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Evaluating the performance of buildings from the user's perception and Life Cycle assessment: Case study of heritage buildings in hot and arid climate regions of Algeria.

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Introductif Chapter

1. General introduction:

Building performance assessment is an essential discipline in the field of architecture and engineering. It aims to measure and analyze the different aspects of a building's efficiency, in particular its energy consumption, its thermal and light comfort, and its impact on the environment (Sinou and Kyvelou (2006)). As buildings are responsible for a significant portion of global energy consumption, improving the energy efficiency of buildings is crucial to reducing costs and greenhouse gas emissions (Allouhi, El Fouih et al. 2015).

Performance assessment makes it possible to identify opportunities to reduce the use of natural resources and, It makes it possible to minimize the carbon footprint of buildings by promoting more sustainable construction and management practices (Ranjetha, Alengaram et al . 2022).

As a result, many regions impose strict standards for the energy performance of buildings, making assessment essential for compliance.

However, assessing building performance relies on several methodologies and tools, including energy simulation, which uses specialized software to model and predict the energy consumption of a building. In situ measurements collect real data on energy consumption, temperature, humidity and lighting inside the building.

Life cycle analysis (LCA) assesses the environmental impact of a building over its entire life cycle, from construction to demolition. Occupant participation is also crucial, as involving end users in the evaluation process can provide valuable information and promote acceptance of improvement initiatives.

This leads us to highlight the importance of assessing building performance using two key methods. User comfort and satisfaction are essential as they spend a large part of their time inside buildings. An efficient building must meet the expectations and needs of its occupants in terms of temperature, light, air quality and noise, which is crucial for their well-being. Additionally, optimal indoor conditions can improve occupant productivity and concentration, while a healthy indoor environment helps reduce health issues related to air quality and thermal discomfort.

Moreover, life cycle analysis (LCA) is crucial because it allows an overall assessment of the impact of a building, taking into account all phases of its life, from the extraction of raw materials to the construction, operation and demolition. It identifies environmental impacts at each stage of the life cycle, including resource use, greenhouse gas emissions and waste production. In addition, LCA promotes continuous improvement by using its results to identify improvement opportunities, thereby optimizing the design and operation of buildings.

All in all, building performance assessment is a multidimensional and dynamic activity, essential for creating living and working spaces that are not only efficient and comfortable, but also sustainable and environmentally friendly. Certification systems, such as LEED, BREEAM or HQE, serve as a reference framework to certify and guide the improvement of building performance (Oviir 2016).

The rise of emerging technologies, such as IoT sensors, artificial intelligence and big data, opens new possibilities for more accurate, real-time assessment of building performance (Mehmood, Chun et al. 2019).

Looking at the subject and its timeline in relation to global developments, there is a clear evolution in the assessment of building performance. In the 1970s and 1980s, the energy crisis sparked global interest in the energy efficiency of buildings, leading to the development of the first energy simulation software to evaluate their performance. During the 1990s-2000s, certification systems such as LEED in the United States, BREEAM in the United Kingdom and HQE in France were introduced to standardize the assessment of building performance, alongside significant advances in energy simulation and modeling tools. Since the 2010s, the increased use of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and Big Data has enabled more accurate, real-time assessments. At the same time, emphasis has been placed on sustainability, climate resilience and environmental impact throughout the life cycle of buildings (Kievani, Tah et al. 2010).

Examining the timeline of building performance assessment in Algeria reveals a distinct development trajectory. In the 1980s-1990s, the first initiatives aimed at improving the energy efficiency of buildings emerged, mainly in large cities like Algiers (Stambouli, Khiat et al. 2012). During the years 2000-2010, national policies were put in place to promote energy efficiency and renewable energy in the building sector, accompanied by pilot projects aimed at testing new technologies and approaches to sustainable construction (Shaikh , Nor et al. 2017).

Since the 2010s, Algeria has adopted stricter standards and regulations for the energy performance of buildings and has strengthened education and training programs for building professionals, directing them towards best practices and new technologies (Bencheikh and Bederina 2020).

However, in Saharan Algeria, the (specific) context with a hot and arid climate presents specific challenges in terms of thermal comfort and energy efficiency, requiring solutions adapted to extreme conditions. Certainly, several studies and research on user perception have been carried out in recent years (Mahmoud and Hine 2016; Santoso, Schrepp et al. 2017; Nani 2019), but few with a qualitative approach and life cycle analysis ancient heritage buildings in the hot and arid climate of Algeria. For around thirty years, the atmospheres resulting from experiences of the sensory world have increasingly interested researchers from various disciplines. This growing interest highlights the importance of understanding the impact of sensory experiences on individuals working in architectural environments (St-Jean, Clark et al. 2022).

When users engage in their professional activities within the built environment of North African oases, the interaction between their professional tasks and the surrounding sensory stimuli becomes an essential aspect that shapes their perceptions and experiences (Cartwright and Cooper 1997). (Cartwright and Cooper 1997). Including those interested in the evaluation of built space based on user perception and behavior.

Furthermore, evaluation methodologies must be flexible enough to adapt to different types of buildings and varied climatic contexts, the present research aims to evaluate the performance of an office building in Kenadsa, in the Béchar region, due to its hot and arid climate and its historical and even heritage importance, by integrating user perception and life cycle analysis (LCA). And this, in order to propose improvements which respect both the built heritage, the specificity of the building and the requirements of durability and comfort in a difficult climatic environment.

We therefore seek to obtain the best possible energy performance while respecting the heritage importance of the building and ensuring the quality of the indoor environment, the health and well-being of users in historic buildings.

This research questions the link between building performance (energy consumption and its impact on the environment) and user perception and behavior.

2. <u>Problematic:</u>

Kenadsa, known as the first electrified city in North Africa and famous for its rich industrial and mining past, has been widely studied by many researchers. These studies mainly focused on the history, urban development and socio-economic impact. Despite numerous comprehensive studies by researchers on various aspects of Kenadsa ranging from Dr. Abderrahmane Moussaoui’s Logics of the sacred and modes of organization of space: The case of South-West Algeria (Hamès 2005), Prof. Laila Benbrahim's examination of urban development and cultural heritage preservation (Benbouazza, Benchekroun et al. 2011), Dr. Hadj Mohammed's Preservation and tourism development of heritage in the Algerian Sahara (Mohamed and Makhloufi 2023), Dr. Nadia Hamdi's exploration of climate adaptation strategies, Dr Benaradj Abdelmalek worked on the spiritual aspect of the knadsa ksar (BENARADJ 2020), to Prof. Ratiba Wided Biara and Dr. Adil Mostadi's Brownfield in the entrance of the town of Kenadsa: an industrial heritage, difficult to assume (Mostadi and Biara 2019). There remains a significant gap in research concerning the energy performance of buildings and user perceptions in Kenadsa. While these studies provide valuable insights into the socio-economic, environmental, and urban planning challenges faced by Kenadsa, none have specifically addressed how the extreme hot and arid climate impacts the energy efficiency and occupant comfort within heritage buildings. This research aims to fill this critical gap by focusing on the energy performance and user comfort of a heritage colonial administrative building, thereby offering original contributions to sustainable building practices in similar climatic conditions. This study will leverage the unique historical and climatic context of Kenadsa to explore innovative solutions for enhancing energy efficiency and user satisfaction, which have not been sufficiently addressed in previous research.

However, it’s a crucial dimension that remains largely unexplored: the energy performance of heritage buildings and the perception of users in a hot and arid climate. Although Kenadsa's extreme climate is conducive to studies on energy performance and thermal comfort, this perspective has been neglected in existing research. This lack of research is all the more relevant since user comfort and satisfaction are key factors for the sustainability and efficiency of buildings, particularly those with heritage value.

In this study, we focus on a heritage colonial administrative building in Kenadsa to fill this gap. This choice of case study brings originality and additional relevance to the theme, because it integrates not only the aspects of heritage conservation but also the contemporary challenges of energy efficiency and occupant comfort.

Kenadsa’s heritage office building, located in a hot and arid climate, faces several distinct challenges. The region's extreme climate results in high temperatures and low humidity, which directly impacts occupant thermal comfort and increases cooling requirements. The external environment, marked by severe climatic conditions, also highlights the need to adopt appropriate architectural and technological solutions to improve the energy efficiency of the building.

In terms of function, as an administrative building, it must provide an interior environment conducive to work, where comfort conditions are essential to maintain user productivity. Temperature fluctuations and thermal insulation issues can reduce comfort levels, leading to reduced employee concentration and performance. It is therefore essential to find solutions that improve user comfort while respecting the heritage characteristics of the building and optimizing its energy efficiency.

Subsequently, the question arises: **How can we improve the energy performance and comfort of occupants of a heritage office building located in a hot and arid climate?**

3. Hypothesis:

In answer to the research question, we assume that:

- The evaluation of the energy performance of Kenadsa's heritage office building based on user perception will highlight the possibilities for improving the energy efficiency of the building, and therefore the comfort of the occupants in a hot and arid climate.

- The Life Cycle Analysis will significantly reduce the overall environmental impact of Kenadsa's heritage office building.

4. Objectifs:

In order to obtain the best possible energy performance of Kenadsa's heritage administrative building and to guarantee the well-being of its users, this research aims to:

1- Evaluate the performance of this building based on user perceptions and behaviours.

2- Evaluate the environmental performance of this building via a life cycle assessment.

5. Methodological approach:

Several researchers have contributed to the assessment of building performance based on user perceptions and life cycle analysis (LCA), providing valuable information that can be applied in different climatic contexts and on various types of buildings. John Smith, for example, used surveys and interviews to assess occupant comfort and satisfaction in a mixed-use office building in a temperate climate, identifying issues with indoor air quality and thermal comfort, and suggesting improvements to ventilation and environmental controls. Similarly (Smith, Coull et al. 1991) Emily Johnson used surveys, focus groups and interviews in a residential complex located in a subtropical climate to address problems of excessive heat gain and inadequate daylighting, recommending shading devices and daylighting solutions. (Johnson, Haggard et al. 2012).

Ahmed Hassan's work has focused on residential towers in arid climates, using LCA to highlight the high embodied energy and carbon footprints associated with traditional building materials, and advocating for sustainable materials and energy-efficient design strategies. (Ahmed 2017). Maria Garcia, by combining qualitative and quantitative methods, assessed energy consumption behaviors on a university campus in a temperate maritime climate, highlighting the need to educate and engage occupants to promote energy conservation (García 2022).

Table 01- Summary table of evaluation approach methods, (Author 2024).

Researcher	Method of Evaluation	Case Study	Climate Context	Problem Identified	Findings
John Smith	Surveys and interviews with occupants	Mixed-use office building	Temperate	Issues with indoor air quality and thermal comfort	Recommended improved ventilation and environmental controls
Emily Johnson	Surveys, focus groups, in-depth interviews	Residential complex	Subtropical	Excessive heat gain and poor natural lighting	Suggested shading devices and daylighting solutions
Ahmed Hassan	Life cycle assessments (LCAs)	High-rise residential tower	Arid	High embodied energy and carbon footprint	Advocated for sustainable materials and energy-efficient designs
Maria Garcia	Qualitative and quantitative approaches	University campus building complex	Temperate maritime	Lack of awareness about energy-saving practices	Highlighted importance of user education and engagement in energy conservation

Several researchers have used human-based modeling (ABM) to assess user perceptions in building performance studies, providing valuable insights into occupant behaviors and their impact on energy consumption and quality of life. The indoor environment. Yan et al. (2015) used GPA to simulate occupant behaviors in residential buildings in different climates in China, highlighting the importance of understanding human factors to improve energy efficiency. Mahdavi and Tahmasebi (2015) applied GPA to office buildings in Austria to assess variability in occupant behavior and its impact on indoor environmental conditions, demonstrating the need for accurate behavioral modeling. Hong et al. (2016) implemented ABM in commercial buildings in the United States, addressing the lack of detailed occupant behavior data in traditional energy simulations and improving the accuracy of these models. Azar and Menassa (2012) focused on office buildings, showing that GPA can effectively capture the variability in human behavior, which is often neglected in conventional energy models. Cao et al. (2017) used GPA in university campus buildings in Sweden, revealing that detailed occupant modeling provides critical information to improve building design and operations to increase energy efficiency and occupant comfort. These studies collectively highlight the utility of GPA in capturing the complex interactions between occupants and building systems, ultimately leading to more efficient and comfortable built environments.

Drawing on these methodologies and results, we will evaluate the performance of Kenadsa's administrative building, which is located in an arid and hot climate, based on user perceptions and LCA. We will combine user feedback on comfort, satisfaction and environmental conditions with a comprehensive LCA of building materials and operational impacts, as well as agent-based modeling of our users' behaviors to confirm their perception. We aim to identify areas of improvement that strengthen both user experience and environmental sustainability. This approach will provide a holistic understanding of building performance in its specific climate context, guiding future strategies for sustainable building management in similar environments.

6. <u>Dissertation's Structure:</u>

In order to achieve the objective of our thesis, it is organized as follows:

This research includes an introduction followed by nine chapters and a general conclusion.

The introductory chapter defines the problem, hypotheses and objectives of the research.

- **Three theoretical chapters**, the aim of which is to clarify the different concepts relating to our theme; on buildings, and its challenges: building's performance, user perception and behavior as well as life cycle analysis.

The fourth chapter concerns the methodological approach.

Chapter five is a description and presentation of the case study (location of the building, its historical significance, its architectural characteristics, its functional use and contextual factors: cultural and socio-economic).

- Three successive chapters then analyze the case study study:

Chapter 6: Objective approach “in situ measurements of physical dimensions”.

Chapter 7: Subjective Approach and Agent-Based Modelling Simulation “perceptual dimensions and behaviors”.

Chapter 8: analysis of the life cycle of the case study.

At the end of this research, a general conclusion summarizes the concepts, methodology and the approach applied to buildings discusses the validity and reliability of data and purposes of the study and avenues for future research.

Chapter 1

1- Buildings' performance

Introduction:

This chapter presents a state of the art in the construction of high-performance, or high-performance, buildings. Energy performance, as well as all the energy issues raised by the buildings. It lists the best-known international labels, environmental certifications relating to these buildings, as well as their performance and efficiency requirements. Therefore, to resolve the challenges linked to energy, economic issues, and environmental (principle of sustainable development) relating to the building sector, several laws and regulations are made available to players in the building sector in all the countries of the world, of which some countries located on both shores of the Mediterranean and neighboring Algeria, presenting the same climate and energy context.

1. Historical Overview:

Following the global economic crises experienced in recent decades, Energy saving has become a major concern. This issue is part of a global economic and environmental dimension aimed at:

Save exhaustible energy resources, reduce greenhouse gases, fight against global warming.

For the building sector, this awareness has resulted in an approach energy in the architectural design of buildings. It aims towards independence total building compared to traditional energy resources.

It is therefore an ecological approach in project design and environmental architecture aimed at creating sustainable buildings in an era of sustainable development. This approach highlights the impact that a building can have on its environment and offers conceptual guidelines to mitigate and improve harmful effects.

Environmental architecture has evolved with the development of new technologies linked to the production of materials, systems, as well as the transformation and distribution of energy. It has progressed from an approach that primarily focuses on integrating the building into its environment to reduce energy consumption and environmental impacts to architecture that significantly integrates new technologies and innovative systems from the industry of materials, insulation, as well as air conditioning, heating and ventilation systems (Liérbard, 2005).

2. Building's performance:

A building is an asset that contributes a secure environment if it is well maintained and leads to continuous improvement throughout its life cycle. It is expensive to procure and the benefits to have them are various. Douglas (1996) defined buildings as being heterogeneous as itis different in its own way such as the location, subsoil conditions, and different access provisions. Each building has its own characteristic according to the differences in the internal and the external environment of the building. Table 1-show five main reasons why buildings are very important nowadays.

Table 2- The significant of building (Douglas, 1996).

Environmental	They provide suitable, internal environments that can resist the adverse effects of climatic conditions for people and commodities.
Economic	They are durable fixed asset with good capital growth potential
Functional	They enable activities, tasks to be carried out, and commodities to behoused under controlled conditions.
Cultural	They reflect the architectural aspirations and historical characteristic of thecommunity within which they reside
Legal	They are required to enable owners and users to comply with certain statutory requirements.

Table 3- Definitions of building performance (De Wilde 2018).

Authors’	**Definitions**
Preiser & Schramm (2002)	Building performance includes notions of use and **effect on human performance**, because performance is assessed in terms of how buildings and building system affect the comfort, effectiveness and well-being of building users.
Keith (1996)	Overall performance of a building should assessed by the combined performance of the building as it affected by **technical capabilities of the building, technological environment and its process** and perhaps most importantly **the individual involve.**
Douglas (1996)	To assess how well a building is behaving overall and in the long term. It is important both in an inter building and intra building sense.
Becker (1996)	All buildings require, throughout their life, a **level of performance and a standard of management** that can provide and sustain conditions suitable for the **well-being of their users.** The approaches to building performance consist of **built ability,**

	flexibility, maintainability, adaptability, and marketability.
Markus (1981)	It is obvious that buildings are **for people**; people pay for them, use them and design them. The design of building consists of **people making decisions** on behalf of other **people that affect another set of people.**

Generally, buildings require a set level of performance to provide a healthy and safe environment. Bluyssen (2009) highlighted that the features for healthy buildings are free from hazardous materials, provide healthy, and comfort environment for the building users throughout the building lifecycle. Therefore, this will influence both the image and value of a building. The main scope of building performance is to assure quality assets that is able to integrate with user perceptions to achieve a desired lead of customer satisfaction. McDougall et al (2002) mentioned that building performance has a strong relationship with building design and building occupants. Building performance is carried out by identifying user perspectives that can definite the buildings perform well and it is an awareness to design the decision making process (Vischer, 2009). In addition, Vischer (2009) mentioned that collaboration of human performance, building performance and social value is needed to assess the overall building performance. Building performance is a process that influences the value of a building by assessing how buildings work and the effectiveness towards the building users (Preiser and Schramm 2005). Douglas (1996) defined building performance as a process to assess the overall progress of a building. It is measured by looking at the technical capabilities, technological environment, business process and individuals' involvement (Alaxender, 1996). There are few definitions of building performance detailed as in Table 2. Awareness of building performance needs to be emphasized, as it is very important to support the core business and to achieve work productivity that will increase the profit margin of an organization. According to Bluyssen (2009), productivity is focus on various components such as well-being, mental drive, job satisfaction, technical competence, environmental factor etc. Therefore, building performance is important whereby it is need to be well maintained in order to fulfil the customer requirements and customer satisfaction to increase the work productivity. Figure 1 shows the building delivery process that comprise of five main steps which is planning, programming, design, construction and occupancy towards the short term and long term objectives. Figure 2 illustrates the inter-relationship between buildings, occupants and occupant needs. This is important to create a quality building by identifying occupants' requirements in order to upgrade and improve the building performance. Prior to this, organizations and management team need to focus on the measurement tools to measure the building performance that can create a comfortable environment for the internal and external customers and will lead to decision making process which can achieve the continuous improvement of a building. The measurement tools that will be discussed in this paper are Post Occupancy Evaluation (POE) and Building Performance Evaluation (BPE) respectively.

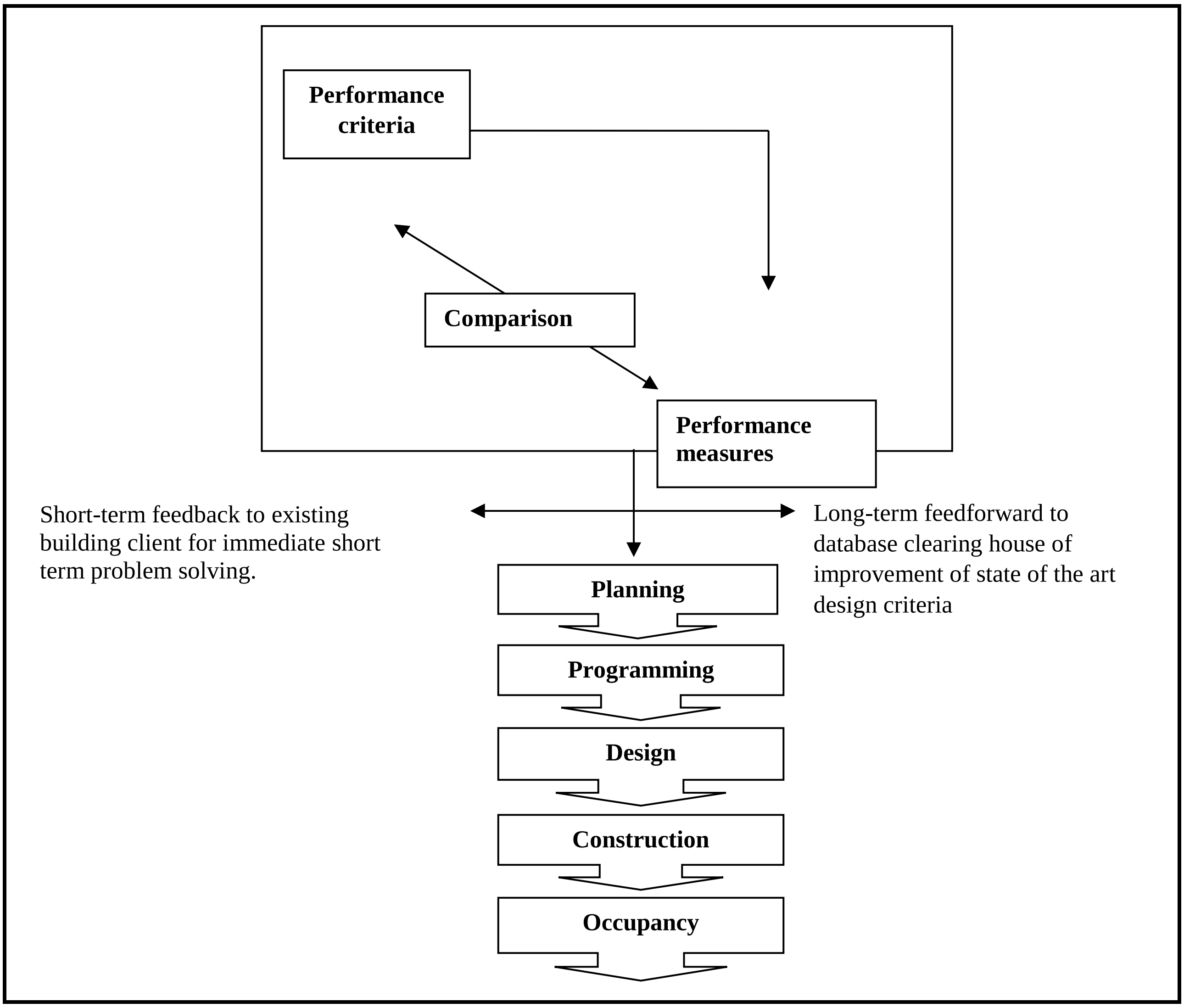

Fig 1- The performance concept in the building delivery process (Preiser, 1995).

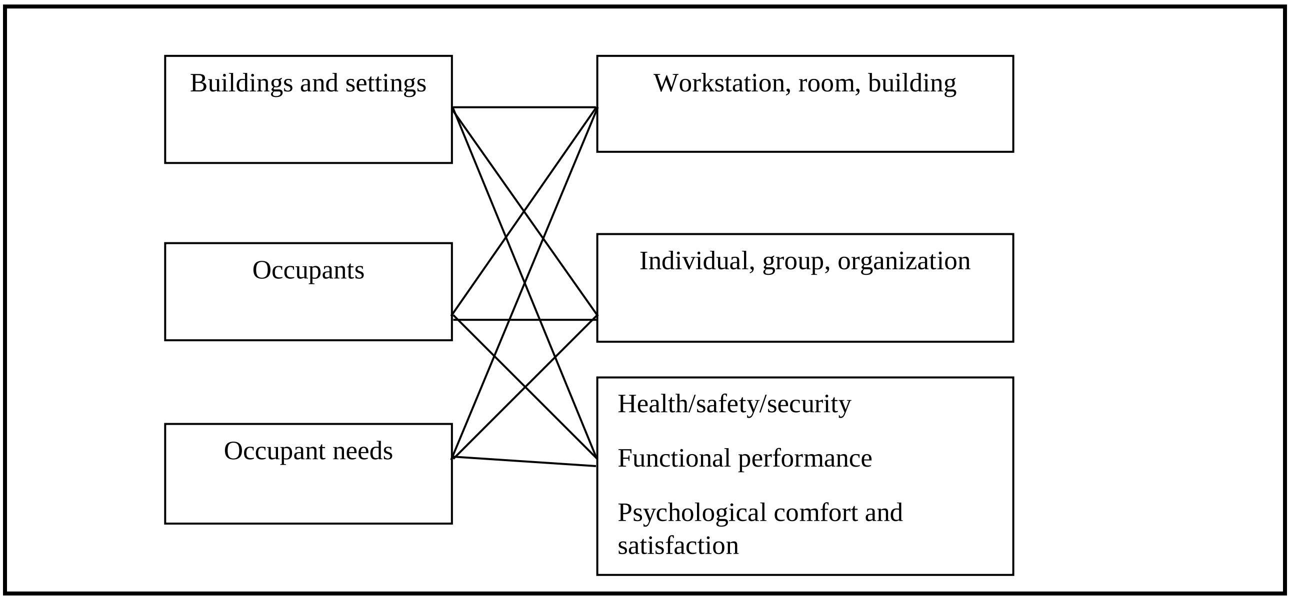

Fig 2- Inter-relationship between buildings, occupants and occupants need (Preiser, 2005).

3. High performance building (HPB) :

An efficient building is a low energy consumption building, that is to say one which requires primary energy consumption (heating systems, domestic hot water production, air conditioning and lighting) lower than the standard laid down by thermal regulations . We are therefore accustomed to defining the performance of a building by its energy performance and therefore its energy consumption alone. However, it is now also necessary to take into account the "carbon" indicator of the building, namely all greenhouse gas emissions linked to its construction, its operation and its (potential) deconstruction.

This approach now has impacts on the choice of construction products (materials and equipment), their origin, their recyclability, and on the type of energy used (gas, electricity, renewable energies, etc.).

High-performance buildings can therefore be achieved through work and strategies to improve energy performance (renovation/rehabilitation operation) but also during construction.

Buildings must also reconcile energy-carbon performance with accessibility, quality of use and occupant comfort.

- Are safe, comfortable and efficient.

- Help owners/occupants achieve business missions.
- Operate reliably with minimum unscheduled downtime and fast recovery.
- Enhance organization and occupant performance, retain/increase value.
- Maintain performance within acceptable tolerances throughout their lifespan.

Definition of high performance building from US Energy Policy Act of 2005:

- A building that integrates and optimizes all major high-performance building attributes, including.
- Energy efficiency.
- Durability.
- Life-cycle performance.
- Occupant productivity.

4. Building performance requirements:

Current developments in terms of requirements in the building industry concern both the increase in performance levels required, and the diversity of performance aspects to consider in the building.

In order to meet growing requirements in terms of energy performance, a range energy solutions and bioclimatic strategies are currently being implemented for several years, and increasingly in building construction projects.

Coming from vernacular constructive and architectural traditions or new technological developments, these systems promise to reduce energy needs buildings, while ensuring the required levels of comfort.

We can cite some examples such as Trombe walls, solar cooling, solar chimneys, phase change materials, green roofs and reflective roofs (Chan et al, 2010) and (Sadineni et al, 2011). Thus, the energy management of buildings will lead to promoting comfort during:

1. Winter: through the collection of free solar input, as well as penetration of the maximum solar radiation which improves visual comfort in this season when light natural is less abundant and more sought after.

2. Summer: by controlling solar input, reducing internal input, implementing work of significant inertia and internal heat evacuation, and limit the effects overheating by sheltering the building from the sun, or by reducing the surface areas of the envelope exposed to the sun. The improvement then consists of choosing the insulation of the envelope, the quality of the glazing and solar protection, and the ventilation and air renewal of the spaces that make up the building.

5. Thermal regulations for buildings:

In order to resolve the challenges linked to energy, economic and environmental issues (the principles of sustainable development) within the building sector, several laws and regulations are made available to building stakeholders in all countries of the world, to ensure a balance between the three-3E parameters: Economy/Energy/Environment of any building project design. The thermal regulations applied to buildings aim to:

1. Set the requirements in terms of energy performance of the envelope: level of thermal insulation, optimization of the glazing rate by orientation, solar protection of windows, etc.

2. Encourage the covering of part of energy needs through energy production using solar thermal and photovoltaic techniques.

3. Require energy efficient air conditioning and heating, lighting and DHW systems, HVAC systems.

4. Limit energy consumption as much as possible in kwh/m^2.year.

6.1. Application of the Thermal Regulations for buildings:

Regulation constitutes a privileged instrument for the building sector (residential and tertiary). Buildings continue to be the main target of regulations. These are developing in a large number of countries, particularly in emerging countries. It is necessary to implement existing thermal regulations, while developing flexible and attractive financial mechanisms for investors and promoters of new buildings and owners of old buildings (built heritage).

In addition, thermal regulations apply to the improvement and renovation of existing buildings. This strategy allows for very significant additional savings. The thermal regulations of a building cover all the points relating to the envelope, the opaque and glazed walls, air conditioning, heating, lighting, DHW.

It recommends the rationalization of energy use by acting directly on the performance of the above-mentioned points, to reduce energy consumption and GHG greenhouse gas emissions.

6.2. Thermal regulations for buildings in Algeria:

Algeria has experienced intense and sustained development in the sectors of the building and construction (major state projects, residential real estate projects and tertiary). This is already leading to great pressure on resources (energy, water, materials, etc.) and significant emissions and impacts (generated) on the environment. Algeria is the first country in the Maghreb to have implemented regulations thermal insulation of buildings since 1997 and which became mandatory from the year 2000. The regulations propose two calculation methods for heating needs and cooling, and whose objective is to control these needs (D.T.R. C3-2, 1997):

1. The static thermal calculation of the building, which the designers must verify that b. The dynamic calculation in variable regime whose designers must compare between the dynamic heating needs (Bdyn.) calculated by STD dynamic thermal simulation software and the basic losses (DB).
2. Regarding the needs of air conditioning, the regulations propose a method of calculation based on the calculation of the heat input of buildings (D.T.R. C 3-4, 1997).

The verification is done in such a way as to have the sum of these calorific contributions of the walls opaque and bay windows is lower than the reference calorific contributions, depending on the climatic zone studied transmission losses from the building are lower than the reference losses.

6. Labels and certifications for the energy efficiency of buildings:

We define a label: as is a voluntary approach, which allows us to go further than the thermal regulations in force. The labels and certifications for the energy efficiency of buildings presented are used as a target to define the energy performance indicators of buildings, and for the case of our research, office buildings in arid regions.

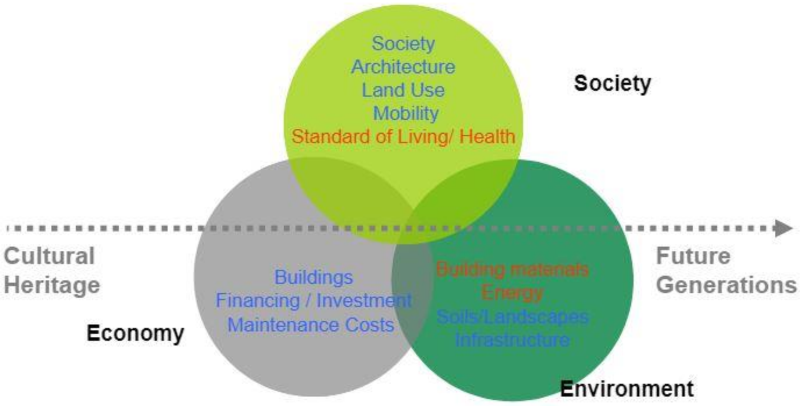

Fig 3- Energy efficient buildings are a key to sustainable development.

(Source: Green Building Congress Chennai, 2010).

7.1. The Passivhaus approach:*

The Passiv’haus label of German origin was developed in 1996 (Passivhaus, 2015). This label is intended for residential and tertiary buildings. To achieve the Passivhaus standard, it is necessary to have:

1. An annual heating requirement < 15kwh/m²/year (final energy).

2. Envelope tightness: n50 < 0.6m3/h/year.

3. Primary energy consumed < 120kwh/m²shab/year (corresponding to the final energy for air conditioning and heating, ventilation and electricity).

The building according to this Passivhaus label must have an envelope with very efficient thermal insulation and very low air permeability and renewable energy sources.

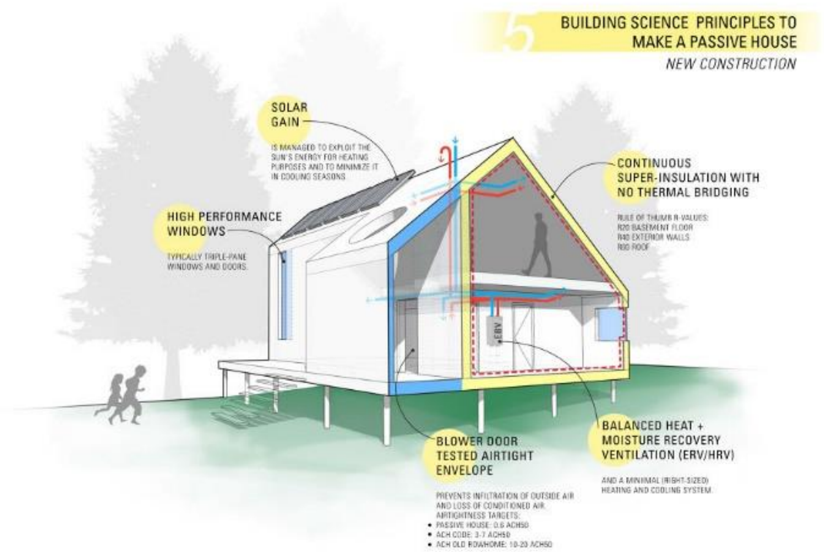

Fig 4- Schematization of the principles of passive house design

(Source: Passivhaus design strategies, 2021).

7.2. The BBC Effinergie label:

The goal of creating the BBC Effinergie and Effinergie+ labels is to design buildings that consume even less energy. From a technical standpoint, the objective is to reduce energy consumption from 50 to 40 kWh per square meter per year. To achieve this, it is necessary to enhance the building structure with various objectives:

1. Improve the building envelope by acting on the Bbio: Bbio < Bbiomax -20% for all buildings.
2. Enhance the energy performance of the building across the five regulatory uses.
3. Enhance the energy performance of tertiary buildings across the five regulatory uses.
4. Improve the building's airtightness by strengthening the air permeability requirement.
5. Enhance the efficiency of ventilation systems by making it mandatory to measure ventilation rates and network permeability to ensure good air quality.

In a second phase, the new Effinergie+ label also aims to engage occupants and users in the overall energy consumption by informing them through predictive calculations and consumption displays. To achieve this, it is necessary to:

6. Mandate an assessment of mobile consumption, considering other energy uses (media, appliances, etc.).
7. Implement consumption meters linked to power outlets.

7.3.<u>The Minergie label:</u>

The Minergie label is aimed at property owners and planners whose level of requirement exceeds the average in terms of quality, comfort, and energy. This label defines six levels of performance (Minergie, 2015):

1. Minergie Standard: for buildings with low energy consumption.
2. Minergie-P (Passive): denotes constructions with very low energy consumption and meets the maximum requirements in terms of quality, comfort, and energy, notably due to excellent building envelope.
3. Minergie-A: combines higher requirements in terms of quality and comfort with maximum energy independence, thanks to significant photovoltaic installations and battery systems for peak load management.
4. Minergie Eco (Minergie with eco materials and consideration of health aspects).
5. Minergie Eco-P: considers criteria related to user health and eco-construction of the building.
6. Minergie Eco-A: considers criteria related to user health and eco-construction of the building.

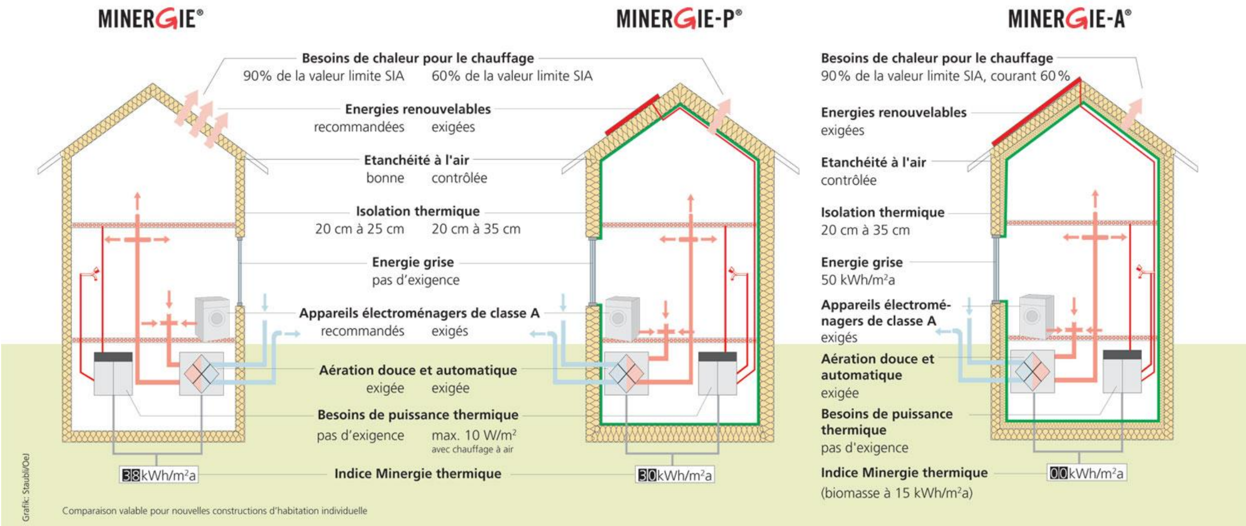

Fig 5- Requirement of Minergie, Minergie-P and Minergie-A standards.

(Source : Minergie, 2007).

7.4.<u> Zero energy buildings :</u>

Zero Energy Building: (USA), Zero Energy Building is a concept that emerged following the construction of a house without heating consumption, in Task 13 “Solar low energy house” of the

Agency Energy International (IEA) under the scientific direction of the Fraunhofer Institute. Through simulations, it has been demonstrated that heating needs can be met by the solar installation, which reduces its consumption to zero. The principles of this label consist of reducing heating needs as much as possible, cooling and electricity, thanks to an envelope and efficient equipment thrifty whose energy needs are met by efficiency gains such as the use of renewable technologies (photovoltaic panels, a turbine wind, or a biogas generator, etc.)

7.5. Low energy buildings:

The Low Energy Consumption Building (or BBC Batiment Basse Consommation) is a label awarded to buildings that have low energy consumption for heating, air conditioning, lighting, domestic hot water (DHW), and ventilation. The low-energy consumption building is defined by the decree of May 8, 2007, relating to the content and conditions for awarding the "high energy performance" label. Buildings for uses other than residential are considered BBC when the conventional primary energy consumption of the building for heating, cooling, ventilation, DHW production, and lighting is less than or equal to 50% of the reference conventional consumption, defined in Article 9 of the decree of May 24, 2006, relating to the 2005 thermal regulations. For residential buildings, the BBC performance objective depends on the climatic zone and altitude. The conventional primary energy consumption of the building for heating, cooling, ventilation, DHW production, and lighting must be less than 50 kWh/m2/year weighted by a geographical coefficient. There are two types of conditions for awarding the BBC label depending on the age of the housing: New housing must not exceed the consumption target of 50 kWh/m2/year. Existing housing must have consumption below 50% of conventional consumption. The consumption target for them is set at 80 kWh/m2/year.

7.6. Energy Management and Energy Efficiency:

The term "energy management" appeared in the early 1980s, later replaced by the term "energy efficiency" with a more comprehensive vision, thus integrating rationalization into the consumption of primary energy resources. This term encompasses energy conservation and aims to reduce energy consumption and associated environmental, economic, and social costs, while also ensuring an increase in the quality of life for all inhabitants of the planet and future generations (principle of sustainable development) (Brundtland, 1987). The energy quality of the building is represented by the Minergie index. This index reflects the volume of final energy required for the energy supply of a building. The calculation of this index takes into account the quality of the building envelope, technical installations, appliances and lighting, energy supply based on renewable energy sources, as well as electricity self-production, provided that there is also controlled air renewal. New buildings must be characterized by the possibility of using renewable energies and covering a portion of their electricity needs through a self-production system. Their Minergie index is set at 55 kWh/m2 per year (weighted final energy).

7.7. The RT 2005 Thermal Regulation:

The first regulation in Europe imposing a minimum energy performance for buildings, the RT 74 Thermal Regulation, dates back to 1974 and follows the first oil crisis. The standards are updated every five years (RT2000, RT 2005, RT2012). The idea of buildings without heating or air conditioning constitutes a revolution in the building sector, which should serve as a model in the years to come. In European countries, habitats have been developed whose total energy consumption is four times lower than those defined by official building regulations. The RT 2005 Thermal Regulation is the current standard for all new constructions since August 31, 2006. On average, a construction complying with the RT2005 standard consumes between 120 and 220 kWh/m²/year (for cooling, heating, hot water, lighting, and ventilation). The HPE standard corresponds to consumption that is less than 10% lower than the RT2005 standard. The THPE standard corresponds to consumption that is less than 20% lower than the RT 2005 standard.

7.8. The RT 2012 Thermal Regulation:

Following the French thermal regulation for new buildings RT 2005, the French thermal regulation RT 2012 sets three requirements in terms of overall energy performance (Legifrance, 2012), namely:

1. Minimum energy efficiency of the building.
2. Limited primary energy consumption.
3. Good summer comfort.

The RT 2012 is the fifth thermal regulation in France. Like the previous RT regulations, it aims to limit energy consumption in housing and tertiary buildings. The RT 2012 is the result of the Grenelle Environment, which translates into action the most ambitious commitments:

a. Reduce energy consumption by 38% by 2020.

b. Decrease greenhouse gas emissions by 50% by the same date.

The RT 2012 imposes a primary energy consumption of less than 50 kWh/m²/year compared to around 150 kWh/m²/year for the RT2005 (this means dividing the energy consumption of buildings by three).

7.9. <u>The High Environmental Quality (HQE):</u>

The HQE association has given two definitions of the environmental quality of buildings: one serving as a foundation, the other being demanding, focused on action.

The environmental quality of a building corresponds to its characteristics, its equipment, and the rest of the plot, which allow it to meet the needs of controlling impacts on the external environment while creating a healthy and comfortable environment.

The demanding definition of the environmental quality of the building clarifies an operational arrangement of requirements called 'targets'.

The fourteen (14) targets selected for the HQE are classified into two (2) domains and four (4) families:

Domain I: Management of impacts on the external environment.

<u>First family: Eco-construction targets.</u>

Target No. 01: Harmonious relationship of buildings with their immediate environment.

Target No. 02: Integrated selection of construction processes and products.

Target No. 03: Low-impact construction site.

<u>Second family: Eco-management targets.</u>

Target No. 04: Energy management.

Target No. 05: Water management.

Target No. 06: Management of waste from activities.

Target No. 07: Maintenance and upkeep management.

Domain II: Creation of a satisfying indoor environment.

<u>Third family: Comfort targets.</u>

Target No. 08: Hygrothermal comfort.

Target No. 09: Acoustic comfort.

Target No. 10: Visual comfort.

Target No. 11: Olfactory comfort.

Fourth family: Health targets.

Target No. 12: Sanitary conditions of spaces. Target No. 13: Air quality.

Target No. 14: Water quality.

7.10. LEED:

The US Green Building Council (USGBC) for the USA and the CAGBC for Canada established leadership in Energy and Environmental Design, this initiative, which is prevalent in the USA, Canada, and Australia, in 1998. Initially, this initiative was dedicated to new tertiary buildings, but now it applies to all types of buildings and involves a comprehensive assessment of the building throughout its lifecycle.

LEED is a building certification dependent on a non-profit governmental organization, the USGBC, U.S. Green Building Council. The LEED Green Building rating system helps professionals improve the quality of their buildings and their environmental impacts. It comprises seven categories, including:

- Sustainable site development.
- Water efficiency.
- Energy and atmosphere.
- Materials and resources.
- Indoor environmental quality.
- Sustainable construction practices.
- Innovation in design and priority regional considerations.

A specific weighting is allocated to each category, allowing the project to accumulate 40 points or more to achieve certification. LEED certification for new constructions or energetically renovated buildings is classified according to four scales:

• Scale 1: Certified 40 – 49 points.

• Scale 2: Silver 50 – 59 points.

• Scale 3: Gold 60 – 69 points.

• Scale 4: Platinum 80 points and above.

7.11. BREEAM:

The Building Research Establishment Environmental Assessment Method, is an assessment method for evaluating the environmental performance of buildings during design, construction, and operation of eco-friendly buildings. It was developed in 1990 in England by the Building Research Establishment (BRE).

This label is a pioneer worldwide in all approaches to environmental quality and energy performance in buildings. The approach followed by this label is a crosscutting "system" approach, based on the allocation of cumulative eco points within the framework of an overall score assessment.

Although this label is the most widespread globally in terms of the number of operations carried out, it has specific climatic and standard usage limitations related to the original environment, hindering its use in environments different from the original one. Additionally, the absence of criteria expressing summer comfort shows the difficulties in adapting this label in countries with hot and dry climates (such as Algeria).

8. Thermal Performance and Energy Efficiency of Buildings:

Energy efficiency can be defined as the ratio between what a system can produce and what it absorbs as energy. It is considered better when the energy system uses the least amount of energy for better profitability, whether it is for heating, cooling, lighting, hot water production, or any other energy needs.

"Consuming less and better for the same thermal comfort" is the goal of energy efficiency. Therefore, two types of energy efficiency are distinguished:

Passive energy efficiency, achieved through the building's elements, its inertia, and the quality of thermal insulation of its envelope, as well as all integrated solar protections and shades.

Active energy efficiency, which involves technical building management and continuous control system between the energy consumption to be managed and the comfort of the users to be ensured (permanently).

9. Building Energy Certificates:

Energy certification is an operational procedure that assesses the energy consumption of a building as well as its actual performance, taking into account the energy management by occupants

(Nadine, 2001). Its purpose is to provide information about the energy performance of the building and its equipment, as well as guidance for technical choices to reduce the energy bill.

10. Building Energy Audit:

The energy audit of a building includes an assessment of the building's condition, a diagnosis of its structure, energy equipment, and technical installations. It is used to analyze the weaknesses of the building and to provide improvement proposals based on technical, economic, and site-specific energy considerations.

11. Building Thermal Balance:

The thermal balance of a building helps to avoid energy waste and calculate the heating and cooling needs of a building. The overall performance is evaluated in kWh/m² per year.

The energy factors that influence the thermal balance of a building are:

11.1. Heat conduction through the envelope:

The absorption of solar radiation on the external surfaces of the envelope contributes to increasing solar gains in summer but reduces losses in winter. For a well-insulated envelope, solar contribution is low and considered negligible.

11.2. Air renewal:

Minimum air renewal is necessary to achieve an acceptable indoor air quality in the building. It represents a heat loss in winter and a heat gain in summer.

11.3. Solar gains through glazing:

This is the amount of solar energy that enters the building through windows and other glazed surfaces. It always represents a heat gain both in summer and winter.

11.4. Internal gains:

This includes all sources of heat inside the building, including occupants, lighting, and other equipment. It always represents a heat gain.

11.5. Energy sources:

This is the amount of energy delivered by any heating or cooling equipment activated to control the indoor environment to ensure comfort.

12. Energy Performance Diagnosis (EPD) of the building:

The energy balance of a building reflects its energy consumption. It demonstrates the effectiveness of the building envelope, its insulation system, on one hand, and the total energy quantity required for the proper functioning of the building, on the other hand. Due to the increase in the real estate market, on one hand, and the necessity of electricity-consuming equipment in residential and tertiary sectors, on the other hand, reducing the energy consumption of buildings is a challenge. In this context, the establishment of minimum requirements with rules relating to the energy performance of buildings constitutes an important first step towards controlling their energy consumption. The Energy Performance Diagnosis (EPD) is part of this energy management regulation, providing building stakeholders and users with a classification ranging from A to G based on consumption and environmental impacts. The Energy Performance Diagnosis (EPD) consists of two parts:

1. A label displays energy consumption (heating, cooling, Domestic Hot Water).
2. Another label displays the impact of these consumptions on greenhouse gas emissions.

A good EPD for a building must follow the following seven instructions:

3. Identify the construction mode of the building (according to its construction period).
4. Understand its thermal functioning (with its active and passive provisions).
5. Have a bioclimatic approach to the building (to interpret consumption).
6. Jointly study its winter thermal behavior and its summer thermal comfort.
7. Consider that the most energy-efficient provisions are passive.
8. Avoid thermal bridges in constructions (especially old buildings).
9. Recommend only improvements that are unlikely to cause disorders.

12.1. Energy and Climate Labels:

The defined energy requirement is visualized on energy and climate labels, with a classification ranging from A to G (from very energy-efficient buildings to poorly energy-efficient buildings), according to the labels (fig.4.6). These energy labels can be summarized as follows:

- **Energy Label:** This is the classification of a building based on its annual consumption per square meter (in kWh primary energy/m^2.year). Seven classes are defined from A to G.
- **Climate Label:** This is the classification of a building based on the annual level of greenhouse gas emissions per square meter associated with consumption (in $kgCO_2/m^2$.year), ranging from class A to class G.

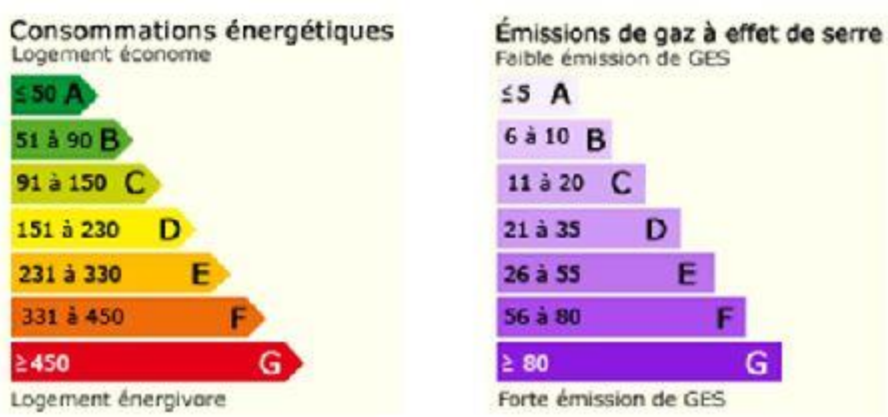

Fig 6- Energy and climate label for buildings. Source : https://energie-reduc.com/renovation/etiquette-energie-immobilier.

