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The use of double skin façade to optimize thermal comfort – Case of public buildings in Constantine –

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Abstract

The idea of sustainable development has been presented as the rescuer of a dying planet since the Rio Summit in 1992. It is an attempt to balance environmental concerns with development at the nexus of the social, ecological, and economic domains.

Energy use is also connected to the CO_2 emissions that hasten climate change. The largest emitter of greenhouse gases is the building industry, which also consumes the most energy.

Environmental problems have become economic problems as a result of political leaders' growing understanding of the effects of climate change.

One of the most important components of a building's energy efficiency is its facade. It improves passenger comfort and tempers the climate. Its functions include lowering energy expenses, fostering a safe and healthy atmosphere, and enhancing the building's aesthetic appeal.

The construction industry has the most potential in the current climate of lowering energy consumption and greenhouse gas emissions; one strategy under consideration is the creation of double facades, also known as double-skin facades.

A double-skin facade is a popular building method among architects, builders, and end users, owing to its excellent quality, aesthetic possibilities, and proven thermal and acoustic insulation benefits. It is possibly the most effective solution for building insulation since it avoids thermal bridging, condensation, and noise problems.

These facades provide control over light penetration, sound, and warmth in rooms induced by solar radiation. When properly constructed, "double-skin facades" can greatly improve occupant comfort.

Our study mostly concentrates on the effectiveness of double-skin facades and how well they optimize thermal comfort. The goal is to illustrate how they might increase the difference in temperature between the inside of the building and the outside. It also aims to show how double-skin facades may improve a building's thermal comfort.

In order to show how successful "double-skin facades" are in terms of thermal comfort; this study will look at the instance of public buildings in Constantine that have double-skin facades but were built with diverse methods and materials.

Keywords: Double skin façade**,** Thermal comfort, Optimization, Public buildings, Constantine, Semi-arid climate.

Résumé

Depuis le Sommet de Rio en 1992, le concept de développement durable est présenté comme le sauveur d'une planète mourante. Il s'agit d'une tentative visant à trouver un équilibre entre les préoccupations environnementales et le développement à la croisée des domaines social, écologique et économique.

La consommation d'énergie est également liée aux émissions de CO_2 qui accélèrent le changement climatique. Le secteur du bâtiment est le plus grand émetteur de gaz à effet de serre, mais aussi le plus gros consommateur d'énergie.

Les problèmes environnementaux sont devenus des problèmes économiques à mesure que les dirigeants politiques ont pris conscience des effets du changement climatique.

L'un des éléments les plus importants de l'efficacité énergétique d'un bâtiment est sa façade. Elle améliore le confort des occupants et tempère le climat. Elle a pour fonction de réduire les dépenses énergétiques, de favoriser une atmosphère sûre et saine et d'améliorer l'esthétique du bâtiment.

Le secteur de la construction est celui qui présente le plus grand potentiel dans le contexte actuel de réduction de la consommation d'énergie et des émissions de gaz à effet de serre ; l'une des stratégies envisagées est la création de doubles façades, également appelées façades à double peau.

La façade à double peau est une méthode de construction très appréciée des architectes, des constructeurs et des utilisateurs finaux en raison de son excellente qualité, de ses possibilités esthétiques et de ses avantages éprouvés en matière d'isolation thermique et acoustique. Elle constitue probablement la solution la plus efficace pour l'isolation des bâtiments, car elle évite les ponts thermiques, la condensation et les problèmes de bruit.

Ces façades permettent de contrôler la pénétration de la lumière, le bruit et la chaleur dans les pièces induits par le rayonnement solaire. Lorsqu'elles sont correctement construites, les « façades à double peau » peuvent considérablement améliorer le confort des occupants.

Notre étude se concentre principalement sur l'efficacité des façades à double peau et sur leur capacité à optimiser le confort thermique. L'objectif est d'illustrer comment elles peuvent augmenter la différence de température entre l'intérieur et l'extérieur du bâtiment. Elle vise également à montrer comment les façades à double peau peuvent améliorer le confort thermique d'un bâtiment.

Afin de démontrer l'efficacité des « façades à double peau » en termes de confort thermique, cette étude se penchera sur l'exemple des bâtiments publics de Constantine qui sont dotés de façades à double peau, mais qui ont été construits avec des méthodes et des matériaux divers.

Mots clés : Façade à double peau, Confort thermique, Optimisation, Bâtiments publics, Constantine, Climat semi-aride.

ملخص

تم تقديم فكرة التنمية المستدامة على أنها المنقذ لكوكب يحتضر منذ قمة ريو في عام 1992. وهي محاولة لتحقيق التوازن بين الشواغل البيئية والتنمية في الصلة بين المجالات الاجتماعية والبيئية والاقتصادية.

يرتبط استخدام الطاقة أيضًا بانبعاثات ثاني أكسيد الكربون التي تسرع من تغير المناخ. أكبر مصدر لانبعاثات غازات الاحتباس الحراري هو صناعة البناء، التي تستهلك أيضًا أكبر قدر من الطاقة.

أصبحت المشاكل البيئية مشاكل اقتصادية نتيجة لفهم القادة السياسيين المتزايد لتأثيرات تغير المناخ.

تعد الواجهة أحد أهم مكونات كفاءة الطاقة في المبنى. فهي تحسن راحة الركاب وتخفف من حدة المناخ. وتشمل وظائفها خفض نفقات الطاقة، وتعزيز جو آمن وصحي، وتحسين المظهر الجمالي للمبنى.

تتمتع صناعة البناء بأكبر إمكانات في ظل المناخ الحالي لخفض استهلاك الطاقة وانبعاثات غازات الدفيئة؛ وإحدى الاستراتيجيات قيد الدراسة هي إنشاء واجهات مزدوجة، تُعرف أيضًا باسم الواجهات ذات الطبقة المزدوجة.

الواجهة المزدوجة هي طريقة بناء شائعة بين المهندسين المعماريين والبنائين والمستخدمين النهائيين، وذلك بفضل جودتها الممتازة وإمكانياتها الجمالية ومزاياها المثبتة في العزل الحراري والصوتي. وهي ربما الحل الأكثر فعالية لعزل المباني لأنها تتجنب مشاكل الجسور الحرارية والتكثيف والضوضاء.

توفر هذه الواجهات التحكم في تغلغل الضوء والصوت والدفء في الغرف الناتج عن الإشعاع الشمسي. عندما يتم بناؤها بشكل صحيح، يمكن أن تحسن" الواجهات المزدوجة "بشكل كبير من راحة السكان.

تركز دراستنا بشكل أساسي على فعالية الواجهات المزدوجة ومدى قدرتها على تحسين الراحة الحرارية. الهدف هو توضيح كيف يمكن أن تزيد من الفرق في درجة الحرارة بين داخل المبنى وخارجه. كما تهدف إلى إظهار كيف يمكن للواجهات المزدوجة أن تحسن الراحة الحرارية للمبنى.

من أجل إظهار مدى نجاح" الواجهات المزدوجة "من حيث الراحة الحرارية، ستنظر هذه الدراسة في مثال المباني العامة في قسنطينة التي لها واجهات مزدوجة ولكنها شُيدت بطرق ومواد متنوعة.

الكلمات المفتاحية: واجهة مزدوجة، الراحة الحرارية، التحسين، المباني العامة، قسنطينة، مناخ شبه جاف.

Contents

Acronyms

DSF	Double Skin facade
T/in	Indoor temperature
T/ex	Exterior Temperature
Ta	Ambiant temperature
Tm	Mean temperature
Tn	Neutral temperature
S/air	Speed of the air
RH	Relative humidity
HVAC	Heating, Ventilation and Air Conditioning
PV	Photovoltaique panels
DTR	Regulatory technical document.
COVID-19	Corona virus disease 2019.
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
PMV	Predicted mean vote
PDD	Predicted Percentage of Dissatisfied
ISO	International Organization for Standardization
O.N.M	National Meteorological Office
CNERIB	National Centre for Integrated Building Studies and Research

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GENERAL INTRODUCTION

1. Introduction

In recent decades, the notion of sustainable development has emerged as a saviour for our planet in peril, aiming to harmonize developmental progress with environmental preservation. The growing consciousness surrounding the consequences of climate change has transformed ecological challenges into pressing economic concerns.

Greenhouse gas and CO_2 emissions, which are linked to energy consumption, are accelerating the phenomenon of global warming. Reducing CO_2 emissions necessitates a decrease in consumption and a transition from fossil fuels to renewable energy sources.

The building industry ranks among the three largest energy-consuming sectors globally, making it one of the most significant contributors to pollution and the leading emitter of greenhouse gases. Almost 40% of heat transfer and energy use in buildings are related to the envelopes; therefore, they have great potential to save energy and lower carbon emissions. (Bao et al., 2023)

The facade serves as a vital architectural instrument, playing a crucial role in enhancing the building's energy efficiency. It regulates the internal climate, ensuring optimal comfort for occupants. Beyond its contribution to the building's aesthetic allure, the facade is instrumental in providing a healthy and secure atmosphere indoors. It enhances acoustic performance in areas prone to noise, harnesses the benefits of natural light, and minimizes energy usage and expenses. In certain designs, it can even produce electricity, further elevating its significance in modern architecture. (Hazem, 2018)

In the context of mitigating greenhouse gas emissions and decreasing energy usage, a variety of passive and active building systems have gained popularity and undergone significant development.

One of the solutions that has gained significant popularity in recent years is the double-skin facade system, which is now regarded as the leading envelope concept.

The double-skin facade consists of a traditional single facade with an additional outer layer. As defined by Safer, this type of facade incorporates a second layer, typically transparent, positioned in front of the standard exterior facade. The two layers are separated by an intervening space known as a cavity. (SAFER, 2006)

The architect Le Corbusier introduced the concept of the “neutralizing wall” at the beginning of the 20th century, which is the basis for the double façade. This involved the installation of heating or air-conditioning systems between two glazed walls on the façade, which allowed light to enter while preventing condensation and chilly walls. Nevertheless, this system was challenging to implement and utilized significantly more energy than traditional heating (or cooling) systems. The emergence of the first ‘modern’ double façades in the early 1980s marked a significant development. Their purpose was to provide supplementary heating during the winter and ventilation during the summer. In the present day, these systems are being applied more frequently to decrease the energy consumption of buildings. Specifically, they are being used to enhance thermal insulation, generate natural convective ventilation, and preheat the air during the winter. (Daverat, 2012)

The role of the DSF is to control the building's temperature, shielding it from weather-related challenges; preventing excessive heat during the summer while reducing reliance on air conditioning; mitigating the impact of cold walls in the winter that cause discomfort by blocking direct wind exposure; and ensuring a comfortable ambient temperature and humidity level.

The double-skin facade can perform two essential functions: it facilitates pre-heating during colder seasons and climates while also providing ventilation in warmer seasons and climates.

2. Problematic

In Algeria, the building sector, including both residential and commercial spaces, accounts for 45.7% of energy usage in Algeria, with an anticipated annual growth rate of 7.1%. The challenge of minimizing energy use is currently a significant concern in our nation, as overlooking environmental factors in the design process has resulted in a notable rise in energy demand, especially during the summer months. As a result, design experts are required to continuously and thoughtfully investigate creative approaches and frameworks that minimize energy use in structures.

The absence of thermal comfort is the primary cause of the high consumption in the building sector, as it compels individuals to employ heating and air conditioning apparatus. Nevertheless, the Algerian market is inundated with inexpensive equipment that, as a result, incurs higher long-term costs due to its high energy consumption. This is the result of the absence of a system for classifying equipment based on its electricity consumption.

In Algeria, the principles of energy efficiency and thermal comfort are largely ignored, and the standards set by thermal regulations are unfortunately not enforced, contradicting the nation's commitment to sustainable development.

In recent years in Algeria, DSF has become very popular, especially in public and commercial buildings. Used especially for their aesthetic value, the thermal performance is not considered at the study’s project phase.

All this leads us to ask a main question:

- What are the main factors that affect the performance of the double skin façade?

And three secondary questions:

- How can double skin facades optimise thermal comfort?
- How double skin perform in a semi-arid climate?
- Which façade’s treatment will have better results?

3. Hypothesis

Different hypotheses are formulated to demonstrate the main statement of this study.

- The DSF acts as a filter between the internal and external environment and decreases the difference between indoor and outdoor temperature.
- The DSF in those buildings was principally used for the visual appeal.
- The combination between different DSF in terms of construction technics and materials is more effective.

4. Objectives

The building envelope; through its protective role in the interior environment and the control of interactions between interior and exterior spaces, is a major reason for the huge energy consumption of buildings, this research highlights the impact of DSF for optimizing indoor thermal comfort and its main aim is to show the performance of DSF in semi-arid climate. The main objectives of this research are:

- Show how DSFs contribute to minimizing heat transfer, leading to a decrease in energy usage.
- Demonstrate how DSFs contribute to enhancing thermal comfort within structures.
- Examine the influence of DSF on the indoor atmosphere regarding thermal comfort.
- Showcase the efficiency of DSF in minimizing temperature disparities between interior and exterior environments.

5. Methodology

To fulfil the primary goals of this research, which focuses on examining the connection between DSF and thermal comfort, the study has been structured in two distinct phases: a theoretical component and a practical component.

In the theoretical part, a detailed theoretical study of the DSF system and the thermal comfort consequence was drawn up in order to gain a better understanding of the problems posed, whether on a global or even national scale, based on the research and bibliographical analysis carried out on numerous previous studies.

In the practical section, in-situ measurements and a questionnaire survey were carried out in three public buildings with DFS in Constantine, city in the North East of Algeria characterized by a semi-arid climate.

Measurements of the climatic parameters (T/in, T/ex, RH, S/air) were taken simultaneously indoor and outdoor each building in two periods (period of under heating in winter and period of over-heating in summer). In order to better diagnose each building, different indoor spaces were studied.

The experimental part is based on a comparative study, because in each case a comparison is made between the outside and inside temperatures and the comfort zone.

Concerning the questionnaire survey, it was carried out in the field with the various users of the areas, both permanent users (employees) and temporary users (visitors).

6. Structure of the thesis

Our thesis begins with an introductory chapter that outlines the main features of the topic, such as a general introduction, research hypotheses and objectives, and research organization. It will then be divided into six chapters, with the first two chapters focusing on the theoretical part of the research, followed by the third and fourth chapters, which are devoted to presenting the study context and case studies, as well as the methodology used. The fifth and sixth chapters are devoted to presenting, analysing, and interpreting the results. Finally, it concludes with a general conclusion.

Chapter 1: Focuses to the presentation of the double-skin façade system, covering its definition, history, types, operation, and everything related to this concept. In addition to a state-of-the-art review of the use of DSFs in buildings and their effectiveness.

Chapter 2: Provides an overview of thermal comfort, followed by a presentation of the relationship between DSF and thermal comfort.

Chapter 3: Presents the study context, which is the city of Constantine, and the city's climate data. This is followed by a description of the three buildings selected as case studies.

Chapter 4: Outlines the research methods in detail and explains the process of conducting in-situ measurements and questionnaire surveys.

Chapter 5: This chapter is devoted to the presentation, analysis, and interpretation of the results obtained by the two approaches, through in-situ measurements and the questionnaire survey.

Chapter 6: Devoted to presentation and discussion of the results obtained by questionnaire survey.

CHAPTER I:

THE DOUBLE SKIN FACADE SYSTEM

I.1 Introduction

Growing awareness of the need for environmentally responsible and energy-efficient architecture is leading to the development of innovative façade technologies. Commonly, designers highlight double-skin facades, also known as DSFs, as efficient solutions to achieve current design objectives. This is because DSFs are able to meet the goals of energy efficiency, comfort, and aesthetic appeal in building exteriors. (Saelens and Hens, 2020)

Although the double-skin facade is not a novel concept, designers are gradually integrating it into their creations. A thorough design is required because of its intricacy and its capacity to respond to a variety of environmental situations. (Poirazis, 2004)

The purpose of this chapter is to provide a comprehensive understanding of the concept of a double skin facade, as well as additional general information regarding the structure, functionality, and applications of the system.

I.2 Definition of the double skin-façade concept

In order to gain a more comprehensive understanding of the double-skin facade, it is beneficial to first define the term "facade" and its function within a building. Subsequently, the double-skin facade concept will be elaborated upon.

According to the dictionary “Larousse”, the word "facade" comes from the Italian word "facciata," and it refers to all of a building's exterior elevations that are important for function or style (main, back, side, street, patio, and garden façades). (“Le petit larousse,” 2010)

Additionally, based on the definitions provided by the Cambridge Dictionary and Oxford Languages, the facade refers to the main front of a structure that faces a street or open area. (“façade,” 2024)

A façade is an important part of any building. It is not only physically separating the inside and outside spaces, but it also has a significant impact on the amount of energy required for heating and cooling.

Experts in the field use facades to improve the aesthetic appeal of a project, make its interior conditions better (especially the acoustic effect in buildings in noisy areas), let in additional sunlight, use less energy while the building is occupied, and even make electric power (solar energy conversion).

The façade's efficiency is linked to its capacity to save energy expenditures and ensure thermal comfort. Predictions indicate that the facade arrangements contribute up to 45% of the building's cooling demands. (Alberto et al., 2017a; Hazem, 2018)

However, meeting all these requirements within a single building project will result in complicated facade designs, prompting experts in the discipline to seek methods for leveraging the essential techniques and systems. One of the most popular alternatives in recent years is the double-skin façade.

Double skin facades (DSF) represent a design strategy in architecture that offers a contemporary aesthetic, enhances visual and thermal comfort inside buildings, and reduces energy consumption.

Many definitions of the double-skin façade system were provided by various authors in a variety of research investigations.

According to Safer, the "double-skin façade" consists of an inner layer and an outer layer. These two layers form a channel whose thickness varies from one façade to another. The height ranges from one story to several stories, and the width ranges from 10 cm to 2 m. (SAFER, 2006)

Pursuant to the definition of Stüdle, the double-skin façade features a sophisticated design characterized by a multi-layered external wall that consists of two separate façade levels. The outer layer is designed to withstand the obstacles that are presented by the surrounding environment. The interior level is responsible for defining the distinct functional spaces and typically provides thermal insulation benefits. The space between these two elevations creates an intermediate setting, typically consisting of multiple levels. (Stüdle, 2015)

For Hu Et al. Two parallel skins or panels, positioned to allow air to flow inside the intermediate cavity, make up a typical DSF. This not only reduces energy consumption but also facilitates natural ventilation. (Hu et al., 2021)

I.3 The history of the double-skin façade concept

As stated by Saelens in 2002, Jean-Baptiste Jobard, who was the head of the Industrial Museum of Brussels, outlined an initial version of a mechanically ventilated multi-layered facade in the year 1849. This facade uses the space between two glass walls to provide warm air during the winter months and cool the building during the summer months. (Lim and Ismail, 2022)

According to Crespo and Neubert (1999), the first Double Skin Curtain Wall appeared in 1903 at the Steiff Factory in Giengen/Brenz, near Ulm, Germany. They emphasized that the top consideration was to get the most daylight while accounting for the cold weather and strong winds in the region. The building features multiple levels, with a ground floor designated for storage and two upper levels dedicated to work areas. The success of the building led to the construction of two additions using the same Double Skin system in 1904 and 1908. However, budgetary constraints led to the construction of the structure using timber instead of steel. All structures are still operational. (R. Heimrath et al., 2005)

***Figure I.1**. The Steiff Toy Factory*

Source: ("Die Steiff Story," n.d.) and (Fissabre and Niethammer, 2009)

Otto Wagner was the winner of the Vienna, Austria, Post Office Savings Bank competition in 1903. Constructed in two stages between 1904 and 1912, the structure features a double-skin skylight in its main hall. (Lim and Ismail, 2022)

In 1928, Moisei Ginzburg conducted research in Russia on the use of double-skin facades, carried out during the building of the Narkomfin community housing project. He applied double-skin stripes to the communal housing block for maintenance purposes and subsequently proposed a new window design. (Barnaś, 2014; Lim and Ismail, 2022)

Le Corbusier was conceptualizing the Centrosoyus, also located in Moscow. A year later, he would embark on the design for the Cite de Refuge (1929) and the Immeuble Clarte (1930) both of which were also in Paris. (W. S. R. Heimrath et al., 2005)

At the start of the 20th century, Le Corbusier tried out methods that used natural physical occurrences to make the inside of his buildings more comfortable. He first used the neutralising wall in 1916 in his Villa Schwob, also known as the Villa Turque (La Chaux de Fonds, Rue de Doubs 167, Switzerland). (Barnaś, 2014)

As Le Corbusier explained in 1964, « Neutralising walls are made of glass or stone or both of them. They consist of two membranes, which form a gap of a few centimeters. Through this gap, which is enveloping the whole building in Moscow hot, and in Dakar cold air is conducted. By that, the inner surface maintains a constant temperature of 18 ° C. The building is tightened hermetically! In the future, no dust will find its way into the rooms. No flies, no gnats will enter. And no noise! ». (R. Heimrath et al., 2005)

In 1929, Le Corbusier unveiled his "La Cite de Refuge" proposal in Paris, wherein he integrated the concept. The concept was further suggested for several structural designs developed between 1928 and 1933 as part of the Centrosoyus in Moscow, as well as for his competition submission for the League of Nations building in 1927.

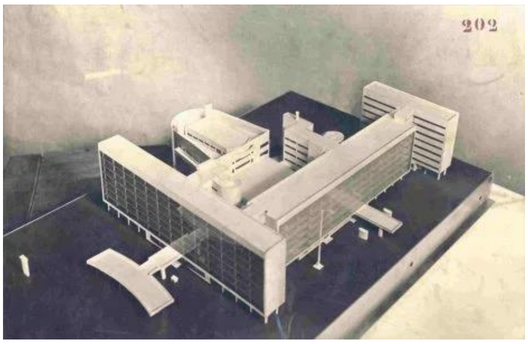


Figure I.2. *The Centrosoyus, Moscow.*

Source: ("Le Corbusier, Centrosoyus, Moscou, Russie, 1928," n.d.)

In 1957, Scandinavia patented the first design concept with air flow between two sets of windows. In 1967, the EKONO company's headquarters in Helsinki, Finland, became the first office building to feature a ventilated window system.

During the energy crisis of the years 1973–1979, there was a significant increase in the pursuit of energy rationalization and a reduction in the total energy consumption of building construction. (Barnaś, 2014)

Until the late 1970s and early 1980s, the manufacture of double-skin glass made very little to no progress. This type of facade became popular in the 1980s. The majority of these facades, including the offices of Leslie and Godwin, took environmental concerns into consideration during their design. Regarding other circumstances, the primary concern is the visual impact of the multiple layers of glass.
Two distinct elements significantly influenced the proliferation of double-skin facades in the 1990s. Environmental problems are increasingly influencing architectural design, both

technically and politically. This is beneficial for corporate architecture since it helps to present a favourable image of "green buildings". (Poirazis, 2004)

During the 2000s, the double skin facade gained popularity not only in colder regions but also in warmer climates, leading to numerous experiments that yielded many positive outcomes for the system. Various warm climates around the world have embraced many uses of double-skinned façades in the last decade. The Shanghai Tower in China stands out as an extraordinary example, featuring the largest separation between its outer curtain wall system and the inner main structure, measuring an impressive 15 meters. (Lim and Ismail, 2022)

Figure I.3. *The Shanghai Tower*

Source: ("Gallery of Gensler Tops Out on World's Second Tallest Skyscraper," n.d.)

A summary of the historical development of the double skin facade throughout the course of time is shown in the following table (table I.1).

Table I.1.*history of the double skin façade.*

Source: (Eslamirad and Sanei, 2016)

History of Double Skin Facades	Time	Highlighted Buildings/ Architect	Where	How
	Ancestors	Window Switzerland	When humanity recognized the advantages of unheated areas next to the primary living quarters in space	- The main house was oriented to the south. - Other departments were acting as buffer zones against the north facade. - The wind flow was regulated using trees, which also minimized the wind's energy and shaded the structures. - Windows shutter in the winter but open in the summer to allow natural ventilation.
		16-17th Century Hayiati or Liakoto (Balkans)	In Greece and Iran: Balkans in general, an attached volume on the basic volume of the building	

			on the second floor. Made by wood and clay	
	1850-1882	Greenhouses	According to Jacob Forst in the Gardeners Chronicle in the UK, south-facing glass walls can create sunspaces.	• Distribute the air that has been heated by the greenhouse effect. • The masonry wall of the structure, a metallic sheet behind it, and an exterior glass layer. • The optimization of daylight to create natural light, while considering the local climate of frigid weather and high winds.
		Early form of Tromb wall	American botanist Edward Mors invented the first solar wall, which French engineers Felix Trombe and Jacques Michel later incorporated into buildings to popularize the concept in the 1960s.	
	1903	Toy Factory Margarete Steiff AG (Germany)	the first Double Skin Curtain Wall appeared in 1903 at the Steiff Factory in Germany.	Get the most daylight while accounting for the cold weather and strong winds in the region.
	1910 -1930	Otto Wagner	Post Office savings bank, in Vienna	• The DSF concept that he proposed for the Cite de Refuge project included a 40% reduction in the budget. • The second skin on the south facade consisted of two levels of large windows with wooden ca sements and heating lines between them.
		Le Corbusier	The Villa schwob in 1916. Centrosoyus, worker's housing, Moscow (1928). Cite De Refuge in Paris (1929). In 1932, Narkomfin community housing by Ginzburg.	
	1957,1967	Airflow window patent.	The first design concept with air flow between two sets of windows (1957) in Sweden.	Enhance the thermal comfort and energy efficiency of residential fenestration.
		Ekono company's headquarters.	In Finland, it is the first office building to feature a ventilated window system.	

I.4 Components of a double-skin facade

A double skin facade refers to a broad category of structures that can be transparent, translucent, or opaque, often utilizing separate layers of building components or materials. Double skin façades employ the two primary construction principles of curtain walls. ("Double-Skin Facades," n.d.)

Wang 2008 stated that the double-skin facades consist of a structure featuring multiple layers: an outer layer, a middle space, and an interior layer.

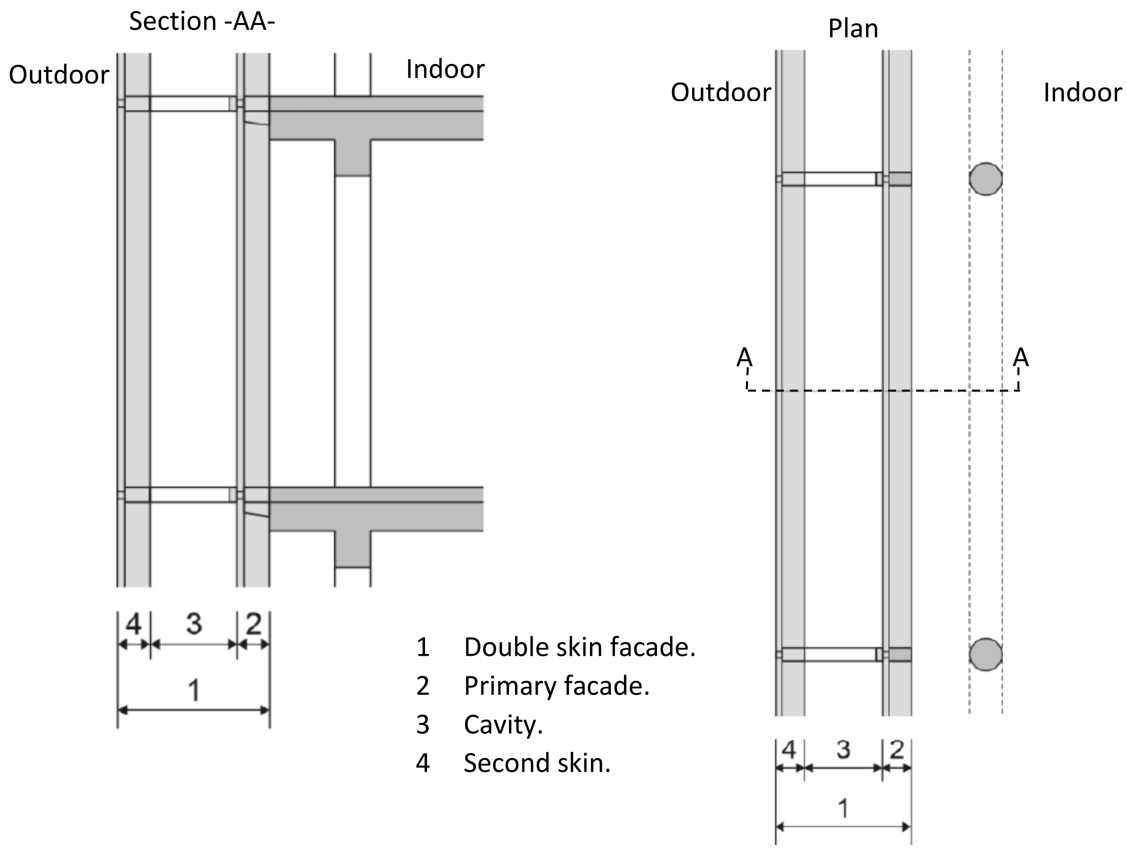


Figure I.4*.Composition of a double skin facade.*

Source: (Stüdle, 2015)

I.4.1 Interior and exterior layers

According to Ding et al. The exterior facade layer (glazing) protects against the elements and improves acoustic isolation from outside sounds. (Ding et al., 2005)

The outer surface of the cavity is composed of a cladding system. Typically, it features a complete glass facade (single glazing). The inner layer of a naturally ventilated exterior features a solid wall alongside a movable window. Completely transparent interior surfaces are also favored. (Poirazis, 2004)

Figure I.5. *A double skin facade.*

Source : (Hazem, 2018)

I.4.2 Cavity

The space can be aerated through various techniques, encompassing both natural and mechanical systems, or a combination of the two. In addition to the airflow within the cavity, the origin and endpoint of air differ according to climatic factors, the purpose of the structure, its geographical setting, and the duration of occupancy. (Poirazis, 2004)

The dimensions of the cavity can fluctuate based on the implemented design, ranging from 10 cm to over 2 m. The breadth impacts the tangible characteristics of the exterior, as well as the methods employed for its maintenance. (R. Heimrath et al., 2005)

It is essential to design the cavity appropriately to take advantage of the thermo-aerodynamic behaviour of the DSF, which is dependent on the duct's thickness, height, and ventilation type. The width of the canal might be rather small, measuring between 0.1 and 0.2 meters. People often employ this channel type because, in most cases, natural ventilation suffices. If the channel's thickness is between 0.2 and 2 meters, it's broad enough to provide access to the inside of the DSF for things like maintenance. (Hazem, 2018)

The airflow rate rises with the channel's width to a specific limit and remains relatively stable concerning the cavity's width, particularly in multi-level facades. As a result, there exists an ideal width for the channel, where the ventilation rate attains its peak value. (Hazem, 2018)

The width is typically employed to differentiate between narrow and wide cavities. The difference between them is of paramount importance in the context of both operational and embodied energy. (Pomponi et al., 2016)

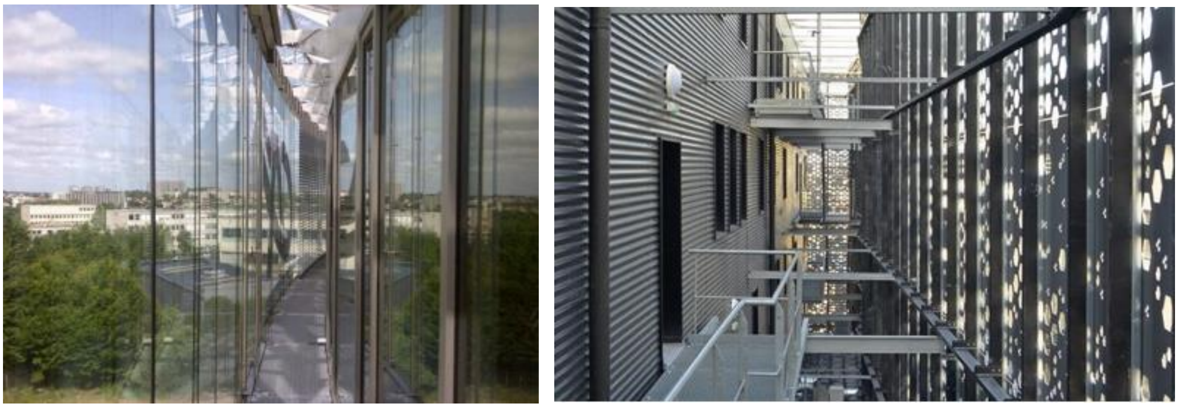


Figure I.6. *Cavity of double skin façade.*

Source : ("Pilotage façade double peau," n.d.) (Moniteur, 2013)

I.4.3 Shading device

In the case of a double-skin facade, particularly those featuring glazing, it is common to incorporate shading elements within the cavities to mitigate glare and limit excessive solar heat absorption during warmer periods. The safeguard can be conveniently found within the space between the two layers in the exterior design. These shade devices, which are protected from wind, rain, and snow, are less costly than those installed on the outside.

The physical behaviour of the DSF is influenced by the characteristics of the solar protection, including its material properties (optical and thermo-physical), dimensions, geometric formations, and position within the channel. Consequently, the solar protection must be chosen in conjunction with the ventilation strategy, cavity geometry, and glazing selection.

The sun protection systems used in the construction of the DSF typically consist of Venetian blinds, roller blinds, or pleated blinds. Additionally, there are sun protection systems, including photovoltaic (PV) panels. This type of shielding not only protects interior areas from unwanted sun radiation but also generates electrical energy. (Poirazis, 2004; Hazem, 2018; Pelletier et al., 2023)

***Figure I.7**. Double skin facade with shading device.*

Source: ("A Double Skin Facade System," n.d.)

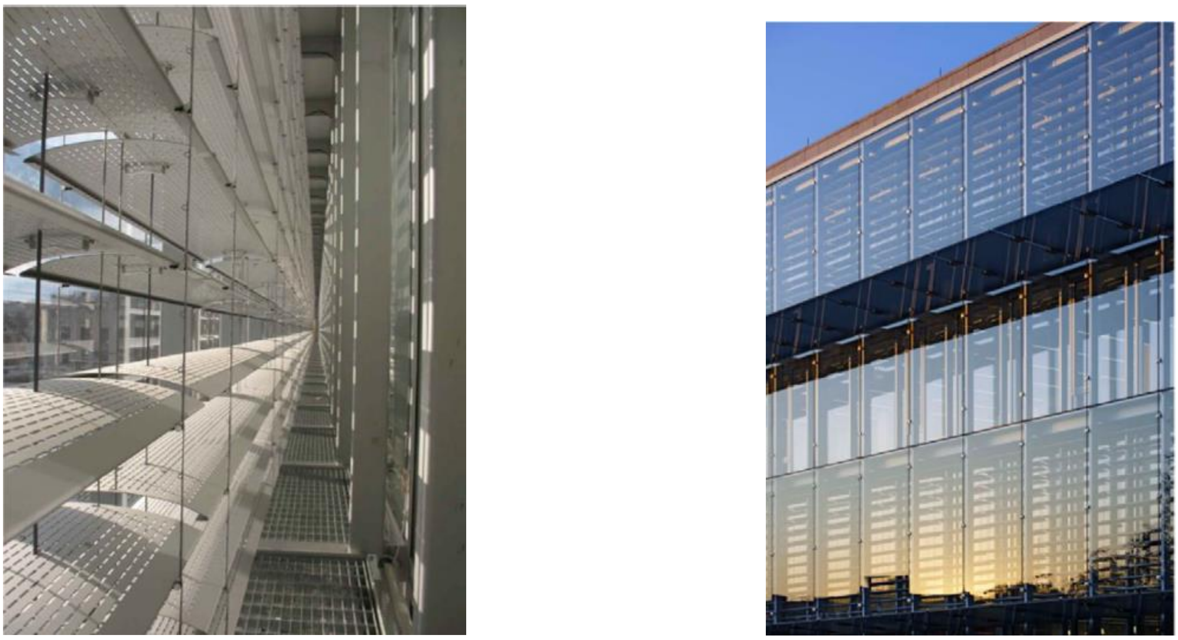


***Figure I.8.** Double skin facade with shading device.*

Source: (Ghaffarianhoseini et al., 2016)

I.4.4 Openings

Openings are positioned in the external and internal skin and sometimes ventilators (For mechanic ventilation) allow the ventilation of the cavity.

Certain facades feature controllable openings that facilitate cavity ventilation. Conversely, some facade designs feature fixed and permanent apertures, making it impossible to control the cavity's ventilation.

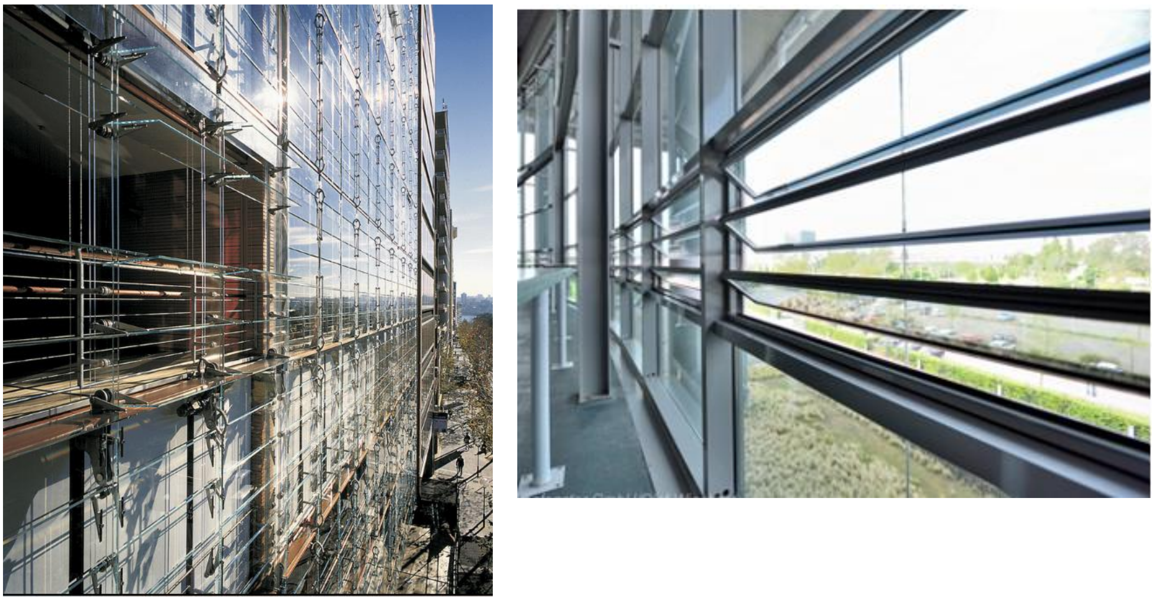


Figure I.9*. Openings in a double skin façade.*

Source: ("How Do Double-Skin Façades Work?," 2024)

I.5 Mechanism and functioning of a double skin facade

The primary mechanism and energy balance are arguably the most vital components of a double-skin façade system. Considering that a DSF employs a natural ventilation approach through the solar chimney effect, it is important to emphasize the dynamics of airflow and heat transfer that take place within the system. In general, the aspects of heat transfer that influence the thermal performance of a double-skin façade system include conduction, convection, and radiation. A notable temperature difference across the outer layer triggers the buoyancy effect, which facilitates the upward movement of air through the cavity to expel accumulated heat from solar radiation or the structure itself at the uppermost point. Wind pressure variations at the openings and the outer surface can influence the movement of air within the cavity. Furthermore, glazed double-skin facades often incorporate shading elements within the cavities to mitigate glare and limit excessive solar heat absorption during warmer seasons. The efficacy of blinds is influenced by their design and positioning in relation to the sun's height and angle throughout the day and across different seasons. (Pelletier et al., 2023)

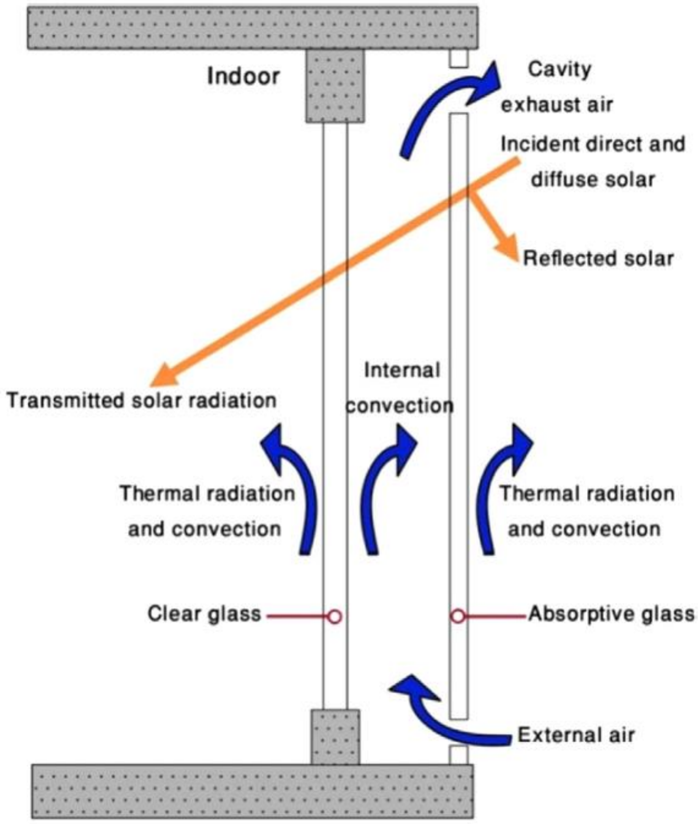


Figure I.10. *Airflow and heat transfer within a naturally ventilated DSF system.*

Source: (Ghaffarianhoseini et al., 2016)

I.6 The double-skin façade principle

The approach of utilizing passive preheating and natural ventilation aims to enhance the indoor microclimate of the structure through thoughtful design elements inherent to the building itself. The fundamental concept entails the integration of an additional cavity for climate regulation at the boundary, where the inner and outer layers converge to form a double-layered enclosure known as a buffer space. Buffer space has the capacity to modulate the environment passively. The exterior layer of the structure features a composite spatial design, enhancing the air heating surface and expanding the area for heat exchange. This location is uniquely designed for structures that harness natural energy.

The cold air flows in through the cavity's inlet, primarily capturing energy from solar radiation, before moving into the indoor environment via the process of induced natural ventilation.

The indoor air temperature serves as a crucial design element influencing thermal comfort, and the advancements mentioned enhance both indoor thermal comfort and air quality, thereby establishing an effective “natural air conditioning system.” The passive preheating natural ventilation cavity is alternatively referred to as the passive heating cavity. The enclosure of the chamber allows for optimal utilization of passive heating strategies, enhancing its effectiveness. The arrangement of space typically places the extra cavity externally, where its temperature exceeds that of both the interior and exterior. This configuration not only supplies fresh, warm air to the inside but also improves the insulation properties of the double-layer facade, minimizing heat loss and energy usage indoors.

The rationality of the link between the cavity of the double skin facade and the outside environment is crucial for the effective conversion of natural resources. The facade serves as the most significant interface between the structure and its surroundings, making its energy-efficient design crucial for overall energy conservation in the building. The advantages and disadvantages of facade energy-saving technology have a direct impact on the overall energy efficiency of the structure. (K. Hou et al., 2021)

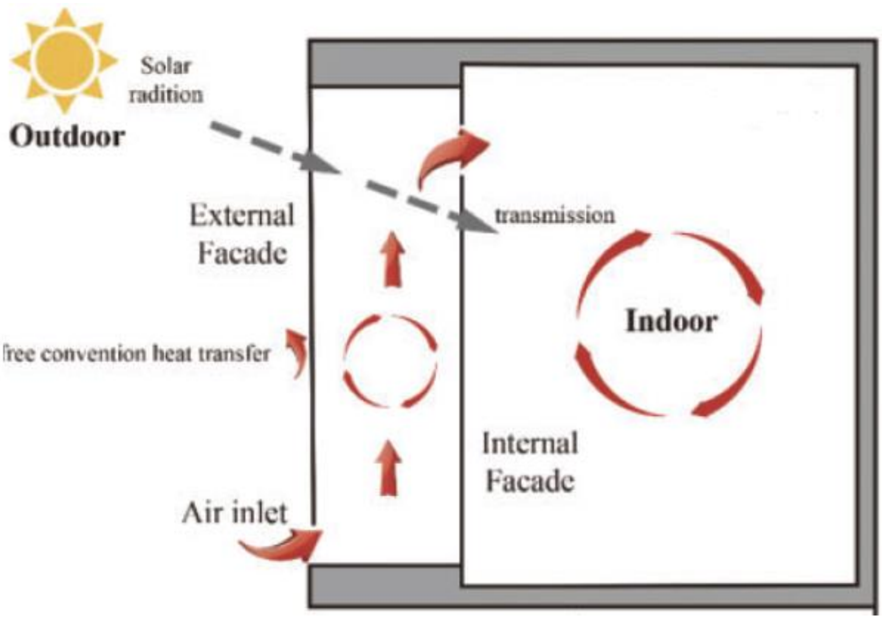


Figure I.11. *Functioning of a naturally ventilated double skin facade.*

Source: (K. Hou et al., 2021)

I.7 Classification of double skin facade

The literature outlines various methods for categorizing double skin façade systems. The systems can be classified according to the construction method, origin, destination, the nature of airflow within the cavity, and other factors. (Poirazis, 2004)

The necessity of a more comprehensive classification of DSF systems is underscored by the fact that various researchers employ a variety of ventilation modes and geometric configurations in their investigations. Using an existing categorization of double-skin facades that was provided by a number of researchers, as well as researchers from the Belgian Building Research Institute, a combined typology was proposed, which included a novel ventilation mode known as the "closed cavity facade." (Pelletier et al., 2023)

The DSFs are classified according to (as shown in table I.2):

- The type of ventilation.
- Ventilation mode.
- The partitioning of the facade.
- The cavity depth.

Table I.2. *Classification of double skin facade.*

Source : Author.

Cavity depth	Portioning of the facade	Type of ventilation	Ventilation mode
Thin profile (Narrow cavity ≤ 40 cm) Thick profile (Wide cavity > 40 cm)	Box window Shaft Box Corridor Multistorey	Natural (Passive) Mechanical (Active) Hybrid (Interactive)	Outdoor air curtain Indoor air curtain Air supply Air exhaust Buffer

I.7.1 Cavity depth

The cavity can serve as a thermal buffer zone, a ventilation channel, or, more often, a combination of both. It can feature natural or mechanical airflow, with variations in both width and height. All these cavity factors play a crucial role in shaping the dimensions of a DSF. The width is often employed to differentiate between narrow and broad cavities. This difference is crucial for both operational and embodied energy.
In the case of smaller air spaces, they can greatly affect the movement and speed of air, while in the latter, larger cavities often indicate a greater volume of building materials, which consequently raises the embodied energy of the design.

Numerical figures exist to differentiate between the two, often using 0.4–0.5m as the limit for a wide cavity.

- A narrow cavity refers to a space that measures less than 40 cm in width.

- A wide cavity is defined as one where the breadth surpasses 40 cm.

The 40 cm restriction is also dictated by the minimum width necessary to provide access to the hollow for maintenance activities. (Pomponi et al., 2016)

I.7.2 Type of ventilation

There are three different methods of ventilation that may be used for the air in the cavity between the two layers of the facade. (Hazem, 2018)

I.7.2.1 Natural ventilation

The chimney effect and wind influence create a major pressure difference that drives natural ventilation. The contact between the cold air at the duct's entry and the warm air causes a difference in pressure and density, enabling the air to travel up the duct. For this sort of ventilation, and in the case of the DSF, air may be fed into the premises for heating reasons, or it can be evacuated (sucked out) to the outside environment to prevent the duct from overheating. Natural ventilation is preferable for structures with several floors, such as offices, since it enables air to flow freely between the floor openings. (Hazem, 2018)

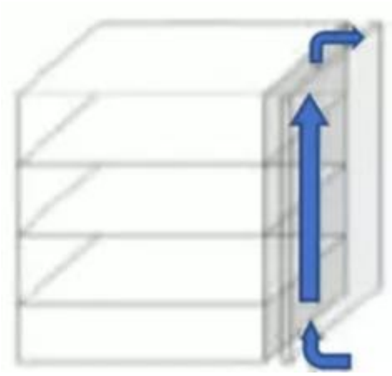


Figure I.12*. Naturally ventilated double skin façade.*

Source: ("Double skin facade," 2021)

I.7.2.2 Mechanical ventilation

In mechanical ventilation, a mechanical fan facilitates airflow via the DSF duct. The size and locations of openings and closures in a duct directly influence the flow's behaviour and structure when air enters and exits, leading to disruptions in the temperature field. The benefit of this ventilation type is its elevated flow rates, leading to increased thermal savings. (Hazem, 2018)

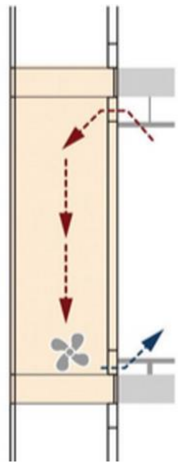


Figure I.13. *Mechanically ventilated double skin façade.*

Source: ("Double-Skin Facades," 2019)

I.7.2.3 Hybrid ventilation

Hybrid ventilation represents a balanced integration of natural and mechanical airflow systems. Hybrid ventilation primarily relies on natural airflow, activating mechanical systems only when natural forces fail to meet the desired performance levels. (Hazem, 2018)

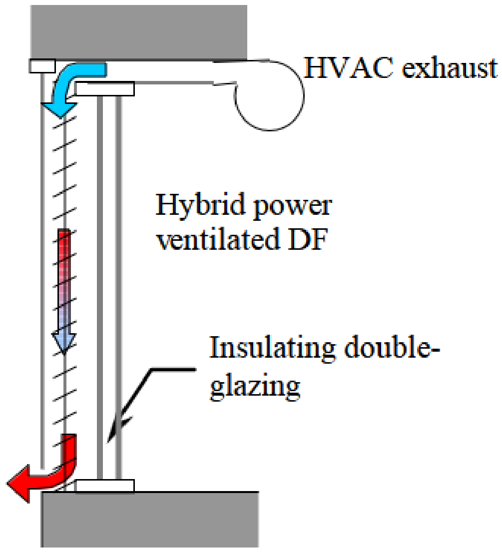


Figure I.14. *Double skin facade with hybrid ventilation.*

Source: (Straube and van Straaten, 2001)

I.7.3 The partitioning of the façade.

