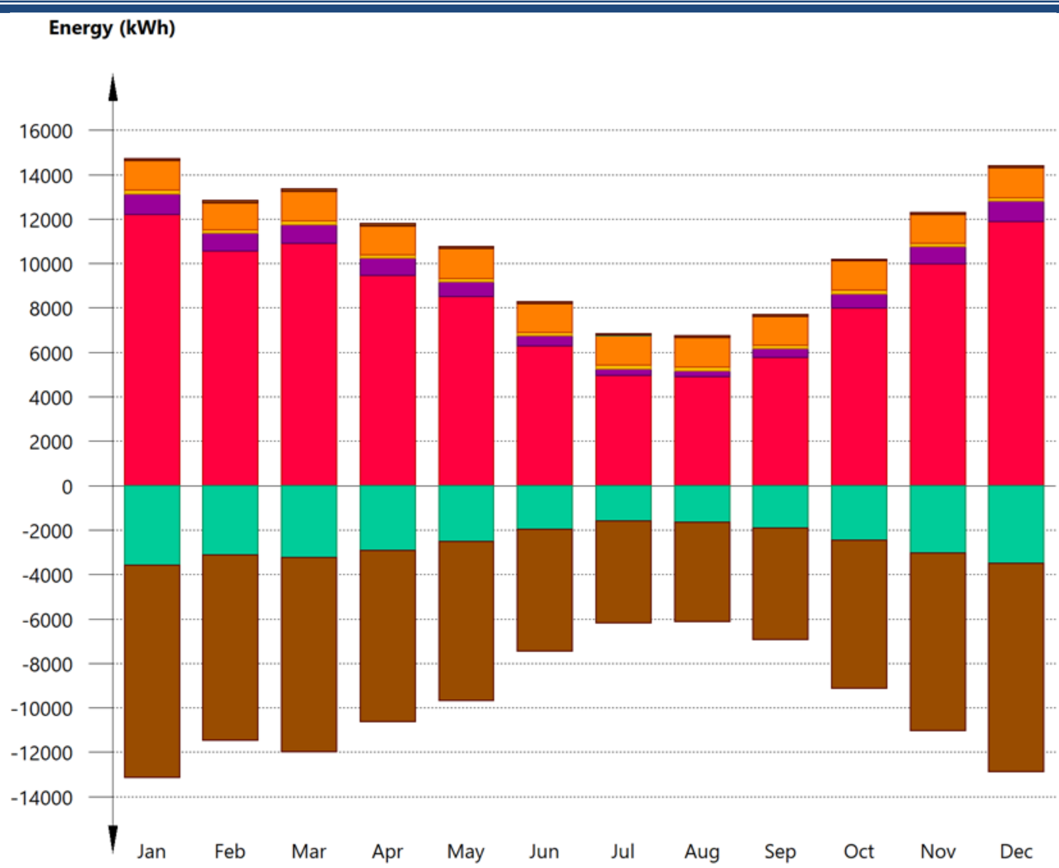


Figure 3.7: *A bar chart illustrating the monthly energy balance, accounting for energy lost or gained through thermal transmission via opaque and light elements (CYPE, 2025)*

The following table displays the numerical values of the preceding bar chart, the energy balance of the whole building, as the sum of the energy involved in the energy balance of each thermal zone of the building calculation model.The sign criteria adopted consists of using positive values for energy contributed to the zone and negative values for energy that is extracted.

Table 3.3 : *Details the energy demand for heating and cooling across the twelve months of the year (CYPE2026)*

	Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	(kWh/m²·year)
Annual energy balance of the building.														
Q_{op}	81.1 -9552.9	109.3 -8365.9	117.2 -8754.0	118.3 -7720.5	77.2 -7138.5	92.1 -5483.3	77.6 -4604.3	85.0 -4478.9	73.6 -5007.0	46.9 -6661.9	79.6 -8007.7	80.8 -9373.8	-84109.91	-232.53
Q_{ve+inf}	-- -3599.0	-- -3116.6	-- -3245.5	-- -2914.4	0.7 -2530.9	0.8 -1975.9	10.6 -1589.9	3.5 -1642.3	0.3 -1923.0	-- -2456.2	-- -3042.6	-- -3505.2	-31525.46	-87.15

Q_{equip}	1345.6	1215.4	1345.6	1302.2	1345.6	1302.2	1345.6	1345.6	1302.2	1345.6	1302.2	1345.6	15843.25	43.80
Q_{light}	156.2	141.1	156.2	151.2	156.2	151.2	156.2	156.2	151.2	156.2	151.2	156.2	1839.60	5.09
Q_{ocup}	923.6	814.2	855.1	760.6	680.1	467.9	287.9	273.0	398.7	641.2	790.8	909.1	7802.09	21.57
Q_H	12203.4	10549.1	10894.3	9471.4	8490.9	6273.9	4964.7	4889.6	5770.0	7983.9	9964.9	11893.3	103349.39	285.72
Q_C	--	--	--	--	--	--	--	--	--	--	--	--	0.00	0.00
Q_{HC}	12203.4	10549.1	10894.3	9471.4	8490.9	6273.9	4964.7	4889.6	5770.0	7983.9	9964.9	11893.3	103349.39	285.72

Where :

Q_{op}:	Energy transfer corresponding to the thermal transmission across opaque elements of the envelope, kWh/m²·year.
Q_w:	Energy transfer corresponding to the thermal transmission across light elements of the envelope, kWh/m²·year.
Q_{ve+inf}:	Energy transfer corresponding to the thermal transmission due to ventilation, kWh/m²·year.
Q_{equip}:	Energy transfer corresponding to the internal heat gain due to internal equipment, kWh/m²·year.
Q_{light}:	Energy transfer corresponding to the internal heat gain due to lighting, kWh/m²·year.
Q_{ocup}:	Energy transfer corresponding to the internal heat gain due to internal occupancy, kWh/m²·year.
Q_H:	Heating energy input, kWh/m²·year.
Q_C:	Cooling energy input, kWh/m²·year.
Q_{HC}:	Heating and cooling energy input, kWh/m²·year.

3.14. Monthly heating and cooling energy demand:

Attending only to the energy demand to be covered by the heating and cooling systems, the energy and instantaneous net power requirements throughout the year are shown below:

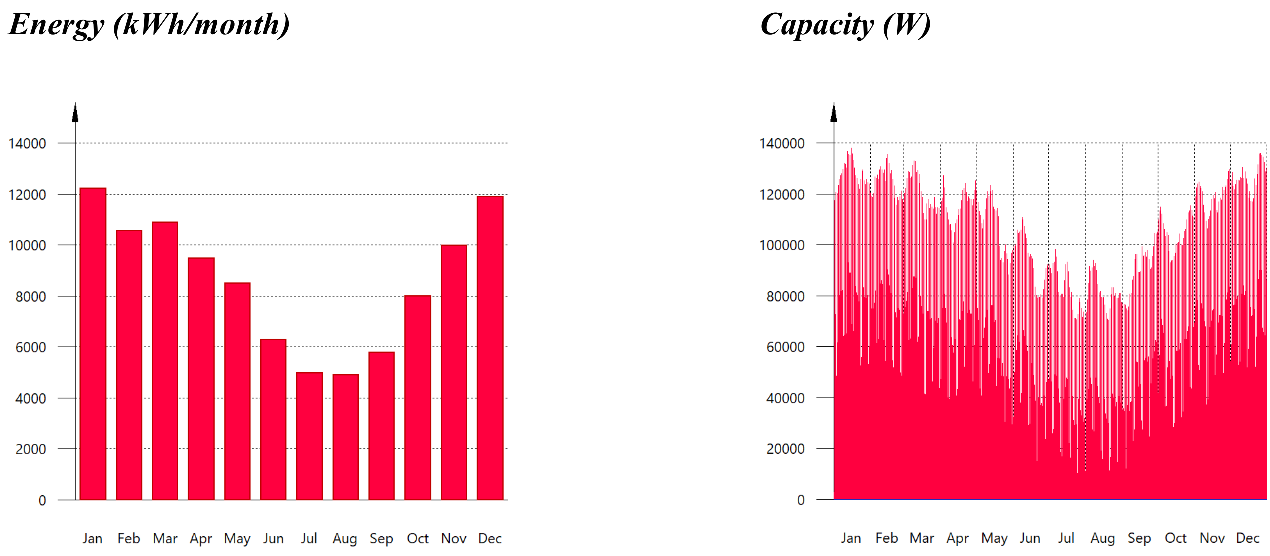


Figure 3.8: *the energy and instantaneous net power requirements throughout the year are shown below (CYPE,* 2025)

3.15. Temperature evolution:

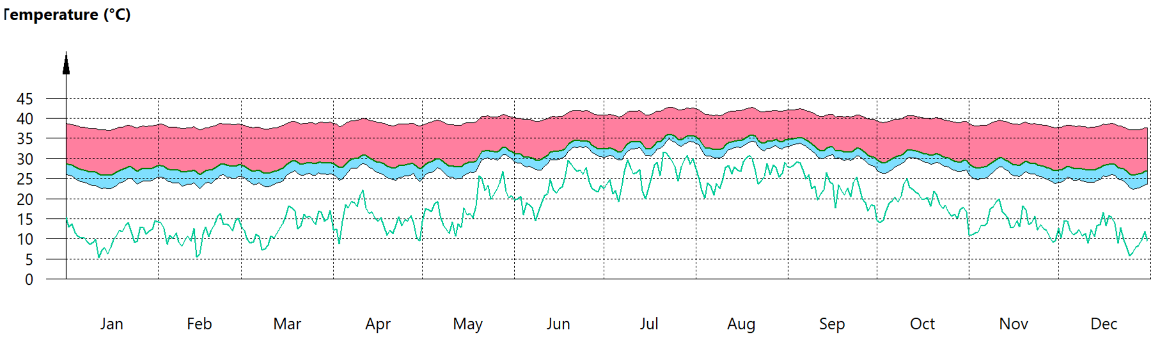


Figure 3.9: *the internal operative temperature is shown in the following graph, which displays the evolution of the minimum, maximum and average temperatures of each day (CYPE*, 2025)

3.16. DESIGN MODEL OF THE BUILDING:

3.16.1. Space groups:

Shown below are the characteristics of the spaces of each calculation zone of the building.