Conclusion:

This chapter illustrates the energy-related issues faced by buildings. It discusses the global economic crises experienced in recent years, as well as concerns regarding the economy, energy management, and reducing emissions and impacts on the environment. For the building sector, this awareness has translated into an energy-oriented approach in architectural design aimed at conserving depletable energy resources, reducing greenhouse gas emissions, and combating climate change. Thus, the concepts of building thermal performance, energy efficiency, and environmental footprint are detailed. The energy performance of a building refers to the amount of energy needed to meet the energy requirements associated with the normal use of the building, which includes the energy used by its technical systems (including ventilation, lighting, heating, cooling, and hot water production systems). To implement the law on energy management and comply with the Kyoto agreements, approaches to aid in the design of new buildings and solutions for the thermal rehabilitation of existing buildings are needed. The goal is to reduce excessive reliance on air conditioning and heating systems, especially for buildings in arid regions with hot and dry climates.

Algeria, like other countries in the Mediterranean basin, has enacted numerous thermal, energy, and environmental regulations and texts. However, in the absence of implementing regulations, these remain ineffective. Hence, there is an urgent need for complementary measures, including incentive mechanisms and the establishment of an appropriate mechanism to promote the improvement of building thermal performance, energy efficiency, optimization in energy use, as well as the reduction of emissions and environmental impacts.

Chapter 2

2- User’s Perception and Behavior

Introduction:

This chapter presents a state of the art in understanding user perception and behaviors is essential for evaluating and designing built environments. How individuals perceive and interact with their environment has a significant impact on their experience, satisfaction and well-being within a space. This theoretical chapter delves deeper interplay between user perception, behaviors, and the built environment, aiming to provide a comprehensive framework for analyzing and integrating these factors into architectural research and practice.

User perception includes the cognitive, emotional, and sensory responses evoked by the physical properties and spatial qualities of the built environment. It includes subjective experiences such as comfort, beauty, privacy and security, which shape individuals' overall satisfaction and connection with space. Additionally, user behaviors refer to the actions, movements and interactions that occupants exhibit in a given environment, reflecting their needs, preferences and social dynamics.

Many perspectives and theoretical frameworks contribute to understanding user perception and behaviors within the built environment. Environmental psychology explores how people perceive and respond to their environments, focusing on the role of environmental stimuli, personal characteristics, and social and cultural influences in shaping behavior. Human factors and ergonomics consider the ergonomic design of spaces to improve ease of use, efficiency and safety, taking into account human capabilities, limitations and preferences.

Additionally, theories such as financial means theory, ecological means theory, and transactional theories of space highlight the dynamic relationship between individuals and their environments, emphasizing the mutual influence of perception and action. These theoretical perspectives provide valuable insights into the underlying mechanisms that determine user behavior, highlighting the importance of considering both objective environmental attributes and subjective interpretations in architectural design and evaluation.

In addition to theoretical frameworks, methodological approaches to studying user perception and behaviors include a range of qualitative and quantitative techniques. Observational studies, interviews, surveys, and participatory design methods provide rich insights into user experiences, preferences, and needs, and capture subjective perceptions and social and cultural dynamics. Additionally, sensor-based technologies, environmental monitoring, and simulation tools enable objective measurements of environmental variables and user interactions, providing experimental data to inform design decisions and performance evaluations.

By bringing together theoretical perspectives, methodological approaches and empirical findings, this chapter seeks to provide a comprehensive understanding of user perception and behaviors within the built environment. By recognizing the subjective and dynamic nature of the human experience, architects and designers can create more responsive, inclusive and user-centered spaces that improve well-being, productivity and social interaction. By integrating user-centered principles into architectural practice, the built environment can better meet the diverse needs of users, strengthen a sense of place, and contribute to sustainable and resilient communities.

1. Historical overview:

Space tells, in a certain way, the world. Each epoch, holder of her own knowledge (scientific, philosophical, religious, etc.), seizes the environment to include it within a more or less coherent system of references. Thus, starting from the recurring tendency to attribute to sight a perceptual and descriptive supremacy over the world, other sensory organization patterns gradually emerge, producing different modes of description.

1.1. Stable space:

Until the 17th century, architecture, essentially governed by rules (symmetries, regulatory lines, modules, ancient orders and other principles geometry and/or mathematics of the Renaissance), rarely speaks of space in a direct way: the treaties endeavor to provide methods of composition relating to the justification of the form, the use of materials and their implementation rather than on the hollow delimited by them. Although considered a void, space is not nothingness, it is a containing things. The observer apprehends space in visual terms only, according to one or more privileged points of view, according to a particular perspective. The spaces are fixed, closed and juxtaposed each other.

1.2. Sensory space:

In the 17th century, with the appearance of the Baroque movement, we witnessed a real liberation from the rules conditioning architecture until then: the spaces open up, interpenetrate. Little by little, we wake up to a sensitivity for the lived environment, but we are not yet talking about truly space. Touch, previously ignored, becomes a priority in the discovery of a constantly evolving world. This change of priority leads to a modification of the man-space relationship: the latter is now defined according to the senses, these bringing individually information coming from reality and going mutually service. We then understand the position of the theorists of the era declaring that space is a fictitious construction since being the result of an act of the senses and not the reflection of reality.

1.3.Movement space:

At the end of the 19th century, it was affirmed that “all the senses contribute to produce a coherent image, but, in addition, the information which reach us over time interlock with each other and complement each other” (Abdallah, Abreu et al. 2007). Space is now a three-dimensional extent traveled by a moving observer, the understanding of this space coming from multiplicity and the heterogeneity of the images offered to the individual. We also associate with space a measurable hydraulic model in which each object, like a container immersed in a body of water, creates a new volume. The same at the moment, priority is given to space in architecture: “Man designs firstly the space which surrounds it and not the physical objects which are carriers of symbolic meaning. All provisions static or mechanical, as well as the materialization of the envelope spatial are only means for the realization of a vaguely anticipated or clearly imagined in architectural creation” (Emetere 2022).

1.4.Substantial space:

The measurable hydraulic space of the 19th century became, in the 20th century, a substance which has a presence that is difficult to describe, substance in which the observer is immersed and from which he observes the world. There are now relationships between objects in space. Perspective vision used until then gives way to a description visiotemporal and spatiotemporal form: the different points of view from which we observe things are equivalent, they bring each one specific information for the construction of the image of the object observed. New construction techniques liberate form architectural and introduce the concept of architectural spatial continuity.

1.5.Object space:

In the middle of the 20th century, space, the main object of perception, was a stable geometric figure. It is: “a three-dimensional figure hollow, produced in a certain way of living and linked to a system of broader representation and symbolization. The character of space would depend, on the shape of its contours that can be described, decompose, cut into pieces, enumerate."(Altın, Amaldi et al. 2007). The architectural approach is therefore essentially plastic, we speak of spatial form, hollow form, and plastic coherence, sequence, density, pressure, energy charge, and two movements appear: one based on Gestalt theory, and the other on an interpretation structural.

Although different, they converge in the fact of considered that a whole is not equal to the sum of its elements and that the sum of elements do not form the whole.

2. PERCEPTIVE PHENOMENA

Our awareness of the world around us is through through perception. The perceived world, representation of the real world, is apprehended using our senses. Although all our senses conspire to the perception of a space, perception is essentially visual (perception of geometric space) and haptic (perception of texture and hardness of materials). However, let us not underestimate the power secondary senses; to be convinced of this, just think of the smell of hot bread coming out of the bakery in the morning, or to the sound of footsteps in a hallway. Several disciplines deal with the perception of space: physiology, epistemology, anthropology. We mainly referred in the framework of this chapter to the psychology of perception which is most apt to provide us with general criteria on the spatial behaviour of man in his environment, although, and we insist, many Individual behavioral variations exist, such as education, age, culture, emotional state…At the risk of repeating ourselves, let us quote Hall: “The relationships that man maintains with his environment depend on both of its sensory apparatus and the way in which it is conditioned to react” (Hicks, Hall et al. 1978); in fact, if the sensory system occupies an important place in perception, past individual experience occupies an equally important place.

2.1. Visual perception:

“Man learns by seeing, and what he learns in turn resonates on this that he sees” (Hicks, Hall et al. 1978). Vision is the major source of information from man, it brings him a greater quantity information and more quickly than the other senses. Below, we will remind you of the way the eye receives information and organizes it. In this Indeed, we will base ourselves essentially on the theories of Gestalt and James Gibson.

2.2. Haptic perception:

Haptic perception involves highly complex processes that simultaneously integrate cutaneous, proprioceptive and motor information linked to haptic exploration movements to form an indissociable whole. Although often unconscious, haptic perception plays a considerable role in the perception of space (the skin and muscles being the most important sensory organs, at least in terms of their extent), and this is because it has the ability to put us in direct contact with the world (apart from a few exceptional cases of loss of tactile sensitivity, such as astereognosia or asomatognosia, our feet are in permanent contact with the ground): variations in pressure and temperature, contact, pleasure and pain could not otherwise be experienced.

2.2.1. Thermal perception:

In addition to the ability to perceive heat and cold, which we can easily understand is useful for human beings (not dying of cold in winter and heat in summer), the ability to perceive variations in temperature is an important factor in our relationship with the people and objects around us: the latter radiate a heat that is specific to them and which, although little perceived by most of us, is of considerable use to the blind. To convince yourself of this, you only need to compare the perceptions felt when gripping a steel or wooden bar, or remember the crowded feeling we have all experienced at some point.

2.2.2. Tactile perception:

To grasp an object, we need to do more than just see it: we need to touch it, feel it, weigh it, and assess its consistency... This contact with things is a fundamental need for children in their discovery of the world (here we refer to the work of Piaget) and it is only after a certain period of learning that they subordinate tactile space to visual space.

A distinction is usually made between cutaneous or passive perception (being touched) and tactilo-kinesthetic or active perception (tactile exploration). The former involves stimulating a part of the skin while the part of the body supporting it remains motionless; the resulting perceptual processing then concerns only the cutaneous information linked to the stimulus applied, since only the superficial layer of the skin is subjected to mechanical deformation. The second results from stimulation of the skin by active exploratory movements of the hand in contact with objects, with perceptual processing deduced from the mechanical deformation of the skin and muscles involved in the exploratory movement.

2.2.3. Kinesthetic perception:

Kinesthesia concerns the perception of our body and the position and movement (speed and direction) of its different parts in space. The kinaesthetic experience is an important factor in the way we experience a space: a space crossed on foot feels completely different from a space crossed in a car. In his book L'espace vivant (Living Space), Jean Cousin, in his analysis of elementary spaces, stresses the importance of kinaesthetic spatial exploration: "We can see that rectangular space, even if many architects deplore it, is directly related to our body and its shapes. For this rectangular space is in fact generated by man's dynamic axes". (Boudin, D'Halluin et al. 1980). Numerous authors, such as Von Meiss, Zevi and Arnheim, abound in this sense. Is the richness of the works of Le Corbusier, Wright, Loos or Van Der Rohe not due to the fact that they are thought out in terms of an architectural journey?

2.2.4. Haptic illusions:

Just as there are optical illusions, there are also haptic illusions. However, the haptic sense turns out to be less 'deceptive' than vision: geometric illusions such as the Müller-Lyer illusion or the overestimation of the vertical are found with an intensity similar to vision, whereas the Titchener illusion is exclusive to the visual sense. Similarly, certain illusions of 3D objects are specific to touch; this is the case with the illusion of bumps created by adding upward or downward forces on a plane.

2.3. Sound perception:

The perception of the direction of a sound results from the disparity of the information received by the two ears. This explains why a stationary observer (i.e. one who is not moving his body or head), with his eyes closed, can easily assess whether a sound is coming from the right or the left, whereas it is difficult for him to localise a sound arriving from in front or behind, from above or below, as the information reaching the ears in the latter two cases is practically identical. On the other hand, if the same observer can move around, his perception of sound will be improved. Three sources of disparity are currently known:

Intensity: It is the main source of information. The head acts as a screen, attenuating the intensity of sound coming from the opposite side.

The moment of excitement: This is the difference in time taken for sound to reach each ear.

Sound phase: Since sound has to travel a different distance to each ear, the result is a phase difference that can tell us the direction of sound.

Apart from its particular use by the blind, hearing plays only a very limited role in the perception of space, given its limited capacity for localisation. The difference not only in the quantity and nature of the information it can process, but also in the amount of space it can control more effectively, gives visual space superiority.

2.4. Olfactory perception:

The mechanism of odour perception is similar to that of hearing: an odorous substance placed laterally to an observer will transmit a greater concentration to the nearest nostril, while a substance placed in front of the observer will communicate the same information to each nostril. While the olfactory system plays an important communicative role in the animal world (identification of individuals, their emotional states, etc.), it is used very little by humans, who are also very poor at localising odours.

2.5. Implications:

We are so well integrated into our universe that it seems obvious to us, a priori, to perceive things as they are and where they are. So it's easy to confuse the perceived world with that of physical objects. However, between the physical world and the perceptual world there is a whole chain of events that must be distinguished:

Firstly, the object perceived visually is spontaneously located at a certain distance in three-dimensional space, despite the two-dimensional nature of the information provided to the eyes.

What's more, while the visual information is being transmitted to us, information of haptic, sound or other origin provides other data about the object perceived. So what initially appeared to be a visual perception ultimately turns out to be a multi-sensory perception.

To represent a space without taking this multi-sensory dimension into account would be to neglect the very existence of its perception: indeed, while the mind can achieve this performance of isolation, the body sees, touches, hears and feels the space at the same time.

So we don't always perceive space as correctly as we might think. Sometimes our perceptual mechanisms fail: these are illusions. So our perceptual mechanisms alone cannot explain our perception of space. PERCEPTIVE PHENOMENA 11

There are a large number of non-perceptual variables, such as personality, socio-cultural background and emotional state, which can have a considerable influence on the perception of the physical world. A space is perceived differently by an individual depending on whether or not it forms part of their experience, their cultural context or whether or not it is associated with their value system.

3. User Comfort:

Comfort is a very subjective topic. Abbaszadeh, Zagreus, Lehrer, & Huizenga (2006) suggest that comfort in the office is achieved through satisfaction of the indoor environmental quality (Abbaszadeh, Zagreus et al. 2006). However, this research is restricted only to acoustic, thermal and visual comfort, indoor air quality and office cleanliness, as outlined by the Green Building Council of Australia (released as an innovative challenge in August, 2013).

4. Thermal Comfort:

This is the condition of mind which expresses satisfaction with the thermal environment (Havenith, Kuklane et al. 2015). It means that an employee wearing a normal amount of clothing feels neither too cold nor too warm (Elaiab 2014). An environment achieves reasonable thermal comfort when at least 80% of its occupants are thermally comfortable (Adeomi, Adeoye et al. 2014). Indoor thermal comfort is affected by physical and environmental factors. Thermal comfort improves happiness and productivity, health and well-being and reduces the energy demands of a building (Autodesk Sustainability Workshop, 2011). One of the best ways of determining whether a group of people are comfortable is by asking them. The simple (seven-point) scale below is often used in laboratory experiments, to the integration of techniques into questionnaires for practical surveys as well as behavioural measures.

Thermal comfort refers to the sensation or state in which the occupants of a building experience a balance or regularity between the two extremes (high/low) of internal temperature. It is a subjective evaluation of the perception of the thermal atmosphere and reflects its feeling of neutrality in relation to a given thermal environment. Maintaining thermal comfort for the occupants of a building or other enclosure is one of the most important objectives of HVAC (heating, ventilation and air conditioning) designers.

Table 4- Scales of Warmth Sensation. Source: (Bedford 1936).

Bedford comfort scale	ASHRAE sensation scale
Much too warm 7	Hot 7
Too warm 6	Warm 6
Comfortably warm 5	Slightly warm 5
Comfortable 4	Neutral 4
Comfortably cool 3	Slightly cool 3

Too cool 2	Cool 2
Much too cool 1	Cold 1

5.1. Factors Affecting Thermal Comfort :

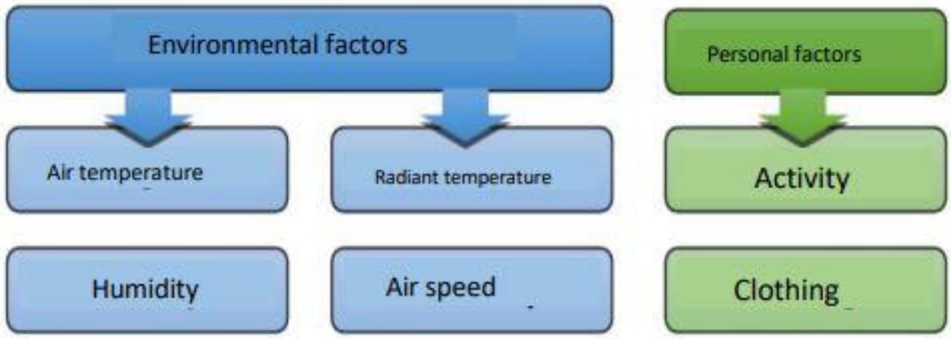

Fig 7- The most important environmental factors affecting thermal comfort (Alwetaishi 2016).

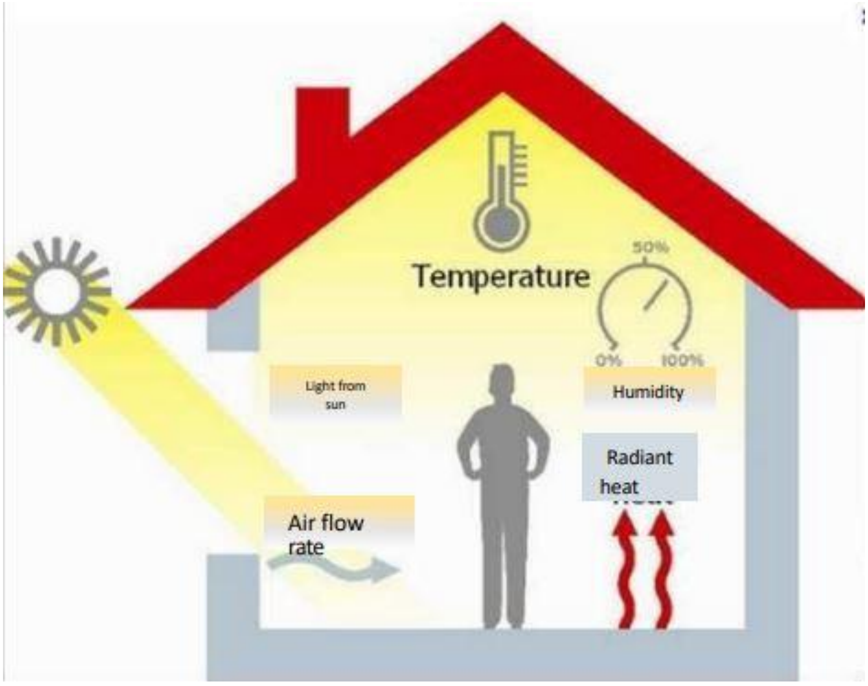

Fig 8- Illustration of the environmental factors affecting thermal comfort (Alwetaishi 2016).

5.1.1. Environmental Factors:

A) - Air Temperature

The cutaneous (skin) temperature of the occupant is strongly influenced by the air temperature and the heat transfer that occurs between the person and the environment. As a result, the thermal comfort of occupants is directly influenced by air temperature (Kim, Shin et al. 2021). The effects of air temperature on thermal comfort have been extensively studied and it has been found that the optimum temperature range for thermal comfort is between 25°C and 26°C. This range can change dramatically depending on the temperature changes encountered in test environments (ichi Tanabe and ichi Kimura 1994; Kim, Shin et al. 2021). The well-being of occupants is determined by the level of discomfort caused by an air temperature that is too high or too low (Kim, Shin et al. 2021).

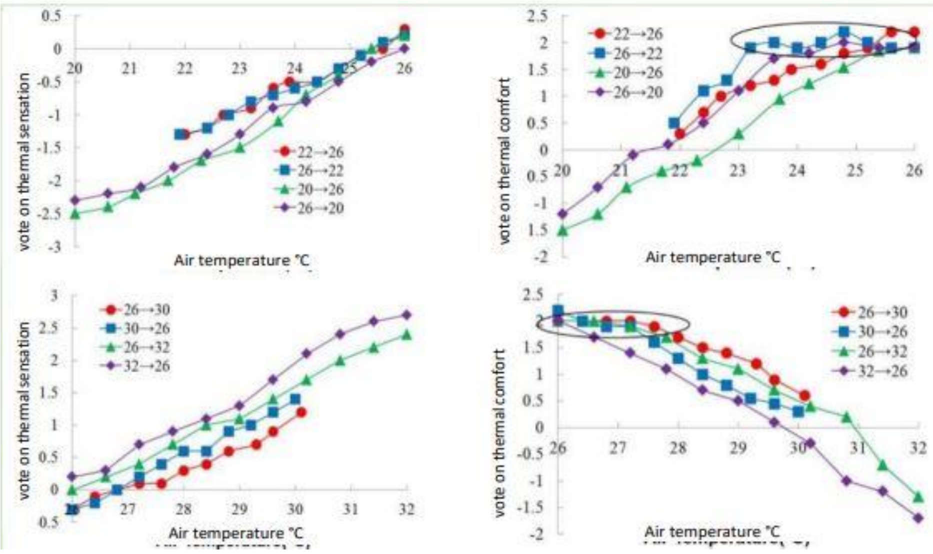

Fig 9- Relationship between air temperature and thermal sensation (Kim, Shin et al. 2021).

When occupants experience high air temperatures, they are exposed to certain effects such as:

- Thermal stress.

- Dehydration.

- Fatigue.

On the other hand, when they are exposed to low temperatures, they can be under the effect of:

- Discomfort.

- Chills.

- Reduced dexterity.

B) - Radiant Temperature:

Radiant temperature is the temperature of the surfaces surrounding a person, and is an important factor in determining indoor thermal comfort (Tomorad, Horvat et al. 2018). It is a physical parameter used to assess the satisfaction of the ambient thermal condition. Radiant temperature is an important environmental parameter that affects building performance and the thermal comfort of occupants (Gan 2001).

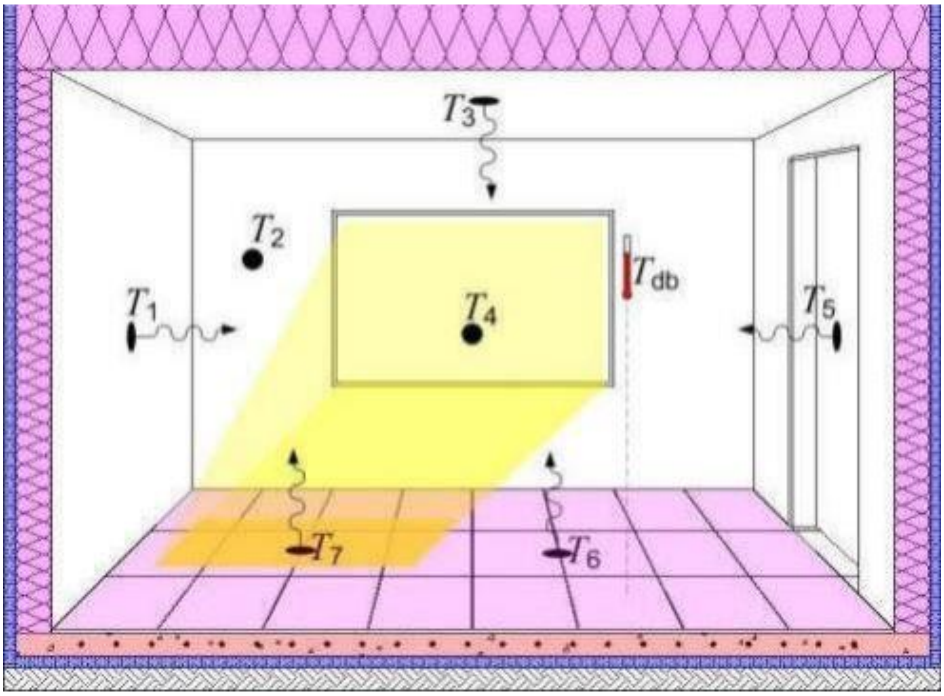

Fig 10- Illustration of the average radiant temperature at different surfaces in a chamber (Xu and Raman 2021).

The effect of radiative heat transfer on thermal comfort has been explored, but it remains a relatively unexploited mechanism for efficiency gains. Controlling radiative heat flows in indoor spaces can help maintain thermal comfort (Xu and Raman 2021). High radiant temperature can cause local differences between body segments and affect the inner surface (Atmaca, Kaynakli et al. 2007).

C) - the relative Humidity of the air:

Relative humidity is a measure of the quantity of water vapour contained in a water-air mixture compared with the maximum possible quantity (Yahia 2019). It is expressed as a percentage and is relative to air temperature. In other words, it is a measure of the actual quantity of water vapour in the air compared with the total quantity of vapour that can exist in the air at its current temperature. While absolute humidity is a measure of the actual amount of water vapour in the air, regardless of air temperature, relative humidity is a measure of the actual amount of water vapour in the air in relation to air temperature.

Relative humidity can have an impact on thermal comfort, but the effect is modest when the air temperature is within the comfort range (Jing, Li et al. 2013).

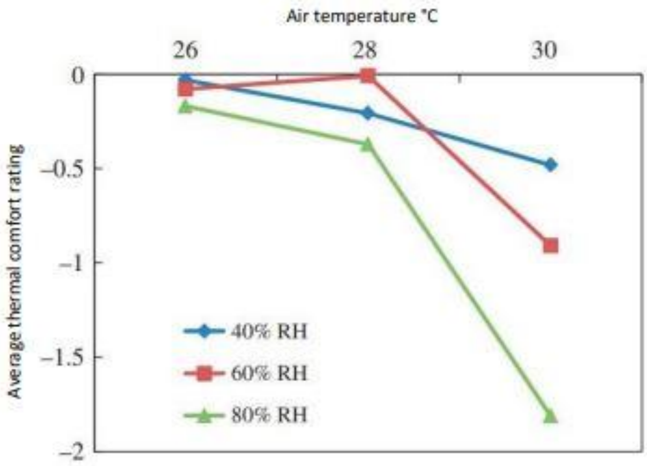

Fig 11- Average thermal comfort vote with different levels of air temperature and relative humidity (Jing, Li et al. 2013).

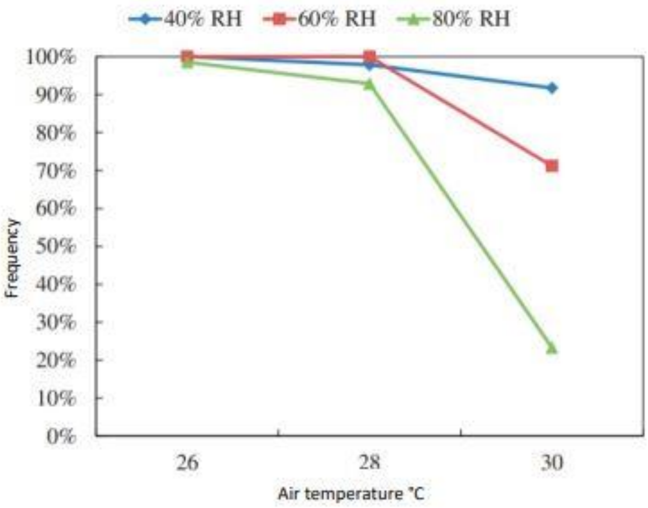

Fig 12- Acceptability of the thermal environment for all conditions (Jing, Li et al. 2013).

When air temperature, air speed and radiation temperature are within a comfortable range, humidity has little effect on human thermal comfort (Kong, Liu et al. 2019). However, higher humidity and air temperature intensify the thermal sensation and reduce perspiration and evaporation from the body, which can lead to discomfort (Djamila, Chu et al. 2014). It has long been accepted that thermal sensations of comfort are affected by relative humidity and that, for equal comfort, a higher temperature is needed to compensate for lower relative humidity (Mora and Bean 2018). Humidity has little effect on the sensation of heat unless the skin is clammy with sweat (Jing, Li et al. 2013).

D) - Air Speed:

Air velocity refers to the speed at which air moves through a space. It is an important factor in thermal comfort, particularly in hot and humid climates where sufficient air speed is necessary to ensure thermal comfort (Yusoff 2020). Air velocity can be affected by various factors, such as the size and configuration of openings in cross-ventilated buildings (Yusoff 2020), the use of ceiling fans and opening windows in free-running office buildings (Manu, Shukla et al. 2014), and the height of buildings in relation to indoor air temperature and velocity (Aflaki, Mahyuddin et al. 2014). Air velocity can have a significant impact on the thermal comfort of buildings. High air velocity is generally desired to restore comfort requirements at higher temperatures (Sansaniwal, Tewari et al. 2020).

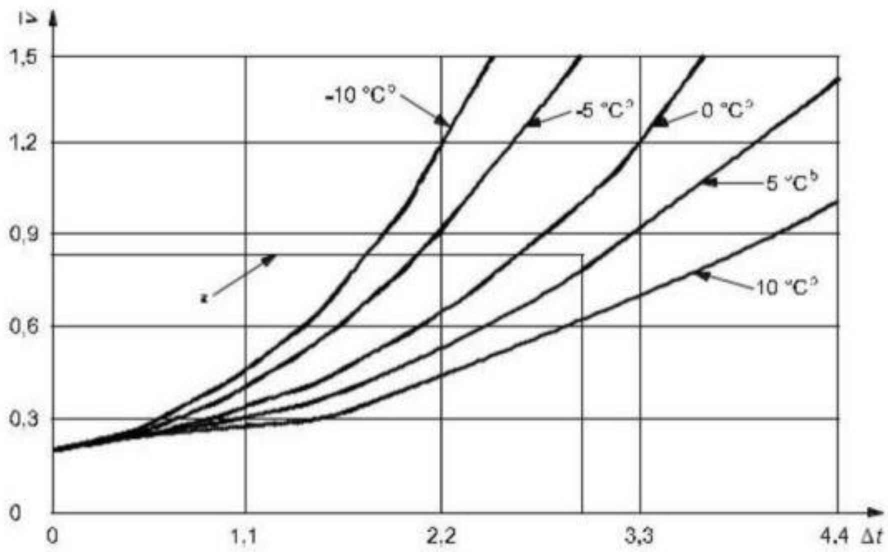

Fig 13- Air velocity required to compensate for temperature increase (Kong, Liu et al. 2019).

The effect of air speed on thermal comfort depends on the temperature of the environment. High air speed can improve thermal comfort in a non-uniform environment, but it can also increase the gap between thermal neutrality and comfort (Song, Duan et al. 2021).

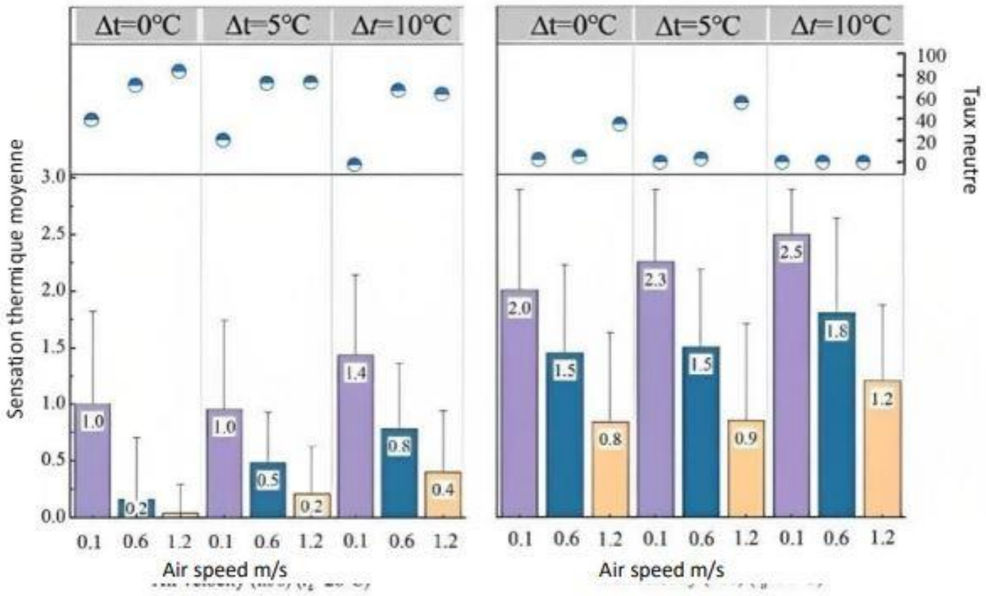

Fig 14- Changes in human thermal sensation with different air speeds (Song, Duan et al. 2021).

When airflow speeds are between 1 m/s and 2 m/s, thermal comfort can be achieved. Increasing airflow velocities above 2 m/s would only reduce the high thermal comfort levels (Roghanchi, Kocsis et al. 2016). Increasing air velocity provides thermal comfort at higher temperatures, and this is implemented in standards such as ANSI/ASHRAE 55 and ISO 7730 (Thunshelle, Nordby et al. 2020). It is also more energy efficient to increase air velocity than to decrease room temperature by cooling. However, there are individual variations in thermal comfort.

5.1.2. Personal factors:

A) - Metabolic rate:

One of the most important aspects in determining a person's thermal comfort is their metabolic rate, which measures the amount of heat their body produces internally (Luo, Wang et al. 2018). Human energy requirements or heat production can be broken down into different components, which is a crucial point in this discipline. One of these, the basal metabolic rate (BMR), symbolises the energy required to sustain life, in particular to maintain body temperature and cardiac and respiratory activity. After 10 to 12 hours of fasting and 8 hours of physical rest, the BMR is normally calculated when the subject is awake and lying supine. Age, sex, height and body composition are the main determinants of BMR, which generally represents 45% to 70 % of daily energy expenditure (Luo, Wang et al. 2018).

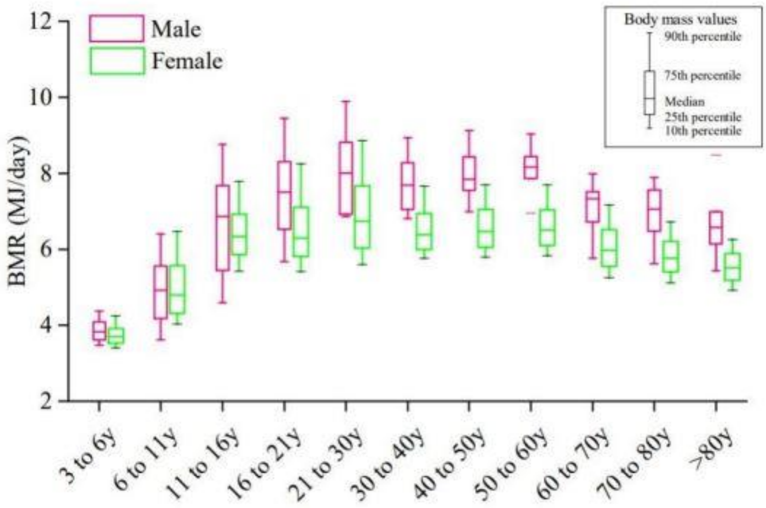

Fig 15- Variance in Metabolic Body Mass Ratio (BMR) associated with age, body mass and gender factors (Luo, Wang et al. 2018).

The impact of metabolic rate on thermal comfort has been analysed in studies, and it has been found that it can influence predicted mean vote (PMV), which is a measure of thermal comfort (Revel, Arnesano et al. 2015).

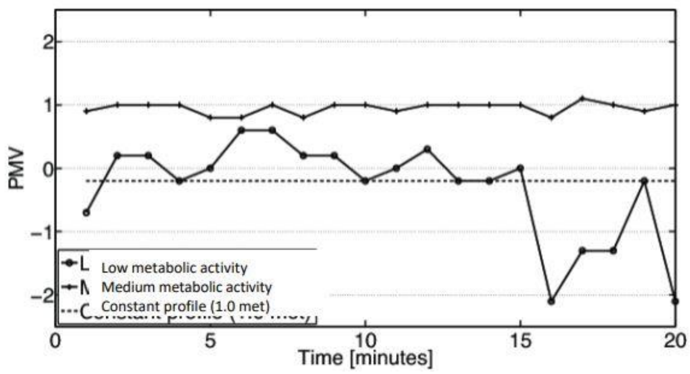

Fig 16- Comparison of average predicted votes calculated for two subjects with different activities (Revel, Arnesano et al. 2015).

Therefore, when designing energy-efficient and comfortable buildings, the level of physical activity linked to body metabolic rate must be taken into account to ensure that occupants are comfortable and productive.

B) - Clothing Insulation:

Clothing is one of the six major factors affecting thermal comfort in buildings (Ongwuttiwat and Sudprasert 2015). Clothing can help the human body to control heat exchange with the environment and maintain a system of thermal equilibrium, resulting in conditions of thermal comfort (Ongwuttiwat and Sudprasert 2015). The thermal insulation of clothing is largely affected by the structural and physical properties of the fabric, such as fibre type, thickness and layering (Atasağun, Okur et al. 2019; Liu, Foged et al. 2022). This is an important parameter for the individual assessment of thermal comfort (Liu, Foged et al. 2022).

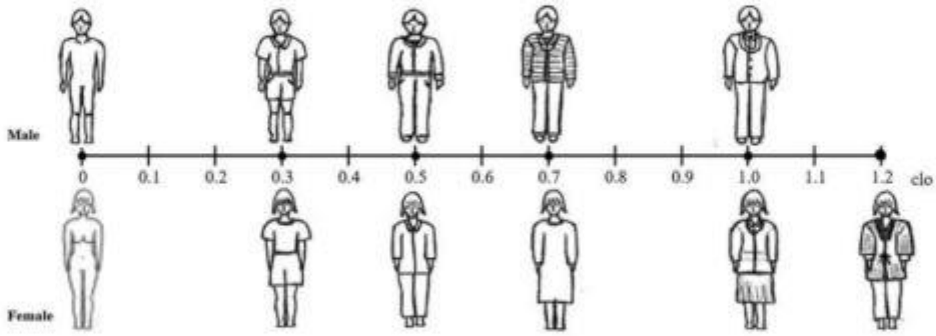

Fig 17- Clothing insulation scale (Rijal, Humphreys et al. 2019).

Table 5- ICL and RCL values for typical clothing ensembles (Oğulata 2007).

Set of clothes	ICL, clo	RCL (m2K/W)
MEN		
Fresh socks, men's underwear,	0.42	0.065
shoes, s.s. shirt, fresh trousers.	0.42	0.065
Warm socks, men's underwear,		
shoes, s.s. woven shirt, fresh trousers. Fresh socks, men's underwear,	0.55	0.085
shoes, cool s.s. knitted shirt, fresh trousers	0.51	0.079
Fresh socks, men's underwear,		
vests, shoes, woven shirt c.s., fresh trousers.	0.73	0.113
Fresh socks, men's underwear, swimwear body suit, shoes, woven		
shirt c.s., warm jacket, and fresh trousers.	0.31	0.048
Fresh socks, men's underwear, shoes, cold trousers.		
Fresh socks, men's underwear, swimwear body, shoes, steel woven	0.77	0.119
shirt stainless steel, warm jacket, warm trousers.		
WOMAN		
Cool dress, tights, women's underwear shoes.	0.21	0.032
Cool s.s. jumper, cool dress, tights, and underwear women's shoes.		
Warm dress, tights, women's underwear, shoes.	0.30	0.046

Warm skirt, warm i.s. blouse, tights, underwear women's clothing,	0.49	0.076
and shoes.	0.41	0.063
Warm jumper, warm skirt, warm blouse, tights, women's underwear,		
and shoes.	0.64	0.099
Warm i.s. jumper, warm trousers, i.s. blouse. Warmth, tights,		
women's underwear, shoes. Warm jumper, warm trousers, tights,	0.77	0.119
underwear, etc. women's clothing, and shoes.	0.59	0.091

With:

ICL: thermal insulation of clothing, clo.

RCL: clothing insulation, m2K/W.

5.2. Measuring thermal comfort:

5.2.1. Direct questioning of occupants:

Direct questioning of occupants about their thermal and air quality sensations is a method used to measure thermal comfort in buildings (Jiang, Iandoli et al. 2019). This method involves asking occupants about their level of comfort or discomfort with the temperature of their environment. It is a subjective method that can provide valuable information about occupants' perceptions of the indoor environment. There are many advantages to this method: Firstly, it provides a subjective assessment of thermal comfort, which is important because thermal comfort is a highly subjective experience.

Secondly, it provides real-time feedback on thermal comfort, which can be used to adjust the indoor environment to improve occupant comfort.

Thirdly, it can provide information on the factors that influence thermal comfort, such as air temperature, humidity and air velocity, which can be used to inform building design and HVAC systems. Fourthly, it can be used to assess the effectiveness of HVAC systems and building design in terms of thermal comfort.

Finally, it can be used to assess the impact of thermal comfort on the health, productivity and well-being of occupants. However, direct questioning of occupants to measure thermal comfort has certain limitations: Perceptions of thermal comfort are subjective and can vary from one individual to another, which can lead to inconsistent results. In addition, occupants may not be able to accurately describe their thermal sensation, especially if they are unfamiliar with the terminology used to describe thermal comfort. Furthermore, direct interrogation can only be carried out at a specific point in time and may not reflect the thermal comfort of occupants over an extended period. Finally, direct questioning is limited to indoor environments and does not allow thermal comfort to be measured in outdoor spaces.

5.2.2. . Practical methods:

Although it is useful to ask each person to answer a questionnaire about their own thermal comfort, this can be impractical and tedious. That's why scientists have been working to develop surrogate measures that can be measured automatically using various sensors (Ongwuttiwat and Sudprasert 2015).

5.2.2.1. Environmental Sensors:

For example, the VMP-PPD model calculates the predicted mean vote (VMP) of the average thermal perception of a group of people using air temperature, mean radiant temperature, air speed, humidity and human variables. The percentage of people likely to be dissatisfied with their thermal environment is determined by the predicted percentage dissatisfaction (PPD), which uses the VMP (Ongwuttiwat and Sudprasert 2015).

5.2.2.2. Body Sensors:

Skin temperature sensors can be used to measure the skin temperature of the upper extremities (finger, hand, and forearm) and study how these temperatures relate to thermal perception. The placement of temperature sensors on the body has also been tested in various configurations, enabling the most effective arrangements to be identified (Ongwuttiwat and Sudprasert 2015).

5.2.2.3. Cameras:

Researchers have recently investigated the use of cameras to predict thermal comfort using advances in machine vision. The thermal perception and thermal comfort of people were correlated with average forehead temperature using infrared (IR) images. Another method is to use the human thermoregulatory process and filter RGB images into visible light using the Eulerian video magnification algorithm to predict thermoregulatory states as a measure of thermal comfort (Ongwuttiwat and Sudprasert 2015).

5.3. Thermal Insulation:

Thermal insulation is the process of reducing heat transfer between objects or spaces. It involves the use of materials with low thermal conductivity, such as fibreglass, cellulose or foam, to reduce heat loss or gain through walls (inside and out), roofs and floors (Yüksel 2016).

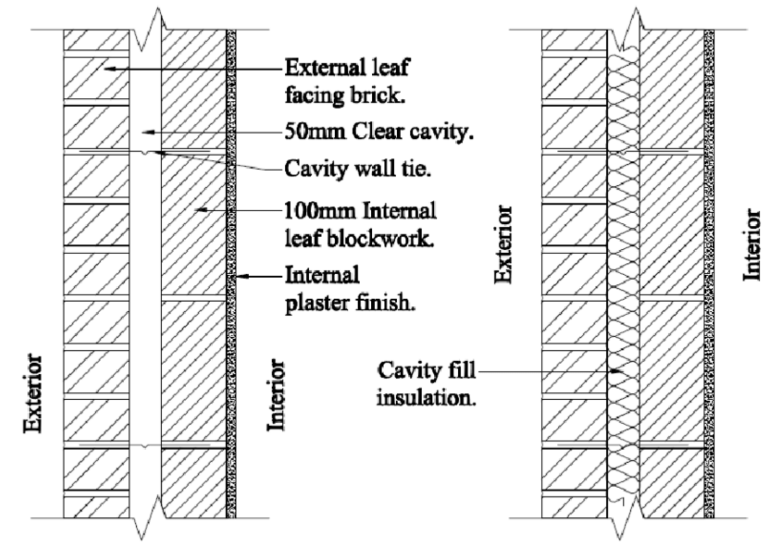

Fig 18- Demonstration of internal and external insulation (Aoual).

The principle of thermal insulation is based on replacing a short heat flow path with low thermal resistance with a long-lasting, high thermal resistance (Mashkoor, Mohammad et al. 2020). Its aim is to maintain a comfortable indoor temperature and improve energy efficiency. Thermal insulation materials enable systems to achieve energy efficiency by limiting conduction, convection and/or radiation while fulfilling one or more functions. These functions can vary in the context of thermal design, numerical simulations and a wide range of engineering problems, such as determining heat loss, temperature field, insulation and cooling conservation, and in a variety of other technologies. Thermal insulation materials can be created in a number of forms, including porous, blanket or mat, rigid, natural, foam and reflective (Yüksel 2016).

5.4. Types of Thermal Insulation:

There are over 40 registered types of thermal insulation material from different parts of the world. These materials can be divided into two types.

These are divided into two broad groups: organic insulation (i.e. carbon-based) and inorganic insulation (i.e. mineral insulation without carbon-hydrogen bonds). The two previous classifications can be subdivided into natural and synthetic insulants on the basis of the sourcing and processing of raw materials (Latif, Bevan et al. 2019). The table below shows a number of types of thermal insulation, each in its own category: (Latif, Bevan et al. 2019)

Inorganic (mineral)		Organic (carbon-based)	
Synthetic	Natural	Synthetic	Natural
Aerogel	Expanded Clay	Expanded polystyrene	Cellulosic fibre
Silicate foam calcium	Expanded Mica	Extruded polystyrene	Cotton Fibre
Cellular Glass	Expanded Perlite	Melamine foam	Linen fibre
Foamed glass	Expanded Vermiculite	Phenolic foam	Hemp fibre
Glass wool	Insulating Clay Bricks	Polyester fibres	Hemp-lime (organic and inorganic)
Plaster foam	Pierre Ponce	Foam from Polyethylene	Cork panel Insulation

Fig 19- Types of thermal insulation (Latif, Bevan et al. 2019).

In addition to the insulation materials listed in the table, a number of advanced insulation materials are available, including transparent insulation materials, vacuum insulation boards and switchable thermal insulation (Latif, Bevan et al. 2019).

5.6. What temperature should be maintained in the office?

CSA Z412-17 “Office Ergonomics – An Application Standard for Ergonomics workstations” recommends the following:

Conditions during summer: optimum temperature of 24.5°C with acceptable range of 23 at 26°C.

Conditions during winter: optimum temperature of 22°C with acceptable range of 20 at 23.5°C.

NOTE: CSA Group indicates that these conditions are based on Table 3 of the ASHRAE 55 standard, with a relative humidity level of 50% and air speed average of <0.15 m/s. Standard 55 - 2013 “Thermal Environmental Conditions for Human Occupancy”, from the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) proposes that the recommended temperature ranges meet the needs of 80% of people. A number of individuals will be uncomfortable, even if the requirements are respected. Additional measures may therefore be necessary. In some cases, the Legislation provides a series of acceptable temperatures for various circumstances. See it information sheet OSH answers Temperature conditions – Legislation to consult the list of applicable laws.

5.7. What should the humidity level and air velocity be in the office?

ASHRAE Standard 55-2013 uses a graphical method for the comfort zone which takes into account factors such as relative humidity, mixing ratio, temperature operative and wet bulb temperature and which includes remarks on clothing, metabolic energy, radiation temperature and air velocity.

According to Appendix F of the ASHRAE standard, no lower humidity limit has been established for thermal comfort. Consequently, this standard does not specify humidity levels minimal.

CSA temperature recommendations (above) are based on humidity average of 50%.

Relative humidity below 20% may cause discomfort due to drying of the mucous membranes and skin. Low relative humidity can also cause the formation of static electricity and, therefore, negatively influence the operation of certain office equipment, such as printers and computers. HAS conversely, a relative humidity level above 70% can lead to the formation of condensation on surfaces and inside building equipment and structures. If the rate remains unchanged, mold and fungus could form at these locations. High humidity also makes the room stuffy.

The Health and Safety Executive (UK) states that between 40% and 70% humidity relative does not have a big impact on thermal comfort.

5.8. What is the effect of air speed?

Air velocity can be created by the air conditioning or ventilation system and by the cold surfaces (e.g. air flowing towards the ground). This air movement influences comfort thermal. Drafts, particularly around the head (head, neck and shoulders) and legs (ankles, feet and legs), can cause discomfort.

Generally, temperatures considered to be in the comfort zone will increase with air speed.

5. **Visual Comfort:**

Means ensuring that people have enough light for their activities, the light has the right quality and balance, and people have good views (Autodesk Sustainability Workshop, 2011). It can be associated to the absence of glare caused by the presence of excessive luminance in the field of view. Most design professionals fail to include lighting requirements at the initial stage, forgetting the fact that this oversight will affect productivity in the workplace if lighting requirements are not met (De Carli and De Giuli 2009). According to Laforgue, Souyri, Fontoynont and Achard, Glare can be categorized into: The uncomfortable glare and the disturbing glare, both reduce visual performance. The availability of daylight is an important requirement, especially for office buildings. Poor quality of lighting in the workplace causes eyestrain, which leads to dizziness and stress. Occupants become disgruntled because of their dissatisfaction with the lights in the building, which will result in reduced productivity as occupants will start spending long periods away from work to consult a medical expert for treatment of their eyes and/or vision problems (Suhre, Shin et al. 2011). Also, one of the main source of dissatisfaction in offices is lack of the physical connection with the outside: the contact with the natural environment is important because it brings dynamism to the indoor and a sense of relax for people (De Carli, De Giuli et al. 2008).

6.1. Natural light:

The natural light that illuminates our planet is that which comes to us from the sun. THE sun emits electromagnetic waves whose spectrum extends from radio waves to gamma rays, passing through light visible. This radiation carries solar energy, essential for all life earthly. In contact with the atmosphere, part of solar radiation is reflected in space, part is absorbed by the atmosphere and clouds and a part is transmitted directly (if the sky is clear) and so indirect (diffuse flow from numerous reflections in the atmosphere). The visible part of the spectrum represents about half of the energy received at the surface of the planet. The no part visible is decomposed between infrared and ultraviolet. When it reaches the surface of the Earth, depending on the albedo of the surface struck, part more or less significant amount of radiation is reflected. The other part of this radiation is absorbed by the Earth's surface to be converted into heat or by human beings living organisms, particularly plants, to enable photosynthesis.

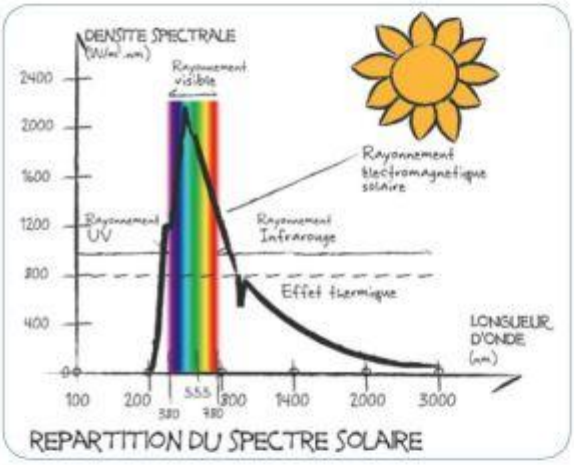

Fig 20- Distribution of the solar spectrum Daylighting – (BIO-TECH Guides 2019).