Based on the geometry of the façade, including the width of the openings and the dimensions of the channel, Oesterle et al. categorize the DSF by the characteristics of the cavity into four distinct categories: box windows, duct-type windows, tunnel-type facades, and multi-story facades. (Hazem, 2018)

I.7.3.1 Box window type:

A box window facade is composed of a structure that features inward-opening casements. The intermediate and internal spaces are ventilated by the external pane's apertures, which facilitate the ingress and egress of air. The façade's air cavity is divided horizontally on a room-to-room basis and vertically at storey height. It is frequently employed in situations where there is a need for additional sound insulation between adjacent rooms or when external noise levels are elevated. (Wong, 2008)

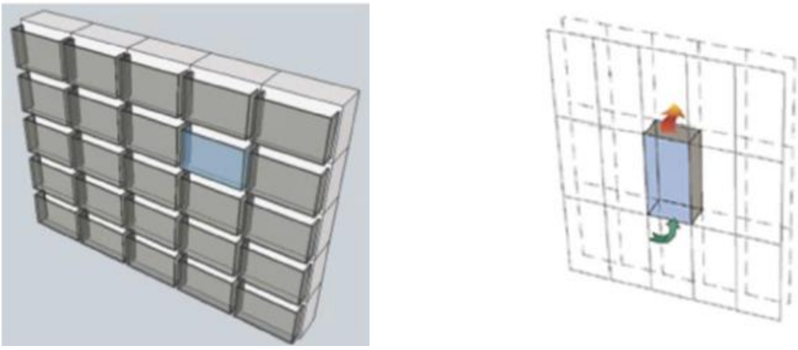


Figure I.15. *Box window facade.*

Source: (Dopudi, 2018; Pelletier et al., 2023)

I.7.3.2 Shaft box type

A shaft-box façade features a series of box windows accompanied by uninterrupted vertical shafts that rise across multiple stories, producing a striking shaft effect. The vertical shafts connect to the adjacent box windows through a bypass opening, allowing the stack effect to draw air from the box windows into the shafts, which then carries it upward to the top where it is released. The design of the façade system incorporates fewer external openings, enhancing thermal uplift within the stack and offering effective insulation against external noise. (Wong, 2008)

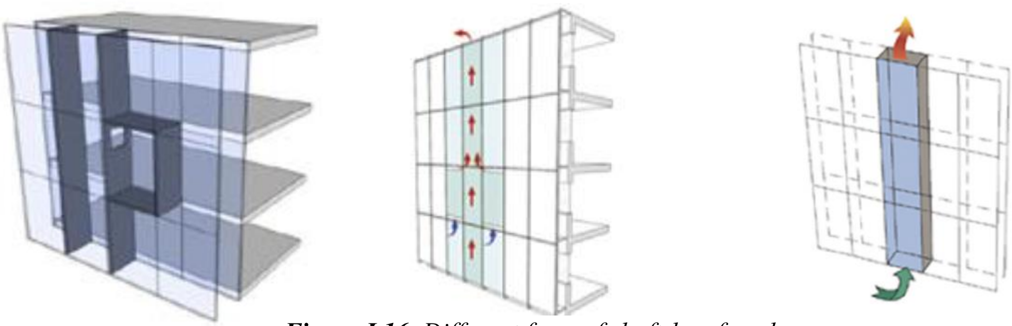


Figure I.16. *Different form of shaft-box façade.*

Source: (Hazem, 2018; Pomponi et al., 2016; Pelletier et al., 2023)

I.7.3.3 Corridor facade:

The construction of a corridor facade involves closing the intermediate space between the two layers at the floor level and incorporating vertical divisions for acoustic and fire protection or ventilation. The openings for intake and extraction in the outer layer are positioned close to the ground and the upper edge, arranged in a staggered pattern from one section to another to avoid any mixing of the incoming and outgoing air. When employing this façade system, it is imperative to prioritize sound transmission between rooms. (Wong, 2008)

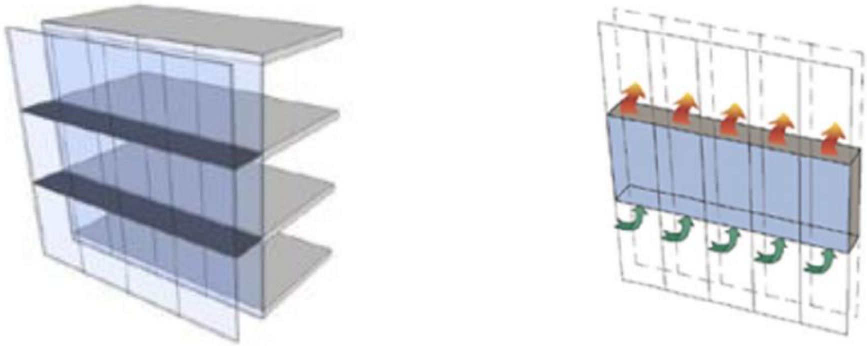


Figure I.17. *Corridor façade.*

Source: (Hazem, 2018; Pelletier et al., 2023)

I.7.3.4 Multi-storey facade:

The intermediate space between the two surfaces of a multi-storey façade is united vertically and horizontally by a number of chambers. The immediate area gets air in and out through big holes near the ground floor, and the roof and the facade are used as air ducts. This design is ideal for environments with elevated external noise levels, as the outer layer maintains a continuous surface without any openings throughout its height. (Wong, 2008)

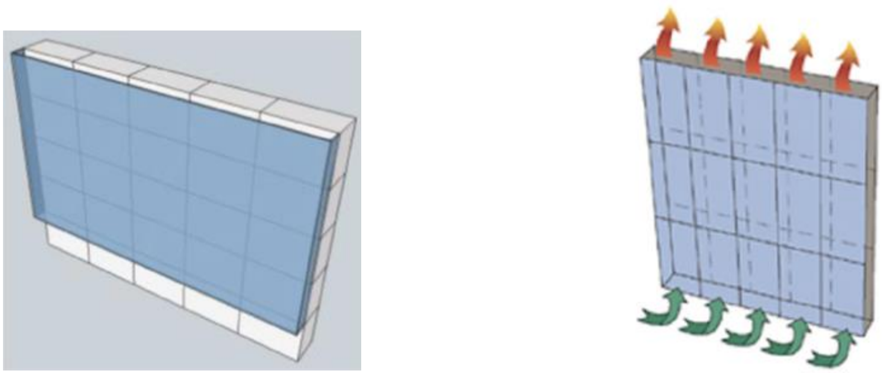


Figure I.18. *Multi-storey façade.*

Source: (Dopudi, 2018; Pelletier et al., 2023)

I.7.4 Ventilation mode

The channel's airflow mode pertains to the source and destination of the air moving between the glass and the sun protection. The ventilation mode operates independently of the ventilation type. At any given time, there is only one way for air to flow through a double-skin façade. However, if a facade incorporates adjustable holes, it can transition between various air styles at different times. Air flows through the channel via two apertures, one located at the bottom and the other at the top. Orienting the bottom and top ports either inside (toward the building) or outward establishes five main ventilation options. (Loncour et al., 2005)

I.7.4.1 Outdoor air curtain

This mode of airflow involves the entry of air from the exterior, followed by its prompt expulsion back outside. The airflow within the cavity creates a protective barrier (an air curtain) that surrounds the exterior facade. (Loncour et al., 2005)

I.7.4.2 Indoor air curtain

The ventilation system draws the air from the chamber's interior and either returns it there or circulates it. As a result, the cavity's ventilation creates an air curtain that envelops the interior facade. (Loncour et al., 2005)

I.7.4.3 Air supply

Outdoor air is used to produce ventilation for the facade. The air is then sent into the room or the ventilation system. Consequently, the building receives air supply from the facade's ventilation system. (Loncour et al., 2005)

I.7.4.4 Air exhaust

The air is drawn from the interior of the room and expelled to the exterior. The building's air can be evacuated through the facade's ventilation. (Loncour et al., 2005)

I.7.4.5 Buffer zone

This ventilation mode is unique because each layer of the double facade is constructed to be impermeable. As a result, the cavity creates a barrier between the inside and outside, making ventilation impossible. (Loncour et al., 2005)

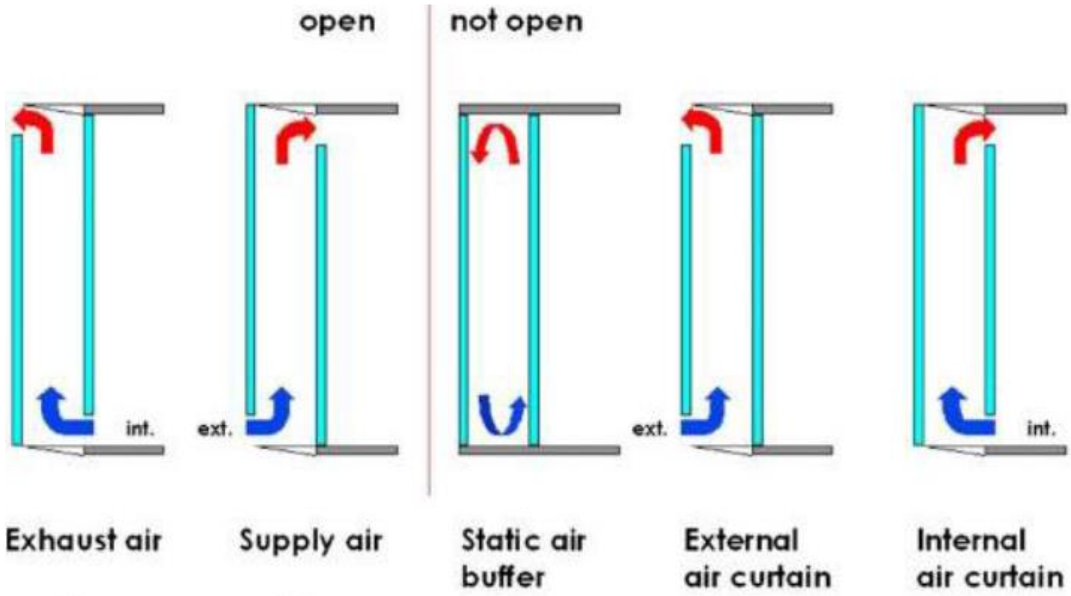


Figure I.20. *The main ventilation modes.*

Source : (Haase et al., 2009a)

The direction of the ventilation flow can be reversed to create four additional variants. These variants share the same terminology as the previously mentioned primary modes. (Loncour et al., 2005)

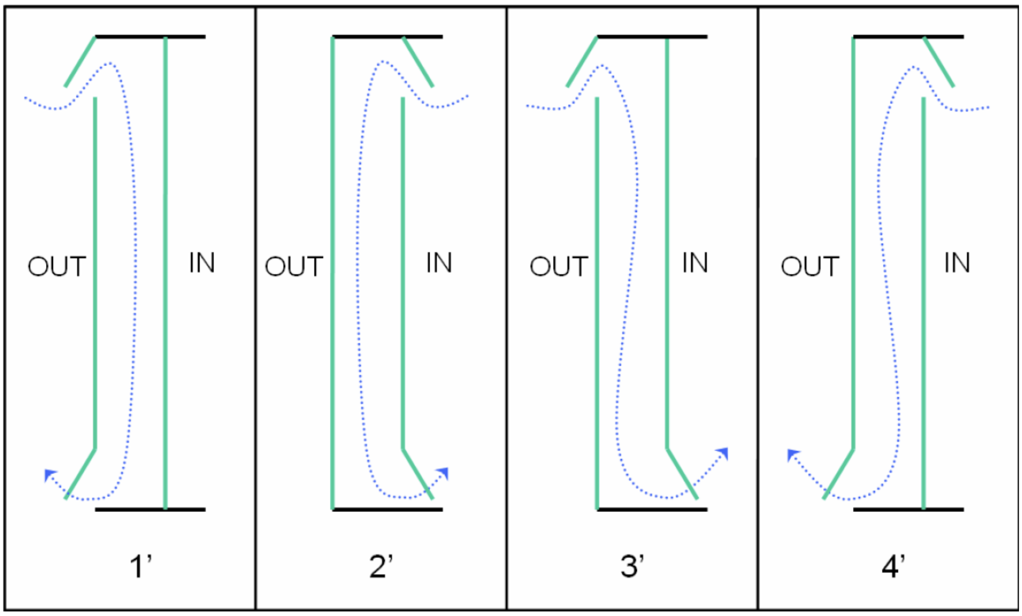


Figure I.21. *The four variants to the main ventilation modes.*

Source: (Loncour et al., 2005)

A final form of ventilation is exclusive to facade designs that integrate apertures into both the top and bottom layers of the component's internal and external skins, as shown in figure . (Loncour et al., 2005)

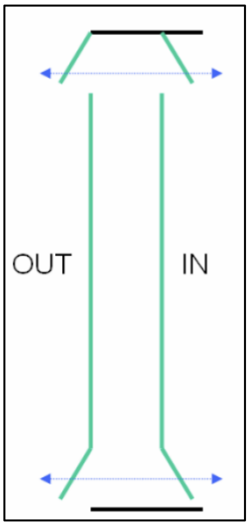


Figure I.22. *Additional special ventilation mode.*

Source: (Loncour et al., 2005)

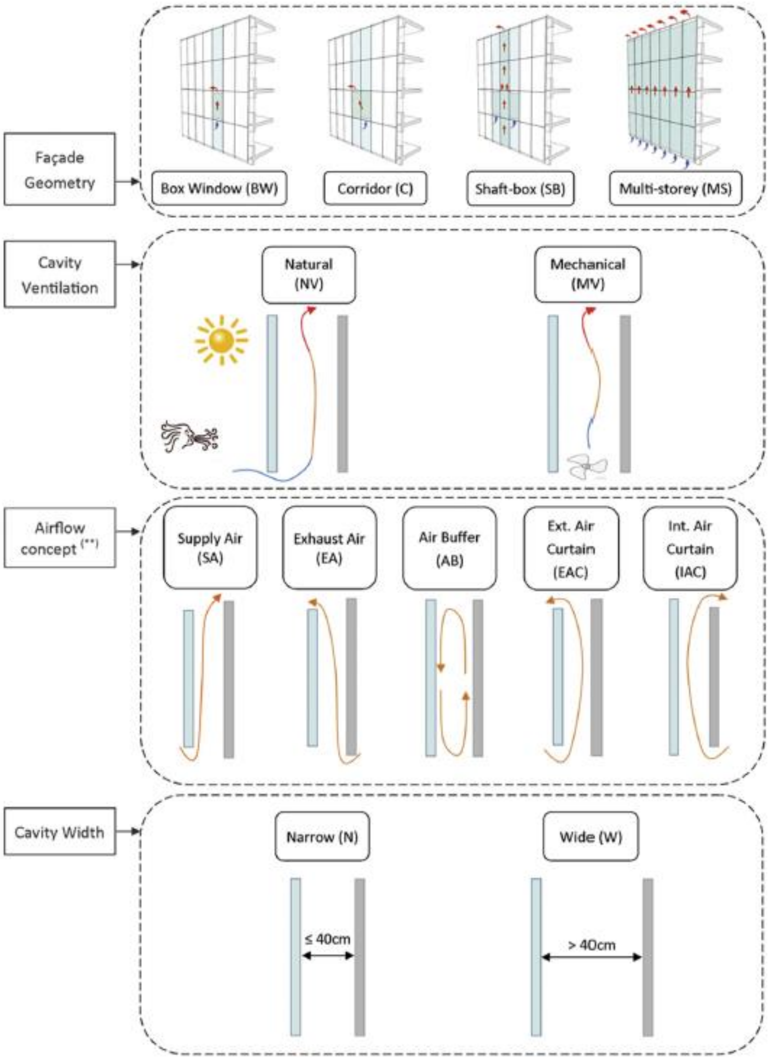


Figure I.23. *Classification of DSFs.*

Source: (Pomponi et al., 2016)

I.8 Types of double skin facades

The double-skin façade is an architectural cladding system with two layers of walls separated by an air gap. The outer layer, generally made of glass, provides protection against the elements, while the inner layer forms the main enclosure of the building. (Barbosa et al., 2015; Safer et al., 2005)

I.8.1 Glazed facades

These types of DSFs are the most prevalent. The transparent surface at the front of the structure moderates the sunlight that enters. They also offer the benefits of natural airflow, temperature regulation, and noise reduction. ("Façade double peau — Ekopedia," n.d.)

Figure I.24. *Glazed double skin façade.*

Source: (Quentin (Webmaster), 2020)

I.8.2 Metal facades

These typically manifest as sun breakers or meshes crafted from aluminium or steel. The main function of this exterior design is to minimize direct solar exposure, thereby preventing excessive heat accumulation during the summer months. It is thus a metallic shell that wholly or partially encases the current structure. Commercial structures frequently employ this method to balance visual appeal and thermal comfort. Once more, the space between the screen and the structure serves as a transitional zone, facilitating the flow of natural air. ("Façade double peau — Ekopedia," n.d.)

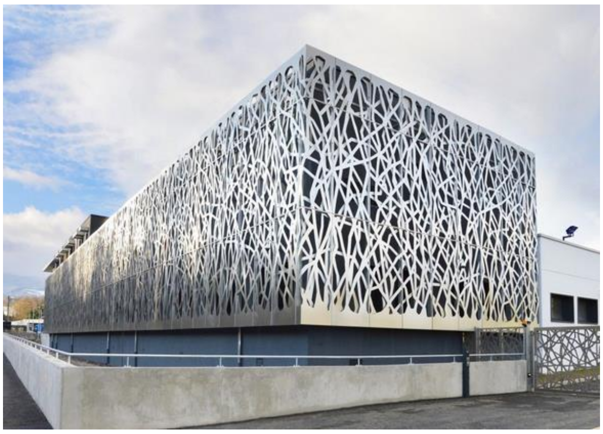



Figure I.25. *Metallic double skin façade.*

Source : ("Parement de façade métallique et parement de facade résille," n.d.; "Proyecto arquitectónico Hospital QuirónSalud Córdoba," n.d.)

Figure I.26. *Double skin steel facade.*

Source: ("Gallery of Bund Finance Centre / Foster + Partners + Heatherwick Studio - 5," n.d.)

I.8.3 Planted facades

The exterior of this dual-layered structure features verdant walls, adorned with vegetation on each side. This verdant facade regulates the temperature during the warmer months. Through the process of evapotranspiration, a green environment elevates the moisture content in the air, fostering a more temperate atmosphere. With effective air circulation, the interior environment can be maintained at a comfortable temperature without relying on mechanical cooling systems.

During the summer months, the lush foliage of the plants fosters two significant effects: firstly, the sun's rays are softened by the verdant barrier, ensuring a comfortable temperature indoors; secondly, the flow of cool air, initially in the transitional space and subsequently within the structure, allows for the elimination of air conditioning needs. During the winter months, the absence of leaves on deciduous trees permits sunlight to filter into the structure, offering a sense of warmth. (“Façade double peau — Ekopedia,” n.d.)

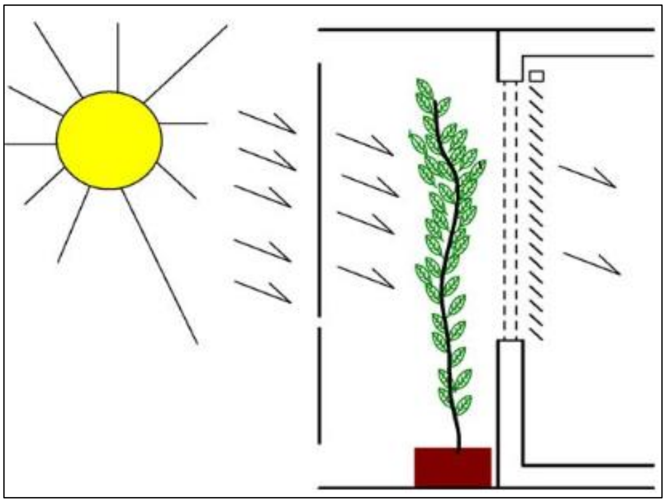


***Figure I.I.27**. Green (planted) double skin façade*

Source:(Alannah, 2024; Stec et al., 2005)

I.8.4 Slatted facades

Timber slats positioned before glass complete the same function as their metallic counterparts.

***Figure I.28.** Wooden double skin façade.*

Source: (“The Green Pine Garden / Scenic Architecture,” 2013)

Figure I.29. *Double-skin wood façade.*

Source: (Viard, 2015)

I.9 Double skin facade construction considerations

The key design criteria affecting air flow and temperature in double-skin façades are (Wang et al., 2022a):

- The dimensions of the top and bottom openings.
- The façade's depth and the location of the shade device, namely the absorption coefficient.
- The shading device's outlet sizes.
- The characteristics of the external and internal layers, namely the solar transmission factor, as well as the U-value and absorption coefficient.

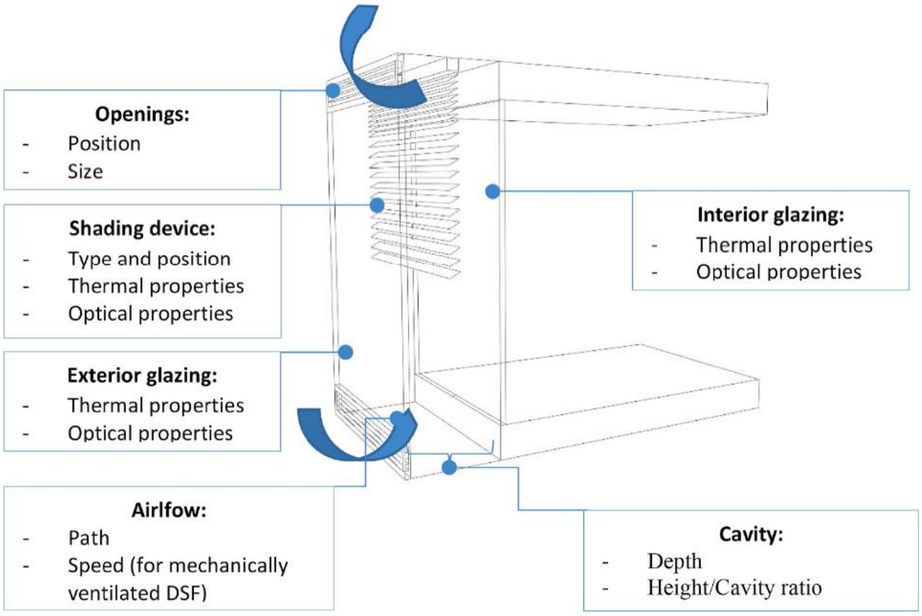


Figure I.30. *The design parameters for a double-skin glazed façade.*

Source: (Jankovic and Goia, 2021)

Memari A.M. et al. in their typology study highlight the importance of considering various factors when designing Double-Skin Facade (DSF) systems, including vertical airflow, air inlet, natural daylighting, noise control, structural resistance, fire protection, maintenance, HVAC considerations, and aesthetics. A multi-disciplinary approach is recommended due to the diverse range of parameters. Designers must evaluate aspects such as aesthetics, durability, cost, visibility, ventilation, HVAC system effects, daylighting impacts, maintenance, constructability, solar gain, weight, structural movement, thermal resistance, and visual transmittance. A checklist, like figure.., helps identify performance attributes across disciplines and highlights areas requiring greater focus. (Memari et al., 2022)

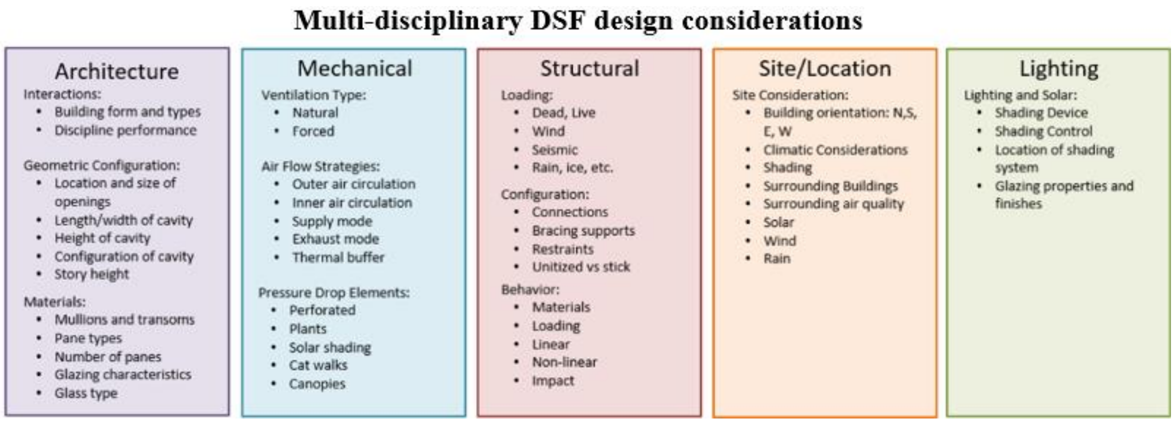


Figure I.31. *Main characteristics to ensure an effective DSF design.*

Source: (Memari et al., 2022)

According to Pelletier K. et al., the effectiveness of ventilation in double-skin façade systems depends on its ability to achieve an adequate airflow rate, facilitating heat recovery and providing fresh air to adjacent areas. The thermal performance of the system ensures it adapts to the environment, minimizing heat loss during heating and overheating during cooling. Key design considerations include climate type, building height, double-skin façade orientation, cavity geometry, glazed external and internal skins, perforated ventilated facades, and shading devices. DSF technology performance fluctuates throughout the day, so it's crucial to evaluate these factors to optimize ventilation and thermal performance. (Pelletier et al., 2023)

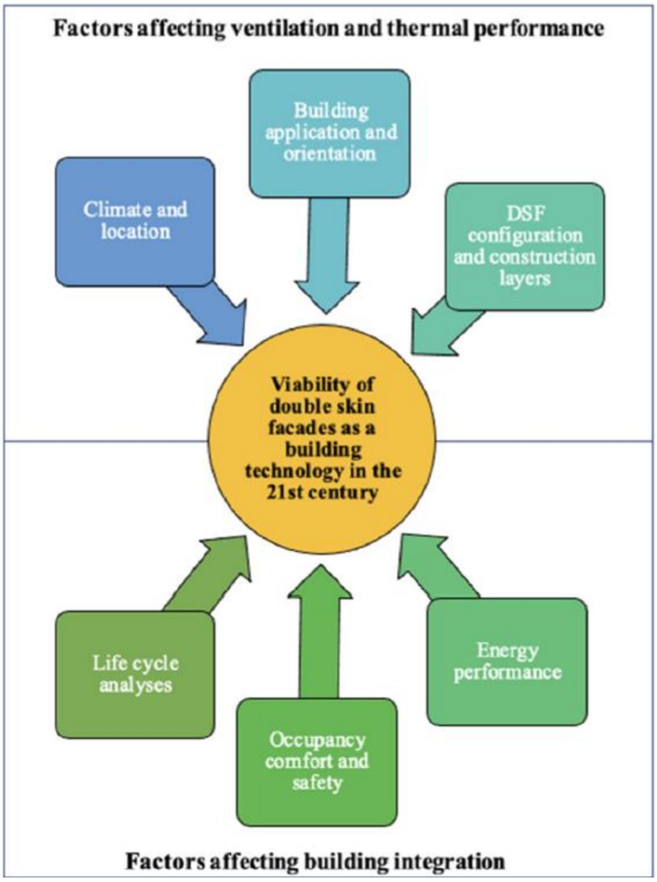


Figure I.32. *Factors influencing the effectiveness of double-skin façades as a 21st century building technology.*

Source: (Pelletier et al., 2023)

I.10 Advantages and disadvantages of DSF

The use of double-skin facades (DSF) has both beneficial and harmful effects on the functionality and performance of buildings. Most studies examining the effectiveness of DSF reveal that its principal advantages are superior thermal insulation and increased acoustic characteristics. These studies outline advantages and disadvantages of DSF, which may be summarized as follows: (Al-awag and Wahab, 2022; Hazem, 2018)

I.10.1 Advantages of DSF

- The increased construction cost of DSF can be compensated for by the decrease in operating expenses.
- The most remarkable characteristic of a DSF is the increase in acoustic insulation. The degree of sound insulation is contingent upon the apertures in the outer face.
- Most research concurs that thermal insulation is enhanced, particularly in winter, owing to the supplementary facade and buffer zone, resulting in less heat loss and an improved total heat transfer coefficient (U).
- The facade's chimney effect, which is generated by sunlight exposure, enables air to exit the channel. It is crucial to verify the location and type of solar protection material when natural ventilation is desired.
- The entire facade is adequately ventilated during the summer months by the forced ventilation of the air duct.
- The potential for ventilation during the night is an important consideration.
- The DSF safeguards the interior environment from atmospheric conditions, like rain.
- Indirect reduction of CO_2 emissions can provide an environmental impact.
- The architectural aesthetics and enhanced design of buildings are notable benefits.
- Elevated amounts of natural light, enhancing interior visual comfort.
- The potential for integration with HVAC systems can lead to a reduction in their operational hours. (Hazem, 2018)

I.10.2 Disadvantages of the DSF

The issue of overheating stands as a crucial concern in the design of a double-skin façade (DSF) and necessitates thorough evaluation. Existing literature identifies several additional disadvantages associated with DSFs, which can be outlined as follows: (Hazem, 2018)

- The potential for elevated air temperatures within the channel necessitates meticulous design of the ventilation cavity to mitigate overheating risks.
- Increased operational expenses arise from maintenance requirements and the need for gaskets, contributing to higher overall costs.
- The dimensions of the ventilation duct typically range from 0.1 to 2 meters, which results in a decrease in the usable surface area.
- Overheating can become a critical issue if the DSF is not designed with adequate considerations.
- In certain DSF designs, fire safety emerges as a significant concern, as the interconnection of the ventilation duct can facilitate fire propagation.

I.11 State of the art

Numerous studies have been conducted on various types of double-skin facade systems, each with distinct parameters. The table below provides a summary of the key findings from some reviewed studies.

Table I.3. *summary of the key findings from some reviewed studies.*

Source: Author.

Authors	Location	Parameter	Type of study	Findings
(Gratia and De Herde, 2004)	Belgium	Natural ventilation	TAS simulation	The wind speed and direction affect building airflow; however, DSF orientation has minimal effect on cross ventilation.
(Hien et al., 2005)	Singapore	Natural ventilation	TAS simulation	Double-glazed facades with natural ventilation were able to reduce energy consumption while increasing thermal comfort.
(Yılmaz and Çetintaş, 2005)	Turkey	Heat losses	Mathematics	In winter period in Istanbul the DSF considerably reduces the energy consumption of the building.
(Charron and Athienitis, 2006)	Canada	PV panels Blinds	Mathematics	Placing a blind in the middle of the cavity of the DSF provides thermal-electric efficiency more than 60%.
(Gratia and De Herde, 2007a)	Belgium	Cavity depth. Glazing proprieties. Openings	TAS simulation	In deeper cavities, the temperature is slightly lower than in shallower DSF. Null wind speed, clear glass transmits 62% of solar energy, whereas reflecting glazing returns 51%. If inner skin is absorbing glazing, 68% of solar energy is absorbed. Cavity temperature drop is not linear to opening size.
(Gratia and De Herde, 2007b)	Belgium	Shading device (Blind)	TAS simulation	Blinds in the center of the cavity enhances thermo-circulation and reduce cooling usage.
(Fung and Yang, 2008)	China	PV modules	Mathematics	Total heat gains are composed mainly of solar gains. PV module solar cell area

				affects total heat gain. PV module thickness have minor effect on heat gain.
(Haase et al., 2009b)	China	Shading devices. Orientation	TRNSYS	Black roller blinds cause high gap temperatures. White roller blinds reduce gap temperatures by 11 °C. Facade design orientation greatly affects yearly cooling load. Efficiency is best for S, SE, and SW direction and lowest for N.
(Baldinelli, 2009)	Italy	Shading devices	Simulation	DSF significantly improves the energy behavior of the building throughout the year.
(Huckemann et al., 2010)	Germany	Thermal comfort	Measurements Questionnaire	Double-skin structures offer a slight thermal comfort benefit over single-skin buildings.
(Fallahi et al., 2010)	Canada	Energy performance	Simulation	DSFs with mechanical ventilation can reduce energy use by 41–59% in the winter and 21%–26% in the summer.
(Rahmani et al., 2012)	Malaysia	Cavity depth.	Simulation	By increasing cavity size by 1m, solar heat gains decrease, while DSF efficiency decreases for larger cavities.
(Joe et al., 2013)	South Korea	Multi-storey DSF	EnergyPlus Simulation	Reduction of 15.8% and 7.2% in energy usage for heating and cooling.
(Joe et al., 2014)	South Korea	Multi-storey DSF	EnergyPlus Simulation	The conditioned zone's energy consumption varies, with an increase of 22.2% for the outer surface of inner layer and a decrease of -5.62% for the DSF design.
(Hazem et al., 2015)	Algeria	Shading devices. Cavity ventilation.	Simulation	The slat angle should exceed 60° to minimize heat flux, and a ventilation channel is necessary when the highest solar radiation on the exterior glazing is blocked by slats.
(Flores Larsen et al., 2015)	Argentina	Glazed DSF	Experimental Measurements	In sunny climates, the summer energy consumption of buildings can be reduced by well-designed DGFs, even when applying West DGFs.
(Ahmed et al., 2015)	-	-	Reviews	DSF greatly improves energy conservation. The negative of DSF is that it may cost more than a single glass façade. DSF is cost-effective in the long term.
(Sanchez et al., 2016)	Spain	Openings. Natural ventilation.	Simulation	Closed outlets are always efficient in winter and ventilation is never advantageous. Summer closed outlets are efficient without sun radiation, but opened vents are better.
(Alberto et al., 2017b)	Southern European countries	DSF performance	Simulation	The airflow path is crucial for DSF efficiency, with multi-storey DSFs presenting 30% less energy demands. Internal gains and facade orientation can significantly impact energy performance.
(Su et al., 2017)	China	DSF performance	Simulation	DSF thermal performance is significantly affected by its structural features. Key factors influencing this performance differ based on the climate zone.
(C. O. Souza et al., 2018)	Brazil	Thermal comfort	Experimental. Simulation	Because DSF blocks direct sun radiation, it lowers environmental temperature. Face measurements suggest that the temperature peaks at about 4:00 PM. The façade's inner face is 25.6°C, and the test cell's inner face

				is 23.6°C, while the exterior temperature is 23.1°C.
(Kim et al., 2018)	South Korea	DSF performance . Energy consumption	EnergyPlus Simulation	DSF model saves 40%, 2%, and 5% for heating, cooling, and total loads without blinds or controls. DSF and exterior blind models can significantly reduce building thermal loads and lighting energy consumption by 27–52% when combined with daylight-based dimming controls and blind raise/lower controls.
(Inan and Basaran, 2019)	Turkey	Heat transfer	Experimental. Numerical	DSF reduced cooling loads by 26% over SSF. DSF was worse than SSF in January. It was proven that cavity-heated air might be utilized to warm HVAC air for winter.
(Qahtan, 2019)	Malaysia.	Thermal performance	Measurements	DSF controls heat gain from outdoor-indoor temperature differences and surface temperature variations. But it's insufficient to protect indoors from direct tropical solar radiation. Peak indoor air temperatures range from 26.4°C to 27.6°C near the DSF, raising the building's cooling needs.
(Manubawa et al., 2020)	Indonesia	Natural Lighting	Measurements Simulation	The secondary skins in the studied building provide shade indoors, but the natural light is only 30 lux, less than the classroom's standard of 250 lux. Without secondary skin, the average light intensity is 310 lux, causing glare and visual discomfort.
Hou et al.	China	Energy saving. Passive preheating.	Experimental Simulation	Ideal curtain wall for air preheating is around 4 m tall, and air supply temperature is inversely proportional to curtain wall thickness. Passive preheating of the natural ventilation chamber provides healthy air flow in the space. DSF retains heat well, making interior temperature regulation easy.
(Tao et al., 2021b)	Australia	Ventilation Cavity gap	Experimental Simulation	The ideal cavity gap is 0.15–0.3 m, and ventilation rises till a vent height 0.4 m. Changing glass type improves greatly ventilation efficiency.
Sotelo-Salasa et al.	Mexico	Thermal performance	Experimental Simulation	For evaporative cooling in hot-arid conditions, the optimal DSF setup is a 0.4 m air cavity, a 25 µm droplet size, and 0.6 m nozzle spacing.
(Tao et al., 2021a)	Australia	Natural ventilation Adjustable louvers	Simulation	Outlet louvers' impacts are significant. Upward-opening louvers (30°-67.5°) increase airflow by 10-14% for two glass types at 45°. However, downward-opening louvers (112.5°-150°) limit natural flow by 6-9% each 10° elevation.
(Tao et al., 2021c)	Australia	Cavity depth Openings	Simulation	The optimal gap depth and openings height for the analysed naturally ventilated DSF are 0.2 m and 0.2-0.3 m, respectively.
(Lin et al., 2022)	China	Energy performance Adjustable Louvers	Experimental	Cavity and interior ventilation work best throughout the day and night. The open external skin enhances daytime cavity ventilation through wind pressure. Optimized louver-type DSF offers great energy savings and reduces overheating risks.

(Wang et al., 2022b)	China	Thermal performance	Experimental	The optimal functioning of the spray-cooling DSF is opening both the upper and lower vents with the spray directed from top to bottom and operating for a duration of 10 to 15 minutes (spray/interval time).
(Ahriz et al., 2022)	Mediterranean climate	Energy performance	Simulation	The results indicated that the three DSF model, (the S14 model), reduced energy consumption during heating by 28% and by 53.5% when cooling a high-rise office building located in the hot, dry summer climate of the Mediterranean.
(Bao et al., 2023)	China	Energy performance	Experimental	The use of Double Plant Skin Façades (DPSF) improves building energy efficiency and the thermal environment. DPSF lowers interior temperature by 3.7°C compared to DSF, reducing cooling energy use by 16%.
(Roberts et al., 2023)	United Kingdom	Visual and energy performance	Simulation	The BIPV-DSF configuration significantly reduced maximum daylight illuminance by 73%, failed to meet indoor visual comfort requirements for office environments, and increased building energy consumption by 8%, making it unsuitable for commercial installation in the UK's climate conditions.
(Barone et al., 2024)	Mediterranean countries	Energy efficiency	Parametric analysis Simulation	A DSF depth of less than 7.0 m reduces heating demands by 5.49% to 0.82%, while a substantial configuration exceeding 6.0 m reduces cooling loads. Deeper air gap cavities improve electricity production, 18.6 kW to 26.8 kW.
(Wang et al., 2024)	China	Energy performance PV/T DSF	Experimental Simulation	The PV/T DSF system showed tenfold higher solar energy utilization compared to conventional PV DSF systems, reducing summer heat gain by 7% and winter heat gain by 70%. It also significantly mitigated winter heat loss by 42% and summer heat gain by 65%.
(Amr and Zekry, 2025)	Egypt	Thermal performance Daylighting and energy efficiency	Simulation	Dynamic DSFs are more effective, providing improved temperature regulation and enhanced daylight distribution compared to static systems. Although DSFs involve higher initial costs than single façades, their long-term cost efficiency is notable, attributed to their durability, reduced maintenance requirements, and substantial energy saving
(Aruta et al., 2025)	Italy	Energy efficiency	Simulation	Natural ventilation alone cannot prevent overheating in the façade cavity due to solar radiation. The type of glazing in DSF is crucial, as its thermal performance varies with season and climate. Therefore, DSF design should be tailored to local energy needs, balancing cooling in summer and heating in winter. The building's overall energy performance largely depends on how glazing interacts with solar exposure year-round.

I.12 Conclusion

The double skin facade of a building acts as a 'filter' between the internal and outside environments, highlighting its significance in minimizing total energy usage. However, badly built façades can cause significant problems with energy consumption.

This chapter, devoted to the double skin facade system, began with a definition of the system, followed by a historical overview of the evolution this system. the components of the double skin were then explained, followed by the operating mode of this type of facade. we also discussed the elements which influence the performance of the double skin, and finally the advantages and disadvantages of this system.

CHAPTER II:
SUSTAINABILITY AND THERMAL COMFORT

II.1 Introduction

The consumption and expenditure of energy in contemporary society have been increasing at a concerning rate.

In this chapter we were able to explore the definitions of thermal comfort while considering the fundamental criteria required for occupant perceived comfort. We further enumerated and reviewed the factors affecting thermal comfort by grouping them into their respective domain. Some of these factors were subjective factors while others were objective factors. Hence to synchronize these factors from different domain into a single evaluation could be a complex endeavour. We further studied and explore the various approaches developed by researchers to evaluated and predict thermal comfort. These approaches were grouped into the heat balance approach and the adaptive comfort approach. Considering the models and methods developed via these approaches, the adaptive thermal comfort approach was suitable for this research because it considers the psychological, socio-cultural and other physical adaptive factors as parameters required for the evaluation of thermal comfort. Among the adaptive comfort models studied, the adaptive predicted mean vote (aPMV) of Yao was adopted due to its relevance to the research objectives.

The principles and equations of the models were able to distinctly evaluate the physiological component and the adaptive component of thermal comfort and then integrate them into a single evaluation. Based on our interest in this model, it was reviewed and some of its parameters were modified and ameliorated to improve its accuracy and functionality. Thus, the (aPMV) model has the prospect to evaluate the psychological component of thermal comfort. This psychological component may be related to the thermal stimuli experienced by the occupants and the information in their memory system.

II.2 Sustainable development

Human activity is directly associated with environmental degradation and current climate change concerns. The Club of Rome, an international think tank, first questioned the economic blueprint for industrialized societies in 1968. In 1972, they published "The Limits to Growth," advocating for economic development and environmental protection. In 1984, the United Nations Assembly appointed Gro Harlem Brundtland to form the World Commission on Environment and Development (Brundtland Commission). The commission's work led to the release of the Brundtland Report "Our Common Future" in 1987, which introduced the concept of "sustainable development," defined as meeting present needs without hindering future generations. Today, the Brundtland Commission is recognized for promoting sustainable development values and principles.

During the 1992 Rio Earth Summit, states committed to sustainable development, aiming to meet current needs without compromising future generations' capacity. Sustainable development is based on environmental risk awareness and aims to reconcile ecological, economic, and social factors. It is based on three principles: considering the "whole life cycle" of materials, developing natural raw materials and renewable energy sources, and reducing materials and energy used in extraction, product use, and waste destruction or recycling.

The Kyoto Summit of 1996 aimed to address climate change, following the Rio Summit's social and cultural focus. The Kyoto Protocol committed nations to reduce average greenhouse gas emissions to 1990 levels from 2008 to 2012. Industrialized countries must reduce energy consumption, transition from fossil fuels to renewables, and implement carbon storage techniques. (Wong, 2008)

The Rio Declaration is linked to Agenda 21, a 21st-century plan that aims to:

- Protect the Earth's atmosphere and integrate land use.
- Combat deforestation.
- Preserve fragile ecosystems.
- Promote sustainable development within rural and agricultural contexts.
- Maintain biodiversity.
- Adopt an environmentally rational approach to biotechnology.
- Protect oceans and coastlines
- Safeguard water supplies and quality.
- Ensure the treatment of waste, including toxic chemicals, radioactive materials, dangerous waste, and solid waste, in an ecologically acceptable manner.

The World Summit on Sustainable Development in 2002 (Earth Summit 2002) took place in Johannesburg, South Africa. The participating countries reaffirmed their commitment to the Rio Declaration and Agenda 21 goals, promising to create national sustainable development strategies by 2005. The Kyoto measures will significantly affect land use, urban planning, and architecture, aiming to lower energy consumption, reduce greenhouse gas emissions, and minimize waste, particularly impacting the building and civil engineering sectors.

Sustainable development principles in building are an effective way to reduce the greenhouse effect and environmental destruction, based on three complementary tenets:

social equity, environmental caution, and economic efficiency. These principles are closely linked to environmental conservation. (Wong, 2008)

II.3 Energy consumption

In 2021, world primary energy consumption reached 171,650 TWh, twice as much as in 1980. Fossil fuels dominated the energy mix, with oil products (30%), coal (27%), and natural gas (24%) being the top three sources. Petroleum products' share fell by 14 points in 40 years, while natural gas and coal's share increased by 7 and 2 points, respectively. Biomass and waste's share remain stable at 10%, while hydropower's percentage is stable at 2.5%. Nuclear power's share increased by 1.6 in 40 years, reaching 5.0%. Other energies like solar, wind, and geothermal increased from 0.2% to 2.7%. (durable, n.d.)

Energy consumption exceeded historical norms in 2023. The G20 has been unable to effectively reduce energy intensity in order to align with the 2°C objective.

Although wind and solar energy production has increased, the proportion of renewables in the overall energy and electricity mix has only marginally improved, leading to a 1.7% rise in CO2 emissions. The reduction rate of the carbon factor is still inadequate to meet the 2°C target. (“Bilan énergétique mondial, édition 2024,” 2024)

Reducing CO_2 emissions necessitates a decrease in consumption and a transition from fossil fuels to renewable energy sources.

Among the three primary sectors contributing to pollution, the construction sector presents the most accessible opportunities for leveraging these two mechanisms. Renewable energy sources, characterized by their low and often intermittent output, such as solar and wind, are more readily harnessed by the construction sector than by industries that demand a steady and substantial power supply. (Daverat, 2012)

II.4 Comfort and energy

The growing focus on 'comfort' is driven by apprehensions regarding climate change. The indoor conditions that individuals have come to anticipate, along with the heating and cooling systems that facilitate these environments, place significant strain on global energy resources. The present standards of comfort are unlikely to remain viable in the future, particularly if their maintenance necessitates a greater reliance on air conditioning to counteract the impacts of global warming. Consequently, it is increasingly urgent to assess alternative concepts of comfort that could promote less resource-intensive methods of thermal regulation. (Chappells and Shove, 2004)

II.5 Thermal comfort

II.5.1 Definition of thermal comfort

II.5.1.1 Definition of comfort

The word comfort is derived from the Latin "Confortare" which means the strengthen, certify, corroborate, provide comfort, relieve, aid, and assist. (Y.-C. Hou et al., 2021)

Comfort is a concept that eludes precise definition and varies greatly from one individual to another. (Lin et al., 2023)

According to the dictionary "Larousse", comfort refers to all the commodities and amenities that produce material well-being. Well-being, ease brought by a clothing item, a piece of furniture, a vehicle, etc. Psychological, intellectual and moral tranquillity achieved by rejecting all preoccupations. ("Le petit larousse," 2010)

In addition, From the definitions given by the Cambridge Dictionary and the Oxford Languages, comfort is the state of being physically relaxed and free from pain, heat, cold, etc; the state of having a pleasant life, with everything that you need. ("comfort noun - Definition," 2025; "confort," 2025)

As indicated by Roulet, one of the key components of ensuring a high-quality indoor environment is satisfying the occupants' requirements, which in turn guarantees their comfort. Comfort is a subjective concept that encompasses a wide variety of sensations. (Roulet, 2008)

A state of physical and mental well-being, a sense of coziness, or a feeling of contentment may all be described by the term "comfort". The various interpretations of comfort have shaped indoor spaces and the thermal regulation strategies they represent. The definitions of comfort have evolved significantly over the past century, leading to substantial consequences for the management of indoor environments and the demand for energy. (Chappells and Shove, 2004)

In architecture, the notion of comfort within structures is primarily associated with sensory comfort, which can be categorized into various types, including visual comfort, acoustic comfort, thermal or hygrothermal comfort, and olfactory comfort, among others.

Thermal comfort refers to the state of not experiencing excessive heat or cold; aeraulic comfort pertains to maintaining acceptable or ideally pleasant indoor air quality; visual comfort involves creating an environment that is both clearly visible and aesthetically pleasing; and acoustic comfort ensures that the space is not overly noisy while allowing important sounds to be distinctly heard. (Roulet, 2008)

II.5.1.2 Thermal comfort definition

Thermal comfort is a complex and multi-dimensional concept, largely influenced by its subjective characteristics. Recognizing its importance, extensive research has been dedicated to this topic, with experts and researchers offering diverse definitions and perspectives over the years. (Mansouri, 2023)

Thermal comfort, according to Fanger (1970), is the state of mind that conveys contentment with the thermal surroundings. The goal is to establish ideal thermal comfort such that the largest proportion of a group experiences thermal comfort, taking into account the biological differences among individuals. (Wong, 2008)

Givoni (1976) defined thermal comfort as « *the absence of irritation and discomfort due to heat or cold, and as a state involving pleasantness* ». (Omoya, 2023)

According to O' Callaghan (1978), thermal comfort is the study of how human reaction is affected by climate. (Wong, 2008)

It is also defined by Hensen in 1991 as «*a state in which there are no driving impulses to correct the environment by the behaviour*». (Omoya, 2023)

ASHRAE present thermal comfort as « *That condition of mind that expresses satisfaction with the thermal environment. Because there are large variations, physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space* ». (ASHRAE Standard 55, 2022)

According to Roulet, the concept of thermal comfort refers to the satisfaction derived from an agreeable arrangement of temperature and heat distribution. (Roulet, 2008)

As indicated by Regnier in his report thermal comfort is an individual's subjective evaluation of their immediate thermal surroundings, reflecting their level of satisfaction with the temperature conditions they experience. (Regnier, 2012)

There are three persuasive reasons to acknowledge the importance of thermal comfort: (Boulebbina, 2022)

- To create an enjoyable atmosphere for individuals,

- To optimize energy consumption efficiently.

- To recommend and enforce recognized standards.

II.5.2 Thermal comfort in buildings

Currently, half of the global population resides in urban areas and spends nearly 90% of their time indoors. Structures are increasingly functioning as thermal machines designed to sustain climate conditions that are conducive to human comfort. People continuously respond to this environment, both consciously and subconsciously. (Batier, 2016)

The comfort of an indoor environment significantly influences individuals' emotional states. In office settings, optimal working conditions enhance our cognitive abilities and overall performance, while thermal comfort plays a crucial role in both well-being and productivity. Additionally, addressing potential health risks is essential for achieving ideal thermal comfort. (Crahmaliuc, 2016)

II.5.3 Parameters affecting thermal comfort

Thermal perception is influenced by the factors of thermal comfort within a specific environment and moment. The thermal balance between the body and its environment is influenced by environmental elements and personal characteristics, while the physical environment and spatial conditions are the main influencing factors. (Regnier, 2012; Mansouri, 2023; Omoya, 2023)

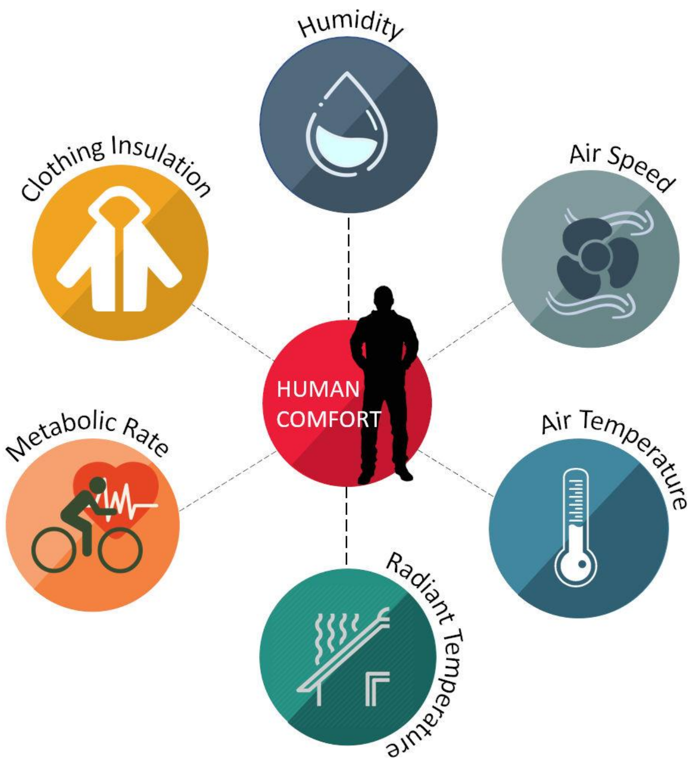


Figure II.1. Factors affecting human thermal comfort.