Table3.4. *Annal thermal load and operational parameters by zone (CYPE.2026)*

	S (m²)	**V** (m³)	**ren$_h$** (1/h)	**ΣQ$_{ocup,s}$** (kWh/year)	**ΣQ$_{ocup,l}$** (kWh/year)	**ΣQ$_{equip,s}$** (kWh/year)	**ΣQ$_{equip,l}$** (kWh/year)	**ΣQ$_{light}$** (kWh/year)	**T^a heat. Average** (°C)	**T^a cool. Average** (°C)
Z (Habitable zone)										
1 (Chambre)	44.33	135.66	0.71	1957.31	1304.87	1941.77	--	61.32	31.0	--
2 (Chambre)	23.08	70.64	0.71	1019.15	679.44	1011.06	--	61.32	31.0	--
3 (Chambre)	10.39	31.80	0.71	458.80	305.86	455.15	--	61.32	31.0	--
4 (Chambre)	21.03	64.35	0.71	928.42	618.95	921.05	--	61.32	31.0	--
5 (Chambre)	10.67	32.64	0.71	470.88	313.92	467.14	--	61.32	31.0	--
6 (Chambre)	10.58	32.36	0.71	466.90	311.27	463.19	--	61.32	31.0	--
7 (Chambre)	44.19	135.21	0.71	1950.90	1300.60	1935.42	--	61.32	31.0	--
8 (Chambre)	44.23	135.33	0.71	1952.57	1301.71	1937.07	--	61.32	31.0	--
9 (Chambre)	10.73	32.83	0.71	473.63	315.75	469.87	--	61.32	31.0	--
10 (Cuisine)	11.25	34.43	0.71	496.74	331.16	492.80	--	61.32	31.0	--
11 (Cuisine)	11.40	34.88	0.71	503.26	335.51	499.27	--	61.32	31.0	--
12 (Cuisine)	11.18	34.20	0.71	493.44	328.96	489.52	--	61.32	31.0	--
13 (Cuisine)	11.32	34.63	0.71	499.60	333.07	495.64	--	61.32	31.0	--
14 (SDB)	3.77	11.53	0.71	166.41	110.94	165.08	--	61.32	31.0	--
15 (SDB)	1.87	5.73	0.71	82.66	55.11	82.01	--	61.32	31.0	--
16 (SDB)	3.78	11.56	0.71	166.82	111.21	165.49	--	61.32	31.0	--
17 (SDB)	1.66	5.08	0.71	73.25	48.83	72.67	--	61.32	31.0	--
18 (SDB)	3.88	11.86	0.71	171.17	114.11	169.81	--	61.32	31.0	--
19 (SDB)	1.63	5.00	0.71	72.18	48.12	71.61	--	61.32	31.0	--
20 (SDB)	1.58	4.83	0.71	69.63	46.42	69.08	--	61.32	31.0	--
21 (SDB)	3.87	11.84	0.71	170.90	113.93	169.54	--	61.32	31.0	--
22 (Hall)	43.78	133.97	0.71	1932.90	1288.60	1917.56	--	61.32	31.0	--
23 (Balcon)	2.47	9.36	0.57	109.11	72.74	108.25	--	61.32	31.0	--
24 (Balcon)	5.70	19.53	0.63	251.52	167.68	249.53	--	61.32	31.0	--
25 (Balcon)	2.62	9.05	0.62	115.53	77.02	114.61	--	61.32	31.0	--
26 (Balcon)	5.14	17.77	0.62	226.82	151.21	225.02	--	61.32	31.0	--
27 (Balcon)	5.15	18.08	0.62	227.38	151.59	225.58	--	61.32	31.0	--
28 (Balcon)	2.60	9.81	0.57	114.80	76.53	113.88	--	61.32	31.0	--
29 (Balcon)	2.53	9.57	0.57	111.77	74.51	110.88	--	61.32	31.0	--
30 (Balcon)	5.33	16.70	0.69	235.54	157.02	233.67	--	61.32	31.0	--
	361.72	**1120.21**	**0.70/0.73***	**15969.98**	**10646.66**	**15843.24**	**--**	**1839.60**	**31.0**	**--**

Where:

S:	Net internal floor area of the space, m².
V:	Internal net volume of the space, m³.
ren_h:	Number of air changes of the space per hour.
*:	Average value of the number of renewals per hour of the air of the habitable zone, including the calculated infiltrations.
$Q_{ocup,s}$:	Sum of the sensible internal heat gain due to occupancy of the space throughout the year, kWh/year.
$Q_{ocup,l}$:	Sum of the latent internal heat gain due to occupancy of the space throughout the year, kWh/year.
$Q_{equip,s}$:	Sum of the sensible internal heat gain due to equipment in the space throughout the year, kWh/year.
$Q_{equip,l}$:	Sum of the latent internal heat gain due to equipment in the space throughout the year, kWh/year.
Q_{light}:	Sum of the internal heat gain due to lighting of the space throughout the year, kWh/year.
T^a heat. Average:	Average value of the heating temperature during the operation intervals, °C.
T^a cool. Average:	Average value of the cooling temperature during the operation intervals, °C.

3.17. Description of the linear thermal bridges: EN ISO 14683 / EN ISO 10211

Table 3.5: *A comprehensive table listing the identified linear thermal bridges (CYPE2026)*

	Length (m)	Y (W/(m·K))
TW Cloisons 30 cm - Murs Ext - Murs Ext * Interior wall	**18.360**	**0.32**
LWo Murs Ext - Murs Ext * Outgoing corner	**12.240**	**0.20**
Ws P1 W10. Opening for window or door.	**1.500**	**0.10**
WI P1 W10. Opening for window or door.	**5.000**	**0.10**

3.18. ENERGY CONSUMPTION CALCULATION RESULTS:

3.18.1. Monthly results:

a) Annual energy consumption of the building:

Table3.6 : *the monthly and annual heating energy consumption (kWh and kWh/m²·year) for the entire building(CYPE2026)*

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	(kWh/m²·year)
BUILDING (S_u = 361.72 m²; V = 1120.21 m³)															
Energy demand	**Heating**	**12203.4**	**10549.1**	**10894.3**	**9471.4**	**8490.9**	**6273.9**	**4964.7**	**4889.6**	**5770.0**	**7983.9**	**9964.9**	**11893.3**	**103349.4**	**285.7**
	DHW	**850.4**	**768.1**	**850.4**	**822.9**	**850.4**	**822.9**	**850.4**	**850.4**	**822.9**	**850.4**	**822.9**	**850.4**	**10012.3**	**27.7**
	TOTAL	**13053.8**	**11317.2**	**11744.6**	**10294.3**	**9341.3**	**7096.8**	**5815.0**	**5739.9**	**6592.9**	**8834.3**	**10787.8**	**12743.7**	**113361.7**	**313.4**
Electricity (f_{cep} = 1.954)	**EF_{heat}**	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,heat}$	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	
	EF_{dhw}	2196.8	1984.2	2196.8	2125.9	2196.8	2125.9	2196.8	2196.8	2125.9	2196.8	2125.9	2196.8	25865.2	71.5
	EP_{dhw}	5202.0	4698.5	5202.0	5034.2	5202.0	5034.2	5202.0	5202.0	5034.2	5202.0	5034.2	5202.0	61248.9	169.3
	$EP_{nr,dhw}$	**4292.7**	**3877.2**	**4292.7**	**4154.2**	**4292.7**	**4154.2**	**4292.7**	**4292.7**	**4154.2**	**4292.7**	**415**	**429**	**50542.6**	**139.7**

												4.2	**2.7**		
	EF_{light}	156.2	141.1	156.2	151.2	156.2	151.2	156.2	156.2	151.2	156.2	151.2	156.2	1839.6	5.1
	EP_{light}	370.0	334.2	370.0	358.0	370.0	358.0	370.0	370.0	358.0	370.0	358.0	370.0	4356.2	12.0
	$EP_{nr,light}$	**305.3**	**275.8**	**305.3**	**295.5**	**305.3**	**295.5**	**305.3**	**305.3**	**295.5**	**305.3**	**295.5**	**305.3**	**3594.7**	**9.9**
Auto-consumed electricity (f_{cep} = 1.954)	**EF**	--	--	--	--	--	--	--	--	--	--	--	--	-150.0	-0.4
	EP	--	--	--	--	--	--	--	--	--	--	--	--	-352.2	-1.0
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	-293.1	-0.8
	$C_{ef,total}$	**2353.0**	**2125.3**	**2353.0**	**2277.1**	**2353.0**	**2277.1**	**2353.0**	**2353.0**	**2277.1**	**2353.0**	**2277.1**	**2353.0**	**27554.8**	**76.2**
	C_{ep}	**5571.9**	**5032.7**	**5571.9**	**5392.2**	**5571.9**	**5392.2**	**5571.9**	**5571.9**	**5392.2**	**5571.9**	**5392.2**	**5571.9**	**65249.8**	**180.4**
	$C_{ep,nr}$	**4598.0**	**4153.0**	**4598.0**	**4449.6**	**4598.0**	**4449.6**	**4598.0**	**4598.0**	**4449.6**	**4598.0**	**4449.6**	**4598.0**	**53844.2**	**148.9**

where:

- S_u: Residential area of the building, m².
- V: Net volume of the habitable zone in the building, m³.
- f_{cep}: Conversion factor for final energy to primary energy obtained from non-renewable sources.
- EF: Final energy consumed by the system at consumption point, kWh.
- EP: Primary energy consumption, kWh.
- EP_{nr}: Non-renewable primary energy consumption, kWh.
- $C_{ef,total}$: Energy consumption at consumption point (final energy), kWh/m²·year.
- C_{ep}: Total primary energy consumption, kWh/m²·year.
- $C_{ep,nr}$: Non-renewable primary energy consumption, kWh/m²·year.

b) Results by habitable zone and month:

Z (S_u = 361.72 m²; V = 1120.21 m³)

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	(kWh/m²·year)
Energy demand	**Heating**	12203.4	10549.1	10894.3	9471.4	8490.9	6273.9	4964.7	4889.6	5770.0	7983.9	9964.9	11893.3	103349.4	285.7
	DHW	850.4	768.1	850.4	822.9	850.4	822.9	850.4	850.4	822.9	850.4	822.9	850.4	10012.3	27.7
	TOTAL	**13053.8**	**11317.2**	**11744.6**	**10294.3**	**9341.3**	**7096.8**	**5815.0**	**5739.9**	**6592.9**	**8834.3**	**10787.8**	**12743.7**	**113361.7**	**313.4**

Table 3.6 : Breaks down energy consumption per zone across the year

		Jan (h)	Feb (h)	Mar (h)	Apr (h)	May (h)	Jun (h)	Jul (h)	Aug (h)	Sep (h)	Oct (h)	Nov (h)	Dec (h)	Year (h)
Unmet load hours*	**Heating**	336	297	323	295	277	216	178	170	195	262	299	336	3185
	Cooling	--	--	--	--	--	--	--	--	--	--	--	--	--

**Number of hours in which the air temperature of the spaces of the zone lies outside the range of the setpoint heating or cooling temperatures, with a margin greater than 0.2 °C for heating and 0.2 °C for cooling.*

Table3.7: *Lists the energy demand for the DHW service, including the net floor area and solar energy coverage percentage*. (CYPE2026).

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	(kWh/m²·year)
Net energy provided	**DHW_{sol}**	--	--	--	--	--	--	--	--	--	--	--	--	--	
	DHW_{sis}	850.4	768.1	850.4	822.9	850.4	822.9	850.4	850.4	822.9	850.4	822.9	850.4	10012.3	27.7

Where :

S_u: Net floor area of the habitable zone, m².

V: Net volume of the habitable zone, m³.

DHW_{sol}: Solar net energy provided, kWh.

DHW_{sis}: Net energy provided by the system, kWh.

3.19. PERFORMANCE OF THE TECHNICAL SERVICE EQUIPMENT:

The final energy consumption (EF) and the seasonal efficiency of the generators that serve the heating, cooling and DHW production services, obtained from the building simulation, are indicated below. The seasonal efficiency expresses the relationship between the thermal energy production of the generator and its total energy consumption.

Table3.8: *Energy Vector and Seasonal Efficiency Analysis(CYPE2026)*

	Overview	**Energy vector**	**EF** (kWh/year)	**Seasonal efficiency**
DHW generators				
Heat1	Hot water boiler	Electricity	12515.43	0.80
DHW equipment		Electricity	13349.79	0.75

Where :

EF: Final energy consumption, kWh/year.

3.20. DESIGN MODEL OF THE BUILDING:

3.20. 1.Energy demand of the building:

a) Heating and cooling energy demand:

Table 3.8. *Heting and cooling energy demand by habitable zone (CYPE2026)*

Habitable zones	$\mathbf{S_u}$ (m^2)	$\mathbf{D_{heat}}$		$\mathbf{D_{cool}}$	
		(kWh/year)	($kWh/m^2\cdot year$)	(kWh/year)	($kWh/m^2\cdot year$)
Z	361.72	103349.39	285.72	--	--
	361.72	103349.39	**285.72**	--	**--**

Where :

S_u: Net floor area of the habitable zone, m^2.

D_{heat}: Calculated value of the heating energy demand, kWh/year.