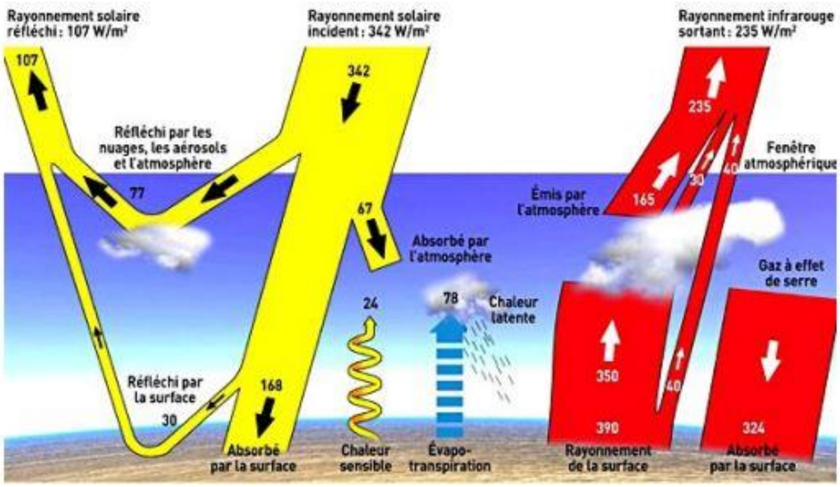

Fig 21- Energy balance of solar radiation and greenhouse effect (Wild, Hakuba et al. 2019).

6.2. Physical quantities:

Light can be defined by several physical quantities that characterize the light source, its transmission and reception by a medium. The main quantities are described in the table below.

Table 6- Definitions of the most common physical quantities (Wild, Hakuba et al. 2019).

Size	Units	Definition
Luminous flux	Lumen (lm)	Light power emitted by a source in all directions
Light intensity	Candéla (cd)	Luminous flux emitted by a point source in a given direction **1 Candela corresponds to the luminous intensity produced by 1 candle**
Luminance	cd/m²	Light intensity of a source in a given direction, divided by the apparent area of this source in the same direction. **It is used to assess the risk of glare. Luminance from the sun can exceed $^{109\ cd/m2}$, and a source becomes dazzling in natural lighting from 2,000 $^{cd/m2}$. In practice, luminance measurements are difficult and costly and in a purpose ofsimplification, recommendations relating à these luminances are formulated directly in terms of LIGHTING values (hence using the luxmeter).**
Illuminance	Lux (lx)	Luminous flux received per unit area. 1 lx = 1 lm/m². **20 lux corresponds to the perception threshold, while other common values are generally calculated using a factor of 1.5, representing the smallest significant difference between 2 lighting levels.** **Under clear skies at midday in summer, horizontal illuminance can be up to 100,000 lux.**

With the diversification of artificial light sources in buildings, the notion of color plays a predominant role, leading to the introduction of the notion of color temperature, expressed in Kelvin (K). It's linked to visual impression and ranges from warm, predominantly orange hues (2,500 K, sun a t horizon) to cool, bluish hues (>5,300 K, sun at zenith). Neutral shades are around 4,000 K. In a survey conducted by Zumtobel Research1 among office users in Europe, a clear preference was expressed for temperatures between 4,000 K and 7,000 K.

<u>6.3. Lighting and well-being:</u>

The French National Institute for Research and Safety (INRS) underlines the link between lighting quality and well-being: "The use of natural light to illuminate workplaces, and the possibility of a view of the outside for those who work there, tend to provide the most appropriate environment for a good physiological and psychological balance of individuals". The lighting ambience of a place is linked to the way in which an individual will be affected by all aspects of his or her lighting environment. It can be broken down into three components:

• Needs, Comfort, Approval.

The lighting ambience of a space will be affected if less attention is paid to any of these three parameters. The excerpt from standard EN 12464-1 reproduced below defines this notion of lighting environment:

For good lighting to be achieved, it is essential that both qualitative and quantitative needs are met, in addition to the required illuminance. Lighting requirements are determined by the satisfaction of three fundamental human needs:

• Visual comfort: the sense of well-being felt by staff contributes in some way to a higher level of productivity and better quality of work,

• Visual performance: staff are able to carry out high-quality visual tasks, even in difficult circumstances and for longer periods,

• Safety.

The most important parameters that determine a lighting ambience with regard to artificial light and natural light are:

• Luminance distribution, • Lighting, • Light direction and interior lighting, • light variability (light levels and color), • color rendering and apparent light color, • Glare, • Flicker.

In addition to lighting, other visual ergonomics parameters influence operators' visual performance, such as:

• Intrinsic properties of the task (size, shape, position, color and reflection of details and background),

• The operator's ophthalmic ability (visual acuity, depth perception, color perception),

• Intentionally designed and enhanced lighting ambience, glare-free lighting, good color rendering, high contrast marks, optical and tactile guidance systems can improve visibility, as well as perception of direction and location (see CIE guidelines on visibility conditions and lighting requirements for accessibility for the elderly and people with disabilities).

Attention to these factors can improve visual performance without the need to increase illuminance.

Requirements:

Requirements are linked to the amount of light needed to carry out an activity in good lighting conditions. These requirements are directly linked to the nature of the activity and therefore to the use of the premises in question. These requirements will be defined, for example, at desk or floor level. This is referred to as the "working plane" or "useful plane". The amount of light required will also depend on the subject itself, its culture or physical condition. Despite this variability, international standards and recommendations define lighting level values.

Comfort:

The notion of comfort is defined here by the absence of discomfort, itself characterized by glare. Glare occurs when the subject experiences discomfort or reduced ability to distinguish details or objects. There are two types of glare: discomfort and incapacitation. Discomfort glare produces an uncomfortable sensation, but does not impair vision of objects. Conversely, incapacitating glare disturbs the vision of objects without necessarily producing an uncomfortable sensation. Discomfort glare produces a drop in visual performance; it is a physiological phenomenon that can be quantified.

6.4. Natural lighting:

6.4.1. Climate and urban context:

A site's level of sunlight will naturally influence its daylight potential. We're talking here only about light transmitted directly, i.e. when the sky is clear. Luminous inputs vary greatly from one region of the globe to another.

In the same way, we can differentiate between a building in a dense urban environment and one on an open site. The potential for capturing and using natural light will be greatly reduced in an urban area with multi-storey buildings. Optimization strategies must therefore be deployed, taking into account the reflection factors of the walls, and recommending the use of different materials. Zenithally or second-day lighting solutions to make the most of access to natural light.

6.4.2. Calculation tools:

The Daylight Factor (DF) is the most widely used indicator for assessing the quality of natural lighting in a building. It calculates the ratio between indoor illuminance at a point on the useful work surface and horizontal outdoor illuminance on a clear site under the most unfavorable conditions, i.e. overcast skies. FLJ is expressed as a percentage.

In the Pre-Project phase, the Daylight Factors of a room are calculated by digital simulation. In the sketch phase, the average FLJ of a room lit by vertical glazing can be estimated using the following formula:

$$FLJmoy = Sv. TL\ \Theta / [ST\ (1-R2)]$$

• Sv: glazing area in m2.

• TL: diffuse transmittance of glazing.

• Θ: angle of sky visible from the center of the glazing, expressed in degrees (90° if no masking is created by buildings or the environment, 60° if a building creates shading between the ground and the first 30 degrees).

• A: total surface area of interior walls (including glazing).

• R: average reflection factor of room walls (default 0.5).

Note that the FLJ calculation does not take into account the orientation of windows, the season or the time of day. It therefore provides a measure of the building's intrinsic ability to capture natural light.

6.4.3. Exterior view:

The quality of views to the outside from a building is obviously linked to the question of natural lighting, and plays an equally important role in the quality of use of the premises, insofar as they create the necessary links with the surrounding space. This contact with the outside world must be carefully balanced, taking into account the use of the building, the quality of the views and the thermal performance of the envelope. Depending on its position, particularly if it is high up, a window will play a role in illuminating the room without offering a view of the outside world.

6.5. Artificial lighting:

A complete lighting project normally comprises 3 phases:

• Choice of lighting.

• The choice of lamps and fixtures, and therefore the choice of color.

• System sizing (number of lamps and luminaries required to achieve the desired illuminance).

6.5.1. Types of lighting:

The choice of lighting type will determine the distribution of luminous flux in the space. The diagram below shows the different classes of luminaries available:

• Direct intensive and direct extensive for downward-directed luminous flux.

• Semi-direct and semi-indirect when the luminous flux is directed partly downwards and partly upwards.

• Indirect when the luminous flux is only directed upwards.

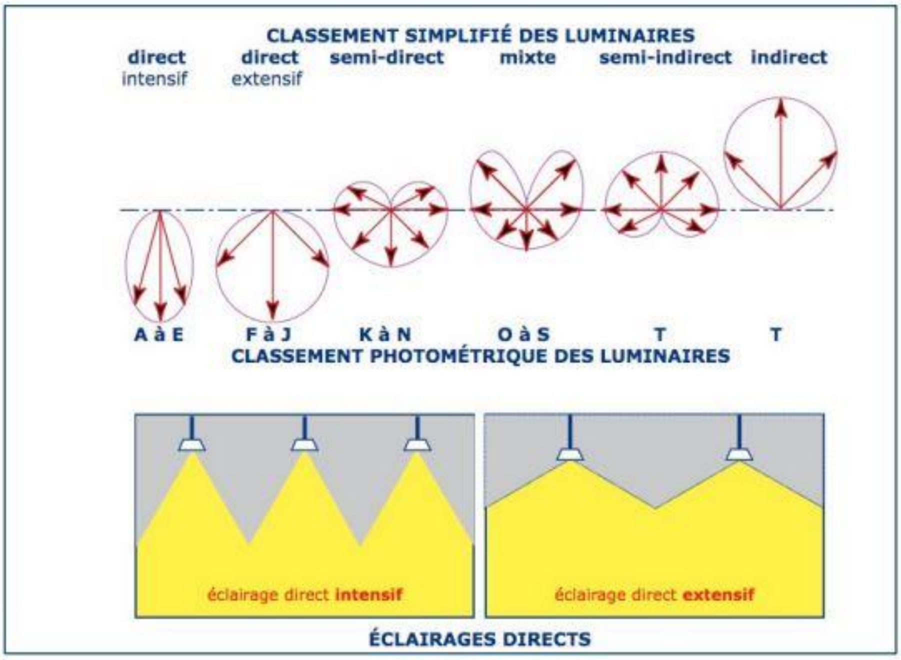

Fig 22 - Lighting type classification Roger Cadiergues - Artificial lighting, RefCad guide nR27.A.

6.5.2. Light sources:

6.5.2.1. Lamps and luminaries:

There are four main types of lamp:

• Those that emit light from the incandescence of a filament, the electric current passing through a tungsten filament heats it to a temperature sufficient to emit light. Halogen lamps are incandescent lamps in which the neutral atmosphere (argon and nitrogen in standard lamps) also contains halogen gases (iodine or bromine).

• These produce visible light by means of an electrical discharge in a gas, and are mainly intended for high spaces requiring fairly high levels of illumination. Light is produced by an electrical discharge in a bulb containing metal halides or highpressure sodium. These sources can't be connected directly to the mains, and use power supply accessories (ballast, ignitor, etc.).

• Discharge lamps, which produce ultraviolet radiation that is transformed into visible light by the fluorescent coating on the tube walls (fluorescent lamps). These lamps require an ignition device (starter) and a current limiter (ballast). Compact fluorescent lamps are made up of fluorescent tubes shaped to occupy a volume similar to that of a conventional light bulb.

• More recently, light-emitting diodes (LEDs) have made their appearance. They are used at very low voltages. Their main advantage is their high luminous efficacy: they convert 15 to 25% of electrical energy into luminous energy (75 to 130 lm/W). The disadvantage of LEDs is that their colorimetric characteristics are rather difficult to control, and several luminescent layers have to be combined to obtain an acceptable color.

They also have low resistance to high temperatures.

6.5.2.2. Key features:

Performance varies widely according to wattage, luminous efficacy, and color and equipment life. The table below shows typical data for each type of source.

6.6. Color temperature:

Light color must also be adapted to the desired illumination level. The Kruithof diagram below defines the color temperature values to be preferred, depending on the level of illumination required.

The comfort zone is Zone B. In zone A, the visual impression is of a lighting ambience that's too warm, as the source temperature is too low for the desired illuminance level. In zone C, the lighting ambience is twilight-like, too cold and the source temperature too high for the illuminance level achieved.

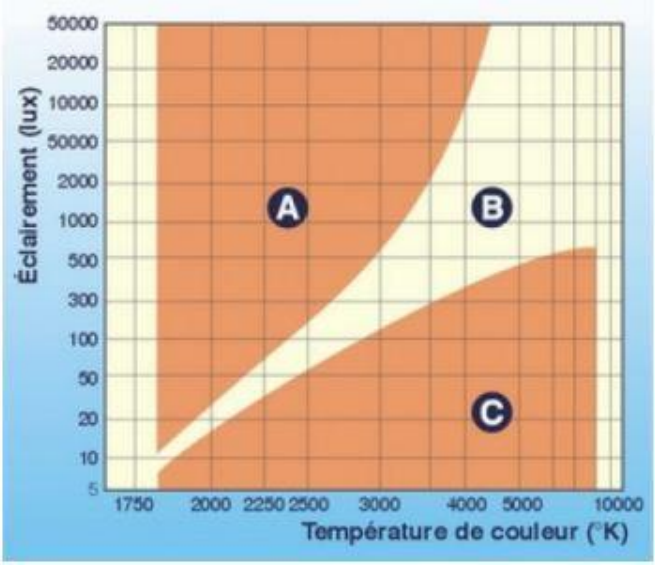

Fig 23- Kruithof diagram ©Architecture ET climat 2013.

6.6.1. Consumption:

The sizing of a lighting system cannot be dissociated from an economic approach that integrates the purchase cost, the cost of energy consumption and the cost of maintenance. The Syndicat de l'éclairage, with the support of ADEME, has published a guide4 which provides a tool for measuring the energy consumption of commercial lighting installations using fluorescent lamps. The table proposed here can be adapted for other lamp technologies. It enables us to analyze all the costs inherent in a lighting system, room by room.

Indoor air quality (IAQ):

IAQ deals with how well the indoor air satisfies the occupants of the building. Inadequate ventilation increases indoor pollutants by not allowing sufficient outdoor air to dilute the emissions from indoor sources (Emuze, Mashili et al. 2013). Environmental Protection Agency (EPA) and others show that indoor environments sometimes can have levels of pollutants that are actually higher than levels found outside. These Pollutants increase the risk of illness, making people uncomfortable, unproductive, and unhappy. Fresh air helps people to be alert and productive. The factors that affect air quality in the indoor environment result from the interaction of the site, climate, building system, potential contaminant sources (e.g., furnishings, moisture sources, work processes/activities, and out- door pollutants), and building occupants (Rossiter 2002). Also, these symptoms of poor IAQ may cause health problems such as irritations of the eyes, mental fatigue and headaches. Constant failure to regularly evaluate the building‘s performance leads to poor indoor environmental quality (IEQ), which may negatively affect the quality of life of the occupants, who will ultimately have to resort to medical treatment (Cho, Lee et al. 2010).

6. The perception of light:

Human vision is a very complex process that is not yet fully understoodntoday despite hundreds of years of study and modeling. The process of vision involves the almost simultaneous interaction of the two eyes and the brain through a network of neurons, receptors and other specialized cells. The first step of this process is the stimulation of light receptors located in the eyes, the conversion of light stimulus or images into signals and the transmission of these electrical signals containing vision information from each eye to the optic nerve. This information is processed in several stages to finally reach the visual cortex of the brain. Visual perception is the excitation of retinal matter which brings into play a reaction photochemical where the coupling is done by an electrical interaction between the wave electromagnetic and the receiver.

7.1 The visual field:

We cannot talk about visual perception without talking about the visual field which is the ability of the eye to grasp visual information which depends on its relative position in the visual field. The visual field is the space delimited by the spatial perception of the eye, without moving the head. Knowing that the visual field is slightly different for each individual, the vertical range of the eyes covers an angle of approximately 130°; it is limited upwards by the eyebrow arches and downwards by the cheeks. The total horizontal field of view of the eyes is approximately 180° when directed towards a fixed object.

Each eye has a viewing angle of approximately 150°. Where the visual fields overlap, humans have binocular vision; they overlap in the middle zone where the same object is seen simultaneously by both eyes but from a different angle. The ability of the eye to grasp visual information depends on its relative position in the visual field. The following graph shows in blue the visual field seen simultaneously by both eyes and in light pink the area seen by each eye separately. The concentric circles delimit the fovea, the ergonoma and the panorama. The fovea is a fairly restricted visual field of 2° which allows us to perceive details and the further we move away from this central field, the more difficult the details are to perceive. The ergonoma is a visual field of 30° relative to the axis of view and it allows us to distinguish shapes. Whereas the panorama is a visual field of 60° relative to the axis of view which allows us to distinguish movements.

7.2. Color perception:

Color brings an additional dimension to lighting. Human behaviors are in fact influenced by emotional responses to the environment and color is one of the main factors in its perception. The color of an object depends on the light that illuminates it: the color blue is a cold color (rich in blue radiation) while the red color is a warm color (rich in red radiation). In addition, you should know that a piece is all the more illuminated when the surfaces that reflect the light are clear. For the eye human, color is a sensation. The receptors in the eye are used to break down light information into electrical signals which will be sent to the optic nerve then to the brain. The eye's receptor system (the retina) is made up of a set of cones and rods: the first being very sensitive to light are responsible for the perception of colors (blue, green, red). The latter, 100 to 500 times more sensitive than the cones, we Allows you to see in low light conditions. The eye sees colors differently differentiated. Each color is associated with a wavelength that we perceive more or less less good. So, we are very sensitive to yellow and see blues and reds poorly. The following diagram shows the perception of colors by the human eye:

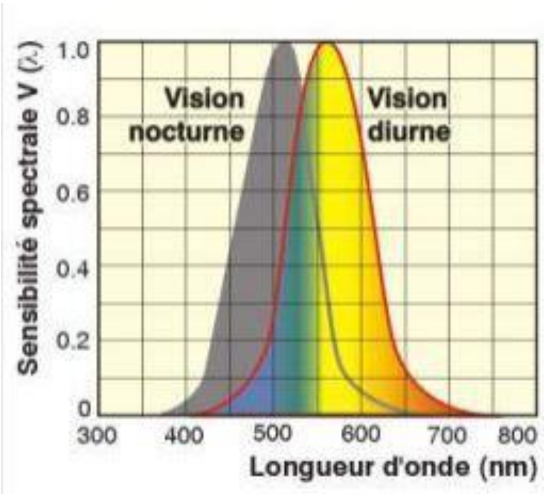

Fig 24- The perception of colors by the eye human (Source: Magali Bodart 2014)

Light is characterized by a reflectance that varies from one color to another. This factor is the ratio between the quantity of light L, falling on a surface and the light l, reflected by this surface. It is expressed in %. The following table gives the different factors reflection for colors:

The nature of light makes colors visible and is described by two measures: the index color rendering CRI, expressed as a percentage, which represents the ability of a source to faithfully render the colors of an object (a CRI of 100 indicates that the light considered contains 100% of existing colors) and the color temperature, measured in degrees Kelvin which designates the hue of the light emitted by a body depending on its temperature (the higher it is, the more the light in question contains large quantities of colors).

7. <u>Human Behavior:</u>

Human behavior is understood as forming the architecture but also architecture can shape human behavior. Humans build buildings in order to meet its own needs, then building that shape the behavior of people who live in the building. The building, designed by humans that was originally built to meet human needs. But the building affects the human way in living the social life and values that exist in life him. This involves between architecture and social stability where both coexist in harmony environment. Human behavior itself is understood as a set of behaviors that possessed by humans and influenced by the customs, attitudes, emotions, values, aesthetics, power, persuasion and genetics.

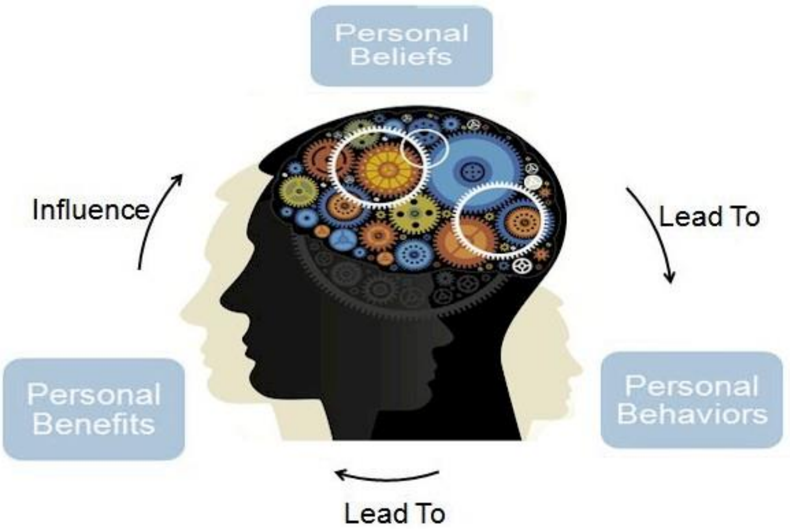

Fig 24- Human behavior, (Source theexplanation 2019).

8. <u>Behavioral Architecture :</u>

Behavioral architecture is an architecture that is able to handle human needs and feelings that adjust to the lifestyle of humans in it. The word "behavior" expresses an awareness of the social structure of the people, a dynamic movement together in time. Just think of a person's behavior in space, then we can make the design.

Behavioral architecture is an architecture that in its application always include behavioral considerations in the design of behavioral connection with the architectural design. that architectural design can be a facilitator of the human behavior or vice versa as a barrier occurrence of human behavior.

9. Principles in the Behavioral Architecture Theme:

The principles of architectural themes of behavior that must be considered in the application of architectural themes of behavior is:

- **Being able to communicate with humans and the environment** a design that must be understood by the wearer through the sensing or imagination of building users, the form presented can be fully understood by the user of the building.
- **Accommodate the activities of the occupants with a comfortable and pleasant** Comfortable physically and psychologically. Physical and physiological fun.

10. Personal Space :

Personal space is an area with an invisible boundary around the human body where others (outside human) should not be entered. Is dynamic (active process to approach or move away from others, which makes it more or less accessible to others). Implementation mechanism of personal space, for example in furniture design, the layout of offices, living rooms.

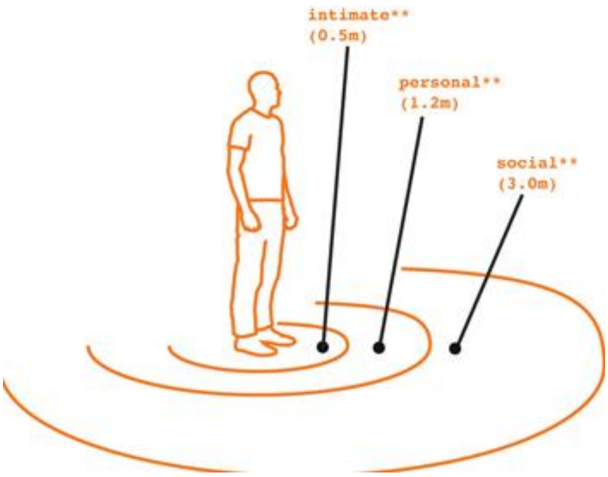

Fig 26- Personel space, *Source theexplanation.*

Personal space is an area around a person with boundaries that are not clear which one cannot enter. Personal space as the distance / area around the individual in which to invade another person, causing the other person to feel the limit is violated, unhappy, and sometimes withdraws. **Some definitions of personal space is implicitly based on the results of research, among others:**

- Personal space boundaries are unclear between a person with another person.
- Real personal space adjacent to itself.
- Setting the personal space is a dynamic process that allows us to get out of it as a change of situation.
- When someone breaks the personal space of others, it can result in anxiety, stress, and even fights.
- The personal space corresponds directly to the distances between people, although there are three orientations from others: face to face, back to back, and direction.

Along with the development of science, human behavior is increasingly used as a benchmark in planning called behavioral architecture approach (behavioral architecture). Humans build a building or outer space to meet human needs where each individual has a different perception of the environment.

11. User's Behaviors:

Behaviors impact workplace and work performance a great deal. In daily professional life at the workplace, you get together with different people who have unlike educational, professional, and family backgrounds. In a diversified workplace environment, employees meet with workers and customers from cultures, languages, dialects, ethnicities, and habitats. Conversely, starting from how an employee, colleague, boss, or subordinate converse with others, to the moods, feelings, and disposition in tasks' performance, they shape the workplace outlook, pleasant or unpleasant work environments, and impact the workplace in terms of organizational performance.

8.1. What is Behavior in the Workplace?

Behavior at the workplace means how an employee behaves when at work with colleagues. The behaviors, positive or negative, define a personality and work ways consequently affecting the task output in particular and employees' performance in general perspective.

It is more formal than being casual with friends due to the appropriateness of the conversations required as per the job descriptions. For example: a lawyer's behaviors and dealings with clientele and colleagues would be different from an employee working in the marketing or finance dominion.

8.2. Importance of good behavior in the Workplace:

Good behavior results in defining a positive workplace environment creating a conduciveness for coworkers and customers to perform at their fullest capacity and enjoy their work. Positive or good behaviors at work also work for employees' capacity building and performance enhancement. Following are a few areas that may be affected by good behavior at the workplace:

Morale: Good behavior at the workplace boosts employee and organizational morale which results in decreased absenteeism and lessened turnover costs.

Productivity: Good (positive) and appropriate requisite behaviors at work improve positivity at the workplace. It attracts team members to work together for a joint target completion timely, consequently enhancing productivity and morale.

Employee Retention: The existing employees have job satisfaction and are retained by the organizations due to a positive work culture because of appropriate and good behaviors at the workplace. This attracts top talent to join your organization as a dream company where proper and encouraging behaviors define organizational design, culture, and improvised productivity.

Company Reputation: Affirmative and progressive positive behaviors at the workplace explain your organizational reputation before clients, employees, and to-be workers. In an era of high info-tech, organizational reputation is no longer hidden and predefines the courage or concern of candidates to apply for any position in the organization or otherwise.

9. Methods for assessing user perception:

Review of qualitative and quantitative methodologies for capturing and analysing user perceptions. There are many varied ways to measure perception in research. The most common forms use research designs such as experimental, correlational, and introspection methods. The use of surveys, questionnaires, as well as tests, are also used.

- Quantitative research is research that collects numerical data. Although commonly quantitative methods are used to investigate perception, qualitative techniques are also used from time to time.
- Perception in research psychology can vary in what it can investigate. An example is a research investigating factors such as culture, motivation and expectations and how they influence perceptual processes.

Conclusion:

In conclusion, this theoretical chapter has explored the multifaceted nature of user perception and behaviors within the built environment, emphasizing their significance in architectural research and practice. By delving into various theoretical perspectives, including environmental psychology, human factors, affordance theory, and transactional theories of space, we have gained valuable insights into the underlying mechanisms shaping how individuals perceive, interact with, and experience their surroundings.

Through a synthesis of theoretical frameworks and methodological approaches, we have highlighted the dynamic interplay between objective environmental features and subjective interpretations, underscoring the importance of considering both in architectural design and evaluation processes. From observational studies and participatory design methods to sensor-based technologies and simulation tools, a diverse array of techniques enables researchers and designers to capture the rich complexities of user experiences, preferences, and needs.

Moreover, this chapter has underscored the holistic nature of user perception and behaviors, which encompass cognitive, emotional, sensory, and social dimensions. Recognizing the subjective and dynamic nature of human experience, architects and designers are empowered to create more responsive, inclusive, and user-centered spaces that enhance well-being, productivity, and social interaction.

Moving forward, it is imperative to continue advancing our understanding of user perception and behaviors within the built environment, particularly in light of emerging trends such as smart technologies, sustainable design, and post-pandemic considerations. By integrating user-centric principles into architectural practice, we can foster environments that not only meet functional requirements but also promote human flourishing, community cohesion, and environmental stewardship.

Ultimately, the integration of user perception and behaviors into architectural research and practice holds the potential to transform the way we design, inhabit, and experience the built environment. By prioritizing human needs, preferences, and experiences, architects and designers can create spaces that not only respond to the demands of today but also anticipate the challenges and opportunities of tomorrow. Through a collaborative and interdisciplinary approach, we can cultivate built environments that enrich lives, foster connections, and sustainably support human flourishing in an ever-changing world.

The psychology of architecture results in a more user-oriented design as it is majorly concerned with people's needs and priorities and acts as a guiding source to develop a better human-interactive space. Also, usually, the perceptions of a designer about a built-form and that of a user are different and the variations are getting more pronounced bringing to the table the importance of Context of designing and communication with the user regarding the same.

Chapter 3

3- Building Life Cycle Assessment (LCA)

Introduction:

This chapter presents a state of the art in understanding the life cycle assessment of buildings. Buildings are often singled out in the fight against climate change. They account for 23% of direct greenhouse gas emissions and 47% of final energy consumption (Marcotullio, Sarzynski et al. 2012). They are also the source of other environmental consequences that seem likely to compromise the ability of future generations to meet their needs (depletion of resources, eutrophication of rivers, acidification of rainfall, production of radioactive waste, etc.). The eco-design of a building involves taking these parameters into account, not just in terms of energy optimization, but also in terms of reducing its environmental impact. The approach presented in this chapter is a decision-making tool. By accurately quantifying environmental impacts, it enables those involved in construction to make the most coherent choice in relation to their objectives. Life Cycle Assessment (LCA) quantifies the environmental impact of a building from "cradle to grave", i.e. from raw material extraction to waste disposal. ISO standards 14040 and 14044 specify the principles and framework applicable to building LCA. Initially developed for industrial products, this method is now used in the construction sector on two scales (Chevalier, 2009):

a) Building materials and products.

b) Buildings or structures.

At the building scale, several tools have been developed around the world to enable these LCA life cycle analyses to be carried out (Peuportier et al., 2004). A third scale is currently being developed: that of the neighborhood, the urban scale. The relationship between the neighborhood and the city is taken into account by data concerning networks (drinking water and wastewater, etc.), transport (cycle paths, distance to public transport, etc.), waste (distances to a landfill, recycling plants, incinerator), climate, and at national level, means of electricity production and other processes and renewable energy sources (Zsigraiová, Tavares et al. 2009).

1. Building life cycle assessment:

Life cycle assessment (LCA) was first developed for industrial products. Its application to the building sector is a cautious one: each building is generally unique, and maintains strong links with both its site and its users (Peuportier and Polster, 2009). What's more, the stability over time on which LCA is based is problematic in the case of a building with its specific features (long lifespan and changes that occur during the lifespan). Life cycle assessments applied to buildings are a useful tool for comparison (Reiter, 2010):

1. Two systems over their full or partial life cycle.

2. The impact of different phases in the same system.

3. A system and its alternatives.

4. A one-reference system.

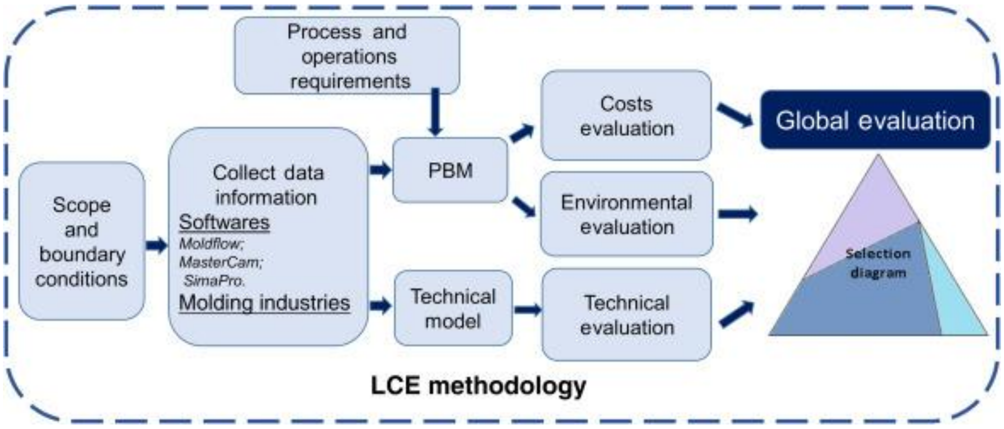

Fig 27- Life cycle approach, (Source: Sustainable Construction Technologies, 2019).

2.1. Building: typology and composition:

The Building LCA model for the "building system" is designed to assess the environmental impacts of a building project, in order to better understand the links between design and impacts, with a view to minimizing them through the development of different variants and alternatives.
It takes into account (Popovici, 2006):
1. Construction of the building and production of its components.
2. Building use (buildings, infrastructures, etc.).
3. Its renovation, and the various operations that can be carried out.
4. Demolition and waste management.

Fig 28- Building life cycle phase. (Source: archDaily 2019).

<u>2.2. Application of life cycle assessment LCA of a building:</u>

For any simplified, comparative LCA approach, the various phases in the life cycle of the buildings studied are grouped into four main stages (Table 7).

• The first stage (pre-production): this is the upstream phase of the building project, encompassing the design and manufacture of building products and materials, aggregates, the extraction of raw materials and the design of plans for the future building.

• The second stage (construction), i.e. site implementation, includes land development, construction of shells, walls and exterior joinery, as well as finishing work. Transportation is also represented here, since the majority of impacts are generated by the transport of materials and machinery during building construction.

• The third phase concerns the use of the building, including water and energy consumption, as well as routine maintenance of the building's spaces (residential, service or office buildings).

• The next phase is maintenance, which consists of replacing building materials and systems at the end of their useful life, to maintain the building's quality, condition and efficiency.

• Finally, dismantling and end-of-life includes the reuse, recovery, storage, recycling, reclamation, landfilling and disposal of materials, as well as land reclamation (reuse of the site for other buildings or uses).

Table 7- Main stages in a building's life cycle. (Source: Thiers, 2008).

Pre-production		Drawing design Raw materials extraction Materials design and manufacture
Construction	Landscaping	Examination of soil constitution (geotechnical study) Foundations / Sanitation Underpinning/Support Landscaping
	Carpentry, wall elevation and exterior joinery	Roofing and covering Low floors / Intermediate floors Walls / External cladding External joinery (doors and windows)
	Finishes	Insulation / Partitions Plumbing / Electricity Heating, air conditioning and ventilation Interior joinery (stairs, doors, handles, baseboards)
	Site clean-up	Residual materials management plan Rental of residual materials containers Sort materials at source to maximize reuse, recycling and recovery
	Transport	Materials / Machinery Employees
Use		Energy consumption Water consumption Housekeeping
Maintenance		Replacement of materials at end-of-life Residual materials management plan Reuse, recovery, storage, recycling, reclamation, landfill and disposal of materials
Dismantling and end-of-life		Reuse, recovery, storage, recycling, reclamation, landfill and disposal of materials Site restoration

A simplified LCA should therefore be circumscribed around similar or identical objectives, function, functional unit and scope of study, in order to obtain comparable, valid and reproducible results (Tab-7).

2.3. LCA life cycle assessment methodology:

Buildings are complex systems involving numerous physical and behavioral phenomena. Eco-design therefore requires us to identify the main causes of environmental impact, and to study solutions for reducing these impacts. Building life-cycle analysis is used for this purpose. It is generally applied statically.

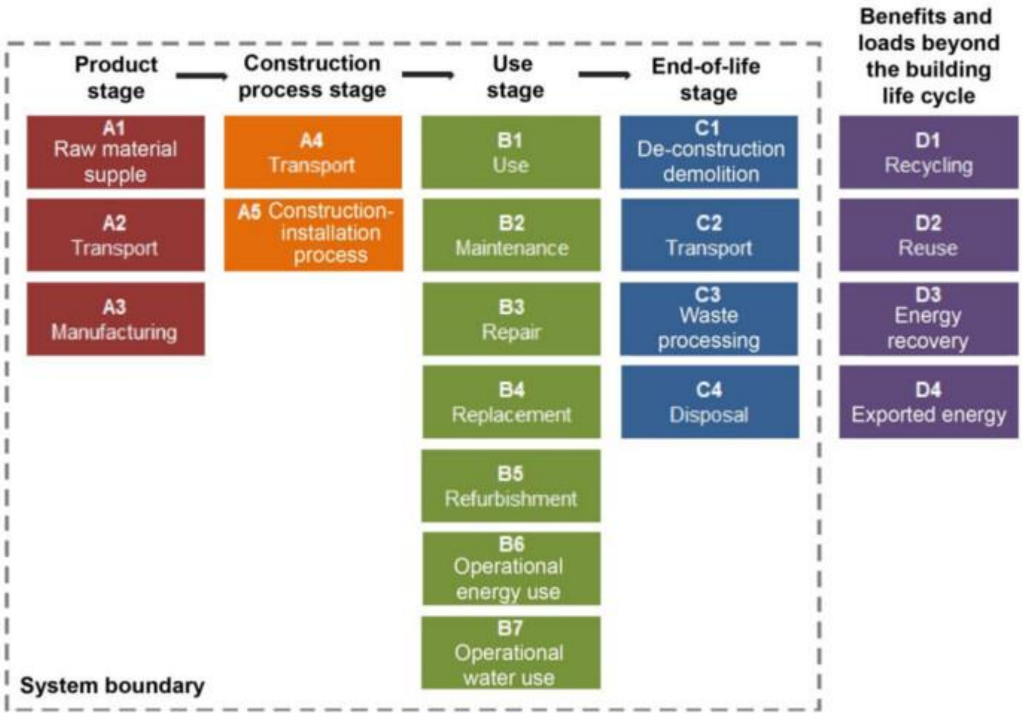

Fig 29- Principle of a building LCA. (Source: archDaily 2019).

2.4. Building modeling:

The function of the system studied by the model will depend on the user's definition of it. However, when comparing two or more variants, similar functions should be maintained. For example, the functional unit of a building is defined by:

• A quantity (number of occupants or users).

• Building functions (residential, commercial, and mixed-use).

• Quality of operation (comfort level: set temperatures, sufficient interior light, ventilation, accessibility, etc.).

• Time (the default life of a new building is 80 years).

The boundaries of the system are also subject to the user's choices, and more specifically to the type of study being carried out, and its purpose. A building has two types of boundaries (Popovici, 2006):

• A first "physical" boundary, which will be considered as including all physical elements of the system (building envelopes, building interiors, etc.).

• A broader boundary of "flows", to take into account upstream and downstream processes that are considered in the system (energy and water production, materials manufacturing and transport, waste treatment, etc.), and to exclude those that are not.

The building system and its boundaries can therefore be represented as follows:

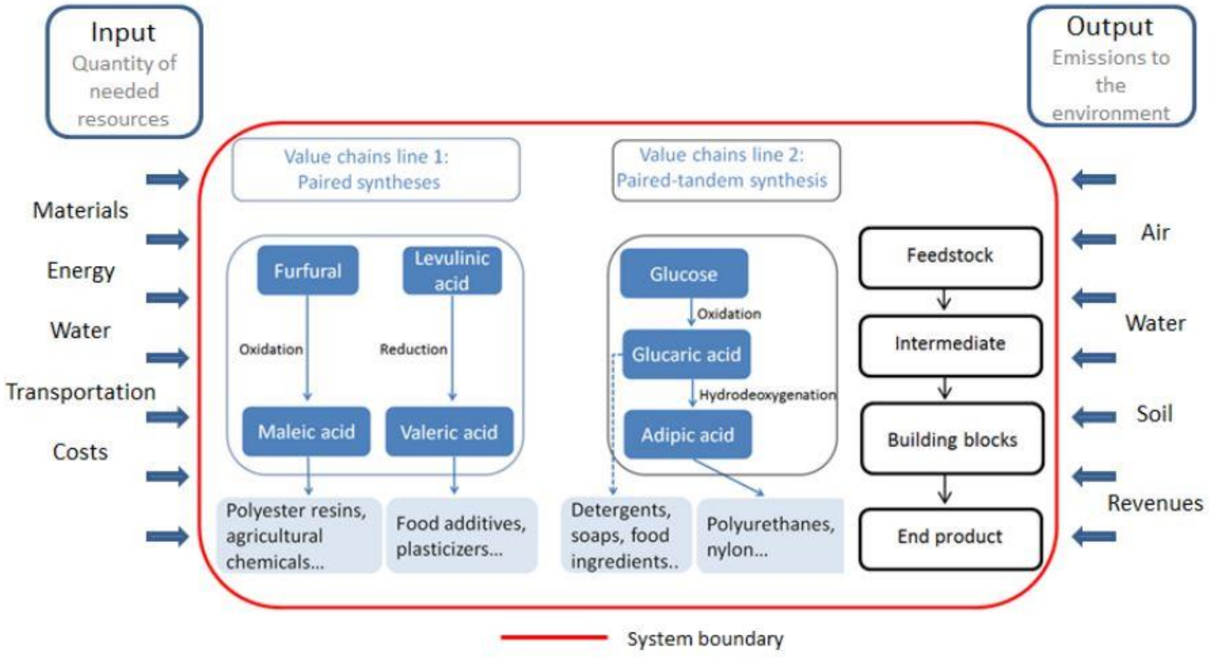

Fig 30- System boundaries for buildings. (Source: Scope and system boundaries of LCA and LCC 2021).

The infrastructures involved in the production of building components, in energy and water production, and in the transport of materials, will be taken into account in the calculation of inventories and impacts (Frischknecht & al, 2004), in order to ensure the rigor of the analysis. The definition of this boundary enables the system to interact with the external environment via elementary flows:

a) Resource flows: water, energy, raw materials.

b) Emissions: gaseous, liquid, solid.

According to the LCA methodology, substances drawn from and emitted to the environment are counted (inventory phase), and environmental indicators are then deduced for the four phases of the building's life cycle:

1. Construction: extraction of raw materials, production and transport of materials.
2. Usage: air conditioning, heating, lighting, ventilation, water consumption....
3. Renovation: replacement of components (windows, floor, ceiling and wall coverings).
4. Demolition: transport and treatment of waste (recovery and landfill).

Aspects relating to the behavior of building users (water and energy consumption, waste treatment, sorting and recycling rates, etc.), the characteristics of the site (transport distances, climate) and the energy sources used (for lighting, air conditioning, heating and ventilation) must also be taken into account. Lifecycle simulation is carried out over an analysis period corresponding to the lifetime of a building (by default, 80 years for new buildings), using an annual time step (Trocmé, 2009).

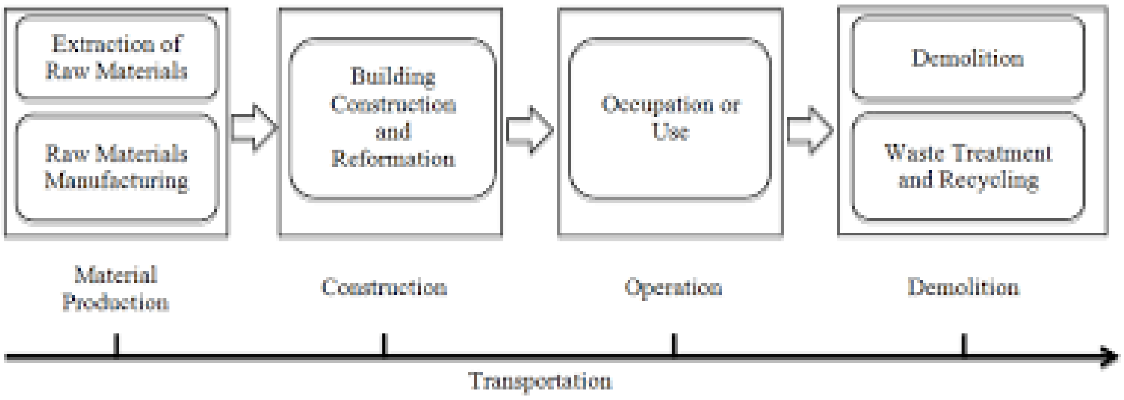

Fig 31- Phases in a building's life cycle. (Source: Sensors 2014).

2.5. Environmental indicators considered:

Environmental data concerning the characteristics of materials and the various processes included in the building system (energy and water production, treatment, etc.).

Waste and wastewater management, transport) are taken from the Ecoinvent database developed by Swiss research institutes, and from the FDES environmental and health declaration sheets for the various materials (Amicarelli, Rana et al. 2024). A life cycle inventory is provided for each process, system, or product and material, according to the reference unit considered (e.g. kg for materials, TJ for energy, tonne-km for freight transport). This is an inventory of all material and energy flows entering (input) and leaving (output) the system, such as:

a) Resources used: rare materials, water, energy.

b) Emissions to air, water and soil: CO_2 to air, ammonia to water, various metals to soil.

c) Waste generated: inert, toxic, radioactive...

The environmental indicators are then assessed over the entire life cycle of the building (table 5). And so other alternatives can be considered, studied and then compared to improve this building from an environmental point of view.

Table 8- Environmental indicators assessed, (Source: Peuportier, 2010).

N°	Environmental Indicator	Unit
1	Cumulative energy demand	GJ
2	Water used	m^3
3	Depletion of abiotic resources	kg antimony
4	Waste products	t
5	Radioactive waste	dm^3
6	Greenhouse effect (a00 years)	t CO eq.$_2$
7	Acidification	kg SO eq.$_2$
8	Eutrophication	kg PO4 eq^{3-}
9	Damage to ecosystem quality due to ecotoxicity	PDF*m^2
10	Damage to health	DALY
11	Photochemical ozone production	kg C2H4eq
12	Odor	m^3 air

PDF*m2: percentage of extinct speciesxm²xan DALY: Disability Adjusted Life Years, Day.

Each simulation tool uses between 8 and 16 indicators in its building life cycle assessment model (Lasvaux & al, 2010).

The advantage of this LCA approach of building is that it avoids all pollution transfers. The analysis tools translate the various environmental indicators into ecopoints or ecoprofiles, radar diagrams, histograms, numerical data and Excel tables. The advantage of this standardization is that it highlights the relative importance of the different indicators used to assess a building's energy and environmental performance. The indicators are also presented by showing the relative contribution of each phase in the building's life cycle. This will enable us to better identify the possibilities for improving a building during the design phase (Peuportier, 2008) for the phase concerned (the one with the greatest impact).

2. The LCA approach, a multi-criteria analysis of buildings:

A general approach to analyzing and simplifying the LCA life cycle assessment model for buildings is proposed, limiting the study to the flows of materials, construction products and systems involved in building construction. The LCA model is multidimensional, and the analysis is a multi-criteria approach. Carrying out an LCA of a building therefore requires data (flows and indicators) for each stage in the life cycle of the many elements and systems involved in its construction (hundreds of materials and material compositions). The problem is therefore akin to the in-depth study o f a database efficient and detailed "building LCA". Life cycle inventories can cover several hundred resource consumption and pollutant emission flows in existing databases (such as the Ecoinvent database) for each material and construction process considered.

These data must be collected from the extraction of raw materials right through to the end of the product's life. Simplification can therefore act on these three aspects

a) LCA parameters (flows and indicators).

b) Contributors.

c) life-cycle phases.

The proposed approach also addresses the analysis of methodological choices for the building LCA database. Indeed, the work already carried out has often highlighted a "black box" effect on existing tools (fig.32). The methodological analysis covers the definition of the model, the system boundaries or the building life cycle inventory nomenclature.

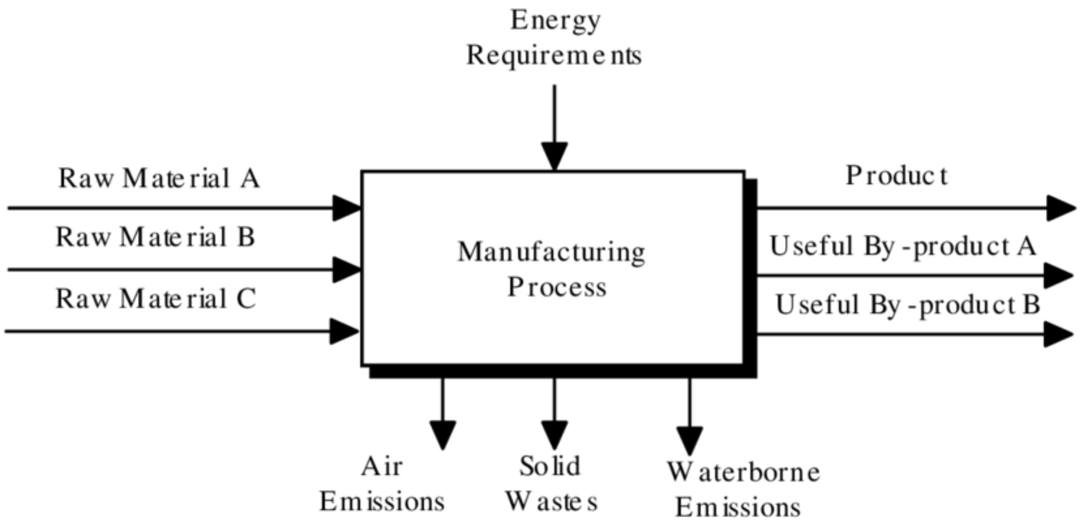

Fig 32- "black box" effect of building LCA databases, (Source: Franklin Associates 2011).

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3. Building assessment tools:

Numerous assessment tools have been developed for buildings. Among other things, they make it possible to use LCA data supplied by manufacturers for construction materials and products intended for the building sector. These tools are based on upstream developments concerning LCA databases and the definition of general methodological principles. Four characteristics define any building LCA model:

1. Definition of system boundaries according to study objectives.

2. The contributor life-cycle inventory calculation phase.

3. The impact assessment phase.

4. The results presentation and interpretation phase (standardization of impacts, sensitivity analyses, third-party communication).

Nearly fifteen tools for building LCA exist internationally. Recent literature reviews have provided a comprehensive overview of these tools (Peuportier et al, 2008).

4.1. Building life cycle assessment tools:

A number of European construction companies, including Bouygues Construction, Eiffage Construction, FLOR, GDF SUEZ and IFPEB, have collectively produced an educational summary of life cycle assessment (LCA) for buildings.

The latter offers "answers to practical questions and insights into the tools available for choosing materials, environmental product declarations (EPDs), environmental and health declaration sheets (EHDSs) and their evolution in relation to technological developments. The aim is to reduce the environmental impact of the building throughout its life cycle, from the extraction of raw materials, to transport, construction, use and end-of-life.

4.2. Characteristics of life cycle assessment tools:

The energy and environmental simulation tools available on the world market as part of these life cycle analysis approaches are (Peuportier et al, 2008): Equer and nova-Equer (Peuportier, 2008), Elodie (CSTB, 2010), Envest (BRE, 2010a), Legep (LEGEP, 2010), Eco-Quantum (IVAM, 2010a), Team Bâtiment (TEAM, 2010), Impact Estimator (Athena Institute, 2010), Bees (NIST, 2010), Ecoeffect (KTH, 2010), Ecosoft (IBO, 2010), Greencalc+ (Sureac, 2010).

These are internationally-developed tools for LCA of buildings, based on different approaches, sometimes reflecting the local context of a country or region. Despite these differences, it is possible to define three common denominators for any building LCA model.