Source: *(Kumar, 2019)*

II.5.3.1 Environmental Factors

- **Air temperature:**

The ambient temperature (Ta) in degrees Celsius refers to the air temperature surrounding the occupants, influenced by both location and time. ("ANSI/ASHRAE Standard 55-," 2013)

The temperature of the surrounding air is the most significant factor affecting the thermal comfort experienced by the occupant. (Berkouk, 2017)

It helps to discern the variations in temperature between the human body and its immediate environment. (Omoya, 2023)

- **Mean radiant temperature**

It represents the average temperature of the surrounding surfaces, weighted by their solid angles, in relation to an occupant. Additionally, it serves as a method to convey how these surface temperatures affect the comfort of individuals within the indoor environment. (Omoya, 2023)

- **Relative humidity**

The relative humidity (RH) of the air is defined as the percentage ratio of the actual quantity of water vapor in the air at a specific temperature, Ta, to the maximum quantity of water vapor that the air can accommodate at that same temperature. (LIEBARD and de HERDE, 2005)

Relative humidity levels ranging from 30% to 70% have a minimal effect on the perception of thermal comfort; however, they remain significant because, under these temperature conditions, the primary mode of heat exchange occurs through evaporation from the skin's surface. Consequently, in a saturated environment where perspiration is no longer feasible, the body frequently experiences discomfort. (LIEBARD and de HERDE, 2005)

- **Air speed**

As defined by ASHRAE 2013 the air speed is the rate of air movement at a point, without regard to direction. ("ANSI/ASHRAE Standard 55-," 2013)

In residential environments, air velocity is required, ensuring it does not exceed 0.2 m/s. (LIEBARD and de HERDE, 2005)

ASHRAE standard 55-2017 stated that air velocity can be increased to adjust for ambient temperatures that beyond the upper limit of tolerable temperatures. (Mansouri, 2023)

II.5.3.2 Personal factors

- **Clothing insulation**

ASHRAE defined clothing insulation as « *The resistance to sensible heat transfer provided by a clothing ensemble (expressed in units of clo)* ». ("ANSI/ASHRAE Standard 55-," 2013)

Clothing serves as insulation, safeguarding the human body from external conditions and offering thermal resistance between the body and its environment. Consequently, clothing is a critical element influencing heat loss from the human body, which needs to be regulated to ensure a comfortable thermal state across various climates. The effectiveness of clothing insulation is quantified using a unit known as Clo. Specifically, 1 Clo represents the insulating capacity of an outfit that includes cotton undergarments, equivalent to the thermal resistance provided by a blanket covering the entire body, with a resistance value of 0.155 m^2K/W. (Boulebbina, 2022)

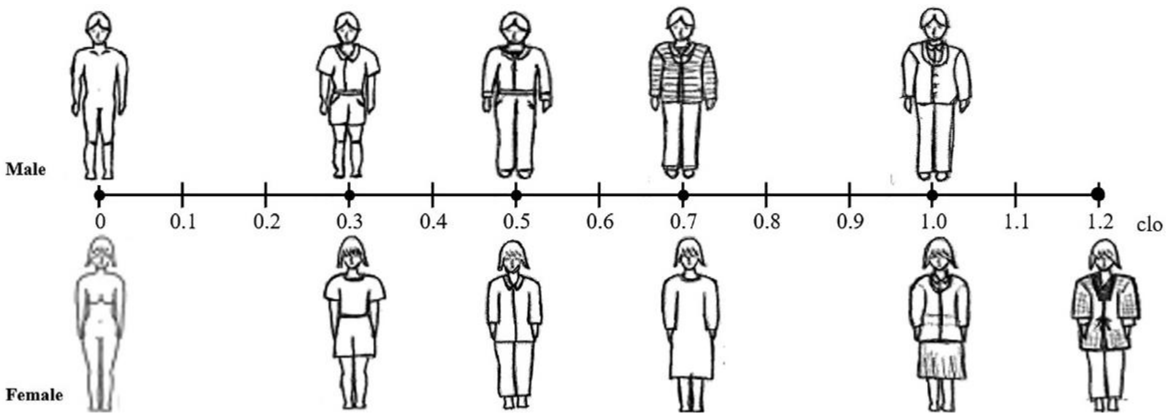


***Figure II.2**. Scale of clothing insulation.*

Source: (Rijal et al., 2019)

- **Metabolic rate**

The conversion rate of chemical energy into heat and mechanical work through an individual's metabolic processes, measured per unit of skin surface area, is determined to be 58.2 W/m² (equivalent to 18.4 Btu/h·ft²). ("ANSI/ASHRAE Standard 55-," 2013)

***Table II.1.** Metabolic rates for typical task.*

Source : (Arendt, 2012)

Activity	Met units	Metabolic rate [W/m^2]
Sleeping	0.7	40
Seated, reading, writing	1.0	60
Typing	1.1	65
Standing, relaxed	1.2	70
Walking on level surface (3.2 km/h)	2.0	115
Driving automobile	1.0-2.0	60-115
House cleaning	2.0-3.4	115-200
Handling 50 kg bags	4.0	235
Dancing, social	2.4-4.4	140-225

Figure II.3. *A chart showing the metabolic rates linked to various physical activities*

Source: (Jenkins, 2019)

II.5.4 Thermal discomfort factors

While overall thermal comfort may be attained, certain areas within buildings can still experience discomfort. An inconsistent thermal environment can lead to discomfort in specific body regions. This thermal dissatisfaction may arise from undesirable cooling or heating of particular body parts, such as the head, feet, or hands, due to air currents. Additionally, local discomfort can result from significant temperature disparities between the head and ankle, excessively hot or cold flooring, or uneven thermal radiation. Various factors can influence thermal comfort: (HEBBAL, 2022)

II.5.4.1 Effect of air currents:

Air currents can induce discomfort and a sensation of cold due to heightened convection between the skin and the surrounding air. The standards suggest maintaining an average air velocity of below 0.15 m/s during winter and 0.25 m/s in summer for individuals engaged in sedentary activities. (MAZARI, 2012)

II.5.4.2 Effect of asymmetric thermal radiation.

Radiation imbalances occur due to heated or cooled surfaces like warm ceilings or thermal glazing. A strong vertical temperature gradient can also cause discomfort, making the head feel warm while the feet stay cool, even if the body is thermally balanced. (MAZARI, 2012)

II.5.4.3 Effect of vertical thermal gradient.

The standard allows a maximum air temperature difference of 3°C between 0.1 m from the ground (ankle level) and 1.1 m from the ground (head level for a seated person). (MAZARI, 2012)

II.5.4.4 Effect of ground temperature.

Excessively high or low floor temperatures can cause foot discomfort. Research indicates that optimal floor temperatures for thermal neutrality are 23°C for standing individuals and 25°C for seated ones, with a dissatisfaction rate of at least 6%. (MAZARI, 2012)

II.5.5 Evaluation of thermal comfort in buildings

Evaluating thermal comfort within buildings enables the identification of internal conditions and environments, as well as the comfort levels experienced by occupants. A variety of methods have been established for this assessment, encompassing both subjective and objective measures, as well as quantitative and qualitative evaluations, employing diverse approaches and indices. (Mansouri, 2023)

II.5.5.1 Evaluation through thermal indices

Thermal indices are essential tools for describing, designing, and evaluating thermal environments. Givoni (1978) emphasized that human responses to thermal conditions cannot be accurately quantified using a single variable like temperature, humidity, or air velocity, as these factors interact and depend on each other. Therefore, it is necessary to assess the combined effect of environmental factors on the body's physiological and sensory responses in a single parameter.

The use of thermal indices in scientific literature varies, with different studies using different indices to assess thermal comfort, such as Hill, Barnard, and Sequeira's 1897 work was based on heat transfer theory, while Winslow, Herrington, and Gagge's 1937 study focused on operative temperature indices. More recently, Fanger's 1970 research introduced the predicted mean vote (PMV) index, and ISO (2005) included average predicted percentage dissatisfied (PPD) and cumulative PPD measures. The subsequent indices are the primary ones frequently utilized. (Mansouri, 2023)

II.5.5.1.1 Environmental models

Several physical environmental factors and indices have been developed to facilitate an easy evaluation of thermal comfort. (Mansouri, 2023)

- **Effective temperature:** Givoni (1978) defines this index as a combination of temperature, humidity, and air velocity, requiring specific comfort limits for each region, ideally between 22 to 27°C. This is calculated through the interaction of wet and dry bulb temperatures and air speed.
- **Equivalent temperature:** This index considers air temperature, radiant temperature, and air velocity.
- **Operative temperature:** Known as perceived comfort temperature or resultant dry temperature, it is calculated by averaging air and surface temperatures: Operative temperature = (Ambient temperature + Surface temperature) / 2.
- **Resultant temperature:** Established through experiments that reach thermal equilibrium between the body and its surroundings.

II.5.5.1.2 The PMV and PPD indices

Fanger (1970) created the two indices: PPD (Predicted Percentage of Dissatisfaction) predicts the percentage of unhappiness with the thermal environment, whereas PMV (Predicted Main Vote) forecasts the average thermal sensation of a group of people. (Mansouri, 2023)

- **The PMV indice**

In practical evaluations of thermal conditions within a space, it is frequently beneficial to evaluate the level of discomfort experienced by occupants. To facilitate this, the PMV-index (Predicted Mean Vote) has been developed. This index uses the psycho-physical scale in Figure below (Figure II.4) to provide a subjective thermal response of a large number of participants.

The PMV index estimates the average thermal sensation of an experienced by a large group of people in a shared environment. However, individual thermal sensations vary around this average, making it important to anticipate the number of people who may experience discomfort due to excessive warmth or coolness. These thermally dissatisfied individuals are often the ones who voice complaints about their surroundings. PMV values vary between -

3 and 3 on the thermal sensation scale. ("https://www.bksv.com/media/doc/BO0016.pdf," n.d.)

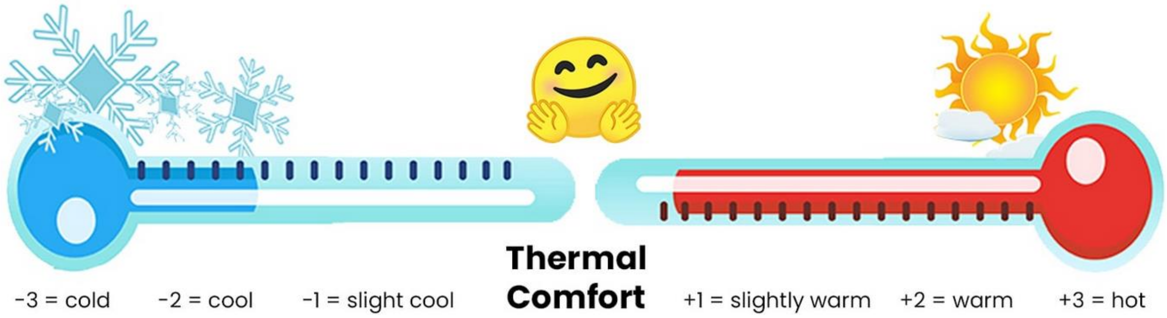


Figure II.4. *Rating Scale of Thermal Comfort.*

Source: ("What is thermal comfort?," 2023)

The PMV equation can be expressed in accordance with the standard (ISO 7730) as follows:

PMV = (0.303e-0.036M + 0.028) {(M – W) – 3.05 × [5.733 – 0.007 (M – W) – pa] – 0.42 × [(M – W) – 5815] – 0.0173 × M (5.87 – pa) – 0.0014 × M (34 – ta) – 3.96 × 10-8 × fcl × [(tcl + 273)4 – (tr+273)4] – fcl × hc (tcl – ta)} (Wong, 2008)

- **The PPD indice**

The Predicted Percentage of Dissatisfaction is defined by ASHRAE as « *An index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV*». ("ANSI/ASHRAE Standard 55-," 2013)

The PPD index (Predicted Percentage of Dissatisfied) provides a quantitative estimate of the number of individuals likely to experience thermal discomfort. It forecasts the proportion of a sizable population that may report feelings of thermal unease, categorized as voting hot (+3), warm (+2), or cool. Once the PMV values are established, the corresponding PPD can be derived. This index indicates the expected number of individuals who will be thermally dissatisfied within a larger group, while the remainder will report feelings of thermal neutrality, slight warmth, or slight coolness. (b00016) ("https://www.bksv.com/media/doc/BO0016.pdf," n.d.)

It can be determined using the following equation:

PPD = 100 – 95exp [- (0,03353 PMV4 + 0,2179 PMV2)]

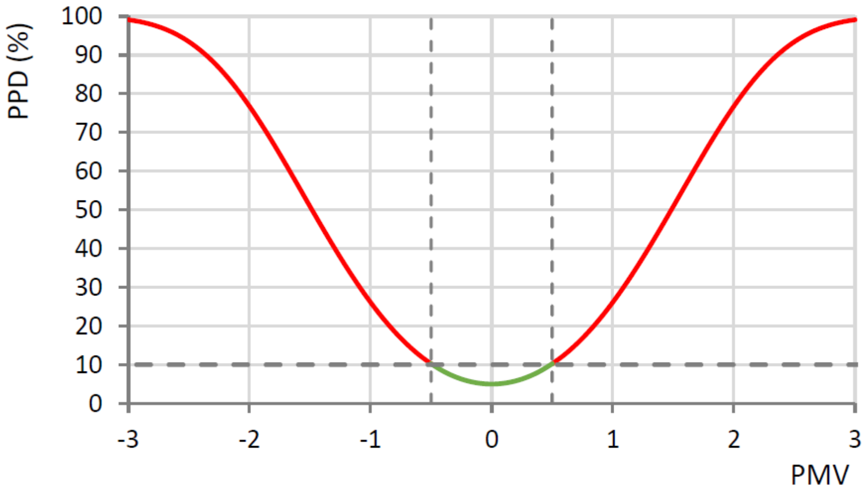


Figure II.5. *The percentage of PPD in relation to PMV.*

Source: (Batier, 2016)

In this context, the ISO 7730 (2005) standard defines the thermal comfort zone using the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD). The comfort zone is characterized by a PMV range of -0.5 to 0.5, corresponding to a PPD of less than 10%. (Mansouri, 2023)

II.5.5.2 Evaluation using graphic tools

Various graphical tools have been created to evaluate thermal comfort and analyze the effects of climate conditions on buildings. These include bioclimatic diagrams, which help identify key architectural strategies for thermal comfort and climate considerations. Notable examples are the Olgyay bioclimatic diagram, the Givoni diagram, the Mahoney tables, and the Szokolay method.

Olgyay's diagram, created in 1953, is regarded as the first bioclimatic diagram. According to Givoni (1976), it pioneered a systematic method of tailoring building design to human requirements and climatic factors. The technique establishes the human comfort zone based on ambient air temperature and humidity, locating it centrally while detailing separate winter and summer ranges that account for seasonal adaptation. (Mansouri, 2023)

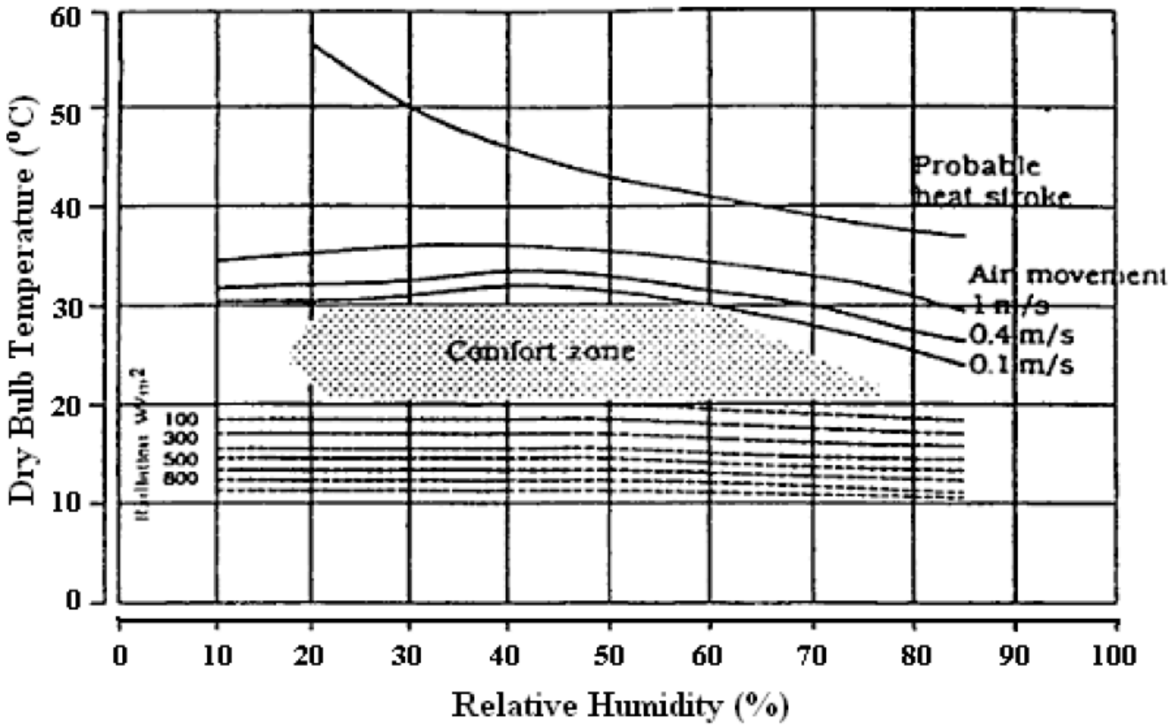


Figure II.6. *Olgyay's Bioclimatic Chart.*

Source: (N. Al-Azri et al., 2012)

The Givoni diagram serves as a psychometric tool that assesses the thermal comfort of individuals by analyzing the ambient air's temperature and humidity. This diagram identifies the comfort zone for a specific duration and outlines the necessary heating and cooling measures to sustain optimal comfort levels.(Mansouri, 2023)

Givoni's chart delineates appropriate cooling methods according to the prevailing outdoor climate. It categorizes five distinct zones: thermal comfort, natural ventilation, high mass, high mass with night ventilation, and evaporative cooling. (N. Al-Azri et al., 2012)

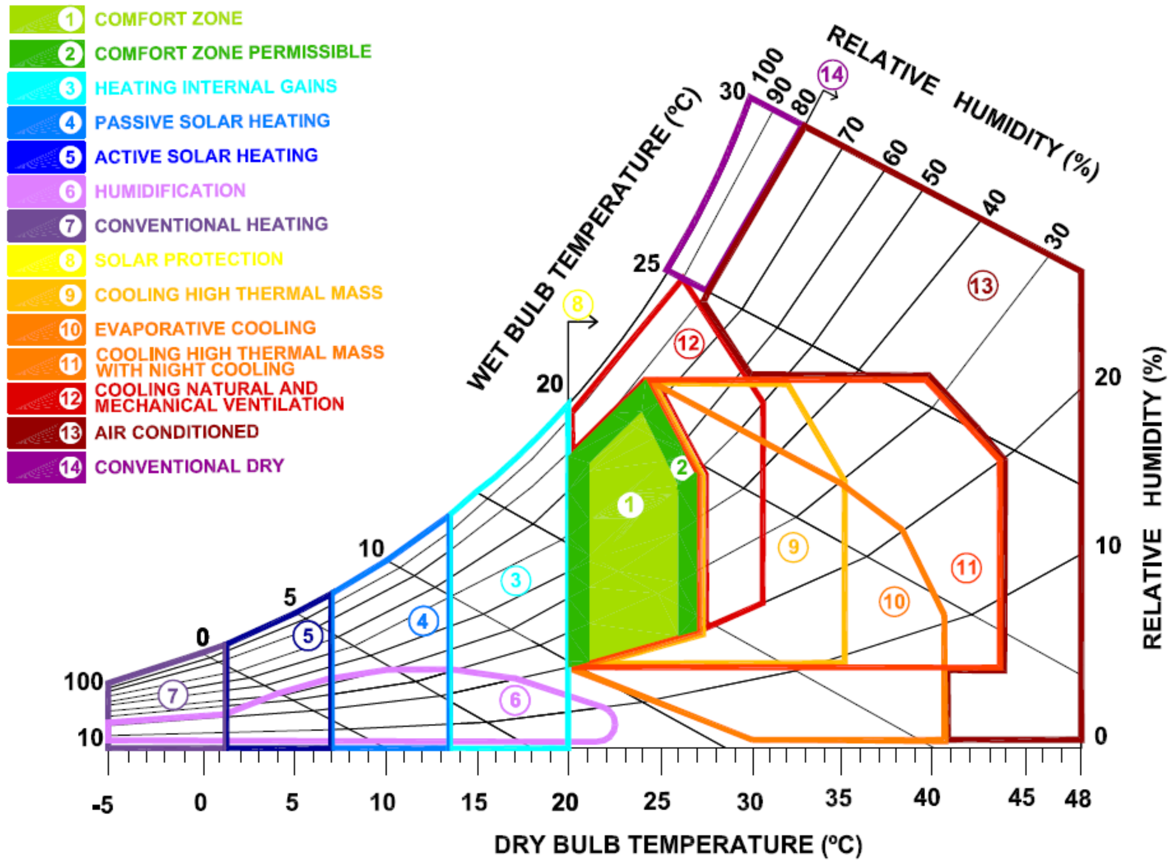


Figure II.7. Psychrometric chart adapted from Givoni.

Source: (Manzano-Agugliaro et al., 2015)

II.5.5.3 Evaluation by on-site survey

In situ studies play a crucial role in evaluating thermal comfort within buildings, as they examine the subject in real-time conditions. These studies may encompass various methods, including physical measurements, surveys, observations, and interviews. Fabbri (2015) notes that the earliest in situ survey was conducted by Bedford in 1936, who assessed the thermal environment experienced by approximately 2,500 workers in a British industry through a questionnaire focused on thermal comfort, utilizing the thermal sensation scale. (Mansouri, 2023)

Nicol (1993) proposed a three-tier classification framework for in situ surveys, which is outlined as follows:

Level 1 focuses on gathering physical measurements of air temperature, potentially including air humidity, at a specific site within a building over a defined period. This data collection employs a range of instruments and devices, yielding objective and quantitative results.

Level 2 involves subjective evaluations obtained through conventional questionnaires that assess thermal comfort. These assessments are conducted concurrently with the measurement of various physical parameters of the thermal environment, such as air temperature, radiant temperature, air velocity, and humidity. The subjective evaluations employ judgment scales, including perception votes, evaluation votes, and preference votes. Level 3 addresses the evaluation of the clothing and activity levels of the participants, which enables the calculation of various comfort indices, notably the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD). The comfort levels indicated by these indices can be compared to the actual comfort experienced by the subjects in situ. (Mansouri, 2023)

II.5.5.4 Evaluation by digital simulation

This evaluation approach emerged alongside advancements in digital modeling systems, which utilize software to replicate various building behaviors. This innovation simplifies the process of modeling and simulating the diverse elements and variables associated with structures. (Mansouri, 2023)

II.5.6 Thermal comfort standards

The concept of thermal comfort within buildings has generated considerable discussion, leading to the establishment of limit or guideline values by numerous professional organizations, which have subsequently been integrated into legal frameworks over time. Several international standards have played a crucial role in enhancing the understanding of thermal comfort, with the objective of ensuring ideal indoor conditions for occupants. (Mansouri, 2023; Wong, 2008)

II.5.6.1 The ISO standard

ISO, the International Organization for Standardization, serves as a global federation comprising national standards organizations. Throughout the years, ISO has introduced several standards related to building heating and thermal comfort. (Mansouri, 2023)

- **ISO 7243,** Ergonomics in High Temperatures: Evaluating Thermal Stress in the Workplace.
- **ISO 7726**, which focuses on the ergonomics of thermal environments, provides guidelines for instruments designed to measure various physical parameters.

- **ISO 7933**, dedicated to the ergonomics of thermal environments, offers a systematic framework for assessing and understanding thermal stress by calculating expected thermal conditions.
- **ISO 8996,** relates to ergonomics in thermal environments, with a particular emphasis on evaluating energy metabolism, outlines six methods for estimating metabolic heat production.
- **ISO 9920,** ergonomics of thermal environments: specifically focusing on the assessment of thermal insulation and the resistance to evaporation provided by clothing. It contains a detailed database of clothing thermal properties based on measurements from heated manikins
- **ISO 10551**, focuses on the ergonomics of thermal environments by evaluating the impact of these environments through the use of subjective judgment scales.
- **ISO/TR 11079,** Evaluation of cold environments: Establishing the necessary insulation for clothing.
- **ISO 7730, 1994:** has been updated to include a long-term assessment method, insights on local thermal discomfort, variable thermal conditions, and adaptation strategies. A detailed annex now categorizes thermal comfort requirements.
- **ISO 7730, 2005:** is based on the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) indices developed by Fanger in 1970. It also provides methods for assessing local discomfort caused by draughts, uneven radiation, and temperature fluctuations. (Mansouri, 2023; Wong, 2008)

II.5.6.2 ASHRAE Standard

ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers)

In the mid-20th century research on thermal comfort in Europe and the United States primarily involved climate chamber experiments. ASHRAE Standard 55, introduced in 1966, addresses Thermal Environmental Conditions for Human Occupancy using a thermal-balance model of the human body. It identifies six key variables affecting thermal comfort: air temperature, radiation, relative humidity, air movement, clothing, and metabolic rate.

The standard aims to provide an objective criterion for thermal comfort by defining personal and environmental factors that can ensure an acceptable indoor thermal environment for at least 80% of occupants. It characterizes thermal sensation as a conscious feeling commonly graded into categories of cold to neutral to hot.

Originally, ASHRAE Standard 55 was designed to guide centrally controlled HVAC systems, its broad application has hindered the development of personalized thermal regulation strategies in naturally ventilated or mixed-mode buildings, which could enhance occupant satisfaction and productivity while reducing energy consumption, particularly in office settings.

The standard is updated every 3 to 7 years based on current research, practical experience, and recommendations from designers, manufacturers, and end-users. The most significant iterations of the standard include the revised editions from 2004, 2010, and 2017.

- **ASHRAE 55-2004:** recognized the high-speed preference for general comfort temperature, adopted the computer model technique, and provided an adaptive research-based strategy that promotes natural ventilation designs.
- **ASHRAE 55-2010:** has reestablished the Standard Effect Temperature (SET) as a means to evaluate and quantify the cooling impact of elevated air velocities and overall indoor air circulation.
- **ASHRAE 55-2017:** introduces an innovative component that considers the impact of direct solar radiation on the thermal comfort of occupants.

II.5.7 Standards and regulations in Algeria

Algerian building regulations categorize documents into four distinct levels.

Level 1 encompasses decrees, orders, and circulars, which outline the general requirements applicable to residential and administrative structures.

Level 2 includes standards or calculation rules, designed to establish the fundamental principles that should be followed during the development of building projects.

Level 3 pertains to execution standards that guide the implementation of construction practices.

Finally, Level 4 consists of quality standards that govern the materials, products, and components used in construction. (“http://revue.enstp.edu.dz/files/article/28/article%208.pdf,” n.d.)

In the realm of building thermal efficiency, a foundational regulatory document addressing winter thermal challenges was developed at CNERIB, driven by the Ministry of Housing. This level 2 regulatory text received approval in January 1997 from a specialized technical group (GTS) and is known as the regulatory technical document (DTR C 3-2) titled ‘Thermal

Regulation of Residential Buildings - Guidelines for Calculating Heat Losses.' Aligned with international standards, the DTR introduces a streamlined approach for assessing heat loss. ("http://revue.enstp.edu.dz/files/article/28/article%208.pdf," n.d.)

The National Centre for Integrated Building Studies and Research (CNERIB) has reported that the Algerian government has enacted a policy aimed at enhancing the management of energy resources. This initiative is encapsulated in Law No. 99-09, established on 28 July 1999, which focuses on energy management, alongside Executive Decree No. 2000-90, issued on 24 April 2000, which outlines thermal regulations for new constructions. Presently, Algeria adheres to the thermal regulation DTR C3.2/4, necessitating distinct compliance assessments for both winter and summer seasons. (Mansouri, 2023)

II.6 Impact of the building envelope on thermal comfort

The envelope of a building is the structural feature that isolates the heated volume from the surrounding environment.

Its major role is to shield its inhabitants from outside threats (climate and noise). Its performance is judged on the one hand by its capacity to handle internal and external passive contributions, and on the other by the amount of comfort it provides to its users. The perception of comfort is often stated in terms of thermal, auditory, visual, and hygienic parameters. ("E-learning," n.d.)

The building envelope, which includes walls, roofs, floors, and openings, is crucial for ensuring thermal comfort as it acts as a barrier between the building's interior and the outside environment. It must not only serve its structural purpose but also withstand thermal and environmental pressures. Key factors that greatly influence this goal include the design and selection of materials for the envelope. (Bahrar, 2018)

Selecting materials based on their thermal properties, including insulation and thermal inertia, plays a crucial role in enhancing the efficiency of the building envelope. Effective thermal insulation minimizes heat loss during winter months, consequently lowering heating demands. Furthermore, high-quality insulation, when paired with external solar shading, aids in preventing excessive heat accumulation in the summer. Additionally, while this is not an exhaustive enumeration, other elements that significantly influence the energy efficiency of the structure include the orientation of the façades and a compact architectural design.

Concurrent with these investigations, a number of writers have shown interest in how thermal inertia affects a building's energy efficiency.

When calculating the value of thermal inertia, external climatic factors like sun radiation and temperature fluctuations must be considered. By storing daily solar gains, thermal inertia, when combined with high-performance insulation, helps lower winter heating energy usage. Additionally, thermal inertia has the effect of reducing the issue of summertime overheating by offering a phase shift for peaks in interior temperatures. According to research by Kossecka and Kosny (2002), high-inertia materials should be positioned within the building envelope, with an emphasis on external insulation. In light of this, phase-change materials are used to increase thin walls' thermal inertia. (Bahrar, 2018)

Optimal indoor environmental quality and thermal comfort for individuals within a building may be maintained via the use of both passive and active measures.

Passive measures include architectural and structural thermal protection strategies including passive solar heating, passive cooling, solar protection, internal heat gain, thermal insulation of the envelope, and thermal inertia of the envelope components. Quality of comfort is also significantly influenced by the way the space is laid out. The following illustrates both hot and cold techniques. (“E-learning,” n.d.)

Active measures should ideally be implemented alongside passive measures. These measures utilize technologies that ensure thermal comfort through mechanical means, including heating and cooling systems. (“E-learning,” n.d.)

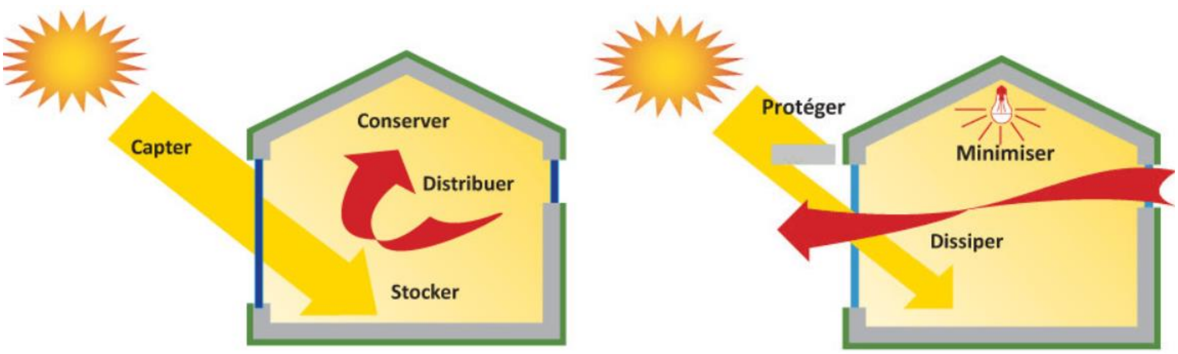


Figure II.8. *Passive hot and cold strategies.*

Source: (“E-learning,” n.d.)

II.7 Double skin facade and thermal comfort

High-quality façade systems require the careful selection and application of top-quality materials, state-of-the-art technologies, and meticulous detailing and installation tailored to the unique context and purpose. An elegantly crafted facade not only shields a structure from the sweltering summer heat but also curtails heat loss in the winter months while harnessing natural elements for optimal heating, cooling, and illumination. Recently, there has been a surge in research and innovation surrounding building facades, especially glazing systems, owing to their remarkable potential to enhance energy efficiency and mitigate the environmental footprint of architectural designs. (Naddaf and Baper, 2023)

Double-skin façades provide demonstrable energy efficiency benefits, including a significant decrease in heating and cooling requirements, due to the cavity's natural thermal control.

In terms of interior comfort, regulated ventilation controls thermal changes and efficiently renews the air, resulting in a more constant temperature and higher air quality. (“Tout savoir sur la façade double peau,” n.d.)

The thermal performance of a system refers to its capacity to adapt to the surrounding environment in a manner that effectively maintains the intended indoor thermal conditions. This involves minimizing heat loss during heating periods and preventing excessive heat during cooling periods. Various design elements play a role in this, including the type of climate and geographical location, the height of the building, the orientation and type of double-skin facade (DSF), the geometry and arrangement of the DSF cavity, the materials used for the external and internal glazing, the presence of perforated ventilated facades, and the implementation of shading devices. It is important to recognize that the performance of DSF technology is not constant; it fluctuates throughout the day, with certain periods experiencing no ventilation at all. (Pelletier et al., 2023)

Heat transfer transpires concurrently across all layers of the double-skin façade, influenced by external environmental factors, the characteristics of the façade layers, and the integrated ventilation system. The air gap between the double skins experiences heightened overheating during elevated ambient temperatures, which can be mitigated by adjusting the openings of the glazing façade, strategically placing shading devices, and optimizing the width of the air gap between the glazing panels. (Wong, 2008)

II.8 DSF and thermal comfort - the state of the art

According to the research conducted by Heinberg et al. (2007), an energy-efficient building envelope is intricately designed with thermal and air barrier components. The findings suggest that the installation of appropriate insulation materials is crucial for establishing an effective thermal barrier; conversely, the use of inadequate insulation can lead to a staggering 30 percent reduction in a building's energy performance. Thus, to achieve a design that maximizes energy efficiency, a comprehensive layer of insulation must envelop the entire structure. Furthermore, as noted by EREC and NREL (2000), the key components of an energy-efficient building include walls, roofs, windows, insulation, air vapor retarders, and caulking. This study emphasizes that the thermal envelope serves to shield indoor environments from external conditions. Additionally, it highlights that energy-efficient buildings typically possess a high R-value, which measures a material's resistance to heat transfer. A low R-value, on the other hand, can result in rapid heat loss. (Daneshkadeh, 2013)

Numerous research studies advocate for the implementation of double-skin facades as a means to mitigate heat gains, thereby enhancing the energy efficiency of low-energy buildings. Shameri et al. specifically highlight the adoption of double-skin facades as a viable strategy for achieving energy conservation in architectural design. Essentially, the concept of double-skin facades (DSFs) involves the integration of two façade layers separated by an air gap or cavity. Gratia elaborates that the evolution of double-skin facades stems from the idea of a façade constructed entirely of glass. Conversely, the research conducted by Mingotti et al. emphasizes the necessity for adaptable openings in both the external and internal layers of DSFs to facilitate adequate air circulation within the cavity and maintain a comfortable atmosphere in the adjacent interior spaces. Consequently, it is evident that temperature regulation and air circulation are intrinsically linked to the dimensions of the cavity; thus, studies by Balocco and Colombari and Balocco indicate that a reduction in cavity width significantly increases the likelihood of overheating in the façade layer, particularly during the summer months. Nevertheless, double-skin facades present an opportunity to incorporate an additional glazing layer, which can enhance visual comfort, improve daylight access, and contribute to superior energy performance. The integration of external and internal façade layers in DSFs also influences the greenhouse effect. Furthermore, regarding the sustainable energy performance of DSFs, Chan et al. illustrate the dynamics of heat transfer and air movement within a section of a DSF. It is crucial to acknowledge that air movement within DSFs is adaptable to meet environmental demands; thus, Haase et al. categorize five distinct types of air movement applicable to DSFs.

In addition to the advantages of double-skin facades, Yilmaz and Cetintas emphasize other beneficial aspects such as sound insulation and improved aesthetic qualities, alongside their sustainable energy performance. Likewise, Byrd and Leardini underscore the function of double-skin facades in noise reduction, while contending that, despite the frequently highlighted advantages of these systems in terms of energy efficiency, quantifying their effectiveness remains challenging, as noted by the Lawrence Berkeley National Laboratories. Conversely, other research has definitively demonstrated the efficacy of double-skin facades in lowering energy consumption, particularly concerning cooling requirements. Consequently, it is suggested that further investigation is necessary to analyze, verify, and potentially enhance these facades to optimize building energy performance. Historically, these facades can also be categorized based on their construction types and ventilation conditions. In terms of construction, they can be classified as continuous or interrupted, while regarding ventilation, they are divided into naturally ventilated, mechanically ventilated, and those employing both methods. Research by Yilmaz and Cetintas, along with Chou et al., indicates that during summer, the primary benefit of double-skin facades is the reduction of solar heat gain, whereas in winter, they contribute to minimizing heat loss and improving thermal performance. Høseggen et al.'s study further supports this by showing that simulations comparing single and double-skin facades confirm that the implementation of double-skin facades leads to a decrease in heating energy demand within buildings. (Ahmed et al., 2015)

II.9 Conclusion

Thermal comfort has been defined as a state of mind and a feeling of environmental thermal satisfaction, making it a highly subjective concept that is complex to assess and achieve. The state of thermal discomfort leads space users to try to cope and achieve thermal comfort through the use of energy by HVAC systems. Excessive use of HVAC systems, which is very common especially in regions with difficult and extreme climatic conditions, negatively affects the energy performance of the building and makes it look energy-intensive. A global orientation towards energy-efficient buildings has emerged to ensure thermal comfort for the building user and a low-energy building through the adoption of different energy efficiency programmes and the application of different strategies on the building envelope to meet the challenge of a climatically integrated and energy-efficient architecture.

CHAPTER III: CONTEXT AND CASE STUDIES

III.1 Introduction

This chapter is devoted to presenting the context of the study along with the three edifices selected as case studies for this research work. We will commence by introducing the city of Constantine, which acts as the backdrop for our investigation. We will accompany this with a brief historical overview and a summary of its climatic conditions. We will then clarify the reasoning behind our choice of case studies, followed by a presentation of the three buildings selected for analysis.

III.2 Presentation of the city of Constantine

« *Constantine has no need for presentations. She presents herself and is duly greeted. She discovers herself and we discover ourselves. She bursts out like a flash at dawn and plays her light along the horizon that she astonishes and arouses* » (Haddad, 1966) that's how Malek Haddad describes Constantine. Also, Guy de Maupassant said « *And here is Constantine, the phenomenal city, Constantine the strange, guarded as if by a serpent coiled at its feet, by the Rhumel, the fantastic Rhumel, a hellish river, flowing at the bottom of a red abyss, as though eternal flames had burnt it* » (Merdaci, 2015)

Magnificent on a rock that is more than 600 meters high. It is traversed by the Rhummel River and encircled by extensive gorges. Because of all of this, it has the strength of an invincible city and provides an incredibly interesting historical and archaeological itinerary. (Benterki, 2016)

Unlike other towns across the world, Constantine is built on a strong limestone foundation. Throughout various historical periods, multiple bridges have been established to facilitate movement from one location to another, leading to its designation as 'the suspended city.' ("Constantine | PDF," n.d.)

Figure III.1. *Constantine.*

Source : ("Visiter Médina de Constantine - Préparez son voyage en Algérie," n.d.)

III.2.1 Geographic location

Constantine is a town in northeastern Algeria (***Figure III.2***). It has a latitude of 36.17 North and a longitude of 07.23 East, with an altitude of 694 m above sea level. It is located roughly 430 km away from Algiers, the capital, and 80 km away from the coast. It occupies a pivotal geographical location between the Tell and the High Plains, equidistant from the littoral to the north and the Aures Massif to the south.

With a total area of 2,278.20km², as shown in (***Figure III.3)*** the town is bounded to the north by the wilaya of Skikda, to the south by the wilaya of Oum El Bouaghi, to the east by the wilaya of Guelma, and to the west by the wilaya of Mila. ("Notre Wilaya - Direction du Tourisme et de l'Artisanat Constantine," 2021)

The wilaya of Constantine is divided into six daïra capitals, or twelve municipalities, according to the most recent administrative division.

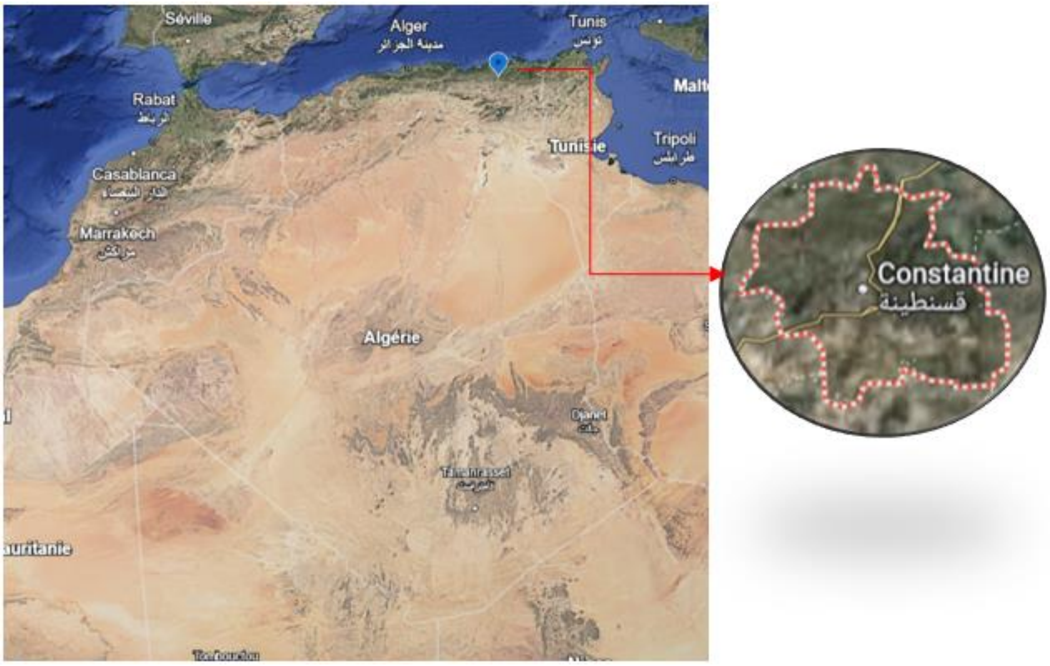


Figure III.2. *The location of Constantine.*

Source: ("Google Maps," n.d.)

Figure III.3. *Constantine within geographical surroundings.*

Source : (Benterki, 2016)

III.2.2 Historical overview of Constantine

Constantine, one of the oldest cities in the world, known as Cirta before, crossed the thresholds of prehistory. Australopithecines are believed to have inhabited the Mansourah plateau for approximately one million years, with their tools being unearthed following the discovery of faceted spheroids in 1945. During the Palaeolithic period (45,000 BC), Neanderthals built enduring dwellings within caves, notably the Mouflon and Ours caves located at the foot of Sidi M'Cid's northern incline.

During the Capsian period, which spanned approximately from 14,000 to 9,000 BC, the Pigeons cave, situated beneath the Boulevard de l'Abîme near the lift, was likely utilized as a refuge by the residents of the Ours and Mouflon caves. Various tools originating from the Neolithic period, approximately between 10,000 and 2,000 BC, have been discovered at this location. The megalithic civilization has left numerous remnants in this area, including dolmens and various monuments. From the Metal Age, artifacts such as a bronze punch and an iron club have been unearthed. Subsequently, the site was inhabited by eight distinct civilizations: Numido-Berber, Phoenician, Roman, Byzantine, Arab, Turkish, French, and Arab-Berber, particularly following the incursion of the Vandals in 429. ("APERCU HISTORIQUE : DE CIRTA A CONSTANTINE.," n.d.)

Constantine received a distinguished status by the Numidian Carthaginian and Numidian Roman civilizations. It served as the capital of the Massyls in the east.

A city with a remarkable history that was minimally changed by the Vandals and the Byzantines. It endured and flourished with the emergence of Arab Islamic civilization in the seventh century, particularly during the Fatimid and subsequently the Hammadid periods, which significantly shaped the city's developmental trajectory.

Numerous iconic structures were constructed within it, enhancing its renown. Regarding its Kasbah, that beautiful creation of the Almohad constructed atop the remnants of the Roman Capitol, it stands as a small enclave within the vastness of the larger city.

The Hafsids (11th to 13th century), deeply invested in the cultural evolution of the city, saw its influence radiate throughout the Maghreb. (Redjel and Benssedik-Bdeir, 2015)

During the Ottoman era (1515-1830), successive rulers prioritized culture, each contributing their unique influence to the artwork of Constantine. During the era of Ahmed Bey, the most recent bey of Constantine, we observed the decline of this dynasty. He strongly resisted the initial French incursion in 1836, and in 1837, Cirta faced a siege. The French colonisation for 130 years left one of the oldest cities in the world with a majestic European city centre as a legacy, showcasing neoclassical features that enhanced its rich architectural heritage, marking the conclusion of a tumultuous history that will forever be embedded in the cobblestones. (Kermiche, 2015)

After the independence in 1962, the city has emerged as Algeria's third largest in population, earning the reputation of the 'capital of the east'.

III.3 Climate in Constantine

Algeria's climate is divided into four distinct climatic zones (A, B, C, and D), each with two sub-zones designated for winter heating assessments, alongside four climatic zones and four sub-zones tailored for summer air conditioning evaluations, in accordance with the thermal regulations DTR 3.2 and DTR 3.4. For this study, the city of Constantine, situated in Zone B, has been chosen. This city experiences a semi-arid climate. The attributes of the selected city are illustrated in Table III.1. ("DTR/Document Technique Règlementaire. Réglementation thermique du bâtiment," 2016)

Table III.1. *Characteristics of Zone B.*

Source:("DTR/Document Technique Règlementaire. Réglementation thermique du bâtiment," 2016)

Climate zone	City	Global monthly horizontal radiation (kWh/m2)	Horizontal monthly diffuse radiation (kWh/m2)	Monthly direct radiation (kWh/m2)	Basic external temperature (° C)
Zone B	Constantine Alt :694 Long:6.37 E Lat:36.17 N	Max : 227 Min : 53 Total annual: 1649	Max : 90 Min : 34 Total annual: 733	Max : 208 Min : 40 Total annual: 1496	Tbe hiver : 01 Tbe été : 37 Moy. annuel: 15.4

III.3.1 Air temperature

According to the graphs (***Figure III.4***), the coldest months in Constantine are January and February, with daily temperatures not exceeding 18°C in winter and night temperature below 0°C. On the other hand, the temperatures go above 40 degrees Celsius during the months of July and August, marking them as the hottest months of the year.

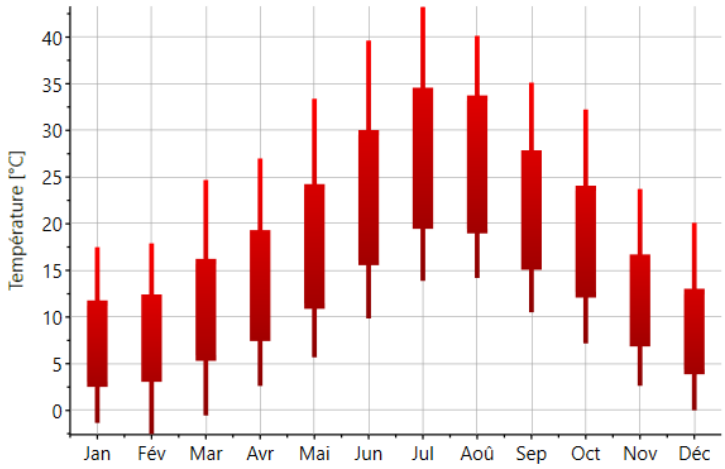


Figure III.4. *Monthly air temperature of Constantine.*

Source: ("Meteonorm 8," n.d.)

III.3.2 Relative humidity

The annual relative humidity typically varies from 60 to 80%, while in summer it falls between 20 and 40%, and in winter it exceeds 60%. The peak value occurs in December, reaching approximately 90%, whereas the lowest point is observed in July, at around 30%.

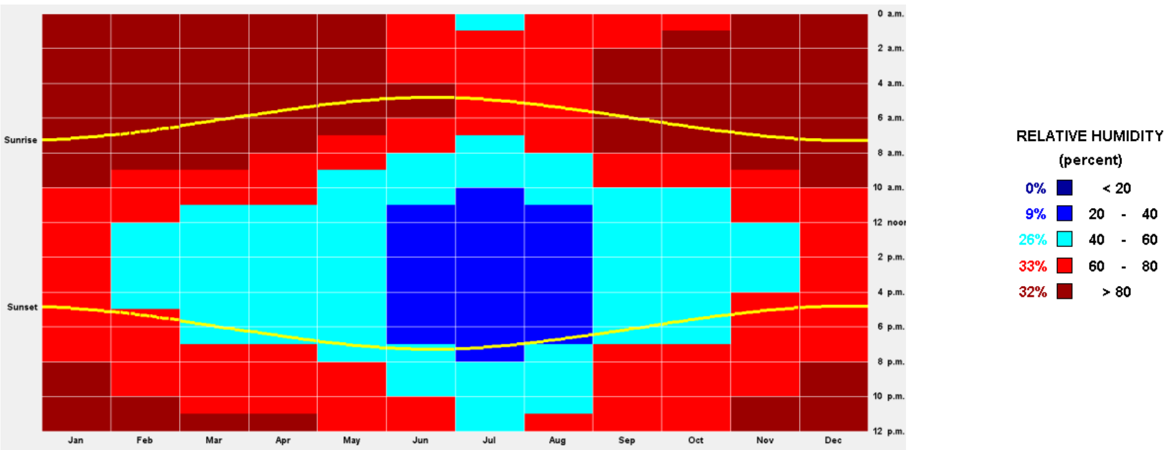


Figure III.5. *Monthly relative humidity of Constantine.*

Source: ("Climate Consultant 6.0," n.d.)

III.3.3 Precipitation

In a year, there is an average of 500 mm of precipitation, which is spread out over approximately 70 days. The months of December and January are the wettest months; both receive an average rainfall of 65 mm, whereas the months of June (11 mm) and July (17 mm) are the driest months.

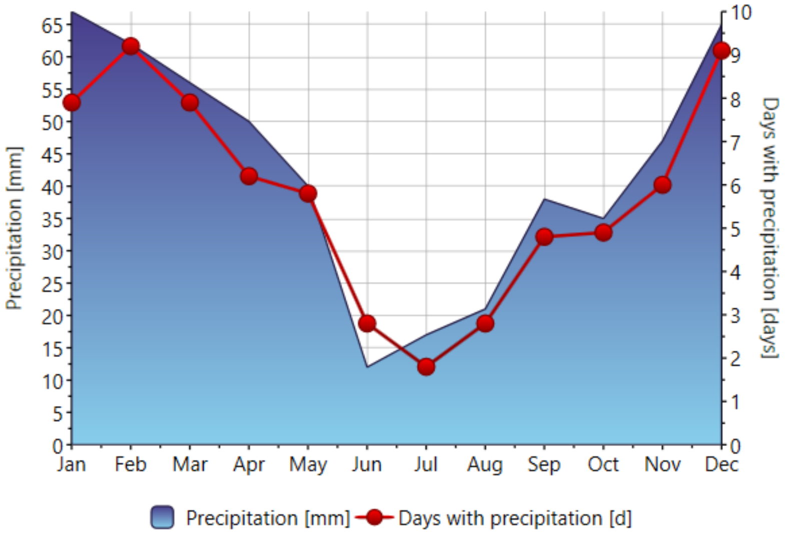


Figure III.6. *Monthly precipitation of Constantine city.*

Source: ("Meteonorm 8," n.d.).

III.3.4 Wind velocity

The mean yearly wind velocity in Constantine is approximately 2.5 m/s. In Constantine, the mean yearly wind velocity is approximately 2.5 m/s. September and October exhibit the lowest speeds, while March, April, and November demonstrate the fastest speeds. The maximum speed attained is approximately 15 m/s.

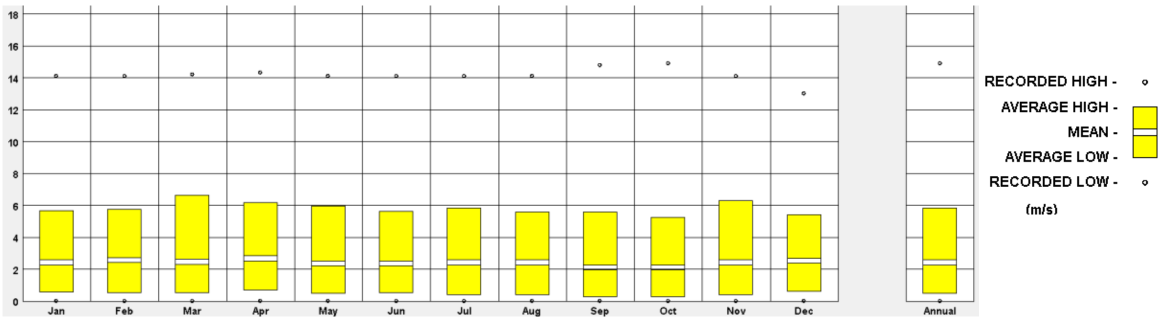


Figure III.7. *Monthly wind velocity of Constantine.*

Source: ("Climate Consultant 6.0," n.d.)

III.3.5 Insolation

The figures (***Figure III.8, Figure III.9***) indicate that global radiation fluctuates between 2 and 3 KWh/m2 in the winter and exceeds 8 KWh/m2 in the summer. Additionally, the sunshine duration is at its lowest in January, with 4.5 hours, and it exceeds 10 hours during the summer.