D_{cool}: Calculated value of the cooling energy demand, $kWh/m^2\cdot year$.

b) Domestic hot water energy demand:

The thermal jump used in the required thermal energy calculation is carried out between a reference temperature defined in the zone, and the temperature of the network water at the location of the planned building, with values of:

***Table 3.9**. Domestic Hot Water Energy Demand Results by Habitable Zone.*

	Jan (°C)	**Feb** (°C)	**Mar** (°C)	**Apr** (°C)	**May** (°C)	**Jun** (°C)	**Jul** (°C)	**Aug** (°C)	**Sep** (°C)	**Oct** (°C)	**Nov** (°C)	**Dec** (°C)
Network water temperature	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

Displayed below are the calculation results of the domestic hot water energy demand calculations for each habitable zone of the building, with the daily demands, the percentage of the demand covered by renewable energy, and the remaining energy to be satisfied using non-renewable energy.

***Table3.10.** Results of Domestic Hot Water Production(CYPE2026)*

Habitable zones	**Q_{DHW}** (l/day)	**T_{ref}** (°C)	**S_u** (m²)	**D_{DHW}** (kWh/year)	(kWh/m²·year)	**$\%_{AS}$** (%)	**$D_{DHW,sis}$** (kWh/year)	(kWh/m²·year)
Z	500.0	60.0	361.72	10012.34	27.68	--	10012.34	27.68
	500.0		**361.72**	10012.34	**27.68**		10012.34	**27.68**

Where :

Q_{DHW}: Daily demanded flow of domestic hot water, l/day.

T_{ref}: Reference temperature, °C.

S_u: Net floor area of the habitable zone, m².

D_{DHW}: Energy demand corresponding to the domestic hot water service, kWh/m²·year.

$\%_{AS}$: Percentage of the energy demand of domestic hot water covered by solar energy, %.

$D_{DHW,sis}$: Domestic hot water energy demand covered by the system, kWh/m²·year.

c) Conversion factors :

Table 3.11: *Energy Conversion Factors and Associated Emissions(CYPE2026)*

Energy vector	C_{ef}		f_{cep}	C_{ep}		$f_{cep,nr}$	$C_{ep,nr}$		f_{co2}	kg CO_2	
	(kWh/year)	(kWh/m²·year)		(kWh/year)	(kWh/m²·year)		(kWh/year)	(kWh/m²·year)		(kg CO_2/year)	(kg CO_2/m²·year)
Electricity obtained from the network	27554.82	76.18	2.368	65249.83	180.39	1.954	53844.16	148.86	0.331	9120.6	25.2
Electricity produced on site (renewable)	150.00	0.41	1.000	150.00	0.41	0.000	--	--	0.000	--	--

Where :

C_{ef}: Energy consumption at consumption point (final energy), kWh/m²·year.

f_{cep}: Conversion factor for final energy to primary energy.

C_{ep}: Primary energy consumption, kWh/m²·year.

$f_{cep,nr}$: Conversion factor for final energy to primary energy obtained from non-renewable sources.

$C_{ep,nr}$: Non-renewable primary energy consumption, kWh/m²·year.

f_{co2}: Final energy to CO_2 emissions conversion factor, kg CO_2/kWh.

kg CO_2: CO_2 emissions, kg CO_2/m²·year.

3.21. Thermal transmittance :

Transmission heat transfer coefficient (EN ISO 13789 :2017)

H_{tr} = 830.25 W/K

Where :

H_{tr}: Transmission heat transfer coefficient (EN ISO 13789:2017), W/K.

$U_{mn} = H_{tr} / \sum A_i = 3.61$ W/(m²·K)

Where :

U_{mn}: Mean thermal transmittance of building fabric (EN ISO 13789:2017), W/(m²·K).

H_{tr}: Transmission heat transfer coefficient not including heat transfer to adjacent buildings, W/K.

A_i: Area of element 'i' of the thermal envelope, excluding the area in contact with adjacent buildings, m².

Table 3.10: *Analysis of Transmission Heat Transfer Coefficients by Building Element(CYPE2026*

	S (m²)	L (m)	H_i (W/K)	$\%H_{tr}$
Total exchange area of the thermal envelope = 229.686 m²				
Façades	208.34	--	254.40	30.64
Interior partitions	5.35	--	8.90	1.07
Fenestration	15.99	--	7.50	0.90
Thermal bridge	--	1118.906	559.45	67.38

Where :

S: Surface, m².

L: Length, m.

H_i: Partial coefficient of the transfer of heat by transmission, W/K.

$\%H_{tr}$: Percentage of the coefficient of the transfer of heat by transmission, %.

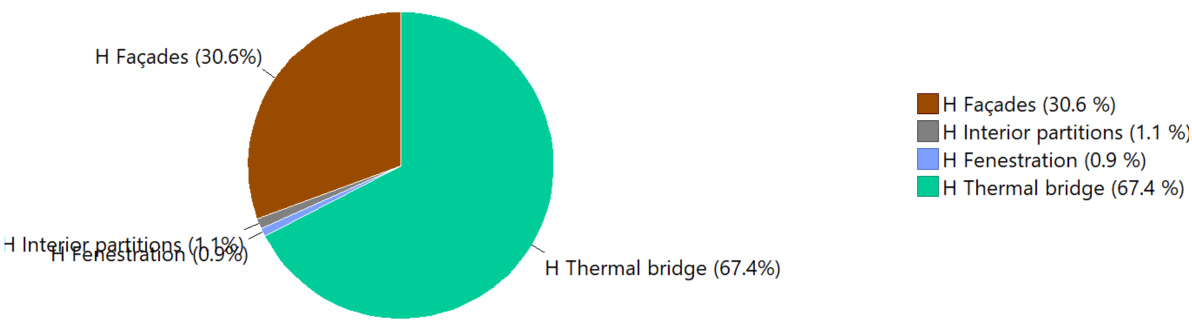


Figure *3.10*:compative analysis of heat losses by transmission (cype ,2025)

a) Air permeability of the thermal envelope:

$n_{50} = 0.629 \cdot (C_o \cdot A_o + C_h \cdot A_h) / V = 1.511\ h^{-1} \leq n_{50,lim} = 5.000\ h^{-1}$ ✓

Where :

n_{50}: *Calculated value of the air change rate with a differential pressure of 50 Pa, h^{-1}.*

$n_{50,lim}$: *Limit value of the air change rate with a differential pressure of 50 Pa, h^{-1}.*

C_o: *Coefficient of the air flow of the opaque part of the thermal envelope, for a differential pressure of 100 Pa, $m^3/(h \cdot m^2)$.*

A_o: *Surface area of the opaque part of the thermal envelope, m^2.*

C_h: *Permeability of the openings of the thermal envelope, for a differential pressure of 100 Pa, $m^3/(h \cdot m^2)$.*

A_h: *Surface area of the openings of the thermal envelope, m^2.*

V: *Internal volume of the thermal envelope, m^3.*

3.22. GEOMETRIC AND CONSTRUCTIVE DESCRIPTION OF THE CALCULATION MODEL:

3.22.1. Space groups:

The characterisation of the thermal envelope of the building is shown below, as well as that of each of the zones that have been included in it:

***Table 3.11**: Thermal Transmittance and Heat Loss Characteristics of Opaque Façades(CYPE2026)*

	S (m^2)	V (m^3)	V_{inf} (m^3)	n_{50} (h^{-1})	V/A (m^3/m^2)
Z	361.72	1244.63	1120.21	1.511	-
Thermal envelope		**361.72**	**1244.63**	**1120.21**	**1.5 5.4**

Where :

S: Net internal floor area, m^2.

V: Internal volume, m^3.

V_{inf}: Internal volume to calculate infiltrations, m^3.

n_{50}: Air change rate with a differential pressure of 50 Pa, h^{-1}.

V/A: Compactness (ratio between the enclosed volume and the exchange surface with the outside), m^3/m^2.

❖ **Characterisation of the elements that make up the thermal envelope**

❖ **Opaque façades**

Opaque façades represent **31.71%** of the coefficient of the transfer of heat by transmission (H_{tr}).

Table 3.12: *Thermal Transmittance and Heat Loss Characteristics of Opaque Façades(CYPE2026)*

	Type	S (m²)	U (W/(m²·K))	U_{lim} (W/(m²·K))	α	O. (°)	S·U (W/K)	
Z								
Façade		63.84	1.22	0.50	0.60	West(270)	77.95	✗
Façade		41.80	1.22	0.50	0.60	North(0)	51.03	✗
Façade		64.02	1.22	0.50	0.60	East(90)	78.17	✗
Façade		38.69	1.22	0.50	0.60	South(180)	47.24	✗
Vertical internal partition		3.30	1.66	0.60	-	-	5.49	✗
Vertical internal partition		2.05	1.66	0.60	-	-	3.41	✗
							263.30	

Where :

S: Surface, m².

U: Thermal transmittance, W/(m²·K).

U_{lim}: Applied limit thermal transmittance, W/(m²·K).

α: Solar absorption coefficient (absorptivity) of the opaque surface.

O.: Surface orientation (azimuth with respect to the north), °.

❖ **Fenestration**

Openings represent **0.90%** of the coefficient of the transfer of heat by transmission (H_{tr}).

Table 3.12: *Summary of Surface Areas and Thermal Performance for Opaque Building Elements CYPE2026*

	S (m²)	O. (°)	F_F (%)	U (W/(m²·K))	U_{lim} (W/(m²·K))	S·U (W/K)	$g_{gl,n}$	
Z								
	1.44	North(0)	-	0	0	0	0	✓
	1.44	North(0)	-	0	0	0	0	✓
	1.44	South(180)	-	0	0	0	0	✓
	1.44	South(180)	-	0	0	0	0	✓
	1.44	South(180)	-	0	0	0	0	✓
	1.44	South(180)	-	0	0	0	0	✓
	1.44	North(0)	-	0	0	0	0	✓
	1.44	North(0)	-	0	0	0	0	✓
	0.36	North(0)	-	0	0	0	0	✓
	0.36	North(0)	-	0	0	0	0	✓

P 1	3.75	South(180)	1.00	2.00	5.70	7.50	0	✓
						7.50		

Where :

S: Surface, m^2.

O.: Surface orientation (azimuth with respect to the north), °.

F_F: Opaque part fraction, %.

U: Thermal transmittance, $W/(m^2 \cdot K)$.

U_{lim}: Applied limit thermal transmittance, $W/(m^2 \cdot K)$.

g_{gl}: Solar heat gain coefficient.

2.2.3. Thermal bridge :

Thermal bridges represent **67.38%** of the coefficient of the transfer of heat by transmission (H_{tr}).

***Table 3.13:** Calculation of heat transfer coefficients for opening(CYPE2026)*

	Type	**L** (m)	**Ψ** (W/(m·K))	**L·Ψ** (W/K)
Z				
Other (not considered in the reference building)	?	1016.903	0.500	508.5
Intersection of façade with screed		72.963	0.500	36.5
Projecting corner of the façades		22.540	0.500	11.3
Window opening		6.500	0.500	3.2
				559.5

Where :

L: Length, m.

Ψ: Linear thermal transmitance, $W/(m \cdot K)$.

3.23. Murs Ext :

3.23.1. Condensation analysis results

- **Surface condensation**

$f_{Rsi} = 0.695 \geq f_{Rsi,\,min} = 0.338$

The building element does not show any signs of surface condensation.

Where :

f_{Rsi}: Internal surface resistance factor, calculated as $(1 - U \cdot R_{si})$, where $U = 1.221\ W/m^2 \cdot K$ and $R_{si} = 0.25\ m^2 \cdot K/W$.

$f_{Rsi,min}$: Minimum internal surface resistance factor, required to avoid the critical surface humidity, calculated using a value of $\varphi_{si,cr} \leq 0.8$.

Interstitial condensationThe building element does not show any sign of interstitial condensation.