1. Environmental input data (materials, products, processes).
2. Methodological assumptions specific to the software.
3. The number of environmental indicators selected for decision support and the type of presentation of results.

4.2.1. Environmental input data:

The input data for life cycle assessment tools are generally different. Each tool uses its own LCA database, insofar as environmental data are a function of context (geographical and technological). For example, the Canadian Impact Estimator uses the ATHENA database, which is representative of North American manufacturing processes. Similarly, the Dutch Eco-Quantum tool uses the MRPI (milieu relevant product informatie) database, which provides representative data on products sold on the Dutch market. On the other hand, several databases can coexist within the same geographical area. This is particularly the case in France. The Equer (then Nova-Equer) tool uses the Swiss Ecoinvent database, while the Elodie tool uses the environmental and health declaration sheets (FDES) in the French INIES database.

Fig 33- Software for building LCA, (Source: LCA software 2023).

4.2.2. Methodological choices:

With regard to methodological choices, and in particular the definition of assessment boundaries, current tools do not have the same assumptions, since they were developed with different objectives in mind. For example, there are assessment tools for:

a) Design assistance.

b) Evaluation assistance.

c) Rehabilitation assistance.

d) And also to help in the choice of materials.

Various elements contribute to and fall within the scope of a building's environmental assessment:

1. The impact of building materials.

2. Impacts induced by construction products and systems.
3. Energy consumption during use.
4. Water consumption during use.
5. Treatment of household waste (from building use).
6. User transport (administrative staff).

5. Environmental declarations :

Environmental declarations in NF P01-010 format are known in France as "Fiches de déclaration environnementale et sanitaire" (FDES or FDE&S). The generic term EPD stands for "Environmental Product Declaration" (Chevallier, 2009).

As a result, comparing products on a product scale without integrating their link with the rest of the building can lead to comparisons being discarded. There are two types of environmental declaration (FDES) in the French program:

5.1. Individual FDES (Fiches de Déclarations Environnementales et Sanitaires):

These data correspond to a commercial product reference (or product range) (AFNOR, 2004). As a result, individual ESFs are most often the property of a manufacturer.

5.2. Collective FDES: (Fiches de Déclarations Environnementales et Sanitaires - environmental and health declaration sheets)

These data are representative of a "typical product" and were collected at the various production sites selected for the study. They are then pooled to draw up a single declaration dedicated to this "product-type" (AFNOR, 2004). As a result, collective environmental product declarations are most often the property of a group of manufacturers, depending on the sector (wood, ceramics, paint, glass, etc....).

5.3. Link between environmental declarations and building certifications:

There are currently a number of international tools for assessing t h e environmental quality of buildings during the design phase. Here we list 5 of the world's best-known tools:

5.3.1. LEED (Leadership Energy Environment Design), the American tool, is mostly applied in the United States, but is difficult to export because it is adapted to American regulations. The evaluation approach is subjective and the evaluation coefficients are arbitrary. This certification can also be found in other countries (USA, Mexico, Brazil, Japan, Italy, Spain, United Arab Emirates, Australia, China and Korea).

5.3.2. GBTool, a tool of Canadian origin, is comprehensive, freely available on the Internet, highly complex and best reserved for experts. It covers both the design (preliminary design and project) and operation phases.

5.3.3. BREEAM, the British tool, was one of the first to appear. Widely used in England and Canada, and developed by the Building Research Establishment, this tool focuses on the design process in its earliest stages, at the sketch stage.

5.3.4. CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), the first Japanese tool, is based on the principles of LEED. It is based on a relationship between exterior and interior environmental impacts. Its distinctive feature is that it introduces the notion of culture and the regional character of construction.

5.3.5. ESCALE, the French tool presented at the Green Building Challenge 2002 conference (GBC 2002), is not available or distributed in France. At the design stage, it simulates expected performance for all targets, without addressing comfort or cost aspects. (Mandellena, 2006).

5.4. Building assessment and analysis methods:

Building assessment methods essentially involve balances (of energy or materials) deduced from measurable quantities such as: energy, water and electricity consumption, temperatures, ventilation rates, envelope tightness, thermal properties of materials, etc. The framework of these balances must be precisely defined: flows studied, system limits, and assumptions. The framework of these balances must be precisely defined: flows studied, system limits, and assumptions.

5.4.1. The energy balance of a building and its representations:

Drawing up an energy balance for a building means assessing the energy supplies and the uses of this energy within the building. The system studied is the building, delimited by its envelope, as well as all the energy systems that interact with this building, such as cogeneration units, boilers, solar panels, geothermal exchangers, air-conditioning units, ventilation units, etc...

5.4.2. Energy accounting and flow balance:

There is no single standardized method for establishing a building's energy balance. Nevertheless, it is possible to construct one based on the energy accounting method used to draw up a country's energy balance, for example:

1. In Algeria, APRUE's mission is to evaluate local energy production and consumption.
2. in France, the method used by the Observatoire de l'Énergie of the Direction Générale de l'Énergie et des Matières Premières OEDGEMP.

The method consists of evaluating local production, imports, exports and changes in energy stocks over the course of a year, as well as the various energy consumption items. Given the proposed definition of a positive-energy building, this method seems easily adaptable to the study of a sustainable building.

6. Building life phases:

Firstly, the environmental impact of buildings, linked to the extraction of natural resources required for their construction. The building manufacturing process, by analogy with an industrial process, involves the extraction of raw materials from the environment, their transport, transformation, manufacture, use and end-of-life.

6.1. The stages in a building's life cycle:

LCA and life cycle cost analysis of a building must cover its entire life cycle. This means that general knowledge of the activities having an impact on the environment in relation to each life-cycle stage is required from t h e outset. According to the European Committee for Standardization standard CEN 350, building life-cycle stages include:

1. The materials production stage.
2. The construction stage.
3. The use phase. 4. The renovation phase.
5. And the end-of-life phase.

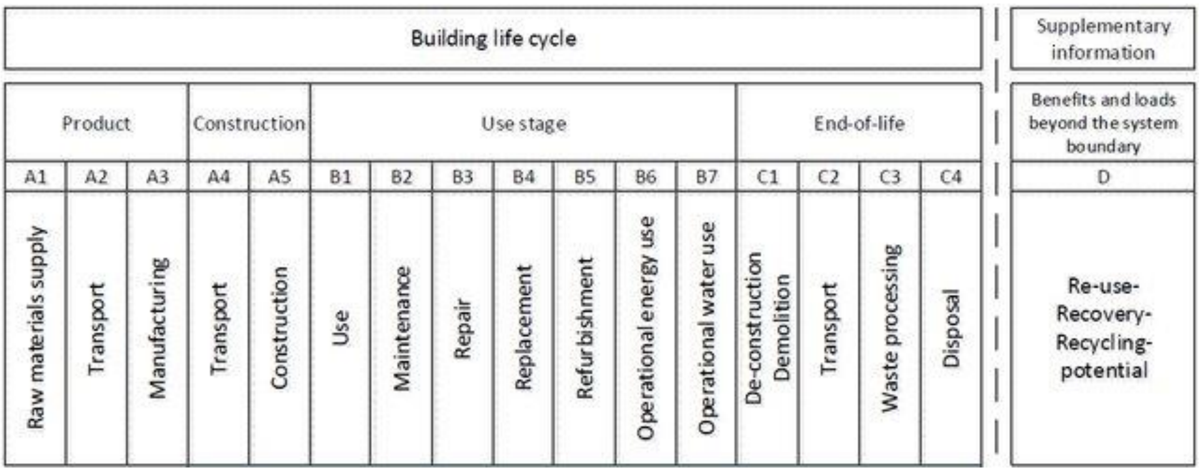


Fig 34- : Building life cycle stages, (Source: Building and Environment 2019).

Any LCA of a building requires a database of data relating to its construction, and depending on the level of detail expected from the LCA, a wide variety and quantity of data may be required. During its lifecycle, the building covers a number of phases, each of which contains units of reference for the players involved (architects, users, owners, etc.), generally differing in nature and decision-makers.

• During the design phase, the functional units are mainly determined by the project owners (architects and engineers).

• During the construction phase, the functional units are determined by the building contractors.

• In renovation, the state of deterioration of the building defines the operations required for renovation, and this diagnosis is generally carried out according to homogeneous elements determined by specialists.

• In the demolition phase, the nature of the materials used and the likely pollution of the soil must be established, with the volume of different types of waste as the reference units.

Establishing these stages enables the selection of those to be considered in the life cycle of both buildings. The LCA should be circumscribed around similar or identical objectives, function, functional unit and scope of study in order to obtain valid, reproducible and comparable results.

7. **Towards environmental building design:**

The architectural design of buildings must take into account all environmental aspects of the building and its context. All expected levels of comfort and performance are taken into account, as well as all energy consumption.

Energy efficiency, energy optimization and a reduced environmental footprint.

a) **The programming phase (the initiative):** this decision is based on an assessment of an organization's needs, or on a market study. All wishes, demands and constraints must then be formalized in a program defining the expected performance levels, and certain desired technical options, as well as characteristics linked to the site and the future building's functionalities.

b) **The design phase:** at this stage, urban constraints are taken into account to define the overall shape of the proposed building or group of buildings.

1. **The sketch:** the main architectural choices concerning form and technical options are made, enabling us to refine our cost and time estimates.

2. **Detailed design:** the building components are increasingly precise, and include interior parts, equipment, updated costs and deadlines.

c) **The design phase (the prescription):** the precise specification of the various materials and components enables a rigorous estimate of investments and very precise deadlines.

d) **The construction phase (site organization):** the work involves detailed execution plans, site planning, integrating personnel, machinery and other equipment. It involves laying the foundations, building shells, finishing works and secondary trades (CES), and coordinating the activities of the various companies involved.

After construction, it's time for acceptance of the building: the project manager and owner check that the program has been followed, and that the building has been completed in line with objectives. Guarantees are formulated, and finishing touches are requested if necessary.

During these different phases, the decision-making process can be modelled by three stages:

1. Identifying a problem.
2. Development of a set of solutions.
3. Choosing a solution.

Environmental assessment tools must be used in this third phase of the decision-making process: comparing the different variants and helping to select the chosen solution. The identification of environmental problems takes place upstream: it is integrated into regulatory constraints, into the project owner's program or is the fruit of the environmental culture of the players involved. The development of solutions depends on the technical culture of those involved and their practical experience of environmental quality.

7.1. Design for environmental building quality:

Building design is a very important point to consider in an LCA approach applied to buildings, as it is the basis for all the choices made. At the design stage, the needs of future occupants and users are assessed, enabling specific choices to be made regarding materials used, energy efficiency, location, air quality, energy and water consumption, etc. (Boucher and Blais, 2010).

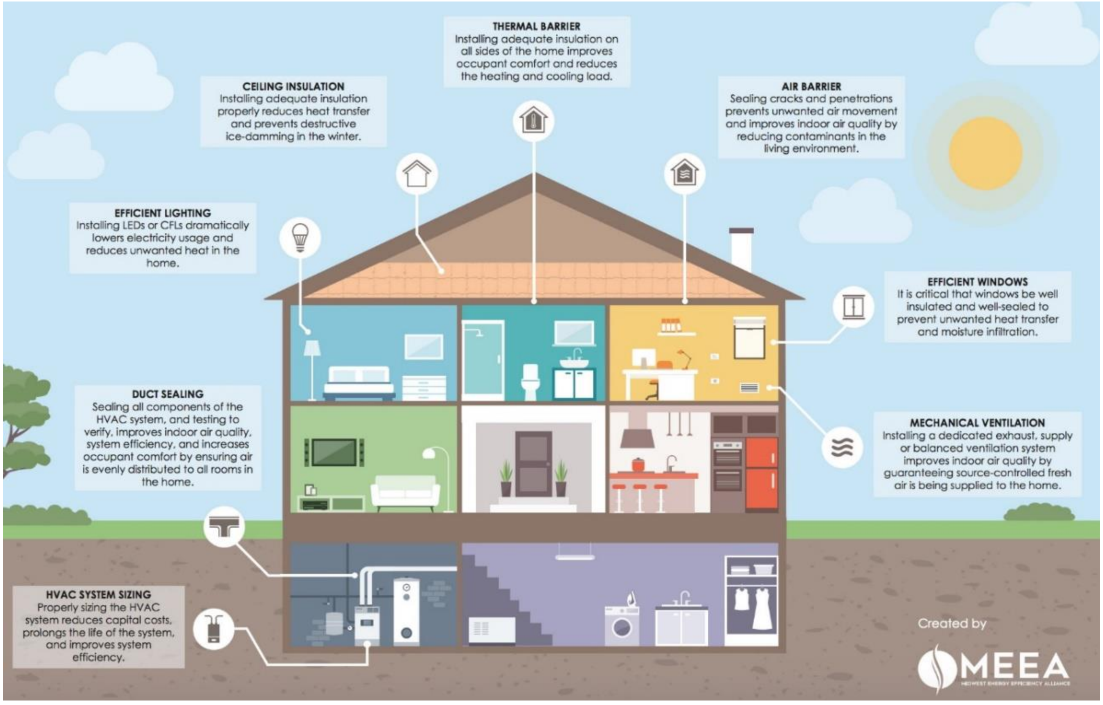


Fig 35- Distinctive features of green buildings, (Source: Green buildings guidelines 2019).

7.2. Building project management system:

To successfully implement an environmental quality approach in a building project, the project owner will adopt a quality approach called "environmental management of the operation", or QEB (Qualité Environnementale du Bâtiment) project management.

7.2.1. Stages in a sustainable building project:

There are two main stages in a building project:

• Step 1: The project management system will systematically begin with an environmental analysis of the site for construction operations: this will enable the project owner to ensure that his construction operation is in line with a logic of sustainable development applied to land management, by addressing the following issues in particular:

1. Consistency between the development of the plot and the local authority's policy on energy, particularly renewable energy (wood, geothermal energy, heating networks, etc.), sewage networks, waste and water resource management, services, travel and transport, etc.
2. Controlling modes of transport and encouraging less polluting forms of transport, especially mass transit.
3. Preservation of ecosystems and biodiversity on the site.
4. Flood risk prevention and pollution control in sensitive areas.

• Step 2: Based on the results of the environmental analysis of the site, the project owner will decide which environmental quality indicators he wishes to implement for the project, and at what level of performance. A 6-topic evaluation grid is therefore proposed, with the aim of facilitating the implementation of QEB-compliant building project management:

Theme 1	Building integration into the site, bioclimatic design
Theme 2	Energy efficiency and water management.
Theme 3	Choice of materials and construction processes.
Theme 4	Health and thermal, acoustic and visual comfort.
Theme 5	Managing nuisance and waste on site.
Theme 6	Monitoring and maintaining performance during the operating phase.

Fig 36- : Building environmental quality themes. Source: HQE-urbanisme/publications, 2013.

• Theme 1 - Building integration into the site, bioclimatic design

The aim is to provide a "passive" approach to most comfort requirements (summer and winter thermal comfort, acoustic comfort, air quality, visual comfort) and to reduce energy needs (natural lighting, solar gain for heating, ventilation). This means making the best possible choice of ground plan, construction principle (choice of inertia....), project architecture (compactness, etc.), facades (materials, openings and dimensions according to orientation, quality of solar protection....), insulation choices, ventilation strategies, etc.

1.1 Building layout and orientation	-Carry out an environmental analysis to reveal the site's assets and constraints in order to optimize the layout: plot orientation, access, masks, T°C service, wind regime, possible compactness, acoustic nuisance, ... in accordance with current regulations. - Apply the principles of bioclimatic design - Anticipate the site's natural hazards.
1.2 Building layout	Define morphologies and organize spaces to take advantage of the site, guarantee summer comfort and natural lighting, and minimize heat loss.
1.3 Outdoor areas	-Design of spaces outdoor spaces that integrate the morphology of the site, the existing plant species and the prevailing winds, site offers and constraints.
1.4 Facades	Drilling and dimensions according to orientations (bioclimatic principles), quality of solar protection and joinery, and type of glazing.

•Theme 2 - Energy efficiency and water management

The aim is to reduce buildings' energy bills and cut greenhouse gas emissions from existing and new buildings. For new buildings, the requirements correspond to the THPE level of RT 2012. A proportion of energy needs must be covered by a renewable energy source. For renovations of older buildings, the thermal requirements are slightly lower. A feasibility study for the integration of a renewable energy solution must be carried out.

2.1 Thermal insulation and inertia	-Give priority to 'passive' comfort requirements (summer and winter thermal comfort, acoustic comfort, air quality, visual comfort) and to reducing energy needs (natural lighting, solar gain for heating) and Optimize compactness (optimized occupancy density).
2.2 Windows and apertures	Encourage passive solar gain and natural lighting, systematize external solar shading of northeast bays at northwest.
2.3 Vegetation	Encourage the planting of : roofs, feet fro m facades an d facades/windows/balconies.

•Theme 3 - Choice of building materials and processes

The aim of this theme is twofold: On the one hand, it's a question of thinking ahead from the outset of the building project, in order to give preference to materials and construction processes that limit the building's environmental impact. On the other hand, the technical choices made must ensure simplified upkeep and maintenance through good building accessibility, as well as a choice of construction products and materials that simplify cleaning and maintenance operations throughout the building's life cycle.

3.1 Choice of materials	-Look for the possibility of using eco-materials or natural materials (from the region, local materials). Respect the list of prohibited materials: mineral fibers and other products.
3.2 Building systems and materials construction	-Favoring construction processes and materials that limit the environmental impacts (minimizing waste), eco-friendly materials -optimize recycling, easy maintenance) Establishthe list of materials, the volumes, the distance supply, in construction/renovation Establish destinations for recycling/recovery/purification. landfill (for construction waste).
3.3Transport of materials	-Minimize transport of materials.

• Theme 4 - Health and thermal, acoustic and visual comfort

The aim is to ensure good thermal comfort conditions in summer and winter, as well a s acoustic and visual comfort. Particular attention will be paid to indoor air quality (humidity, materials used and their impact on human health).

4.1 Controlling thermal comfort	-Ensure good thermal comfort. - Reduction of internal inputs. - Size and distribution of glazing according to orientation
4.3 Visual comfort	-Ensure comfortable natural lighting and good brightness throughout the building. Especially in bathrooms, WCs and common areas. - Avoid glare and reflections indoors.
4.3 Impact of materials on environment and health	Choose materials that do not adversely affect the health and quality of your home indoor air

• Theme 5 - Managing nuisance and waste on the worksite

In line with the CUB (Bordeaux Urban Community) clean worksite charter, worksites must integrate principles of nuisance reduction and risk limitation (health, safety, water and soil pollution), as well as waste and dust.

5.1 Clean site	- Reducing noise pollution -Risks of air pollution (burning prohibited), water and soil pollution.
5.2 Professional training	Before and during the worksite, hold information and awareness-raising meetings on the issues and obligations relating to energy efficiency and the environment. clean worksite.

• Theme 6 - Monitoring and maintaining performance during the operating phase

One of the main aims of this approach is to monitor building projects. In the operating phase. This should enable us to assess the actual performance of the buildings, and ensure that the recommendations implemented contribute to the ultimate objective of controlling operating costs, and consequently keeping costs down for building users.

6.1 Display and monitoring	Present projected operating costs: air-conditioning, heating, domestic hot water and subscriptions, upkeep and maintenance costs.
6.2 Efficient use by occupants	Plan and install metering equipment t o provide information to occupants/users. - Training occupants and raising their awareness of usage issues rational use of resources
6.3 Performance monitoring during the operating phase	-Provide a protocol for monitoring the building's environmental performance over the first two years of operation, including calculations for the DEPEB display.

A building involves a large number of materials, systems and sub-systems, particularly during the construction phase. To simplify the model, these are classified into three main categories:

1. Materials, corresponding to basic, non-decomposable materials (bricks, wood, sand, water, gravel, etc.).
2. Factory-assembled components (water pipes, windows, doors, insulation panels, etc.).
3. Assemblies, larger components that cannot be fully assembled in the factory (walls, foundations, networks, etc.).

These elements constitute the elementary components as considered in the description of the building's physical structure. They will be aggregated according to the characteristics of the elements considered. For the construction phase, the basic production processes for materials, components and assemblies, as well as their transportation.

The waste generated corresponds to surplus materials produced and transported. In many cases, recycling waste can limit environmental impact by avoiding the need for a treatment process and the production of new products.

There are two types of recycling:

a) closed-loop, where the material can be reused for the same purpose in a similar condition.

b) open-loop, where the material, often a composite, cannot be reused as is (e.g. concrete), (Polster, 1995).

7.2.2 The functional unit: of a building covers many aspects, including:

-Floor space: the functional unit of a building can be reduced to 1 m² of floor space, for example. However, different types of use imply different conditions (temperature setpoints, occupancy scenarios, regulatory requirements, etc.). These data will be compared with average reference values for each use. For the same technology, it should also be noted that environmental performance per m² often decreases with building size.

Thus, the building LCA method adopted here includes the definition of building types taking into account:

a) Use: the functional unit considers a given use (housing, offices, mixed use, etc.), which will determine comfort requirements, occupancy characteristics and conditions of use.

b) The level of comfort, which depends on a number of factors: thermal (definition o f a maximum temperature for a typical year, or taking in to account Discomfort Degree Days (DDD)), luminosity (taking into account average natural lighting or Daylight Factor (DLF)), and acoustic (with protective devices whose characteristics are regulated), air quality (regulatory hygienic flow rates)...

c) Lifespan: given the long lifespan of buildings, the use phase represents one of the key factors in environmental impact. These will be strongly determined by the building's thermal and energy behaviour, involving heating and/or air-conditioning consumption to achieve the temperature setpoints defined in the functional unit. Assessment of the environmental impact of the use phase is therefore based on the building's STD dynamic thermal simulation.

By entering the description of a building (geometry, composition and characteristics of walls, characteristics of joinery, geographical location), occupancy and use scenarios, the various equipment present and weather data for the chosen site, the model calculates the building's energy requirements and the temperatures of the various thermal zones considered (Peuportier and Sommereux,1990).

8. Materials Lifecycle analysis:

Analyzing the life cycle of a material, product or service enables us to assess the pressure it exerts on resources and the environment (energy consumption and emissions). This then enables us to study alternatives for improving the product and trying to reduce this pressure (Energy/Impact).

A product's life cycle assessment (LCA) aims to systematically evaluate the environmental effects of the product's life, as well as the flows (materials and energy) entering and leaving (input and output) at each stage of the product's life (Barnard, Arias et al. 2021).

8.1. Results of material life cycle analysis:

A material or product that scores well in a life cycle assessment is one that (Sun, Rydh et al. 2003):

• Uses few natural resources (materials, energy) during manufacture, use or disposal.

• Uses renewable and/or recycled and recyclable natural resources in its manufacture.

• Can be reused or recycled at the end of its life.

• Contributes little or nothing to pollution, impacts, emissions, global warming, and does not destroy ecosystems or harm biodiversity throughout its life cycle (manufacture, use, disposal).

• Contributes to safeguarding or restoring ecosystems and biodiversity.

8.3. Valuing the life cycle of materials:

Adding value to the life cycle of a material used in a building means delaying its replacement, or allowing it to be recycled. The design of details, in particular the connections between components, the suitability of the material for its intended use and maintenance are all ways of taking full advantage of, or extending, the useful life of the material and subsequently that of the building in question.

8.4. Choice of materials:

The choice of construction techniques, systems and materials is the synthesis of the analysis of constraints applied to the building project. Analysis criteria include: stability, functional and performance constraints (mechanical, thermal or water resistance, mass, fire resistance, wear and weather resistance); aesthetics; health and environmental impacts; and cost (Borg 2011).

To assess and compare the overall environmental impact of one material with another, tools based on life cycle analysis can be used. The results of such an analysis are added to those concerning thermal performance, to offer a broader view of the environmental issues involved in choosing a material.

Life Cycle Assessment (LCA) assesses the environmental impact of materials or products over the entire lifecycle of a building, from the acquisition of raw materials to production, use, end-of-life treatment, recycling and disposal. In concrete terms, life-cycle analyses can be used to establish databases that enable the Eco balance of an element, a wall, the envelope or, more broadly, the building as a whole.

Various assessment tools based on the principle of life cycle assessment (LCA) are available, providing a solid reference base for studies designed to guide the choice of construction techniques and materials on the basis of environmental criteria.

We have identified two main types of tool:

a) Checklist tools, which evaluate LCA results for products, components or materials, the CRTE tools (Resource Center for Environmental Technologies) -Luxembourg), Cradle 2 Cradle certified products, and the INIES database listing FDES (Fiches de Déclaration Environnementale ET Sanitaire), which provides environmental data on a material throughout its life cycle.

b) Ecobilan" tools, or specific software, can be used to carry out an environmental assessment of an original wall based on its materials and components. Examples include ECO-BAT (Switzerland), ECOSOFT (Austria) and BAUBOOK (Austria).

Their principle is to ensure that, for equivalent technical and technological performance, the construction material or product chosen has the least possible impact on the environment under the same conditions.

8.5. Indicators for choosing materials:

For the building project as a whole, effective consideration of the LCA life cycles of the building and materials is assessed according to:

- The frequency of renovation work.
- Minimize the costs and waste involved in making these changes.
- Potential for reusing space
- Opt for recycled or reused materials in building construction.
- Opt for natural and recyclable materials in the project in relation to the volume or total cost of materials.

8.6. Objectives for the choice of materials:

The choice of environmentally-friendly materials, adapted to the context with a life-cycle assessment, is presented in three levels (Khanna, Wadhwa et al. 2022):

a. Minimum target:

Design assemblies in such a way that materials can be replaced and salvaged, or that access to techniques and technical hoppers can be gained by dismantling and without undue demolition. Use materials and techniques that promote the longevity of components, and are adapted to stresses (weathering/wear, etc.).

b. Recommended target:

Favoring the use of ecological materials and materials derived from recovery, recycled and/or recyclable materials. Choose materials that minimize environmental impact, based on a product life-cycle analysis (LCA).

c. Optimum aim:

Encourage the use of natural or fully recyclable materials. Identify the health risks associated with each building material and component, and make choices based on "0" impact. Anticipate wall and component dismantling processes right from the design stage.

8.7. Product impact and building impact:

Some products claim a share of the impacts avoided by the building as a result of their use in it. For example, thermal insulation products for walls, floors and roofs, as well as insulating glass units, provide the comfort and performance expected of a building, while saving energy and thus reducing environmental impact.

9. Impact scale:

Any LCA approach includes a part of "inputs" (resources) and a part of "outputs" (impact, emissions and other effects). In the case of a building, the scale of these impacts is crucial, and they can be located in the following levels:

9.1. General or global:

It no longer has an upper limit, but generally includes continental impacts such as air and sea surface pollution.

9.2. Regional:

This level of impact more or less includes the continuous ecosystems of a region or several regions. The simplest method is to associate impacts due to human activities in the construction sector with regional and city plans.

9.3. Local:

The impact of a building at this scale concerns the site, affecting the microclimate around the building. The building plot can be part of this scale.

9.4. Building interior:

The indoor climate is influenced by certain types of impact (EASE, 2010)

10. Life cycle assessment tools Building LCA:

Several building lifecycle analysis software packages are available to players in the building sector. The 2 most widely used in Europe (France) are presented below:

10.1. Elodie: measures the overall impact of buildings on the environment. Developed in 2008 by the Centre Scientifique ET Technique des Bâtiment CSTB (France). It's a decision-making tool. Elodie uses FDES sheets from the INIES database to calculate the environmental impact of buildings, as well as data from the Swiss Ecoinvent database.

To carry out an LCA with Elodie, the project is broken down into islands and then zones. In each building, six contributors have to be filled in, corresponding to different sources of environmental impact over the building's life cycle:

• Component contributor: building materials and equipment.
• Energy contributor: energy consumption during use.
• Water contributor: water consumption in use phase.
• Trip contributor: occupant trips (user transportation).
• Construction site contributor: construction-related impacts not taken into account in the EHDS.
• Waste contributor: production of waste during use.

The quantities of materials used in the building under study are entered manually in Elodie's component contributor. They must then be assigned an ESDS. For the energy contributor, the data must also be entered manually, after running a dynamic thermal simulation STD of the building in another software package. To quantify environmental impacts, 17 indicators are defined in the FDES. However, only 9 of these can be used by all Elodie contributors.

10.2. EQUER /nova-EQUER: EQUER is a life cycle assessment (LCA) tool for buildings, developed since 1995 by the Ecole des Mines de Paris - Paris Tech (Centre d'Energétique ET Procédés). Developed under the scientific responsibility of Bruno Peuportier, from the Centre d'Energétique ET Procédés at the Ecole Nationale Supérieure des Mines de Paris, EQUER is published by IZUBA Energies (France).

This is the building environmental quality assessment tool chosen for the LCA of tertiary buildings, and in particular elementary school, with the aim of helping stakeholders to better understand the consequences of their choices.

Such an analysis tool can be used by all building professionals. Architects can better justify their project to the client, by presenting a rigorous environmental balance sheet. It is a computer simulation tool that facilitates the comparison of variants, thus providing a decision-making aid. Linking with a thermal simulation tool establishes the link between energy and environmental analysis, and is the result of linking ALCYONE, COMFIE and EQUER (nova Equer) software.

Nova-Equer then imports from Pléiades the quantities of materials used in the construction of the building, as well as all air conditioning, heating, DHW and photovoltaic production requirements, etc., which are used to calculate the environmental performance and assess the main environmental impacts (greenhouse effect, eutrophication, water consumption, etc.) of a building resulting from its construction, use, renovation and destruction.

10.3. Archicad LCA plugin:

Once all necessary input data are obtained by means of geometry analysis and user input, you can start the data input into the VIP-Core calculation engine built into ARCHICAD.

Graphisoft Center Danmark just released a public beta version of DesignLCA, a plugin for Archicad 26 that facilitates EcoDesigner Star to calculate a project's CO_2 footprint throughout a given period ($CO_2eq/m^2/year$). DesignLCA calculates the Global Warming Potential as an early-stage life cycle assessment.

With this method, designers can quickly read their projects' CO_2 footprint where both construction and operation phases are considered.

There is a Danish version of the plugin prepared to meet the Danish regulations to be implemented in 2023. There is also an international version where values and settings need to be adjusted to meet your local regulations, demands and Environmental Product Declarations (EPD).

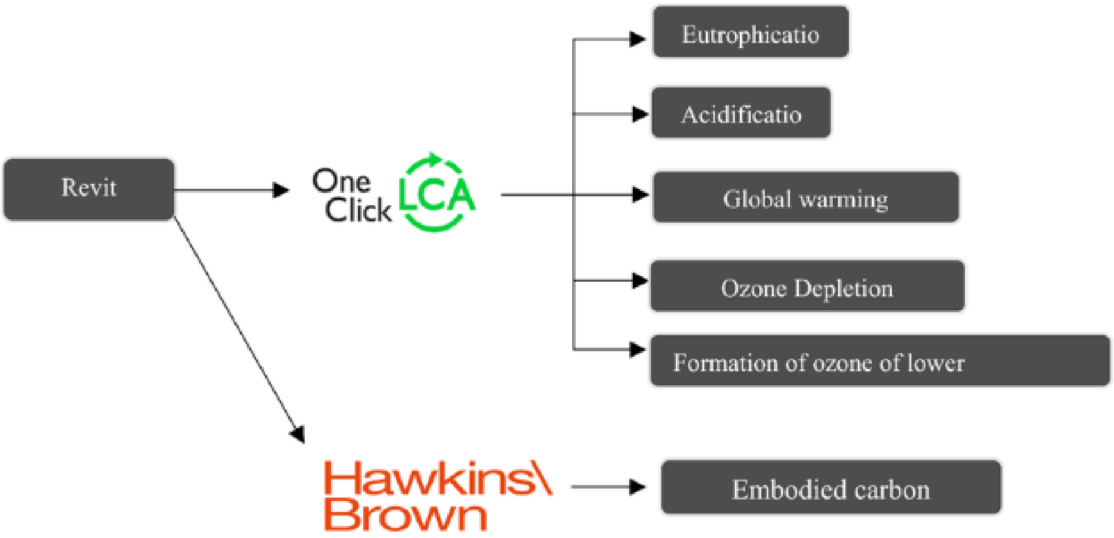


Fig 37- : Input/output chaining between assessment tools. (Source: One click LCA 2023).

One Click LCA is the world's leading life cycle assessment software that helps you calculate and reduce the environmental impacts of your building and infrastructure projects, products and portfolio in an easy and automated way. The software combines intuitive functions with the world's largest construction LCA database for fast and effective automated life-cycle assessments. One Click LCA platform is used in over 120 countries and it serves manufacturers, consultants, designers, contractors, and investors to decarbonize the entire construction value chain. The software can be used for buildings, infrastructure, renovations,construction products and materials, as well as portfoliosOne Click LCA incorporates a constantly updated, rigorously quality assured database of 130 000+ datasets, of which 2500+ are unique and proprietary data, and all world's EPD programs.

Conclusion:

Life Cycle Assessment (LCA) is applied to buildings, and is the most scientific, standardized and consensual tool for environmental assessment. The generic standards (14040 and 14044) quickly served as a basis for more specific adaptation to building materials and HVAC systems. As the building's impact is reduced during use (through improved insulation, systems and equipment), the share of impact linked to materials is becoming increasingly important. In this way, the building will have less impact on the environment during use and throughout its life cycle. Lifecycle analysis highlights the important role of energy in a building's overall environmental balance. It can be used to guide the development and assess the value of innovative technologies.

This chapter has illustrated that LCA is not merely a tool for quantifying energy consumption or emissions but is a comprehensive framework that integrates a wide array of environmental aspects. It encapsulates energy use, resource depletion, water consumption, waste generation, and emissions to air, water, and soil. By encompassing these diverse environmental impacts, LCA provides a detailed picture of the sustainability performance of a building, enabling stakeholders to make informed decisions aimed at reducing adverse environmental effects.One of the key insights gained from this theoretical analysis is the importance of considering the entire life cycle of a building, rather than focusing solely on the operational phase. Traditional assessments often emphasize energy consumption during the usage phase, overlooking significant impacts arising from the production of building materials and the construction process. LCA rectifies this by offering a cradle-to-grave perspective, ensuring that hidden environmental costs are brought to light and addressed.

Moreover, the chapter has highlighted the role of LCA in fostering innovation in building design and materials. By identifying the stages and processes that contribute most to environmental degradation, LCA can guide architects, engineers, and policymakers toward more sustainable choices. This includes selecting materials with lower environmental footprints, designing buildings for energy efficiency, and planning for end-of-life scenarios that prioritize recycling and reuse. Such innovations are crucial for achieving the broader goals of sustainable development and mitigating the impacts of climate change.

The theoretical framework of LCA also emphasizes the importance of integrating user perceptions and behaviors into the assessment. Understanding how occupants interact with the building and how their behaviors influence energy use and environmental impact is essential for creating realistic and effective sustainability strategies. User behavior can significantly alter the operational performance of a building, and LCA must account for this variability to provide accurate and actionable insights.

Furthermore, the application of LCA in heritage buildings, as explored in this chapter, presents unique challenges and opportunities. Heritage buildings possess historical, cultural, and architectural value that must be preserved while enhancing their environmental performance. LCA provides a means to balance these often competing priorities by offering a structured approach to evaluate and minimize environmental impacts without compromising the integrity of the heritage asset.

In conclusion, the theoretical exploration of LCA in the context of heritage office buildings reaffirms its value as an indispensable tool for achieving sustainability in the built environment. By offering a comprehensive, cradle-to-grave perspective.

Chapter 4

4- Methodological Approach Chapter

1. Introduction:

This chapter presents the methodological process and the explanation of each method and its purpose. The methodology of this research is designed to provide a comprehensive evaluation of the heritage office building in Kenadsa, located in the oasis settlement of Kenadsa. The study is motivated by the need to balance heritage preservation with modern requirements for energy efficiency and occupant well-being, a challenge underscored by previous work from notable authors such as Jean Carroon, S. McLennan, John Straube, and Lisa Heschong. These scholars have laid the groundwork in understanding the importance of integrating sustainability in heritage conservation, the impact of environmental conditions on building performance, and the critical role of user-centered design.

Given the historical significance and unique environmental conditions of this building, a multifaceted approach is essential to understand the complex interplay between its architectural features, environmental factors, and user behaviors. This methodological chapter outlines the systematic process undertaken to achieve this goal, divided into four main work packages: architectural data collection, multisensory environment observation, qualitative user data collection, and life cycle assessment.

In the first phase, the focus is on gathering extensive architectural data to build a foundational understanding of the building's physical characteristics. This includes detailed assessments of the construction system, materials used, spatial layout, orientation, and specific functions of each office space. Additionally, user travel habits and occupancy levels are recorded to inform subsequent analyses and simulations.

The second phase shifts to observing the multisensory environment within the building. Critical factors such as thermal comfort, indoor air quality, luminous comfort, and daylighting are meticulously measured at strategically positioned observational stations. These observations provide vital quantitative data that reveal how different environmental conditions impact the user experience.

In the third phase, a qualitative approach is employed to delve deeper into the personal experiences of the building's users. Through in situ questionnaire investigations conducted after work experiences, we capture subjective perceptions and behaviors. This phase aims to elucidate the relationship between environmental perceptions and resultant behaviors, providing a holistic view of user interactions within the multisensory built environment. It involves also initiating agent-based modeling in Rhino 7 software using the QUELIA AGENT plug-in. This includes integrating weather data for our selected city, Kenadsa (Bechar), which is exported from Climate Studio software. We completed the modeling of each behavior in every office, accurately reflecting the number of users in each location. This was achieved by leveraging the plug-in's capabilities to simulate behaviors in the actual thermal and light environment, based on quantitative measurements of temperature and brightness in each office.

Together, these three work packages form a robust and comprehensive methodology that not only evaluates the heritage office building's performance but also offers valuable insights into optimizing its design and management. By integrating quantitative measurements with qualitative insights, this research aims to enhance user comfort, productivity, and sustainability in heritage office buildings.

Fourth phase is all about Life Cycle Assessment (LCA) for the Kenadsa heritage office building. The evaluation focuses on the building's energy performance, environmental impact, and overall sustainability. Utilizing advanced tools such as the ArchiCAD 22 energy evaluation tool and the One Click LCA plugin in Rhinoceros software 7, a comprehensive assessment was conducted to understand the building's performance across various parameters.

2. Process of Methods:

2.1. Multisensory Approach:

The methodology adopted for this research employs a multisensory approach to comprehensively understand the various environmental factors affecting user comfort and well-being within the heritage office building. This approach is crucial for capturing a holistic view of the indoor environment, encompassing thermal, luminous, and visual conditions.

2.2. Quantitative Method 'Objective Approach':

A quantitative methodology was chosen to obtain precise and objective measurements. This approach involves the systematic collection of numerical data, which is essential for conducting accurate and reliable analyses. The specific steps in this methodology include:

- **Data Collection:** Utilizing advanced in situ instruments to measure key environmental parameters such as temperature, humidity, brightness, and glare at various points within the building.

- **Measurement Stations:** The red circles on the floor plan denote the measurement stations. These strategic points were selected to gather data that represent the building's environmental characteristics comprehensively. By positioning these stations in critical areas, the study ensures that the collected data accurately reflect the conditions experienced by users.

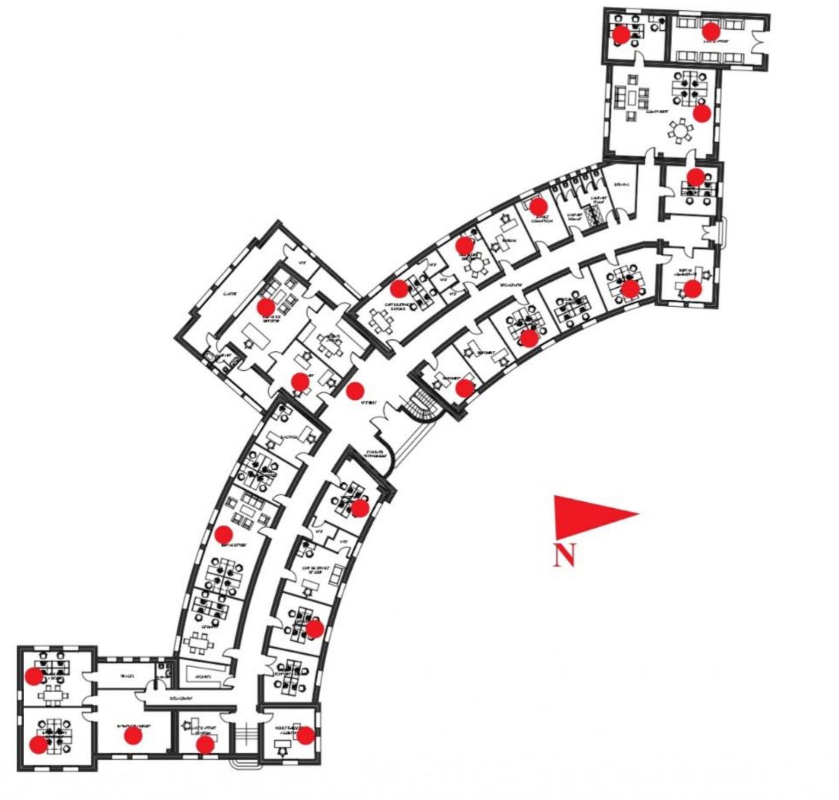


Fig 38- The measurements stations of the physical dimensions (Author 2024).

2.3. <u>Data-Driven Approach:</u>

The primary objective of employing a data-driven approach is to ensure that the research is grounded in empirical evidence. This involves the following processes:

- **Data Analysis:** The collected data are analyzed to identify patterns and correlations between environmental conditions and user comfort and behaviors.
- **Simulation:** The data serve as the foundational input for subsequent agent-based modeling simulations. These simulations help in understanding how different environmental factors impact user productivity and energy consumption.

3. Broader Objectives:

The broader objectives of this methodology are twofold:

Optimizing Energy Consumption: By understanding the environmental conditions and user behaviors, the research aims to identify opportunities for reducing energy consumption. This includes promoting behaviors that minimize energy waste and optimizing the use of natural light and ventilation.

Fostering Environmentally Friendly Behaviors: Encouraging users to adopt behaviors that align with environmental sustainability. This involves creating a comfortable indoor environment that naturally incentivizes users to reduce reliance on artificial lighting and climate control systems.

4. Symbolism of Measurement Stations

The red circles representing measurement stations are symbolic of the strategic and meticulous planning involved in the data collection phase. These stations were carefully selected to provide a comprehensive understanding of the building's environmental characteristics, ensuring that the data collected are both relevant and representative.

By integrating a multisensory approach with quantitative data collection, this methodology provides a robust framework for assessing and optimizing the environmental performance of the heritage office building. This comprehensive understanding is essential for making informed decisions that enhance user comfort, improve productivity, and promote sustainable practices.

"In order to evaluate and analyze the multisensory perception and behavior of office users in their offices of the heritage administrative building of Kenadsa which is located in Kenadsa oasis settlement. The first study was based on a subjective qualitative approach, based on in situ questionnaire investigations carried out after each user's work experience. In this study, two surveys were conducted in the laboratory, in two stages, after the observation of several short-term in situ, Thermal temperature and visual lighting that were done in winter and summer in different offices. We investigated the user's perception at first and then their behaviors as a result of their perception. Investigating the relationship between them after the interpretation of each result."

4.1. Objective:

The objective of this methodology is to evaluate and analyze the multisensory perception and behavior of office users in the heritage administrative building of Kenadsa, located in the Kenadsa oasis settlement. This study aims to understand how environmental factors such as thermal temperature and visual lighting influence user comfort and behavior.

5. In depth explanation of the Methodological Approach:

The methodology comprises both qualitative and quantitative approaches, with a focus on in situ observations and laboratory surveys.

5.1. Qualitative Method:

5.1.1. In Situ Questionnaire Investigations:

- **Purpose:** To gather subjective data on users' perceptions and behaviors in their actual work environment.
- **Timing:** Conducted after each user’s work experience to capture immediate and accurate perceptions.
- **Content:** Questions focused on users' comfort levels, satisfaction with the thermal and luminous conditions, and any behaviors adopted in response to these conditions.

5.1.2. Laboratory Surveys:

- **Stages:** Conducted in two stages to complement the in situ data.
- **Participants:** Office users who participated in the in situ investigations.

5.1.3. Data Collection:

- **Stage One:** Focused on initial perceptions of the thermal and luminous environments.
- **Stage Two:** Investigated the behaviors resulting from these perceptions.

5.2. Quantitative Method:

a- in Situ Observations:

Purpose: To obtain precise measurements of the thermal and luminous environments.

- **Measurements:** Conducted in various offices during winter and summer to capture seasonal variations.
- **Instruments:** Utilized advanced tools to measure temperature and lighting conditions.

b- Data Collection and Analysis:

c- Measurement Stations:

- **Locations:** Red circles on the floor plan indicate the strategic points where measurements were taken.
- **Rationale:** These stations were chosen to provide a comprehensive understanding of the building's environmental conditions.

d- **Data Integration:**

- **Subjective Data:** User perceptions and behaviors gathered from questionnaires.
- **Objective Data:** Quantitative measurements of thermal and luminous conditions.

e- **Analysis:**

- **Interpretation:** Investigating the relationship between users' perceptions and their resultant behaviors.
- **Correlation:** Analyzing how different environmental conditions influence user comfort and productivity.

5.3. Synthesis:

- **Findings:** Identifying patterns and correlations to inform the design and management of heritage office buildings.
- **Recommendations:** Providing insights for optimizing environmental conditions to enhance user comfort and energy efficiency.

6. Instruments and techniques used in the investigation process:

The initial phase involves an intensive data collection effort. The first lot concerns the Architectural Heritage Office building in Kenadsa. The aim is to collect comprehensive information covering various aspects, such as the construction system and materials used, the shape and layout of the building, its orientation and the specific functions of each office. Additionally, the study includes an examination of office travel habits and a comprehensive assessment of user numbers. This data recovery process plays a vital role in initiating fieldwork and subsequent experimentation.

The second part of the research data collection focused on the observation aspects of data collection, specifically in the realm of the multisensory environment within the selected case study of Kenadsa's architectural heritage office building. The critical factors under scrutiny included

Thermal Comfort, Indoor Air Quality, Luminous Comfort, and Daylighting. This phase employed meticulous circles to denote observational stations strategically positioned within the building using several in situ measurements of the physical dimensions of the environment, recorded during different users work “Luxmiter kit” and “Testo 480”.

Fig 39- Luxmiter kit instrument (Author 2024). Fig 40- Testo 480 instrument (Author 2024).

The third part of the research involved a qualitative approach to the collection of personal data, specifically targeting users of the Kenadsa Heritage Office Building. This qualitative research aims to delve deeper into the complex relationship between users’ perceptions and their subsequent behaviors within a multisensory built environment (Hamlili, Dakhia et al. 2024).

So our methodological process were divided to five stages:

- Stage one: Physical context and case study.
- Stage two: Subjective Approach and Used Questionnaire.
- Stage three: Objective Approach “in situ physical dimensions measurements”.
- Stage four: Agent based modelling and simulation of our resulted user’s behaviors and physical dimensions.
- Stage five: Life cycle assessment of the case study.

Explanation of Behavior Code Table:

Overview

The Behavior Code Table 5 is an essential component in the systematic modeling of user behaviors within the simulation software used to evaluate the performance of Kenadsa's heritage office building. This table provides a detailed classification of each observed behavior, assigning a unique code to streamline the representation and analysis of these behaviors in the simulation environment.

Purpose and Function

The primary purpose of the Behavior Code Table is to simplify and standardize the way behaviors are incorporated into the simulation software. By assigning unique codes to each behavior, the table ensures that the software can efficiently manage and differentiate a wide range of behaviors, facilitating a more accurate and nuanced simulation of user interactions within the building.

Example of Coding

For instance, the first thermal behavior might be labeled as TB1, which stands for "Thermal Behavior 1." This coding system provides a shorthand reference that the software can use to quickly incorporate and differentiate this specific behavior from others. Such codes are practical tools for identifying, organizing, and implementing various behaviors within the simulation, enhancing both clarity and efficiency.

Benefits of a Standardized Coding System

Adopting a standardized coding system for behaviors offers several key benefits:

- **Clarity:** Clear and consistent codes make it easier for researchers and software to understand and manage different behaviors.
- **Efficiency:** Unique codes allow the software to quickly reference and apply specific behaviors, speeding up the modeling process.
- **Flexibility:** The system can accommodate a wide range of behaviors, making it adaptable to various scenarios and user interactions.

Accuracy: Standardized codes help ensure that behaviors are consistently represented in the simulation, leading to more reliable results.

Impact on Simulation and Analysis

The use of the Behavior Code Table enhances the simulation's ability to accurately reflect user responses to the building's thermal and luminous conditions. By systematically cataloging and coding behaviors, the table allows for a more detailed and precise analysis of how users interact with and respond to different environmental conditions within the building. This, in turn, contributes to a deeper understanding of user satisfaction, comfort, and productivity, informing strategies for improving building performance.

Agent Based Modeling Method:

Contemporary ABM may be perceived as an explicit computational simulation method to build and analyze agent-based models, or simply to study ABMs created by other researchers likely to be related. An agent-based model is a computational simulation model composed of autonomous decision-making entities, aggregated in populations and interacting with each other or with the environment. A comprehensive definition of the ABM concept can be found in Wileman (2021) paper.

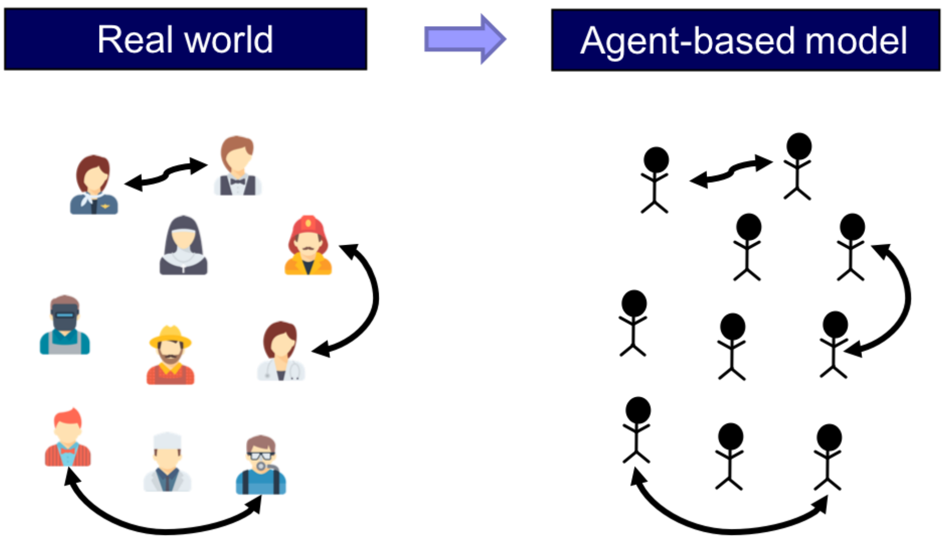


Fig 41- Agent Based Modelling, (Source University libraries 2019)

Many definitions have been proposed for ABM but Ruggeri (2016) review showed that there is no unanimous agreement. An explicit definition in Bonabeau (2002) paper is: “Agent-based modeling is a new way to understand how complex systems work. It captures and reproduces the intricate patterns of threading and interconnection that give birth to collective, hard-to-predict phenomena such as financial crises, widespread technological adoption, global pandemics, crowded urban streets and roads. The agents in models, be they people, companies, molecules, animals, cells or genes, are characterized by their behavior—by what they do or what they decide—and their heterogeneity. They are organized in a multitude of entities and are, in large part, autonomous. They sense their environment and act upon it according to their needs and desires as determined by the state of the entity, other nearby entities and the overall environment. They acquire knowledge and develop social structures, reallocate their tasks, change their behavior adaptively, just like living entities, governed by the more or less defined rules of the system. Each agent has limited influence over the entire scenario and individually might not be able to affect change directly on the system, although collectively could be able to do so" (Qi et al., 2021).