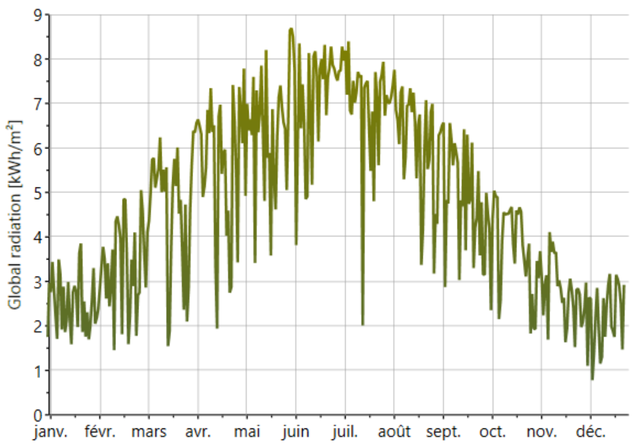


Figure III.8. *Monthly global radiation of Constantine.*

Source: ("Meteonorm 8," n.d.)

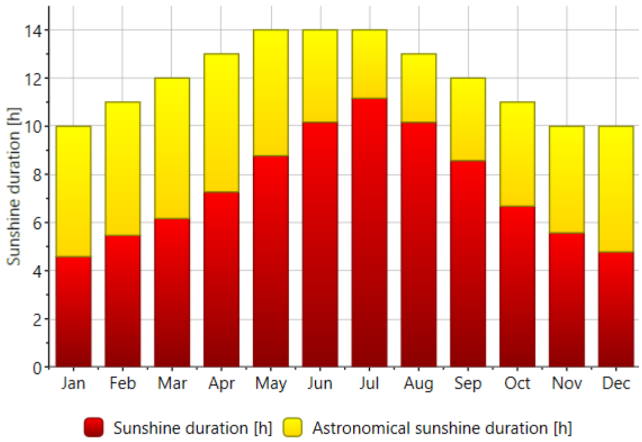


Figure III.9. *Monthly Sunshine duration.*

Source: ("Meteonorm 8," n.d.)

III.4 Choice and presentation of case studies

In December 2012, Constantine was appointed Capital of Arab Culture 2015 by ALESCO and has gained from several initiatives. (FANTAZI, 2021)

The "Constantine, Capital of Arab Culture" event has sparked a number of initiatives, including the construction of new buildings and rehabilitation efforts. Future plans include the main public library and the 3,000-seat Zenith Constantine theater, among other projects. The restoration will include the "Tiddis" archaeological site, the Massinissa tomb, the mosques and Zaouias, the Malek Haddad and Al Khalifa cultural institutions, the Medersa, and others. (BENDAOUD, 2016)

For case study analysis, we selected three cultural public buildings among these major projects, each featuring a DSF envelope treatment. Two new edifices were constructed in 2014-2015, and an existing structure was renovated and rebuilt during the same period.

- Example 1: The palace of culture “Al Khalifa” (Ex.1).
- Example 2: The public library “MOSTAPHA NATOUR” (Ex.2).
- Example 3: The performance hall “AHMED BEY” (Zenith Constantine) (Ex.3).

Figure III.10. *The position of the three studied buildings.*

Source: (“Google Maps,” n.d.)*, Author's photos 2022.*

III.4.1 The palace of culture “MOHAMMED LAID AL KHALIFA”

III.4.1.1 Presentation and history

Located in the Place of Martyrs, at the city's core, in a strategic and panoramic position. (“Palais de la culture Mohamed Laïd Al Khalifa à Constantine,” n.d.)

Figure III.11. *The position of the palace of culture.*

Source: (“Google Maps,” n.d.)

A colonial edifice, constructed by the Citroën company to replace the old seed hall (1851-1933), was inaugurated in 1933. Following independence, at the conclusion of the 1980s, the Citroën garage, characterized by its imposing and colossal architecture, was repurposed into a cultural center. (Courrier, 2015 ; “Histoire de Constantine et de ses communautés,” n.d.)

Figure III.12. *The old seed hall.*

Source : (Adcha, 2008)

Figure III.13. *The Citroen garage.*

Source : (Adcha, 2008)

During 2014-2015, for the Constantine Capital of Arab Culture initiative, the building underwent refurbishment, refitting, and enhancement, resulting in an entire transformation. The center has experienced a remarkable enhancement in its aesthetic attractiveness and it has been converted from a cultural center into a palace of culture. (courrier, 2015a)

Figure III.14. *The palace of Culture "MOHAMMED LAID AL KHALIFA" before rehabilitation.*

Source: D.E.P (Direction of public buildings).

Figure III.15. *The palace of Culture "MOHAMMED LAID AL KHALIFA" after rehabilitation.*

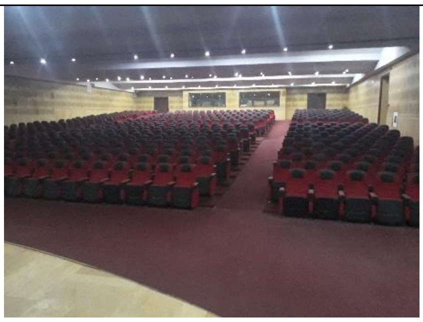
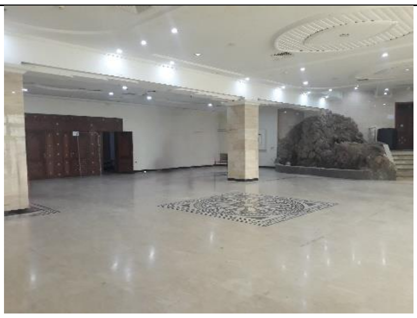
Source: Author 2022.

III.4.1.2 Architectural composition

This neo-Moorish-style edifice has a total area of 8,795.37 m² and is structured across three levels. The upper level features a spacious reading area (120 places); the middle level comprises two large exhibition rooms (400 m2 and 270 m2) beside a 255-seat conference room, while the ground floor contains a 666-seat auditorium, a VIP room, and halls. Following the 2015 cultural event, a section of the palace was designated as the headquarters for the wilaya's Department of Culture. (BENDAOUD, 2016 ; "Palais de la culture Mohamed Laïd Al Khalifa à Constantine," n.d.)

Table III.2. *different spaces of the palace of culture.*

Source: Author.

Spaces	Area	Photos
Performance room	980.40 m² / 666 Seat.	
VIP room	172.55 m²	
Hall leading to the VIP lounge	270.85 m²	
Hall leading to the performance room	297.4 m²	
Conference room	355.62 m² / 255 Seat.	

Reading area	711.35 m²	
Reading Area	284.84 m²	

III.4.1.3 Building's different facades

The building has a double-skin envelope, but the treatment of the double-skin facades is different on each side, in terms of techniques and materials.

The northeastern facade features a double-skin design (***Figure III.16***). The inner layer consists of a facade made from a double wall of hollow terracotta bricks, which includes double-glazed openings, while the outer layer is composed of a metal mashrabiya panel. Additionally, a portion of the facade incorporates a curtain wall with double glazing.

Figure III.16. *The North-East facade of the palace of culture, Constantine.*

Source: Author 2022.

The northern and eastern facades feature a double-skin design, where the outer layer is made up of metal mashrabiya panels.

This architectural approach not only enhances the aesthetic appeal but also provides functional benefits such as improved insulation and ventilation while maintaining privacy.

Figure III.17. *The North facade of the palace of culture, Constantine.*

Source: Author 2022.

Although they use different materials, the northwestern, southwestern, southeastern, and southern facades are all built similarly to double-skin facades. The interior layer has two walls made of hollow terracotta bricks, while the outside layer is made up of terracotta panels.

This architectural decision aims to improve both the aesthetic appeal and the weather resistance of the building.

Figure III.18. *The South-East and East facades of the palace of culture, Constantine.*

Source: Author 2022.

Figure III.19. *The South-West and North-west facades of the palace of culture, Constantine.*

Source: Author 2022.

The figure (***Figure III.20***) show the different facades of the palace of culture “AL KHALIFA”.

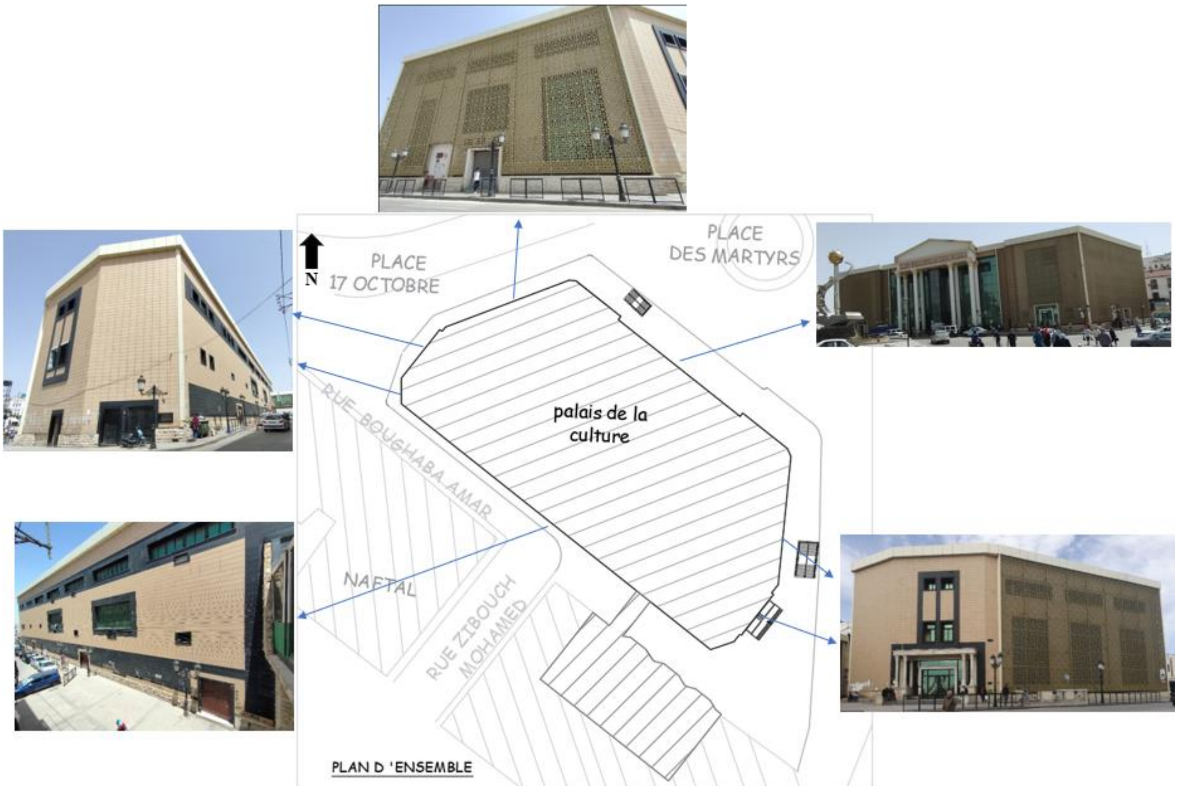


Figure III.20. *Different facades of the palace of culture.*

Source: Author 2022.

III.4.2 The public library “MOSTAPHA NATOUR”

III.4.2.1 Presentation

On Boulevard des "Frères Zaâmouche" in central Constantine, the principal public reading library, "Mustapha Nettour," stands in an advantageous location next to the railway station and directly across from the taxi and bus terminal. It replaced an old, destroyed building.

Figure III.21. *The position of the public library.*

Source: (“Google Maps,” n.d.).

The library was built in the Maghreb architectural style by an Algerian design office and construction company and opened its doors to the public in 2015.

The facility, situated on an archaeological site and in close proximity to four bridges (Salah Bey, Sidi Rached, Bab El Kantara, and Mellah Slimane), provides tourists with a magnificent panoramic view of ancient Cirta and its rock formations. Within the reading rooms, members can pause to unwind and reorganize their thoughts while reflecting on the Mellah Slimane footbridge. Gazing south and west, people can admire the charm of the historic town prior to crossing the Bab El Kantara bridge to the north. The environment and the distant war memorial atop Sidi M'cid rock will captivate the visitor. The facility is the first of its kind in the wilaya, featuring modern Islamic architecture and offering a unique experience for visitors to appreciate the historic town's charm. (“Bibliothèque principale de la lecture publique à Constantine,” n.d.; “Constantine - Bibliothèque urbaine de Bab El Kantara « Une bouffée d’oxygène » culturelle pour la ville,” n.d.)


Figure III.22. *The public library "MOSTAPHA NATTOUR"*

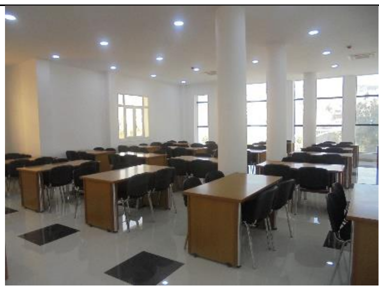
Source: Author.

III.4.2.2 Architectural composition

The library spans an impressive 3,000 m2, thoughtfully arranged across three levels and an underground. The lower level features a children's reading room and workshops, while the main floor boasts a conference room accommodating 200 attendees, a reading area for researchers, a lending space, a multifunctional room, and a spacious hall. On the first floor, there is a 170 m² reading area, an internet facility, and administrative offices. The highest level features a 222 m2 reading room and a lending area.

Table III.3. *Different spaces of the main library.*

Source: Author 2022.

Spaces	Area	Photos
Main reading room	222.10 m²	
Second reading room	170.81 m²	

Children’s reading room	169 m²	
Children's workshop	37.61 m²	
Researcher’s reading room	88.67 m²	
Hall / Reception	150.20 m²	
Conference room	305.46 m² / 200 seat	
Internet room	52.51 m²	

III.4.3 Building's different facades

The building features different facades characterized by distinct construction techniques and materials.

The northeastern, southeastern and northwestern facades consist of double-glazed curtain walls integrated with double-skin facades. In the sections featuring double-skin facades, the inner layer is constructed from reinforced concrete, serving as an integral component of the structure (including load-bearing walls, etc.), whereas the outer layer is composed of terracotta panels.

Figure III.23. *Southeastern facade of the public library of Constantine.*

Source: Author 2022.

Figure III.24. *The northeast facade of the public library of Constantine.*

Source: Author 2022.

Figure III.25. *The northwestern facade of the public library of Constantine.*

Source: Author 2022.

The facades situated on the southeast, southwest and northeast sides of the building feature a double-skin design. The inner layer consists of double walls in hollow terracotta brick. In contrast, the outer layer is composed of arranged terracotta panels.

This innovative facade system which enhances the aesthetic appeal and contributes to the building's overall energy efficiency, effectively combines functionality with modern architectural style.

Figure III.26. *The southwestern facade of the public library of Constantine.*

Source: Author 2022.

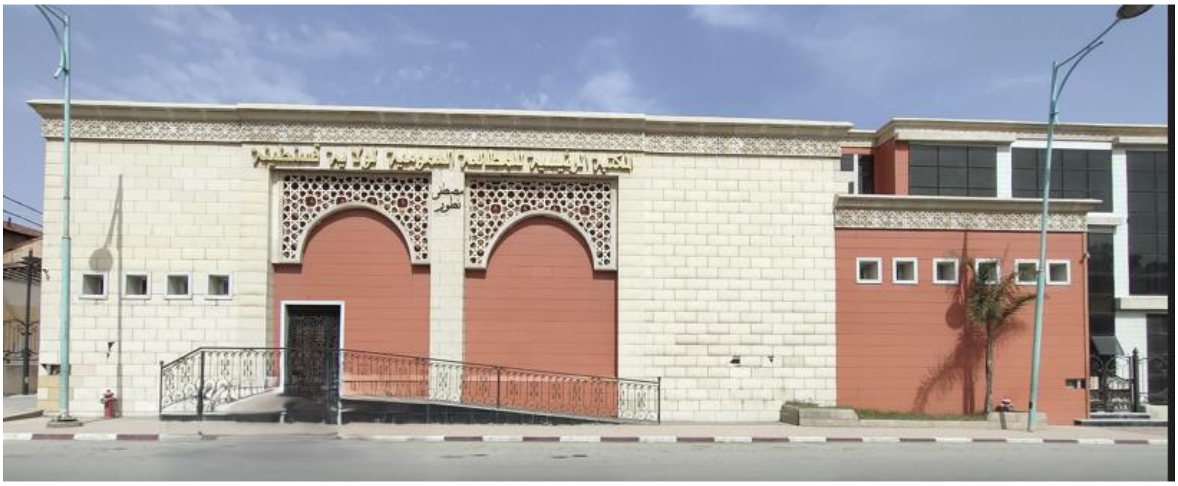


Figure III.27. *The southeastern facade of the public library of Constantine.*

Source: Author 2022.

Figure III.28. *The northeastern facade of the public library of Constantine.*

Source: Author 2022.

The traditional single-skin facade on the west and southwest sides consists of double walls in hollow terracotta brick paired with double-glazed windows.

Figure III.29. *The northwest facade of the public library of Constantine.*

Source: Author 2022.

Figure III.30. *The southwest facade of the public library of Constantine.*

Source: Author 2022.

The figure presented below (***Figure III.29***) show the different facades on each side of the public library building in Constantine.

Figure III.31. *Different facades of the public library.*

Source: Author 2022.

III.4.4 The performance hall "AHMED BEY" (Zenith Constantine)

III.4.4.1 Presentation of the building

The site is located on a sloping site on the southern outskirts of the city of Constantine, looking north towards the city and south towards the airport. The site is easily accessible, with two main roads leading to various locations in the vicinity. The Airport Expressway on the west side provides access to the airport to the south, while the same road leads to the N79 and the city to the north. (CSCEC, 2013)

The Zenith Constantine project was completed under the supervision of the DEP, in collaboration with the Chinese design office CCDI Group, the Lebanese design office "Dar al-Handasa" as an assistant to the project owner, and the Chinese construction company CSCEC. It opened its doors for public access on April 16, 2015. (courrier, 2015b)

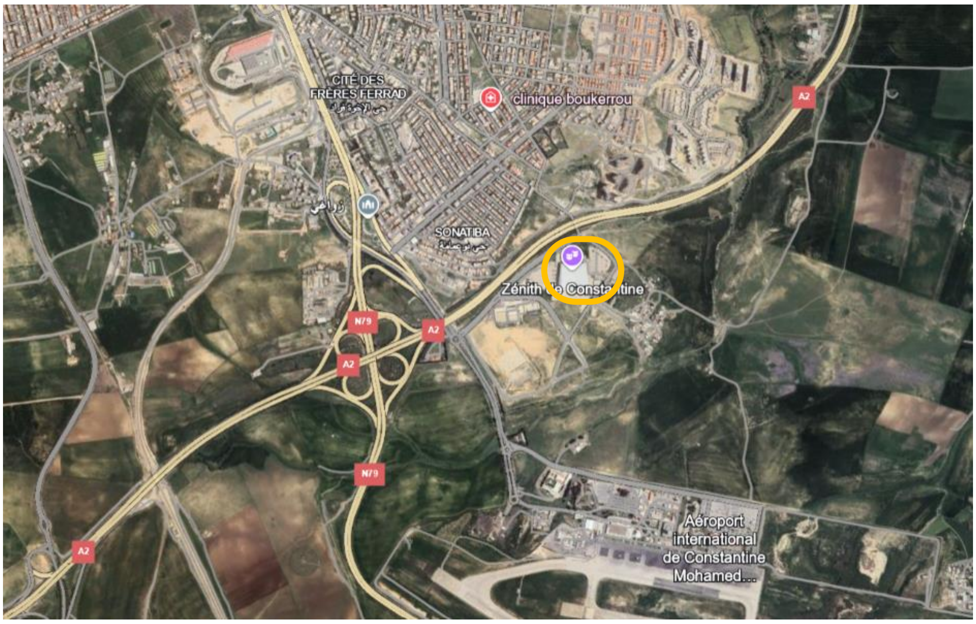


Figure III.32. *The position of the performance hall (Zenith Constantine)*

Source: ("Google Maps," n.d.).

Figure III.33. *The performance hall "AHMED BEY"*

Source: Author 2022.

III.4.5 Architectural composition

The building has a surface area of 38220 m2, whereas the site covers approximately 60,000 m2. It has four levels above and one below ground.

The performance hall features a striking zenith design, encompassing a stage area of 38.5 by 26 meters, complemented by a stage width of 53 meters. The seating arrangement consists of three distinct areas: standing, temporary, and fixed, accommodating approximately 3,000 individuals in total.

On either side of the stage, there are spaces designated for performances: the ground floor primarily accommodates the make-up and dressing rooms; the first floor houses the producer's room, a lounge for actors and actresses, a restaurant, a café, and other performance-related facilities; the second floor contains the rehearsal room, recording studio, and multimedia and audio-visual data rooms; the third floor is allocated for the gymnasium, office, and staff rest areas.

The audience accesses the theatre from the first-floor platform, going to their seats via the staircase. Atriums have been erected in specific areas of the hall, providing spectators access to the service hall on the ground floor.

The building also features two small performance halls with 300 and 150 seats, arranged symmetrically along the building's axis. In the basement, which is the base level of the stage, there is an evacuation hall. On the ground floor, where the spectators' entrance is located, there are spectator service rooms, such as a café and snack bar around the auditorium. There is a staircase leading to the platform on the first floor, where the main entrance hall for spectators of the large auditorium is located. (CSCEC, 2013)

Table III.4. *Different spaces of the performance hall "ZENITH".*

Source: Author.

Spaces	Area / Description	Photos
The performance hall	Around 13000 m²/ 3000 seat (with the possibility of adding 1,000 removable chairs)	
The hall of spectators' access	At the first floor	

The two small auditoriums	150 and 300 seat (they are symmetric and similar)	
Gathering hall	At the second floor, it is a space for gathering and relaxation adjacent to the recording studios	
Exposition hall	Around 2.400 m2 At the ground floor	
V.I.P room	At the ground floor	

III.4.5.1 Building's different facades

Despite employing various building techniques and materials, this third edifice similarly includes double-skin facades on each side.

A double-skin facade is located on the northeast, north-west and southeast elevations. It consists of an initial skin constructed from hollow terracotta brick or a reinforced concrete wall for structural support, followed by a buffer zone (corridor), and finally, a second skin that resembles the first, featuring decorative triangular openings.

Figure III.34. *The North-East facade of the performance hall of Constantine.*

Source: Author 2022.

Figure III.35. *The South-East facade of the performance hall of Constantine.*

Source: Author 2022.

Figure III.36. *The North-west facade of the performance hall of Constantine.*

Source: Author 2022.

The northwest and southeast facades are entirely enveloped in glass. On the ground level, the facade showcases a double-skin design, incorporating an internal layer of reinforced concrete for robust structural support, complemented by a wall in hollow terracotta brick, followed by a channel, and an external layer of white lacquered glass. On the other hand, a curtain wall composed of tempered double glazing is present on the upper levels.

Figure III.37. *The South-east facade of the performance hall of Constantine.*

Source: Author 2022.

Figure III.38. *The North-west facade of the performance hall of Constantine.*

Source: Author 2022.

Figure III.39. *The North-west facade of the performance hall of Constantine.*

Source: Author 2022.

The southern (Southwestern) facade of the auditorium features an arched double skin, with doors that lead into the entrance hall for spectators. This hall is characterized by an arched glass curtain wall facade that overlooks the square, providing a broad view (Figure III.36). Consequently, it can be described as a triple-skin facade, with the temple space (the hall).

The double skin consists of an inner layer made of reinforced concrete and an outer layer constructed from aluminium panels, with a channel located between the two layers. (Figure III.37)

Figure III.40. *The South facade of the performance hall of Constantine.*

Source: Author 2022.

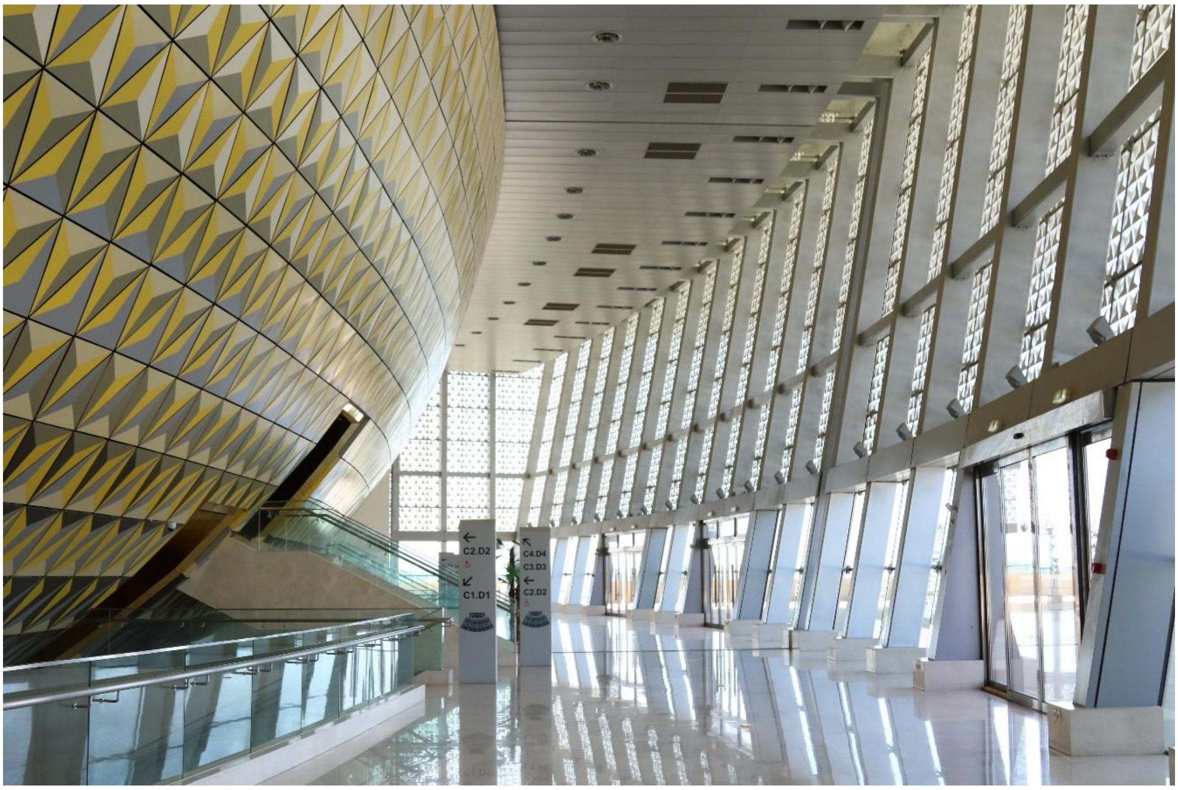


Figure III.41. *The South DSF of the performance hall and the entrance hall.*

Source: Author 2022.

The picture below illustrates the various facades of the performance hall “AHMED BEY” (Zenith Constantine), as well as the locations of each one.

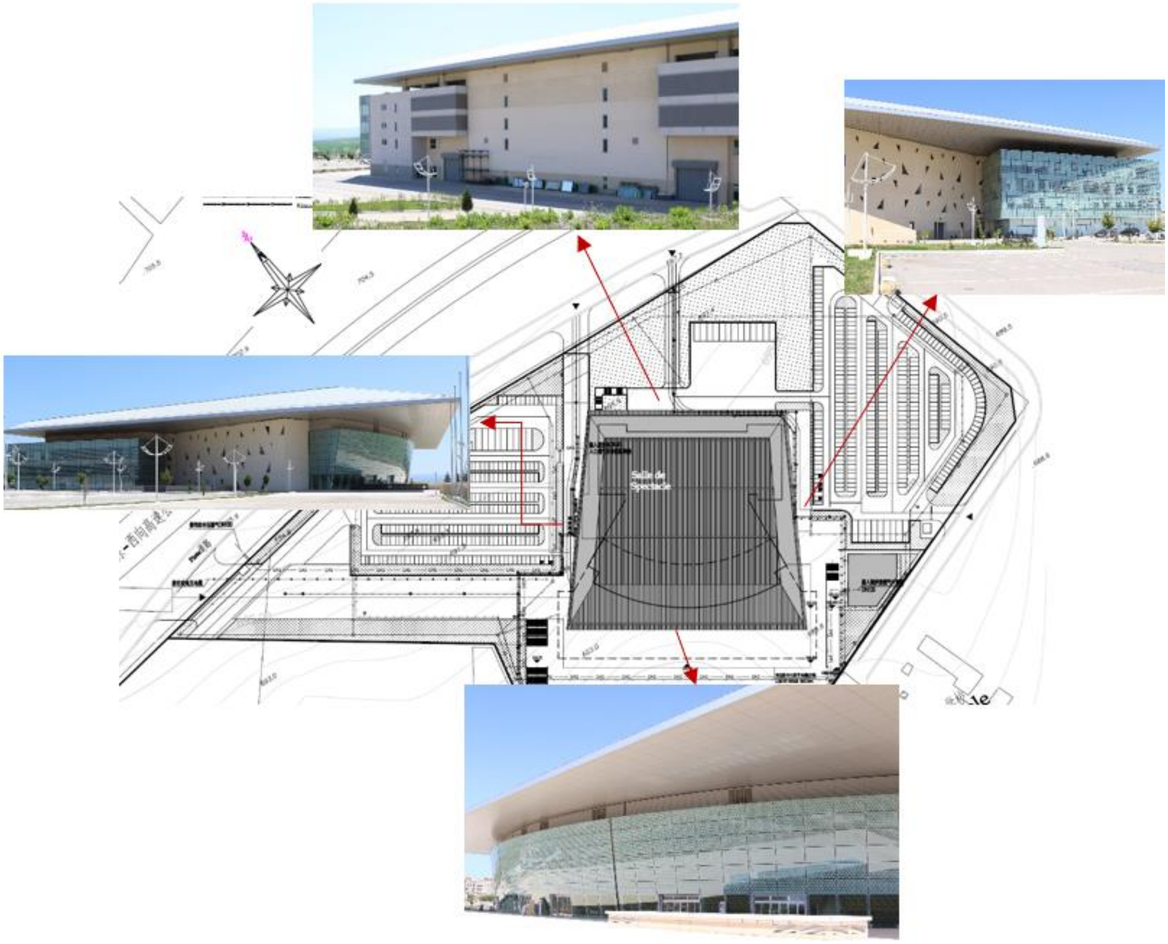


Figure III.42. *Different facades of the performance hall.*

Source: Author 2022.

III.5 Conclusion

This chapter, dedicated to outlining the research context, commences with an overview of the city of Constantine, recognized as the capital of eastern Algeria and characterized by a semi-arid climate. This was followed by a historical review and an exposition of the city's climatic conditions. The selection of case studies was subsequently implemented. The last section of the chapter provides a detailed analysis of the three edifices with double-skin facades, which serve as case studies in our research work.

CHAPTER IV:

METHODOLOGY AND MATERIALS

IV.1 Introduction

To investigate the role of double-skin facades in optimizing thermal comfort, two research approaches were utilized: in-situ measurements and a questionnaire survey.

This chapter intends to provide a comprehensive and detailed explanation of the methodologies employed in this investigation.

The initial section focuses on presenting and explaining the initial method, which is in situ measurements, as well as the corresponding measuring tools employed.

The second half of the chapter describes the second approach, the in-situ questionnaire survey, accompanied by the scaling calculation.

IV.2 Methodology

In order to achieve the main objective of our study, which is to analyse the impact of double skin on thermal comfort in public buildings and to verify the proposed hypotheses, a methodology consisting of two main steps was followed.

The first step concerns the qualitative approach and the preliminary survey and aims to analyse the three buildings under study. It is carried out in several phases:

- Determination of case studies.
- Collecting data and information about the studied buildings: Descriptions, history, plans, documentation, architectural features, construction details, etc.
- Preparing visits and appointments with the equipment managers to ensure study’s success.
- Familiarizing oneself with the research sites.
- Taking photos.

The second stage concerns the quantitative approach, which aims to analyse the impact of the use of double skin on thermal comfort in the three buildings studied through:

- In-situ measurements: indoor and outdoor measurements taken in different spaces in the three studied building which are compared to the comfort zone.
- A questionnaire survey: was conducted in the three public facilities studied using a paper questionnaire distributed to various users of the buildings (employees, visitors, etc.).

IV.3 Tools used

- The climate data for the city of Constantine was compiled using “Meteonorm 8” and “Climate Consultant” software, while the data for 2021 was recorded at the Ain El Bey weather station.
- The plans and elevations of the study project, and the project specifications with photos of the construction sites, were obtained from the Public Equipment Direction “D.E.P” and the Culture Direction of Constantine.
- The psychrometric diagram was created using “Climate Consultant” software.
- For the calculation of the comfort zone temperature, we used the method of Szokolay.
- Data management and visualisation obtained from the questionnaire is carried out using Microsoft Excel.
- To conduct the in-situ campaign measures, many thermo-hygrometers and multifunction meters were utilized.

IV.3.1 Measurement instruments

For the in-situ measurements of the climatic data, many instruments were used: Temperature and humidity data logger (USB PCE-HT 71N and PCE-HT 71N-ICA. 2015, 2019), thermo-hygrometer: climate data logger TROTEC (BL30, Ed. 2015), thermo-hygrometer Chauvin Arnoux (C.A846, 692670A00, Ed.5, 2013), and multifunction luxmeters Lutron (LM-8000).

Figure IV.1. *Temperature and humidity data logger USB PCE-HT 71N and PCE-HT 71N-ICA.*

Source: Author.

Figure IV.2. *Climate data logger TROTEC BL.30.*

Source: Author.

Figure IV.3. *Thermo-hygrometer Chauvin Arnoux (Left). Multifunction Lutron LM-8000 (Right).*

Source: Author.

The following table (Table VI.1) shows the technical characteristics of each used device.

Table IV.1. *Presentation of measuring tools.*

Source: Author.

Instrument	Characteristics	Use
Temperature and humidity data logger “USB PCE-HT 71N” and “PCE-HT 71N-ICA”.	Range: 0 to 100%RH; -40°F to 22°F (-40°C to 105°C) Accuracy: ±3%RH; ±2°F/1°C Resolution: 0.1%RH; 0.1°F/°C	Facilitate the measurement of temperature and humidity; these instruments were used

	Memory: 21,000 readings each for temperature and humidity Measuring rate: Selectable from 1 sec to 24 hours Battery life: Approximately 3 years Analysis software: Windows 98/2000/XP/Win7/Win8/Vista/Mac OS Size: 5.1" x 1.2" x 1" (130mm x 30mm x 25mm) Weight: 0.88oz (25g) Battery: 3.6V Lithium (1pc)	for the purpose of measuring the relative humidity and temperature for various interior and exterior spaces.
Climate data logger "TROTEC BL.30".	Memory p to 32.000 measured values Include: battery, software CD and CD and lockable wall holder Measuring range relative humidity 0 to 100% Measuring range temperature -40 to +70°C	This instrument was used for measuring the relative humidity and temperature for various interior spaces.
Thermo-hygrometer: "Chauvin Arnoux C.A846".	Maximum absolute temperature measurement +60°C Maximum humidity measurement 100% RH Optimal temperature measurement accuracy ±0.5°C Temperature measurement resolution 0.1°C Optimal humidity measurement accuracy ±2.5% RH Humidity measurement resolution 0.1% RH Minimum operating temperature -20°C Maximum operating temperature +60°C	This instrument was used for the purpose of measuring the relative humidity and temperature for various exterior spaces.
Multifunction lux meter : « Lutron LM-8000. »	**Air Velocity marge:** 80 to 5910 ft/min; 0.4 to 30.0 m/s; 1.4 to 108.0 km/h; 0.9 to 67.0 mile/h; 0.8 to 58.3 knots. **Accuracy:** ≤ 20 m/s: ± 3% F.S. > 20 m/s: ± 4% F.S. **Temperature / Humidity rage:** 10 to 95 %RH; 32 to 122°F; 0 to 50°C. **Accuracy:** < 70% RH: ± 4 %RH; ≥70% RH: ± (4%rdg + 1.2 %RH); ± 2.5°F; ± 1.2°C. **Light marge:** 0 to 20,000 Lux; 0 to 2,000 Ft-cd **Accuracy:** ± 5% rdg ± 8 dgt. **Temperature (Type K):** -148 to 2372°F; -100 to 1300°C. **Accuracy:** ± (1% rdg + 2°F); ± (1% rdg + 1°C)	Permit the assessment of temperature, relative humidity, air speed, and illumination. They were utilized to measure the air velocity, external temperature, and relative humidity in both the outside and inside of structures

IV.4 Procedure for in-situ measurements

To showcase the effectiveness and the impact of double-skin facades in enhancing indoor thermal comfort, three public buildings in Constantine city were studied.

Indoor and outdoor measurements were taken during the two extreme periods of the year 2021: during the winter, the cold period, and the summer period of excessive heat.

Several climate variables were measured in this study, including outdoor temperature (T/ex), indoor temperature (T/in), relative humidity (RH) indoors and outside, and air speed (S/air).

After detailed study and analysis and regular visits to the three buildings, the most used and most visited areas were identified as the bridges for measurement.

The first phase of measurements took place in the summer, from 8 to 20 August 2019. However, measurements in winter, in February 2020, were interrupted by the closure of buildings due to COVID.

Due to COVID, all facilities and public spaces were closed for almost a year. Even after reopening in 2021, all cultural events were cancelled; then in 2022, they resumed but were restricted.

Given that the three buildings studied are cultural facilities, we encountered several obstacles when taking measurements. The facilities were partially occupied because of COVID safeguards and social distancing measures, such as the public library, or were unoccupied or solely occupied by personnel and employees, like AL KHALIFA and Zenith.

The data were collected over a period of around 10 days for each period; more accurately, from 11 to 24 January 2021 for the cold period and from 4 to 14 August 2021 for the warm period.

Our study utilized data from a single representative day, specifically the coldest or hottest of the four. The typical days we pick for our study are January 15, 2021, during the under-heating phase, and August 13, 2021, during the overheating season.

Initially, measurements were obtained in each structure, concurrently outside and in different interior spaces, during a two-day period, using the identical technique for all three buildings. To produce a more accurate comparison study, measurements were made in all three buildings at the same time; however, due to a lack of measuring equipment, they were taken in three interior places in each.

To assess each structure for this study, we selected three interior environments featuring double-skin facades (DSF): The initial space denotes the primary function, while the subsequent spaces serve different functions. They possess various envelope treatments.

The interior measuring stations are positioned in the middle of the room to track the ambient air temperature (the temperature users would encounter), therefore proving the effectiveness of the DSF in improving thermal comfort. As for external measurement points, they were taken in the shade next to the building or on the terrace (in Al Khalifa's case).

For more precise and accurate results, measurements were taken every half hour at all measurement points in the three buildings.

In order to demonstrate the temperature differential between the interior and exterior of the building, the measures were obtained without turning on the heating, air conditioning, or ventilation systems. Additionally, the areas were left empty during the opening hours of the equipment.

After acquiring the data for all measurements, we compared "T/ex," "T/in," and the comfort zone temperature in order to assess whether or not a DSF could provide thermal comfort without the utilization of heating or cooling systems.

IV.4.1 Identifying the hottest and coldest periods

The climate analysis of the city of Constantine has enabled identification of the underheating period (the coldest months of the year) and the overheating period (the hottest months).

According to the graph depicting the temperature range (Figure VI.6) alongside the dry bulb temperature (Figures VI.4 and VI.5), the underheating period, marked by temperatures dipping below 20°C, spans from December to February. January stands out as the coldest month, persistently remaining outside the comfort zone, with temperatures fluctuating between -2 and 16°C. In contrast, the overheating period, characterized by temperatures surpassing 24°C, takes place from June to September, with August acknowledged as the hottest month, showcasing temperatures ranging from 14° to 39°C. The periods of thermal comfort, situated within the comfort zone (20–24°C), are observed during the days of May, the afternoons of October, and the evenings and mornings of June and September.

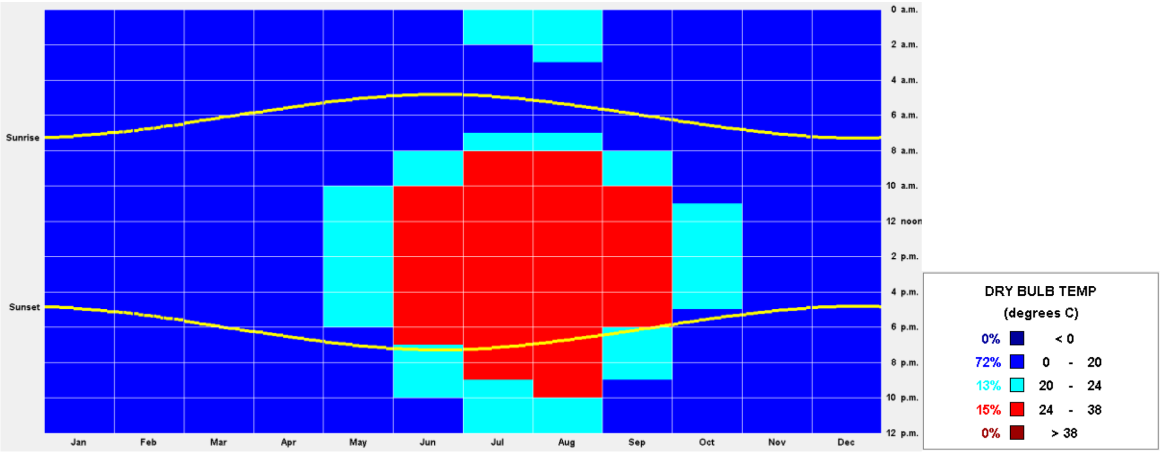


Figure IV.4. *Monthly dry bulb teperature.*

Source: ("Climate Consultant 6.0," n.d.)

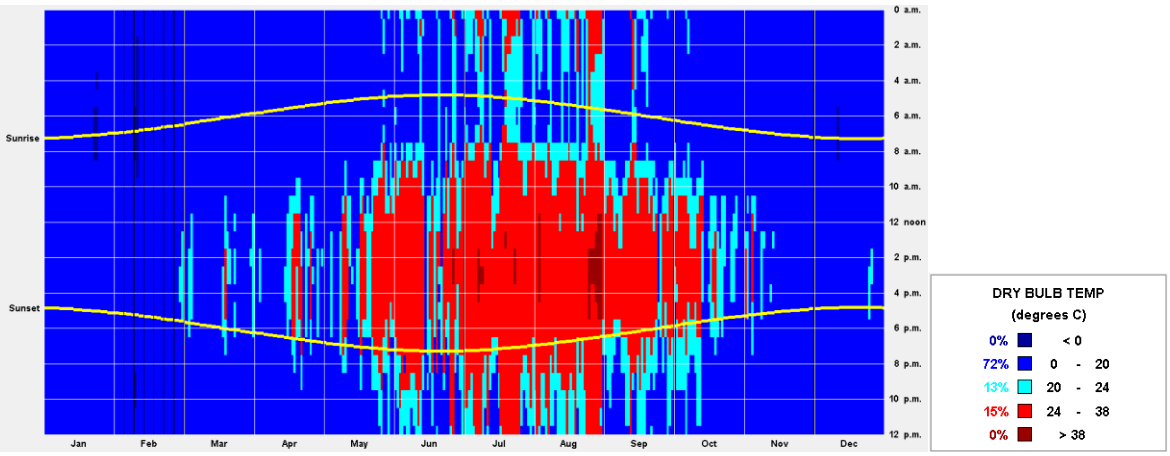


Figure IV.5. *Daily dry bulb teperature.*

Source: ("Climate Consultant 6.0," n.d.)

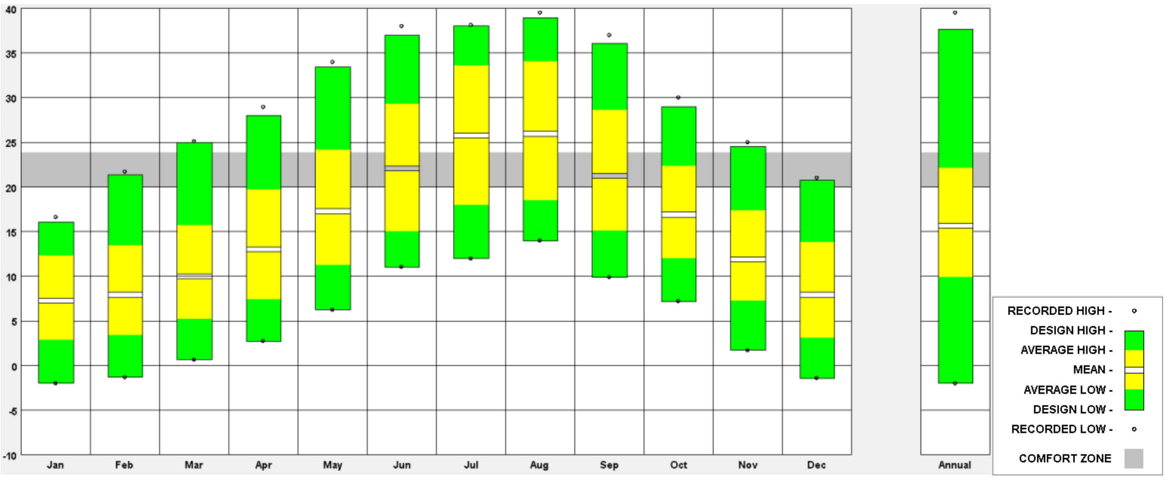


Figure IV.6. *Teperature range of Constantine city.*

Source: ("Climate Consultant 6.0," n.d.).

- **Psychrometric diagram**

Based on the location's climate data, the psychometric diagram is used as a decision-making tool to establish a number of architectural design elements. It lists the necessities and suggestions for every month of the year, along with the times of seasonal comfort.

The utilization of Szokolay's psychrometric chart in the context of the city of Constantine indicates that passive solar heating can enhance comfort levels throughout the winter months, specifically December, January, and February, along with a considerable portion of March, April, and November. Although passive heating remains essential, a degree of comfort is achieved during the relatively mild weather experienced in the late summer months (September and October) and the early spring (May). The mass effect, which facilitates direct evaporative cooling and promotes air movement via natural ventilation, becomes necessary during the summer months beginning in May. Additionally, nighttime ventilation is crucial during the hottest months, namely July and August.

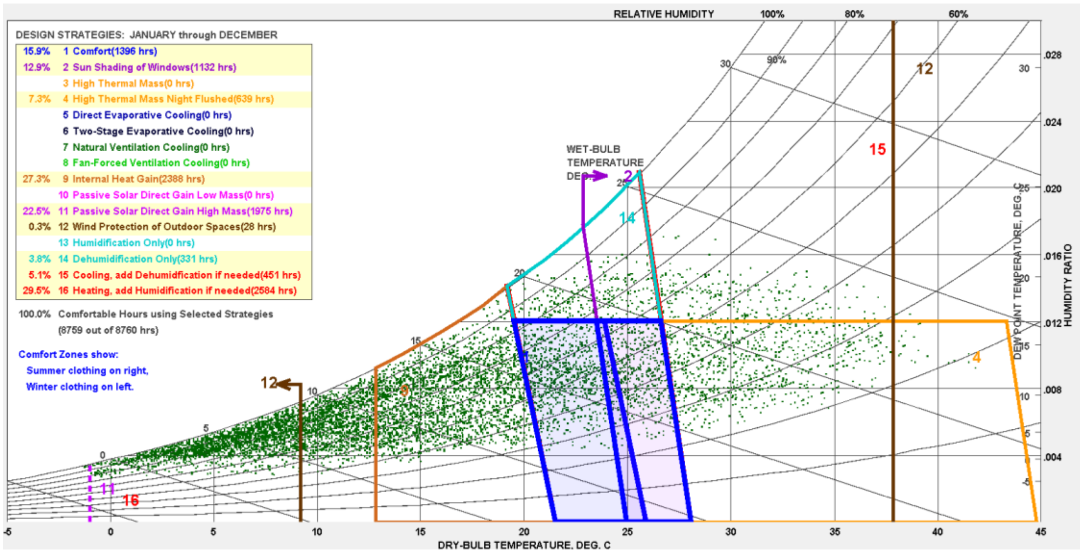


Figure IV.7. Psychrometric diagram (Constantine).

Source : ("Climate Consultant 6.0," n.d.).

IV.4.2 Calculation of the comfort zone temperature

The "comfort zone" refers to the range of meteorological circumstances within which most people would not experience any thermal discomfort, either of heat or of cold.(Givoni, 1992)

The Szokolay method of neutral temperature (Szokolay, 1986) was utilized in order to determine the comfort zone temperature of Constantine city.

$T_n = 17.6 + (0.31 \times T_m)$

The comfort zone can be defined as Tn - 2.5 to Tn + 2.5°C.

In our analysis, the "Tm" of January is utilized to represent winter season, whereas the "Tm" for August is employed for summer of the year 2021.

In winter (January): “Tm” = 9°C.

“Tn” = 17.6 + (0.31 x 9). “Tn” = 20.39°C.

So, comfort zone temperature in winter is between 17.9 and 22.9°C.

In summer (August): “Tm” = 32°C

“Tn” = 17.6 + (0.31 x 32). “Tn” = 27.52°C.

So, comfort zone temperature in summer is between 25° and 30°C.

IV.5 Questionnaire survey method

A survey was conducted to assess users' sensations, appreciation, evaluation, and satisfaction with the thermal environment of the spaces in the three studied buildings. This questionnaire was distributed during two distinct periods: the overheating phase in summer and the underheating phase in winter. Although it was carried out in the same months as the in-situ measurements, it took place in a different year due to the COVID lockdown.

The survey was executed in the field using a methodological tool grounded on a questionnaire. It was executed after the utilization and occupation of the spaces in 2023.

The questionnaire is distributed in paper format directly to the users of the analysed spaces in the three case studies and subsequently collected upon completion. A major challenge faced during this survey is the refusal to participate, as the three buildings serve cultural purposes and host exhibitions and musical performances; many users and visitors decline to engage, stating that they are attending a show for enjoyment and choose not to respond.

The questionnaires were distributed in our presence during the opening hours of the equipment, and the questions were explained separately, then collected on the same day.

The results were processed manually and the graphs were made with the “Microsoft Office Excel”.

Considering that comfort is a feeling of warmth that is unique to each individual, this survey aims to:

- Evaluating if users are satisfied with the thermal environment.
- Estimating the level of thermal comfort in the spaces.
- Determining the level of clothing worn by users (PPE insulation).
- Determining the Work rate and metabolic heat, because the impact of work rate on thermal comfort is critical because physical activity creates more body heat.

IV.5.1 Questionnaire organization

A study of earlier research served as the foundation for the questionnaire's development. It is also important to note that the questionnaire was constructed utilizing the ASHRAE scale and Fanger's model for measuring interior thermal environments.

The questionnaire was structured based on the following guidelines:

- Precise and direct inquiries.
- Queries utilizing clear and exact language.
- Questions that provide options and open-ended inquiries were avoided.

Before distributing the questionnaires, explanations of the study's objective and recommendations were provided. We emphasized that all responses must be authentic and not influenced by anyone else's answers.

The questionnaire delivered to users of the three buildings, includes four distinct sections (Figure VI.7) which together include a total of eleven (11) questions.

- **The first section**: This section aims to construct a profile of the respondents; it includes questions concerning users' general information, like age and gender, as well as the position of the user within the building or space.
- **The second axis:** Where the respondents are invited to provide their level of clothing and asked to give a description of their work rate.
- **The third axis:** Focuses on thermal sensation of the users and their thermal preference.
- **The fourth axis:** The questions concern the evaluation of the thermal environment and the satisfaction of users.

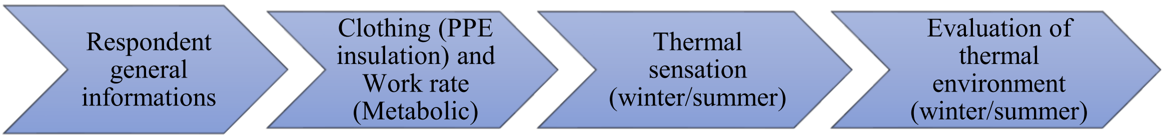


Figure IV.8. *The main points of the questionnaire.*

Source: Author 2025.

IV.5.2 Sample selection

Following the preliminary survey and several visits to the three buildings selected as case studies, the questionnaire was submitted to all users present in the spaces studied, whether visitors or employees.