- **Hygrothermal design conditions**

The internal and external hygrothermal conditions used to carry out the condensation calculations are the following:

Table3.15: *Surface condensation analysis results(CYPE2026)*													
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
External conditions													
Temperature, θ_e	(°C)	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Relative humidity, φ_e	(%)	50	50	50	50	50	50	50	50	50	50	50	50
Internal conditions													
Temperature, θ_i	(°C)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Relative humidity, φ_i	(%)	60	60	60	60	60	60	60	60	60	60	60	60

The psychrometric diagram associated with the location, with a height above sea level of **800 m**, is displayed below. Represented using straight line segments are the transitions from each external design condition to its corresponding internal condition.

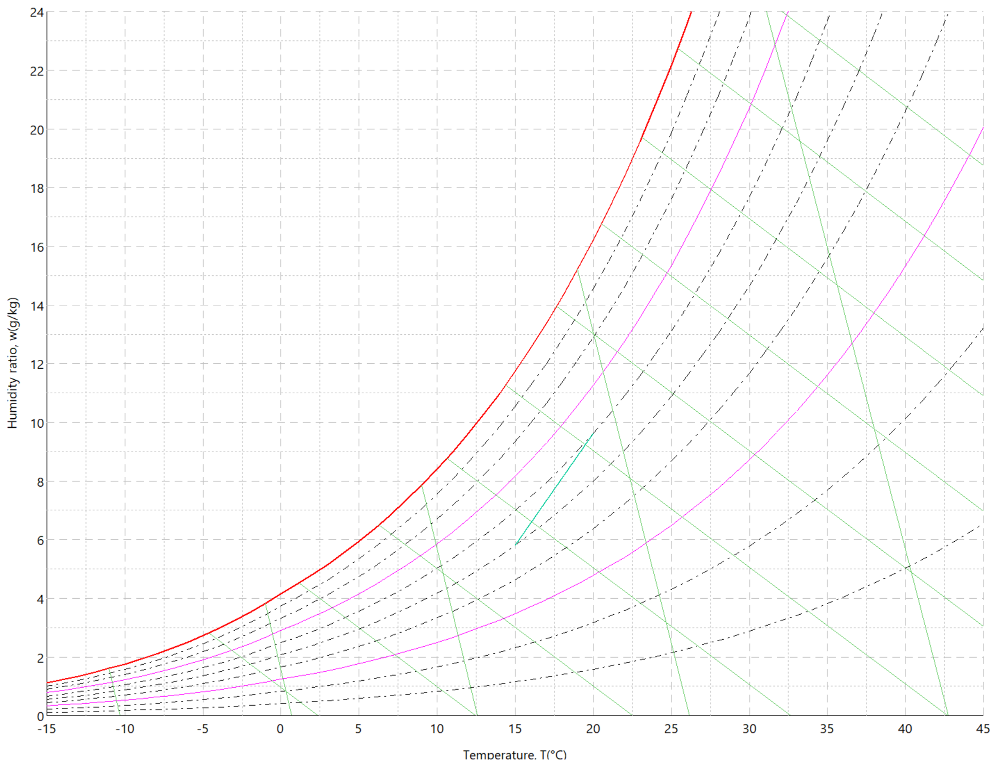


Figure 3.11: Psychometric chart of Al evolutions

Description of the building element

Below is the section diagram of the composition of the building element:

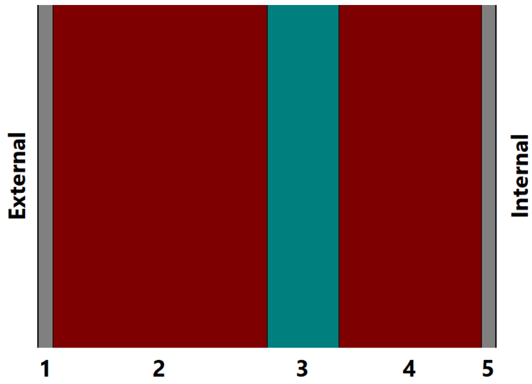


Figure 3.12: Graphical reparesentation of the multilayer structure of the outer wall (cype ,2025)

The thermal properties and water vapour diffusion properties of the homogenous layers of the parallel sides making up the design model of the building element are as follows:

Table 3.16: *Thermal and physical properties of the layers constituting the external wallCYPE2026*

	Murs Ext	**e** (cm)	**λ** (W/m·K)	**R** (m²·K/W)	**M**	**S_d** (m)
R_{se}				0.04		
1	Mortier (Masse volumique sèche 1700)	1.0	1.000	0.01000	8	0.08
2	Terre cuite (Masse volumique nominale 2000)	15.0	0.790	0.18987	13	1.95
3	Polystyrène	5.0	0.160	0.31250	100000	5000
4	Terre cuite (Masse volumique nominale 2000)	10.0	0.790	0.12658	13	1.3
5	Mortier (Masse volumique sèche 1700)	1.0	1.000	0.01000	8	0.08
R_{si}				0.13		

Where :

e: Thickness, cm.

λ: Thermal conductivity of the material, W/(m·K).

R: Thermal resistance of the material, m²·K/W.

μ: Water vapour diffusion resistance factor of the material.

S_d: Equivalent air thickness against the water vapour diffusion, m.

R_{se}: External surface thermal resistance of the element, m²·K/W.

R_{si}: Internal surface thermal resistance of the element, m²·K/W.

The design information regarding the hygrothermal parameters of the complete element, derived from the homogenous layer model, is the following:

Magnitude	Units	Value
Total thickness of the element, e_T	cm	32.0
Total thermal resistance, R_T	m²·K/W	0.8190

Total equivalent air thickness, $S_{d,T}$	m	5003.41
Thermal transmittance, U	W/(m²·K)	1.221
Internal surface resistance factor, f_{Rsi}	--	0.695

Where :

E_T: Total thickness of the element, cm.

R_T: Total thermal resistance of the element, sum of the thermal resistance of each layer, including surface resistances R_{se} and R_{si}, m²·K/W.

S_{dT}: Total equivalent air thickness, sum of the equivalent thickness of each layer of the element, m.

U: Thermal transmittance of the element, calculated as the inverse of the total thermal resistance, W/(m²·K).

f_{Rsi}: Internal surface resistance factor, calculated as (1 - U·R_{si}), where U = 1.221 W/m²·K and R_{si} = 0.25 m²·K/W.

3.24.Calculation of the internal surface temperature required to avoid the critical surface humidity:

With the aim to prevent the adverse affects of the critical surface humidity, the maximum relative humidity on the internal surface has been limited to a value of $\boldsymbol{\varphi_{si,\,cr} \leq 0.8}$.

Given the external and internal hygrothermal conditions, $f_{Rsi,\,min}$ is calculated as follows:

Table 3.17: *Monthly calculation of the minimum required internal surface temperature factor (fRsi,min) to prevent surface condensation(CYPE2026)*

	θ_e (°C)	φ_e (%)	θ_i (°C)	φ_i (%)	P_i (Pa)	P_{sat} (θ_{si}) (Pa)	$\theta_{si,min}$ (°C)	$f_{Rsi,min}$
January	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
February	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
March	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
April	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
May	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
June	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
July	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
August	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
September	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
October	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
November	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
December	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338

Where :

θ_e: External air temperature, °C.

φ_e: Relative humidity of the external air, %.

θ_i: Internal air temperature, °C.

φ_i: Relative humidity of the internal air, increased by a safety coefficient 5%, %.

P_i: Vapour pressure in the internal air, Pa.

$P_{sat}(\theta_{si})$: Minimum acceptable water vapour saturation pressure for the internal surface, Pa.

$\theta_{si,min}$: Minimum acceptable internal surface temperature, calculated based on the minimum acceptable saturation pressure, °C.

$f_{Rsi,min}$: Minimum internal surface resistance factor.

Given that $\mathbf{f_{Rsi} = 0.695 > f_{Rsi,min} = 0.338}$, no surface condensation occurs in the building element.

3.24.1. Interstitial condensation calculation

Displayed below are the results obtained in the analysis of the temperatures and pressures at each interphase of the homogenous layers making up the design model of the building element.

- **Calculation of the interstitial condensation in the month of January.**

Table 3.17: *Summary of hygrothermal design conditions for condensation calculation CYPE2026*

Murs Ext	θ (°C)	P_{sat} (Pa)	P_n (Pa)	φ (%)	g_c (g/(m²·month))	M_a (g/m²)
External air	15.00	1704.407	852.204	50.0		
External surface	15.24	1731.389	852.204	49.2	--	--
Interface 1-2	15.31	1738.193	852.212	49.0	--	--
Interface 2-3	16.46	1871.900	852.427	45.5	--	--
Interface 3-4	18.37	2111.630	1402.019	66.4	--	--
Interface 4-5	19.15	2216.130	1402.162	63.3	--	--
Internal surface	19.21	2224.575	1402.171	63.0	--	--
Internal air	20.00	2336.951	1402.171	60.0		

Where :

θ: Temperature, °C.

P_{sat}: Water vapour saturation pressure, Pa.

P_n: Water vapour pressure, Pa.

φ: Relative humidity, %.

g_c: Condensation flow density, g/(m²·month).

M_a: Accumulated humidity content per unit area, g/m².

❖ **Graphical representation of the foreseen interstitial condensation**

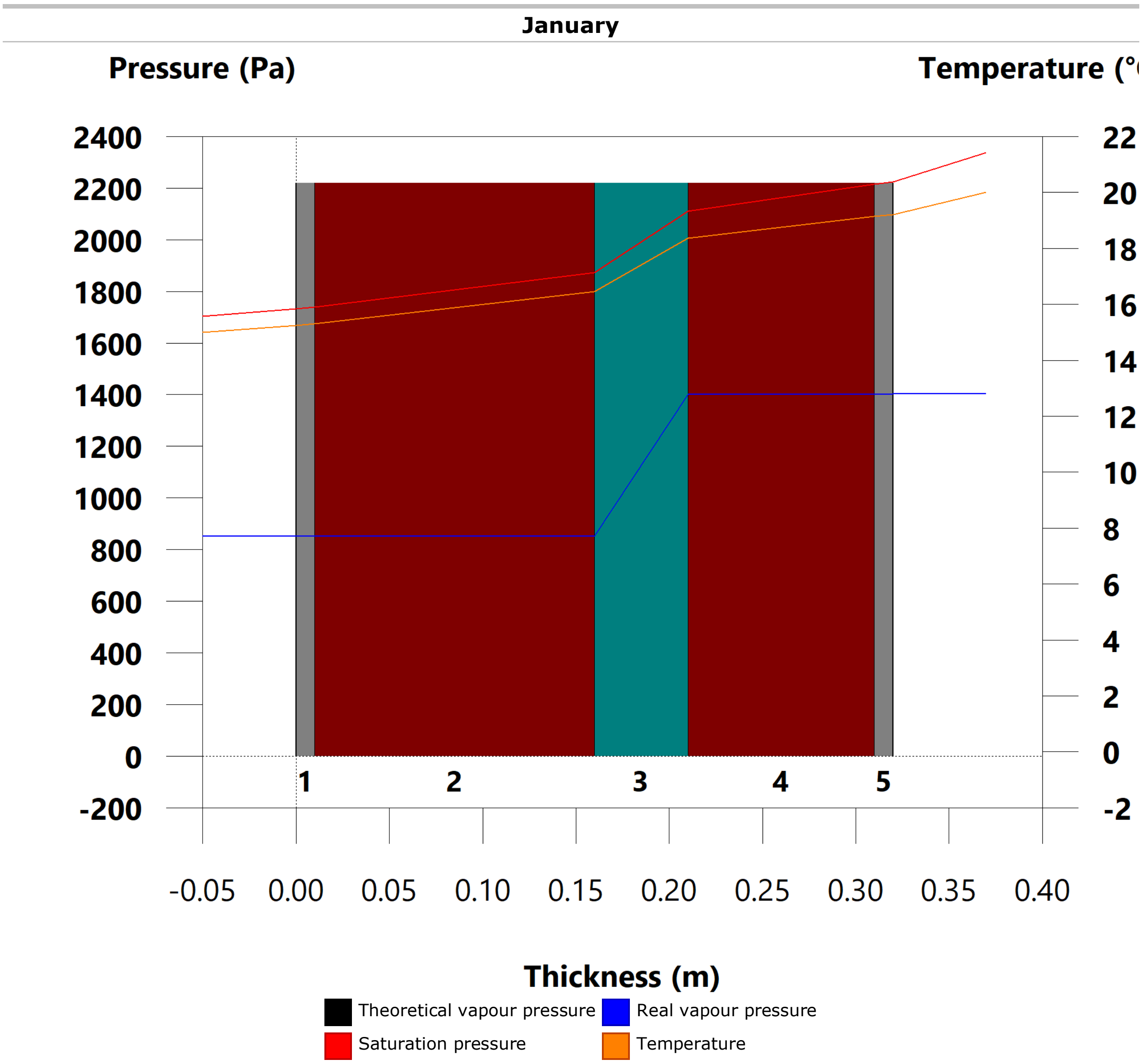


Figure 3.13: Glaser diagram of the wall under the climatic conditions of January (cype, 2025)

3.25. Cloisons 30 cm:

3.25.1. Condensation analysis results :

➤ **Surface condensation**

$$f_{Rsi} = 0.585 \geq f_{Rsi,\ min} = 0.338$$

The building element does not show any signs of surface condensation.