The key attribute of complex systems is that their main characteristic is the global system behavior simultaneously emerging from the actions and interactions of simple local entities—agents—making up the system. Agent-based modeling (ABM) is based on this concept. Introduced by the work of Guy Adam (1952) and further developed by the works of Craig Reynolds (1987) in the field of computer graphics, in its contemporary form, the term ABM most evidently appears in Nigel Gilbert's book published in 1995,(E. J. Newman, 2011).

<u>Definition and Basic Concepts</u>

At any given time (for discrete-time models), or over a small interval of time (for continuous-time models), an agent can have some limited set of discrete states or a continuous state. Agents also have attributes or specific properties. Initial agent attributes' values, method of agent protocol assignment, and distribution of these initial values are defined in the ABM specification. As a result of interactions between agents and/or between agents and their environment, the states and/or attributes of agents can change. When it comes to ABM, the system starts to come into its own: at every point of time, the simulation will yield new outputs regarding the state of the agent. When all desired simulation runs are complete, the model implementation and outputs can be statistically characterized, and ABM can be evaluated on specified outcome measures. This characterization will also allow insight to be gained from the particular processes driving the system-wide outcomes yielded for the various simulation runs. The main criterion to consider is whether the model was capable of providing useful accurate representation of an actual system

(Miller et al., 2010). ABM requires technique, as all computer experimentation, to be verified and validated.

Agent-based modeling (ABM) is a bottom-up computational method in which a set of autonomous individuals (agents) move, represent, interact with each other, and the environment, and change their state according to defined rules (M El-Sayed et al., 2012). This is accomplished by advancing the simulation clock by clock (up to a specified end-time or until a specified stopping condition is met). A number of different areas of application include financial markets, healthcare, urban dynamics, environmental systems, computational criminology, crowd behavior, and archaeology (Dahlke et al., 2020). Usually, agents perform various interactions, and these interactions produce system-wide outcomes.

Applications in Various Fields

The other application in which social scientists have adopted agent-based models in investigating urban and regional processes is infrastructure and transport, scholars have developed models where agents can analyze and act upon their physical environment (Steinbacher et al., 2021). In this context, people are seeking to approach a job the shortest commuting distance, and given a situation where the actors need to avoid paying taxes, prices at the boundaries are driven to three different levels such that high taxes are paid at the cheap boundary, and the goods are smuggled across those boundaries where taxes are low. If relatively more taxes are paid at one boundary, it becomes harder and longer to reach the cheaper boundary, resulting in weaker coupling across the region and larger width of the region where floating and a potentially resulting urban extension occurs. Further, a simulation has revealed that vocational education-level can differ between the regions and can be both: identical and different.

Agent-based modeling (ABM) is a method used to simulate the actions and interactions of autonomous, rational, and homogeneous agents in order to better understand the functioning of a system (Quera-Bofarull et al., 2023). It provides a way to understand how agents' interactions will translate into macroscopic trends overtime, relying of the emergence of many ant-like interactions at lower, more microscopic levels. ABM could be used in different underspecified systems and used to understand the possible equilibrium states of these systems. The ABM is used in many fields such as ecosystems, markets, human geography, and general systems theory.agent-based modeling (ABM), has been a key tool in the study of urban segregation (Tseng et al., 2017). By constructing computer-simulated cities populated by agents to model people, Schelling (1971; 1978) was able to find genuine neighborhoods of immense separation between opposing types only on the basis of individuals wanting to be part of socially mixed local neighborhoods.

Application on our research case study:

Stage 1: Data Collection and Preparation

Weather Data Integration:

City Selection: Kenadsa (Bechar) was chosen for its specific climate conditions.

Data Export: Weather data, including temperature, humidity, and solar radiation, was exported from Climate Studio software. This data provides a comprehensive understanding of the environmental conditions that impact building performance.

Stage 2: Behavior Coding and Classification

Behavior Identification:

Cataloging Behaviors: Different user behaviors were identified and cataloged, focusing on responses to thermal and lighting conditions within the building.

Assignment of Codes: Each behavior was assigned a unique code (e.g., TB1 for "Thermal Behavior 1" and LB1 for "Lighting Behavior 1"). This systematic classification helps in organizing and referencing behaviors efficiently.

Stage 3: Agent-Based Modeling

Software Utilization:

Rhino 7 and QUELIA AGENT Plug-in and Archicad 22: Rhino 7 software, equipped with the QUELIA AGENT plug-in, was used for agent-based modeling.

Integration of Weather Data: The weather data from Climate Studio was integrated into the modeling environment to simulate real-world conditions.

Modeling User Behaviors:

Accurate User Representation: Each behavior was modeled to reflect the actual number of users in each office space. This ensures that the simulation accurately portrays user interactions within the building.

Simulation of Behaviors: The QUELIA AGENT plug-in was leveraged to simulate behaviors based on quantitative measurements of temperature and brightness in each office. This allows for precise modeling of how users respond to varying thermal and lighting conditions.

Stage 4: Analysis and Interpretation.

Simulation Execution:

Behavioral Simulation: The modeled behaviors were run through simulations to observe how users interact with the building's thermal and lighting environments.

Data Analysis: The results from these simulations were analyzed to understand the impact of different behaviors on the building's performance and user comfort.

Outcome Assessment:

Evaluation of Results: The outcomes of the simulations were assessed to determine the effectiveness of the behavior coding system and the accuracy of the agent-based modeling.

Recommendations: Based on the analysis, recommendations were made for optimizing building design and operation to enhance user comfort and energy efficiency.

This methodology provides a structured approach to understanding and simulating user behaviors in response to environmental conditions. By integrating weather data, systematically coding behaviors, and utilizing advanced modeling software, we can effectively analyze and improve building performance and user experience.

Life cycle assessment evaluation method:

Energy Performance

The energy performance of the Kenadsa heritage office building was evaluated to determine its efficiency in terms of energy consumption and thermal regulation. The ArchiCAD 22 energy evaluation tool enabled detailed modeling of the building's energy use, considering factors such as insulation, window types, and HVAC systems.

Key Findings:

- ✓ Energy Consumption: The building's energy consumption patterns were mapped, identifying areas with high energy use and potential for efficiency improvements.

- ✓ Thermal Regulation: Analysis of thermal comfort levels indicated how effectively the building maintains comfortable temperatures across different seasons.
- ✓ Environmental Impact: The environmental impact assessment focused on quantifying the building's carbon footprint and other environmental parameters throughout its life cycle. The One Click LCA plugin provided a robust framework for calculating these impacts, taking into account the building materials, construction processes, and operational energy use.

Key Findings:

- ✓ Carbon Footprint: The total carbon emissions associated with the building's life cycle were calculated, highlighting the stages with the highest environmental impact.
- ✓ Material Impact: The environmental impact of various construction materials was assessed, identifying opportunities for using more sustainable alternatives.

Sustainability Assessment:

The overall sustainability of the Kenadsa heritage office building was assessed by integrating the results from the energy performance and environmental impact evaluations. This holistic approach provided insights into the building's long-term sustainability and areas for improvement.

Key Findings:

- ✓ Sustainable Practices: Recommendations were made for incorporating sustainable practices in the building's operation and maintenance to reduce its environmental footprint.
- ✓ Lifecycle Efficiency: The assessment identified strategies to enhance the building's lifecycle efficiency, from construction to demolition.

Synthesis:

The Life Cycle Assessment (LCA) of the Kenadsa heritage office building revealed critical insights into its energy performance, environmental impact, and sustainability. By leveraging advanced tools like ArchiCAD 22 and One Click LCA, the study provided a detailed understanding of how the building performs across various parameters. The findings underscore the importance of integrating sustainable practices and optimizing energy use to enhance the overall efficiency and environmental performance of heritage buildings in arid regions like Bechar.

Conclusion:

This rigorous and multi-dimensional methodological approach adopted in this research provides a holistic and in-depth perspective of the performance assessment of the heritage office building in Kenadsa. By integrating two complementary methods, namely the assessment of user perceptions and life cycle analysis, this study aims to provide a comprehensive understanding of the challenges and opportunities related to the sustainability and energy efficiency of this building historical. Indeed, by considering the perspectives of occupants and analyzing the environmental impact over its entire life cycle, we can develop specific and practical recommendations to improve its performance while preserving its unique heritage character.

The evaluation of user perceptions constitutes an essential pillar of this approach, making it possible to collect valuable data on the comfort, satisfaction and needs of occupants. By conducting surveys, interviews and on-site observations, we will be able to identify areas where the building meets user expectations and those where improvements are needed. This information will be crucial to guide recommendations to optimize living and working conditions inside the building, taking into account Kenadsa's specific climatic requirements, characterized by an arid and hot climate.

On the other hand, life cycle analysis offers a long-term perspective on the environmental footprint of the building, from its construction to its demolition. By evaluating the materials used, energy consumption and waste management practices at each stage of the life cycle, we will be able to precisely quantify its impact on natural resources and greenhouse gas emissions. This analysis will make it possible to identify the most effective interventions to reduce the carbon footprint of the building while preserving its heritage integrity.

By combining these two complementary approaches, we will be able to formulate strategic and targeted recommendations to improve the overall performance of the heritage office building in Kenadsa. These recommendations could include technical solutions to improve energy efficiency, such as installing more efficient heating and cooling systems or improving thermal insulation.

Additionally, conservation and preservation measures could be proposed to maintain the architectural and historical integrity of the building while integrating sustainable practices.

In conclusion, this methodological approach provides a robust and integrated framework for assessing and improving the performance of the heritage office building in Kenadsa. By combining user perspectives with an in-depth analysis of its environmental impact, we will be able to formulate practical and sustainable recommendations that meet the needs of occupants while preserving its cultural and architectural heritage.

Chapter 5

5- Case Study Presentation

Introduction:

This chapter presents in detail the heritage building of an administrative nature as an object under study. It highlights its particular context due to its history and its architectural and socio-cultural characteristics, with regard to the oasis of Kenadsa located in the oasis of the wilaya of Bechar (about twenty kilometers from this main town)

Notwithstanding, a difficult environment to live in, a dry, hot and arid climate, studies on the environmental footprint of buildings in general and office buildings in particular are lacking. Therefore, the building selected for this study offers a relevant opportunity to examine the integration of user perception, behaviors and environmental sustainability in such a geographical framework.

This chapter will present the context under study, namely the city of Kenadsa (Bechar), will review the architectural production of buildings during the different periods: the colonial period, post-colonial, post-independence and the recent period.

The urban and architectural specificities of buildings and office buildings in particular will be highlighted during these periods.

1. Presentation of Kenadsa's city;:

Kenadsa is a Saharan commune in Algeria in the wilaya of Béchar located 22 km west of Béchar.

The commune of Kenadsa is located on the north-western limit of the wilaya of Béchar, on the border with Morocco. It affects the communes of Boukais in the north, Lahmar in the northeast, Béchar in the east and southeast, Abadla in the south and Meridja in the west.

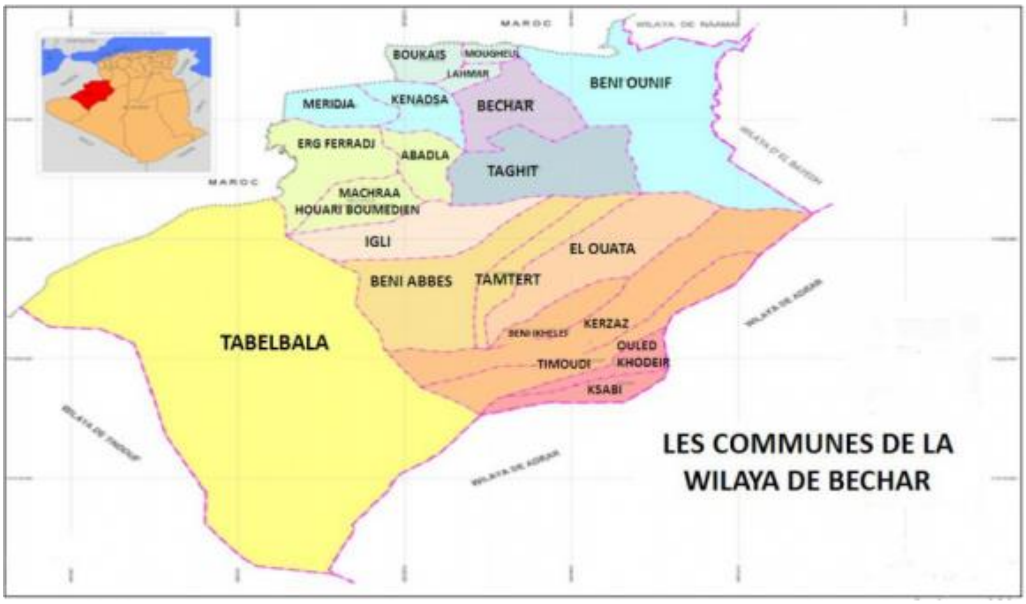


Fig 42- the surrounding communities of Kenadsa, (Source: Monograph Wilaya, 2016)

The city of Kenadsa is one of the most important Saharan cities known for its centuries-old history, the beauty of its landscape, its heritage sites and its religious, cultural and tourist monuments, but also its literary and intellectual personalities, witnesses of its particularity and its originality.

2. Geographic Location:

The study area is located in the southwest of Algeria, in the Kenadsa region (31° 33′ 32″ north, 2° 25′ 24″ west) (Figure. 43). It is characterized by an arid climate where the average annual precipitation is 102 mm (the monthly averages are: September: 8.8 mm, October: 15.58 mm, November: 13.6 mm, December: 7.7 mm, January: 6.46 mm, February: 10.41 mm, March: 12.24 mm, April: 4.57 mm, May: 11.27 mm, June: 6.6 mm, July: 1.89 mm, August: 3.21 mm.) and the average temperature is 21°C, for the measurements taken at the Bechar station, over the 1988-2010 series.

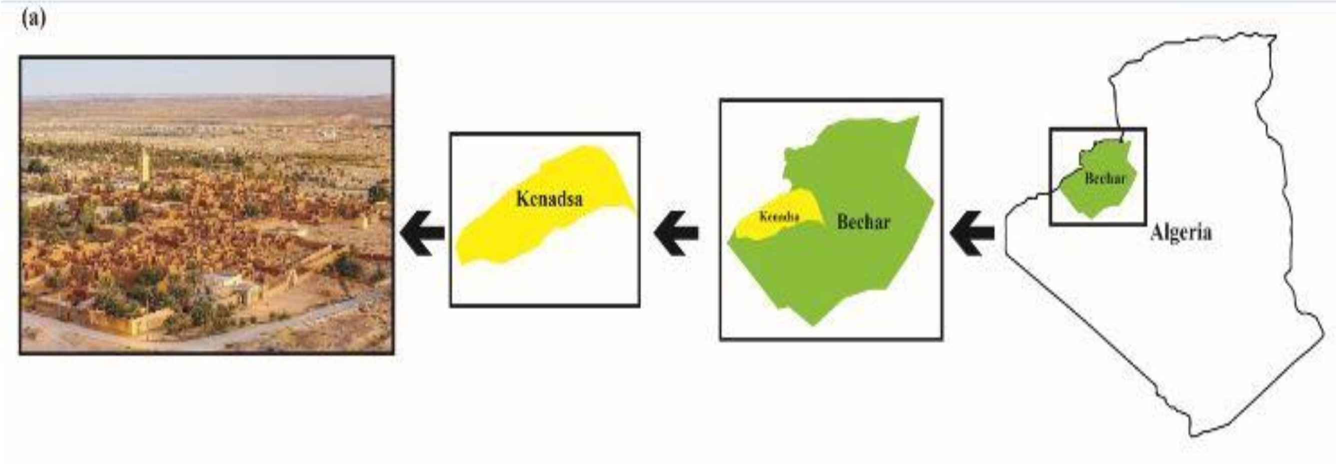


Fig 43- Case study: (a) Situation of the city of Bechar “Kenadsa”, (Author 2024)

3. Climate and Geological Overview:

The climate that reigns in Kenadsa is desert type, characterized by a scarcity of precipitation (precipitation is on average 45mm/year), and an average annual temperature of 20.5 °C, air humidity is low, despite the presence palm groves which promote the creation of a microclimate (Mostadi and Biara 2019). From a geological point of view, this oasis is built on carboniferous lands, dominated to the north by Cretaceous formations. These terrains are arranged in a monocline, separated by an angular unconformity. The Carboniferous terrains are of Westphalian age, affected by a network of NE-SW direction faults. It is a powerful series of sandstone bars interrupted by marly and clayey levels.

Fig 44- a photograph showing the extent of the carboniferous terrains (Source: Gerard Geider 2007).

The climate of Bechar ‘Kenadsa’ is subtropical desert, with mild winters (during which it can be cold at night) and very hot and sunny summers.

The city is located in western Algeria, near 32 degrees north latitude and 780 meters above sea level.

In winter, when the cold air from the north manages to reach this area, there can be cold days, with minimums of 0°C or a little below and maximums of 6/7°C. In January 1992 and January 2005, the temperature dropped to -5°C.

In summer, the altitude tempers the heat a little, however, in the worst times the temperature can reach 44/45°C from June to September (Climates to travel 2023).

3.1. Temperature:

The average temperature of the coldest month (January) is 10.0°C, which of the hottest month (July) is 34.2°C. Here are the average temperatures (Climates to travel 2023).

3.2. Precipitation:

Precipitation totals 100 millimeters per year: it is therefore at desert level. In the least rainy month (July) they rise to 2 mm, in the rainiest month (November) they rise to 20 mm. Here is the average precipitation (Climates to travel 2023).

3.3. Sunshine :

There is an average of 3,560 hours of sunshine per year. Here is the average hours of sunshine per day (Climates to travel 2023).

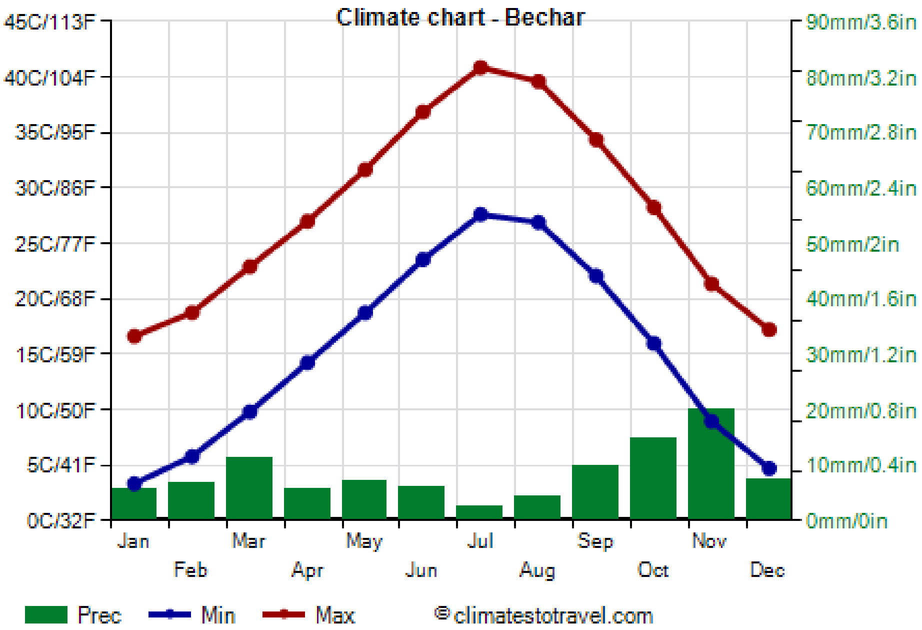


Fig 45- Climate Chart Bechar (Source: Climate to travel 2023).

4. <u>Historical context :</u>

BECHAR- The ancient district of the Casbah, the beating heart of the Ksar of Kenadsa (wilaya of Bechar), still bears witness, through its two mosques, its zawiya, its alleys and its tombs, to the beauty of the architecture and the rich history of the ksour of Saoura, despite the desertion of its inhabitants for modern houses and the collapse of certain facades of this ancient palace classified as national heritage since 1999 and which dates back more than 8 centuries.

Fig 46- Kenadsa’s Ksar, (Source: Ksar de Kenadsa 2017).

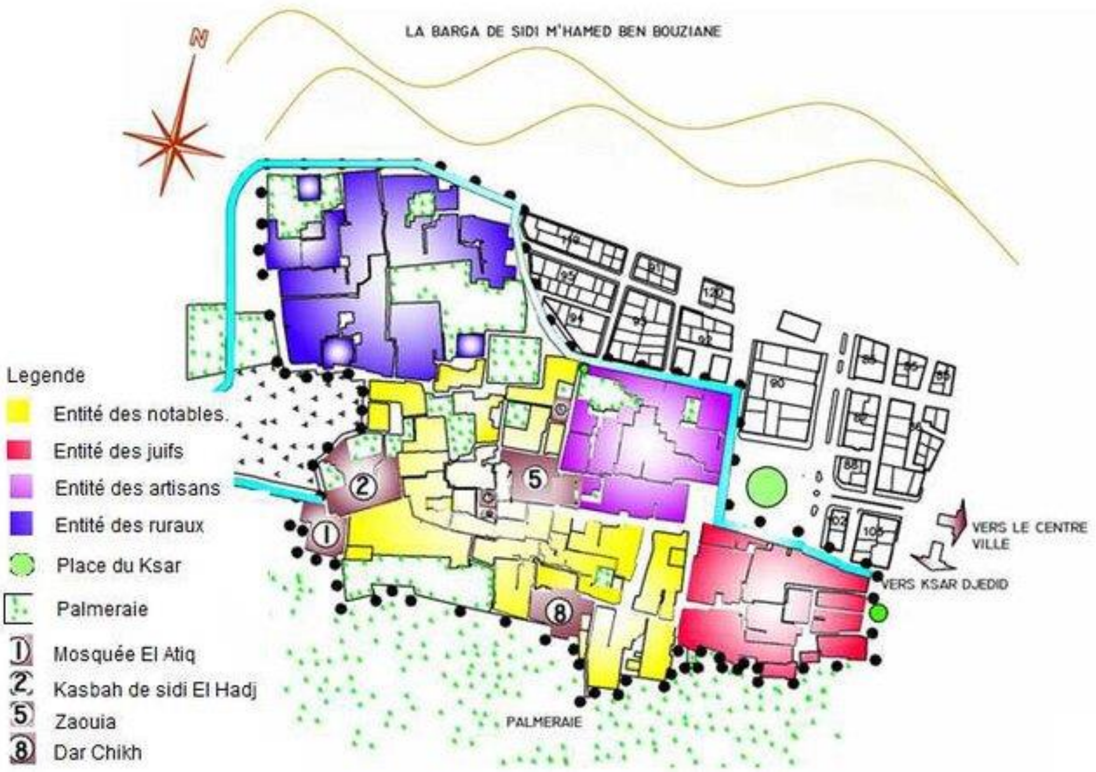


Fig 47- Ksar Kenadsa map, The legend (entity of notables, entities of Jews, entities of artisans, entities of rural, Place of ksar, Palmeraie El Atiq Mosque, Kasbah of sidi lhadj, zaouia, dar el chikh (Source: Boutabba. H et al. 2012).

This old neighborhood is home to the old mosque of Sid el Hadj ben Ahmed and the mosque of Sidi M'hamed Ben Bouziane, in addition to the tomb of Lalla Oum Kelthoum and numerous narrow alleys and paths.

Faithful to their religious, social and cultural vocation, these two mosques “continue to be a place of welcome and prayer, particularly on Fridays and during religious holidays.

The ksar is also distinguished by its “Ziania Kendoussia” cabinet which contains many old and rare manuscripts on religion, literature and the history of the region. It is also a cultural center with its various scientific and cultural activities and events.More than eight centuries old, the old Ksar of Kenadsa, an immutable symbol of the city, is one of the most majestic ksour (palaces) of Béchar and Saoura in terms of architectural beauty and historical heritage wealth, even if the Most of its buildings have fallen into ruin, with the exception of the central alley known as the “Casbah” with its two mosque towns, a cemetery and its countless cramped paths. This majestic Ksar, built from a mixture of earth, where clay and palm leaves mix, houses the zaouïa ziyaniya which has disciples from the Malian city of Timbuktu, the Sahel and Algeria, in addition to the so-called "library". ziyania kandoussia”, founded by a child of the ksar and containing many rare manuscripts on religion, Sufism, literature and the history of the region. The history of Kenadsa dates back thousands of years... Its municipal museum displays a series of stone tools used by the early inhabitants, such as scrapers, spears, arrows and stone pestles, in addition numerous rock carvings. Many stuffed animals are also exhibited there to recall the diversity of fauna in the Saoura region, like birds, snakes, lizards, otters and ibexes, which live near the “Djorf Torba” dam (at 30 km from Kenadsa), in addition to fossils dating back millions of years. Saoura is prized for its captivating natural beauty, Rocky Mountains, dunes and a picturesque oasis next to which the ancient ksar was built.

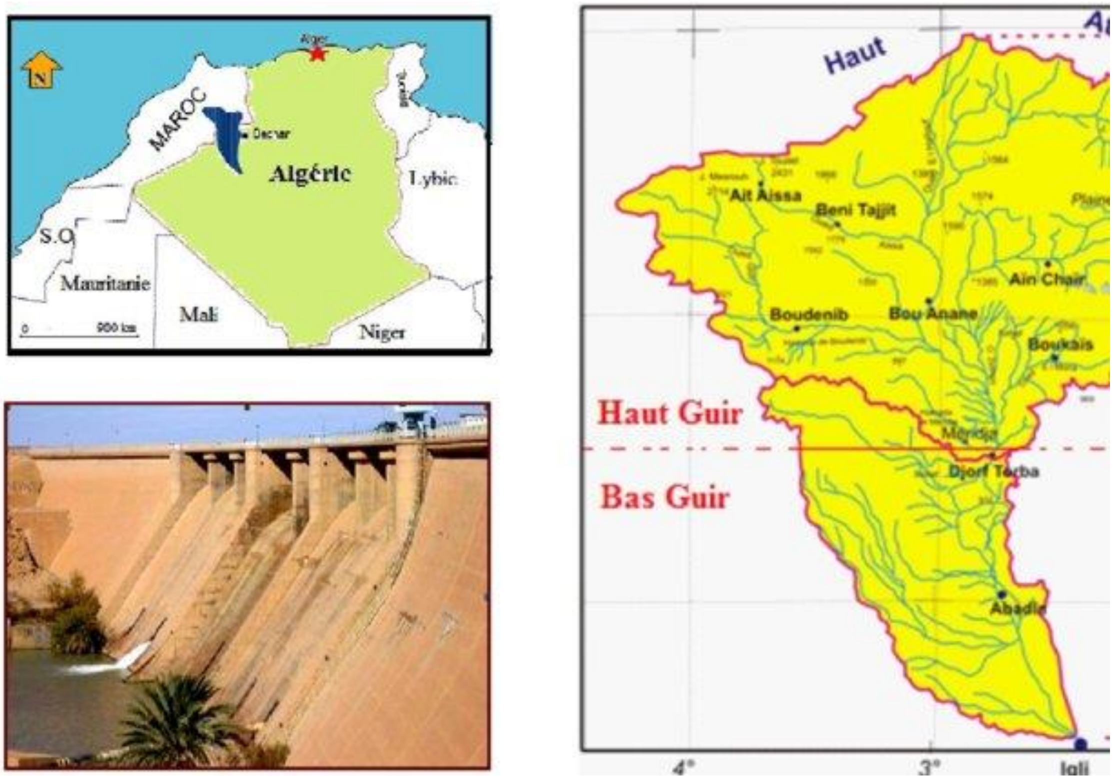


Fig 48- Location of the Djorf Torba dam, hydrographic profile and distribution of rainfall stations on the Oued Guir BV (Source: International Journal for Environment& Global ClimateChange 2016).

5. Urban specificities of Kenadsa:

Throughout its history, the city of Kenadsa has gone through different political, social and economic contexts which have had a direct impact on spatial production. Indeed, on a morphological level, the city of Kénadsa is presented in three (03) urban forms but identifiable by their own organizations, structures and architecture. This horizontal stratification of the three urban entities is the expression of a historical evolution where each illustrates a specific historical period, there was:

The Ksar, so-called traditional production, represents the old core and historic center. It is a morphological fabric, supporting the original morphological elements, organized by a system of winding streets and alleys, it overlooks the palm grove.

The European city (the colonial city), (or city of the beginning of the 20th century) corresponds to the colonial period. The produced space obeyed a logic other than that of the traditional one. In an orthogonal frame, the colonial city is far from the Ksar, with urban planning supporting the buildings representing the new power with a particular architecture.

New part, result of different development plans from the post-independence and contemporary periods, in the form of standard housing estates and facilities.

5.1. Ksar of Kénadsa, an important ksar in southwest Algeria:

The Kenadsa ksar is part of all the Algerian ksours. Only in the last century, this ksar must still have been a true Saharan city, it is considered among the most important ancient cities of the southwest region for its cultural, religious, spiritual dimension, and also for its architectural value.

It played a pivotal role and a crossroads between North Africa and sub-Saharan Africa. An archival notice, classified among a batch of documents established before March 1893, describes Kenadsa in these terms: "The Ksar of Kenadsa, one of the most important". The ksar is the center of the zaouïa ziania which radiated over an entire territory, on this socio-cultural institution, Gehard Rohlfs (1862) in "travel and exploration in the Sahara" tells us kenadsa with around 5000 inhabitants, has a zaouïa famous in the region", and in particular Emile F. Gautier (1905) in "Report on a geological and geographical mission in the region of Figuig" adds even more << On these nomads the famous zaouia of Kenadsa exercises a religious ascendancy, it would be Exaggeration to call an authority. It has an aspect of ancient prosperity; it is announced from afar by a graceful minaret built of bricks, (...), it is the architecture of Tlemcen, Fez and Marrakech that it recalls >> 12. In 1904, Isabelle Eberhardt in her book "Written on the sand" describes Kenadsa in the words "Kenadsa rises in front of us, a large ksar in toub of a dark and warm color, preceded, to the left, by very green lush gardens".

The ksar of Kenadsa with its historical specificities and its architectural and urban planning riches contains a symbolic charge. Given the historical and religious monuments it contains (the old mosque, the tomb of Sidi Abderrahmane, that of Lala Oum Kelthoum, mosque of Sheikh ben Bouziane, the Dwiryas....) but also the common character and the arrangements urban that exudes its authenticity. Urbanity that the ksar becomes a heritage, a common good, and was classified as a "historical monument" and national heritage to be preserved.

5.2. The town of Kenadsa during the colonial period:

In fact, this period was characterized by several facts including the process of French installation was carried out in successive stages: it includes three (03) phases which are included and extend from 1887 to 1942. A first in 1887 was characterized by the construction of a military fort, the second phase created the city by a theory of separation from the existing. Finally, a third phase was mainly characterized by the densification of the new town and the appearance of neighborhoods.

5.2.1. The military installation in 1887, a theory of separation:

Materialized by the establishment of a military fort outside the ksar. It is called Bel-hadi contrary to what was done before in most Algerian towns in the first years of the occupation, the French settled far from the ksar. This logic aimed to dissociate two fabrics and two morphologically incompatible urban logics. This installation symbolizes a new political system that would manage and control the region.

5.2.2. The installation of the coal mine in 1910:

After the discovery of coal in 190813, it was only later, in 1917, which the ore began to be exploited.

5.3. The European city 1939:

5.3.1. Duality between colonial legacy and historical core:

The Ksar of Kenadsa represents one of the main urban landmarks of the city. Although the ksar occupies a modest space compared to the entire urban area and is in a state of degradation, it continues to represent a cultural and religious sanctuary par excellence. And by testimonies existences its architectural wealth especially in the part of dwiriyat. In a quote from Amina Zine. There is the ksar which still faces the new, or so-called modern, center, and which is increasingly deserted, but whose architectural and urban planning quality is such that it manages to keep its quality as a historic center of reference: the case of kenadsa is eloquent. Indeed, this ksar, and in particular "the residential complex of heikh >> formed of small precious palaces facing the surrounding Saharan bareness, remains the center despite its degraded and abandoned state.

5.3.2. What is Kénadsa’s share?

Faced with this separation strategy, in the southwest, the case of the town of Kenadsa represents the first example of this planned separation (T.SOUAMI, 2003). The town of Kenadsa constituted a special case among all the Saharan agglomerations, its town planning and development plan was drawn up in 19418. The plan is represented as follows: the industrial town of Kenadsa was built at a significant distance from the Ksar. The designers of the project imagined a “ksar el djedid” (a new ksar) below the original, still at a respectable distance) and intended it for some of the Muslim inhabitants. »" as illustrated in figure 49. The old town (the ksar) has become the historic space 19 while the new town is transformed into the town centre, the plan placed the

The designers of the project imagined a “ksar el djedid” (a new ksar) below the original, still at a respectable distance) and intended it for some of the Muslim inhabitants. As illustrated in figure 49. The old town (the ksar) became the historic space while the new town was transformed into the city center, the plan distanced the ksar and isolated the Ksourian habitat. Indeed, Robert Tinthoin (1948) once again well described the image of this situation in this passage, "Apart from the old constricted ksar and the Bel Hadi military post, Kénadsa has, since 1920, spread out the sieges of its mines and its two European and indigenous cities, with straight streets with villas, collective housing, Kabyle village, workers' camp. The workers' city has been built since 1940. These towns have power stations, laundries, railways, swimming pools, open-air cinema, and sports grounds, in a harsh climate characterized by temperature variations reaching 50 degrees.

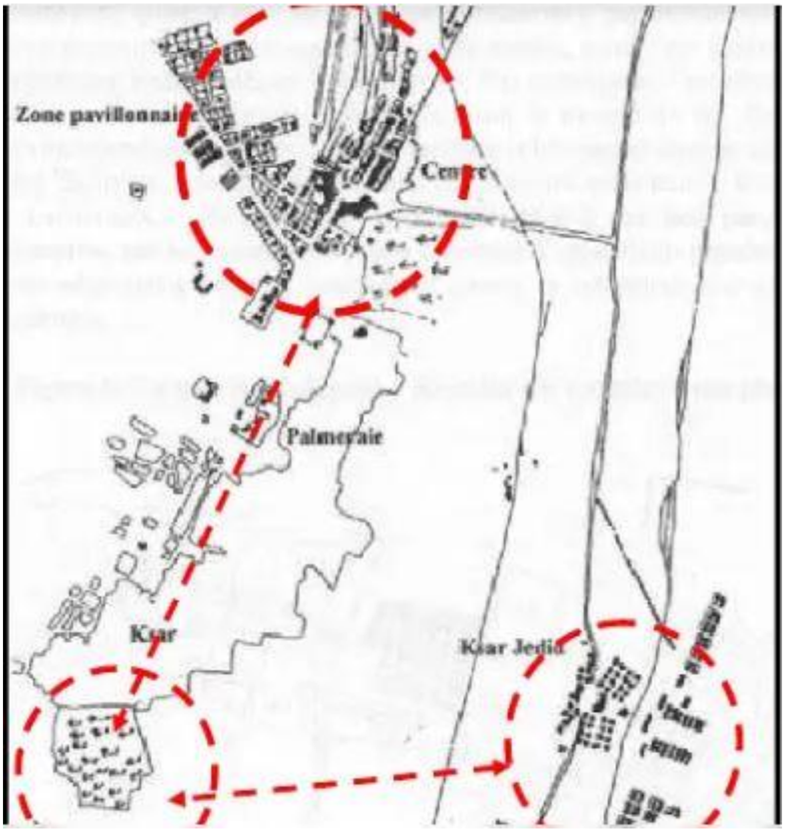


Fig 49- urban plan of the city of kenadsa 1941 “Kenadsa”, (Houillère of south west Oran 1941).

The theory of separation in the plane of kenadsa.

5.3.3. <u>The colonial city and its organization:</u>

The 1940s, marked by the outbreak of the Second World War, a strong demand for coal was felt, which further attracted the workforce necessary for the operation of the Kenadsa coal mine, which pushed or accelerated the phenomenon, it must be remembered that it is the creation of workers' towns (European center) with housing for workers, "The first housing planned in the south was carried out in Kenadsa, then the first town with its own town planning plan. For Taoufik Souami (2003) significant problems of appropriation and neighborhood arise in this type of housing. However, the founding of the workers' town, launch of the housing program associated with equipment and services / two workers' in the middle

Taoufik Souami (2003) significant problems of appropriation and neighborhood arise in this type of housing. However, the founding of the workers' town, launch of a housing program associated with equipment and services "Two workers' towns were built in the middle of the desert in Kenadsa and Bechar Djedid; they are equipped with modern facilities, power stations, schools, hospitals, swimming pools, market gardens....etc.

A new center was created after the ksar, it is the time of a change, from a ksar of an agricultural and transit nature to a town of an administrative and industrial nature. From a historic core (the ksar) which is characterized by a structure of winding streets and alleys and compact buildings; to a Europeanized center, introduces a network of fairly wide roads, distributing islands, a regular layout" alternating public space and private space, with a zoning policy (residential zone, industrial zone, administrative zone) as planning and projection tool, and this is what we find in Tony Garnier's industrial city. The plan of the European city “resumed the planning instruments”

The European city plan “resumed the planning and development instruments used since the end of the 19th century for industrial cities.

The colonial town planning was composed of a main artery along which were installed socio-educational, administrative and health buildings, individual houses with small gardens and two main squares intended for the HSO center (Houillères du Sud Oranais , current Place du 1 Mai “administrative heritage building”), on one side and the administrative center (the Place de l'APC) on the other. Indeed, it is a structuring axis which represents a real axis of growth, has polarized urban development on which public buildings will be located. The European city installed a new urban order or public spaces organized around squares used for military parades but also for the exercise of colonial sociability (town hall, cafes, bars, etc.).

Fig 50- Two main squares intended for the HSO center (Houillères du Sud Oranais, current Place du 1 Mai “administrative heritage building”), on one side and the administrative center (the Place de l'APC) on the other (Author 2024).

Fig 51- heritage Office building APC, (author 2024).

5.4. Colonial architecture and the reinterpretation of the architectural vocabulary of the ksar:

Despite the new mode of perception of space introduced by the settlers marked by the logic of separation at the urban level and the distinction between the two fabrics, the ksar is deployed by its compact and introverted morphology, and a labyrinthine and hierarchical road system, d on the one hand and on the other hand the colonial city with its regular, fragmented and extroverted layouts; we nevertheless note a strong reminiscence of the neo-Moorish style (Arabism) in the colonial buildings, drawing inspiration from the Ksourian architectural vocabulary. The style adopted in these buildings is a form of adaptation and reinterpretation of traditional Ksourian architecture through the stylization of forms and the use of architectural elements.

The architectural aspect of public buildings such as hospitals, schools, APCs and also in colonial villas where facade architecture is embodied, the French settlers drew from the traditional vocabulary of the ksar by integrating architectural elements from traditions such as arcature systems, but with another language.

6. Criteria for the city of Kenadsa:

Kenadsa is a specimen of a city in the Sahara, bringing together both the traditional city, the provisions of French colonial town planning, as well as the various voluntary (planned) urban interventions in independent Algeria.

In Kenadsa, there is a well-defined administrative city which includes all the office buildings. The first administrative buildings are located in the city center (buildings of thecolonial period).

This choice of city is not accidental, because Kenadsa is also representative of the cities located in arid regions, with all the particularities of a hot and dry climate, humidity very low relative and a very low rate of rainfall, with all that can result as urban and architectural intervention to best adapt to this climate and preserve the environment.

This is what favored our choice of the city of Kenadsa for the energy study and environmental impact of its built environment through its public buildings and more particularly the office buildings.

Fig 52- satellite view of the city of kenadsa, (Google maps 2024).

7. Criteria for the sample building:

Given the total absence of any study on the environmental footprint of buildings in offices, it was deemed useful for us to carry out the exploratory study, our choice of the sample is justified by:

1. The building is representative of the colonial period of urban growth of the city of Kenadsa (a heritage building).

2. Diversity of the architectural and urban morphology of the city of Kenadsa.

3. The orientation of the office building.

4. The typology of office spaces (partitioned office, landscaped office, open office, etc.).

5. The office opening rate for these buildings.

6. Architectural typology and treatment of facades.

7. The materials used for the building envelope.

8. Air conditioning, heating and ventilation systems.

8. Administrative heritage office building of Kenadsa « Case study » :

8.1. Presentation and location:

Kenadsa inherited colonial urbanization, which since French colonization in Algeria, has given birth to a sufficient number of public or administrative buildings, including one of the most important, “the office building”, made by the architect Charles Henri Montaland in 1941 (Belkacem Izala), which will be our case study. As we moved forward with our research (Figure

53), we planned to explore various aspects related to the architecture and history of the administrative building.

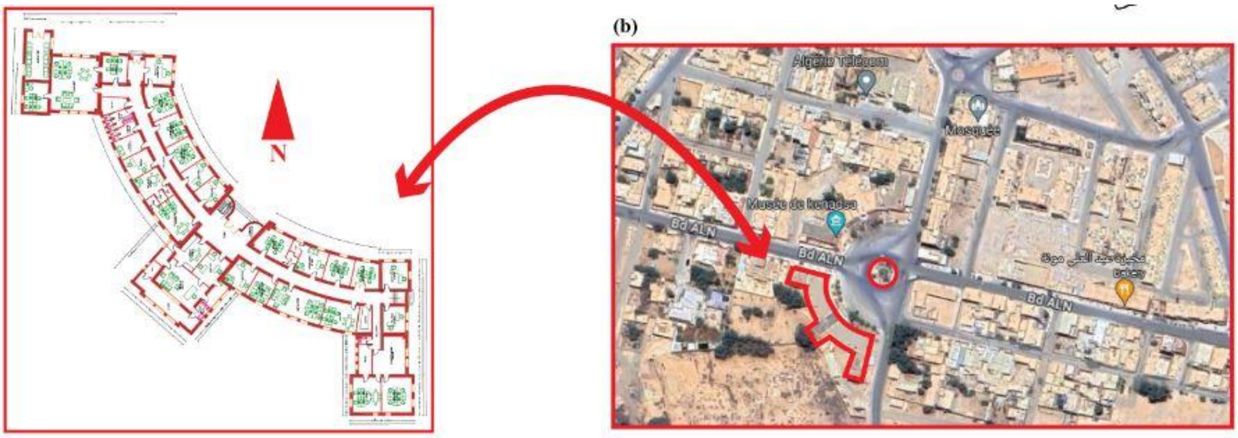


Fig 53- Our case study plan and location, (Author 2024).

Fig 54- Kenadsa’s heritage administrative office building, (author 2024).

8.2. Case study materials:

In the construction of the specified building, a comprehensive integration of building materials was employed (see Table 9) (Berkouk, Bouzir et al. 2018). External walls are designed as double walls using hollow bricks, consisting of a 15 cm layer towards the outside and another 15 cm layer towards the inside, separated by a 5 cm air gap. The external side is coated with cement plaster, while the internal side receives a 2.5 cm plaster layer. Interior walls are constructed using a single brick wall, employing 15cm thick brick walls. Ceilings and floors are implemented as hollow slabs. Weather data from the selected city, Bechar, specifically Kenadsa, were integrated into the construction process, utilizing information exported from the Climate Studio location plug-in. Furthermore, a statistical study is conducted using SPSS software 25, emphasizing a comprehensive analysis of data, possibly related to the building's performance or environmental impact (Hamlili, Dakhia et al. 2024).

Table 9- Envelope materials and their thermal characteristics (Berkouk, Bouzir et al. 2018).

Building element	Material used	Thermal conductivity (W/mK)	Thickness (m)
Exterior Walls	Cement Plaster	1.4	0.025
	Hollow brick	0.5	0.15
	Air blade	0.31	0.5
	Hollow brick	0.5	0.15
	Gypsum Plaster	0.35	0.025
Interior Walls	Gypsum plaster	0.35	0.025
	Hollow brick	0.5	0.1
	Gypsum plaster	0.35	0.025
Low and intermediate Floors	Gypsum Plaster	0.35	0.025
	Solid slab	1.45	0.25
	Mortar	1.4	0.5
	Flooring	2.1	0.8
Terrace floor	Gypsum plaster	0.35	0.025
	Hollow body + compression slab	1.45	0.25
	Isolation	0.1	0.05
	Slope shape	1.15	0.05
	Water tightness	0.04	0.03

8.3. Case study climatic characteristics:

The monthly distribution of the air velocity, the temperature, and the relative humidity of the city are shown in Figure 55, respectively. These figures indicate that most part of the year is outside the comfort zone, except some periods of the months of September, October, March, and April. Another zone includes November to February where the building may require heating to ensure the comfort of the occupants. The third zone from May to September presents a period of hot season. The insolation exceeds 3,500 h/year, and the direct solar radiation may reach 800 W/m^2 on the horizontal surface. In summer, the temperature in the shade exceeds 40°C, and the amplitude between the day and the night is approximately 15°C, whereas the relative humidity remains low at about 27% (Fezzioui, Draoui et al. 2008; Khoukhi and Fezzioui 2012).

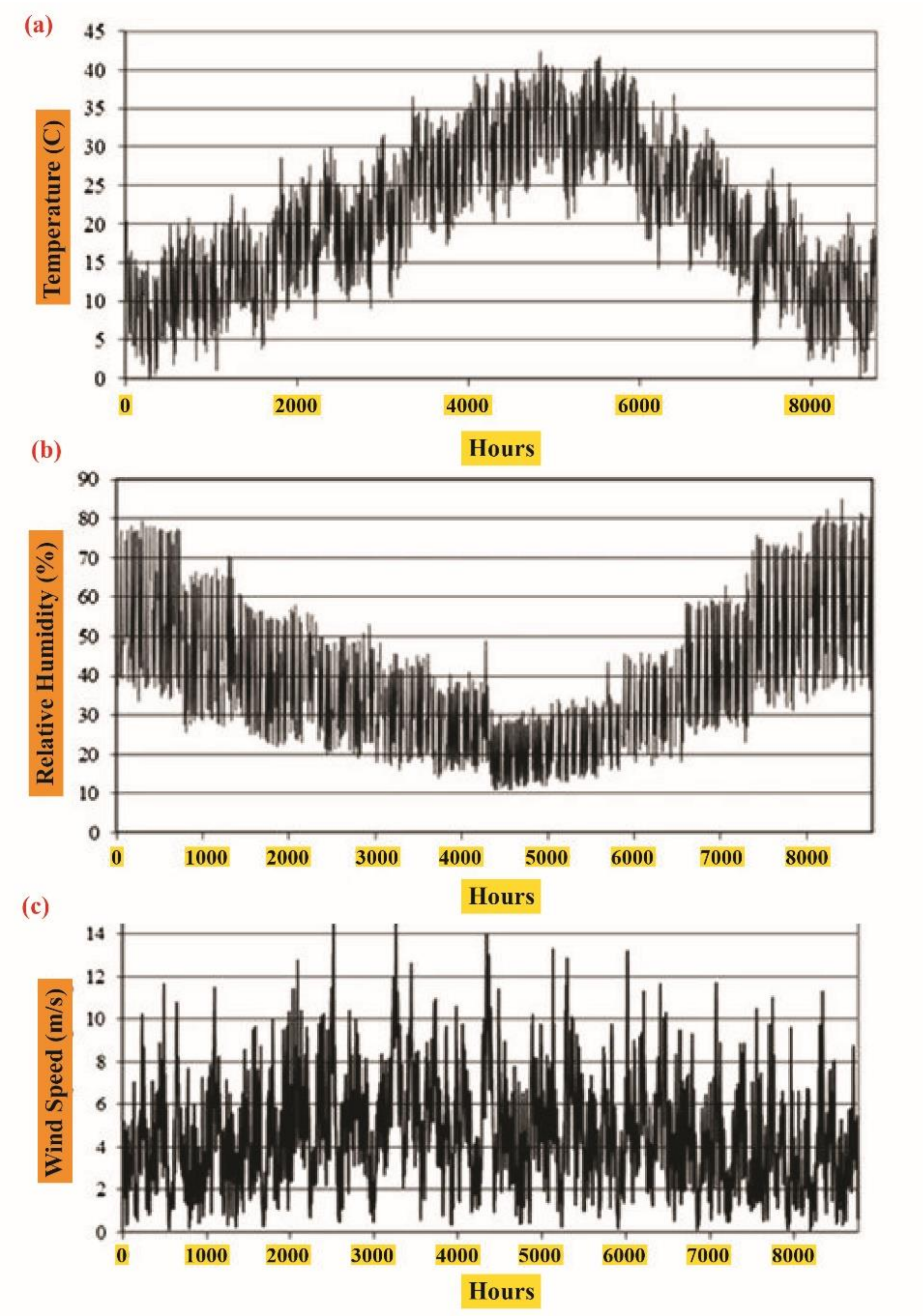


Fig 55- Climatic Data of Kenadsa city: (a) Monthly distribution of the outside temperature, (b) Monthly distribution of the relative humidity, (c) Monthly distribution of the wind speed (Fezzioui, Draoui et al. 2008; Khoukhi and Fezzioui 2012).

8.3.1. <u>Description of the building:</u>

The research focuses on two distinct indoor spaces within the Kenadsa heritage office building: the user's office and the public spaces where clients are received. Fig 58-b illustrates the layout of these spaces, depicting a well-defined arrangement conducive to both functionality and aesthetic appeal.

Fig 56- 26 offices in the case study. 21 studied offices in green color. (Author 2024).

8.3.2. Geometry and functionality of the building:

In this layout, the public space begins with open areas on two sides (marked in yellow), leading into long corridors flanked by additional spaces designated for public reception. The private director's office (highlighted in green) is strategically positioned between access points and semi-private routes, forming part of the gallery space. This office is situated amidst a quarter-circle-shaped configuration, bordered by administrative staff offices and closely located user offices (highlighted in red). The overall building morphology also follows a quarter-circle shape, with slightly wider spacing between offices compared to the initial shape.

8.3.3. Building Architectural Typologie:

A covered passage serves as a transition space between offices, leading to a spacious reception hall situated centrally within the building. This placement creates a symmetrical relationship and facilitates smooth access for the public. The adaptive reuse of the heritage office building encompasses three key areas: a municipal treasury area, a tax revenue area, and the administrative building area. Notably, there are two semi-private access points from one side, enhancing accessibility and organizational efficiency.


Fig 57- interior of the building, (a) covered passage, (b) reception area, (Author 2024).