The survey utilizes a random sampling technique, allowing it to include all users of the spaces who have consented to participate. This method guarantees a varied representation of perspectives. Conducted over four days, the questionnaire is accessible to all individuals in the space who have opted to join the study. This approach facilitates thorough data collection from a broad spectrum of participants, thereby improving the reliability of the survey findings.

The following table (Table VI.2) shows the number of people surveyed in the three buildings studied.

Table IV.2*. Number of respondents in each building.*

Source: Author 2025.

Studied building	**Palace of culture “AL KHALIFA”**	**Public library “Mostapha Natour”**	**Performance hall “Zenith Constantine”**
Number of respondents	40	106	80

IV.6 The studied spaces

In order to conduct a more in-depth study of the buildings and obtain more accurate results, three areas were selected for on-site measurements and questionnaire surveys. These areas are the most frequently used and most visited by building users and are those that house the main functions of the buildings. The spaces studied all have double-skin facades with different construction techniques and materials.

IV.6.1.1 The exhibition hall

This exhibition space is located on the ground floor (Figure IV.6) and consists of three halls:

- A large hall (297.4 m²) located at the main entrance on the southeast side of the building, which also serves as the public entrance to the auditorium (Figure IV.8; Figure IV.9). This space has different double-skin facades; those on the south and southeast sides have a second skin made of terracotta panels, and the one on the east side has a second skin made of metal mashrabiya panels, as shown in (Figure IV.7).
- A second hall (270.85 m²) to the northeast side which also serves as the entrance to the auditorium's VIP lounge (Figure IV.11; Figure IV.12). This space has a double-glazed curtain wall facade on northeast side, as shown in (Figure IV.7).
- And a small hall to the east that connects the two and serves as a distribution point to the other levels of the building. This space has double-skin facades with a second skin of metal mashrabiya panels on the east and northeast sides (Figure IV.7).

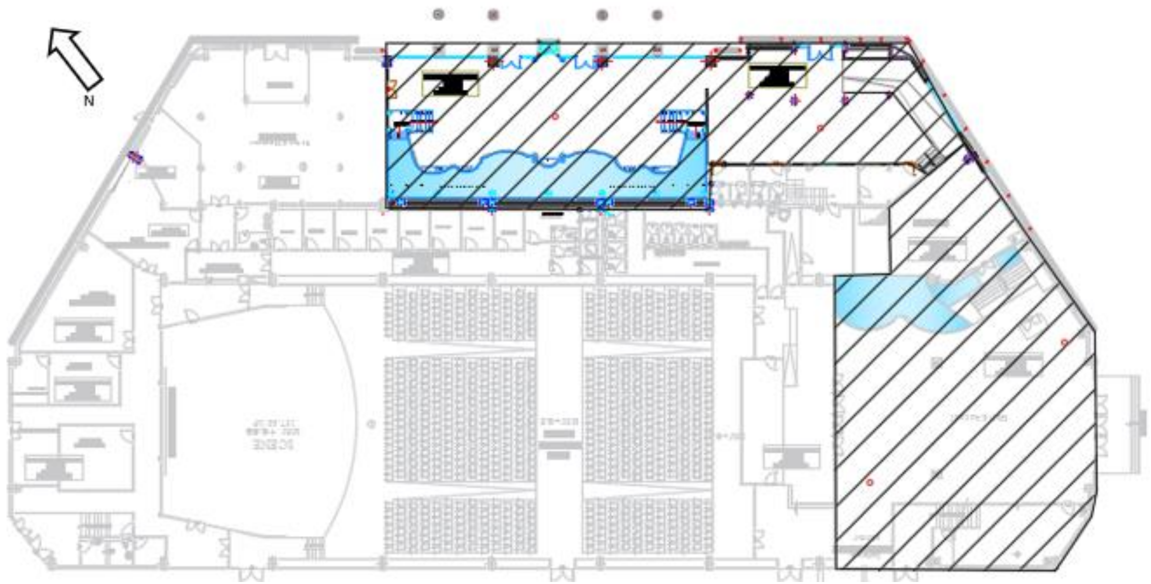


Figure IV.9. *Location of the exhibition hall in the building.*

Source: D.E.P, modified by author.

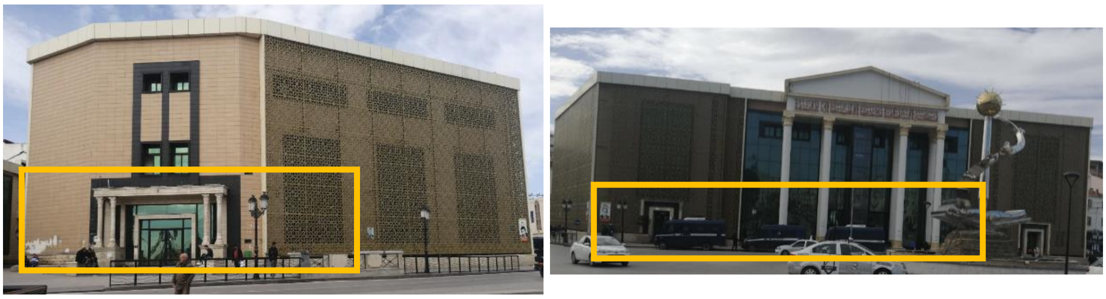


Figure IV.10. *Southeastern and eastern facades (Left); Northeastern facade (Right).*

Source: Author 2025.

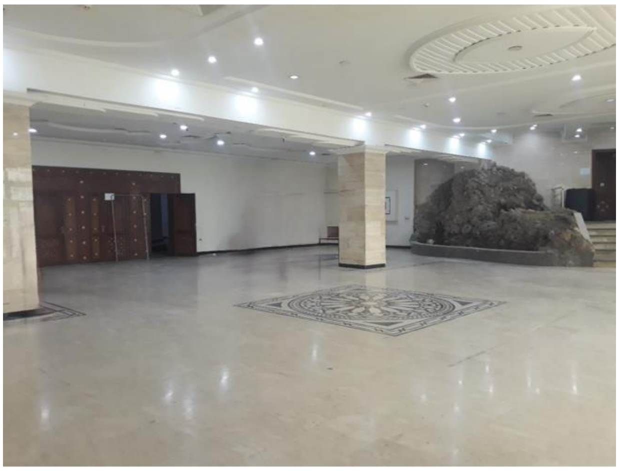


Figure IV.11. *Hall of the main public entrance (Empty).*

Source: Author 2023.

Figure IV.12. *Hall of the main public entrance during an exhibition.*

Source: Author 2022.

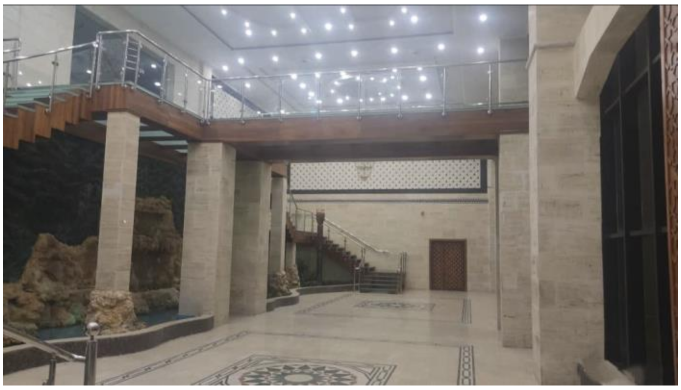


Figure IV.13. *Hall of the VIP Lounge entrance (Empty).*

Source: Author 2023.

Figure IV.14. *Hall of the VIP Lounge entrance during exhibition.*

Source: Author 2022.

Figure IV.15. *Hall of distribution (empty).*

Source: Author 2022.

IV.6.1.2 The performance room

The auditorium is located on the ground floor on the west side of the building (Figure IV.13). With a capacity of 666 seats, it occasionally hosts cultural events such as children's shows, plays, musical performances, and others (Figure IV.15; Figure VI.16; Figure IV.17).

This space has a double-skin facade with a second skin made of terracotta panels on the southwest side (Figure IV.14).

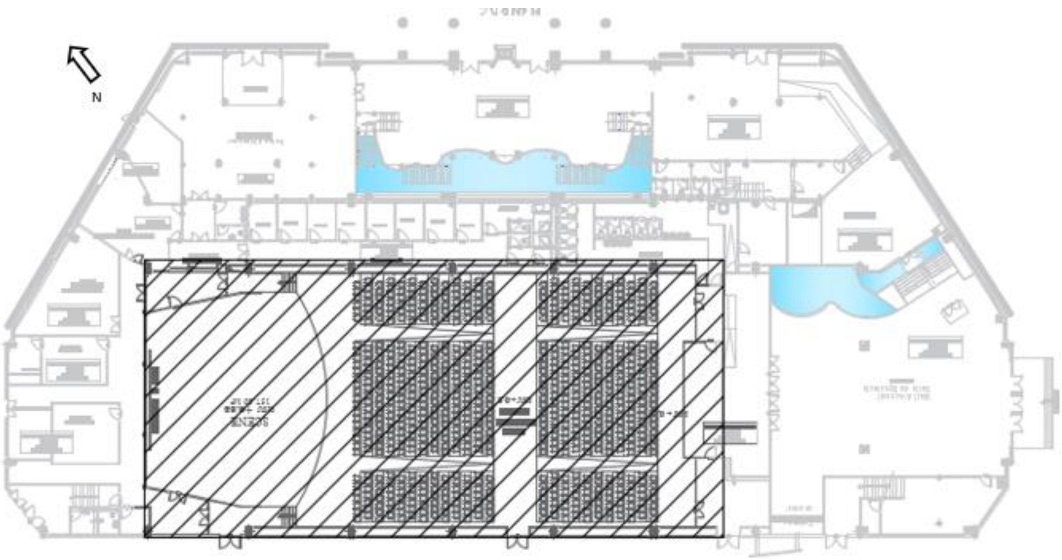


Figure IV.16. *Location of the performance room in the building.*

Source: D.E.P, modified by author.

Figure IV.17. *Southwestern facade of the performance room.*

Source: Author 2022.

Figure IV.18. *The performance room (Empty).*

Source: Author 2024.

Figure IV.19. *The performance room during an event.*

Source: Author 2024.

Figure IV.20. *The performance room during an event.*

Source: Author 2024.

IV.6.1.3 Conference room

It is located on the first floor, on the west side of the building (Figure IV.18). This room has 255 seats and is occasionally used for conferences and study days (Figure IV.20).

It has a double skin facade with a second skin made of terracotta panels on the southwest side (Figure IV.19).

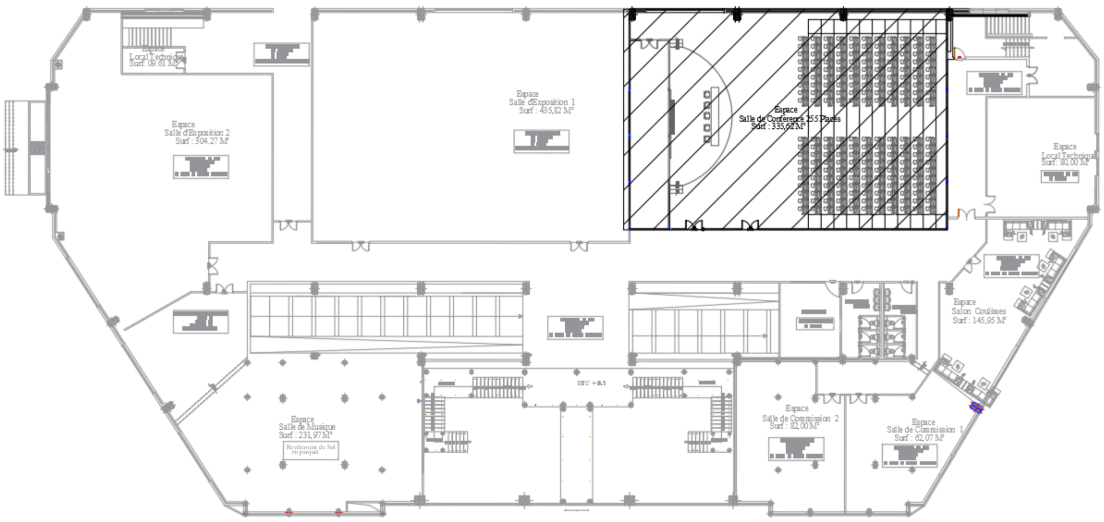


Figure IV.21. *The location of the conference room in the building.*

Source: D.E.P, modified by author.

Figure IV.22. *Southwestern façade of the conference room.*

Source: Author 2022.

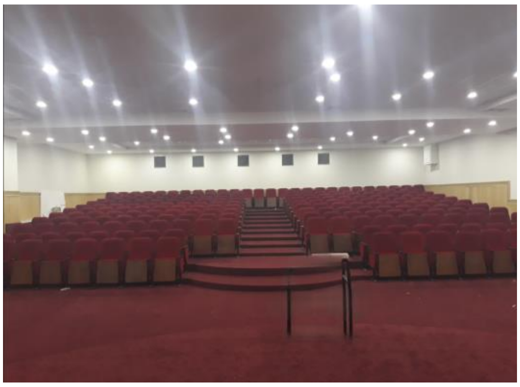


Figure IV.23. *The conference room (Empty).*

Source: Author 2023.

IV.6.2 The public library of Constantine (Ex.2)

Four primary areas were examined to better study this building: the conference room, the main reading room, the secondary reading room, and the children's reading room. They all have double-skin facades.

IV.6.2.1 The conference room

Located on the ground floor at the south side of the building (Figure IV.21), it has 200 seats and is occasionally used for various events for children or adults related to literature.

The conference room, along with its different sections, is situated in a distinct block that is connected to the main building. All facades feature a double-skin design, with the outer layer constructed from terracotta panels (Figure IV.22; Figure IV.23).

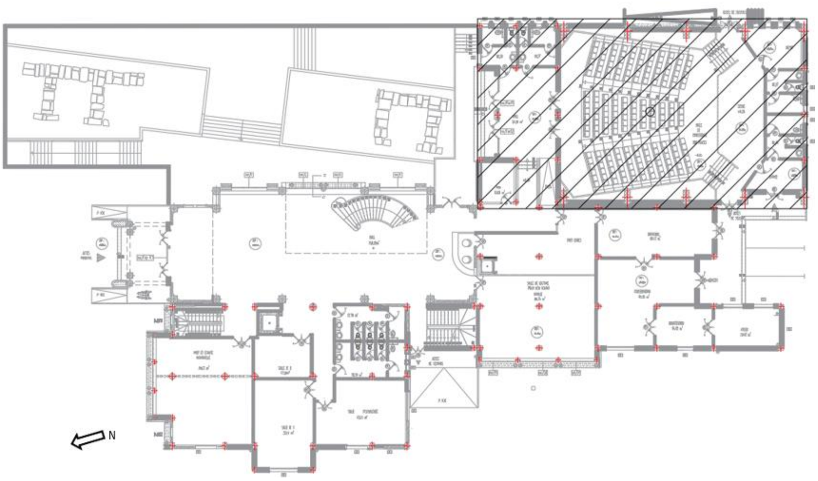


Figure IV.24. *Location of the conference room in the building.*

Source: D.E.P, modified by author.

Figure IV.25. *The southwest facade of the conference room.*

Source: Author 2022.

Figure IV.26. *The southeast facade of the conference room.*

Source: Author 2022.

Figure IV.27. *The conference room (Empty).*

Source: Author 2022.

Figure IV.28. *The conference room during an event.*

Source: Author 2023.

IV.6.2.2 The main reading room

Situated on the second floor (Figure IV.26), the main reading room is the largest, with an area of 222.10 m². It contains 50 tables seating four people each, giving it a capacity of 200 readers (Figure VI.29).

The facades on the northeast and southeast sides feature a double-skin design, with an outer layer of terracotta panels harmoniously integrated with double-glazed curtain wall façades (Figure IV.27; Figure IV.28). In contrast, the southwest façade presents a conventional style, characterized by double walls constructed from hollow terracotta bricks.

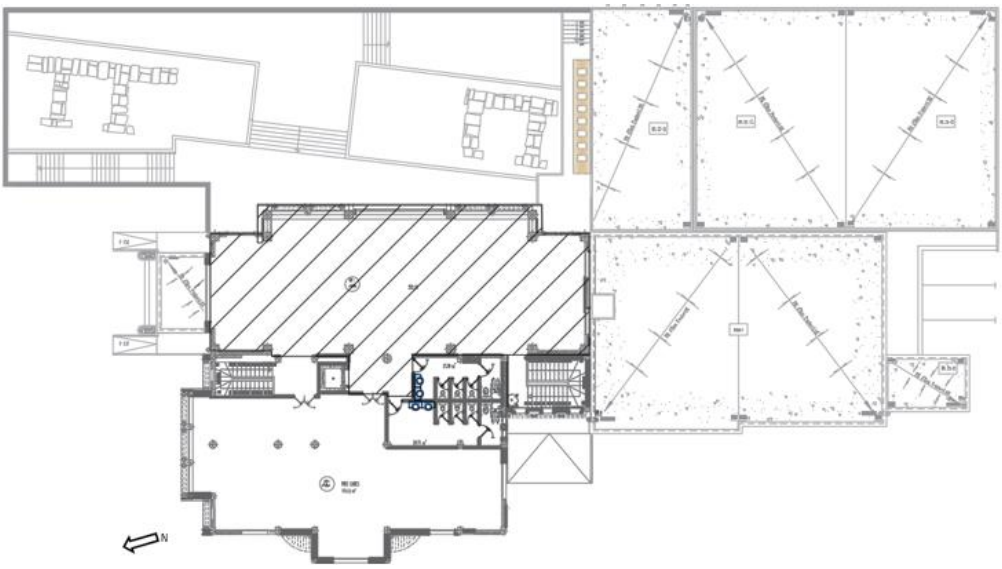


Figure IV.29. *Location of the main reading room in the building.*

Source: D.E.P, modified by author.

Figure IV.30. *Southeastern facade of the main reading room.*

Source: Author 2022.

Figure IV.31. *Northeastern facade of the main reading room.*

Source: Author 2022.

Figure IV.32. *Interior view of the main reading room.*

Source: Author 2022.

IV.6.2.3 The secondary reading room

Situated on the first floor (Figure IV.30), this room has a surface area of 170.81 m² and is equipped with 35 tables (each accommodating 4 individuals), resulting in a total capacity of 140 individuals (Figure IV.34).

The northeastern facade of this section has a double-skin design with a second layer of terracotta panels, in addition to a double-glazed curtain wall (Figure IV.31). In contrast, the northwest and southwest facades are more traditional, with double walls composed of hollow terracotta bricks (Figure IV.32; Figure IV.33).

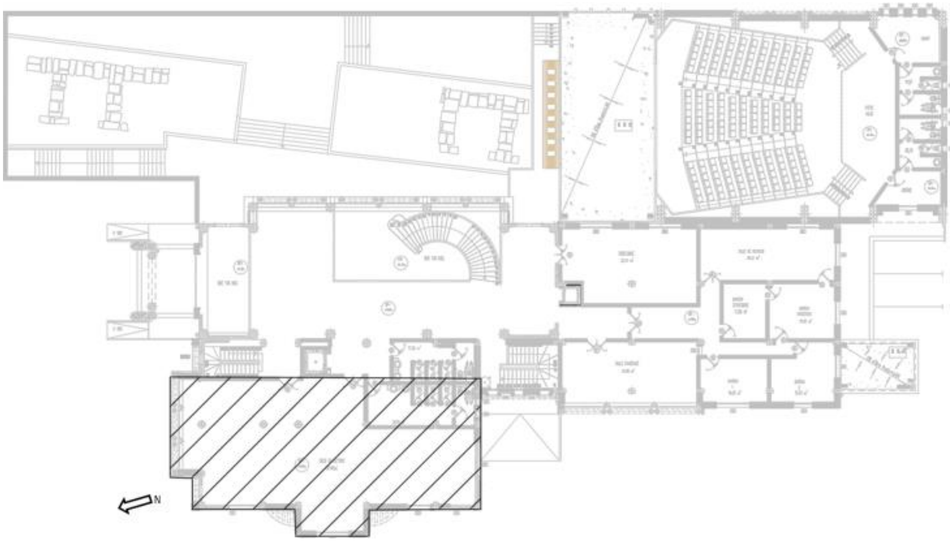


Figure IV.33. *Location of the secondary reading room in the building.*

Source: D.E.P, modified by author.

Figure IV.34. *Northeastern facade of the secondary reading room.*

Source: Author 2022.

Figure IV.35. *Southwestern facade of the secondary reading room.*

Source: Author 2022.

Figure IV.36. *Northwestern facade of the secondary reading room.*

Source: Author 2022.

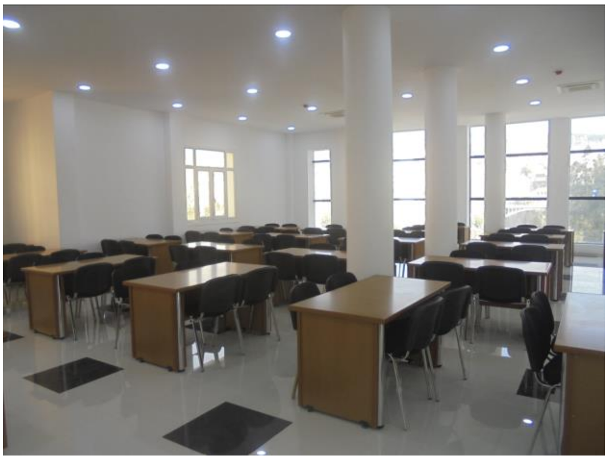


Figure IV.37. *Interior view of the secondary reading room.*

Source: Author 2022.

IV.6.2.4 The children's reading room

The reading room of children is Situated on the underground with an area of 169 m², it is surrounded by spaces designated to many activities for children (Figure IV.35; Figure IV.36). It has a double skin facade with an outer skin made of terracotta panels, with double glazed curtain wall, faced to the southeast (Figure IV.37).

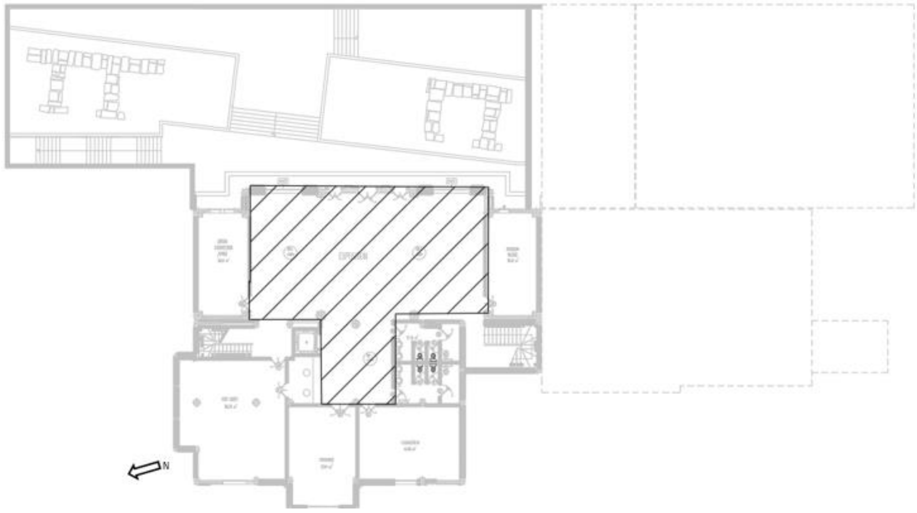


Figure IV.38. *Location of the children's reading room in the building.*

Source: D.E.P, modified by author.

Figure IV.39. *Interior view of the children's reading room.*

Source: Author 2022.

Figure IV.40. *Interior view of the children's reading room.*

Source: Author 2022.

IV.6.3 The performance hall "Zenith Constantine" (Ex.3)

In this third case study, we examined three interior spaces: the performance hall, the public entrance hall, and the relaxation area next to the recording studios.

IV.6.3.1 The performance hall

Situated at the heart of the structure (Figure IV.38), with a surface area of approximately 13,000 m², this space has a capacity of 3,000 seats spread over three levels, with the potential to add 1,000 detachable chairs (Figure IV.39; Figure IV.40).

The southern facade of the auditorium features an arched double skin composed of an inner layer made of reinforced concrete and an outer layer constructed from aluminium panels; between the two layers there is a cavity (Figure IV.41).

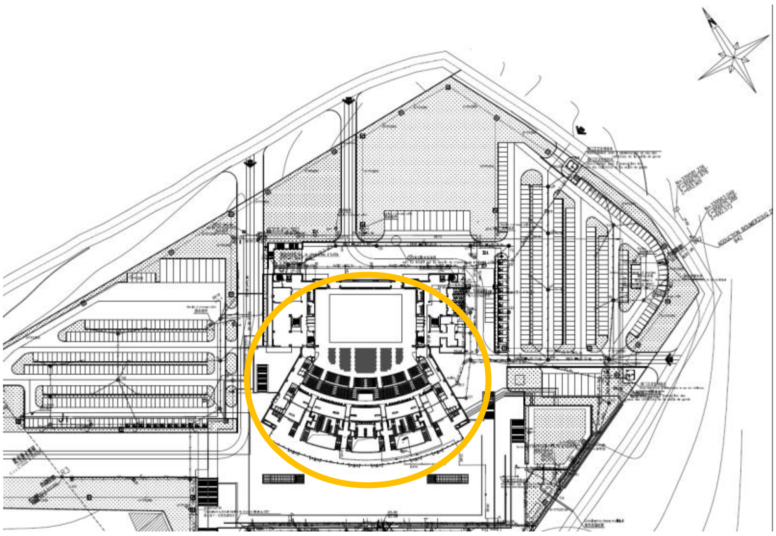


Figure IV.41. *Location of the performance hall in the building.*

Source: (CSCEC, 2013).

Figure IV.42. *Interior view of the performance hall (Empty).*

Source: Author 2022.

Figure IV.43. *Interior view of the performance hall during an event.*

Source: Author 2023.

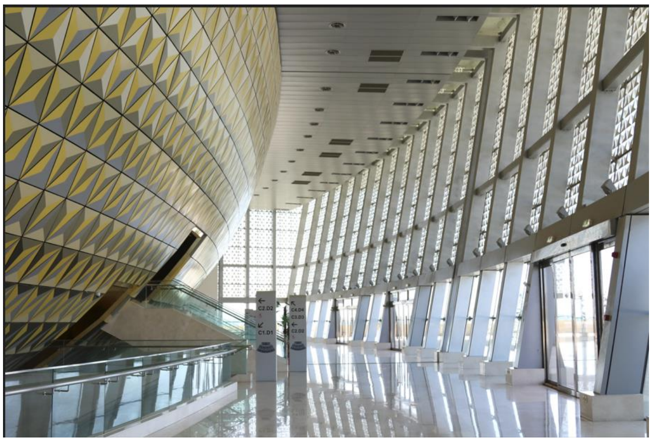


Figure IV.44. *The southern facade of the auditorium.*

Source: Author 2022.

IV.6.3.2 The public entrance hall

Situated on the first floor at the southern side of the building (Figure IV.42), this area functions as the primary entrance for spectators, with multiple doors granting access to the auditorium. This area is characterized by an arched glazed curtain wall that overlooks the square, offering a panoramic view (Figure IV.43). The facade serves as a tertiary layer for the auditorium, designating this hall as a transitional space (Figure IV.41).

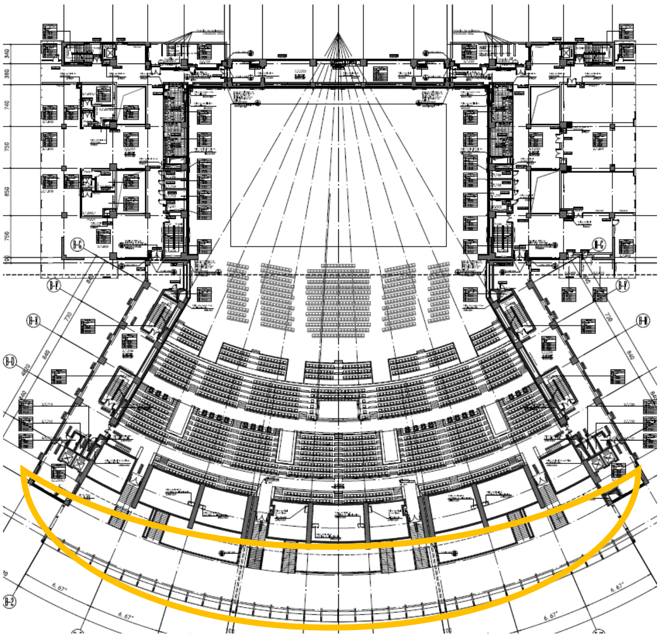


Figure IV.45. *Location of the public entrance hall in the building.*

Source: (CSCEC, 2013).

Figure IV.46. *Facade of the public entrance hall.*

Source: Author 2022.

IV.6.3.3 The relaxation and gathering area

This area is located next to the recording studio, on the second floor, specifically on the northwest side of the building (Figure IV.45). The façade on this side is completely made of glass; it features a double-glazed curtain wall (Figure IV.46). This is an open area with masonry partitions that establish a buffer zone between the interior space and the curtain wall, as illustrated in (Figures IV.47; Figure IV.48), from which the façade can be regarded as a double skin.

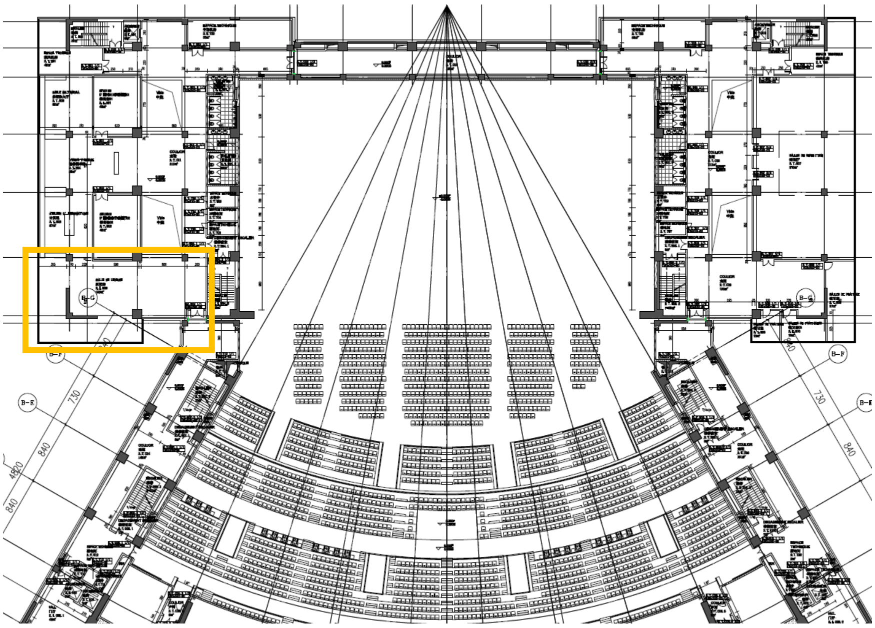


Figure IV.47. *Location of the relaxation and gathering area in the building.*

Source: (CSCEC, 2013).

Figure IV.48. *Facade of the relaxation and gathering area (Northwest façade).*

Source: Author 2022.

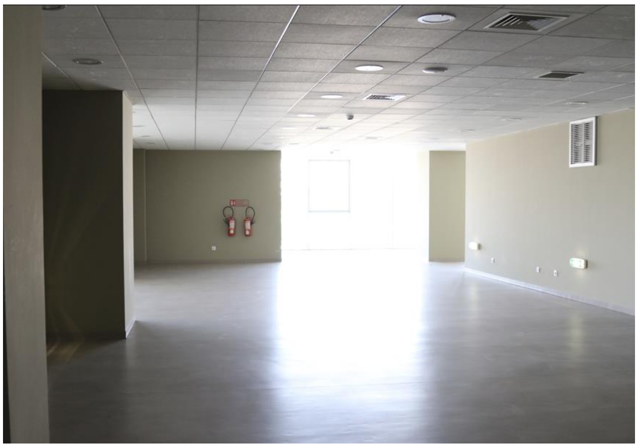


Figure IV.49*. Interior view of the relaxation and gathering area.*

Source: Author 2022.

Figure IV.50. *Interior view of the relaxation and gathering area.*

Source: Author 2022.

IV.7 position of measurement points

The primary aim of our research is to investigate the influence of DSF on thermal comfort. To achieve this, it is essential to assess various parameters, including outdoor temperature, indoor ambient temperature, indoor and outdoor relative humidity, and air velocity. For the measurement of these parameters, thermo-hygrometer data loggers were installed both inside the studied spaces and outside, alongside manual multifunction devices. The indoor instruments were positioned on a base 1.5 meters above the floor, located at the center of the spaces, to measure the ambient temperature. This temperature reflects the conditions experienced by the users of the spaces, with the objective of illustrating how DSF contributes to the optimization of thermal comfort.

IV.7.1 Palace of culture "AL Khalifa"

In this first case, the building is located in the city center in a very crowded area. In order not to distort the results and to ensure the safety of the measuring devices, a data logger was installed on the terrace of the building to record the outside temperature. I also took the temperature myself in front of the building using manual devices, along with other parameters.

The following figures show the locations of the measuring instruments inside the building.

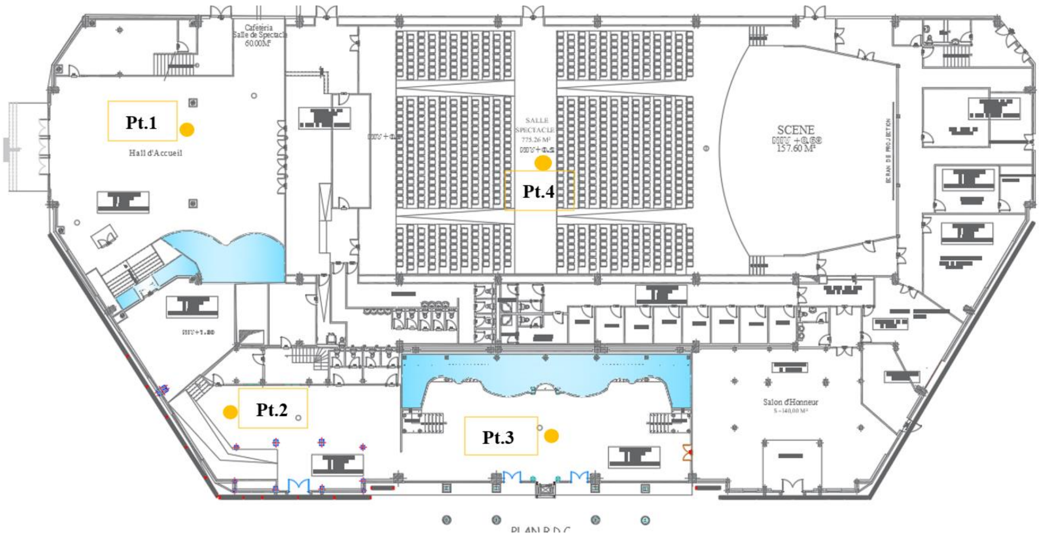


Figure IV.51. *Position of the measurement points on the ground floor.*

Source: D.E.P, modified by author.

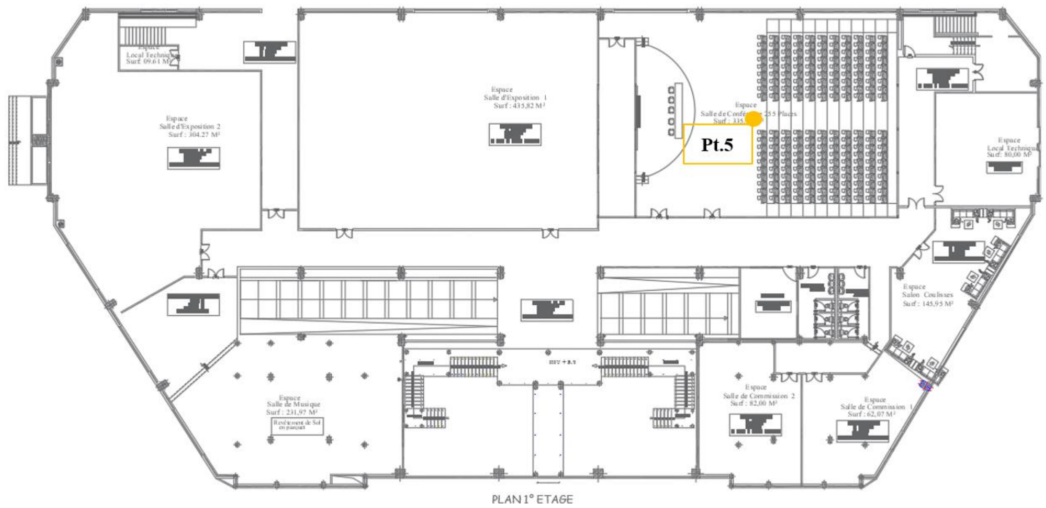


Figure IV.52*.Position of the measurement points on the first floor (Conference room).*

Source: D.E.P, modified by author.

IV.7.2 Public library of Constantine

To measure the outside temperature, a data logger was installed in the building's garden. In addition, I made measurements of various characteristics myself in front of the building with manual instruments. The images below indicate the positions of the measurement instruments both within and outside the structure.

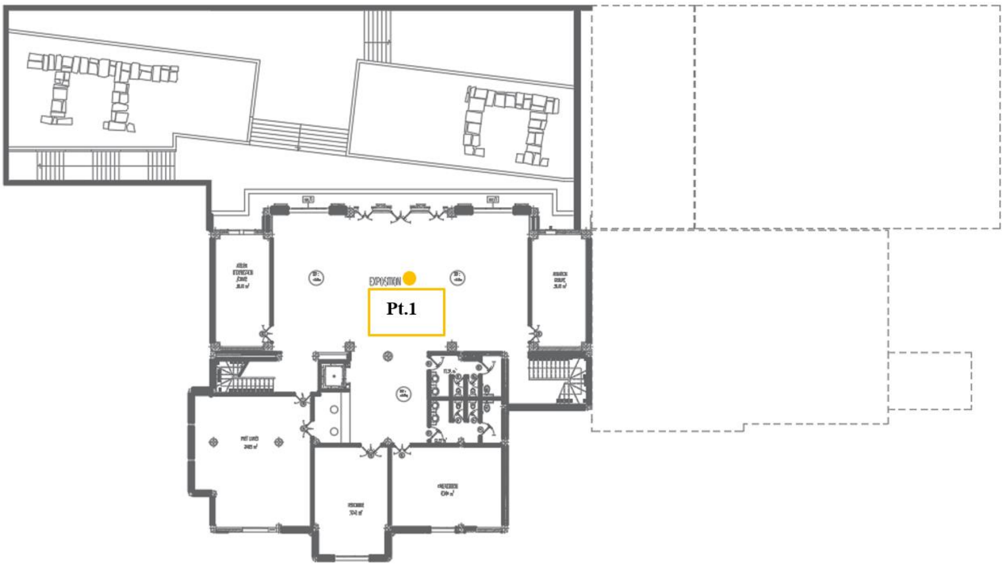


Figure IV.53. *Position of the measurement points on the underground.*

Source: D.E.P, modified by author.

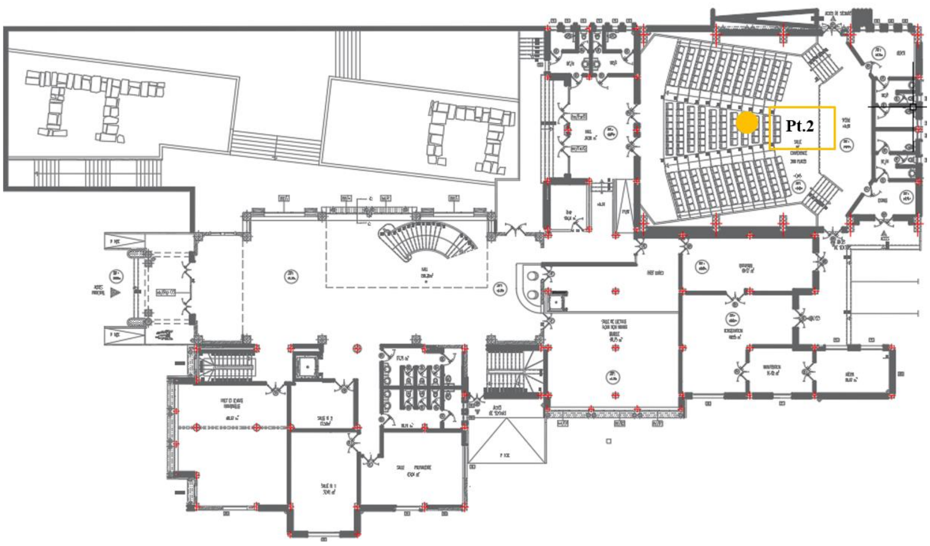


Figure IV.54. *Position of the measurement points on the ground floor (Conference room).*

Source: D.E.P, modified by author.

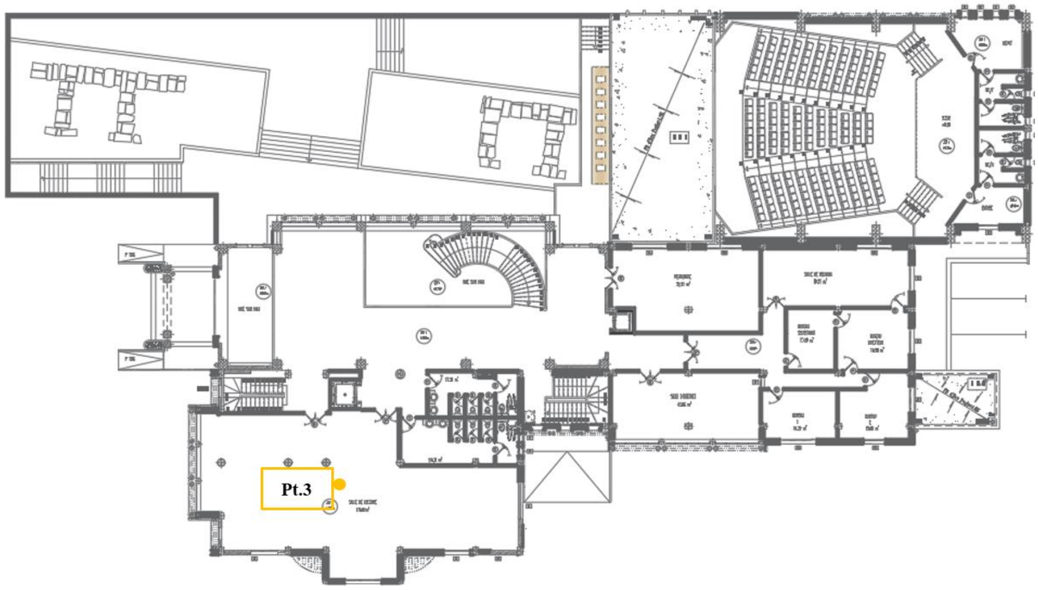


Figure IV.55. *Position of the measurement points on the first floor.*

Source: D.E.P, modified by author.

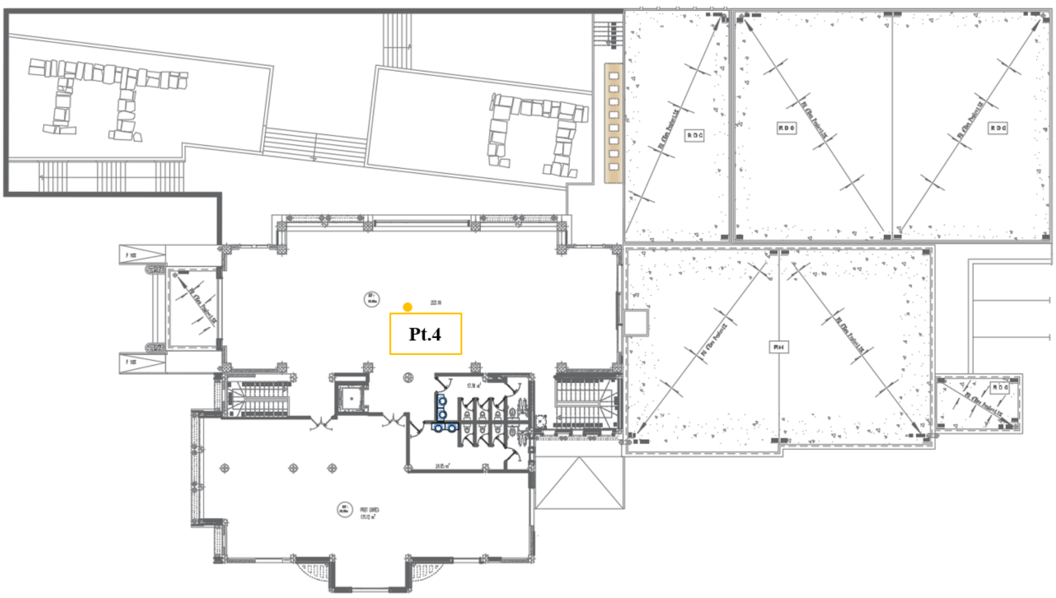


Figure IV.56. *Position of the measurement points on the first floor.*

Source: D.E.P, modified by author.

IV.7.3 The performance hall "Zenith Constantine"

Measurements in the auditorium are taken at several points, with data loggers placed at different levels. External measurements are taken on the esplanade, sheltered from the sun.

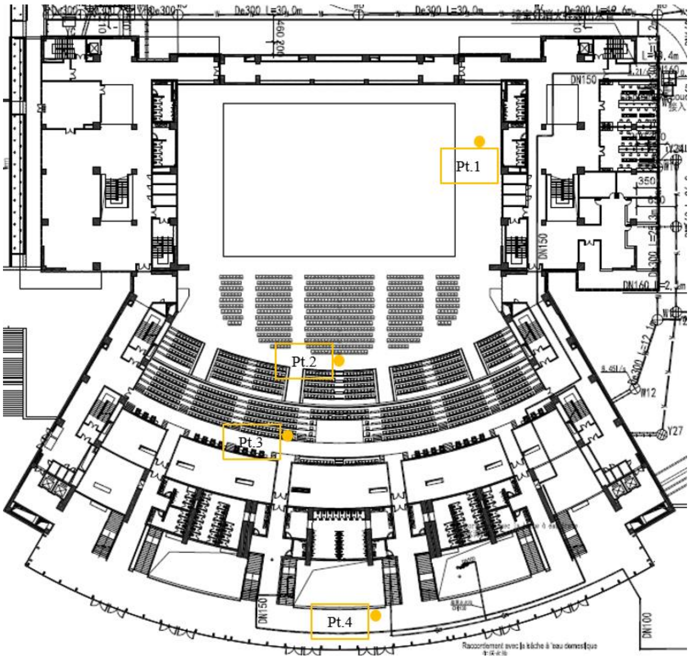


Figure IV.57. *Position of the measurement points in the performance hall.*

Source:(CSCEC, 2013).

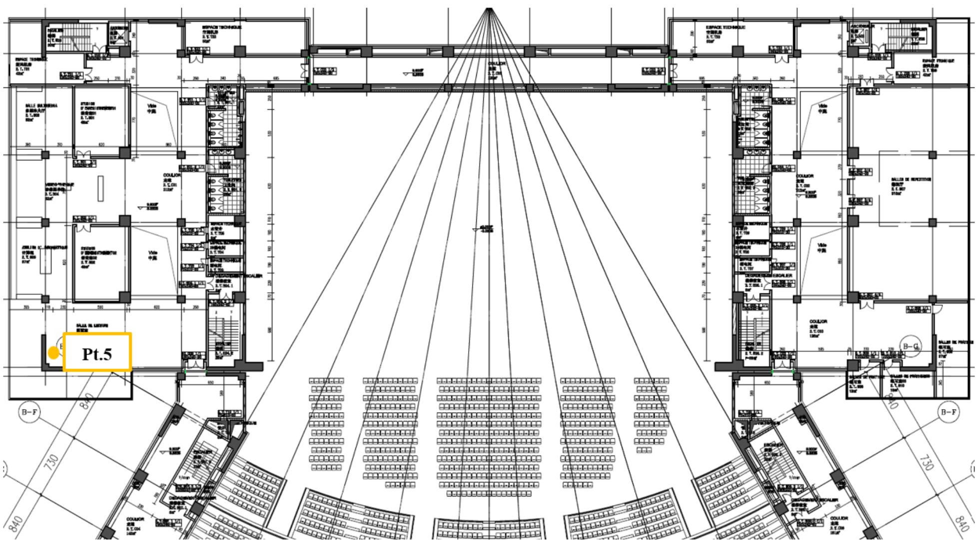


Figure IV.58. *Position of the measurement points in the relaxation and gathering area.*

Source: (CSCEC, 2013).

IV.8 Conclusion

This chapter is dedicated to presenting the methodologies, strategies, and instruments employed. The initial section offers a comprehensive overview of the study's execution, detailing all the methods and tools utilized throughout its various phases. Following this, a meticulous account of the in-situ measurements is presented, encompassing the identification of both hot and cold periods, as well as the calculation of the comfort temperature zone. This is succeeded by an explanation of the questionnaire survey's implementation and the organization of the questionnaire itself. The second section focuses on justifying the selection of interior spaces for the study and measurement, providing a description of each area, along with a demonstration of the location of measurement points.

CHAPTER V: RESULTS AND DISCUSSION OF THE IN-SITU MEASUREMENTS

V.1 Introduction

This chapter focuses on the presentation and interpretation of the findings from field investigations. As previously detailed in the preceding chapter, the fieldwork encompasses a series of in-situ measurements alongside a questionnaire survey carried out during two distinct periods (underheating and overheating) across three public buildings, each featuring double-skin facades (DSFs) constructed with varying techniques and materials.

This chapter presents, interprets, and discusses the outcomes of the in-situ measurements, aiming to evaluate the influence of DSFs on thermal comfort within the selected buildings and to compare the indoor hygrothermal conditions across them. Temperature and relative humidity data will be illustrated in graphical format (utilizing Excel software).

The last part of the chapter summarizes and compares the results to assess the effectiveness of DSFs in enhancing thermal comfort and to examine how different construction techniques and materials affect their performance.

V.2 In-situ measurement results

Using the various measuring instruments and in accordance with the protocol explained in the previous chapter, measurements were conducted in January 2021 for the underheating phase and August 2021 for the overheating period. They were collected simultaneously throughout multiple days in each period, but for our investigation, we selected the results from three typical days (the coldest and hottest).

V.3 Underheating period

Over a span of three days (15,16 and 17 January 2021), measurements of the climatic parameters (T/in, T/ex, RH, and S/air) were made concurrently at various locations within the three public buildings that were studied.

V.3.1 Palace of Culture

V.3.1.1 Results of the first measurement day

Results of the first day of January are presented in the graphs below.

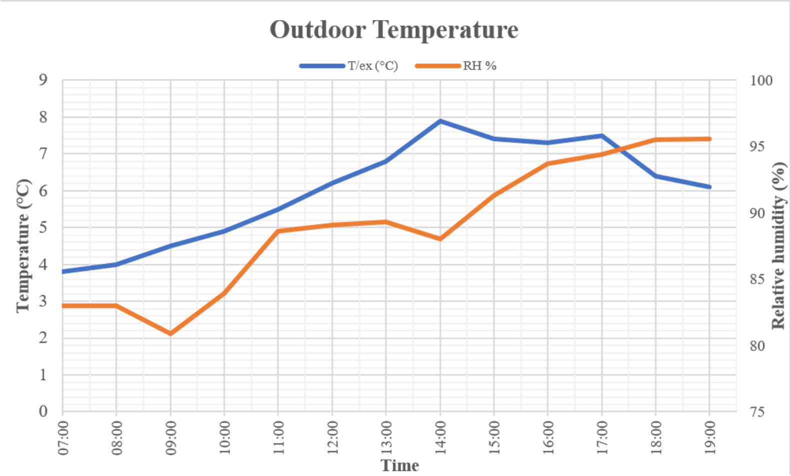


Figure V.1. *Outdoor temperature and relative humidity for "Ex.1".*

Source: Author 2025.