Where :

f_{Rsi}: Internal surface resistance factor, calculated as (1 - U·R_{si}), where U = 1.662 W/m²·K and R_{si} = 0.25 m²·K/W.

$f_{Rsi,min}$: Minimum internal surface resistance factor, required to avoid the critical surface humidity, calculated using a value of $\varphi_{si,cr} \leq 0.8$.

➤ **Interstitial condensation**

The building element does not show any sign of interstitial condensation.

➤ **Hygrothermal design conditions**

The internal and external hygrothermal conditions used to carry out the condensation calculations are the following:

***Table 3.18**: Composition and characteristics of the homogeneous layers for the 30 cm partition wall (CYPE2026)*

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
External conditions													
Temperature, θ_e	(°C)	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Relative humidity, φ_e	(%)	50	50	50	50	50	50	50	50	50	50	50	50
Internal conditions													
Temperature, θ_i	(°C)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Relative humidity, φ_i	(%)	60	60	60	60	60	60	60	60	60	60	60	60

The psychrometric diagram associated with the location, with a height above sea level of **800 m**, is displayed below. Represented using straight line segments are the transitions from each external design condition to its corresponding internal condition.

➤ **Description of the building element**

Below is the section diagram of the composition of the building element:

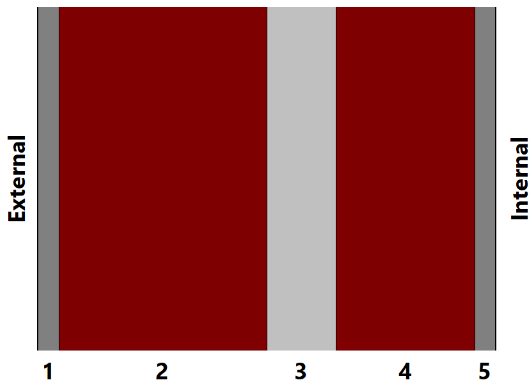


Figure 3.14: Multilayer structure and identification of homogeneous wall of the envelope (cype,2025)

The thermal properties and water vapour diffusion properties of the homogenous layers of the parallel sides making up the design model of the building element are as follows:

***Table 3.19**: Calculation of the minimum temperature factor(CYPE2026)*

	Cloisons 30 cm	e (cm)	λ (W/m·K)	R (m^2·K/W)	μ	S_d (m)
R_{se}				0.13		
1	Mortier (Masse volumique sèche 1700)	1.5	1.000	0.01500	8	0.12
2	Terre cuite (Masse volumique nominale 2200)	15.0	0.920	0.16304	13	1.95
3	Aire	5.0		0.04000		0.01
4	Terre cuite (Masse volumique nominale 2200)	10.0	0.920	0.10870	13	1.3
5	Mortier (Masse volumique sèche 1700)	1.5	1.000	0.01500	8	0.12
R_{si}				0.13		

Where :

e: Thickness, cm.

λ: Thermal conductivity of the material, W/(m·K).

R: Thermal resistance of the material, m^2·K/W.

μ: Water vapour diffusion resistance factor of the material.

S_d: Equivalent air thickness against the water vapour diffusion, m.

R_{se}: External surface thermal resistance of the element, m^2·K/W.

R_{si}: Internal surface thermal resistance of the element, m^2·K/W.

The design information regarding the hygrothermal parameters of the complete element, derived from the homogenous layer model, is the following:

Magnitude	Units	Value
Total thickness of the element, e_T	cm	33.0
Total thermal resistance, R_T	m^2·K/W	0.6017
Total equivalent air thickness, $S_{d,T}$	m	3.50
Thermal transmittance, U	W/(m^2·K)	1.662
Internal surface resistance factor, f_{Rsi}	--	0.585

Where :

E_T: Total thickness of the element, cm.

R_T: Total thermal resistance of the element, sum of the thermal resistance of each layer, including surface resistances R_{se} and R_{si}, m^2·K/W.

S_{dT}: Total equivalent air thickness, sum of the equivalent thickness of each layer of the element, m.

U: Thermal transmittance of the element, calculated as the inverse of the total thermal resistance, W/(m^2·K).

f_{Rsi}: Internal surface resistance factor, calculated as (1 - U·R_{si}), where U = 1.662 W/m²·K and R_{si} = 0.25 m²·K/W.

3.26. Calculation of the internal surface temperature required to avoid the critical surface humidity:

With the aim to prevent the adverse affects of the critical surface humidity, the maximum relative humidity on the internal surface has been limited to a value of $\boldsymbol{\varphi_{si,\,cr} \leq 0.8}$.

Given the external and internal hygrothermal conditions, $f_{Rsi,\,min}$ is calculated as follows:

***Table 3.20**: Calculation of interstitial condensation for the 30 cm partition in January(CYPE2026)*

	θ_e (°C)	ϕ_e (%)	θ_i (°C)	ϕ_i (%)	P_i (Pa)	P_{sat} (θ_{si}) (Pa)	$\theta_{si,min}$ (°C)	$f_{Rsi,min}$
January	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
February	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
March	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
April	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
May	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
June	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
July	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
August	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
September	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
October	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
November	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338
December	15.0	50.0	20.0	65.0	1519.02	1898.77	16.7	0.338

Where :

θ_e: External air temperature, °C.

φ_e: Relative humidity of the external air, %.

θ_i: Internal air temperature, °C.

φ_i: Relative humidity of the internal air, increased by a safety coefficient 5%, %.

P_i: Vapour pressure in the internal air, Pa.

$P_{sat}(\theta_{si})$: Minimum acceptable water vapour saturation pressure for the internal surface, Pa.

$\theta_{si,min}$: Minimum acceptable internal surface temperature, calculated based on the minimum acceptable saturation pressure, °C.

$f_{Rsi,min}$: Minimum internal surface resistance factor.

Given that $\mathbf{f_{Rsi} = 0.585 > f_{Rsi,min} = 0.338}$, no surface condensation occurs in the building element.

3.26.1. Interstitial condensation calculation:

Displayed below are the results obtained in the analysis of the temperatures and pressures at each interphase of the homogenous layers making up the design model of the building element.

- **Calculation of the interstitial condensation in the month of January.**

Table3.21 : *Annual evolution of the indoor temperature(CYPE2026)*

Cloisons 30 cm	θ (°C)	P_{sat} (Pa)	P_n (Pa)	ϕ (%)	g_c (g/(m²·month))	M_a (g/m²)
External air	15.00	1704.407	852.204	50.0		
External surface	16.08	1826.609	852.204	46.7	--	--
Interface 1-2	16.20	1841.191	871.060	47.3	--	--
Interface 2-3	17.56	2006.401	1177.470	58.7	--	--
Interface 3-4	17.89	2048.862	1179.041	57.5	--	--
Interface 4-5	18.80	2168.244	1383.315	63.8	--	--
Internal surface	18.92	2185.187	1402.171	64.2	--	--
Internal air	20.00	2336.951	1402.171	60.0		

Where :

θ: Temperature, °C.

P_{sat}: Water vapour saturation pressure, Pa.

P_n: Water vapour pressure, Pa.

φ: Relative humidity, %.

g_c: Condensation flow density, g/(m²·month).

M_a: Accumulated humidity content per unit area, g/m².

3.27.Graphical representation of the foreseen interstitial condensation:

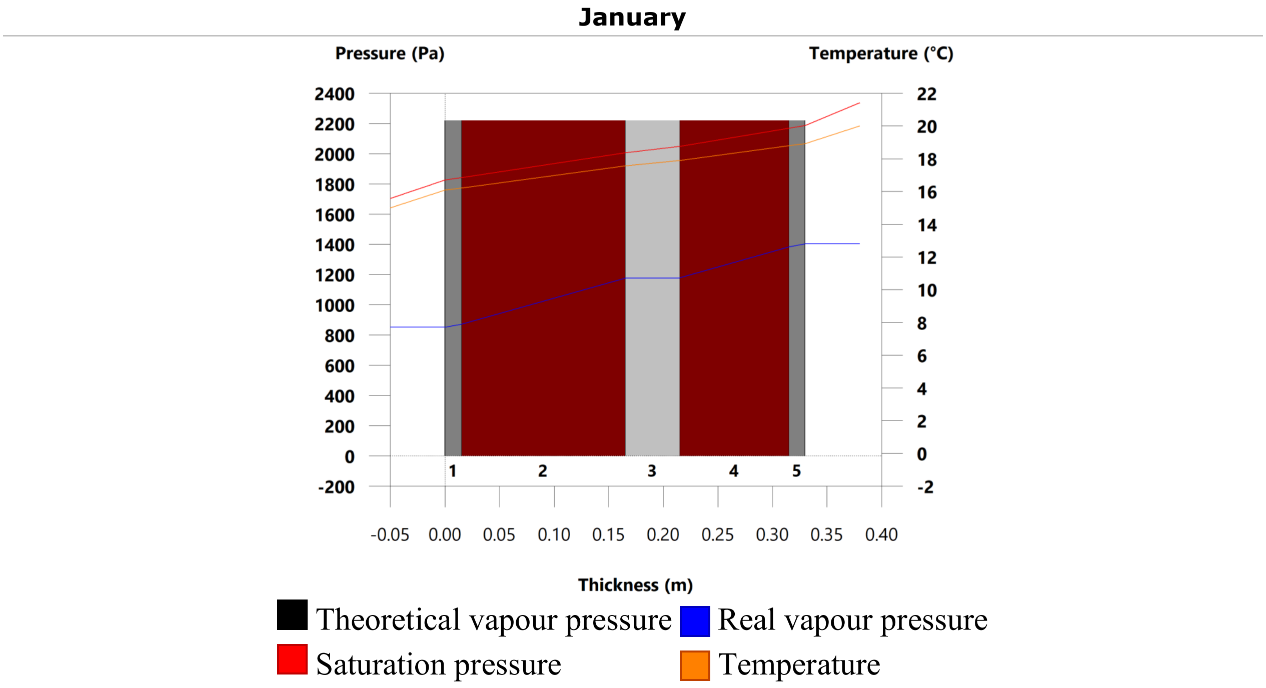


Figure 3.14: Simulation of the thermo-hygrometric parameters of the buildind element in January (cype,2025)