Regarding sanitary facilities, there are two semi-private and one private restroom, ensuring adequate amenities for both users and visitors. The building features four elevations and a centralized public access point, contributing to its functional design and ease of navigation (Hamlili, Dakhia et al. 2024).

8.3.4. **Building's environment:**

The building's form was originally influenced by the shape of the adjacent roundabout transition, as depicted in Figure 58.a.

Interestingly, the building shares a similar architectural style with the neighbouring Kenadsa museum, both designed by the same architect. This cohesive design approach fosters a welcoming and positive atmosphere for visitors, reflecting a unified aesthetic vision within the heritage site.

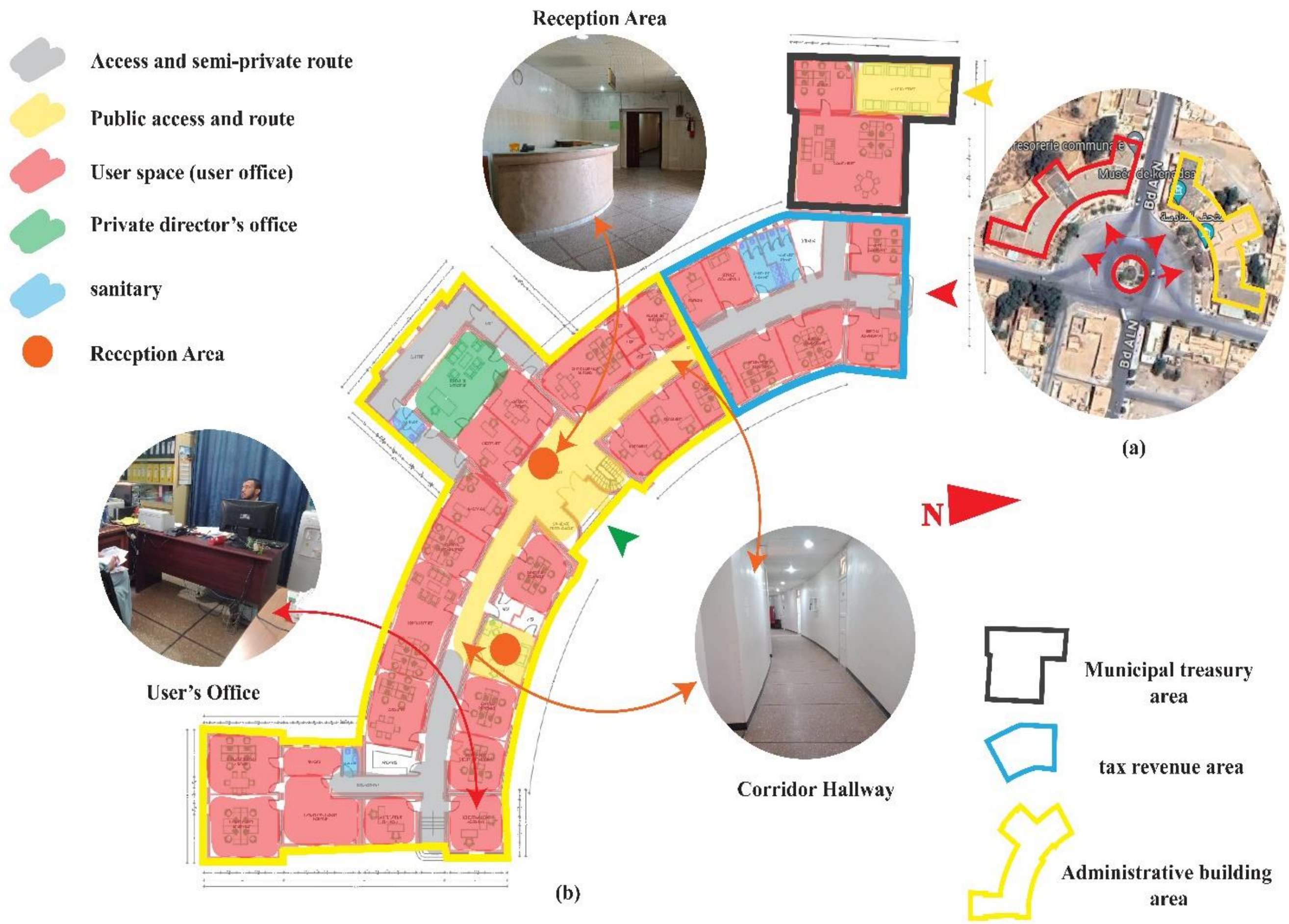


Fig 58- Case study analysis: (a) the form of the building and the surroundings forms, (b) distribution of spaces (Hamlili, Dakhia et al. 2024).

Conclusion:

In conclusion, the case study chapter has provided a detailed examination of the Kenadsa heritage office building, focusing on its architectural layout, functional divisions, and adaptive reuse. Through a thorough analysis of the indoor spaces, including the user's office and public reception areas, key insights into the building's design and organizational features have been revealed.

The layout of the building, characterized by quarter-circle shapes and symmetrical arrangements, reflects a deliberate effort to optimize functionality while maintaining aesthetic coherence. The strategic placement of public reception areas, private offices, and transitional spaces demonstrates a thoughtful approach to spatial organization, facilitating efficient circulation and user interaction.

Moreover, the adaptive reuse of the heritage office building underscores its historical significance and cultural heritage, with distinct areas dedicated to municipal services, tax revenue, and administrative functions. The integration of semi-private access points and sanitary facilities ensures accessibility and convenience for both users and visitors, enhancing the overall usability of the building.

Furthermore, the architectural consistency between the heritage office building and the adjacent Kenadsa museum, both designed by the same architect, contributes to a cohesive and welcoming atmosphere within the heritage site. This harmonious design approach reflects a unified vision for the preservation and promotion of cultural heritage in the region.

Overall, the case study of the Kenadsa heritage office building offers valuable insights into the intersection of architectural design, historical preservation, and functional usability. By examining the building's layout, spatial organization, and adaptive reuse, this chapter contributes to a deeper understanding of the built environment's role in shaping cultural identity, fostering community engagement, and promoting sustainable development in heritage sites.

Chapter 6

6- Objective Approach Chapter

Introduction:

Over the past decade, researchers have extensively investigated the influence of the indoor environment on occupant satisfaction. The findings unequivocally demonstrate that the indoor setting plays a pivotal role in shaping occupants' productivity and the efficiency of their activities (Kamaruzzaman et al., 2018; Kim et al., 2013; Bluyssen et al., 2011). Good building performance and sustainability in the built environment places an important emphasis on occupant satisfaction, aiming to ensure that the indoor environment supports the health, comfort, and productivity of its users. The ultimate objective of Indoor Environmental Quality is to promote occupants' well-being and productivity. Kamaruzzaman et al. (2011) further support the notion that green and high-performance buildings excel in providing a healthier indoor environment for occupants. Their agreement underscores the positive impact of sustainable and high-performance building practices on the well-being and health of individuals within indoor spaces.

In this research, the heritage office building of Kenadsa was chosen as the case study due to the importance of "the office building" made by the architect Charles Henri Montaland in 1941 (Belkacem Izala). In this phase for our research, we focused on the quantitative aspects of data collection, specifically in the realm of the multisensory environment within the selected case study. The critical factors under scrutiny included Thermal Comfort, Indoor Air Quality, Luminous Comfort, and Daylighting. This phase employed a meticulous approach to gather precise measurements, employed red circles to denote measurement stations strategically positioned within the building.

Therefore, our study focuses to evaluate Kenadsa’s heritage office building, the main objectives of this approach are:

1. To evaluate the physical dimensions of the indoor space, thermal and luminous environment of Kenadsa’s heritage office building located in the oasis of Bechar.
1. To evaluate our case study offices’ performance based on the physical dimensions of each office.
2. To examine if there are correlations between the physical dimensions.

2. Investigation Process:

In order to evaluate and analyze the multisensory interactions of users in their offices of the heritage administrative building of Kenadsa. We followed the following process:

The first phase was based on an objective approach using several in situ measurements of the physical dimensions of the environment, recorded during different users work.

Fig 59- Flowchart of research methodology incorporated in this phase of our study (Author, 2024)

2.1. Objective approach and Materials used:

The multisensory approach adopted in this data collection phase underscores the commitment to comprehensively understanding the environmental factors that contribute to user comfort and well-being. By employing a quantitative methodology, the research aimed to derive precise measurements that were serve as foundational data for subsequent analyses and simulations. This data-driven approach was pivotal in informing the broader objectives of optimizing energy consumption and fostering environmentally friendly behaviors within the heritage office building "our case study". As the red circles denote the measurement stations, they symbolize the strategic points where data were gathered to paint a detailed picture of the building's environmental characteristics.

2.1.1. The physical dimensions of the luminous and thermal environment:

In assessing the physical dimensions of the luminous environment at various indoor stations, the study employed in situ measurements of luminance, a crucial parameter in evaluating the luminous environment. These measurements were conducted using a "luxmeter kit" compatible with the "Testo 480 multifunctional meter"(Chen, Wang et al. 2022). Additionally, the multifunction meter (Testo 480) was utilized to gauge the thermal environment dimensions, encompassing ambient air temperature (Ta) and relative humidity (RH). The purpose of these physical measurements was to capture the current conditions within the building, shedding light on the actual state of the environment. The objective was to explore potential correlations between physical aspects of the measured physical dimensions, providing valuable insights into the interplay between users' experiences and the tangible characteristics of the indoor environment (Hamlili, Dakhia et al. 2024).

Fig 60- The measurements stations of the physical dimensions, (Author, 2023).

3. Results :

3.1. Distribution of the Physical Dimensions of the Environment during the work hours in the building:

The initial stage of this research was centered on mapping the distribution of physical environmental dimensions throughout the indoor heritage office building during working hours.

The objective was to gain insights into the real-time thermal and luminous conditions experienced within the workspace. This involved a comprehensive assessment of the spatial variations in thermal and luminous parameters, providing a detailed understanding of the actual environmental conditions during the operational hours of the heritage office building.

Figure 61b provides a visual representation of the location of each office within the heritage office building and its respective areas, enhancing the understanding of spatial variations in thermal conditions. These findings contributed to a comprehensive overview of the thermal atmosphere, emphasizing the impact of solar exposure and spatial orientation on indoor office spaces.

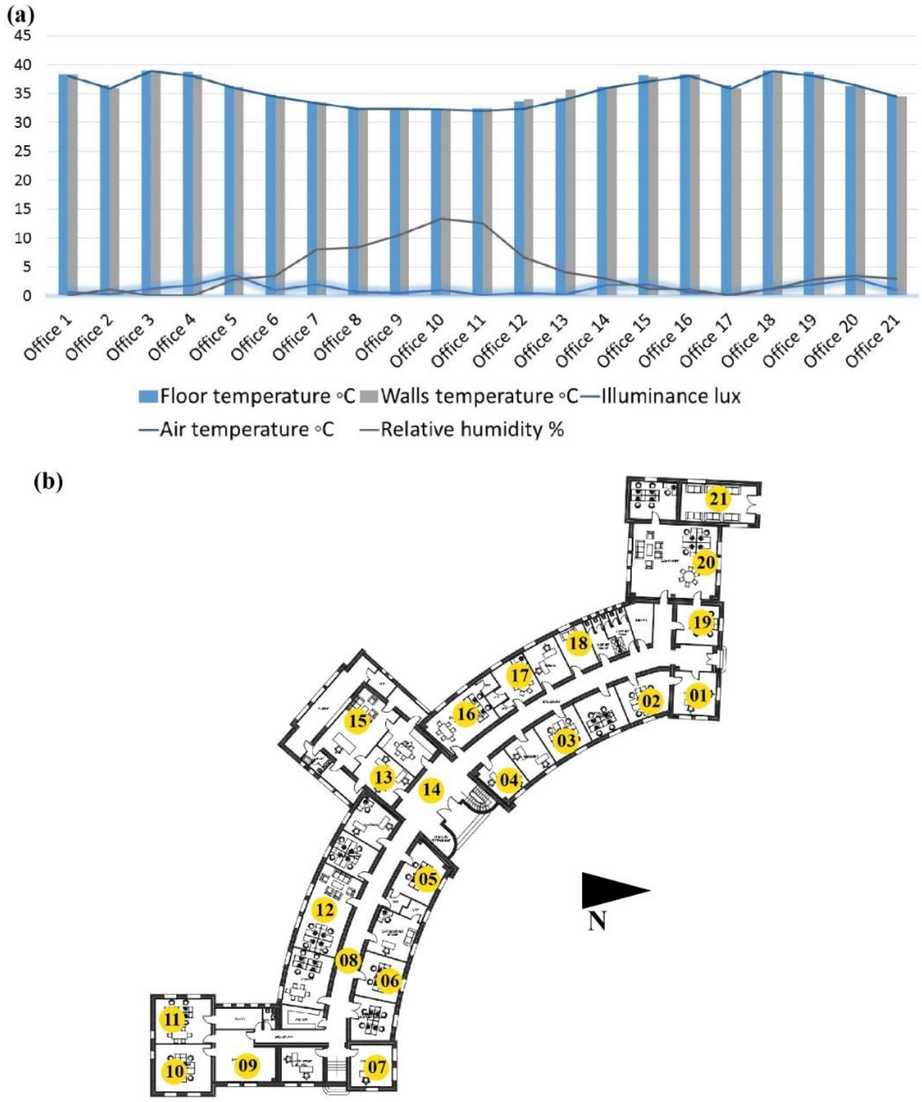


Fig 61- Case study**:** (a) Representation of the physical dimensions' distribution for each chosen office, (b) Offices' location in the building (Hamlili, Dakhia et al. 2024).

3.1.1. Distribution of the luminous physical dimensions environment:

The distribution of illuminance, “floor, walls and air temperature” and relative humidity as a function of space from the work experience in the different office spaces in our case study (Municipal Treasury area, Tax Revenue area, Administrative building area). Regarding the dimensions of the luminous environment, it was observed in Figure 61 that the work offices were characterized by illumination levels that vary between 0.19 lux and 3.57 lux, with an average value of 1.963 lux between the different workspace zones.

Table 10- Luminous physical dimensions of the first typical office, (Author 2024).

Measurements' location in the office	Lighting (lux)	Luminance (lm) (01)	Luminance (lm) (02)
01	0.63	0.095	0.28
02	0.31	0.44	1.44
03	1.03	0.52	1.61
04	1.93	1.75	1.66
05	3.57	2.59	2.02
06	0.98	0.82	1.41
07	1.94	0.11	0.60
08	0.68	0.026	0.15

Table 11- Luminous physical dimensions of the second typical office, (Author 2024).

Measurements' location in the office	Lighting (lux)	Luminance (lm) (01)	Luminance (lm) (02)
01	0.60	0.23	0.34
02	0.26	0.23	0.38

03	1.15	0.24	0.30
04	1.64	0.20	0.29
05	0.77	0.22	0.46
06	/	0.17	0.24
07	/	0.19	0.44

Table 12- Luminous physical dimensions of the third typical office, (Author 2024).

Measurements' location in the office	Lighting (lux)	Luminance (lm) (01)	Luminance (lm) (02)
01	0.072	2.19	3.52
02	0.088	3.91	10.85
03	0.068	1.33	2.83
04	0.067	3.90	6.35
05	0.77	1.57	2.48
06	/	2.79	4.14
07	/	1.49	1.78

Table 13- Luminous physical dimensions of the corridor (08), (Author 2024).

Measurements' location in the office	Lighting (lux)	Luminance (lm) (01)	Luminance (lm) (02)
01	0.17	0.010	0.019
02	0.17	0.063	0.085
03	0.016	0.15	0.25
04	0.06	0.20	0.25
05	0.42	0.22	0.15

06	0.35	0.17	0.10
07	0.36	0.35	0.48

3.1.2. Distribution of the thermal physical dimensions environment:

In Figure 61, the thermal conditions of various indoor office spaces were assessed, presenting ambient air temperature, floor and walls temperature, and relative humidity, along with the corresponding office locations and numbers. Figure 61a reveals that the recorded ambient air temperature in indoor workplaces averages 35.4°C (±1.04°C), with an average relative humidity of 7.15% (±2.47%). The ambient floor temperature in the administrative building area averages 35.5°C, while the walls' temperature was recorded at 36.5°C. Throughout the indoor workspaces, the thermal comfort stress level for occupants ranged from neutral (no thermal stress) to slightly warm (slight thermal stress). User discomfort is primarily attributed to direct solar radiation exposure, particularly evident in offices 01, 02 (Tax Avenue area) and offices 03, 04, 05, 06, 07, and 09, 10 (administrative building area with South orientation). Conversely, in offices shaded by trees and other buildings, a significant temperature difference of 7.79°C was observed, particularly in the office building's north-oriented offices. Temperatures in this area range from 32.2°C to 38.9°C, averaging 35.55°C. Figure 61a illustrates that temperatures in south-oriented offices are higher than those in the North. The corridor route, located in the middle of the building, recorded an average ambient air temperature (Ta) of 30.75°C, with a standard deviation of 5.56°C, and a mean relative humidity of 12.6%.

Table 14- Thermal Physical dimensions of each office, (Author 2024).

Measurements ‘ location	Floor’s temperature °C	Walls’s temperature °C	Air’s temperature °C	Relative humidity %
01	38.3	38.3	38	0
02	36.4	35.9	35.8	1.1
03	39	39	38.9	0
05	38.7	38.3	38.1	0

06	36.3	36.1	36	2.8
07	34.8	34.5	34.5	3.5
08	33.6	33.4	33.5	8
09	32.4	32.4	32.4	8.4
10	32.1	32.2	32.4	10.5
11	32.1	32	32.1	13.3
12	32.4	32.4	32.4	12.6
13	34.8	34	34.2	6.7
14	35.1	36.1	36	1.1
15	38.3	38.3	38	0
16	38	37.8	37	0.8
17	36.3	36.1	36	2.8
18	39	39	38.9	0.7
19	38.7	38.3	38.1	0.6
20	36.3	36.1	36	2.8
21	34.8	34.5	34.5	3.5

3.2. Correlations between the Dimensions of the Physical Environment:

Table 15 summarizes the correlations between the different physical dimensions collected by the three office areas in our building to verify the association between these different variables, which represent the luminous environment (Illuminance), the thermal environment (Ta, Tf, Tw and RH). Table 15 shows a significant correlation between the physical dimensions. Concerning the association between the luminous and thermal environment dimensions, it was found that illuminance had strong correlations with relative humidity, with correlation coefficients of −0.212, respectively. The relative humidity had a significant correlation with the air temperature, floor temperature, walls temperature, with a correlation coefficient of −0.864, -0.886, -0.881 (p-value = 0.000), respectively. Moreover, it was also seen that illuminance had a significant correlation with the thermal dimensions (walls temperature with correlation coefficients -0.290, floor temperature with correlation coefficients -0.313, air temperature with correlation coefficients -0.354.

Table 15- Pearson correlation between physical dimensions (Pearson coefficient [C], Sig. [S]), (Hamlili, Dakhia et al. 2024).

	Illuminance lux	Relative humidity %	Walls temperature	Floor temperature	Air temperature
Illuminance lux	S C	**0.221**	0.290	0.313	0.354
Relative humidity %	0.336	S C	0.881	0.886	0.864
Walls temperature	0.202	0.010	S C	0.987	0.976
Floor temperature	0.143	0.010	0.010	S C	0.987
Air temperature	0.116	0.010	0.010	0.010	S C

Conclusion:

The detailed analysis revealed critical insights into the thermal and luminous conditions. The findings from this stage of our reasech is about the thermal and luminous environment, suggest a temperature variation, there's a significant temperature difference between offices exposed to direct solar radiation and those shaded, indicating the impact of orientation.

Solar Exposure Discomfort, offices facing South experience discomfort due to direct solar radiation, while shaded areas show more comfort and ambient temperature, average ambient air temperature is 35.4°C, with notable variations across different office zones. User Discomfort, discomfort is linked to solar radiation exposure, particularly in South-oriented offices and the orientation Impact, North-oriented offices show a temperature range of 32.2°C to 38.9°C, with an average of 35.55°C, highlighting the impact of orientation. Corridor Conditions, the corridor route, located centrally, records an average ambient air temperature of 30.75°C and 12.6% relative humidity.

From our second stage, the findings suggest that illuminance has a significant correlation with the thermal dimensions (walls temperature with correlation coefficients -0.290, floor temperature with correlation coefficients -0.313, air temperature with correlation coefficients -0.354.

Chapter 7

7- Subjective approach and agent based modelling simulation “perceptual dimensions and behaviours”

Introduction:

Buildings passed down to us from the past are of great importance in shaping our modern society. Heritage includes a range of items such as buildings, structures, artefacts and areas that hold historical, aesthetic and architectural significance. Three key factors play a pivotal role in determining whether a property deserves heritage status: historical significance, integrity, and context. Architectural heritage designates a cultural asset transmitted from one civilization to another, which materializes its traces and describes a historical event in view of its values. Like other countries, Algeria has a very rich architectural heritage, which bears witness to the desire of several colonisations: Roman, Arab-Turkish, French. Furthermore, the French colonial legacy through these various faces constitutes the large part of this heritage, which is imposed to this day in the urban landscape of the majority of the country's cities. One of the favourite urbanisation’s area for the French colonisation is the oasis areas. Oasis settlements, often associated with resilience in arid conditions, occupy a unique position in vast deserts and semi-desert regions. Traditionally viewed as vibrant landscapes adorned with bodies of water and palm trees against a backdrop of sandy deserts, oases symbolize the harmonious convergence of human habitation and cultural identity in challenging environments (Hamlili, Dakhia et al. 2024).

In the heart of the Saoura region, located in the Berber oasis of Kenadsa, more precisely in the lively town of Knadasa, which they knew one of the important oasis heritage settlements. Saoura oasis also known by its devaluation and decline of a rich architectural and urban heritage. The traditional urban heritage that contains the old Ksar more than eight centuries old, the old Ksar of Kenadsa and Since French colonization in Algeria, a colonial heritage urban where new urban forms appeared, that have been juxtaposed. They made a sufficient number of public or administrative buildings, among the most important buildings, the administration building made by the architect Charles Montaland in 1941. It stands as an important building: the heritage administrative office building of Knadasa. This building occupies a special place because it is located in one the most famous oases in Algeria (DE KENADSA ; Mostadi and Biara 2019). It plays an essential role in improving institutional services for the inhabitants of this desert city.

During the last decades, Kenadsa has undergone significant transformations. These shifts influenced its architectural development resulting in various impacts on the environment. While these oasis regions are undergoing rapid urbanization, the expansion is concentrated within the verdant palm groves rather than the surrounding desert expanse. This urbanization strategy poses environmental challenges, including the imminent impact of climate change, which threatens to render these settlements excessively hot and uninhabitable in the coming decades. To face these challenges, it is necessary to delve deeper into the structures and urban spaces within these oases and to understand their architectural and human aspects. When individuals carry out their work activities in the surrounding areas of oases, the dynamic relationship between their work-related tasks and the sensory elements of their environment becomes a critical factor influencing their overall perceptions and experiences (Cartwright and Cooper 1997). This includes people who have an interest in evaluating building spaces through the lens of user perceptions and behaviors.

Our research focused on Quantitative and Qualitative Subjectively Data Collection, specifically targeting users of the Heritage office Building in Kenadsa. This quantitative survey about qualitative perceptions aimed to delve into the intricate relationship between users' perceptions and subsequent behaviors within the multisensory environment of the building (Lorusso and Bosch 2018). Therefore, our study focuses to evaluate Kenadsa heritage office building's performance based on its users' perceptions, the main objectives of this study are:

1. To evaluate the perceptual dimensions of the indoor space, thermal and luminous environment of Kenadsa's heritage office building located in the oasis of Bechar, Algeria.
2. To evaluate our case study offices' performance based on the perception and behaviors of their users.

1. Investigation Process:

In order to evaluate and analyze the multisensory perception and behavior of office users in their offices of the heritage administrative building of Kenadsa which is located in Kenadsa oasis settlement (see figure 62). We have conducted 2 parallel studies:

The first study was based on a subjective qualitative approach, based on in situ questionnaire investigations carried out after each user's work experience. In this study, two surveys were conducted in the laboratory, in two stages, after the observation of several short-term in situ, Thermal temperature and visual lighting that were done in winter and summer in different offices (Hamlili, Dakhia et al. 2024). We investigated the user's perception at first and then their behaviors as a result of their perception. Investigating the relationship between them after the interpretation of each result.

	Analytical Qualtitative Study Of Kenadsa's Heritage Office Building	
Data Collection	**Architectural Case study**	**Subjectively Qualtitative Approach**
Objective	**To evaluate the perceptual dimensions of the indoor space, thermal and luminous environment**	
Results and Discussion	**Identification of the perceptions and behaviors of each user office** **Correlation between the Dimensions of the perceptual Environment and offices' location**	

Fig 62- Flowchart of research methodology incorporated in the study (Author, 2024).

Figure 62 illustrates the methodological process used in this research project. The initial phase involves an intensive data collection effort focused on three main work packages. The first lot concerns the Architectural Heritage Office building in Kenadsa. The aim is to collect comprehensive information covering various aspects, such as the construction system and materials used, the shape and layout of the building, its orientation and the specific functions of each office. Additionally, the study includes an examination of office travel habits and a comprehensive assessment of user numbers. This data recovery process plays a vital role in initiating fieldwork and subsequent experimentation (Hamlili, Dakhia et al. 2024).

The second part of the research data collection focused on the observation aspects of data collection, specifically in the realm of the multisensory environment within the selected case study of Kenadsa's architectural heritage office building. The critical factors under scrutiny included Thermal Comfort, Indoor Air Quality, Luminous Comfort, and Daylighting. This phase employed meticulous circles to denote observational stations strategically positioned within the building.

The third part of the research involved a qualitative approach to the collection of personal data, specifically targeting users of the Kenadsa Heritage Office Building. This qualitative research aims to delve deeper into the complex relationship between users' perceptions and their subsequent behaviors within a multisensory built environment (Lorusso and Bosch 2018).

2.1. Stage one: Subjective Approach and Used Questionnaire:

a. Creating our Questionnaire:

In the second part of our study, we took a more personal approach by drawing on our experiences with thermo-visual work. Our goal was to understand the sensory aspects within each indoor space of the heritage office building and to get a sense of how both users and offices behaved.

To make this happen, we had two main tasks. First, we needed to collect a wide range of data to create surveys that really captured the details of users' experiences in our case study. This meant looking into things like how comfortable the environment was, the historical significance it held, and how much energy was being used.

Table 16- The construction of the 03 questionnaires, (author, 2024).

Questionnaire/ Content	Language	Target population	Number of responses	Method of administration	Type of questions
Questionnaire 1 Thermal environment	Arabic/French	The users (the workers) of kenadsa’s office heritage building	51	Human collection Direct human contact: Door-to-door	-Leading questions -Alternative questions -Multiple choice questions.
Questionnaire 2 Luminous environment	Arabic/French	The users (the workers) of kenadsa’s office heritage building	51	Human collection Direct human contact: Door-to-door	-Leading questions -Alternative questions -Multiple choice questions.
Questionnaire 3 User Behaviors	Arabic/French	The users (the workers) of kenadsa’s office heritage building	51	Human collection Direct human contact: Door-to-door	-Leading questions -Alternative questions -Multiple choice questions.

When creating these surveys, we focused on identifying positive behaviors that contribute to energy efficiency and sustainability while respecting the historic value of the building (table 17) (Khoukhi and Fezzioui 2012). At the same time, we wanted to identify behaviors that would have greater environmental impact and greater energy consumption. In undertaking this qualitative journey, our aim was to reveal the human side of a heritage building, recognizing that the way people see and behave in their surroundings greatly affects the overall environmental impact.

Table 17- Identified behaviors at workplaces (Ashforth, Caza et al. 2024).

Positive friendly behaviors at work	Negative unfriendly behaviors at work
1. *Employee Awareness and Engagement:* • Employee's awareness of their energy usage and its impact on the environment. 2. *Lightning and Equipment Usage:* • Turn off lights, computers, and other equipment when not in use, including during lunch breaks and after working hours. • Switch to energy-efficient LED lighting. 3. *Heating, Ventilation, and Air Conditioning (HVAC) Systems:* • Dress appropriately for the season to minimize the need for excessive heating or cooling. • Adjust temperature settings during non-working hours.	- *Employee Lack of Awareness and Disengagement:* • Employees being unaware of their energy usage and showing indifference to its impact on the environment. - *Lightning and Equipment Usage:* • Leave lights, computers, and other equipment on when not in use, even during lunch breaks and after working hours. • Stick to traditional, energy-inefficient lighting instead of switching to energy-efficient LED lighting. - *Heating, Ventilation, and Air Conditioning (HVAC) Systems:* • Dress inappropriately for the season, leading to the need for excessive heating or cooling. • Keep temperature settings unchanged during non-working hours, contributing to unnecessary energy consumption.

2.1.1. Thermal environment questionnaire :

	N		Very	Fairly	Little	Neutral	Little	Fairly	Very	
Thermal environment	10	Hot1	3	2	1	0	-1	-2	-3	Cold1
	11	Humid	3	2	1	0	-1	-2	-3	Dry
	12	Satisfied2	3	2	1	0	-1	-2	-3	Dissatisfied2
Temperature stability	13	Different	3	2	1	0	-1	-2	-3	Similar
Feeling of cold walls	14	Hot2	3	2	1	0	-1	-2	-3	Cold2
State	15	Comfortable2	3	2	1	0	-1	-2	-3	Uncomfortable2
Movement of indoor air	16	Strong	3	2	1	0	-1	-2	-3	Weak

Fig 63- Thermal environment questionnaire (Hamlili, Dakhia et al. 2024).

2.1.2. Luminous environment questionnaire :

	N		Very	Fairly	Little	Neutral	Little	Fairly	Very	
Luminous environment	1	Uniform	3	2	1	0	-1	-2	-3	Non-Uniform
	2	Bright1	3	2	1	0	-1	-2	-3	Dark1
	3	Contrast	3	2	1	0	-1	-2	-3	Low contrast
	4	Glaring	3	2	1	0	-1	-2	-3	No glare
	5	Attention	3	2	1	0	-1	-2	-3	Distraction
	6	Pleasant	3	2	1	0	-1	-2	-3	Unpleasant
Common areas										
State of satisfaction	7	Bright2	3	2	1	0	-1	-2	-3	Dark2
State	8	Satisfied1	3	2	1	0	-1	-2	-3	Dissatisfied1
	9	Comfortable1	3	2	1	0	-1	-2	-3	Uncomfortable1

Fig 64- Luminous environment questionnaire (Hamlili, Dakhia et al. 2024).

2.1.3. User behaviors questionnaire :

	N	Not at all	Early morning	All morning	Lunch break	Afternoon	All the day
User Behaviors							
Opening windows for ventilation	17	3	2	1	0	-1	-2
Use shutters/blinds	18	3	2	1	0	-1	-2
Air conditioning use	19	3	2	1	0	-1	-2
Heating use	20	3	2	1	0	-1	-2
Turn off the lights, microns during your lunch break	21	3	2	1	0	-1	-2
Use of ceiling Lamps	22	3	2	1	0	-1	-2

	N	2h	2h-4h	4h-6h	6h-8h	8h-10h
Air conditionning time use	23	2	1	0	-1	-2
Heating system time use	24	2	1	0	-1	-2
Artificial light on time use	25	2	1	0	-1	-2

Fig 65- User behaviours questionnaire (Hamlili, Dakhia et al. 2024).

The questionnaire crafted for this study encompassed 25 attributes, as detailed in Figure 63,64,65. The first nine attributes specifically target the assessment of the luminous environment, covering aspects such as Uniformity, Brightness, Contrast, Glare, Concentration, Pleasantness, and overall Satisfaction and Comfort with the environment. The idea behind the Concentration function and Attention-Distraction attributes drew inspiration from the contrast variables outlined in the works of Demers et al. (Chen, Wang et al. 2022)

Attributes 10, 11, and 14, which focus on the evaluation of the thermal environment, are adapted from previous studies, incorporating scales like Hot-Cold and Humid-Dry used in thermal sensation votes (TSV) and humidity sensation votes (HSV). Furthermore, attributes 13 and 16 gauge the sensation of temperature stability during the day and the movement of indoor air. Attributes 12 and 15 measure Satisfaction and Comfort concerning the thermal environment (Hamlili, Dakhia et al. 2024).

Moving to user behaviors, attributes 17 to 20 are directed at behaviors related to the thermal environment, while attributes 21 and 22 focus on behaviors associated with the luminous environment. The remaining attributes (23 to 25) delve into the time use of heating systems, air conditioners, and artificial lights.

For each attribute in the questionnaire, a rating scale from 3 to -3 was proposed for the multisensory evaluation of the heritage office building. Data analysis, conducted using IBM-SPSS software, aimed to examine the semantic differences in multisensory evaluation for the heritage office building.

Table 18- Method of constructing the 03 questionnaires and their goals. (Author, 2024).

Dimensions	Components	Goals
Luminous environment aspects	- Uniform / Non-uniform - Bright1/ Dark1 - Contrast/ Low contrast - Glaring / No glare - Attention/ Distraction - Pleasant/ Unpleasant - Bright2/ Dark2	The first nine were all about the lighting environment, things like how even the lighting was, how bright it felt, if there was any glare, and if it was pleasant and comfortable overall.
Thermal environment aspects	- Hot1/ Cold1 - Humid/ Dry - Satisfied2/ Dissatisfied2 - Different/ Similar - Hot2/ Cold2 - Comfortable2/ Uncomfortable2 - Strong/ Weak - Satisfied1/ Dissatisfied - Comfortable1/ Uncomfortable1	Attributes 10, 11, and 14 focused on how people felt about the temperature in the space, borrowing ideas from past studies that used scales like Hot-Cold and Humid-Dry in thermal sensation votes. Other attributes looked at how stable the temperature felt throughout the day and the movement of indoor air.
State of satisfaction/comfort	- Satisfied2/ Dissatisfied2 - Comfortable2/ Uncomfortable2 - Satisfied1/ Dissatisfied - Comfortable1/ Uncomfortable1	Assessing satisfaction and comfort in the thermal environment and luminous environment.
User behaviors aspects	- Artificial light on time use - Heating system time use - Air conditionning time use - Turn off the lights, - microns during your - lunch break - Use of ceiling Lamps - Air conditioning use - Use shutters/blinds - Opening windows for ventilation - Heating use	Attributes 17 to 20 explored actions related to the thermal environment, while 21 and 22 were all about behaviors related to the lighting. The last set of attributes (23 to 25) dug into how people use heating systems, air conditioners, and artificial lights in their daily lives.

In the second part of our work, we paid close attention to the survey objectives, ensuring that each question was worded thoughtfully. Designed to understand how users perceive their environment and behave, these surveys have become our tools to dig deeper into how their environment impacts their experiences. We took a more personal and detailed approach, going beyond simple numbers to understand the qualitative aspects of how people interact with the building.

2.3. Participants

For this study, we had fifty-one (51) people participate in thermo-visual work experiences at the heritage office building in Kenadsa. Their ages ranged from 26 to 46 years old. We split them into two groups, each assigned to a different workspace. The first group, made up of administrative staff, included 83% females and 17% males. In the second group, representing employees, there were 43.8% females and 56.3% males.

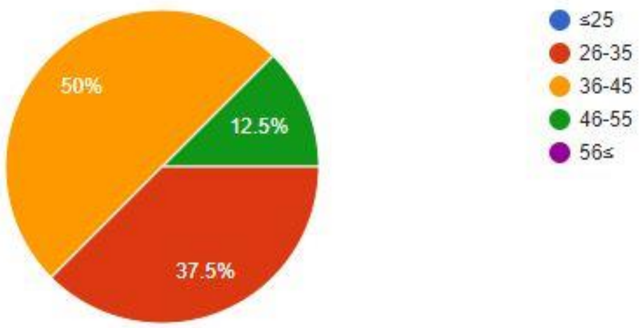


Fig 66- Global results of participants ‘2 groups’, (Source: Author 2024).

3. Results of the survey:

3.1. Identification of the perceptions and behaviors of each user office:

The next phase of this research involves identifying and analyzing the perceptions and behaviors of users in each office and space within the heritage office building. The analysis focuses on evaluating sensory perceptions and behaviors through user assessments, specifically tailored to each office. Table 19 provides a detailed analysis of the average perception results for each index used in our questionnaire. These indices correspond to the evaluation of the multisensory physical environments of the offices within our case study.

Fig 67- Offices' location in the building, (Source: Author 2024).

Table 19- The perceptual data average results analysis of the physical environment (Hamlili, Dakhia et al. 2024).

Offices	Indices	Perception Average results	
Global Analysis	From 01 to 16	Uniform (60.5%)	Non-uniform (39.5%).
		Bright1 (81.3%)	Dark1 (18.7%).
		Contrast (62.5%)	Low contrast (37.5%).
		Glaring (66.3%)	No glare (33.5%).
		Attention (56.3%)	Distraction (34.7%).
		Pleasant (57.3%)	Unpleasant (42.7%).
		Bright2 (18.5%)	Dark2 (60.5%).
		Satisfied1 (81.3%)	Dissatisfied (81.5%).
		Comfortable1 (56.2%)	Uncomfortable1 (43.8%).
		Hot1 (38%)	Cold1 (62%).
		Humid (12.7%)	Dry (87.3%).

	Satisfied2 (84.8%)	Dissatisfied2 (15.2%).
	Different (75%)	Similar (25%).
	Hot2 (23.3%)	Cold2 (76.3%).
	Comfortable2 (66.1%)	Uncomfortable2 (33.9%).
	Strong (52.5%)	Weak (47.5%).

Table 19 sheds light on the initial average perception results, primarily centered around the thermal perception function of the office spaces. This includes aspects like Humid-Dry, Pleasant3-Unpleasant, Satisfied-Dissatisfied, Hot-Cold, different-similar, comfortable-uncomfortable, all related to the sensation of humidity, pleasantness, satisfaction, temperature similarities, and thermal sensation. The second set of perception results is generally linked to the visual perception of the luminous environment, involving Contrast-Low Contrast, Bright1-Dark1, Pleasant-Unpleasant, Bright2-Dark2. These are tied to the sensations of contrast, brightness, and pleasantness. The third set of perception results pertains to the dimensions of visual environment perception, encompassing Uniform-Non-uniform, Glaring-No glare, Attention-Distraction, which are associated with uniformity, glare, and concentration (Hamlili, Dakhia et al. 2024).

In summary, Table 19 provides an overview of average perception results for different indices related to indoor office spaces, globally categorized across all offices (indexed from 01 to 16). Each index corresponds to a specific aspect of the environment, and the percentages indicate the proportion of respondents or participants perceiving the environment in a particular way. Here is a breakdown for each index:

Uniformity (60.5%): Perceived the environment as uniform, while (39.5%) perceived it as non-uniform.

Brightness (Bright1 and Dark1) (81.3%): Perceived the environment as bright, while (18.7%) perceived it as dark.

Contrast (62.5%): Perceived a contrasted environment, while (37.5%) perceived it as having low contrast.

Glare (66.3%): Reported glare in the environment, while (33.5%) did not perceive any glare.

Attention and Distraction (56.3%): Reported an attention-grabbing environment, while (34.7%) found it distracting.

Pleasantness (57.3%): Found the environment pleasant, while (42.7%) found it unpleasant.

Brightness (Bright2 and Dark2) (18.5%): Perceived the environment as bright, while (60.5%) perceived it as dark.

Satisfaction1 (81.3%): Were satisfied, while (18.5%) were dissatisfied.

Comfortable1 (56.2%): Found the environment comfortable, while (43.8%) found it uncomfortable.

Hot1 and Cold1 (38%): Perceived the environment as hot, while (62%) perceived it as cold.

Humidity (12.7%): Perceived the environment as humid, while (87.3%) perceived it as dry.

Satisfaction2 (84.8%): Were satisfied, while (15.2%) were dissatisfied.

Difference and Similarity (75%): Perceived a different environment, while (25%) perceived it as similar.

Hot2 and Cold2 (23.3%): Perceived the environment as hot, while (76.3%) perceived it as cold.

Comfortable2 (66.1%): Found the environment comfortable, while (33.9%) found it uncomfortable.

Strength (52.5%): Perceived a strong environment, while (47.5%) perceived it as weak.

These results offer valuable insights into how users perceive various aspects of indoor office spaces, providing crucial feedback on environmental conditions and the overall user experience.

Table 20-The identification of user’s behaviours and its duration in each office (w.winter, s.summer) (Hamlili, Dakhia et al. 2024)

Office	Location	Number of users	Behaviors	Duration of the behavior
01	Northern side	02	20 (2, 1), 17 (0,-1), 18 (3)w, 19 (1,-1), 18 (1,0,-1)s, 22 (1w,-1w, 1s,-1s), 21(0).	23 (-2), 24 (0), 25 (-1).
02	Northern side	02	20 (-2), 17 (0), 18 (1)w, 19 (1,-2), 18 (0,-1)s, 22 (-1w,-1s), 21(0).	23 (-2), 24 (-2), 25 (-2).
03	Northern side	03	20 (2, 1), 17 (-1), 18 (3)w, 19 (-2), 18 (2,1)s, 22 (1w,-1w, 1s,-1s).	23 (-1), 24 (-1), 25 (-2).
04	Northern side	01	20 (-2), 17 (2), 18 (3)w, 19 (-2), 18 (-1)s, 22(1w,-1w,-1s), 21(0).	23 (-2), 24 (-1), 25 (-1).

05	Northern side	02	20 (2), 17 (2), 18 (3)w, 19 (0,-1), 18 (-1)s, 22 (1w,-1w,-1s), 21(0).	23 (0), 24 (-1), 25 (-1).
06	Northern side	03	20 (2, 1), 17 (2,0), 18 (3)w, 19 (2,1,-1,-2), 18 (-1)s, 22 (1w,-1w,-1s).	23 (-1), 24 (-1), 25 (-1).
07	Northern side	02	20 (2, 1), 17 (2), 18 (3)w, 19 (-2), 18 (-1,-2)s, 22 (1w,-1w), 21(0).	23 (-1), 24 (-1), 25 (-1).
08	East side	02	20 (2, 1), 17 (-1), 18 (-1)w, 19 (1,-2), 18 (-1,-1)s, 22 (1w,-1w, 1s,-1s), 21(0).	23 (-1), 24 (-1), 25 (-1).
09	Southern-east side	01	20 (1, -2), 17 (-1), 18 (-1)w, 19(-2), 18 (0,-1)s, 22 (-1w,-1s), 21(0).	23 (0), 24 (-1), 25 (0).
10	Southern-east side	02	20 (2, 1), 17 (0,-1), 18 (3)w, 19 (0,-1), 18 (-1)s, 22 (1w, 1s), 21(0).	23 (-1), 24 (-1), 25 (0).
11	Southern-west side	02	20 (2, 1), 17 (2,0), 18 (3)w, 19 (1,-1), 18 (-1)s, 22 (1w, 1s), 21(0).	23 (-1), 24 (-1), 25 (0).
12	Southern side	04	20 (2, 1), 17 (0), 18 (1)w, 19 (1,0), 18 (1,-1)s, 22 (1w,-1w, 1s,-1s), 21(0).	23 (-1), 24 (-2), 25 (-2).
13	Middle side	04	20 (2, 1), 17 (0), 18 (1)w, 19 (1,0), 22 (1w,-1w,-1s), 21(0).	23 (0), 24 (-2), 25 (-1).
14	Middle side	01	20 (2, 1), 17 (0,-1), 18 (3)w, 19 (1,-1), 18 (1,-1)s, 22 (1w,-1w, 1s), 21(0).	23 (0), 24 (-1), 25 (-1).
15	Southern-west side	01	20 (2, 1), 17 (1), 18 (1,-1)w, 19 (1,0), 18 (1,-1)s, 22 (1w,-1w,-1s), 21(0).	23 (-1), 24 (-2), 25 (-2).
16	Southern-west side	02	20 (2, 1), 17 (0), 18 (3)w, 19 (1,-1), 18 (2,1,-1)s, 22 (1w,-1w, 1s,-1s), 21(0).	23 (-2), 24 (-1), 25 (-1).
17	Southern-west side	02	20 (2, 1), 17 (0), 18 (3)w, 19 (1,-1), 18 (2,1,-1)s, 22 (1w,-1w, 1s,-1s), 21(0).	23 (-2), 24 (-1), 25 (-1).
18	Southern-west side	01	20 (2, 1), 17 (0), 18 (3)w, 19 (1,-1), 18 (2,1,-1)s, 22 (1w,-1w, 1s,-1s), 21(0).	23 (-2), 24 (-1), 25 (-1).
19	Northern side	02	20 (2, 1), 17 (1), 18 (1,-1)w, 19 (1,0), 18 (1,-1)s, 22 (1w,-1w,-1s), 21(0).	23 (-1), 24 (-2), 25 (-2).
20	Northern and southern side	04	20 (2, 1), 17 (1), 18 (1,-1)w, 19 (1,0), 18 (1,-1)s, 22 (1w,-1w,-1s), 21(0).	23 (-1), 24 (-2), 25 (-2).
21	Northern side	03	20 (2, 1), 17 (2,0), 18 (3)w, 18 (1,-1), 18 (-1)s, 22 (1w, 1s), 21(0).	23 (-1), 24 (-1), 25 (0).

Let us take a closer look at Table 20, which gives us a detailed snapshot of the offices within Kenadsa's heritage office building. Each office, marked with a unique number, is situated on different sides of the building, Northern side, Eastern side, Southern-east side, Southern-west side, Southern side, and Middle side.

To understand the dynamic of each office, the table tells us how many people use each space. However, the real focus is on the behaviors observed in these offices, with each behavior identified by a number and detailed with sub-behaviors in parentheses. For example, you might see Behavior 20 with sub-behaviors like 2 and 1. The table also tells us how long or intense each behavior is like the duration of Behavior 23 with an intensity of -2.

This info is gold when it comes to understanding how people behave in different offices across the building. Noticeably, offices on the same side tend to have similar behaviors and durations. An interesting point is the difference in behavior duration between offices on the northern and southern sides, hinting at how energy use might vary with the seasons. In addition, offices with solar protection measures, like blinds, seem to use artificial lights more often.

The analysis underscores the importance of considering user behavior in optimizing energy use and environmental comfort within the building. It sheds light on tendencies related to lighting, heating, and cooling systems. Notably, the recognition of the corridor as a relatively dark area by most users adds valuable insights into occupants' perceptions of the built environment.

3.2 Stage 2: Correlations between the Dimensions of the perceptual Environment and offices' location:

The results from the third stage of this study provide valuable insights into user perceptions and behaviors within Kenadsa's Heritage Office Building, shedding light on various aspects related to thermal, luminous, and visual environment perceptions, as well as user behaviors.

Thermal Perception: Users generally perceive the environment as slightly warm, with variations in humidity, satisfaction, comfort, and perceived temperature. This nuanced understanding of thermal perception is essential for creating environments that cater to the preferences of the occupants.

Luminous Perception: Findings indicate variations in brightness, contrast, and glare perceptions, influencing users' attention, distraction, and overall pleasantness. This suggests the importance of carefully designing lighting conditions to enhance both visual comfort and the overall experience of the users.

Visual Environment Perception: Users' perceptions of uniformity, glare, and attention vary, impacting their concentration. This emphasizes the intricate interplay between visual environment attributes and users' cognitive responses, highlighting the need for thoughtful design considerations in these aspects.

User Behaviors: Each office exhibits specific behaviors and durations, suggesting a tailored response to environmental conditions. Similar behaviors among offices in the same location or side highlight the influence of the immediate surroundings on occupants' actions.

Disparities in behavior duration between northern and southern side offices indicate varying energy consumption patterns in different seasons. This finding is crucial for optimizing energy use and enhancing sustainability. Offices employing solar protection measures, such as blinds, tend to rely more on artificial lights. This observation underscores the importance of considering the impact of design elements on user behaviors and energy usage. Users perceive the corridor as relatively dark, affecting their overall experience. Addressing this perception can contribute to a more positive user experience and may influence future design decisions.

In summary, the comprehensive findings offer a holistic understanding of how users perceive and interact with their office environment. The information gleaned from thermal, luminous, and visual perceptions, coupled with insights into user behaviors, provides a solid foundation for making informed design decisions aimed at optimizing user experience, energy efficiency, and overall sustainability within Kenadsa's Heritage Office Building.

3.3. Codification of the user's behaviors:

The Behavior Code Table 21, which is the third classification table, provides a systematic cataloging of behaviors by assigning each one a unique code. This structured approach simplifies the representation of behaviors within the simulation software. For instance, the first thermal behavior might be labeled as TB1 (standing for "Thermal Behavior 1" or a similar designation), allowing the software to use this shorthand reference to efficiently incorporate and differentiate various behaviors. These codes are practical for identifying, organizing, and implementing behaviors within the modeling environment. By using a standardized coding system, the software enhances its ability to manage and simulate diverse behaviors across different scenarios and user interactions. This streamlined representation improves the clarity and efficiency of the modeling process, enabling more effective analysis of user responses to a building's thermal and lighting conditions (Hamlili, Dakhia et al. 2024).

User's Behaviors	Behavior's type	Codes (Modelization agent-based modeling)
Air conditionner use 4h-6h/6h-8h/8h-10h	Thermal behaviour	TB1, TB2, TB3
heating system time use 4h-6h/6h-8h/8h-10h	Thermal behaviour	TB4,TB5,TB6
Ceiling Lamps light time use 4h-6h/6h-8h/8h-10h	Luminous behaviour	LB1,LB2,LB3
Turn off artificial light and microns during lunch break	Luminous behaviour	LB4
Use shutters/blinds	Thermal and luminous behaviour	TLB
Opening windows for ventilation	Ventilation behaviour	VB

Table 21-The codification of user's behaviours and its duration in each office for the Agent-based modelling (Hamlili, Dakhia et al. 2024).

3.4. Stage 3: Behaviour's Agent based modelling simulation study:

The third stage involves initiating agent-based modeling in Rhino 7 software using the QUELIA AGENT plug-in. This includes integrating weather data for our selected city, Kenadsa (Bechar), which is exported from Climate Studio software. We completed the modeling of each behavior in every office, accurately reflecting the number of users in each location. This was achieved by leveraging the plug-in's capabilities to simulate behaviors in the actual thermal and light environment, based on quantitative measurements of temperature and brightness in each office.