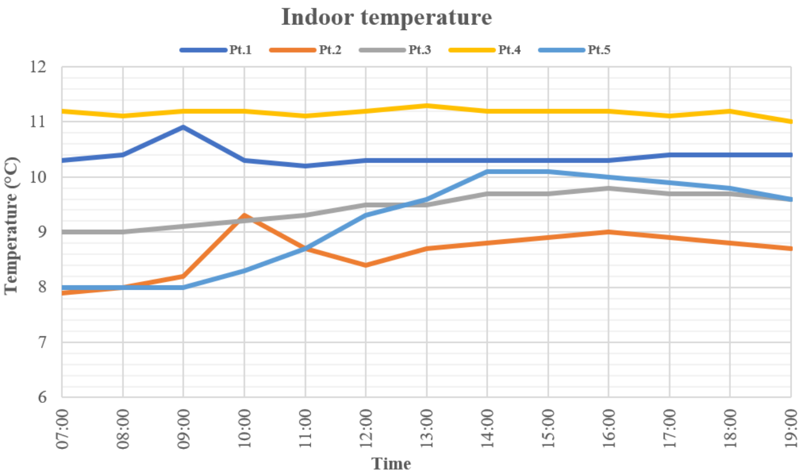


Figure V.2. *Indoor temperature for all measurement points "Ex.1".*

Source: Author 2025.

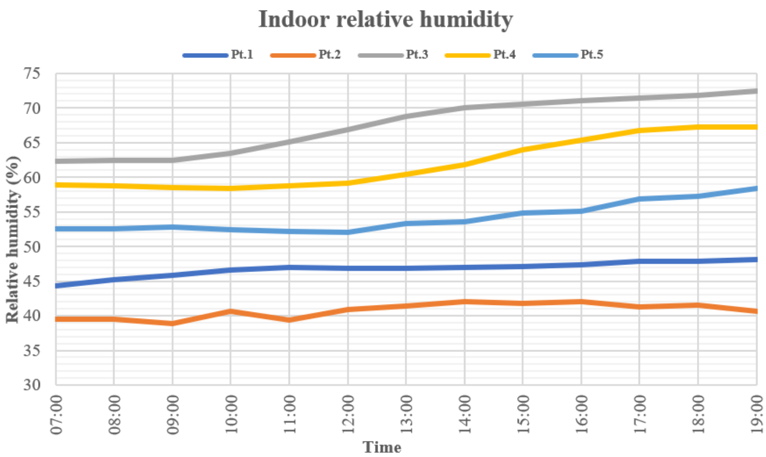


Figure V.3*. Indoor relative humidity for all measurement points "Ex.1".*

Source: Author 2025.

Table V.1. *Speed of air during the first measurement day at "Ex.1".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.1	0.3	0.1	1.5	1.3	0.8	0.5	0.1	0.3	0.5	0.6	0.8	0.3
Pt.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.2	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.1
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0

The ambient "T/in" varies from 10.1 to 10.9°C at the first measurement location "Pt.1," from 7.9 to 9.3°C, at "Pt.2," from 9° to 9.8°C, at "Pt.3," from 11° to 11.3°C, at "Pt.4," and from 8 to 10.3 at "Pt.5", as the figures above demonstrate. The "T/ex" ranges from 3.8 to 7.9°C. Consequently, the inside and outdoor temperatures differ between 3.3° and 7.2°C.

Despite the temperature differential between the outside and inside of the building, the "T/in" is unable to reach the comfort zone (17.9°–22.9°C); thus, a heating system must be included as a compensatory measure.

According to (Figure V.3) the relative humidity inside the building is between 35% and 75% which is comfortable.

The data in the table above indicate that the “S/air” is about 1.5 m/s outside the building, while at the inside it is about 0 m/s

We see that the north side at “Pt.4” has a greater RH because of the water basin and a lower "T/in" despite the façade being a double-glazed curtain wall.

V.3.1.2 Results of the second measurement day

At this second measurement day, the "T/ex" ranges from 4.9 to 7.3°C. While, as shown in figure V.5, the “T/in is between 10.8 and 12.1°C, at "Pt.1," from 8 to 9.7°C, at "Pt.2," from 9.4° to 9.9°C, at "Pt.3," from 10.1° to 11°C, at "Pt.4," and from 11.1 to 11.6 at "Pt.5".

Consequently, the difference between the inside and outdoor temperatures is between 3° and 7°C. But this is not sufficient to reach the comfortable temperature.

Figure V.6, show that relative humidity inside the building ranges from 35% to 75% which is comfortable.

The air velocity is about 0 m/s in the building, and between 0.3 and 1.6 at the outdoor.

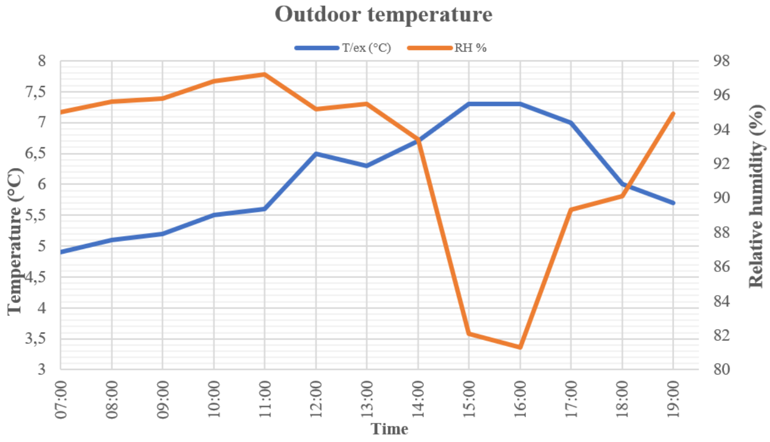


Figure V.4. *Outdoor temperature and relative humidity for "Ex.1".*

Source: Author 2025.

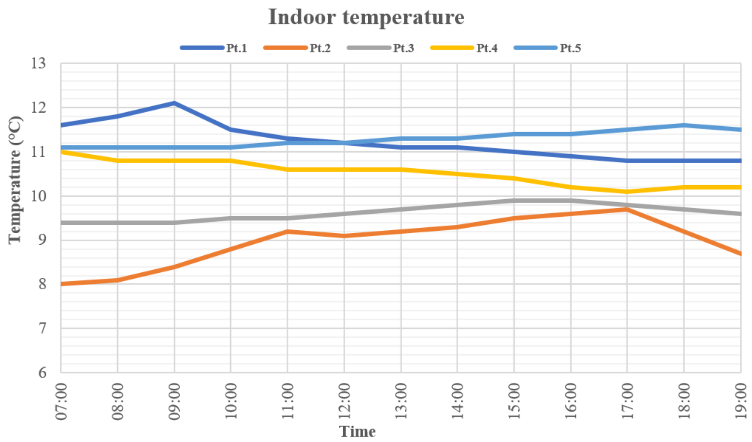


Figure V.5. *Indoor temperature for all measurement points "Ex.1".*

Source: Author 2025.

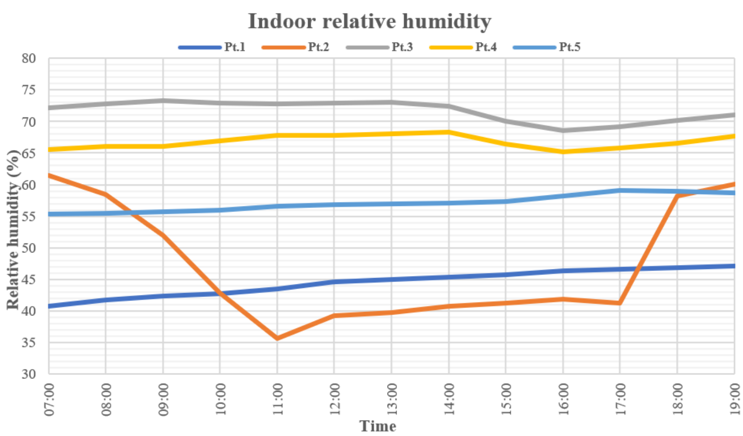


Figure V.6. *Indoor relative humidity for all measurement points "Ex.1".*

Source: Author 2025.

Table V.2. *Speed of air during the second measurement day at "Ex.1".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.4	0.3	0.9	1.6	0.4	0.1	0.5	0.9	0.5	1.2	0.8	1.0	0.9
Pt.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Pt.2	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.0
Pt.3	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1

V.3.1.3 Results of the third measurement day

For the last measurement day as shown in the following figures, the "T/in" varies from 10.7 to 11.2°C, at "Pt.1," from 9 to 9.8°C, at "Pt.2," from 8.8° to 10°C, at "Pt.3," from 10.6° to 10.9°C, at "Pt.4," and from 11.4 to 11.6 at "Pt.5". The "T/ex" ranges from 3.8 to 7.9°C. The “T/ex” is between 5.2 and 12°C

So, the inside and outdoor temperatures differ between 1° and 7°C.

The indoor temperatures inside the building are lower than the temperature of comfort, while the relative humidity is comfortable (between 40 and 70%).

The external air speed ranges from 0.3 to 1.5 m/s, while inside the building, it hovers around 0 m/s throughout the day.

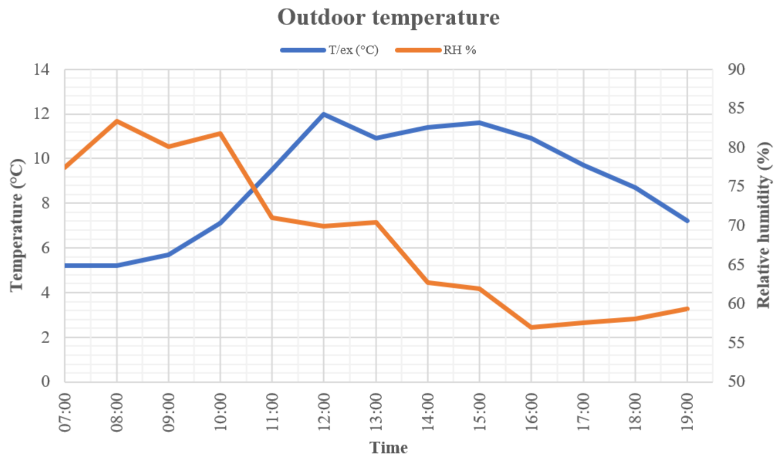


Figure V.7. *Outdoor temperature and relative humidity for “Ex.1” at the third day.*

Source: Author 2025.

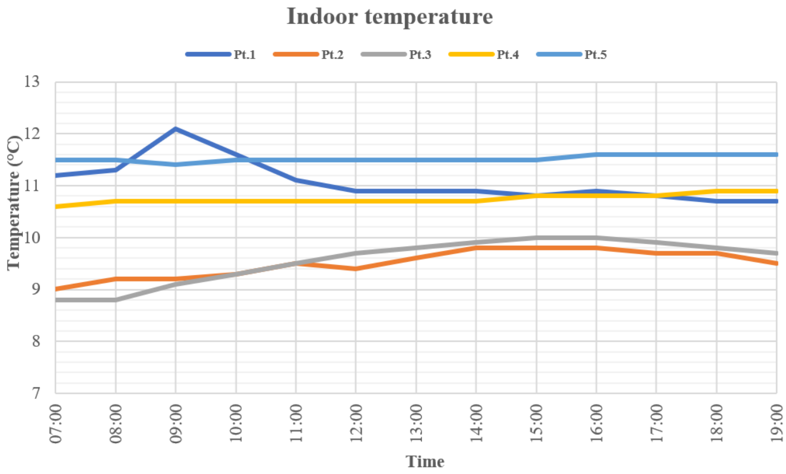


Figure V.8. *Indoor temperature for all measurement points "Ex.1" at the third day.*

Source: Author 2025.

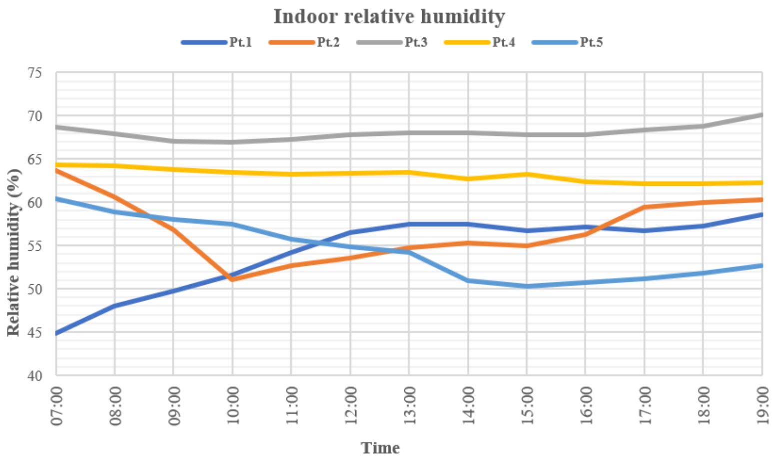


Figure V.9. *Indoor relative humidity for all measurement points "Ex.1" at the third day.*

Source: Author 2025.

Table V.3. *Speed of air during the third measurement day at "Ex.1".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.4	0.3	0.6	0.8	1.4	1.2	0.6	1.2	1.5	0.8	0.5	0.4	1.0
Pt.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Pt.2	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1

V.3.2 Public library of Constantine

V.3.2.1 Results of the first measurement day

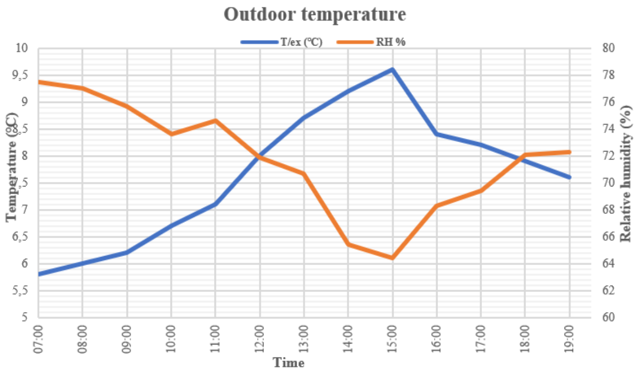


Figure V.10. *Outdoor temperature and relative humidity for "Ex.2".*

Source: Author 2025.

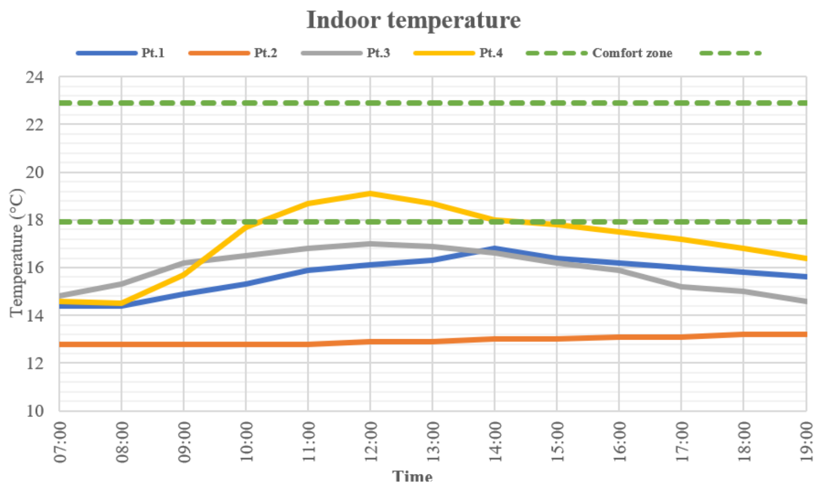


Figure V.11. *Indoor temperature for all measurement points "Ex.2".*

Source: Author 2025.

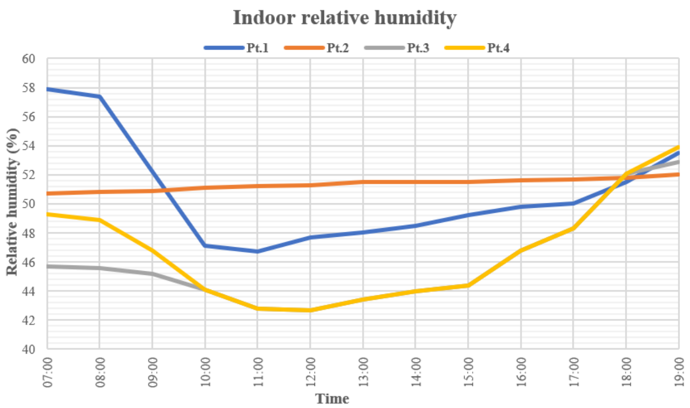


Figure V.12. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.4. *Speed of air during the first measurement day at "Ex.2".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	1.6	1.1	0.8	1.7	1.0	1.1	1.6	1.9	1.9	1.8	1.9	2.0	2.2
Pt.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

In the second building for the first day, the “T/in” ranges between 14.4° and 16.8°C, at “Pt.1, between 12.8° and 13.2°C, at “Pt.2, between 14.6° and 17°C, at “Pt.3”, and between 14.5° and 19.1°C, at “Pt.4”, while the “T/ex” ranges from 3.3 to 7.2°C. Therefore, the difference between “T/in” and “T/ex” is from 7 to 12°C.

The results show that the “T/in” in the reading room has reached the comfort zone temperature (18.4°-22.4°C) causing energy savings by eliminating the need for a heating system. However, in the conference room, despite the temperature difference, this is insufficient; but if the room is full, the temperature will rise and exceed the comfort zone temperature, eliminating the need for the heating system.

The relative humidity varies from 42 to 58%, which is comfortable. And the wind blows at a speed ranging from 0.8 to 2.2 m/s in front of the building, while it is 0 m/s inside the building.

V.3.2.2 Results of the second measurement day

In the second measurement day, the “T/in” is from 14.7° to 16.7°C in “Pt.1”, from 13.1° and 13.4°C, at “Pt.2”, from 15.1° and 17.9°C, at “Pt.3”, and from 15.8 to 19.4°C, at “Pt.4”, while the “T/ex” ranges from 4.9 to 7.8°C.

The difference between “T/in” and “T/ex” is about 8.1°C and 11.6°C.

The “T/in” in the secondary reading room reached the comfort temperature 17.9 during two hours, so the thermal environment is acceptable. And in the reading room “Pt.4” it has reached the comfort zone temperature (18.4°-22.4°C) so the heating system is not needed.

As shown in (Figure V.15), the relative humidity is comfortable because it varies between 42% and 58%.

The wind velocity in front of the building ranges from 0.1 to 1.6, while inside the building it is 0 m/s.

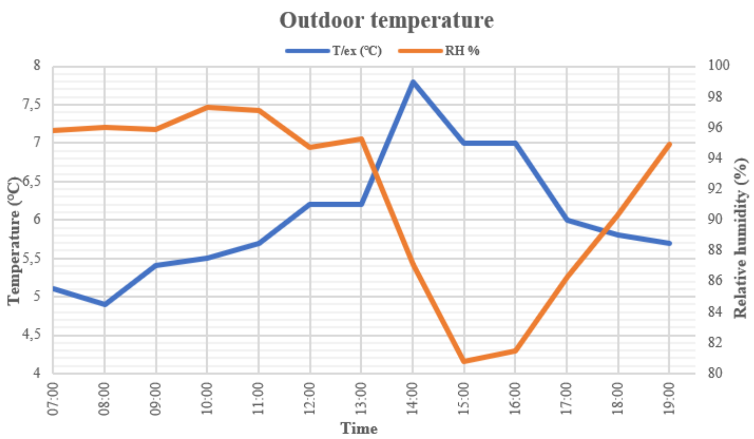


Figure V.13. *Outdoor temperature and relative humidity for "Ex.2".*

Source: Author 2025.

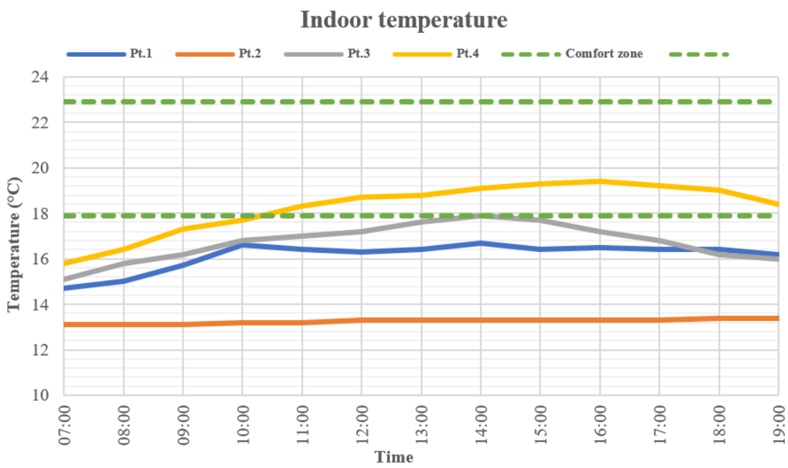


Figure V.14. *Indoor temperature for all measurement points "Ex.2".*

Source: Author 2025.

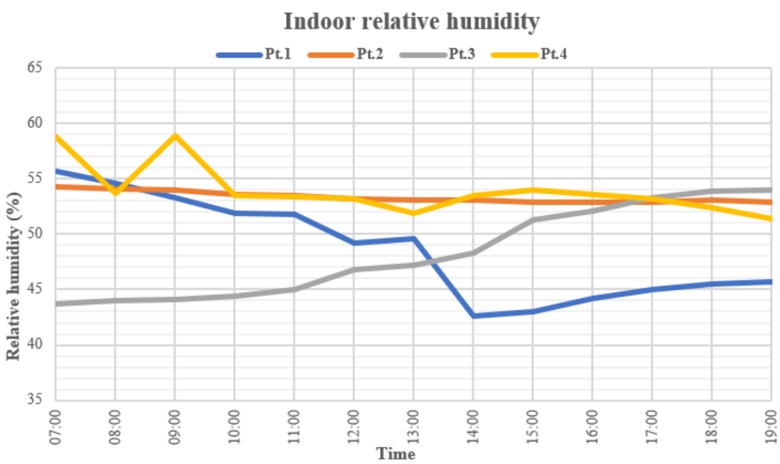


Figure V.15. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.5. *Speed of air during the second measurement day at "Ex.2".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	2.2	2.1	1.9	2.3	2.1	2.0	1.8	1.7	1.6	1.9	1.8	1.9	1.7
Pt.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

V.3.2.3 Results of the third measurement day

For the last day measurements, “T/ex” is from 5.6 to 12.4°C. Whereas, the ambient temperature inside the building ranges from 14.8 to 17.6°C, at “Pt.1”, from 13.1 to 13.4°C, at “Pt.2”, from 16.4 to 18.5°C, at “Pt.3”, and from 22.3 to 26.8°C, at “Pt.4”.

There is a great difference between the outdoor and indoor temperature, it is about 16.7°C.

The indoor relative humidity is from 44 to 66%, which mean a comfortable environment.

In front of the building, the wind speed is 0.1 to 1.6 m/s, while inside the building it is 0 m/s.

The comfort temperature is reached in the secondary reading room (during 5 hours), and in the main reading room during all day.

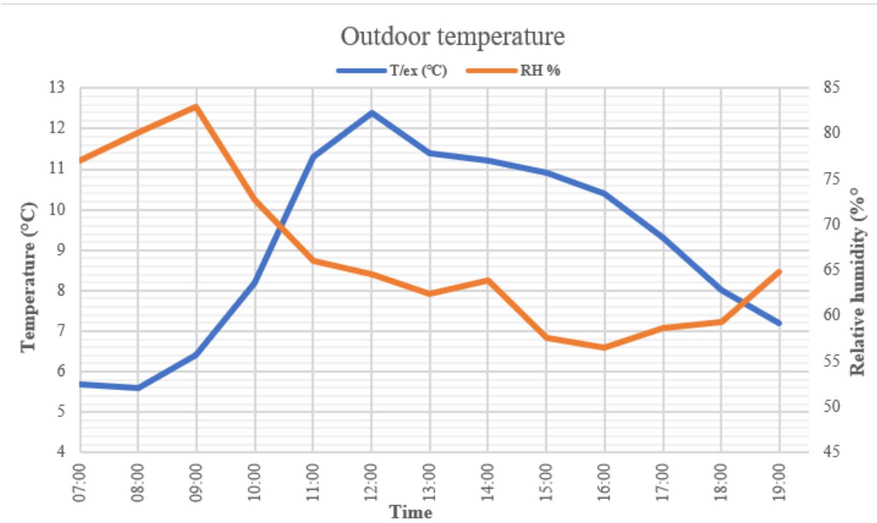


Figure V.16. *Outdoor temperature and relative humidity for “Ex.2”.*

Source: Author 2025.

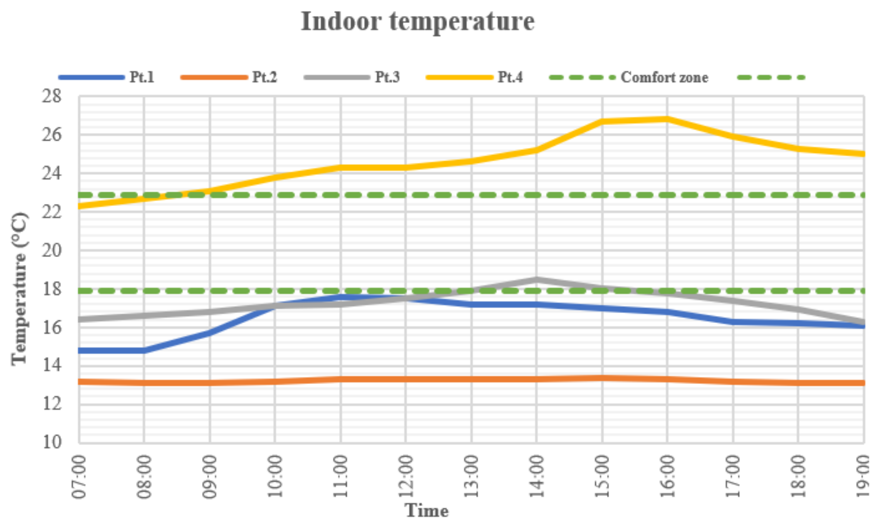


Figure V.17. *Indoor temperature for all measurement points "Ex.2".*

Source: Author 2025.

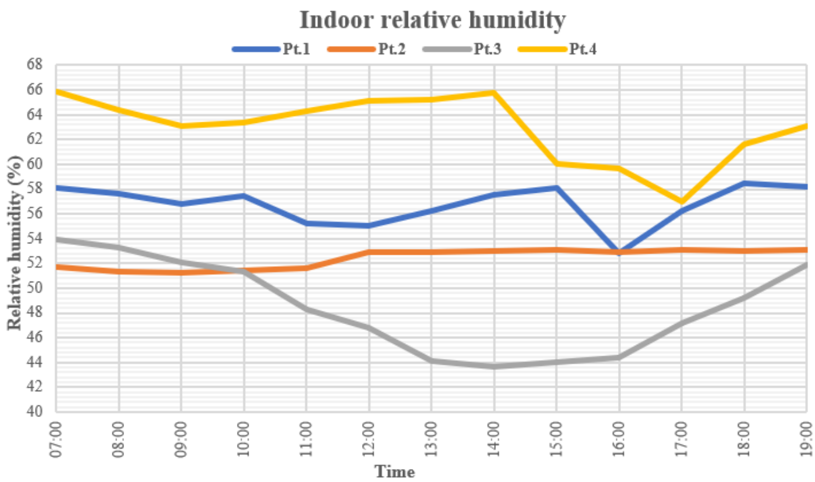


Figure V.18. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.6. *Speed of air during the third measurement day at "Ex.2".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.8	0.9	1.4	1.1	1.3	1.2	1.0	0.9	0.8	1.1	1.2	1.3	1.4
Pt.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

V.3.3 Performance hall "Zenith Constantine"

V.3.3.1 Results of the first measurement day

According to the data from the first day measurements, "T/ex" is from 6.2 to 9.4°C. Whereas, the "T/in" ranges from 11.2 to 12°C, at "Pt.1", from 12.5 to 12.9°C, at "Pt.2", from 12.7 to 13.3°C, at "Pt.3", from 12.9 to 13.8°C, at "Pt.4", and from 13 to 13.3°C, at "Pt.5".

Although the temperature difference between indoors and outdoors is between 4.4 and 6.8°C, the comfort temperature is not maintained.

The indoor relative humidity ranges from 66% to 75%, which is considered comfortable. Meanwhile, the air speed within the building hovers around 0 m/s, whereas it varies from 0.5 to 2.2 m/s outside.

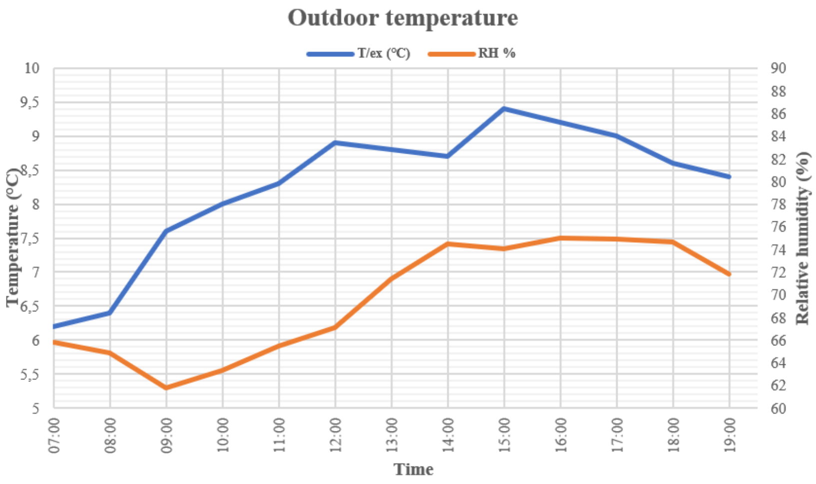


Figure V.19*.Outdoor temperature and relative humidity for "Ex.3".*

Source: Author 2025.

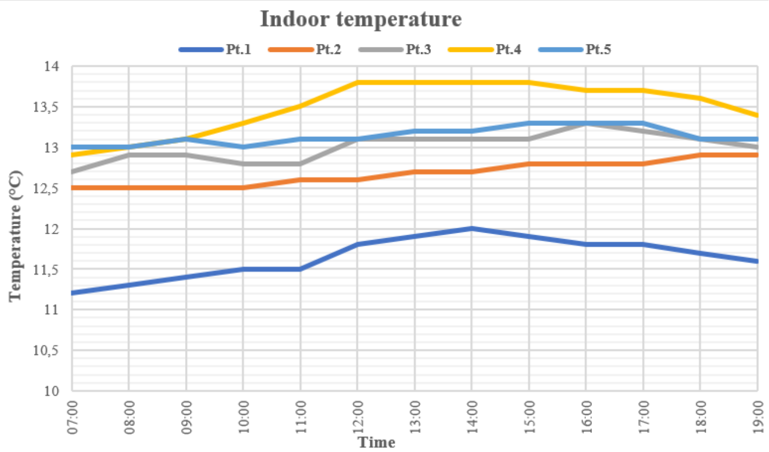


Figure V.20. *Indoor temperature for all measurement points "Ex.3".*

Source: Author 2025.

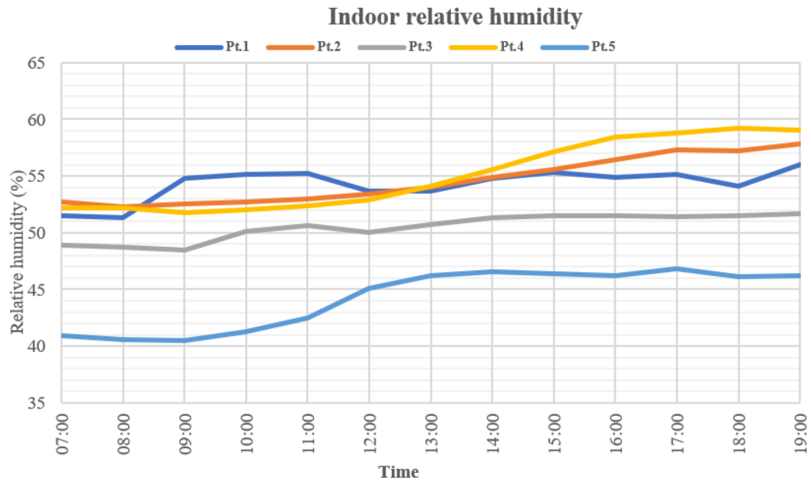


Figure V.21. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.7. *Speed of air during the first measurement day at "Ex.3".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	1.7	1.9	1.4	2.2	1.8	1.1	1.3	1.6	1.4	1.3	1.9	1.6	1.5
Pt.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

V.3.3.2 Results of the second measurement day

In the second measurements day, "T/ex" is from 6.8 to 10.1°C, and the "T/in" varies from 13 to 13.3°C, at "Pt.1", from 12.5 to 12.9°C, at "Pt.2", from 13.2 to 13.6°C, at "Pt.3", from 12.4 to 15°C, at "Pt.4", and from 13.4 to 13.8°C, at "Pt.5". The relative humidity indoor at the all spaces is from 44 to 58%, which is comfortable.

Despite the difference of temperature between "T/ex" and "T/in" is about 5.6 to 6.2°C, the comfort temperature is not reached.

Outside the edifice the wind velocity ranges from 3.3 to 5.5 m/s, whereas within the indoor spaces it registers at 0 and 0.2 m/s.

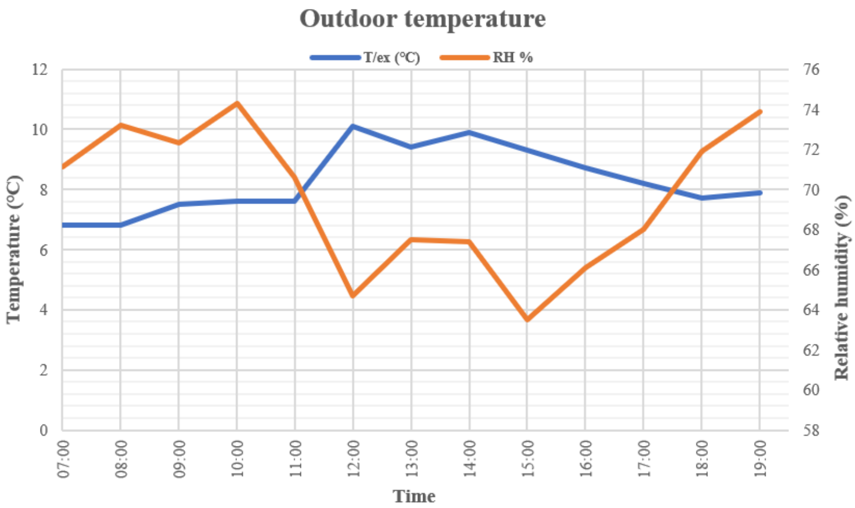


Figure V.22. *Outdoor temperature and relative humidity for "Ex.3".*

Source: Author 2025.

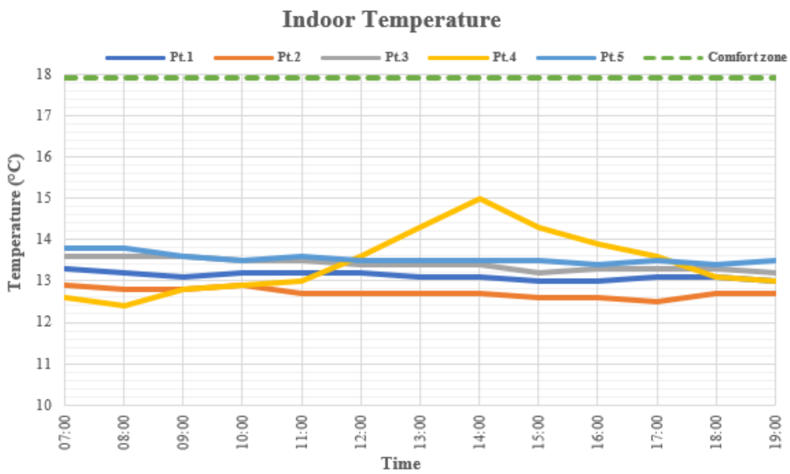


Figure V.23. *Indoor temperature for all measurement points "Ex.3".*

Source: Author 2025.

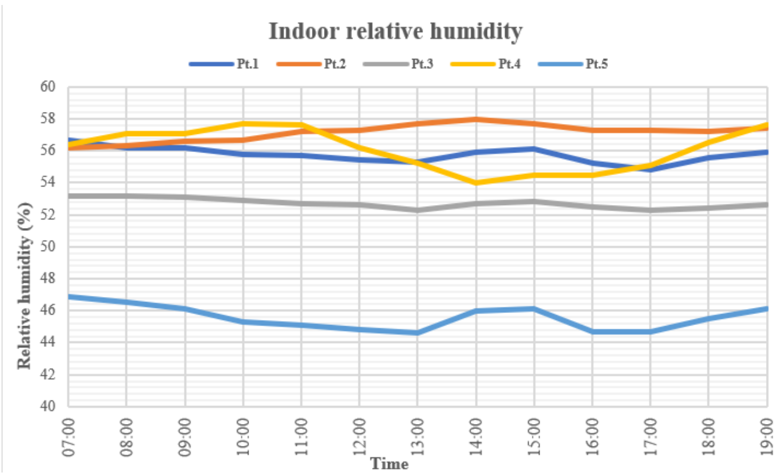


Figure V.24. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.8. *Speed of air during the second measurement day at "Ex.3".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	3.8	3.3	4.1	4.7	5.2	5.5	3.3	3.0	3.8	5.0	3.6	3.5	3.3
Pt.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

V.3.3.3 Results of the third measurement day

The measurements of the third day represented in the following figures shows that, “T/ex” is from 6.1 to 16.1°C, and the “T/in” at “Pt.1” varies from 13.2 to 13.9°C, from 12.9 to 13.1°C, at “Pt.2”, from 13.9 to 14.2°C, at “Pt.3”, from 11.9 to 22.7°C, at “Pt.4”, and from 14.2 to 14.5°C, at “Pt.5”. And the indoor RH rangers between 35 to 55%, which is comfortable.

The difference of temperature between “T/ex” and “T/in” is about 8°C, the comfort temperature is reached at “Pt.4”, where the facade is double glazed curtain wall.

The table presented below indicates that the velocity of the air within the building is about 0 m/s, while the external air speed varies between 0.3 and 1.4 m/s.

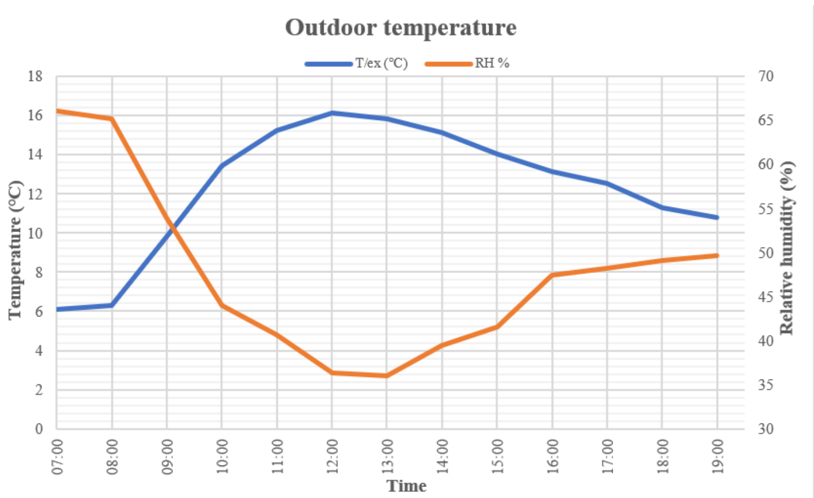


Figure V.25. *Outdoor temperature and relative humidity for “Ex.3”.*

Source: Author 2025.

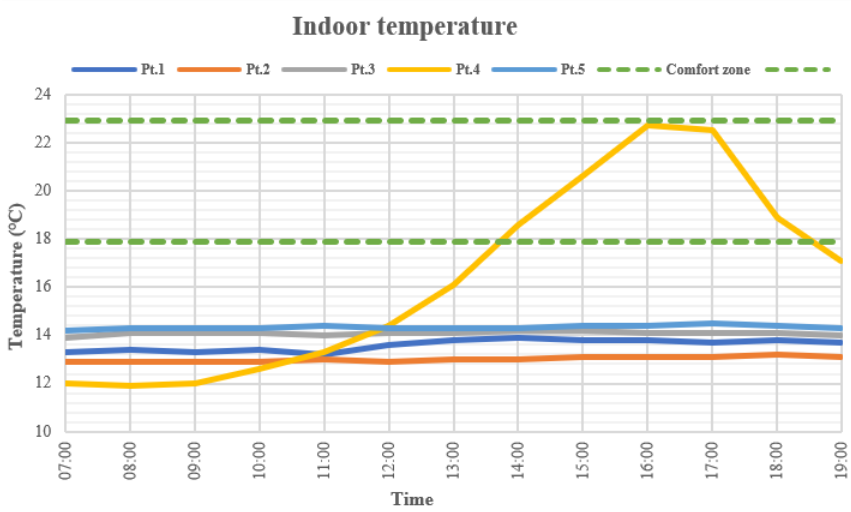


Figure V.26. *Indoor temperature for all measurement points "Ex.3".*

Source: Author 2025.

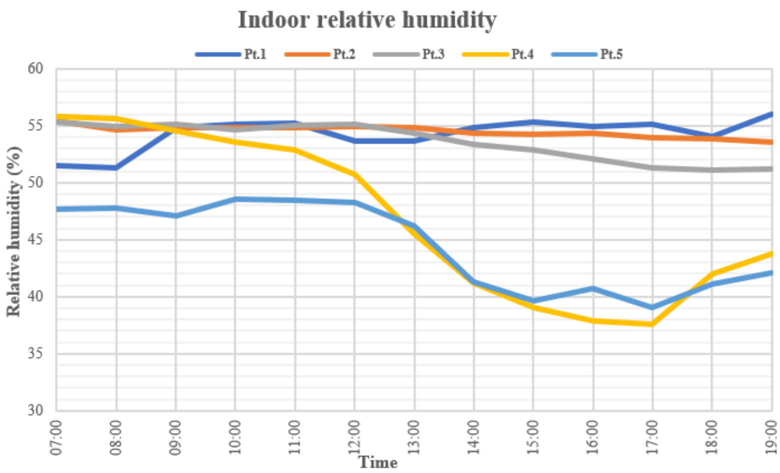


Figure V.27. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.9. *Speed of air during the third measurement day at "Ex.3".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	1.1	1.2	0.3	0.4	0.6	0.5	0.3	0.4	0.6	0.5	0.6	1.1	1.4
Pt.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

V.3.4 Discussion and observation

Table V.10. *Temperature in the three buildings in winter.*

Source: Author 2025.

Case study		Ex.1: AL KHALIFA					Ex.2: Public Library				Ex.3: Zenith Constantine				
Date	Hours	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5	Pt.1	Pt.2	Pt.3	Pt.4	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5
15/ 01/ 2021	07:00	10,3	7,9	9	11,2	8	14,4	12,8	14,8	14,6	11,2	12,5	12,7	12,9	13
	08:00	10,4	8	9	11.1	8	14.4	12.8	15.3	14.5	11.3	12.5	12.9	13	13
	09:00	10.9	8.2	9.1	11.2	8	14.9	12.8	16.2	15.7	11.4	12.5	12.9	13.1	13.1
	10:00	10.3	9.3	9.2	11.2	8.3	15.3	12.8	16.5	17.7	11.5	12.5	12.8	13.3	13
	11:00	10.2	8.7	9.3	11.2	8.7	15.9	12.8	16.8	18.7	11.5	12.6	12.8	13.5	13.1
	12:00	10.3	8.4	9.5	11.2	9.3	16.1	12.9	17	19.1	11.8	12.6	13.1	13.8	13.1
	13:00	10.3	8.7	9.5	11.3	9.6	16.3	12.9	16.9	18.7	11.9	12.7	13.1	13.8	13.2
	14:00	10.3	8.8	9.7	11.2	10.1	16.8	13	16.6	18	12	12.7	13.1	13.8	13.2
	15:00	10.3	8.9	9.7	11.2	10.1	16.4	13	16.2	17.8	11.9	12.8	13.1	13.8	13.3
	16:00	10.3	9	9.8	11.2	10	16.2	13.1	15.9	17.5	11.8	12.8	13.3	13.7	13.3
	17:00	10.4	8.9	9.7	11.1	9.9	16	13.1	15.2	17.2	11.8	12.8	13.2	13.7	13.3
	18:00	10.4	8.8	9.7	11.2	9.8	15.8	13.2	15	16.8	11.7	12.9	13.1	13.6	13.1
	19:00	10.4	8.7	9.6	11	9.6	15.6	13.2	14.6	16.4	11.6	12.9	13	13.4	13.1
16/ 01/ 2021	07:00	11,6	8	9,4	11	11,1	14,7	13,1	15,1	15,8	13,3	12,9	13,6	12,6	13,8
	08:00	11.8	8.1	9.4	10.8	11.1	15	13.1	15.8	16.4	13.2	12.8	13.6	12.4	13.8
	09:00	12.1	8.4	9.4	10.8	11.1	15.7	13.1	16.2	17.3	13.1	12.8	13.6	12.8	13.6
	10:00	11.5	8.8	9.5	10.8	11.1	16.6	13.2	16.8	17.7	13.2	12.9	13.5	12.9	13.5
	11:00	11.3	9.2	9.5	10.6	11.2	16.4	13.2	17	18.3	13.2	12.7	13.5	13	13.6
	12:00	11.2	9.1	9.6	10.6	11.2	16.3	13.3	17.2	18.7	13.2	12.7	13.4	13.6	13.5
	13:00	11.1	9.2	9.7	10.6	11.3	16.4	13.3	17.6	18.8	13.1	12.7	13.4	14.3	13.5
	14:00	11.1	9.3	9.8	10.5	11.3	16.7	13.3	17.9	19.1	13.1	12.7	13.4	15	13.5
	15:00	11	9.5	9.9	10.4	11.4	16.4	13.3	17.7	19.3	13	12.6	13.2	14.3	13.5
	16:00	10.9	9.6	9.9	10.2	11.4	16.5	13.3	17.2	19.4	13	12.6	13.3	13.9	13.4
	17:00	10.8	9.7	9.8	10.1	11.5	16.4	13.3	16.8	19.2	13.1	12.5	13.3	13.6	13.5
	18:00	10.8	9.2	9.7	10.2	11.6	16.4	13.4	16.2	19	13.1	12.7	13.3	13.1	13.4
	19:00	10.8	8.7	9.6	10.2	11.5	16.2	13.4	16	18.4	13	12.7	13.2	13	13.5
17/ 01/ 2021	07:00	11,2	9	8,8	10,6	11,5	14,8	13,2	16,4	22,3	13,3	12,9	13,9	12	14,2
	08:00	11.3	9.2	8.8	10.7	11.5	14.8	13.1	16.6	22.7	13.4	12.9	14.1	11.9	14.3
	09:00	12.1	9.2	9.1	10.7	11.4	15.7	13.1	16.8	23.1	13.3	12.9	14.1	12	14.3
	10:00	11.6	9.3	9.3	10.7	11.5	17.1	13.2	17.1	23.8	13.4	12.9	14.1	12.6	14.3
	11:00	11.1	9.5	9.5	10.7	11.5	17.6	13.3	17.2	24.3	13.2	13	14	13.3	14.4
	12:00	10.9	9.4	9.7	10.7	11.5	17.5	13.3	17.5	24.3	13.6	12.9	14.1	14.4	14.3
	13:00	10.9	9.6	9.8	10.7	11.5	17.2	13.3	17.9	24.6	13.8	13	14.1	16.1	14.3
	14:00	10.9	9.8	9.9	10.7	11.5	17.2	13.3	18.5	25.2	13.9	13	14.2	18.6	14.3
	15:00	10.8	9.8	10	10.8	11.5	17	13.4	18	26.7	13.8	13.1	14.2	20.6	14.4
	16:00	10.9	9.8	10	10.8	11.6	16.8	13.3	17.8	26.8	13.8	13.1	14.1	22.7	14.4
	17:00	10.8	9.7	9.9	10.8	11.6	16.3	13.2	17.4	25.9	13.7	13.1	14.1	22.5	14.5
	18:00	10.7	9.7	9.8	10.9	11.6	16.2	13.1	16.9	25.3	13.8	13.2	14.1	18.9	14.4
	19:00	10.7	9.5	9.7	10.9	11.6	16.1	13.1	16.3	25	13.7	13.1	14	17.1	14.3

Table V.11. *Relative humidity in the three buildings in winter.*

Source: Author 2025.

Case study		Ex.1: AL KHALIFA					Ex.2: Public Library				Ex.3: Zenith Constantine				
Date	Hours	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5	Pt.1	Pt.2	Pt.3	Pt.4	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5
15/ 01/ 2021	07:00	44,3	39,5	62,3	58,9	52,6	57,9	50,7	45,7	49,3	51,5	52,7	48,9	52,2	40,9
	08:00	45.2	39.5	62.4	58.7	52.6	57.4	50.8	45.6	48.9	51.3	52.3	48.7	52.2	40.6
	09:00	45.9	38.9	62.4	58.5	52.8	52.2	50.9	45.2	46.8	54.8	52.5	48.5	51.8	40.5
	10:00	46.6	40.7	63.4	58.4	52.4	47.1	51.1	44.1	44.1	55.1	52.7	50.1	52	41.3
	11:00	47	39.4	65.1	58.8	52.2	46.7	51.2	42.8	42.8	55.2	53	50.6	52.4	42.5
	12:00	46.8	40.9	66.9	59.1	52	47.7	51.3	42.7	42.7	53.7	53.4	50	52.9	45.1
	13:00	46.9	41.4	68.8	60.4	53.3	48	51.5	43.4	43.4	53.7	54	50.7	54.1	46.2
	14:00	47	42	70	61.8	53.6	48.5	51.5	44	44	54.8	54.9	51.3	55.6	46.6
	15:00	47.1	41.8	70.5	64	54.8	49.2	51.5	44.4	44.4	55.3	55.6	51.5	57.1	46.4
	16:00	47.3	42	71.1	65.3	55.1	49.8	51.6	46.8	46.8	54.9	56.4	51.5	58.4	46.2
	17:00	47.9	31.3	71.4	66.8	56.8	50	51.7	48.3	48.3	55.1	57.3	51.4	58.8	46.8
	18:00	47.9	41.5	71.8	67.2	57.2	51.5	51.8	52.1	52.1	54.1	57.2	51.5	59.2	46.1
	19:00	48.1	40.7	72.5	67.2	58.4	53.5	52	52.9	53.9	56	57.8	51.7	59	46.2
16/ 01/ 2021	07:00	40,8	61,4	72,2	65,6	55,4	55,7	54,3	43,7	58,8	56,7	56,2	53,2	56,4	46,9
	08:00	41.7	58.4	72.8	66.1	55.5	54.6	54.1	44	53.7	56.2	56.3	53.2	57.1	46.5
	09:00	42.3	52	73.3	66.1	55.7	53.3	54	44.1	58.9	56.2	56.6	53.1	57.1	46.1
	10:00	42.7	42.8	72.9	66.9	56	51.9	53.6	44.4	53.5	55.8	56.7	52.9	57.7	45.3
	11:00	43.5	35.6	72.8	67.8	56.6	51.8	53.5	45	53.4	55.7	57.2	52.7	57.6	45.1
	12:00	44.6	39.2	72.9	67.8	56.8	49.2	53.2	46.8	53.2	55.4	57.3	52.6	56.2	44.8
	13:00	45	39.7	73	68	56.9	49.6	53.1	47.2	51.9	55.3	57.7	52.3	55.2	44.6
	14:00	45.3	40.7	72.4	68.3	57.1	42.6	53.1	48.3	53.5	55.9	58	52.7	54	46
	15:00	45.7	41.2	70.1	66.4	57.3	43	52.9	51.3	54	56.1	57.7	52.8	54.5	46.1
	16:00	46.3	41.9	68.6	65.2	58.2	44.2	52.9	52.1	53.6	55.2	57.3	52.5	54.5	44.7
	17:00	46.6	41.3	69.2	65.8	59.1	45	52.9	53.3	53.2	54.8	57.3	52.3	55.1	44.7
	18:00	46.9	58.2	70.2	66.6	58.9	45.5	53.1	53.9	52.4	55.6	57.2	52.4	56.5	45.5
	19:00	47.1	60.1	71.1	67.7	58.7	45.7	52.9	54	51.4	55.9	57.4	52.6	57.6	46.1
17/ 01/ 2021	07:00	44,8	63,7	68,7	64,3	60,4	58,1	51,7	53,9	65,9	51,5	55,4	55,3	55,8	47,7
	08:00	48	60.6	67.9	64.2	58.9	57.6	51.3	53.3	64.4	51.3	54.6	54.9	55.6	47.8
	09:00	49.7	56.8	67	63.8	58	56.8	51.2	52.1	63.1	54.8	54.8	55.1	54.5	47.1
	10:00	51.6	51.1	66.9	63.5	57.5	57.4	51.4	51.3	63.4	55.1	54.8	54.6	53.6	48.6
	11:00	54.2	52.7	67.3	63.2	55.7	55.2	51.6	48.3	64.3	55.2	54.8	55	52.9	48.5
	12:00	56.5	53.6	67.8	63.3	54.9	55	52.9	46.8	65.1	53.7	54.9	55.1	50.7	48.3
	13:00	57.5	54.7	68	63.4	54.2	56.2	52.9	44.1	65.2	53.7	54.8	54.4	45.5	46.2
	14:00	57.5	55.3	68	62.7	50.9	57.5	53	43.7	65.8	54.8	54.4	53.4	41.2	41.3
	15:00	56.7	55	67.8	63.2	50.3	58.1	53.1	44	60	55.3	54.3	52.9	39.1	39.6
	16:00	57.1	56.3	67.8	62.4	50.7	52.8	52.9	44.4	59.7	54.9	54.4	52.1	37.9	40.7
	17:00	56.7	59.4	68.4	62.1	51.2	56.2	53.1	47.2	57	55.1	54	51.3	37.6	39.1
	18:00	57.2	60	67.8	62.1	51.8	58.5	53	49.2	61.6	54.1	53.9	51.1	42	41.1
	19:00	58.6	60.3	70.1	62.3	52.7	58.2	53.1	51.9	63.1	56	53.6	51.2	43.8	42.1

The comfort zone temperature in winter (17.9° to 22.9°C) is reached in the second building (Ex. 2) in two spaces, the main and the secondary reading rooms, and in the third building (Ex. 3) at the public entrance hall. However, the comfort temperature has not been achieved in the other spaces.