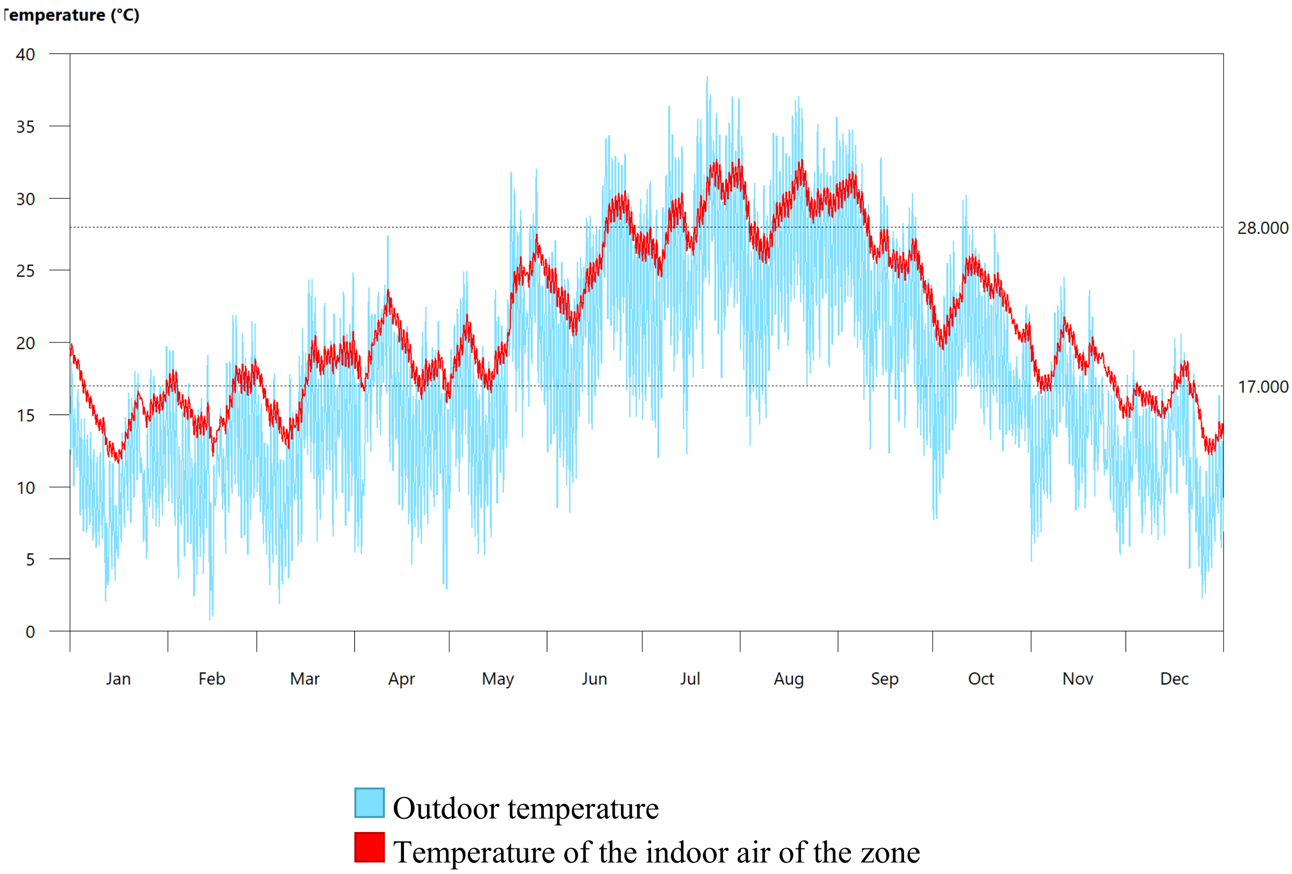


Figure 3.16:Annual evolution of the outside temperature (Cype,2025)

***Table 3.22**: Annual evolution of the indoor temperature(CYPE2026)*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Maximum comfort temperature (28.0 °C)													
$T_{in,max}$ (°C)	19.9	18.9	20.7	23.7	27.5	30.5	32.7	32.7	31.9	26.1	21.8	18.8	32.7
$T_{int} > T_{max,comf}$ (Hour)	0	0	0	0	0	196	448	574	228	0	0	0	1446
$T_{int} > T_{max,comf}$ (Hour/Occupancy)	0	0	0	0	0	196	448	574	228	0	0	0	1446
Minimum comfort temperature (17.0 °C)													
$T_{in,min}$ (°C)	11.6	12.1	12.6	15.8	16.1	20.4	24.5	25.4	22.3	19.4	14.8	12.2	11.6
$T_{int} < T_{min,comf}$ (Hour)	626	478	326	65	26	0	0	0	0	0	111	609	2241
$T_{int} < T_{min,comf}$ (Hour/Occupancy)	626	478	326	65	26	0	0	0	0	0	111	609	2241
Unmet load hours*													
Heating (Hour)	336.00	297.25	323.00	294.50	277.00	216.25	177.75	170.25	195.25	262.25	299.00	336.00	3184.50
Heating (Hour/Occupancy)	336.00	297.25	323.00	294.50	277.00	216.25	177.75	170.25	195.25	262.25	299.00	336.00	3184.50
Cooling (Hour)	--	--	--	--	--	--	--	--	--	--	--	--	0
Cooling (Hour/Occupancy)	--	--	--	--	--	--	--	--	--	--	--	--	0

*Number of hours in which the air temperature of the spaces of the zone lies outside the range of the setpoint heating or cooling temperatures, with a margin greater than 0.2 °C for heating and 0.2 °C for cooling.

Where :

T_{int}: Temperature of the indoor air of the zone, °C.

$T_{in,max}$: Maximum temperature of the indoor air of the zone, °C.

$T_{in,min}$: Minimum temperature of the indoor air of the zone, °C.

$T_{max,comf}$: Maximum comfort temperature, °C.

$T_{min,comf}$: Minimum comfort temperature, °C.

In conclusion, the results of this study, based on the CYPE 2026 methodology, showed that the performance of the building under consideration requires careful treatment of thermal bridges, which are the main cause of heat loss, whilst ensuring a thermal envelope that complies with condensation standards (ISO 13788). The figures also indicate that the annual demand for heating (285.72 kWh/m²) and the need to maintain temperatures within the thermal comfort range necessitate the adoption of improved design strategies; such as increasing insulation efficiency and managing heat exchange to ensure a sustainable indoor environment that is more energy-efficient."

Overall Conclusion:

The final-year project provides students with an opportunity to apply the knowledge acquired during their studies. This experience has also enabled us to gain an understanding of methods for calculating and analysing structures, and to apply regulations such as: RPA2024. In this project, we studied a reinforced concrete building from a structural perspective and analysed its thermal performance. The results showed that the building meets the required stability and resistance criteria. We used ETABS software to interpret the results, which enabled us to determine the reinforcement requirements for the various structural elements. It is very important for the civil engineer and the architect to work in close collaboration from the start of the project to avoid any inadequate designs and to achieve seismic safety without significant additional cost and its thermal performance and energy consumption were also assessed." ThereWe noted some heat losses and certain shortcomings that could affect the building's efficiency." A thermal analysis of the building was carried out using CYPE software to assess energy performance and study heat losses. The results obtained allowed us to determine the effectiveness of the insulation and systems used within the building, «The results of this study, conducted in accordance with methodology, show that a building's performance is closely linked to the efficiency of its thermal envelope. Analyses revealed that thermal bridges represent the most significant challenge, as they account for a large proportion of total heat loss, which directly affects energy consumption rates for heating. Furthermore, condensation studies confirmed that the materials used comply with technical standards (ISO 13788) and are free from moisture-related risks, whilst thermal comfort data highlights the need for design improvements to maintain indoor temperatures within comfortable ranges (17–28 °C) throughout the year.

In conclusion, this study confirms that improving a building's energy performance requires an integrated strategy, ranging from addressing thermal bridges and enhancing insulation to improving the efficiency of technical systems, thereby ultimately ensuring a sustainable indoor environment that is more energy-efficient. and We proposed improving thermal insulation and using more efficient systems to reduce energy consumption." In the future, this study could be further developed by utilising renewable energy and modern building materials to improve overall performance.

BIBLIOGRAPHY

The Rules :

- ***RPA2024 :** Règlement Parasismique Algérien.*
- ***BAEL91** : Béton Armé Aux Etats Limites.*
- ***BAEL99** : Béton Armé Aux Etats Limites.*
- ***D.T.R.B.C 2.2** : Document Technique Réglementaire (charges permanentes et charges d'exploitation).*
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- • DTR **C3-4 (1997) :** *Règlement Technique Algérien - "Règles de calcul des apports thermiques des bâtiments"*, Ministère de l'Habitat, Alger, Algérie.

Articles And Books :

- **ISO 9869-1:2014.** *Thermal insulation — Building elements — In-situ measurement of thermal resistance and thermal transmittance — Part 1: Heat flow meter method. International Organization for Standardization*.
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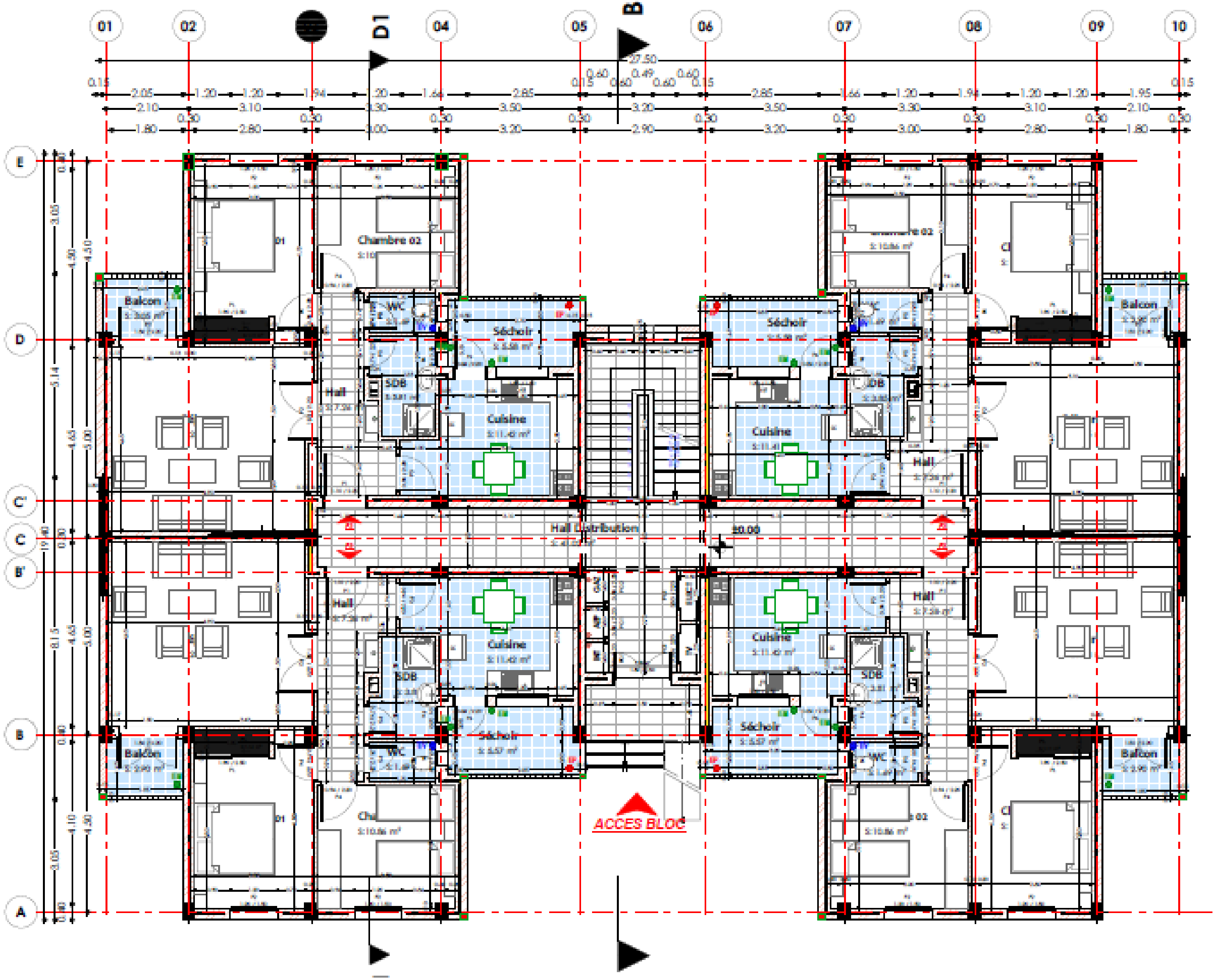
- *Antoine. (S.d.). Déperditions thermiques : de quoi s'agit-il et quelles sont les solutions. Hellio. [Lien consulté].*
- The Effectiveness of Thermal Insulation in Different Types of Buildings in Hot Climates (Journal of Thermal Envelope and Building Science,2004)
- *(Dong, Y; Kong, Mousavi,Rimanchi,B & Yap (2023))*