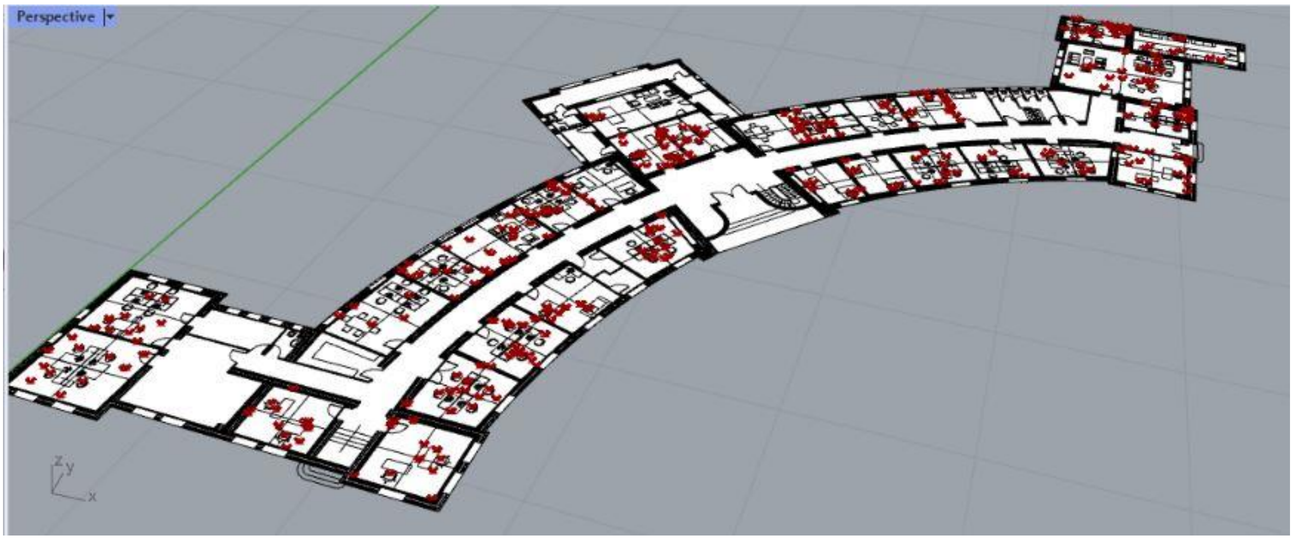


Fig 68- "A perspective view of the modeling phase of our case study" (Hamlili, Dakhia et al. 2024) (Author 2024).

Figure 69 illustrates the process of the agent-based modeling simulation study for our building case study. Specifically, Figure 69 (a, b, c) depicts the modeling process of our agents, while Figure 69 (d, e, f) shows the simulation of agent speed and lifespan in each office under the given physical environment conditions. These conditions include the actual thermal and luminous environments and the overall performance of the building. In the software, the duration of work is represented by the lifespan of the agents (users) in the simulation. Similarly, the user's performance speed is depicted by the movement speed of the agents in the simulation.

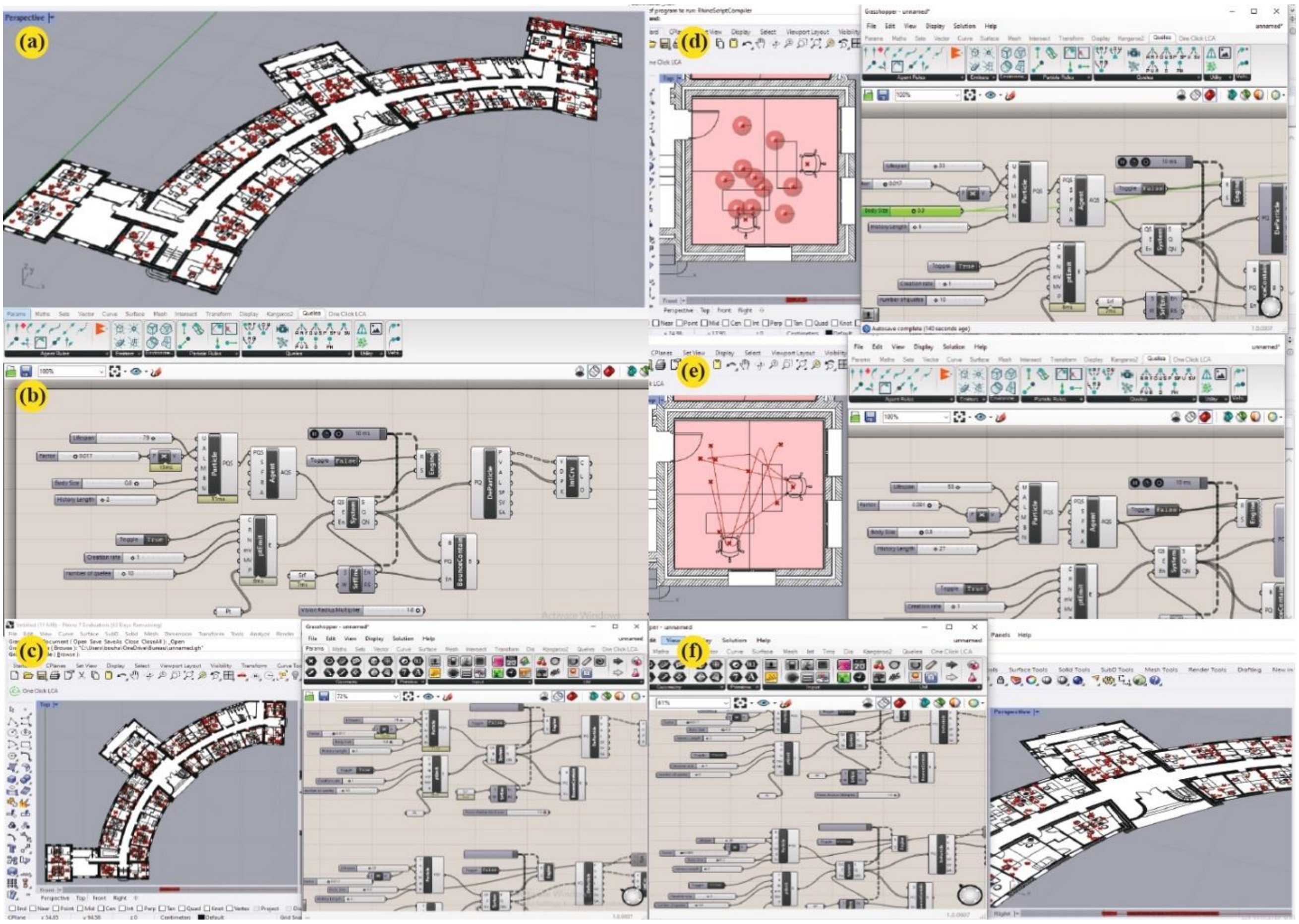


Fig 69 - Representation of the Behaviours Agent based modelling simulation study process in Kenadsa's heritage office building: (a) users agent in each studied office of the case study, (b) Modelization process of one office environnement, (c) and (f) Modelization final process "all offices", (d) and (e) agents' speed and life span final result (Hamlili, Dakhia et al. 2024).

From our agent-based modeling simulation observations, we conducted two stages of simulation: one with the presence of users' behaviors and one without. This approach was designed to determine the optimal thermal and luminous office environment that maximizes user productivity in our case study.

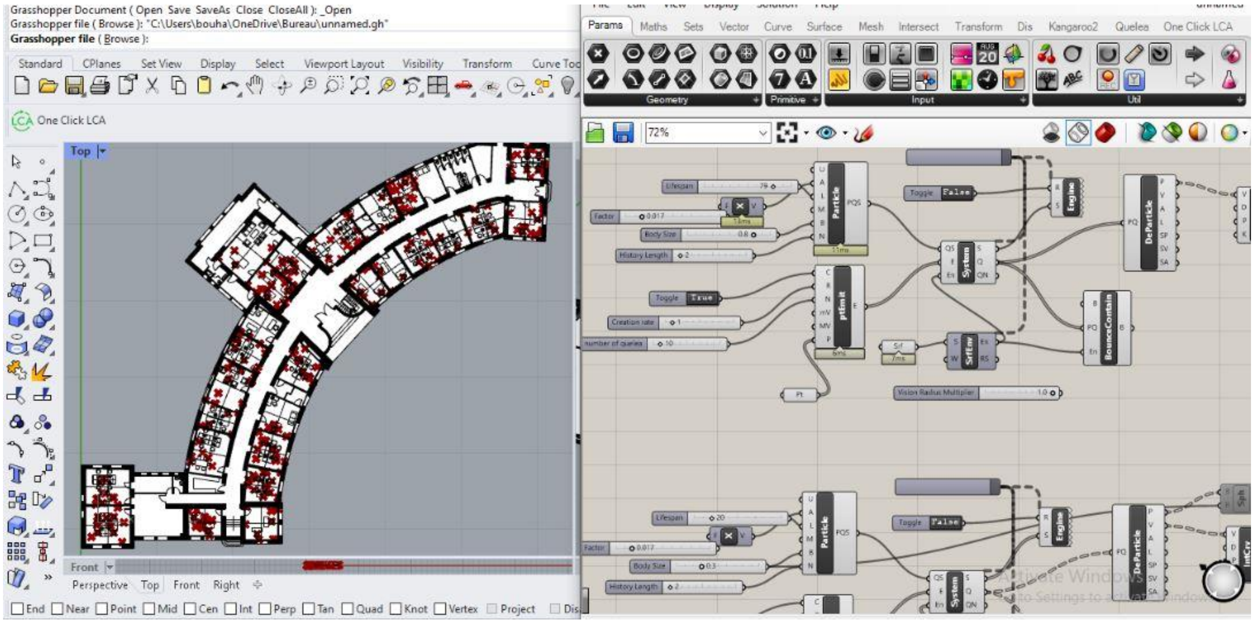


Fig 70 - “Agent-based modelling” of the final process for “all offices” (Author 2024).

Firstly, we identified three types of offices:

1. **Optimal Environment without Energy-Wasting Behaviors:** These offices (01, 02, 07, 09, 21 in Figure 67) have an optimal luminous and thermal environment. Users in these offices reported a comfortable state without engaging in energy-wasting behaviors. In the simulation, agents in these offices disappeared quickly and moved fast, indicating a short job execution time and high user performance speed.

2. **Optimal Environment with Energy-Wasting Behaviors:** These offices (03, 04, 05, 06, 08, 13, 14, 16 in Figure 67) also have an optimal luminous and thermal environment. Users reported comfort but engaged in energy-wasting behaviors. Despite this, the simulation results were similar to the first type, with agents disappearing quickly and moving fast, reflecting high performance.

3. **Suboptimal Environment with Energy-Wasting Behaviors:** These offices (10, 11, 12, 15, 17, 18, 20 in Figure 67) have the worst luminous and thermal environments. Users reported discomfort and engaged in energy-wasting behaviors. In these offices, the simulation showed a low speed of user performance and a long duration of job execution, as indicated by the slower movement and longer lifespan of agents in Figure 71.

These findings highlight the significant impact of thermal and luminous conditions on user productivity, with optimal environments enhancing performance and suboptimal conditions leading to reduced efficiency.

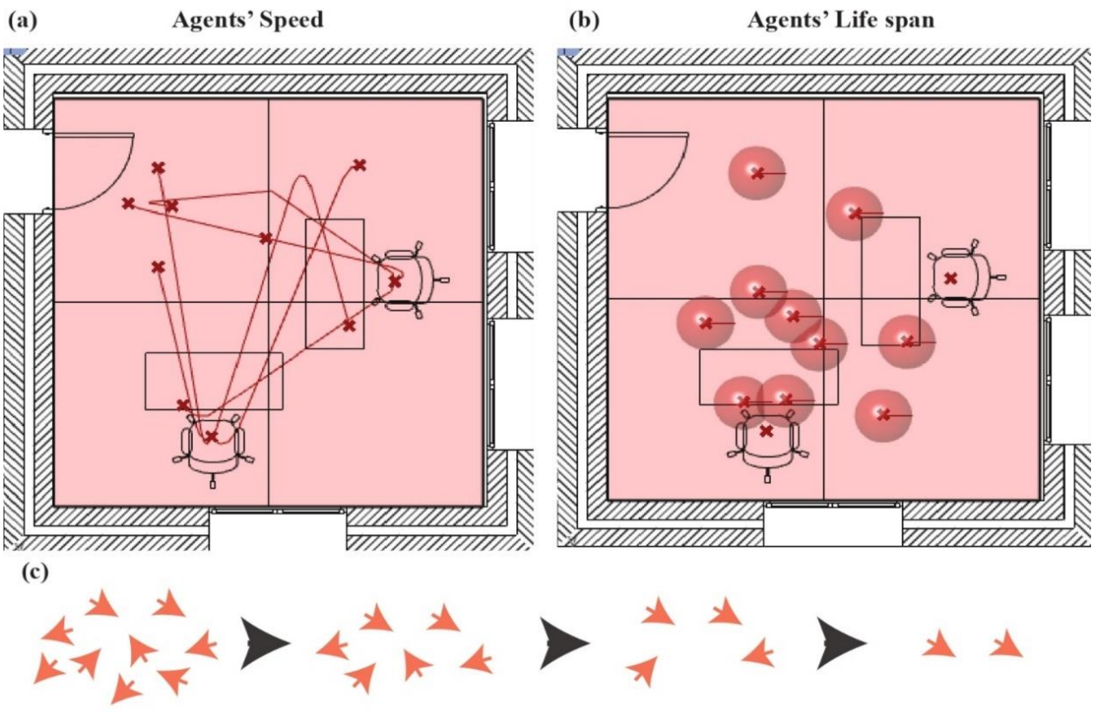


Fig 71- Representation of agents' speed and life span in a chosen sample office from Kenadsa's heritage office building: (c) agent's behaviors lifespan "disappearance"(Hamlili, Dakhia et al. 2024).

4. Synthesizing the perception and behaviors' evaluation:

The third stage of this study focused on user perceptions, revealing nuanced insights into how users experience the thermal and luminous environments within the heritage office building.

User Perceptions:

- **Thermal Perception:** Users generally perceive the environment as slightly warm, with variations in humidity, satisfaction, comfort, and perceived temperature. This suggests that while the overall thermal environment is manageable, specific factors such as humidity can significantly affect user comfort.
- **Luminous Perception:** Perceptions of brightness, contrast, and glare vary among users, influencing their attention, distraction levels, and overall pleasantness. This highlights the

importance of managing light conditions to maintain a comfortable and productive workspace.

- **Visual Environment Perception:** Variations in perceptions of uniformity, glare, and attention affect users' concentration. Ensuring a uniform visual environment with minimal glare is crucial for maintaining focus and reducing distractions.

User Behaviors:

The findings indicate that each office has its own specific behaviors and durations. Notably, offices located on the same side of the building exhibit similar behaviors and durations, underscoring the influence of environmental conditions. Disparities in behavior duration between northern and southern side offices suggest different energy consumption patterns across seasons. Additionally, offices that use solar protection measures like blinds tend to rely more on artificial lighting. Users also perceive the corridor as a relatively dark area, which negatively impacts their overall experience.

Agent-Based Modeling:

The fourth stage involved agent-based modeling, which distinguished between offices with optimal and suboptimal conditions, considering the presence or absence of energy-wasting or overconsumption behaviors. The simulation revealed that offices with optimal conditions and minimal energy-wasting behaviors exhibit faster agent disappearance and movement speed, indicating higher user productivity. This suggests that optimizing environmental conditions can lead to significant improvements in user performance.

The findings from this study provide valuable insights for optimizing the design of heritage office buildings. Key takeaways include:

- Environmental Conditions: The importance of maintaining optimal thermal and luminous environments to enhance user comfort and productivity is paramount.

- Behavior Patterns: Recognizing the influence of specific behaviors and environmental conditions on energy consumption and productivity can guide effective management strategies.

- Simulation Insights: Agent-based modeling offers a dynamic representation of user behaviors, providing a deeper understanding of how environmental conditions impact building functionality.

By addressing these factors, designers and managers can create more comfortable, efficient, and productive workspaces within heritage office buildings.

Conclusion:

The third stage of this study focused on user perceptions, revealing nuanced insights into how users experience the thermal and light environments within the heritage office building. Users generally perceive the thermal environment as slightly warm, with variations in humidity, satisfaction, comfort and perceived temperature, indicating that although the overall thermal environment is manageable, specific factors such as Humidity can significantly affect comfort. Perceptions of brightness, contrast and glare vary among users, influencing their attention, distraction levels and overall enjoyment, highlighting the importance of managing lighting conditions for a productive workspace. Variations in perception of the visual environment, such as uniformity and glare, affect concentration, requiring a uniform visual environment with minimal glare to maintain concentration. Each office has specific behaviors and durations, with offices on the same side exhibiting similar behaviors due to environmental conditions and differences between north and south offices suggesting varying energy consumption patterns across seasons. Offices using sun protection measures like blinds tend to rely more on artificial lighting, and users perceive the hallway as dark, impacting their overall experience. Agent-based modeling distinguished between offices with optimal and suboptimal conditions, revealing that offices with optimal conditions and minimal energy wasting behaviors exhibit higher agent disappearance and movement speed. Fast, indicating higher user productivity. These findings highlight the importance of maintaining optimal thermal and light environments to improve comfort and productivity, understanding behavioral patterns to guide effective management strategies, and using agent-based modeling to better understand the impact of environmental conditions on the functionality of buildings. By addressing these factors, designers and managers can create more comfortable, efficient and productive workspaces within heritage office buildings.

The strength of this research is mainly due to its comprehensive Analysis, its subjective approach. The study provides a thorough examination of indoor environmental conditions, user perceptions, and behaviors within a heritage office building. It covers aspects such as ambient temperature, humidity, luminosity, and visual environment, offering a holistic view. This study used also the user-Centric Approach, by integrating user perceptions and behaviors; the study adopts a user-centric perspective. This approach recognizes the importance of users' experiences and preferences in building design and operation.

Chapter 8

8- Life cycle assessment of our case study

Introduction:

This chapter presents the results of the Life Cycle Assessment (LCA) for the Kenadsa heritage office building, located in the oasis of Bechar. The evaluation focuses on the building's energy performance, environmental impact, and overall sustainability. Using the ArchiCAD 22 energy evaluation tool and the One Click LCA plugin in Rhinoceros software 7, a comprehensive assessment was conducted to understand the building's performance across various parameters. It presents a detailed life cycle assessment evaluation of Kenadsa’s heritage office building, is renowned for its rich cultural heritage and historical significance as an oasis settlement. This arid region, characterized by its harsh climatic conditions, has necessitated the development of adaptive architectural solutions that balance functionality, environmental responsiveness, and cultural preservation. Within this context, the Kenadsa heritage office building stands as a testament to the region's architectural ingenuity and historical legacy. Evaluating the performance of such a building is crucial, not only for preserving its historical value but also for ensuring its functionality and sustainability in a modern context.

An office building is intended primarily for the reception and service of users. It must therefore offer favorable conditions for the reception and work of the staff present on throughout the working of each week. Defining the performance indicators of a building means having carefully listed the functions that the building must fulfill for users.

We therefore leaned into priority on the needs and comfort of users (employees) in their offices. The spatio-temporal organization is important, it must respond to specific needs employees (administrative and technical) and users of this tertiary building: in in this case, the heritage administrative building of Kenadsa. Most of these needs will be reflected by quality of life and comfort indicators. Of use (visual, thermal, air quality, etc.) for the occupants of the spaces in this building.

The results of energy simulations make it possible to define consumption energy costs of this same building throughout its life cycle, starting with the building in its initial state, and after each level of improvement considered. The levels and rates of comfort or discomfort will then be defined. Then, each level of energy consumption corresponds to a footprint environmental damage caused by the use of this building. These are indicators of environmental impacts at a global level, or by phase of the life cycle of the building and which will be focused by type of impact on human health, air quality, hygiene and ecosystems.

1. **Modelisation and Simulation of the case study 'Input's information':**

2.1. Building Overview:

Location: Kenadsa, Bechar, Algeria.

Building Use: Office building.

Gross Floor Area: 1,014.36 m².

Construction Gross Surface Area: 1,879.26 m².

Ventilated Volume: 4,154.94 m³.

Reflectance Rate: 7%.

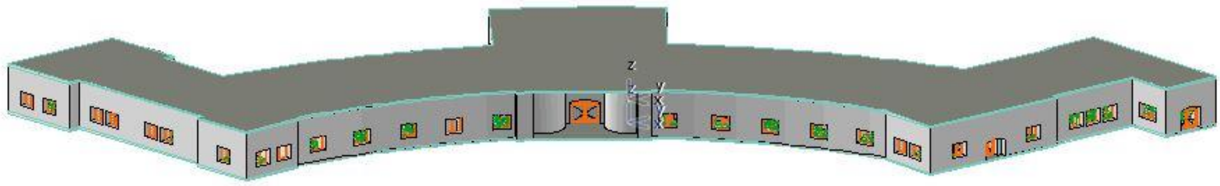


Fig 72- Kenadsa's heritage office building 3D model, (Author 2024).

Fig 73- Kenadsa's heritage office building structure elements "axonomitrical view", (Author 2024).

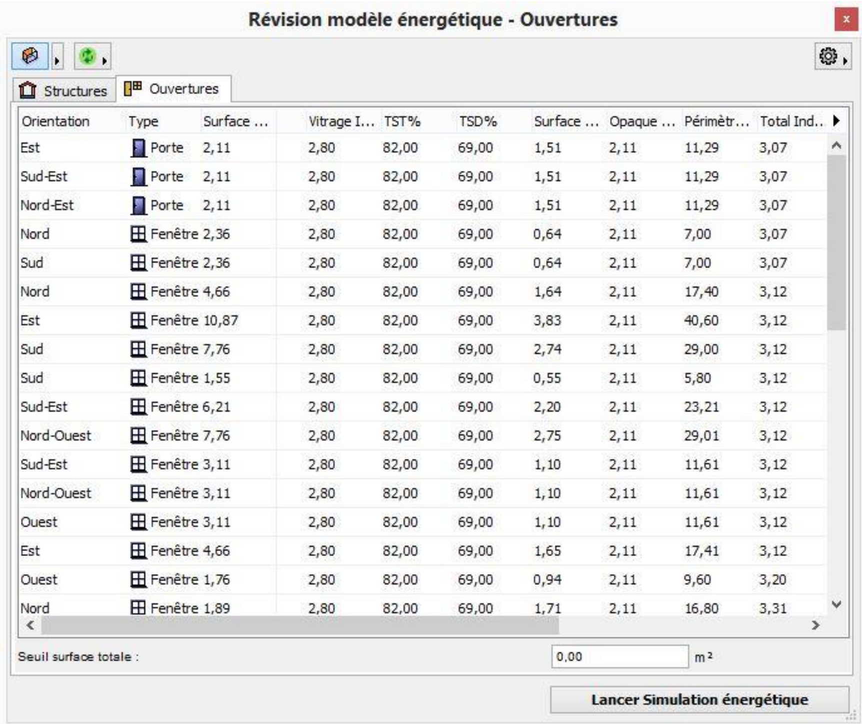
2.2. The creation of the energy model of the case study:

The parameters of an energy model for a building. Here is an overview of each section:

2.2.1. Energy model review - Openings:

List of openings (doors and windows) with their characteristics: orientation, type, surface, glazing, TST%, TSD%, opaque surface, perimeter, and indicative total.

TST% and TSD% refer to total solar transmission and solar scattering, respectively.



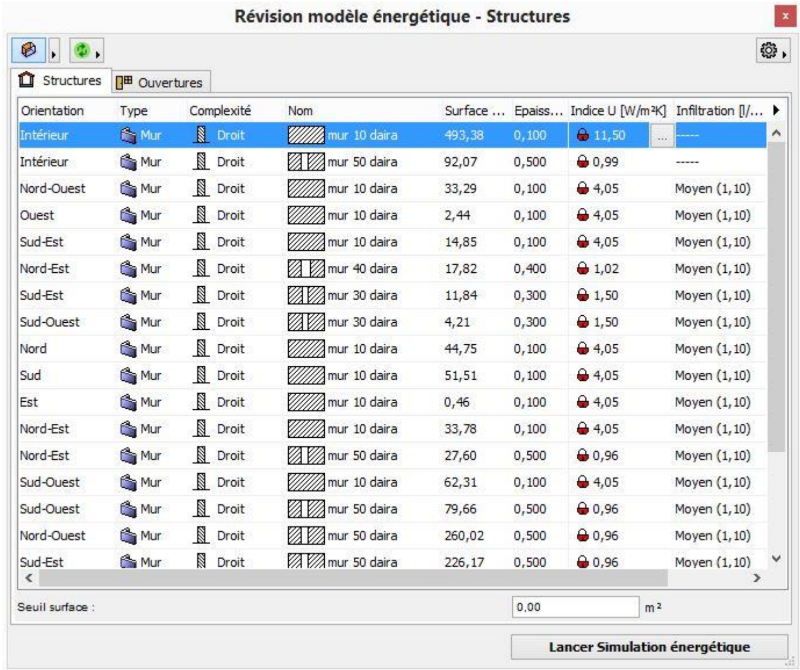
Orientation	Type	Surface ...	Vitrage I...	TST%	TSD%	Surface ...	Opaque ...	Périmètr...	Total Ind..
Est	Porte	2,11	2,80	82,00	69,00	1,51	2,11	11,29	3,07
Sud-Est	Porte	2,11	2,80	82,00	69,00	1,51	2,11	11,29	3,07
Nord-Est	Porte	2,11	2,80	82,00	69,00	1,51	2,11	11,29	3,07
Nord	Fenêtre	2,36	2,80	82,00	69,00	0,64	2,11	7,00	3,07
Sud	Fenêtre	2,36	2,80	82,00	69,00	0,64	2,11	7,00	3,07
Nord	Fenêtre	4,66	2,80	82,00	69,00	1,64	2,11	17,40	3,12
Est	Fenêtre	10,87	2,80	82,00	69,00	3,83	2,11	40,60	3,12
Sud	Fenêtre	7,76	2,80	82,00	69,00	2,74	2,11	29,00	3,12
Sud	Fenêtre	1,55	2,80	82,00	69,00	0,55	2,11	5,80	3,12
Sud-Est	Fenêtre	6,21	2,80	82,00	69,00	2,20	2,11	23,21	3,12
Nord-Ouest	Fenêtre	7,76	2,80	82,00	69,00	2,75	2,11	29,01	3,12
Sud-Est	Fenêtre	3,11	2,80	82,00	69,00	1,10	2,11	11,61	3,12
Nord-Ouest	Fenêtre	3,11	2,80	82,00	69,00	1,10	2,11	11,61	3,12
Ouest	Fenêtre	3,11	2,80	82,00	69,00	1,10	2,11	11,61	3,12
Est	Fenêtre	4,66	2,80	82,00	69,00	1,65	2,11	17,41	3,12
Ouest	Fenêtre	1,76	2,80	82,00	69,00	0,94	2,11	9,60	3,20
Nord	Fenêtre	1,89	2,80	82,00	69,00	1,71	2,11	16,80	3,31

Fig 74- List of openings (doors and windows) with their characteristics, (Author 2024).

2.2.2. <u>Energy model revision - Structures:</u>

List of structures (walls) with their characteristics: orientation, type, complexity, name, surface, thickness, U index (thermal transmission coefficient), and infiltration.

The U rating is crucial in determining heat loss through walls.



Révision modèle énergétique - Structures

Structures | Ouvertures

Orientation	Type	Complexité	Nom	Surface ...	Epaiss...	Indice U [W/m²K]	Infiltration [l/...
Intérieur	Mur	Droit	mur 10 daira	493,38	0,100	11,50	-----
Intérieur	Mur	Droit	mur 50 daira	92,07	0,500	0,99	-----
Nord-Ouest	Mur	Droit	mur 10 daira	33,29	0,100	4,05	Moyen (1,10)
Ouest	Mur	Droit	mur 10 daira	2,44	0,100	4,05	Moyen (1,10)
Sud-Est	Mur	Droit	mur 10 daira	14,85	0,100	4,05	Moyen (1,10)
Nord-Est	Mur	Droit	mur 40 daira	17,82	0,400	1,02	Moyen (1,10)
Sud-Est	Mur	Droit	mur 30 daira	11,84	0,300	1,50	Moyen (1,10)
Sud-Ouest	Mur	Droit	mur 30 daira	4,21	0,300	1,50	Moyen (1,10)
Nord	Mur	Droit	mur 10 daira	44,75	0,100	4,05	Moyen (1,10)
Sud	Mur	Droit	mur 10 daira	51,51	0,100	4,05	Moyen (1,10)
Est	Mur	Droit	mur 10 daira	0,46	0,100	4,05	Moyen (1,10)
Nord-Est	Mur	Droit	mur 10 daira	33,78	0,100	4,05	Moyen (1,10)
Nord-Est	Mur	Droit	mur 50 daira	27,60	0,500	0,96	Moyen (1,10)
Sud-Ouest	Mur	Droit	mur 10 daira	62,31	0,100	4,05	Moyen (1,10)
Sud-Ouest	Mur	Droit	mur 50 daira	79,66	0,500	0,96	Moyen (1,10)
Nord-Ouest	Mur	Droit	mur 50 daira	260,02	0,500	0,96	Moyen (1,10)
Sud-Est	Mur	Droit	mur 50 daira	226,17	0,500	0,96	Moyen (1,10)

Seuil surface : 0,00 m²

Lancer Simulation énergétique

Fig 75- List of structures (walls) with their characteristics, (Author 2024).

2.2.3. Usage profile (holiday hours:

Definition of the main use of the building (here, a personal office).

Information on occupancy type (non-residential), human heat gain, hot water service load, and humidity loads.

Daily schedules with recurrence, dates and usage in hours.

Graphs of internal temperature and internal heat gain, divided between people, lighting and equipment.

This information is used to perform an energy simulation to evaluate the thermal performance of the building and find ways to optimize its energy efficiency.

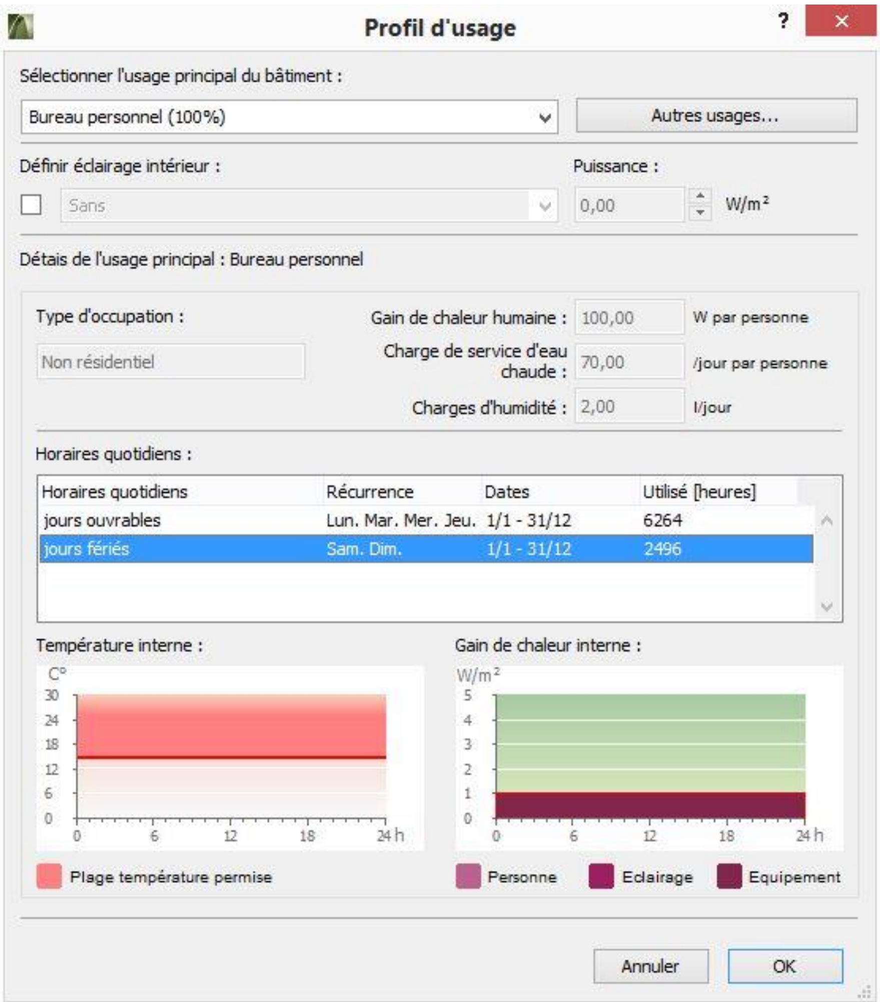


Fig 76- Usage profile, holiday hours, (Author 2024).

The figures provided are from the building energy simulation software, likely used for thermal and energy analysis of buildings (LCA software). Here's a breakdown of each screen and its significance:

2.2.4. Usage Profile (working hours):

- **Usage Type Selection:** The primary use of the building is selected as "Bureau personnel" (Personal Office).
- **Interior Lighting:** This section is set to "Sans" (None), indicating no additional internal lighting load is considered.
- **Occupancy Details:** Specifies heat gain per person, service hot water load, and humidity loads. Here, it's set for a non-residential building with values for human heat gain, hot water load, and humidity charges.

- **Temperature and Internal Heat Gain Charts:** Visual representation of acceptable temperature ranges and heat gains from people, lighting, and equipment.
- **Daily Schedules:** Shows two schedules:

- Working Days: Monday to Friday with a total usage of 6264 hours annually.
- Holidays: Saturday and Sunday with a total usage of 2496 hours annually.
-

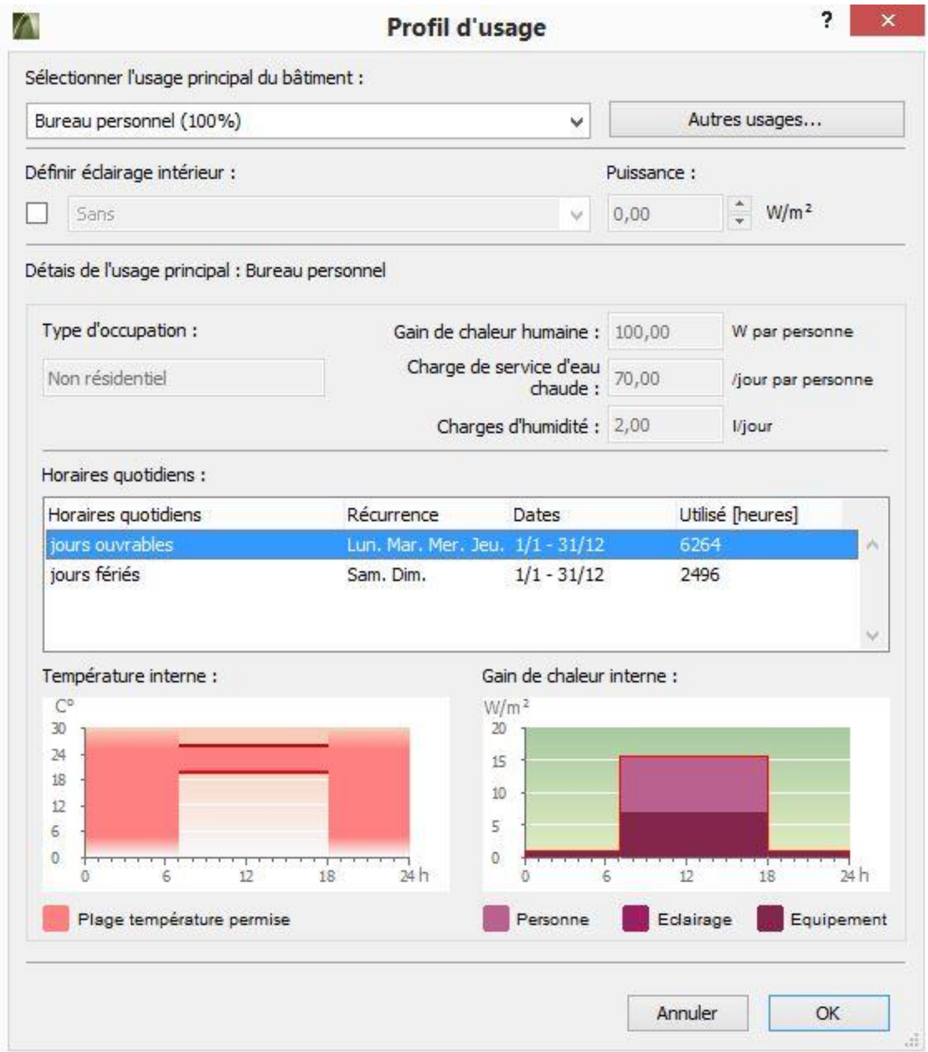


Fig 77- Usage profile, working hours, (Author 2024).

2.2.5. <u>Environment Options:</u>

- **Location and Climate:** Geographical coordinates are set with climate data sourced from an IWEC (International Weather for Energy Calculations) file.

- **Ground Connection Type:** Indicates the connection type to the terrain, set to "à Zéro Projet" (to Zero Project), which might refer to a baseline level for the project.
- **Soil Type:** Selected as "Gravier" (Gravel) with specific thermal conductivity, density, and heat capacity values.
- **Environment Settings:** The surrounding environment is set to "Pavage" (Pavement).
- **Wind Protection and External Shadows:** Options for wind protection and external shading are available but not specified here.

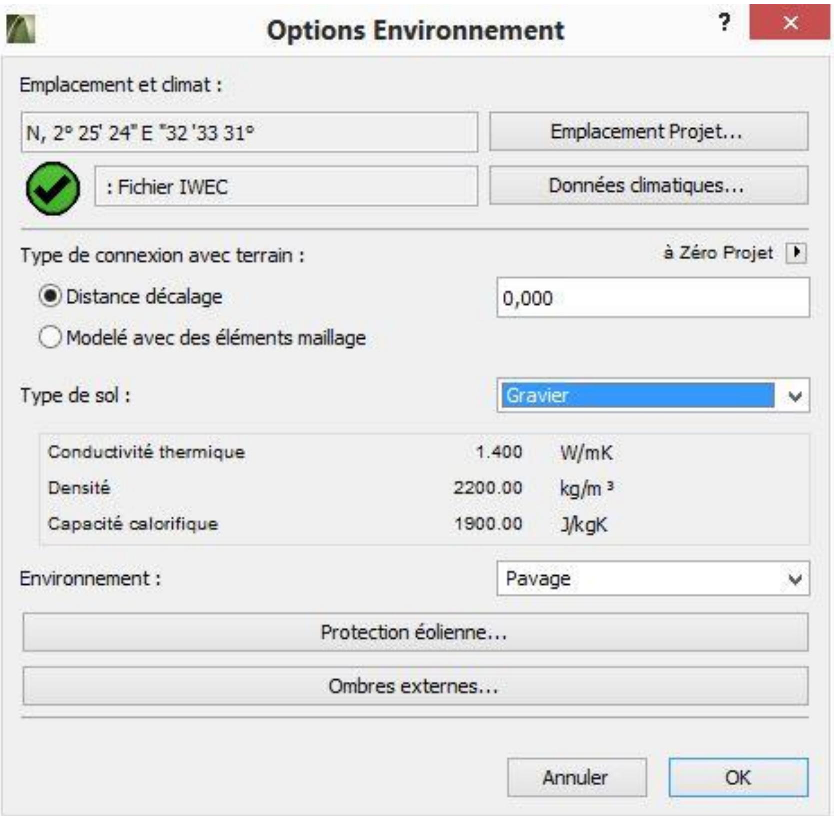


Fig 78- Environment Options, (Author 2024).

2.2.6. (External Shading):

- Orientation and Shading: Lists various orientations (East, South-East, South, South-West, West) with shading conditions:

✓ East: Non-shaded.

✓ South-East: Non-shaded.

✓ South: Non-shaded.

✓ South-West: Partially shaded.

✓ West: Shaded.

Fig 79- External Shading, (Author 2024).

2.2.7. <u>Purpose and Usage:</u>

- **Building Energy Simulations:** These settings are used to simulate the thermal and energy performance of a building. Adjusting these parameters helps in understanding the energy consumption, heating, cooling loads, and overall environmental comfort.
- **Design Optimization:** Helps architects, engineers, and designers optimize building design for energy efficiency, occupant comfort, and environmental impact.
- **Compliance and Certification:** Such simulations are often required for compliance with energy codes, standards, and certifications (e.g., LEED, BREEAM).

2.2.8. <u>Recommendations for Use:</u>

- **Accurate Input Data:** Ensure all input data (occupancy, schedules, location, and environmental settings) accurately reflect the real-world conditions of the building for precise simulation results.
- **Review Shading Settings:** External shading significantly impacts solar heat gain; review and adjust shading settings to align with the actual surroundings.
- **Thermal Properties:** Validate thermal properties of materials and ground type to ensure they are representative of the actual building components.

These configurations are critical for accurate simulation outcomes, which guide effective building design and energy management decisions.

2.2.9. Wind protection analysis:

The chart shows different levels of wind protection for various orientations (e.g., Nord, Nord-Est, Sud, etc.), indicating which parts of the building are protected from wind and which are not.

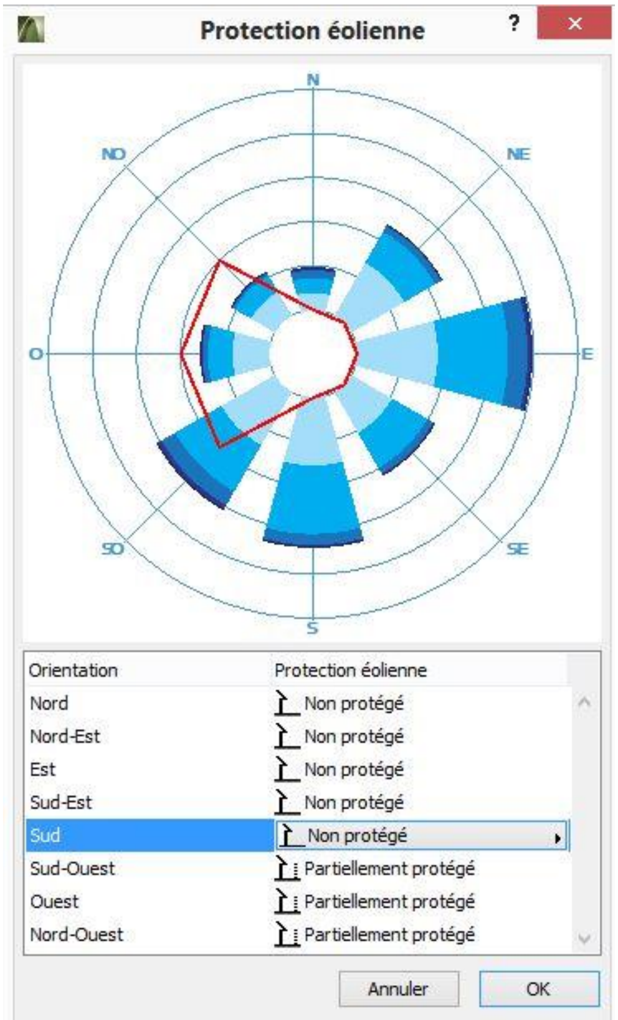


Fig 80- wind protection analysis of the case study, (Author 2024).

3. Overview of Thermal Zones:

Kenadsa’s heritage office building is divided into several thermal zones based on the function of the spaces, occupancy patterns, and environmental requirements. The primary thermal zones identified are:

- User's Office Spaces.
- Public Spaces.

- Administrative Areas.
- Support and Service Areas.
- Corridors and Transitional Spaces.

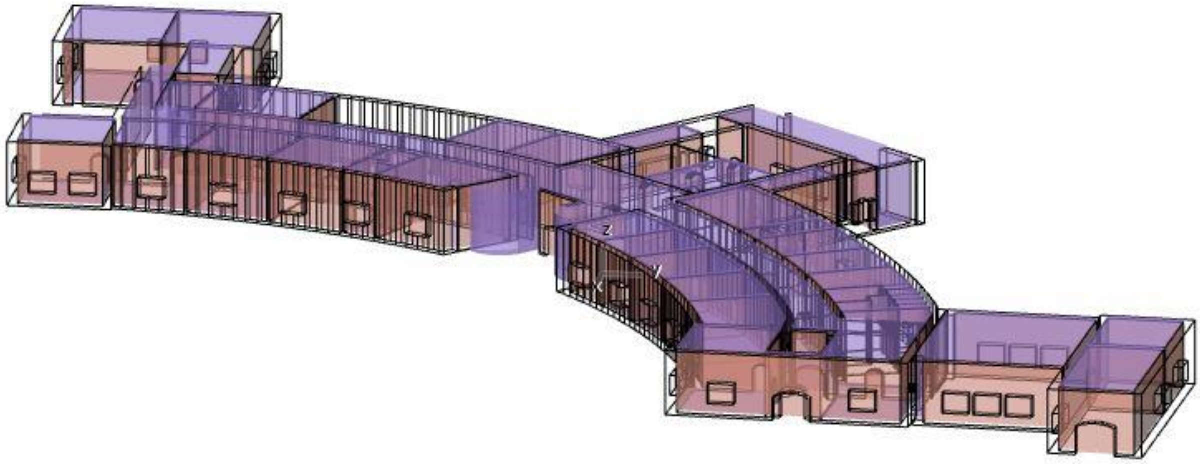


Fig 81- Thermal zones of the case study "3D view", (Author 2024).

Each thermal zone has distinct characteristics that influence its thermal performance and energy needs.

1. **User's Office Spaces:**

Description:

- **Function:** These spaces are designated for individual work and are typically used throughout the day.
- **Occupancy:** High during working hours, with limited use outside of office hours.

Thermal Characteristics:

- **Heating and Cooling Demand:** Moderate to high due to continuous occupancy and equipment use.
- **Thermal Comfort Requirements:** High priority to ensure a comfortable working environment.
- **Energy Efficiency Measures:** Insulation, energy-efficient windows, and individual climate control systems.

Performance:

- **Thermal Performance:** Effective in maintaining stable temperatures due to controlled occupancy and usage patterns.
- **Energy Consumption:** Significant due to prolonged use of heating, cooling, and office equipment.

2. **Public Spaces:**

Description:

- **Function:** Areas where the public interacts with office personnel, including reception areas and waiting rooms.
- **Occupancy:** Variable, with peaks during business hours.

Thermal Characteristics:

- **Heating and Cooling Demand:** High during peak times due to varying occupancy levels and open space design.
- **Thermal Comfort Requirements:** Essential for creating a welcoming environment for visitors.
- **Energy Efficiency Measures:** Zoned HVAC systems to cater to fluctuating occupancy, use of natural ventilation when possible.

Performance:

- **Thermal Performance:** Challenges in maintaining consistent temperatures due to variable occupancy.
- **Energy Consumption:** Fluctuates with occupancy, necessitating adaptive HVAC control systems.

4. Administrative Areas:

Description:

- **Function:** Shared workspaces and meeting rooms used by staff.
- **Occupancy:** Moderate, with specific peak times for meetings and collaborative work.

Thermal Characteristics:

- **Heating and Cooling Demand:** Moderate, with periods of higher demand during meetings.
- **Thermal Comfort Requirements:** Important for ensuring productive work environments during peak usage.
- **Energy Efficiency Measures:** Centralized climate control, use of energy-efficient lighting and equipment.

Performance:

- **Thermal Performance:** Generally stable due to consistent usage patterns.
- **Energy Consumption:** Managed through centralized control systems, optimized for periods of high and low use.

5. <u>Support and Service Areas:</u>

Description:

- **Function:** Includes storage rooms, maintenance areas, and other non-occupational spaces.
- **Occupancy:** Low, with sporadic use.

Thermal Characteristics:

- Heating and Cooling Demand: Low, primarily for maintaining basic environmental conditions.
- Thermal Comfort Requirements: Minimal, as these areas are not regularly occupied.
- Energy Efficiency Measures: Minimal heating and cooling, reliance on passive measures such as insulation.

Performance:

- Thermal Performance: Adequate for the intended use, with low energy demands.
- Energy Consumption: Minimal, focused on maintaining baseline conditions.

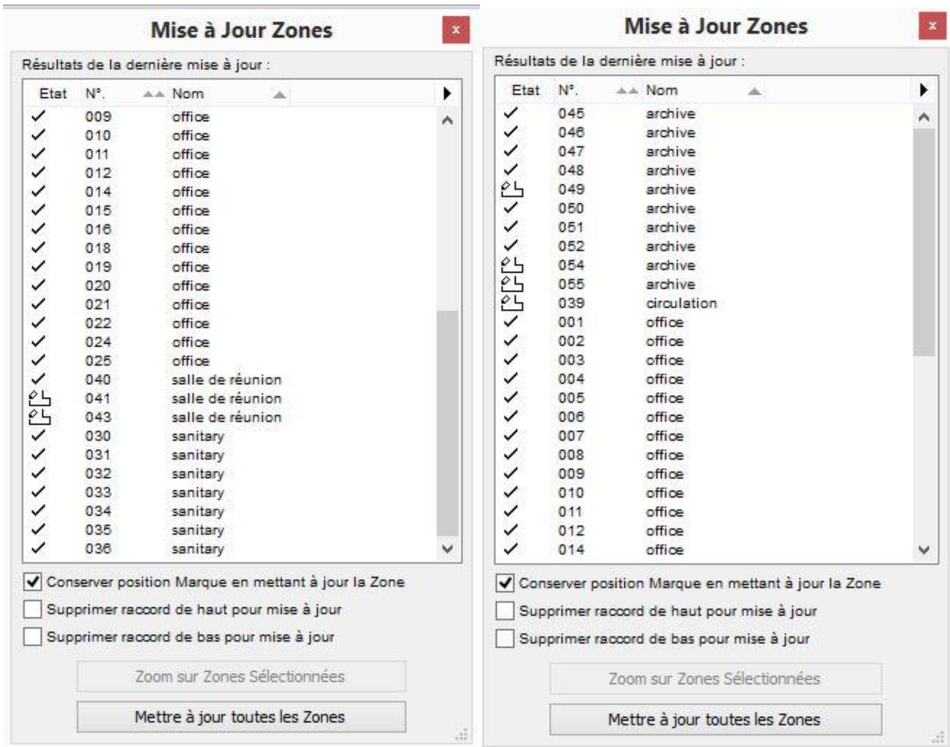


Fig 82- Thermal zones of the case study, (Author 2024).

6. Corridors and Transitional Spaces:

Description:

- **Function:** Passageways connecting different areas of the building.
- **Occupancy:** Continuous but low-density traffic.

Thermal Characteristics:

- **Heating and Cooling Demand:** Moderate, to ensure comfort while moving between zones.
- **Thermal Comfort Requirements:** Important for maintaining overall building comfort.
- **Energy Efficiency Measures:** Natural ventilation, use of thermal mass to stabilize temperatures.

Performance:

- **Thermal Performance:** Varies with external conditions, supplemented by passive measures.
- **Energy Consumption:** Moderate, balanced by passive heating and cooling strategies.