The relative humidity is generally comfortable in all spaces over the three buildings, except for the VIP hall in the palace of culture, “Pt.3”, because of the presence of the water basin.

Based on the analysis of the various examples over the three days, it can be observed that the ambient temperature in spaces with a glass curtain wall reached a comfortable level, while completely enclosed spaces were the coldest (such as the conference rooms and performance hall in Ex. 1 and Ex. 2, which are occasionally used).

The spaces with double-glazed curtain-walls oriented north are colder than those oriented west, east, or south.

From the analysis of the (03) three cases, the “DSF” allows a substantial difference in “T/in” in comparison with “T/ex” about 7°C in the palace of culture, about 16.7°C in the public library, and about 8°C in the performance hall.

V.4 Overheating period

Over a span of three days (12,13 and 14 August 2021), measurements of the climatic parameters (T/in, T/ex, RH, and S/air) were made concurrently at various locations within the three public buildings that were studied.

V.4.1 Palace of Culture

V.4.1.1 Results of the first measurement day

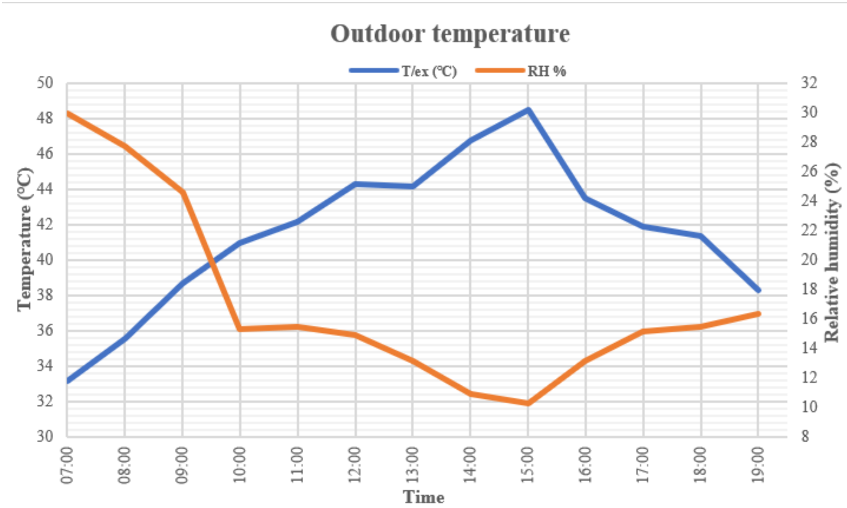


Figure V.28. *Outdoor temperature and relative humidity for “Ex.1”.*

Source: Author 2025.

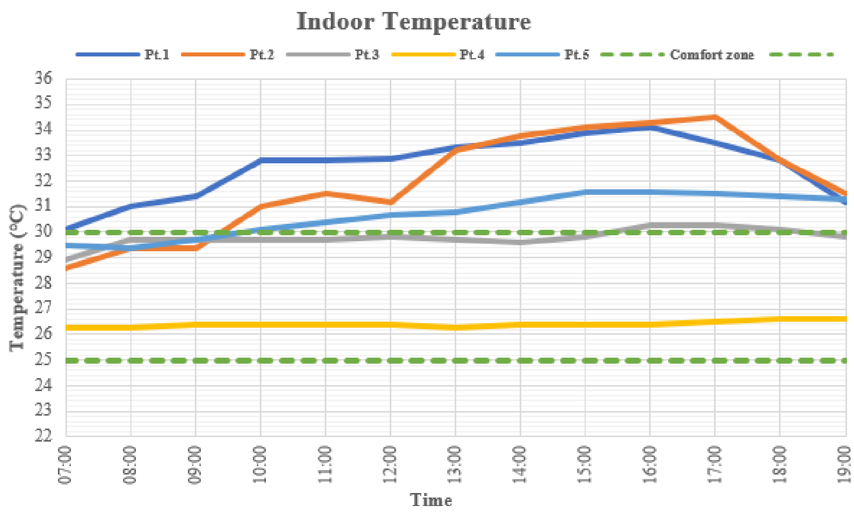


Figure V.29. *Indoor temperature for all measurement points "Ex.1".*

Source: Author 2025.

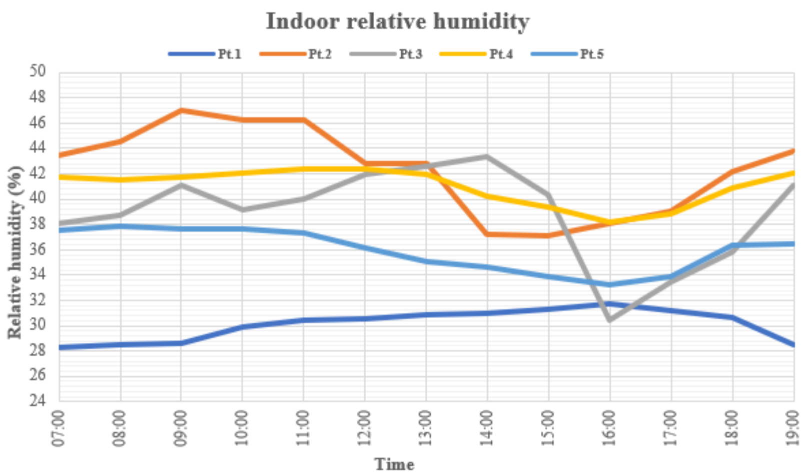


Figure V.30. *Indoor relative humidity for all measurement points "Ex.1".*

Source: Author 2025.

Table V.12. *Speed of air during the first measurement day at "Ex.1".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	2.2	1.5	1.2	1.9	0.6	1.7	1.6	1.9	2.5	3.0	3.3	2.2	2.1
Pt.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Based on the prior data, the “T/ex” fluctuates between 33.2 and 48.5°C. At the initial measurement point, “Pt. 1”, the “T/in” ranges from 30.1° to 34.1°C; at “Pt. 2”, it varies between 28.6° and 34.5°C; at “Pt. 3”, it is between 28.9° and 30.3°C; at “Pt. 4”, it is between 26.3° and 26.6°C; and at “Pt. 5”, it ranges from 29.4° to 31.6°C. The graph indicates that the temperature is elevated in “Pt.1” and “Pt.2”, located on the northeast, east, and southeast sides. Conversely, the “T/in” is lower at “Pt.4”, which is in the performance room. The disparity between “T/in” and “T/ex” is recorded as 7°C to 21.9°C; however, this range remains inadequate to reach the comfort zone temperature (25°–30°C), thereby necessitating the implementation of an air conditioning system, especially at “Pt.1” and “Pt.2”. In the performance hall “Pt.4” and in the northeastern side of the exhibition hall “Pt.3”, the indoor temperature is within the comfort zone, thus eliminating the requirement for air conditioning in these spaces, except during events when the hall is occasionally at full capacity (688 seats). The relative humidity inside the building is between 28 and 48%, which is acceptable and comfortable.

The air velocity ranges from 0.6 to 3.3 m/s outside the building and from 0 to 0.2 m/s inside the spaces.

V.4.1.2 Results of the second measurement day

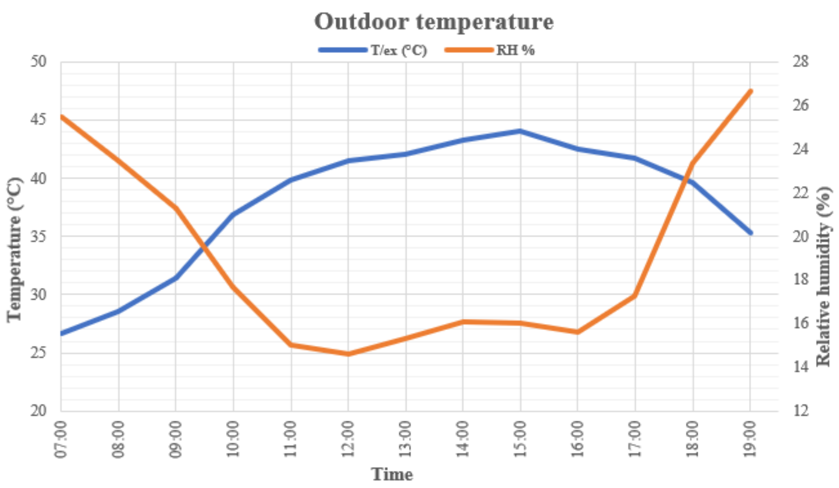


Figure V.31. *Outdoor temperature and relative humidity for “Ex.1”.*

Source: Author 2025.

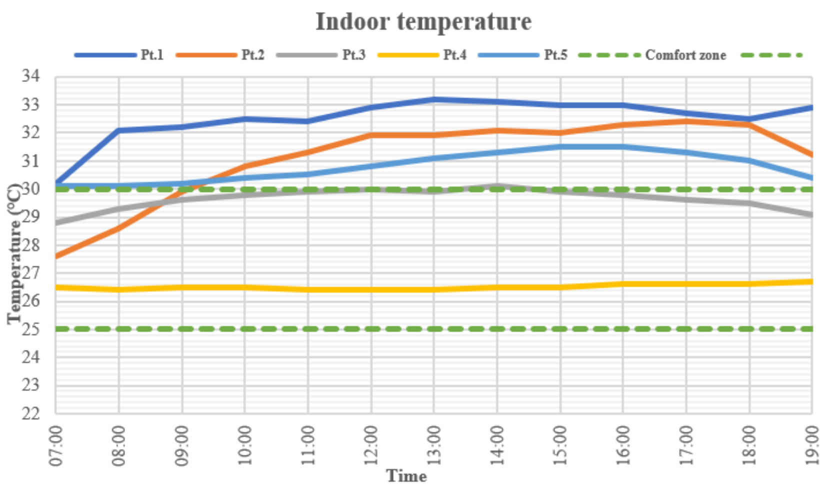


Figure V.32. *Indoor temperature for all measurement points "Ex.1".*

Source: Author 2025.

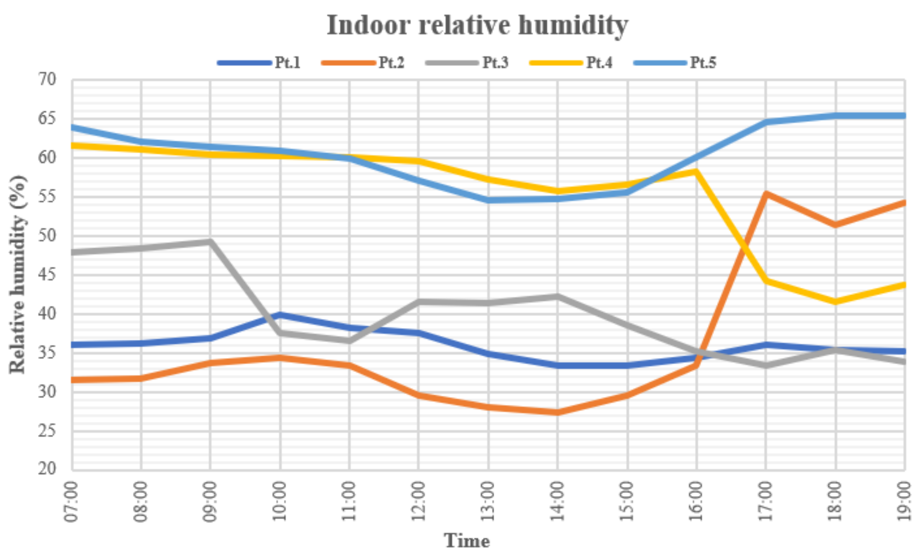


Figure V.33. *Indoor relative humidity for all measurement points "Ex.1".*

Source: Author 2025.

Table V.13. *Speed of air during the second measurement day at "Ex.1".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.8	1.6	1.9	0.9	0.6	1.7	1.6	1.9	2.5	3.3	2.3	2.2	3.0
Pt.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pt.2	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.2
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The graphs above show that the “T/ex” varies from 26.7 to 44.1°C. In the performance room “Pt.4,” the “T/in” is about 26°C, and in the northeastern exhibition hall “Pt.3,” the “T/in” is between 28.8 and 30.1°C, which means that “T/in” in these spaces is within the comfort zone. The hottest space, the biggest exhibition hall “Pt.1”, has a “T/in” between 30.2 and 33.2°C, while “Pt.2” and “Pt.5” have “T/in” between 27.6 and 32.3°C and between 30.1 and 31.5°C, respectively, with three hours within the comfort zone.

A difference of 10.6 to 17.5°C is observed between the external temperature “T/ex” and the internal temperature “T/in”.

Inside the building, the relative humidity ranges from 23 to 30% at “Pt.2”, which results in a dry indoor environment. While at the other measurements points, it is between 30 and 60%.

Outside the building, the wind blows at a speed ranging from 0.6 to 3.3 m/s, while inside the spaces it ranges from 0 to 0.2 m/s.

V.4.1.3 Results of the third measurement day

According to data in the figures below, “T/ex” ranges from 26.1 to 41.1°C. Whereas the “T/in” is between 29.2 and 33°C, at “Pt.1”, between 27 and 31.7°C, at “Pt.2”, between 28.6 and 29.9°C, at “Pt.3”, between 26.3 and 26.8°C, at “Pt.4”, and between 27.3 and 30.1°C.

There is a variance of 8.1 to 14.3°C between “T/in” and “T/ex”. Despite this difference, “T/in” at “Pt.1” and “Pt.2” is outside the comfort zone, but at “Pt.3”, “Pt.4” and “Pt.5” the temperatures are within the comfort zone.

At all measurement places within the building, the relative humidity ranges from 30 to 65%.

whereas the wind speed is between 0 and 0.2 m/s inside the building and between 0.8 and 3.3 m/s outside.

Table V.14. *Speed of air during the third measurement day at "Ex.1".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	2.5	3.3	1.9	1.1	2.2	1.7	1.6	0.8	1.7	2.2	3.0	2.5	2.2
Pt.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pt.2	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.2
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

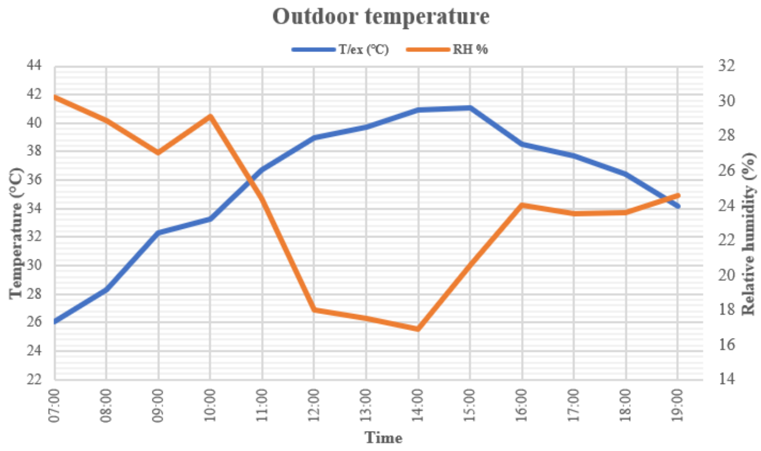


Figure V.34. *Outdoor temperature and relative humidity for "Ex.1".*

Source: Author 2025.

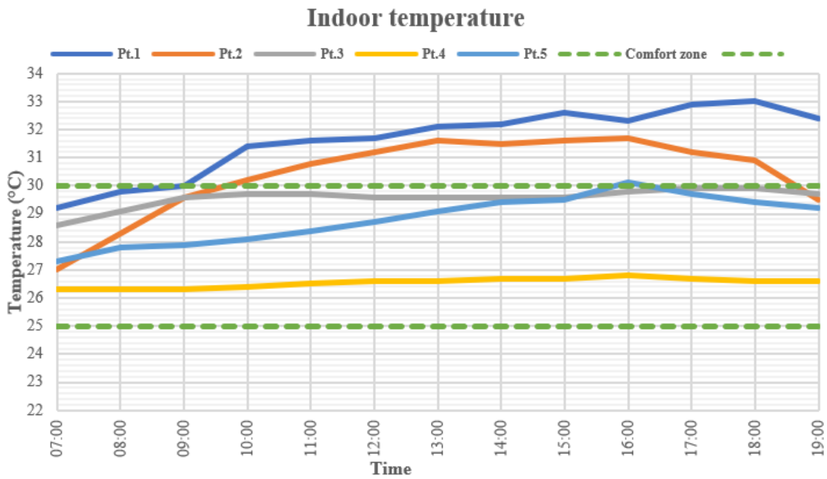


Figure V.35. *Indoor temperature for all measurement points "Ex.1".*

Source: Author 2025.

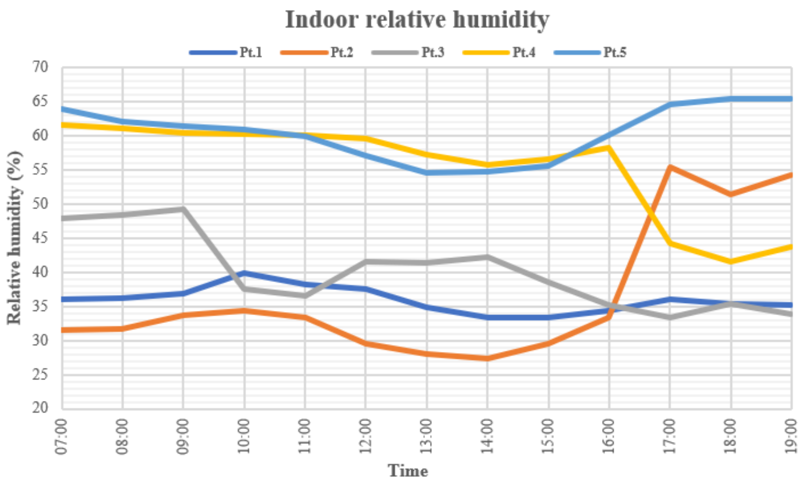


Figure V.36. *Indoor relative humidity for all measurement points "Ex.1"*

Source: Author 2025.

V.4.2 Public library of Constantine

V.4.2.1 Results of the first measurement day

On the first day of measurement in the second building, “T/in” ranges from 28.8 to 30.8°C, at “Pt.1”, from 27.2 to 28.9°C, at “Pt.2”, from 32.5 to 34.5°C, at “Pt.3”, and from 34.2 to 36.8°C, at “Pt.4”. On the outside, “T/ex” varies from 32.8 to 41.4°C. As a result, the temperature differential between the inside and outdoors ranges from 4.6 to 12.5°C.

Although the relative humidity at “Pt.2” is between 50.4 and 64.2%, which is comfortable, it is between 11 and 29% at the other measurement points, resulting in a dry atmosphere.

While the air velocity varies between 0.2 and 4.7 m/s around the building, and between 0 and 0.2 m/s inside the spaces.

The conference room and children's reading room are comfortable, but the other rooms are hotter.

Table V.15. *Speed of air during the first measurement day at "Ex.2".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	1.1	2.5	0.9	0.3	0.2	0.8	0.8	1.7	3.6	3.6	4.7	4.4	2.2
Pt.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

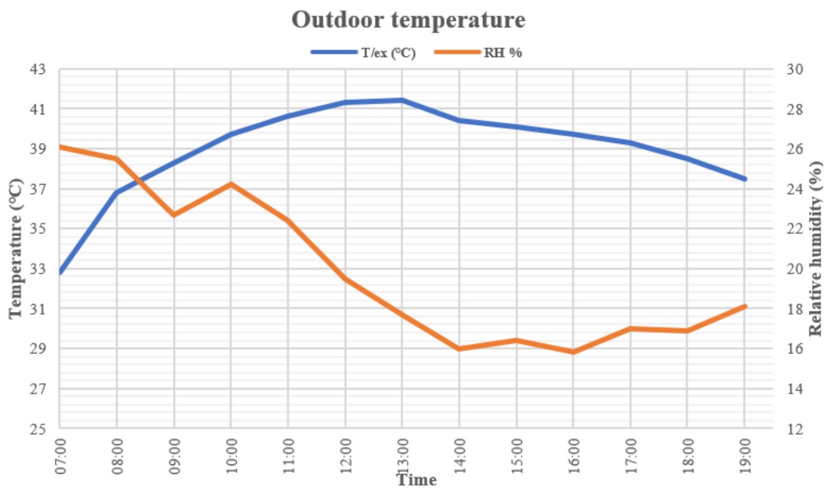


Figure V.37. *Outdoor temperature and relative humidity for “Ex.2”.*

Source: Author 2025.

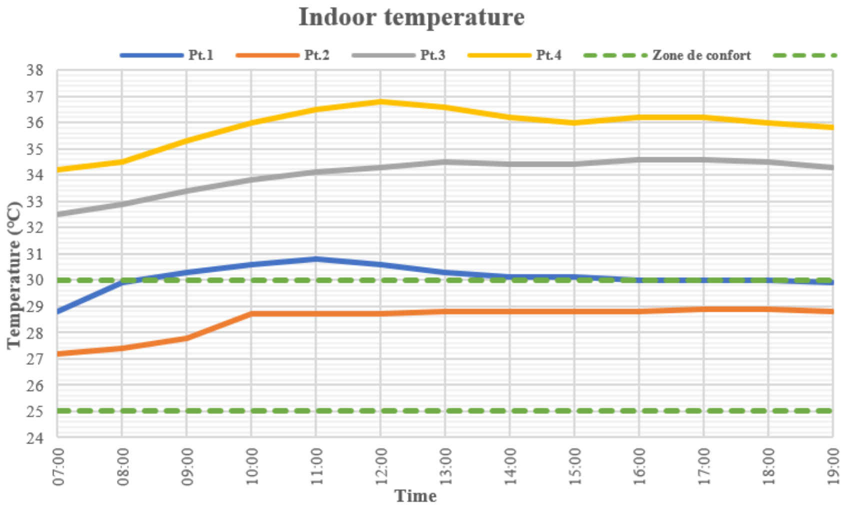


Figure V.38. *Indoor temperature for all measurement points “Ex.2”.*

Source: Author 2025.

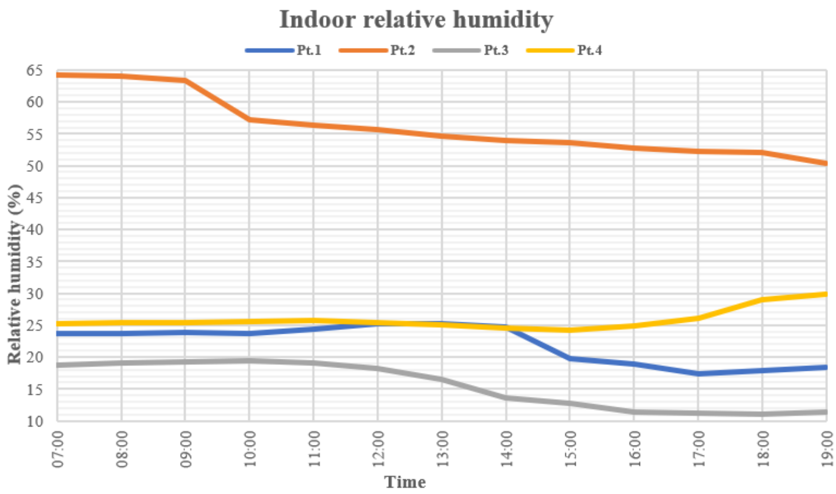


Figure V.39. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

V.4.2.2 Results of the second measurement day

The data presented below indicate that the "T/ex" fluctuates between 27.1° and 40.4°C. At “Pt.1”, the temperature “T/in” varies from 29° to 30.4°C; at “Pt.2”, it is from 28.3 to 28.9°C; at “Pt.3”, from 30.1 to 32.4 °C; and at “Pt.4”, it is from 34 to 36.2°C. While “T/ex” ranges from 28.4° to 29°C.

Consequently, the temperature difference between "T/in" and "T/ex" is between 8°C and 11.5°C. It is observed that “T/in” at “Pt.1” and “Pt.2” falls within the comfort zone, suggesting that these spaces are relatively comfortable, and air conditioning is not needed.

Conversely, at “Pt.3” and “Pt.4”, where the "T/in" exceeds the comfort zone temperature, an air conditioning system is deemed necessary.

The speed of the air within spaces is between 0 and 0.2 m/s, and between 0.1 and 2.2 m/s in front of the building.

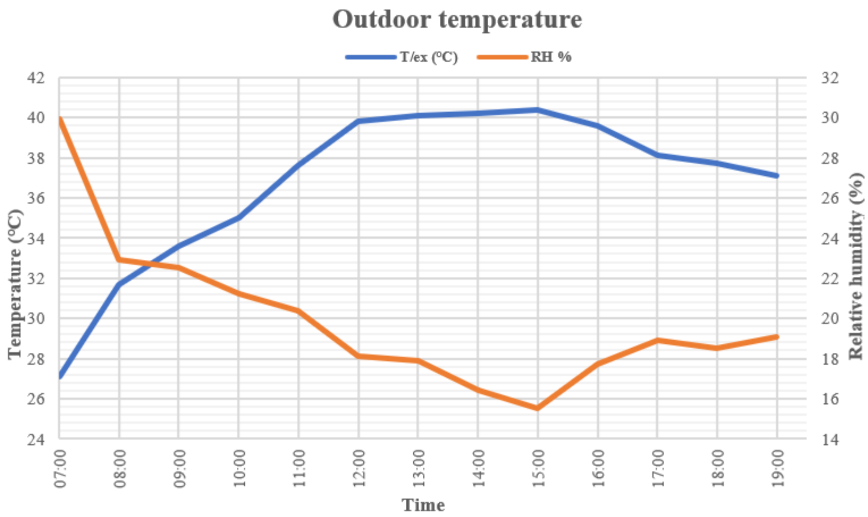


Figure V.40. *Outdoor temperature and relative humidity for “Ex.2”.*

Source: Author 2025.

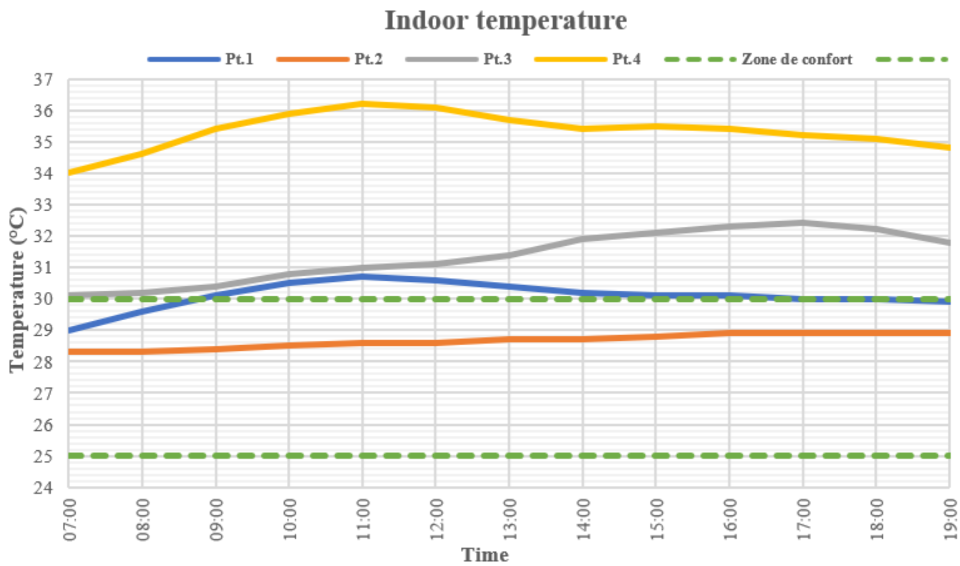


Figure V.41. *Indoor temperature for all measurement points “Ex.2”.*

Source: Author 2025.

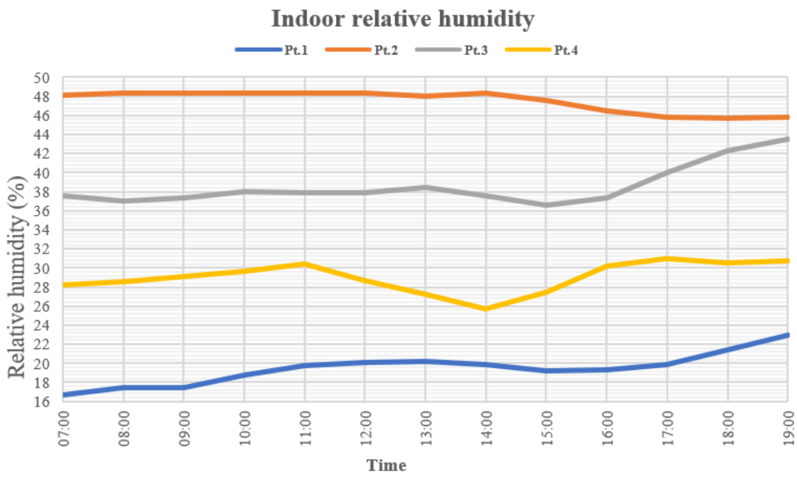


Figure V.42. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.16. *Speed of air during the second measurement day at "Ex.2".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.2	0.3	0.1	0.3	0.6	0.8	1.7	2.0	2.2	0.9	1.4	1.6	1.2
Pt.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.1	0.1	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.0

V.4.2.3 Results of the third measurement day

The data presented below indicate that the temperature "T/ex" fluctuates between 28.6 and 39.5°C. Meanwhile, "T/in" varies from 28.9 to 30.9°C, at "Pt.1"; from 28.5 to 29.2°C, at "Pt.2"; from 29.1 to 31.5°C, at "Pt.3"; and from 32.2 to 34.7°C, at "Pt.4". The relative humidity (RH) within the building is recorded at 20 to 25% at "Pt.1", resulting in a dry environment, whereas in the other areas, it ranges from 32 to 48%, providing a more comfortable atmosphere. It is evident that the temperature "T/in" at both "Pt.1" and "Pt.2" falls within the comfort zone, ensuring a comfortable environment, while the other locations are notably less comfortable due to higher temperatures.

However, Table V.17 shows that the air velocity varies between 0.2 and 4.3 m/s at the exterior of the building and between 0 and 0.2 m/s inside the spaces.

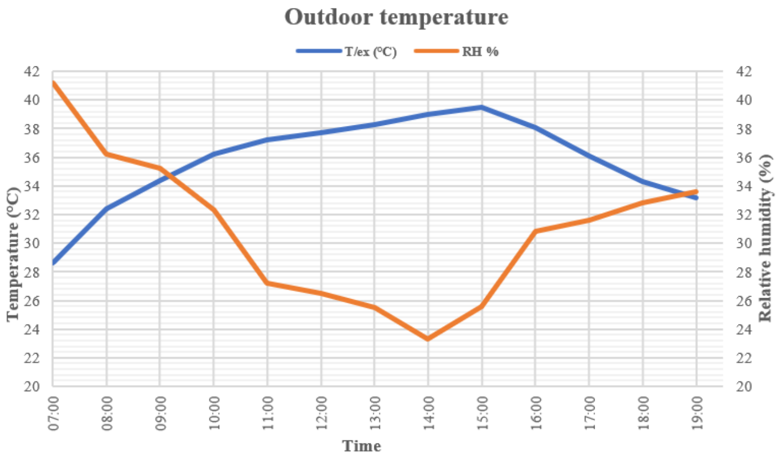


Figure V.43. *Outdoor temperature and relative humidity for "Ex.2".*

Source: Author 2025.

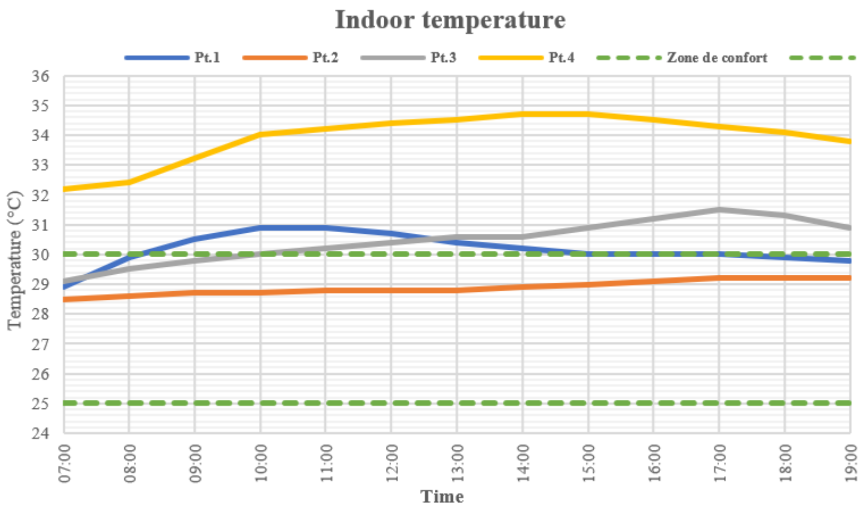


Figure V.44. *Indoor temperature for all measurement points "Ex.2".*

Source: Author 2025.

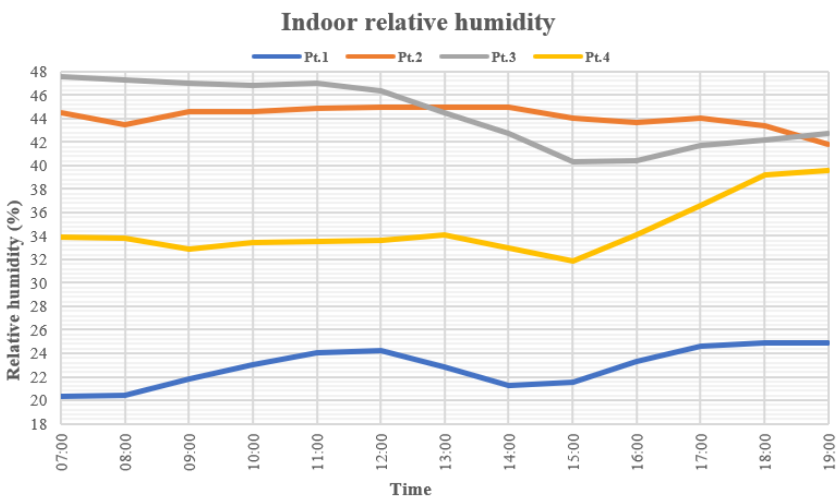


Figure V.45. *Indoor relative humidity for all measurement points "Ex.2".*

Source: Author 2025.

Table V.17. *Speed of air during the third measurement day at "Ex.2".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.3	0.4	0.6	0.2	0.7	0.6	1.1	2.3	3.3	0.9	1.4	4.3	2.2
Pt.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.1	0.2	0.1
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.2	0.1

V.4.3 Performance hall “Zenith Constantine”

V.4.3.1 Results of the first measurement day

The measurements taken on the first day in the third building indicate that the “T/ex” varies between 27.9 and 44.3°C. The “T/in” fluctuates from 27.5 to 28.5°C, at “Pt.1”; from 29.1 to 30.6°C, at “Pt.2”; from 28.4 to 30.1°C, at “Pt.3”; from 30.4 to 36.9°C, at “Pt.4”; and from 31.8 to 33.6°C, at “Pt.5”. Consequently, the temperature differential between the interior and exterior ranges from 7.4 to 15.8°C. The indoor relative humidity is recorded between 12.4 and 30% at “Pt.4” and “Pt.5”, indicating a dry environment. At “Pt.2”, it ranges from 22.4 to 38.2%, which is considered dry in the morning but acceptable in the evening. In contrast, at “Pt.1” and “Pt.3”, the RH is between 36 and 48%, providing a comfortable atmosphere.

Around the building, outside, the air speed ranges from 0.2 to 3.9 m/s, while inside it ranges from 0 to 0.2 m/s.

It is noted that the internal temperature (“T/in”) within the performance hall (“Pt.1”, “Pt.2”, “Pt.3”) remains within the comfort zone, thereby ensuring a comfortable environment.

Conversely, in the south-facing glazed corridor (“Pt.4”) and the gathering hall (“Pt.5”), the temperatures are elevated, resulting in discomfort within these spaces.

Table V.18. *Speed of air during the first measurement day at "Ex.3".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	0.3	0.2	0.8	1.4	0.3	0.2	2.5	3.6	1.4	3.1	2.8	3.9	2.5
Pt.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.2	0.1	0.1	0.1
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

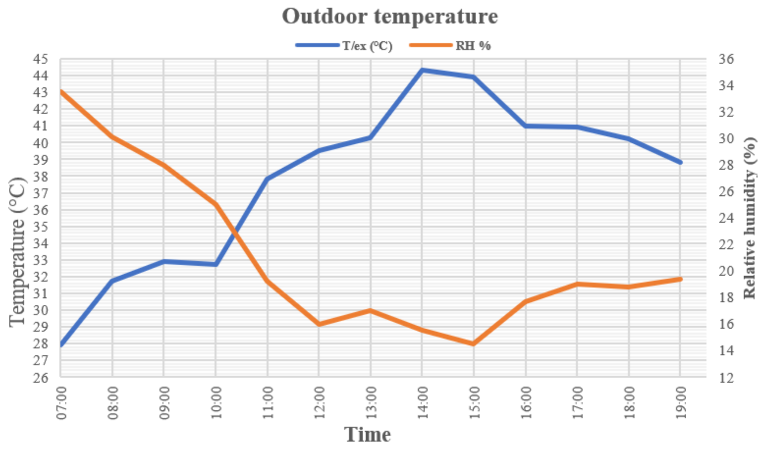


Figure V.46. Outdoor temperature and relative humidity for "Ex.3".

Source: Author 2025.

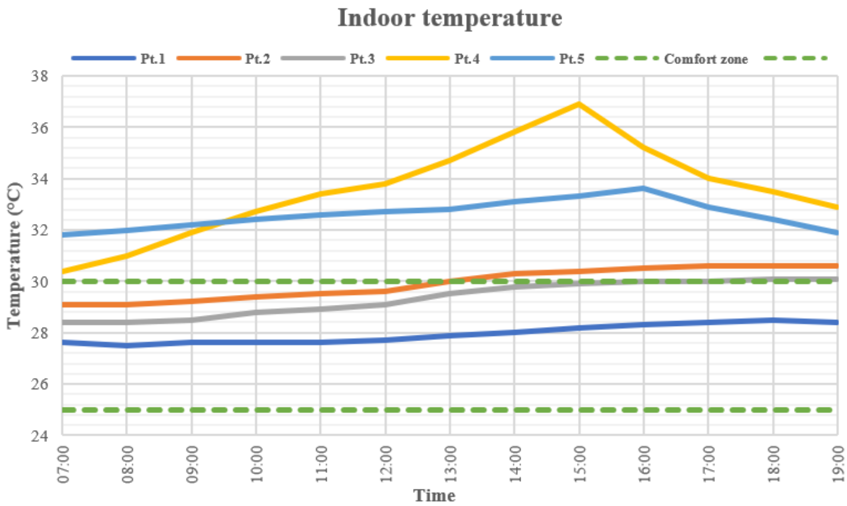


Figure V.47. Indoor temperature for all measurement points "Ex.3".

Source: Author 2025.

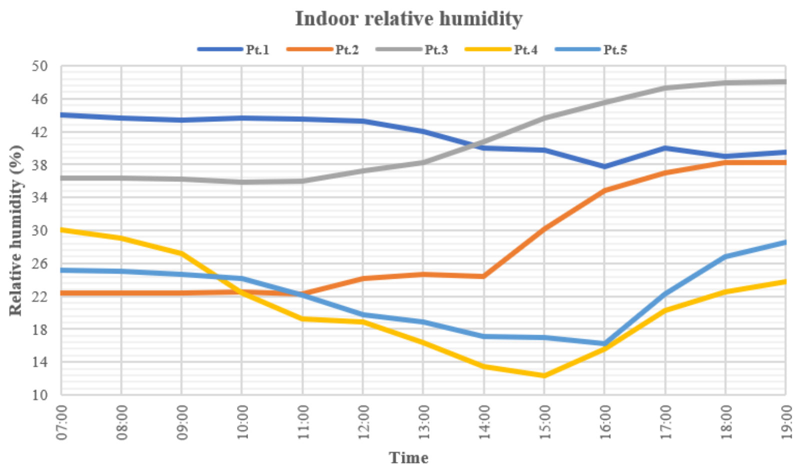


Figure V.48. Indoor relative humidity for all measurement points "Ex.3".

Source: Author 2025.

V.4.3.2 Results of the second measurement day

The figures below show that "T/in" spans from 26.9 to 28.5°C, at "Pt.1"; from 29.1 to 30.4°C, at "Pt.2"; from 28.3 to 30°C, at "Pt.3", from 29.9 to 34.8°C, at "Pt.4"; and from 28.5 to 33.1°C, at "Pt.5". While "T/ex" fluctuates between 26.6 and 42.6°C. As a result, the difference between "T/ex" and "T/in" is between 7.8 and 14.1°C.

Whereas the air velocity is between 0.1 and 2.2 m/s outside and between 0 and 0.2 m/s within the building.

The relative humidity inside the building varies from 19.7 to 31% at "Pt.4" and "Pt.5", resulting in a dry atmosphere. However, at the other points it is from 32 to 58% making the environment comfortable.

It is observed that the temperature within the performance hall is in the comfort zone, which is comfortable. In contrast, temperatures at "Pt.4" and "Pt.5" exceed the comfort zone, making the spaces uncomfortable.

Table V.19. *Speed of air during the second measurement day at "Ex.3".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	2.2	0.8	0.2	0.1	1.3	0.3	1.4	0.2	0.1	1.7	2.2	1.6	0.9
Pt.1	0.2	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

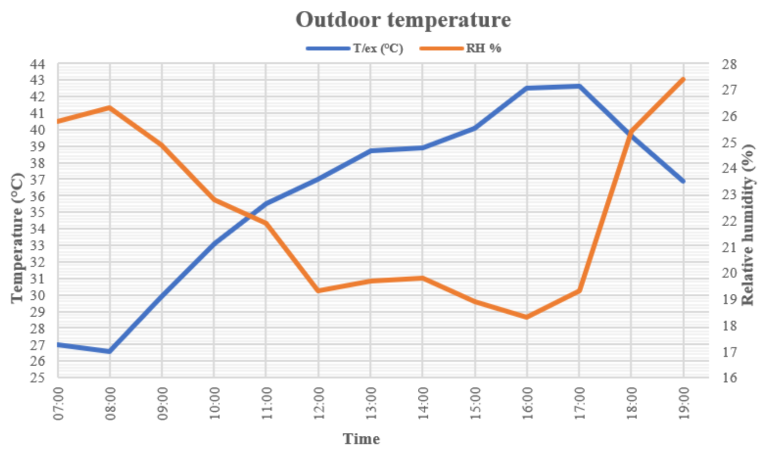


Figure V.49. *Outdoor temperature and relative humidity for "Ex.3".*

Source: Author 2025.

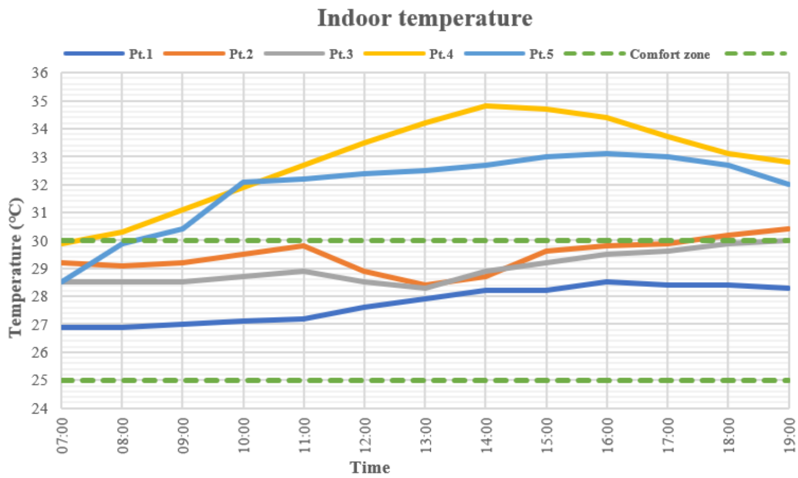


Figure V.50. Indoor temperature for all measurement points "Ex.3".

Source: Author 2025.

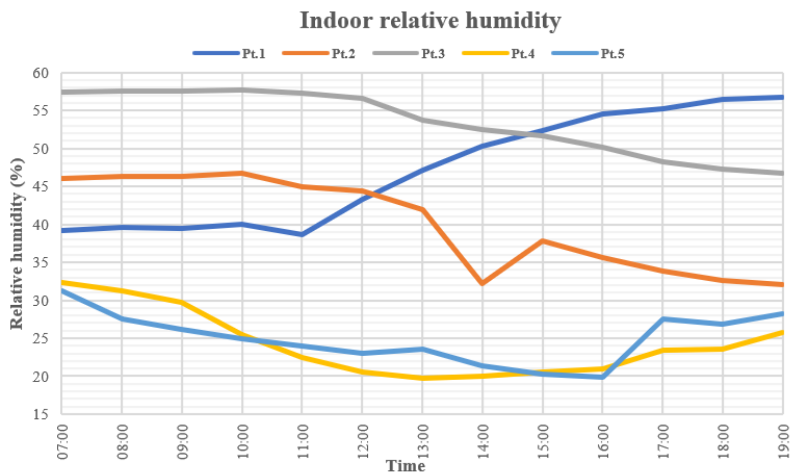


***Figure V.51.** Indoor relative humidity for all measurement points "Ex.3".*

Source: Author 2025.

V.4.3.3 Results of the third measurement day

The results show that the "T/ex" varies between 21° and 41.6°C. In the performance hall, "T/in" fluctuates from 26.8° to 27.9°C, at "Pt.1"; from 28.5 to 29.8°C, at "Pt.2"; and from 28.3 to 29.3°C, at "Pt.3"; while in the south-facing glazed corridor "Pt.4", it ranges from 30.1 to 33.3°C. In the gathering hall "Pt.5", it is recorded between 27.8 and 32.9°C.

Consequently, there exists a temperature differential from 8.7 to 13.7°C. Yet the "T/in" remains within a comfortable range in the performance hall. Nevertheless, in the glazed corridor "Pt.4" and the gathering hall "Pt.5", the "T/in" surpasses the comfortable level, thereby requiring the use of an air conditioning system.

Furthermore, it is observed that the wind speed ranges from 0 to 0.2 m/s within the building, while it varies from 0.3 to 3.9 m/s in the external environment.

In the gathering hall "Pt.5" the relative humidity is between 17 and 27%, creating a dry environment in the space. While at the other spaces it is between 30 and 65%, offering a more comfortable atmosphere.

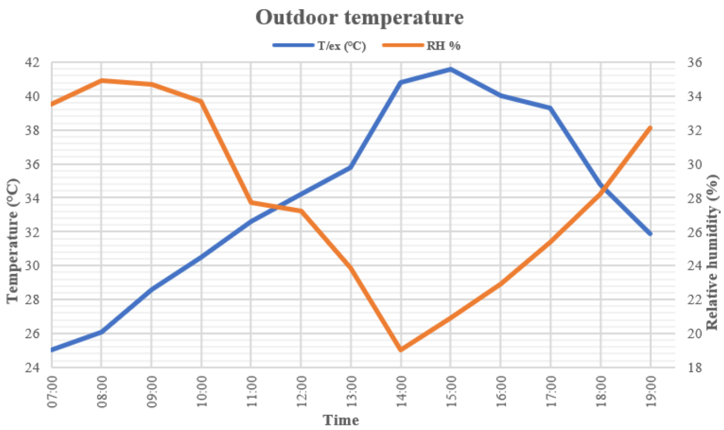


Figure V.52. *Outdoor temperature and relative humidity for "Ex.3".*

Source: Author 2025.

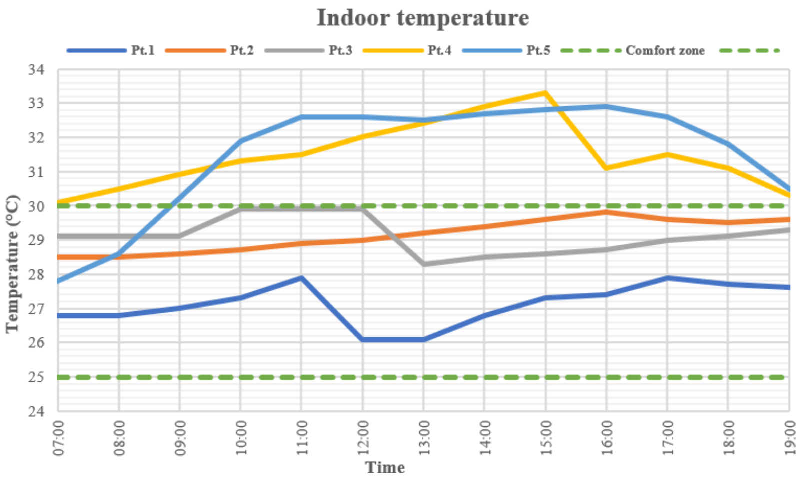


Figure V.53. *Indoor temperature for all measurement points "Ex.3".*

Source: Author 2025.

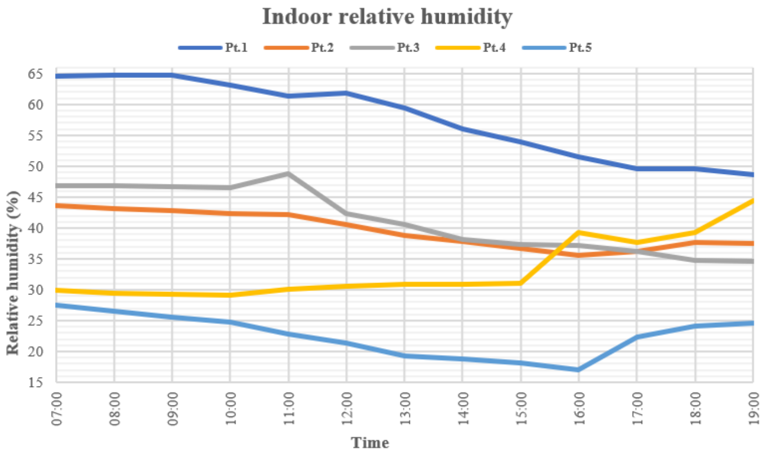


Figure V.54. *Indoor relative humidity for all measurement points "Ex.3".*

Source: Author 2025.