Software:

- **ETABS 2022**
- **CYPE 2026**
- **AUTOCAD 2017**
- **WORD+Excel 2016**



01
02
D1
04
05
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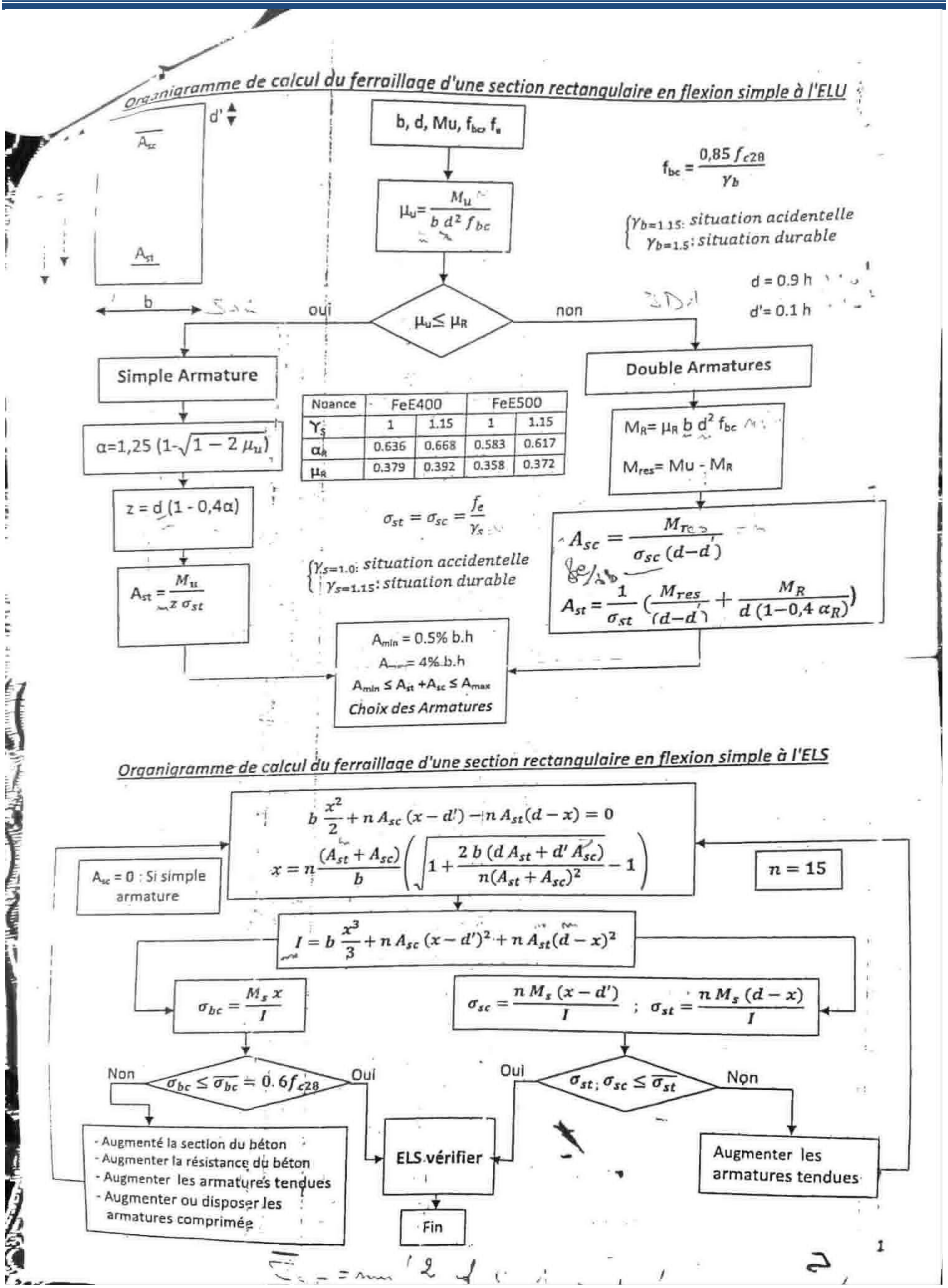
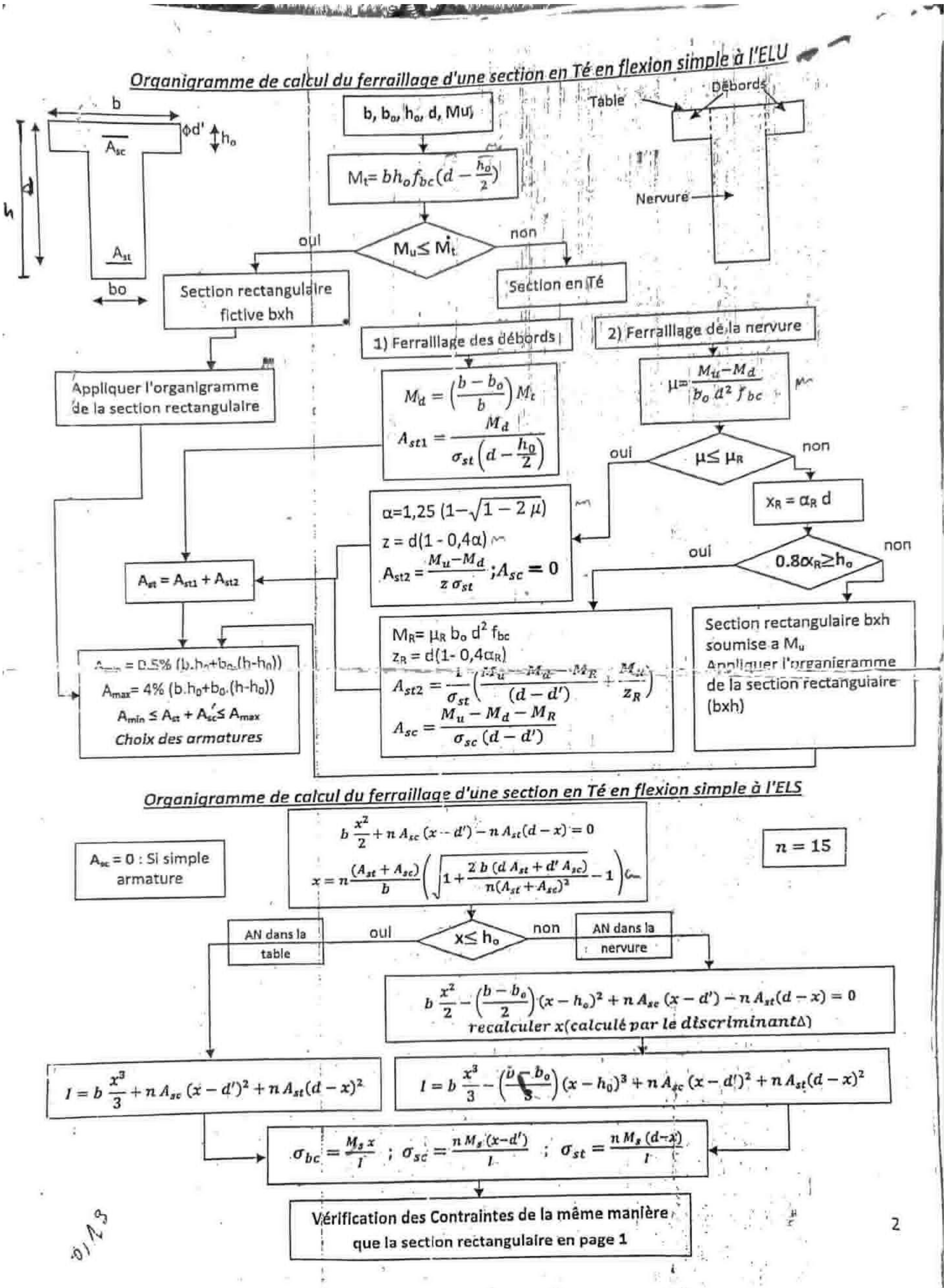
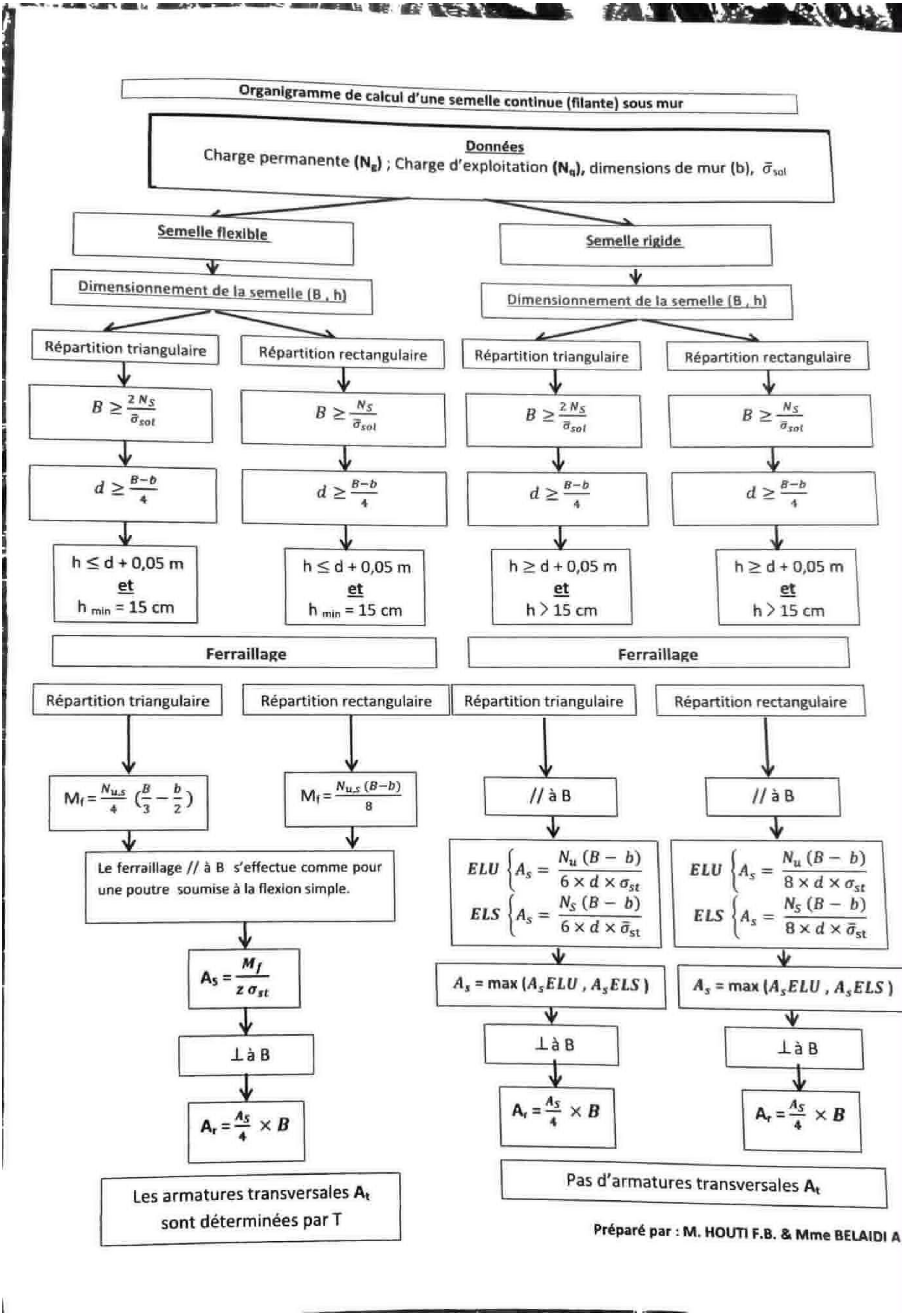
08
09
10
27.50
E
D
C'
C
B'
B
A
Chambre 02
Balcon
WC
Séchoir
SDB
Hall
Cuisine
Hall Distribution
±0.00
ACCES BLOC