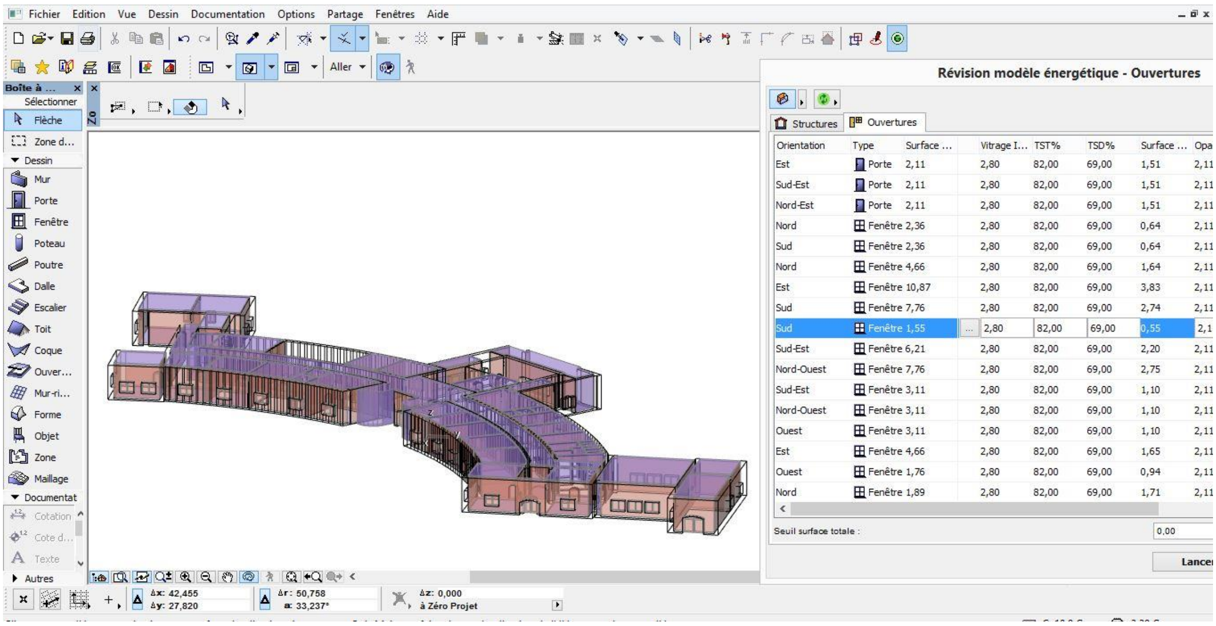


Fig 83- Thermal zones of the case study “3D view”, (Author 2024).

3. Life cycle assessment results:

4.1. Energy Performance:

The energy performance of the building was evaluated to understand its heating, cooling, and overall energy consumption. Key parameters include:

4.1.1. Annual Specific Energy Demands:

- **Heating Energy Demand:** 14.12 kWh/m²a.
- **Cooling Energy Demand:** 118.81 kWh/m²a.
- **Total Net Energy Demand:** 132.94 kWh/m²a.

Type source	Energie: Nom source	Energie: Quantité kWh/a	Energie: Coût EUR/a	Emission CO_2 kg/a
Fossile	Gaz naturel	42423	--	9163
Secondaire	Electricité	28503	--	6156
	Refroid. collectif	114959	--	74494
Total :		185886	Non applicable	89814*

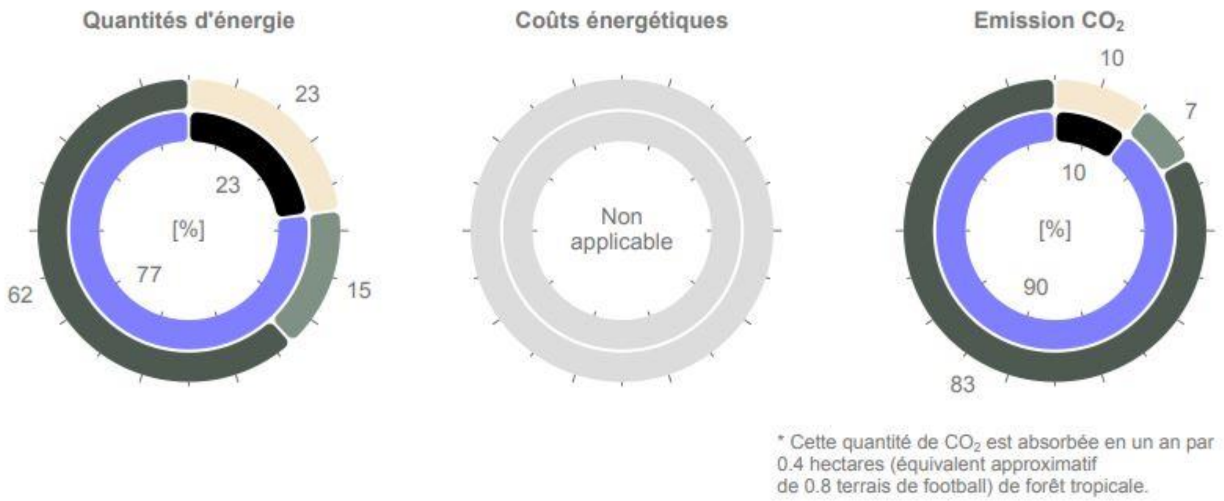


Fig 84- Energy performance of the case study, (Author 2024).

4.1.2. Annual Energy Consumption:

- **Total Energy Consumption:** 197.38 kWh/m²a.
- **Fuel Consumption:** 64.44 kWh/m²a.
- **Primary Energy Consumption:** 120.31 kWh/m²a.

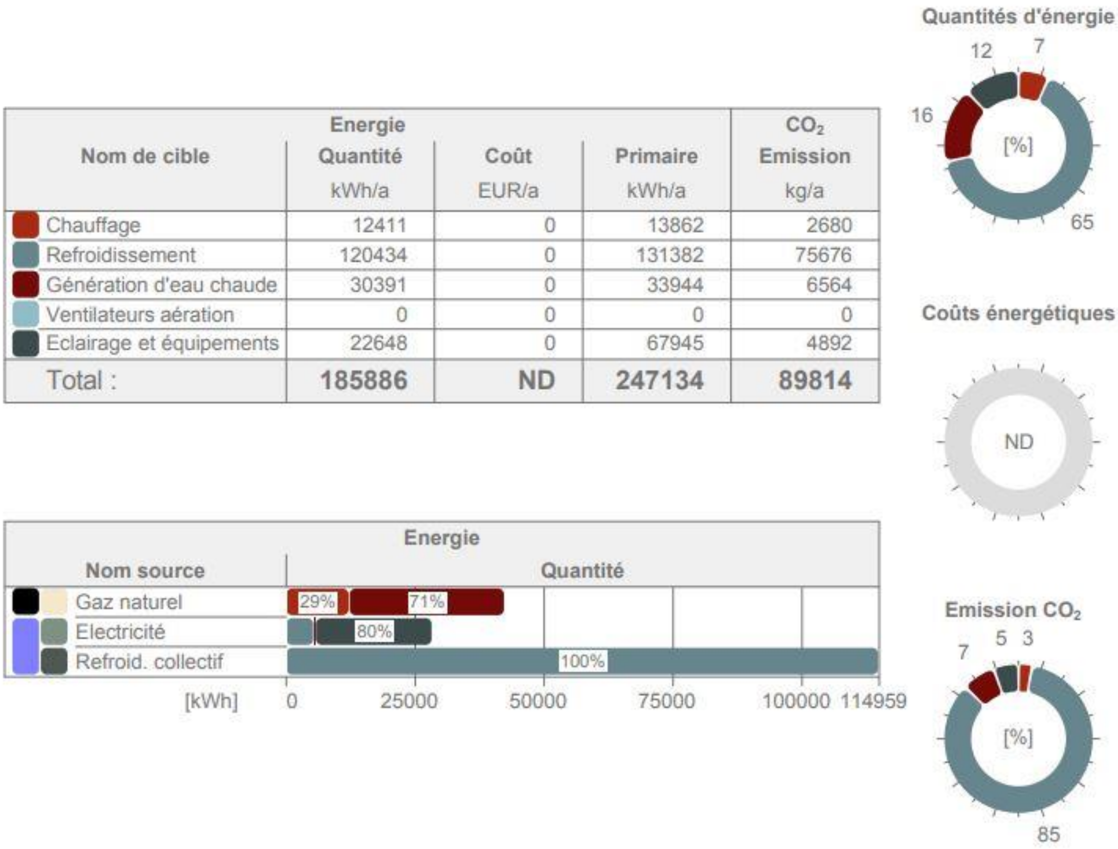
4. Carbon Emissions:

CO2 Emissions: 13.92 kg/m²a.

5. Energy Consumption by Source:

The energy sources contributing to the building's consumption were analyzed, highlighting the following:

- **Renewable Energy:** 11,575 kWh/a (68%).
- **Natural Gas:** 33,468 kWh/a (19%).
- **Electricity:** 22,648 kWh/a (13%).



Nom de cible	Energie Quantité kWh/a	Coût EUR/a	Primaire kWh/a	CO_2 Emission kg/a
Chauffage	12411	0	13862	2680
Refroidissement	120434	0	131382	75676
Génération d'eau chaude	30391	0	33944	6564
Ventilateurs aération	0	0	0	0
Eclairage et équipements	22648	0	67945	4892
Total :	185886	ND	247134	89814

Fig 85- Energy consumption by source 'case study', (Author 2024).

6. Monthly Energy Balance:

The monthly energy balance provides insights into energy inflow and outflow over the year. Key findings include:

8.1. Energy Input:

- Natural Heat Sources.
- Solar Gain.
- Internal Heat Gain.
- Lighting and Equipment.

8.2.Energy Output:

- Transmission Losses.
- Infiltration.
- Natural Ventilation.
- Water Heating.
- Natural Cooling.

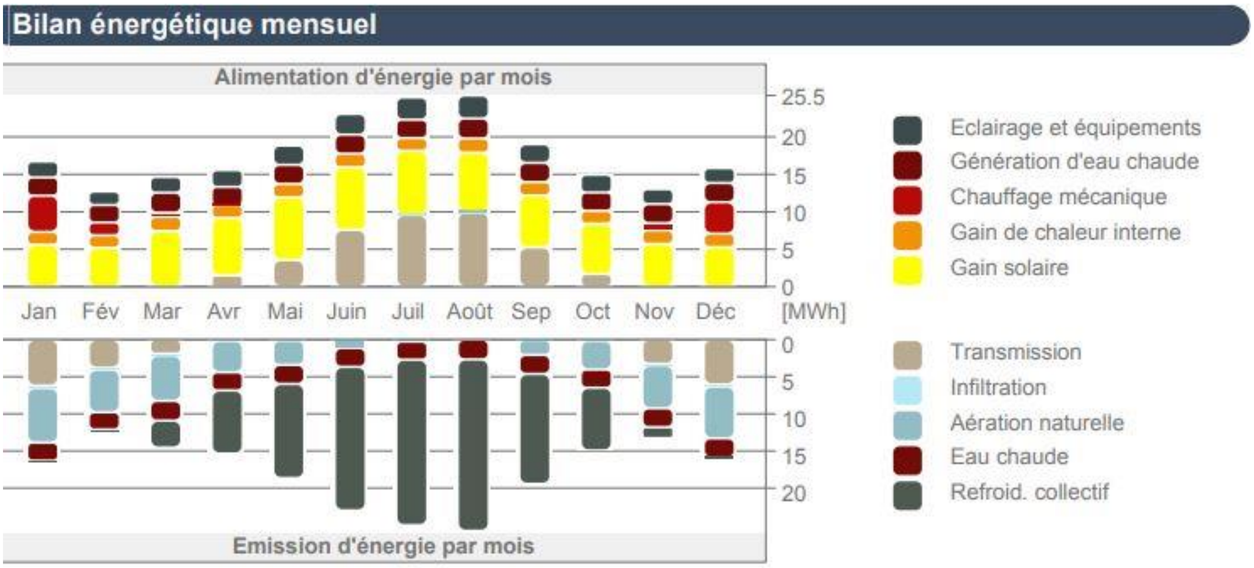


Fig 86- monthly energy balance 'case study', (Author 2024).

9. Environmental Impact:

The environmental impact assessment, measured in CO2 emissions, reflects the building's carbon footprint over a year:

- **Total Annual CO2 Emissions:** 13,922 kg.

- **CO_2 Absorption Equivalent:** The amount of CO_2 emitted can be absorbed by approximately 0.1 hectares (equivalent to two tennis courts) of tropical forest annually.

10. LCA Evaluation:

The LCA evaluation focused on various stages of the building's lifecycle, considering both direct and indirect environmental impacts:

- **Material Extraction and Processing:** Evaluation of the materials used in construction and their environmental burdens.
- **Construction Phase:** Analysis of energy consumption and emissions during the construction phase.
- **Operational Phase:** Detailed assessment of energy use for heating, cooling, lighting, and equipment.
- **End-of-Life:** Consideration of demolition and recycling processes, and their associated impacts.

11. Key Findings:

Energy Efficiency: The building demonstrates a moderate level of energy efficiency, with significant cooling demands due to the arid climate.

Carbon Footprint: The building's carbon footprint is relatively low, attributed to the integration of renewable energy sources.

Sustainable Design: The heritage office building's design reflects a balance between preserving cultural heritage and incorporating modern energy-efficient technologies.

Conclusion:

This detailed study on the energy performance of the Kenadsa heritage administrative building offers an exhaustive vision of the thermal and light conditions. The assessment of thermal conditions revealed significant variations in temperature between offices exposed to direct solar radiation and those located in the shade, thus highlighting the impact of orientation. South-facing offices experience discomfort due to direct solar radiation, while shaded areas offer more comfort with an average ambient temperature of 35.4°C, but with notable variations between different office areas. In addition, the thermal comfort of users is directly linked to their exposure to solar radiation, particularly in south-facing offices, where the temperature range varies from 32.2°C to 38.9°C with an average of 35.55°C, once again emphasizing the importance of orientation. The central corridor records an average temperature of 30.75°C with a relative humidity of 12.6%, which also influences user comfort.

The light evaluation results show a significant correlation between illuminance and thermal dimensions, such as wall temperature (correlation coefficients -0.290), floor temperature (-0.313) and air temperature (-0.313). -0.354). These correlations indicate that lighting plays a crucial role in users' thermal perception and therefore in their overall comfort. Using advanced simulation tools like ArchiCAD 22 and the One Click LCA plugin in Rhinoceros 7, the study provided a detailed analysis of the building's energy performance, revealing a specific annual energy consumption for heating and cooling of 14, 13 kWh/m²a and 125.73 kWh/m²a respectively, with a total net consumption of 139.86 kWh/m²a.

The results of this research are essential to optimize the design of heritage administrative buildings, highlighting the importance of environmental conditions for user comfort and productivity. In conclusion, the study demonstrates that optimal management of thermal and light environments can considerably improve user performance, thus reducing energy-intensive behavior and increasing the overall efficiency of workspaces. This provides a solid basis for more effective management strategies, implementing design and management measures that meet specific user needs while minimizing environmental impact.
The LCA of the Kenadsa heritage office building provides a comprehensive understanding of its energy performance and environmental impact. The integration of renewable energy sources and efficient design strategies has contributed to its overall sustainability. These findings offer valuable insights for future projects aiming to balance heritage preservation with environmental sustainability. Through continued evaluation and improvement, the Kenadsa heritage office building can serve as a model for sustainable heritage building practices in similar climatic and cultural contexts.

General Conclusion

General Conclusion:

The Kenadsa heritage office building, located in the oasis settlement of Kenadsa in southwest Algeria, is a prime example of the challenges faced by heritage buildings in hot and arid climates. This research aimed to evaluate the building's performance from multiple perspectives, focusing on user perceptions, environmental performance, and the integration of sustainable practices without compromising the building's historical integrity. The study was motivated by the need to balance heritage preservation with modern requirements for energy efficiency and occupant well-being, a challenge underscored by previous work from notable authors such as Jean Carroon, S. McLennan, John Straube, and Lisa Heschong. These scholars have laid the groundwork in understanding the importance of integrating sustainability in heritage conservation, the impact of environmental conditions on building performance, and the critical role of user-centered design.

The primary objective of this research was twofold: to evaluate the energy performance of the Kenadsa heritage office building based on user perceptions and behaviors, and to assess its environmental performance through a comprehensive Life Cycle Assessment (LCA). Addressing these objectives required a multidimensional methodological approach that combined qualitative and quantitative methods, as well as advanced modeling techniques. The path taken through the research was methodical, starting with a detailed literature review to contextualize the study within existing scholarship, followed by a thorough presentation of the case study building, its historical context, and architectural features. The methodology chapter outlined the mixed-methods approach, which included qualitative surveys to gather user perceptions on comfort and satisfaction, quantitative measurements of thermal and luminous environments using field instruments, agent-based modeling to simulate user interactions under varying conditions, and LCA to evaluate the building's overall environmental impact.

The results chapter presented a wealth of data collected from user surveys and in situ measurements, providing a nuanced understanding of how different environmental conditions affect user comfort and behavior. For instance, the findings revealed significant variations in temperature and lighting conditions within the building, with offices exposed to direct solar radiation experiencing higher temperatures and lower comfort levels compared to shaded areas. This highlighted the impact of building orientation on thermal comfort, with South-facing offices reporting higher discomfort due to direct solar exposure, while North-oriented offices showed a more moderate temperature range. The average ambient air temperature recorded was 35.4°C, with notable variations across different office zones, indicating the need for targeted interventions to improve thermal comfort. The corridor, located centrally within the building, was found to have an average ambient air temperature of 30.75°C and relative humidity of 12.6%, which was perceived as a relatively dark and less comfortable area by users.

The LCA, conducted using ArchiCAD 22 and the One Click LCA plugin in Rhinoceros software 7, provided a comprehensive evaluation of the building's energy performance and environmental impact. The analysis revealed that offices with optimal luminous and thermal environments exhibited higher user comfort and productivity, with minimal energy-wasting behaviors. Conversely, offices with poor environmental conditions demonstrated lower user performance and higher energy consumption, underscoring the critical need for optimizing environmental conditions to enhance both comfort and energy efficiency. The agent-based modeling further confirmed these findings by simulating user behaviors and interactions under different scenarios, providing a dynamic representation of how environmental factors influence user performance and satisfaction.

The study's conclusions were multifaceted, offering valuable insights for the design and management of heritage office buildings. It confirmed the initial hypotheses that evaluating energy performance based on user perception could highlight opportunities for improving energy efficiency and occupant comfort, and that LCA could significantly reduce the building's overall environmental impact. The findings underscored the importance of maintaining optimal thermal and luminous environments to enhance user comfort and productivity, recognizing the influence of specific behaviors and environmental conditions on energy consumption and performance. The agent-based modeling approach proved to be an effective tool for understanding user behaviors and their impact on building functionality, providing a deeper understanding of how to manage and optimize heritage buildings sustainably.

However, the research also acknowledged several limitations. The scope was restricted to a single building, which may limit the generalizability of the findings to other heritage buildings in different climates. Potential biases in user surveys and the constraints of the agent-based modeling in capturing the full complexity of real-world behaviors were also noted. Despite these limitations, the study provides a robust framework for future research and practical applications. Future studies could extend this research to other heritage buildings in similar climates, enhance simulation models with more diverse environmental scenarios, and investigate the long-term impacts of the recommended interventions on energy performance and user comfort. Additionally, developing more sophisticated tools for integrating user feedback into building management systems could further improve the sustainability and functionality of heritage buildings.

In conclusion, this research offers a comprehensive evaluation of the Kenadsa heritage office building, demonstrating how sustainable practices can significantly enhance both energy performance and user comfort. The findings advocate for a balanced approach that respects historical integrity while embracing modern efficiency strategies. The methodologies and insights presented contribute significantly to the discourse on heritage building management, providing a valuable blueprint for similar studies and practical implementations in comparable contexts. This holistic understanding of building performance in its specific climate context is crucial for guiding future strategies for sustainable building management, ensuring that heritage buildings can meet contemporary needs while preserving their historical value.

Research Limitations:

- Specific Climatic Context: The research focuses exclusively on a heritage building located in an arid and hot climate, thus limiting the generalization of the results to other climatic contexts. Conclusions drawn from this study may not be directly applicable to buildings located in temperate, cold, or humid climates.
- Subjective Data: Rating based on user perception relies on subjective data, which may vary based on individual experiences and personal biases. Although quantitative methods have been used to supplement these perceptions, interpretation of results may still be influenced by subjective variability.
- Technology and Modeling: The use of specific software such as ArchiCAD 22 and the One Click LCA plugin in Rhinoceros Software 7 imposes technical constraints and limitations inherent to these tools. Energy and environmental assessment results may vary with the use of different software or simulation methods.
- Sampling: Sampling users for surveys and in situ measurements may not be representative of all occupants or varying usage conditions over time. User behaviors and perceptions can change depending on the seasons, times of day, or years.
- Temporality of Measurements: Measurements carried out during surveys and in situ observations are limited to specific periods. Seasonal variations and long-term climate changes have not been fully considered, which may affect the robustness of the conclusions.

Research Perspectives:

- Generalization to Various Climatic Contexts: To broaden the applicability of the results, similar studies could be carried out in heritage buildings located in different climatic contexts. This would make it possible to compare energy performance and occupant comfort across various environmental conditions.
- Integration of Advanced Technologies: Integrating more advanced and diverse technologies into assessments, such as smart sensors, automated energy management systems, and artificial intelligence-based simulations, could provide more accurate data and insights more in-depth.
- Longitudinal Studies: Implementing longitudinal studies would help track variations in user perceptions and behaviors over longer periods of time, including seasonal changes and long-term climate trends.
- Deepening Qualitative Methods: Deepening qualitative methods, such as in-depth interviews or focus groups, could enrich the understanding of user perceptions and behaviors beyond traditional surveys.
- Exploration of Innovative Architectural Solutions: Future research could explore and test innovative architectural and technological solutions to improve energy efficiency and occupant comfort, while respecting the heritage character of buildings.
- Interdisciplinary Approaches: The integration of interdisciplinary approaches, involving experts in architecture, engineering, social sciences and the environment, could provide a more holistic and multidimensional view of challenges and solutions.
- Impact of Policies and Regulations: Studying the impact of local policies and regulations on the management and renovation of heritage buildings could provide practical recommendations for policy makers and building managers.

In short, this research opens the way to more in-depth and diversified studies, aimed at optimizing the energy performance and comfort of heritage buildings, while respecting their historical and cultural characteristics.

Appendix A

Quastionnaire Survey :

22/05/2024 16:40 Questionnaire sur la perception des usagers et le comportement humaine

Questionnaire sur la perception des usagers et le comportement humaine

Madame, Monsieur,

Tout d'abord, je vous remercie pour votre participation à ce questionnaire qui rentre dans le cadre de la réalisation d'une thèse de doctorat en architecture que je prépare sous l'encadrement de Dr .Dakhia azzeddine au sein du laboratoire LACOMOFA à l'université Mohammed Khider de Biskra.

Dans cette optique, je me permets de vous solliciter de bien vouloir remplir ce questionnaire et je vous serais reconnaissant si vous cochez par (X) sur la réponse que vous choisissez afin de vous décrire votre propre point de vue, sachant que le questionnaire est anonyme et est élaboré à des fins strictement académiques, ne comportant pas de réponses fausses et d'autres correctes.

D'autre part, je vous informe que votre participation à ce questionnaire est fortement essentielle à la réussite de notre travail de recherche.

Enfin je vous remercie infiniment pour votre coopération et pour votre compréhension. Veuillez agréer l'expression des mes salutations les plus distinguées.

https://docs.google.com/forms/d/1zsxhnYfTmbfJwcfw6qNqbAgQlO1396qqLAkEJCugAck/edit 1/15

1. Age :

Mark only one oval.

- ≤25
- 26-35
- 36-45
- 46-55
- 56≤

2. Sex :

Mark only one oval.

- Masculin
- Féminin

3. Combien de personnes occupent ce meme espace ? (Bureau)

Mark only one oval.

- 2
- 3
- 4
- 5
- Plus de 5

4. Avez vous une idée sur la consommation énergétique de votre bâtiment ?

Mark only one oval.

- Oui
- Non

5. Si oui, merci de préciser le montant de votre facture énergétique par an

____

6. Pendant la période hivernale, comment vous sentez par rapport à la température intérieurs de votre espace ?

Mark only one oval.

- Très chaud
- Chaud
- Légèrement chaud
- Neutre
- Légèrement froid
- Froid
- Très froid

7. Généralement, cette sensation implique un état de satisfaction:

Mark only one oval.

- Très satisfait
- Satisfait
- Peu satisfait
- Peu insatisfait
- Insatisfait
- Très insatisfait

8. En hiver, comment jugez vous le niveau de l'humidité de votre espace ?

Mark only one oval.

- Très humide
- Humide
- Acceptable
- Sec
- Très sec

9. Que pensez vous de la stabilité du température pendant la journée ?

Mark only one oval.

- Pas de différence
- Petite différence
- Moyenne différence
- Très haute différence

10. Quelle sont les moments ou vous utilisez le plus de chauffage?

Check all that apply.

- [ ] Début de la mâtinée
- [ ] Tous les matinées
- [ ] Pause-midi
- [ ] Aprés-midi
- [ ] Toute la journée (horaire de Bureau)

11. Ressentez vous un mouvement d'air d'interieur des espaces ?

Mark only one oval.

- Oui, très fort
- Moyen
- Non, aucun

12. Quelle est la période de la journée ou vous procéder à l'ouverture des fenêtres pour la ventilation ?

Check all that apply.

- [ ] Début de la matinée
- [ ] Tous les matinées
- [ ] Pause-midi
- [ ] Aprés-midi
- [ ] Toutes la journée (horaire de bureau)

13. Ressentez-vous des parois froides?

Mark only one oval.

- ( ) Pas du tout
- ( ) Légèrement froid
- ( ) Froid
- ( ) Très froid

14. Utilisez-vous les volets/Stores en hiver pour se protéger du soleil (comme protecteur solaire) ?

Check all that apply.

- [ ] Pas du tout
- [ ] Début de matinée
- [ ] Toutes la matinée
- [ ] Pause-midi
- [ ] Aprés-midi
- [ ] Toutes la journée

15. Pendant la période estivale, comment vous sentez par rapport à la température intérieurs de votre espace ?

Mark only one oval.

- Très chaud
- Chaud
- Légèrement chaud
- Neutre
- Légèrement froid
- Froid
- Très froid

16. Généralement, cette sensation implique un état de satisfaction :

Mark only one oval.

- Très satisfait
- Satisfait
- Peu satisfait
- Peu insatisfait
- Insatisfait
- Très insatisfait

17. D'après vous, l'environnement thermique de votre espace pendant la période estivale est:

Mark only one oval.

- Acceptable
- Peu acceptable
- moins acceptable
- inacceptable

18. En été, comment jugez vous le niveau de l'humidité de votre espace ?

Mark only one oval.

- Très humide
- Humide
- Acceptable
- Sec
- Très sec

19. Que pensez vous de la stabilité de la température pendant la journée d'été ?

Mark only one oval.

- Aucun différence
- Peu de différence
- Moyenne différence
- Très remarquable

20. Quelle est la période de la journée ou vous utilisez de la climatisation ?

Check all that apply.

- [ ] Début de la matinée
- [ ] Toute la matinées
- [ ] Pause-midi
- [ ] Apres-midi
- [ ] Toutes la journée

21. A quelles période de la journée vous procédez à l'ouverture des fenêtres pour ventilation ?

Check all that apply.

- [ ] Début de la matinée
- [ ] Toute la matinées
- [ ] Pause-midi
- [ ] Aprés-midi
- [ ] Toutes la journée

22. Utilisez-vous les volets/Stores en été ?

Check all that apply.

- [ ] Début de la matinée
- [ ] Toute la matinée
- [ ] Pause-midi
- [ ] Aprés-midi
- [ ] Toute la journée

23. Utilisez-vous des lampes de bureaux (si elle existe) ?

Check all that apply.

- [ ] Matin en hiver
- [ ] Après midi en hiver
- [ ] Matin en été
- [ ] Après midi en été

24. Utilisez-vous les plafonniers ?

Check all that apply.

- [ ] Matin en hiver
- [ ] Après midi en hiver
- [ ] Matin en été
- [ ] Après midi en été

25. Est ce que vous éteignez les lumières, microns durant votre pause déjeuner ?

Mark only one oval.

- Oui
- Non

26. Sentez vous éblouis par la lumière naturelle ?

Mark only one oval.

- Option 1
- Faible d'éblouissement
- Peu d'éblouissement
- Fort d'éblouissement

27. Etes-vous éblouis par les éclairages artificiels ?

Mark only one oval.

- Option 1
- Faible éblouissement
- Eblouissement pour temps
- Fort éblouissement

28. Trouvez-vous les parties communes trop sombres ?

Mark only one oval.

- Option 1
- Moyen sombre
- Sombre
- Très sombre

29. Trouvez-vous les parties communes trop sombres ?

Mark only one oval.

- Oui
- Non

30. En été, estimez vous que l'environnement lumineux de votre espace est satisfaisant ?

Mark only one oval.

- Fortement satisfait
- Satisfait
- Neutre
- Insatisfait
- Fortement insatisfait

31. Pendant la période estivale, êtes vous généralement dans un état:

Mark only one oval.

- Très confortable
- Confortable
- Peu confortable
- Peu inconfortable
- Inconfortable
- Très inconfortable

32. Pour vous l'environnement lumineux de votre espace pendant la période estivale est :

Mark only one oval.

- Très acceptable
- Acceptable
- Moins acceptable
- Inacceptable

33. En hiver, estimez vous que l'environnement lumineux de votre espace est satisfaisant ?

Mark only one oval.

- Fortement satisfait
- Satisfait
- Neutre
- Insatisfait
- Fortement insatisfait

34. Pendant la période hivernale, que sentez vous dans l'espace intérieurs ?

Mark only one oval.

- Très confortable
- Confortable
- Peu confortable
- Peu inconfortable
- Inconfortable
- Très inconfortable

35. Pour vous l'environnement lumineux de votre espace pendant la période hivernale est :

Mark only one oval.

- Très acceptable
- Acceptable
- Moins acceptable
- Inacceptable

36. Pour éviter les rayonnements solaires, utilisez vous généralement une protection du soleil par:

Mark only one oval.

- Rideau
- Store
- Persienne

37. Acceptez vous que l'utilisation d'un système de climatisation (rafraichissement) est indispensable pendant l'été pour avoir un environnement thermique optimal dans votre espace?

Mark only one oval.

- Fortement d'accord
- D'accord
- Neutre
- Désaccord
- Fortement désaccord

38. En été, combien d'heures de la journée utilisez vous votre système de climatisation ?

Mark only one oval.

- < 2h
- 2h-4h
- 4h-6h
- 6h-8h
- 8h <

39. Pendant l'hiver, avez vous besoin d'un système de chauffage pour avoir un environnement thermique acceptable dans votre espace ?

Mark only one oval.

- Fortement d'accord
- D'accord
- Neutre
- Désaccord
- Fortement désaccord

40. En hiver, combien d'heures de la journée avez vous utilisez votre système de chauffage?

Mark only one oval.

- < 2h
- 2h-4h
- 4h-6h
- 6h-8h
- 8h <

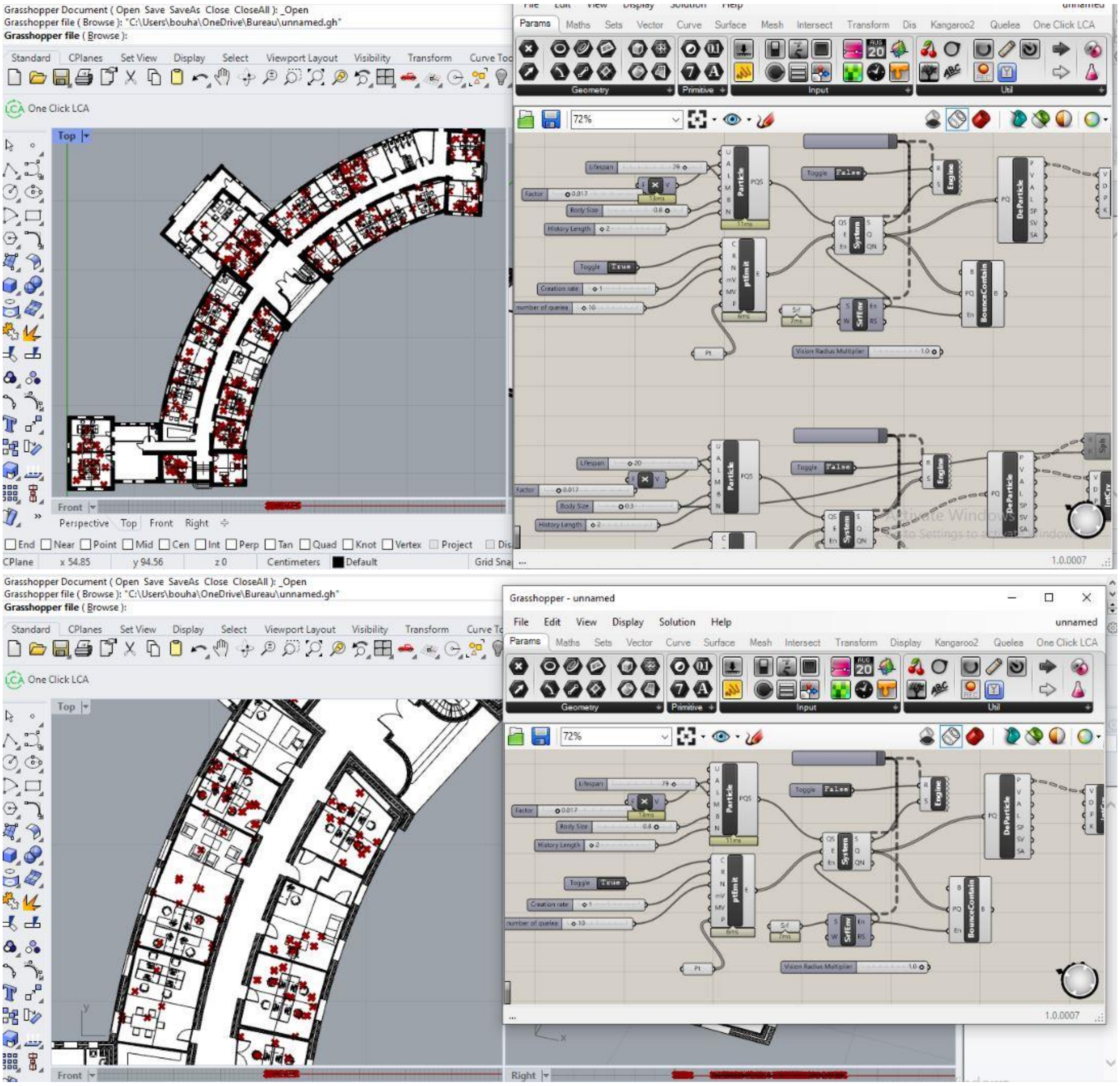
41. Généralement, combien d'heures de la journée avez vous allumez la lumière artificielle dans votre espace?

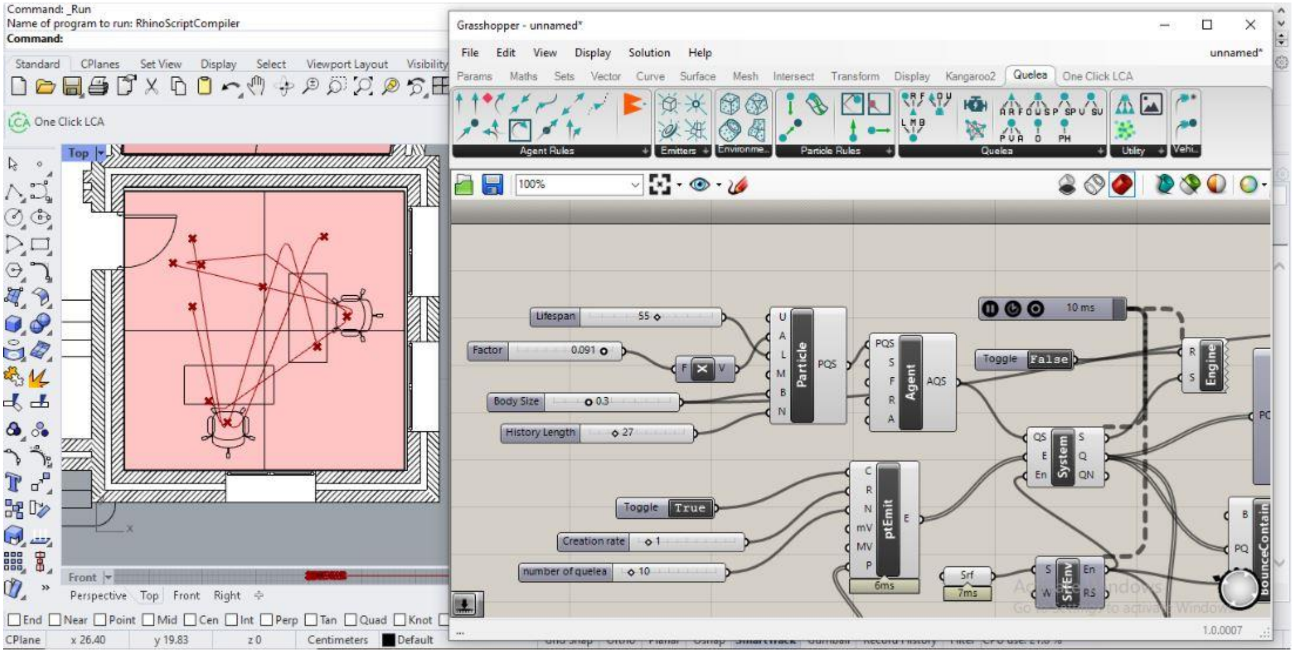
Mark only one oval.

- < 2h
- 2h-4h
- 4h-6h
- 6h-8h
- 8h <

Appendix B

Agent Based Modeling Simulation Rhinoceros 7 and Grasshopper




Command: _Run
Name of program to run: RhinoScriptCompiler
Command:
Grasshopper - unnamed*
File Edit View Display Solution Help
Lifespan 55
Factor 0.091
Body Size 0.3
History Length 27
Particle
Agent
Toggle False
Engine
System
Toggle True
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ptEmit
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BounceContain
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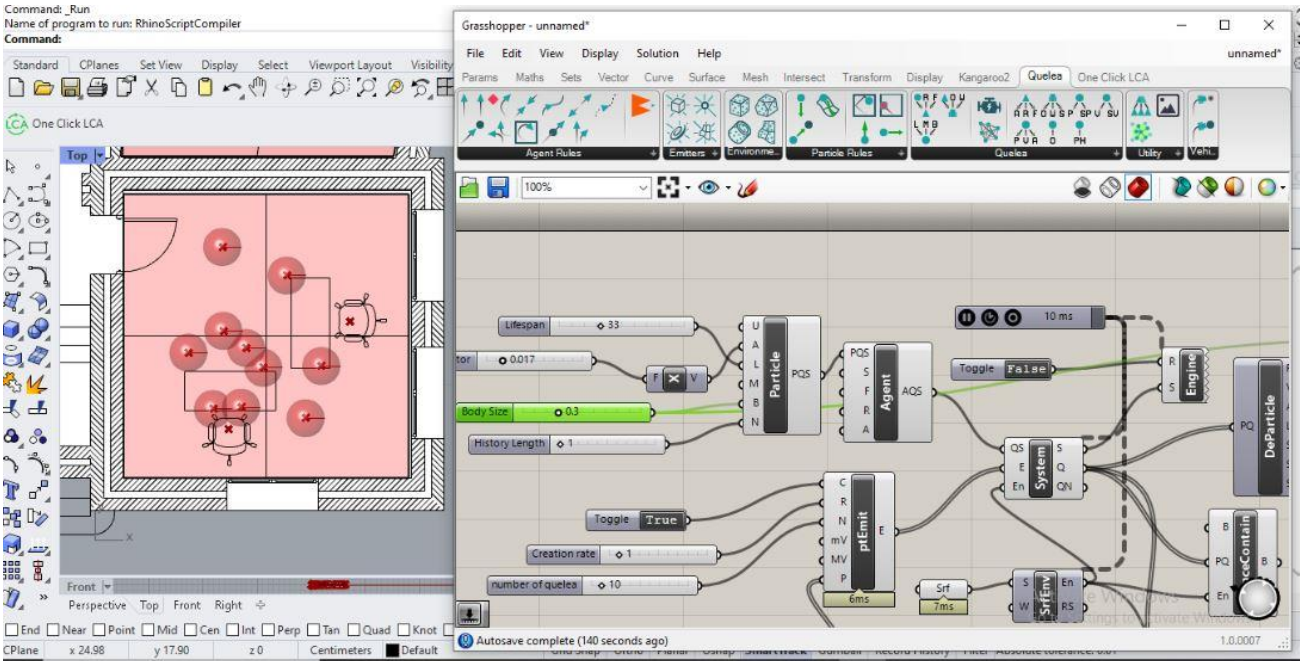
Command: _Run
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Command:
Grasshopper - unnamed*
File Edit View Display Solution Help
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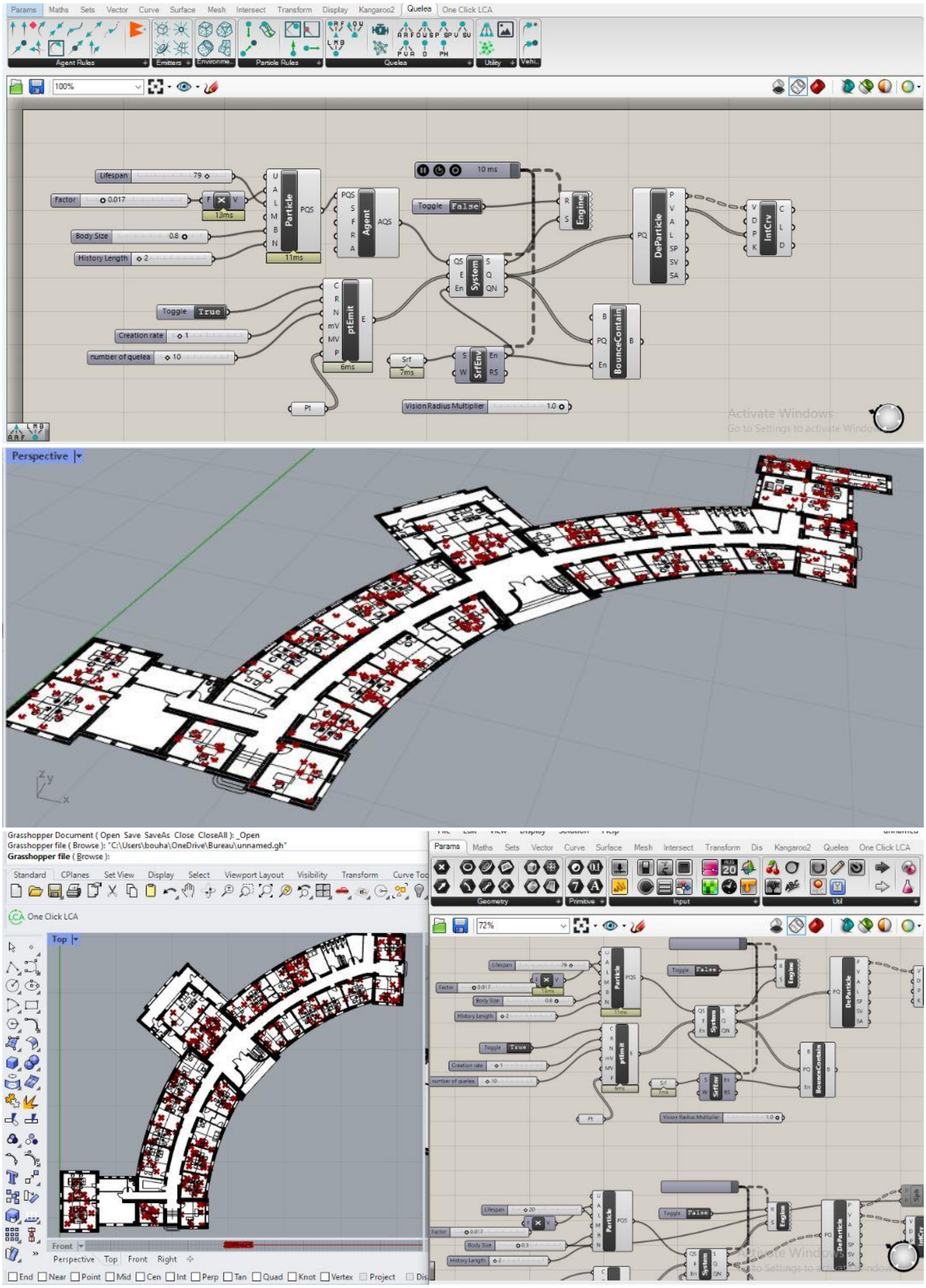

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Abstract

This research evaluates the performance of a heritage office building in Kenadsa, an oasis settlement in the southwest of Algeria, emphasizing user perception as a key metric. A multidimensional approach was employed, integrating both quantitative and qualitative methodologies, along with agent-based modeling. Field surveys and in situ measurements of the building's physical dimensions, thermal, and luminous environments provided a comprehensive understanding of user experiences and behaviors. The quantitative aspect involved agent-based modeling to simulate user interactions, incorporating physical dimensions, spatial layout, historical context, and user behavior. Findings revealed significant variations in user perceptions and behaviors under different environmental conditions, impacting satisfaction, spatial utilization, and productivity. A Life Cycle Assessment (LCA) conducted using ArchiCAD 22 and One Click LCA plugin in Rhinoceros software 7 evaluated the building's energy performance and environmental impact. Results indicated that offices with optimal luminous and thermal environments exhibited higher user comfort and productivity, with minimal energy-wasted behaviors. Conversely, offices with poor environmental conditions demonstrated lower user performance and higher energy consumption. The study underscores the importance of integrating sustainable practices and optimizing environmental conditions to enhance the performance and user satisfaction of heritage office buildings. This research contributes valuable insights for the design and management of heritage office buildings, emphasizing the critical role of environmental conditions in influencing user comfort and productivity. The agent-based modeling approach provides a dynamic representation of user behaviors, enhancing the understanding of the building's functionality and informing strategies for sustainable improvements. The findings advocate for a balanced approach that respects historical integrity while embracing modern efficiency strategies, offering a comprehensive blueprint for similar studies and practical implementations in comparable contexts.

Keywords: Heritage Office Building, User Perception, Building Performance Evaluation, Life Cycle Assessment (LCA), Agent-Based Modeling, quantitative and qualitative methods.

Résumé

Cette recherche évalue la performance d'un immeuble de bureaux patrimonial à Kenadsa, une oasis dans le sud-ouest de l'Algérie, en mettant l'accent sur la perception des utilisateurs comme mesure clé. Une approche multidimensionnelle a été utilisée, intégrant des méthodologies quantitatives et qualitatives, ainsi qu'une modélisation basée sur les agents. Des enquêtes sur le terrain et des mesures in situ des dimensions physiques, des environnements thermiques et lumineux du bâtiment ont permis une compréhension globale des expériences et des comportements des utilisateurs. L'aspect quantitatif impliquait une modélisation basée sur des agents pour simuler les interactions des utilisateurs, intégrant les dimensions physiques, la disposition spatiale, le contexte historique et le comportement des utilisateurs. Les résultats ont révélé des variations significatives dans les perceptions et les comportements des utilisateurs dans différentes conditions environnementales, ayant un impact sur la satisfaction, l'utilisation de l'espace et la productivité. Une analyse du cycle de vie (ACV) réalisée à l'aide d'ArchiCAD 22 et du plugin One Click LCA du logiciel Rhinoceros 7 a évalué la performance énergétique et l'impact environnemental du bâtiment. Les résultats ont indiqué que les bureaux dotés d'environnements lumineux et thermiques optimaux présentaient un confort d'utilisation et une productivité plus élevés, avec des comportements de gaspillage d'énergie minimes. À l’inverse, les bureaux présentant de mauvaises conditions environnementales affichent des performances utilisateur inférieures et une consommation d’énergie plus élevée. L'étude souligne l'importance d'intégrer des pratiques durables et d'optimiser les conditions environnementales pour améliorer la performance et la satisfaction des utilisateurs des immeubles de bureaux patrimoniaux. Cette recherche apporte des informations précieuses pour la conception et la gestion des immeubles de bureaux patrimoniaux, en soulignant le rôle essentiel des conditions environnementales dans l’influence du confort et de la productivité des utilisateurs. L'approche de modélisation basée sur les agents fournit une représentation dynamique des comportements des utilisateurs, améliorant la compréhension de la fonctionnalité du bâtiment et éclairant les stratégies d'améliorations durables. Les résultats plaident en faveur d'une approche équilibrée qui respecte l'intégrité historique tout en adoptant des stratégies d'efficacité modernes, offrant un modèle complet pour des études similaires et des mises en œuvre pratiques dans des contextes comparables.

Mots-clés : Bâtiment de bureaux patrimonial, perception des utilisateurs, évaluation des performances du bâtiment, analyse du cycle de vie (ACV), modélisation basée sur les agents, méthodes quantitatives et qualitatives.

الملخص

يقوم هذا البحث بتقييم أداء مبنى المكاتب التراثي في قنادسة، وهي واحة تقع في جنوب غرب الجزائر، مع التركيز على تصور المستخدم كمقياس رئيسي. وتم استخدام نهج متعدد الأبعاد، يدمج المنهجيات الكمية والنوعية، إلى جانب النمذجة القائمة على الوكيل. قدمت المسوحات الميدانية والقياسات الموقعية للأبعاد المادية للمبنى والبيئات الحرارية والمضيئة فهمًا شاملاً لتجارب المستخدم وسلوكياته. وتضمن الجانب الكمي النمذجة القائمة على الوكيل لمحاكاة تفاعلات المستخدم، ودمج الأبعاد المادية، والتخطيط المكاني، والسياق التاريخي، وسلوك المستخدم. كشفت النتائج عن اختلافات كبيرة في تصورات المستخدم وسلوكياته في ظل ظروف بيئية مختلفة، مما يؤثر على الرضا والاستخدام المكاني والإنتاجية. تم إجراء تقييم دورة الحياة (LCA) باستخدام البرنامج المساعد ArchiCAD 22 و One Click LCAفي برنامج Rhinoceros 7 لتقييم أداء الطاقة في المبنى وتأثيره البيئي. أشارت النتائج إلى أن المكاتب ذات البيئات المضيئة والحرارية المثالية أظهرت راحة أكبر للمستخدم وإنتاجية، مع الحد الأدنى من سلوكيات إهدار الطاقة. وعلى العكس من ذلك، أظهرت المكاتب ذات الظروف البيئية السيئة أداءً أقل للمستخدم وارتفاعًا في استهلاك الطاقة. وتؤكد الدراسة على أهمية دمج الممارسات المستدامة وتحسين الظروف البيئية لتعزيز الأداء ورضا المستخدمين للمباني المكتبية التراثية. يساهم هذا البحث برؤى قيمة لتصميم وإدارة مباني المكاتب التراثية، مع التركيز على الدور الحاسم للظروف البيئية في التأثير على راحة المستخدم وإنتاجيته. يوفر نهج النمذجة القائم على الوكيل تمثيلاً ديناميكيًا لسلوكيات المستخدم، مما يعزز فهم وظائف المبنى وإبلاغ الاستراتيجيات من أجل التحسينات المستدامة. وتدعو النتائج إلى اتباع نهج متوازن يحترم السلامة التاريخية مع تبني استراتيجيات الكفاءة الحديثة، ويقدم مخططًا شاملاً لدراسات مماثلة وتطبيقات عملية في سياقات قابلة للمقارنة.

الكلمات المفتاحية: مبنى المكاتب التراثية، تصور المستخدم، تقييم أداء المبنى، تحليل دورة الحياة (LCA)، النمذجة القائمة على المستخدم، الأساليب الكمية والنوعية.

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