Organigramme de calcul du ferraillage d'une section rectangulaire en flexion simple à l'ELU
b, d, Mu, f_{bc}, f_e
$\mu_u = \frac{M_u}{b\,d^2 f_{bc}}$
$f_{bc} = \frac{0,85 f_{c28}}{\gamma_b}$
$\gamma_{b=1.15}$: situation acidentelle
$\gamma_{b=1.5}$: situation durable
d = 0.9 h
d'= 0.1 h
$\mu_u \leq \mu_R$
oui
non
Simple Armature
Double Armatures
α=1,25 (1-$\sqrt{1-2\mu_u}$)
z = d (1 - 0,4α)
$A_{st} = \frac{M_u}{z\,\sigma_{st}}$
Nuance | FeE400 | FeE500
γ_s | 1 | 1.15 | 1 | 1.15
α_R | 0.636 | 0.668 | 0.583 | 0.617
μ_R | 0.379 | 0.392 | 0.358 | 0.372
$\sigma_{st} = \sigma_{sc} = \frac{f_e}{\gamma_s}$
$\gamma_{s=1.0}$: situation accidentelle
$\gamma_{s=1.15}$: situation durable
$M_R = \mu_R\, b\, d^2 f_{bc}$
M_{res} = Mu - M_R
$A_{sc} = \frac{M_{res}}{\sigma_{sc}(d-d')}$
$A_{st} = \frac{1}{\sigma_{st}}\left(\frac{M_{res}}{(d-d')} + \frac{M_R}{d(1-0,4\alpha_R)}\right)$
A_{min} = 0.5% b.h
A_{max} = 4% b.h
$A_{min} \leq A_{st} + A_{sc} \leq A_{max}$
Choix des Armatures
Organigramme de calcul du ferraillage d'une section rectangulaire en flexion simple à l'ELS
$b\frac{x^2}{2} + n A_{sc}(x-d') - n A_{st}(d-x) = 0$
$x = n\frac{(A_{st}+A_{sc})}{b}\left(\sqrt{1+\frac{2b(d A_{st}+d' A_{sc})}{n(A_{st}+A_{sc})^2}} - 1\right)$
A_{sc} = 0 : Si simple armature
$n = 15$
$I = b\frac{x^3}{3} + n A_{sc}(x-d')^2 + n A_{st}(d-x)^2$
$\sigma_{bc} = \frac{M_s\, x}{I}$
$\sigma_{sc} = \frac{n M_s (x-d')}{I}$; $\sigma_{st} = \frac{n M_s (d-x)}{I}$
Non
$\sigma_{bc} \leq \overline{\sigma_{bc}} = 0.6 f_{c28}$
Oui
Oui
$\sigma_{st}; \sigma_{sc} \leq \overline{\sigma_{st}}$
Non
- Augmenté la section du béton
- Augmenter la résistance du béton
- Augmenter les armatures tendues
- Augmenter ou disposer les armatures comprimée
ELS vérifier
Augmenter les armatures tendues
Fin


Organigramme de calcul du ferraillage d'une section en Té en flexion simple à l'ELU
b
ϕd'
h_o
A_{sc}
h
d
A_{st}
bo
Table
Débords
Nervure
b, b_o, h_o, d, Mu
$M_t = b h_o f_{bc}(d - \frac{h_o}{2})$
oui
non
$M_u \leq M_t$
Section rectangulaire fictive bxh
Section en Té
Appliquer l'organigramme de la section rectangulaire
1) Ferraillage des débords
2) Ferraillage de la nervure
$M_d = \left(\frac{b-b_o}{b}\right) M_t$
$A_{st1} = \frac{M_d}{\sigma_{st}\left(d - \frac{h_0}{2}\right)}$
$\mu = \frac{M_u - M_d}{b_o d^2 f_{bc}}$
$\mu \leq \mu_R$
$x_R = \alpha_R d$
$\alpha = 1{,}25\,(1 - \sqrt{1 - 2\mu})$
$z = d(1 - 0{,}4\alpha)$
$A_{st2} = \frac{M_u - M_d}{z\,\sigma_{st}}$; $A_{sc} = 0$
$0.8\alpha_R \geq h_o$
$A_{st} = A_{st1} + A_{st2}$
$M_R = \mu_R b_o d^2 f_{bc}$
$z_R = d(1 - 0{,}4\alpha_R)$
$A_{st2} = \frac{1}{\sigma_{st}}\left(\frac{M_u - M_d - M_R}{(d - d')} + \frac{M_u}{z_R}\right)$
$A_{sc} = \frac{M_u - M_d - M_R}{\sigma_{sc}(d - d')}$
Section rectangulaire bxh soumise a M_u
Appliquer l'organigramme de la section rectangulaire (bxh)
A_{min} = 0.5% ($b.h_o + b_o.(h - h_o)$)
A_{max} = 4% ($b.h_o + b_o.(h - h_o)$)
$A_{min} \leq A_{st} + A'_{sc} \leq A_{max}$
Choix des armatures
Organigramme de calcul du ferraillage d'une section en Té en flexion simple à l'ELS
$A_{sc} = 0$: Si simple armature
$b\frac{x^2}{2} + n A_{sc}(x - d') - n A_{st}(d - x) = 0$
$x = n\frac{(A_{st} + A_{sc})}{b}\left(\sqrt{1 + \frac{2b(d A_{st} + d' A_{sc})}{n(A_{st} + A_{sc})^2}} - 1\right)$
$n = 15$
AN dans la table
oui
$x \leq h_o$
non
AN dans la nervure
$b\frac{x^2}{2} - \left(\frac{b - b_o}{2}\right)(x - h_o)^2 + n A_{sc}(x - d') - n A_{st}(d - x) = 0$
recalculer x(calculé par le discriminantΔ)
$I = b\frac{x^3}{3} + n A_{sc}(x - d')^2 + n A_{st}(d - x)^2$
$I = b\frac{x^3}{3} - \left(\frac{b - b_o}{3}\right)(x - h_0)^3 + n A_{sc}(x - d')^2 + n A_{st}(d - x)^2$
$\sigma_{bc} = \frac{M_s x}{I}$; $\sigma_{sc} = \frac{n M_s (x - d')}{I}$; $\sigma_{st} = \frac{n M_s (d - x)}{I}$
Vérification des Contraintes de la même manière que la section rectangulaire en page 1
2


Organigramme de calcul d'une semelle continue (filante) sous mur
Données
Charge permanente (N_g) ; Charge d'exploitation (N_q), dimensions de mur (b), $\bar{\sigma}_{sol}$
Semelle flexible
Semelle rigide
Dimensionnement de la semelle (B , h)
Dimensionnement de la semelle (B , h)
Répartition triangulaire
Répartition rectangulaire
Répartition triangulaire
Répartition rectangulaire
$B \geq \frac{2\,N_S}{\bar{\sigma}_{sol}}$
$B \geq \frac{N_S}{\bar{\sigma}_{sol}}$
$B \geq \frac{2\,N_S}{\bar{\sigma}_{sol}}$
$B \geq \frac{N_S}{\bar{\sigma}_{sol}}$
$d \geq \frac{B-b}{4}$
$d \geq \frac{B-b}{4}$
$d \geq \frac{B-b}{4}$
$d \geq \frac{B-b}{4}$
h ≤ d + 0,05 m et h_{min} = 15 cm
h ≤ d + 0,05 m et h_{min} = 15 cm
h ≥ d + 0,05 m et h > 15 cm
h ≥ d + 0,05 m et h > 15 cm
Ferraillage
Ferraillage
Répartition triangulaire
Répartition rectangulaire
Répartition triangulaire
Répartition rectangulaire
$M_f = \frac{N_{u,s}}{4}\left(\frac{B}{3} - \frac{b}{2}\right)$
$M_f = \frac{N_{u,s}\,(B-b)}{8}$
// à B
// à B
Le ferraillage // à B s'effectue comme pour une poutre soumise à la flexion simple.
$ELU \left\{ A_s = \frac{N_u\,(B-b)}{6 \times d \times \sigma_{st}} \right.$
$ELS \left\{ A_s = \frac{N_S\,(B-b)}{6 \times d \times \bar{\sigma}_{st}} \right.$
$ELU \left\{ A_s = \frac{N_u\,(B-b)}{8 \times d \times \sigma_{st}} \right.$
$ELS \left\{ A_s = \frac{N_S\,(B-b)}{8 \times d \times \bar{\sigma}_{st}} \right.$
$A_S = \frac{M_f}{z\,\sigma_{st}}$
$A_s = \max(A_s ELU\,,\, A_s ELS)$
$A_s = \max(A_s ELU\,,\, A_s ELS)$
⊥ à B
⊥ à B
⊥ à B
$A_r = \frac{A_S}{4} \times B$
$A_r = \frac{A_S}{4} \times B$
$A_r = \frac{A_S}{4} \times B$
Les armatures transversales A_t sont déterminées par T
Pas d'armatures transversales A_t
Préparé par : M. HOUTI F.B. & Mme BELAIDI A

Ø mm	Poids au ml [kg]	nbre / Périmètre cm	SECTIONS EN CENTIMETRES CARRES									
			1	2	3	4	5	6	7	8	9	10
5	0.154	1.6	0.20	0.39	0.59	0.79	0.98	1.18	1.37	1.57	1.77	1.96
6	0.222	1.9	0.28	0.57	0.85	1.13	1.41	1.70	1.98	2.26	2.54	2.83
8	0.392	2.5	0.50	1.01	1.51	2.01	2.51	3.02	3.52	4.02	4.52	5.03
10	0.613	3.1	0.79	1.57	2.36	3.14	3.93	4.71	5.50	6.26	7.07	7.85
12	0.882	3.8	1.13	2.26	3.39	4.52	5.65	6.79	7.92	9.03	10.18	11.31
14	1.201	4.4	1.54	3.08	4.62	6.16	7.70	9.24	10.78	12.32	13.85	15.39
16	1.568	5.0	2.01	4.02	6.03	8.04	10.05	12.06	14.07	16.08	18.10	20.11
20	2.450	6.3	3.14	6.28	9.42	12.57	15.70	18.85	21.99	25.13	28.27	31.42
25	3.826	7.8	4.91	9.82	14.73	19.63	24.54	29.45	34.36	39.27	44.18	49.09
32	6.273	10.0	8.04	16.08	24.13	32.17	40.21	48.25	56.30	64.34	72.39	80.42
40	9.802	12.6	12.57	25.13	37.70	50.27	62.83	75.36	87.96	100.53	113.10	125.66