Table V.20. *Speed of air during the third measurement day at "Ex.3".*

Source: Author 2025.

	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Ext.	1.3	0.5	0.8	0.3	0.6	1.4	0.8	0.3	2.8	3.9	1.9	1.6	1.4
Pt.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.2	0.2	0.2	0.1	0.1
Pt.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.0
Pt.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pt.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

V.4.4 Discussion and observations

To enable comparison, the tables below summarize the data collected in the three buildings over the period of three days of measurements. The first table highlights the temperatures measured (Table V.21), while the second table displays the relative humidity (Table V.22).

Table V.21. *Temperature in the three buildings in summer.*

Source: Author 2025.

Case study		Ex.1: AL KHALIFA					Ex.2: Public Library				Ex.3: Zenith Constantine				
Date	Hours	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5	Pt.1	Pt.2	Pt.3	Pt.4	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5
12/ 08/ 2021	07:00	30,1	28,6	28,9	26,3	29,5	28,8	27,2	32,5	34,2	27,6	29,1	28,4	30,4	31,8
	08:00	31	29.4	29.7	26.3	29.4	29.9	27.4	32.9	34.5	27.5	29.1	28.4	31	32
	09:00	31.4	29.4	29.7	26.4	29.7	30.3	27.8	33.4	35.3	27.6	29.2	28.5	31.9	32.2
	10:00	32.8	31	29.7	26.4	30.1	30.6	28.7	33.8	36	27.6	29.4	28.5	32.7	32.4
	11:00	32.8	31.5	29.7	26.4	30.4	30.8	28.7	34.1	36.5	27.6	29.5	28.8	33.4	32.6
	12:00	32.9	31.2	29.8	26.4	30.7	30.6	28.7	34.3	36.8	27.7	29.6	29.1	33.8	32.7
	13:00	33.3	33.2	29.7	26.3	30.8	30.3	28.8	34.5	36.6	27.9	30	29.5	34.7	32.8
	14:00	33.5	33.8	29.6	26.4	31.2	30.1	28.8	34.4	36.2	28	30.3	29.8	35.8	33.1
	15:00	33.9	34.1	29.8	26.4	31.6	30.1	28.8	34.4	36	28.2	30.4	29.9	36.9	33.3
	16:00	34.1	34.3	30.3	26.4	31.6	30	28.8	34.6	36.2	28.3	30.5	30	35.2	33.6
	17:00	33.5	34.5	30.3	26.5	31.5	30	28.9	34.6	36.2	28.4	30.6	30	34	32.9
	18:00	32.5	32.8	30.1	26.6	31.4	30	28.9	34.5	36	28.5	30.6	30.1	33.5	32.4
	19:00	31.2	31.5	29.8	26.6	31.3	29.9	28.8	34.3	35.8	28.4	30.6	30.1	32.9	31.9
13/ 08/ 2021	07:00	30,2	27,6	28,8	26,5	30,1	29	28,3	30,1	34	26,9	29,2	28,5	29,9	28,5
	08:00	32.1	28.6	29.3	26.4	30.1	29.6	28.3	30.2	34.6	26.9	29.1	28.5	30.3	29.9
	09:00	32.2	29.9	29.6	26.5	30.2	30.1	28.4	30.4	35.4	27	29.2	28.5	31.1	30.4
	10:00	32.5	30.8	29.8	26.5	30.4	30.5	28.5	30.8	35.9	27.1	29.5	28.7	31.9	32.1
	11:00	32.4	31.3	29.9	26.4	30.5	30.7	28.6	31	36.2	27.2	29.8	28.9	32.7	32.2
	12:00	32.9	31.9	30	26.4	30.8	30.6	28.6	31.1	36.1	27.6	28.9	28.5	33.5	32.4
	13:00	33.2	31.9	29.9	26.4	31.1	30.4	28.7	31.4	35.7	27.9	28.4	28.3	34.2	32.5
	14:00	33.1	32.1	30.1	26.5	31.3	30.2	28.7	31.9	35.4	28.2	28.7	28.9	34.8	32.7
	15:00	33	32	29.9	26.5	31.5	30.1	28.8	32.1	35.5	28.2	29.6	29.2	34.7	33
	16:00	33	32.3	29.8	26.6	31.5	30.1	28.9	31.3	35.4	28.5	29.8	29.5	34.4	33.1
	17:00	32.7	32.4	29.6	26.6	31.3	30	28.9	32.4	35.2	28.4	29.9	29.6	33.7	33
	18:00	32.5	32.3	29.5	26.6	31	30	28.9	32.2	35.1	28.4	30.2	29.9	33.1	32.7
	19:00	32.9	31.2	29.1	26.7	30.4	29.9	28.9	31.8	34.8	28.3	30.4	30	32.8	32
14/ 08/ 2021	07:00	29,2	27	28,6	26,3	27,3	28,9	28,5	29,1	32,2	26,8	28,5	29,1	30,1	27,8
	08:00	29.8	28.3	29.1	26.3	27.8	29.9	28.6	29.5	32.4	26.8	28.5	29.1	30.5	28.6
	09:00	30	29.6	29.6	26.3	27.9	30.5	28.7	29.8	33.2	27	28.6	29.1	30.9	30.2
	10:00	31.4	30.2	29.7	26.4	28.1	30.9	28.7	30	34	27.3	28.7	29.9	31.3	31.9
	11:00	31.6	30.8	29.7	26.5	28.4	30.9	28.8	30.2	34.2	27.9	28.9	29.9	31.5	32.6
	12:00	31.7	31.2	29.6	26.6	28.7	30.7	28.8	30.4	34.4	26.1	29	29.9	32	32.6
	13:00	32.1	31.6	29.6	26.6	29.1	30.4	28.8	30.6	34.5	26.1	29.2	28.3	32.4	32.5
	14:00	32.2	31.5	29.6	26.7	29.4	30.2	28.9	30.6	34.7	26.8	29.4	28.5	32.9	32.7
	15:00	32.6	31.6	29.6	26.7	29.5	30	29	30.9	34.7	27.3	29.6	28.6	33.3	32.8
	16:00	32.3	31.7	29.8	26.8	30.1	30	29.1	31.2	34.5	27.4	29.8	28.7	31.1	32.9
	17:00	32.9	31.2	29.9	26.7	29.7	30	29.2	31.5	34.3	27.9	29.6	29	31.5	32.6
	18:00	33	30.9	29.9	26.6	29.4	29.9	29.2	31.3	34.1	27.7	29.5	29.1	31.1	31.8
	19:00	32.4	29.5	29.7	26.6	29.2	29.8	29.2	30.9	33.8	27.6	29.6	29.3	30.3	30.5

Table V.22. *Relative humidity in the three buildings in summer.*

Source: Author 2025.

Case study		Ex.1: AL KHALIFA					Ex.2: Public Library				Ex.3: Zenith Constantine				
Date	Hours	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5	Pt.1	Pt.2	Pt.3	Pt.4	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5
12 / 08 / 2021	07:00	28,3	43,5	38,1	41,7	37,5	23,6	64,2	18,8	25,2	44	22,4	36,4	30,1	25,1
	08:00	28.5	44.5	38.7	41.5	37.9	23.7	64.1	19.1	25.4	43.6	22.4	36.3	29.1	25
	09:00	28.6	47	41.1	41.7	37.7	23.8	63.4	19.3	25.4	43.4	22.4	36.2	27.2	24.7
	10:00	29.9	46.3	39.2	42.1	37.7	23.7	57.2	19.4	25.6	43.7	22.5	35.9	22.4	24.2
	11:00	30.4	46.3	40	42.4	37.3	24.4	56.3	19.1	25.8	43.5	22.3	36	19.2	22.2
	12:00	30.5	42.8	42	42.4	36.1	25.2	55.6	18.2	25.4	43.3	24.2	37.3	18.9	19.7
	13:00	30.9	42.8	42.6	42	35.1	25.3	54.6	16.5	25	42	24.6	38.3	16.3	18.9
	14:00	31	37.2	43.4	40.2	34.6	24.7	54	13.6	24.6	40	24.4	40.8	13.4	17.1
	15:00	31.3	37.1	40.3	39.4	33.9	19.8	53.6	12.7	24.2	39.7	30.2	43.7	12.4	17
	16:00	31.7	38.1	30.4	38.2	33.2	18.9	52.8	11.3	24.8	37.7	34.9	45.6	15.6	16.3
	17:00	31.2	39.1	33.5	38.8	33.9	17.4	52.3	11.2	26.1	40	37	47.3	20.3	22.3
	18:00	30.6	42.2	35.8	40.9	36.4	17.8	52.1	11.1	28.9	39	38.2	47.9	22.5	26.8
	19:00	28.5	43.8	41.1	42.1	36.5	18.3	50.4	11.4	29.9	39.5	38.3	48.1	23.8	28.6
13 / 08 / 2021	07:00	45,6	26,5	52,4	36	45,3	16,7	48.1	37,6	28,2	39,2	46	57,4	32,4	31,2
	08:00	31	26	51.4	35.8	46.9	17.4	48.4	37	28.6	39.6	46.3	57.6	31.2	27.5
	09:00	30	25.2	52.2	35.8	50.6	17.5	48.3	37.4	29.1	39.4	46.3	57.5	29.8	26.1
	10:00	27.5	25.3	51.9	36.1	50.8	18.8	48.4	38	29.6	40	46.7	57.7	25.5	25
	11:00	28.9	24.2	51	36.1	52.4	19.8	48.4	37.9	30.4	38.6	44.9	57.3	22.4	24
	12:00	30.3	23.5	52.6	35.6	52.7	20.1	48.4	37.9	28.7	43.3	44.4	56.6	20.6	23
	13:00	33	25.2	52.8	35.2	52.4	20.2	48	38.4	27.2	47.1	41.9	53.7	19.7	23.6
	14:00	33.5	25.4	52.6	32.6	50.9	19.9	48.3	37.6	25.7	50.3	32.2	52.5	20	21.4
	15:00	35.6	25.2	55.5	31.3	51.6	19.2	47.6	36.6	27.5	52.3	37.8	51.6	20.5	20.3
	16:00	35.6	26.1	55.2	30	52	19.2	46.5	37.4	30.2	54.6	35.6	50.1	21	19.9
	17:00	38.3	27	55.7	33.1	53.6	19.9	45.8	40	31	55.2	33.9	48.3	23.4	27.5
	18:00	39.2	30.9	56.2	35.5	53.5	21.4	45.7	42.3	30.5	56.4	32.6	47.3	23.5	26.9
	19:00	51.6	31	60.5	36.1	53.6	23	45.8	43.5	30.8	54.7	32.1	46.7	25.7	28.2
14 / 08 / 2021	07:00	36,1	31,5	47,8	61,5	63,8	20,3	44,5	47,6	33,9	64,5	43,7	46,9	29,9	27,5
	08:00	36.2	31.7	48.4	61	62	20.4	43.5	47.3	33.8	64.7	43.2	46.8	29.5	26.6
	09:00	36.9	33.7	49.2	60.3	61.3	21.8	44.6	47	32.9	64.7	42.8	46.7	29.3	25.6
	10:00	39.9	34.3	37.6	60.2	60.9	23	44.6	46.8	33.4	63.2	42.3	46.6	29.1	24.8
	11:00	38.2	33.4	36.6	60	59.8	24	44.9	47	33.5	61.3	42.1	48.8	30	22.9
	12:00	37.5	29.5	41.6	59.6	57	24.2	45	46.4	33.6	61.9	40.5	42.3	30.6	21.3
	13:00	34.8	28.1	41.4	57.2	54.5	22.8	45	44.5	34.1	59.4	38.8	40.5	30.9	19.3
	14:00	33.3	27.4	42.2	55.7	54.7	21.3	45	42.7	33	56.1	37.8	38.1	30.9	18.8
	15:00	33.3	28.5	38.5	56.6	55.5	21.5	44	40.3	31.9	54	36.7	37.4	31	18.2
	16:00	34.4	33.3	35.2	58.2	60.1	23.3	43.7	40.4	34.1	51.5	35.6	37.1	39.3	17.1
	17:00	36.1	55.4	33.3	44.2	64.6	24.6	44	41.7	36.6	49.6	36.2	36.2	37.6	22.4
	18:00	35.4	51.3	35.4	41.6	65.4	24.9	43.4	42.2	39.2	49.6	37.6	34.7	39.2	24.1
	19:00	35.2	54.2	33.9	43.7	65.3	24.9	41.8	42.7	39.6	48.6	37.5	34.6	44.5	24.6

During the summer, the ideal comfort zone temperature, ranging from 25°C to 30°C, is attained in the VIP hall, the performance room and conference room of “Ex.1”, as well as in the conference room and children's reading room of “Ex.2”, and in the performance hall of the third building, “Ex.3”.

Relative humidity is generally comfortable in the three buildings studied, except in the children's reading room (Pt. 1), where the environment is a little dry (below 20% at certain times of the day) and in the gathering hall (Pt. 5) of the performance hall.

The areas featuring facades of double-glazed curtain walls facing south, east, or west experienced a greenhouse effect due to insufficient ventilation within the building, as users tend to close all openings to activate the air conditioning system ("Ex.2" and "Ex.3"). In contrast, spaces oriented towards the north maintain comfortable temperatures, as proved in "Ex.1".

It is observed that completely enclosed spaces without openings are more comfortable compared to the others during the summer season. These spaces are characterized by double-skin facades, with the exterior layer made of terracotta panels.

The data collected from the three buildings show that the DSF produces a large temperature difference between the inside and outside throughout the summer. The difference is around 22°C in the cultural palace "Ex.1", 12.5°C in the public library "Ex.2", and 16°C in the performance hall "Ex.3".

V.5 Conclusion

In this chapter, which was devoted to the results and discussion of in situ measurements, the first part was the presentation and discussion of the results for the winter period, followed by summary tables and observations. Then, the second part was the discussion of the results for the summer period, also followed by summary tables with observations.

Analysis and comparison of the results of the measured climate parameters (T/ex, T/in, RH, S/air) shows that

- The DSF increases the temperature differential between the inside and outside environments by up to 16°C in winter and 22°C in summer.
- The DSF's performance is influenced by the kind of building material and its orientation.
- When a material is oriented differently, its performance changes.
- In the cases studied, DSFs combined with double-glazed curtain walls are effective in winter, especially when south-facing, and provide thermal comfort without the need for a heating system. Conversely, in summer, they provide a greenhouse effect because of inadequate ventilation.

- Spaces featuring ‘DSF’ with terracotta panels are more comfortable than others in summer.
- The spaces with less opening have a more comfortable temperature than the others, especially in summer.
- “DSF” provides significant energy savings.
- The way the space is used significantly affects the effectiveness of the “DSF”, because it influences the ventilation, which is an essential point in the “DSF’s” functioning.

CHAPTER VI: RESULTS OF THE QUESTIONNAIRE SURVEY

VI.1 Introduction

This chapter presents the results and discussions obtained from the second method used, namely the questionnaire survey.

The first section of this chapter is dedicated to presenting the findings from the questionnaire survey, which serves to enhance the credibility of the in-situ measurement results. The gathered data will be analysed using Excel software.

The second part is reserved for observations made following the results obtained in the three buildings studied.

VI.2 Palace of Culture

VI.2.1 General information

The age and the gender of the respondents must be required to obtain more faithful results.

Based on the results obtained from the data in this first building studied, men represented 64% of respondents in terms of gender, and in terms of age, 15.8% were under 25, 15.8% were between 25 and 30, 27.3% were between 30 and 40, 22.8% were between 40 and 50, 16% between 50 and 60, and only 2.3% were over 60 years old.

Table VI.1. *Gender of the respondents in the palace of culture "Ex.1".*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	63.6	36.4

Table VI.2. *Age of the respondents in the palace of culture "Ex.1".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Percentage (%)	15.8	15.8	27.3	22.8	16	2.3

The participants are distributed throughout the building as follows: 61.4% are in the large exhibition hall at the main public entry, 18.2% are in the first-floor conference room, 11.3% are in the hall at the entrance of the VIP lounge, and 9.1% are in the distribution hall.

Table VI.3. *Emplacement of the respondents in the palace of culture "Ex.1".*

Source: Author 2025.

Emplacement	"Pt.1"	"Pt.2"	"Pt.3	"Pt.5"
Percentage (%)	61.4	9.1	11.3	18.2

VI.2.2 Hall of the main public entrance

VI.2.2.1 General information

In the vast exhibition hall at the primary public entry to the performance room, 70.4% of those polled were men, while 29.6% were women. 26% are between 30 and 40 years old, 22% are under 25, 18.5% are between 25 and 30, 15% are between 40 and 50, 15% are between 50 and 60, and 3.8% are above 60.

Furthermore, according to the numbers below, around 60% of respondents have a clothing level of 0.4 *Clo*, 22% have a level of 0.6 *Clo*, 11% have a level of 0.3 *Clo*, and 7% have a level of 0.5 *Clo*. In terms of activity level, 33% said 2 *MET*, 30% said 1.4 *MET*, 22% said 1.6 *MET*, and 15% said 1.2 *MET*.

Table VI.4. *Gender of the respondents in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	70.4	29.6

Table VI.5. *Age of the respondents in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Male (%)	18.5	14.8	14.8	7.4	11.1	3.8
Female (%)	3.7	3.7	11.1	7.4	3.7	0
Total (%)	22.2	18.5	25.9	14.8	14.8	3.8

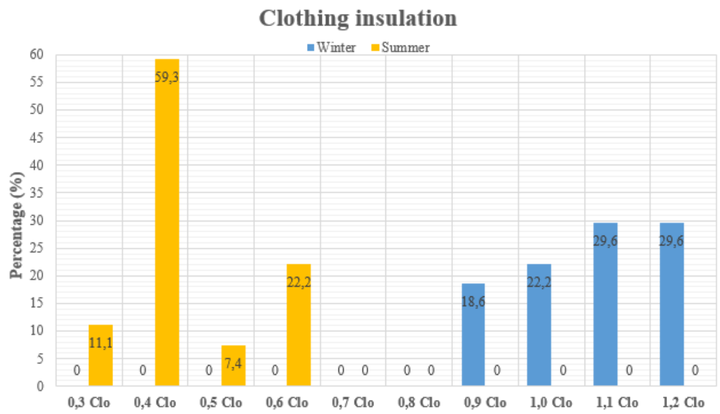


Figure VI.1. *Clothing insulation of the respondents in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

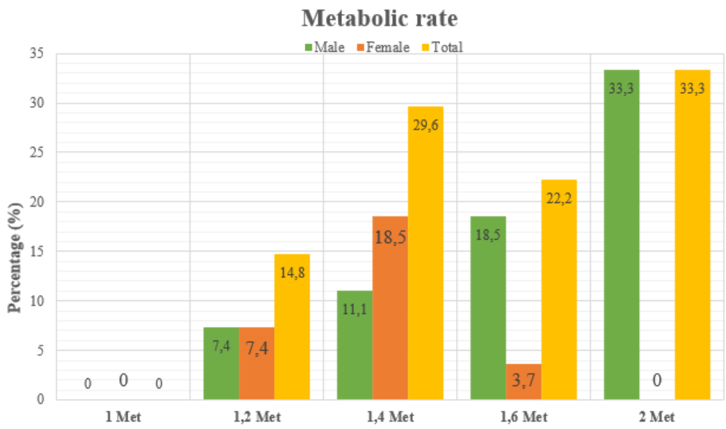


Figure VI.2. *Metabolic rate of the respondents in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

VI.2.2.2 Thermal comfort evaluation

- **Thermal sensation**

According to the statistics, 33% of respondents were feeling fresh, 30% were feeling slightly fresh, 26% were feeling neutral, and 11% were experiencing cold. In the summer, 30% feel slightly warm, 26% feel warm, 18% feel hot, and 26% feel neutral.

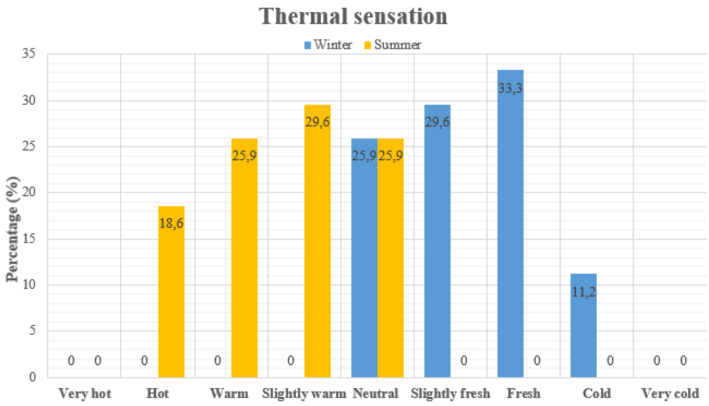


Figure VI.3. *Thermal sensation of respondents in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

- **Comfort**

Based on the graph, in winter, 44.5% of participants said the space was just uncomfortable, 25.9% said it was uncomfortable, 3.7% said it was very uncomfortable, and just 3.7% said it was comfortable. In the summer, 48% find that the space is just comfortable, 19% find it comfortable, 22% think it is just uncomfortable, and 11% find it uncomfortable.

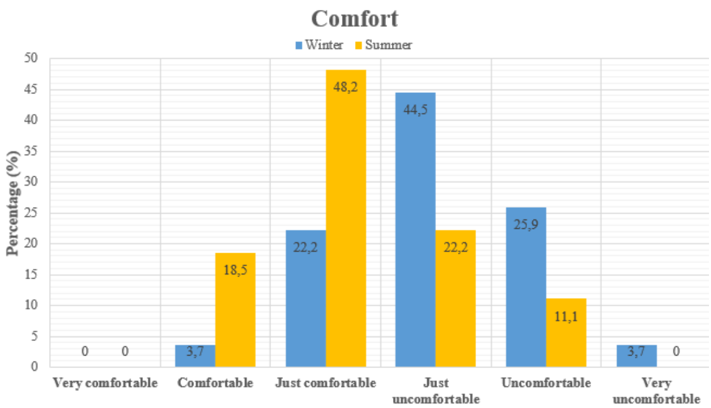


Figure VI.4. *Thermal comfort according to respondents in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

- **Thermal preference**

In winter, 44.4% of interviewees in this space prefer to have it a little warmer, 40.8% prefer to have it warmer, and 7.4% prefer to have it much warmer, while 7.4% are neutral. In summer, 44.4% prefer to have it cooler, 44.4% prefer to have it cooler, and 11.2% are neutral.

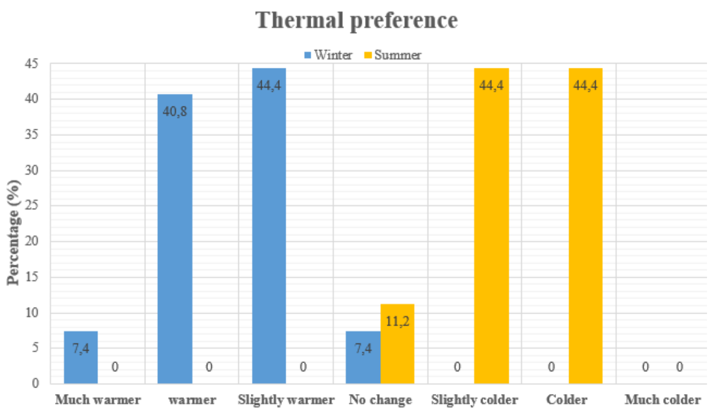


Figure VI.5. *Thermal Preference of respondents in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

- **Thermal environment acceptability**

The thermal conditions in this space are considered "just unacceptable" by 48% of users during the winter season, with 26% deeming them unacceptable, 18.5% finding them just acceptable, and 7.5% remaining neutral. In contrast, 78% of respondents regard the thermal environment as satisfactory (just acceptable) in the summer, while 11% view it as very unacceptable, 7% as just unacceptable, and 4% as neutral.

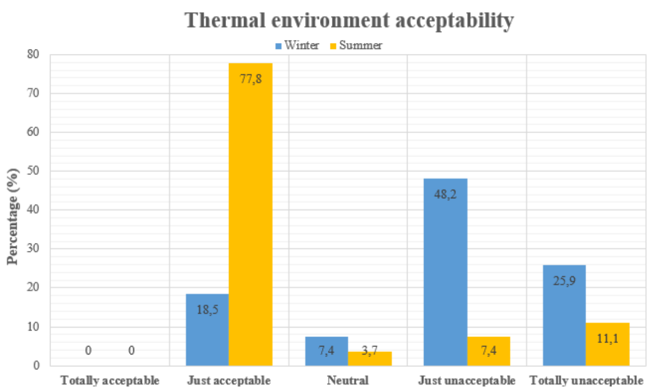


Figure VI.6. *Thermal environment acceptability of respondents in the main public entrance hall "Pt.1".*

Source: Author 2025.

- **Satisfaction**

The majority, with 66.7% of those surveyed, find the thermal environment usually unsatisfactory in the winter, whereas 89% find it generally satisfactory in the summer.

According to the poll, the thermal environment in the hall of the main public entrance is more comfortable in the summer than in the winter.

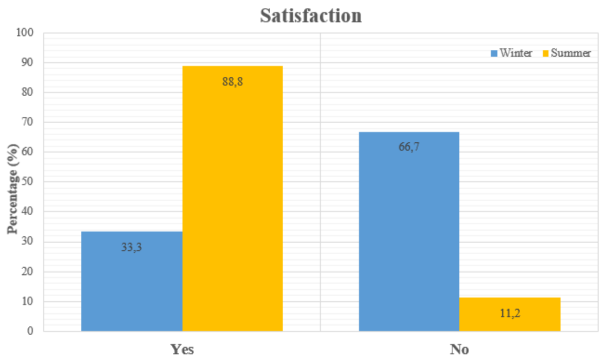


Figure VI.7. *Thermal satisfaction in the hall of the main public entrance "Pt.1".*

Source: Author 2025.

VI.2.3 The hall of distribution

VI.2.3.1 General information

In the modest exhibition space, known as the distribution hall, the participant consists of 50% men and 50% women. Among these individuals, 50% fall within the age range of 30 to 40 years, 25% are aged between 40 and 50 years, and the remaining 25% are between 25 and 30 years.

The graphical data reveal that in the winter season, 50% of participants show a clothing insulation level of 1.2 *Clo*, while 25% indicate a level of 1.1 *Clo*, and the remaining 25% report a level of 1.0 *Clo*. Conversely, in the summer season, 50% of respondents exhibit a clothing insulation level of 0.4 *Clo*, with 25% at 0.5 Clo and another 25% at 0.6 *Clo*. In terms of metabolic activity, 50% of participants indicated an activity level of 1.6 *MET*, 25% reported 1.2 *MET*, and the remaining 25% noted a level of 2.0 *MET*.

Table VI.6. *Gender of the respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

Gender	**Male**	**Female**
Percentage (%)	50	50

Table VI.7. *Age of the respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Male (%)	0	25	0	25	0	0
Female (%)	0	0	50	0	0	0
Total (%)	0	25	50	25	0	0

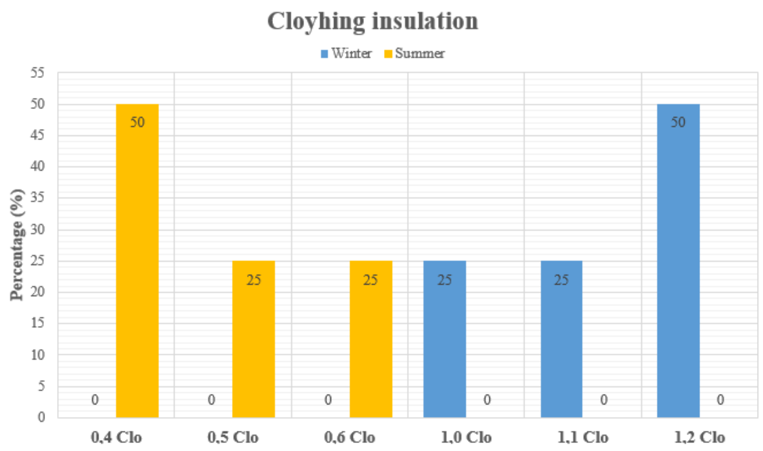


Figure VI.8. *Clothing insulation of the respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

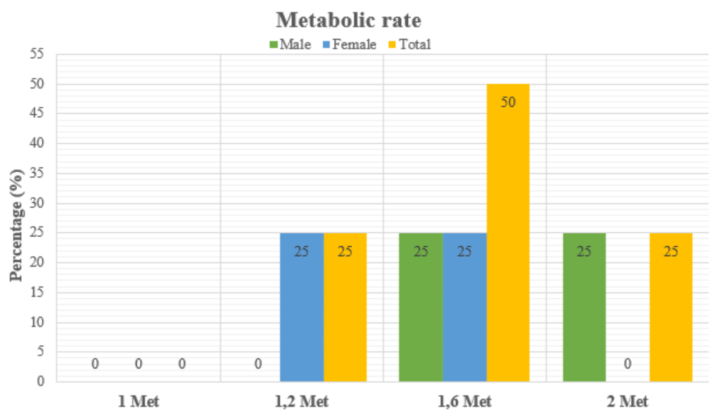


Figure VI.9. *Metabolic rate of the respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

VI.2.3.2 Thermal comfort evaluation

- **Thermal sensation**

According to the data collected, 50% of participants report feeling slightly fresh, and 50% report feeling fresh throughout the winter. 50% of people feel neutral, 25% are somewhat warm, and 25% are warm during the summer.

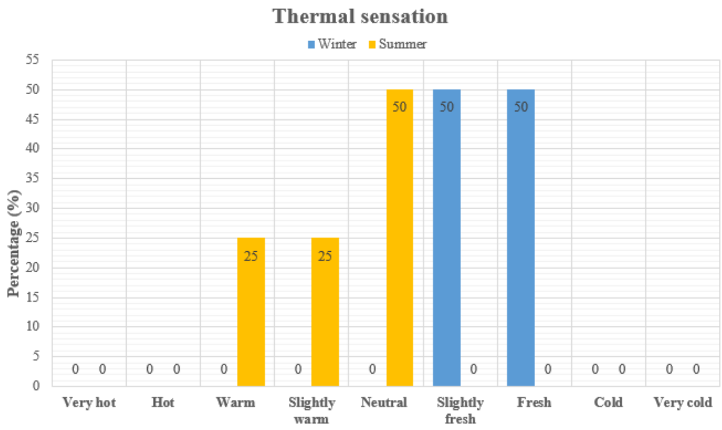


Figure VI.10. *Thermal sensation of the respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

- **Comfort**

In winter, half of the participants feel the space is thermally uncomfortable, 25% just uncomfortable, and 25% just comfortable. In the summer, 50% find it comfortable, 25% find it just comfortable, and 25% find it just uncomfortable.

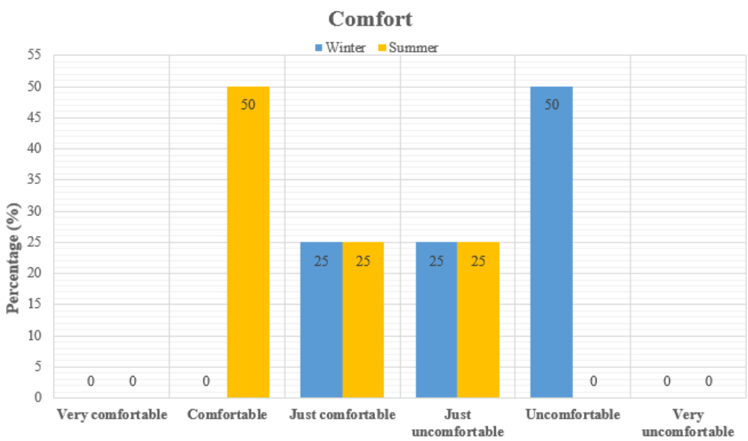


Figure VI.11. *Thermal comfort according to respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

- **Thermal preference**

According to the replies, in the winter, 50% like it to be slightly warmer, 25% prefer it to be warmer, and 25% prefer it to be much warmer. In the summer, 50% are neutral, 25% prefer it slightly colder, and 25% prefer it colder.

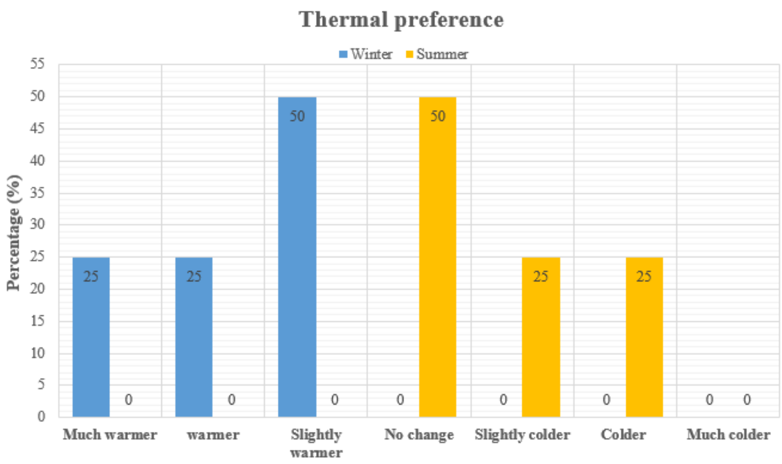


Figure VI.12. *Thermal preference of the respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

- **Thermal environment acceptability**

During winter, 50% of survey participants consider the thermal environment in this space to be totally unacceptable, 25% consider it unacceptable, and 25% consider it just acceptable. During summer, 75% consider it acceptable, while 25% are neutral.

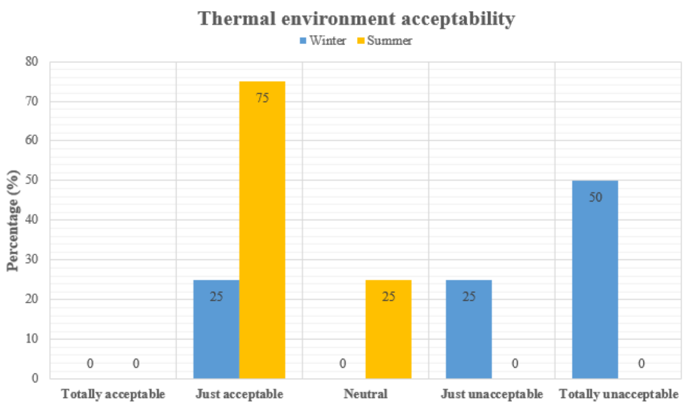


Figure VI.13. *Thermal environment acceptability by the respondents in the hall of distribution "Pt.2".*

Source: Author 2025.

- **Thermal satisfaction**

All users who participated in our survey are satisfied with the thermal environment in summer, but in winter only 25% are satisfied and 75% are dissatisfied.

To summarize, the thermal environment in the distribution hall (Pt.2) is more comfortable in the summer than in the winter.

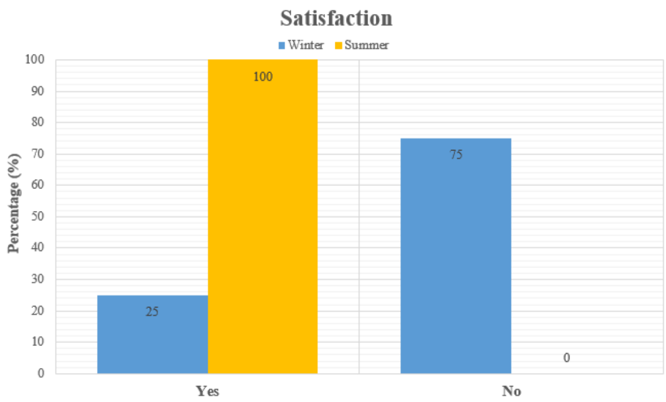


Figure VI.14. *Thermal satisfaction in the hall of distribution "Pt.2".*

Source: Author 2025.

VI.2.4 Hall of the VIP lounge entrance

VI.2.4.1 General information

In the third exhibition hall located northeast at the entrance to the main hall, 60% of survey participants are men. 40% are between 30 and 40 years old, 20% are under 25, 20% are between 40 and 50, and 20% are between 50 and 60.

The winter clothing insulation among the participants is as follows: 40% have 1 *Clo*, 20% have 1.1 *Clo*, and 40% have 1.2 *Clo*. During the summer, the distribution is 40% at 0.4 Clo, 20% at 0.3 *Clo*, 20% at 0.5 *Clo*, and 20% at 0.6 *Clo*. Their metabolic rate is recorded as 1.6 *MET* for 40%, 1.2 *MET* for 20%, 1.4 *MET* for 20%, and 2 *MET* for 20%.

Table VI.8. *Gender of the respondents in the hall of the VIP lounge entrance "Pt.3".*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	60	40

Table VI.9. *Age of the respondents in the hall of the VIP lounge entrance "Pt.3".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 -50	50 - 60	+60
Male (%)	20	0	20	0	20	0
Female (%)	0	0	20	20	0	0
Total (%)	20	0	40	20	20	0

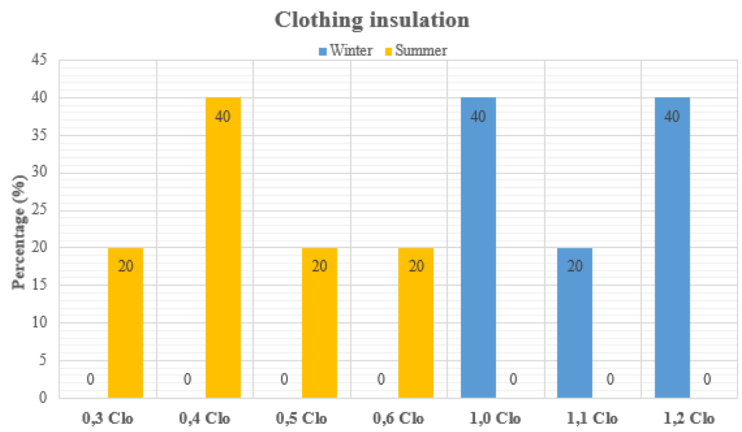


Figure VI.15. *Clothing insulation of the respondents in the hall of the VIP lounge entrance "Pt.3".*

Source: Author 2025.

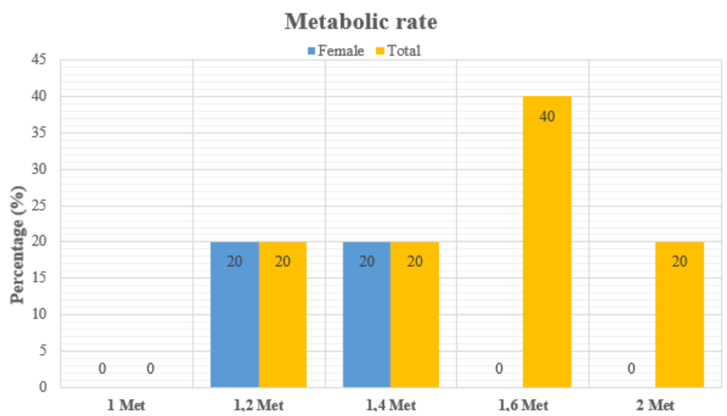


Figure VI.16. *Metabolic rate of the respondents in the hall of the VIP lounge entrance "Pt.3".*

Source: Author 2025.

VI.2.4.2 Thermal comfort evaluation

- **Thermal sensation**

During the winter season, 40% of participants say they feel a little cold, 40% say they feel cold, and 20% feel very cold. During the summer season, 80% say they feel neutral, and 20% say they feel slightly warm.

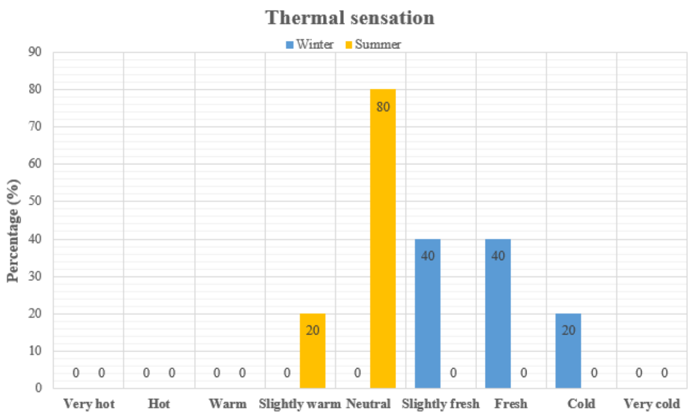


Figure VI.17. *Thermal sensation of the respondents in the hall of the VIP lounge entrance "Pt.3".*

Source: Author 2025.

- **Comfort**

Concerning thermal comfort, 20% of participants find the area just comfortable, 40% find it just uncomfortable, and 40% find it uncomfortable during the winter. 40% find it comfortable, and 60% find it just comfortable in the summertime.

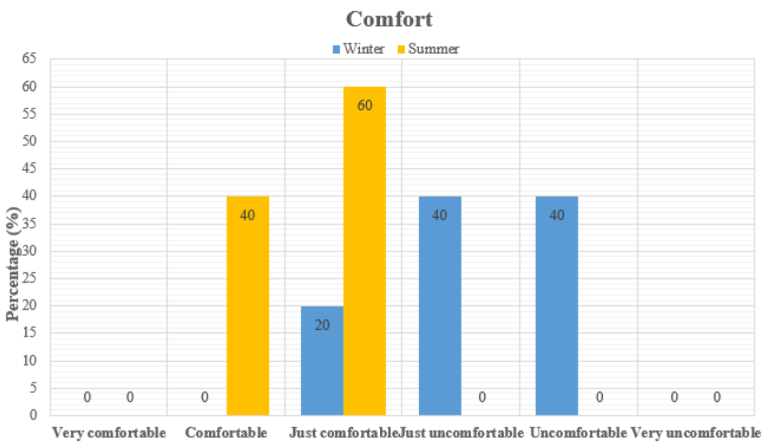


Figure VI.18. *Thermal comfort according to respondents in the hall of the VIP lounge entrance "Pt.3".*

Source: Author 2025.

- **Thermal preference**

40% of participants prefer to have a slightly warmer environment during winter, 40% prefer to have a warmer setting, and 20% prefer to feel much warmer. In summer, 20% prefer to have a slightly cooler environment, while 80% prefer that the thermal conditions remain unchanged.

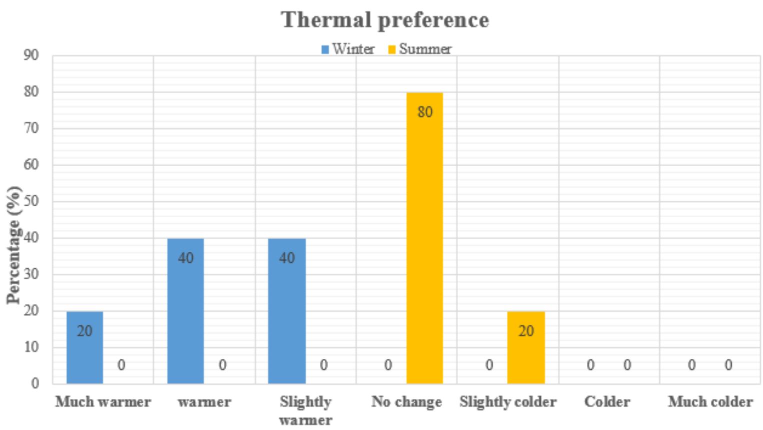


Figure VI.19. Thermal preference of the respondents in the hall of the VIP lounge entrance "Pt.3".

Source: Author 2025.

- **Thermal environment acceptability**

In winter, 40% of respondents consider the thermal environment to be totally unacceptable, 40% consider it just unacceptable, and only 20% consider it just acceptable. In summer, however, 80% consider it just acceptable, and 20% consider it totally acceptable.

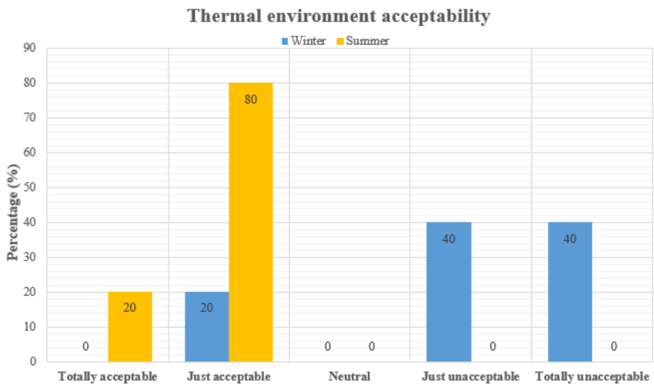


Figure VI.20. Thermal environment acceptability by the respondents in the VIP lounge entrance hall "Pt.3".

Source: Author 2025.

- **Thermal satisfaction**

The entire participant group is satisfied with the thermal environment in this space during the summer, but in contrast to the winter, only 20% are satisfied, while 80% are dissatisfied with this environment.

The hall of the VIP lounge entrance is comfortable in summer, not in winter, as indicated by the survey results.

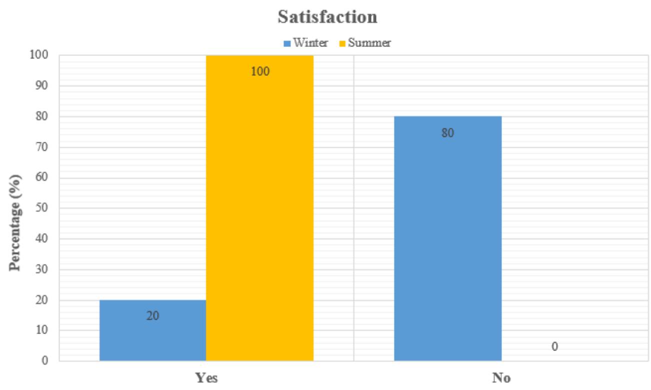


Figure VI.21. *Thermal satisfaction in the hall of the VIP lounge entrance "Pt.3".*

Source: Author 2025.

VI.2.5 The conference room

VI.2.5.1 General information

On the first floor, in the conference room, 50% of the respondents are men, while the rest are women. Among these individuals surveyed, 62.5% fall within the age range of 40 to 50 years, 25% are aged between 50 and 60 years, and 12.5% are between 25 and 30 years.

The winter clothing insulation among responders is 1.2 *Clo* for 75%, 1.1 *Clo* for 12.5%, and 0.9 *Clo* for 12.5%. In the summer, it is 0.6 *Clo* for 50%, 0.5 *Clo* for 12.5%, and 0.4 *Clo* for 37.5%. In terms of metabolic rate, 50% of responders have 1.6 *MET*, whereas the other 50% have 2 *MET*.

Table VI.10. *Gender of the respondents in the conference room "Pt.5".*

Source: Author 2025.

Gender	Male	Female
Percentage	50	50

Table VI.11. *Age of the respondents in the conference room "Pt.5".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Male (%)	0	12.5	0	25	12.5	0
Female (%)	0	0	0	37.5	12.5	0
Total (%)	0	12.5	0	62.5	25	0

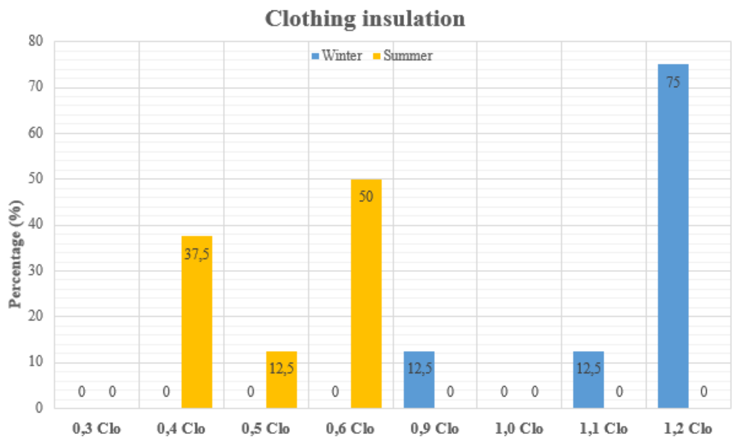


Figure VI.22. *Clothing insulation of the respondents in the conference room "Pt.5".*

Source: Author 2025.

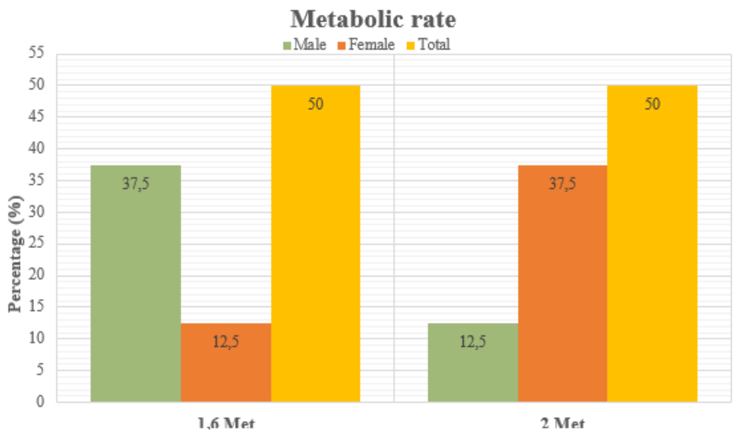


Figure VI.23. *Metabolic rate of the respondents in the conference room "Pt.5".*

Source: Author 2025.

VI.2.5.2 Thermal comfort evaluation

- **Thermal sensation**

In winter, 50% of participants report that it is extremely cold in this space, while 25% say it is cold, 12.5% describe it as fresh, and another 12.5% find it slightly fresh. During the summer, 62.5% feel that it is very hot, 12.5% consider it warm, 12.5% perceive it as slightly warm, and 12.5% remain neutral.

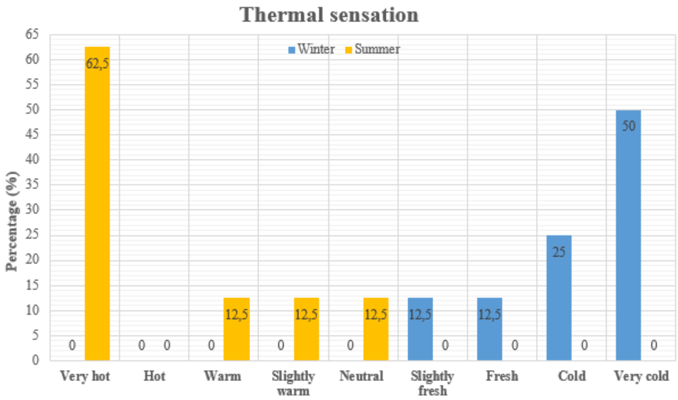


Figure VI.24. *Thermal sensation of the respondents in the conference room "Pt.5".*

Source: Author 2025.

- **Comfort**

Regarding thermal comfort in this 'Pt.5' space, it is very uncomfortable in both winter and summer for 62.5% of respondents, uncomfortable for 25% in winter and 12.5% in summer, just uncomfortable in winter for 12.5%, just comfortable in summer for 12.5%, and comfortable only in summer for 12.5%.

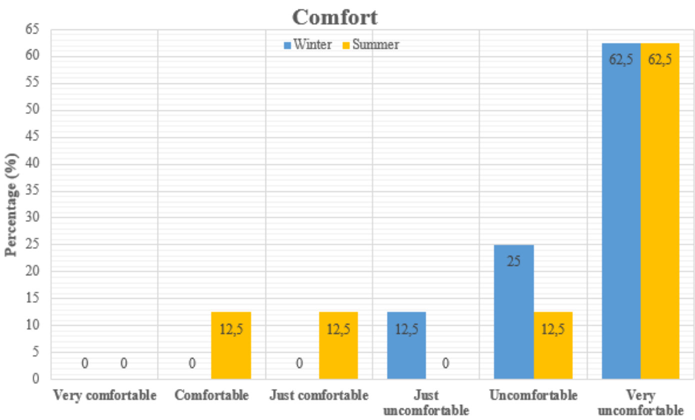


Figure VI.25. *Thermal comfort according to the respondents in the conference room "Pt.5".*

Source: Author 2025.

- **Thermal preference**

In winter, 75% of respondents prefer a warmer temperature, and 25% prefer it to be warmer. In summer, 62.5% prefer a cooler temperature, 25% prefer it to be a little cooler, and 12.5% prefer it to remain unchanged.

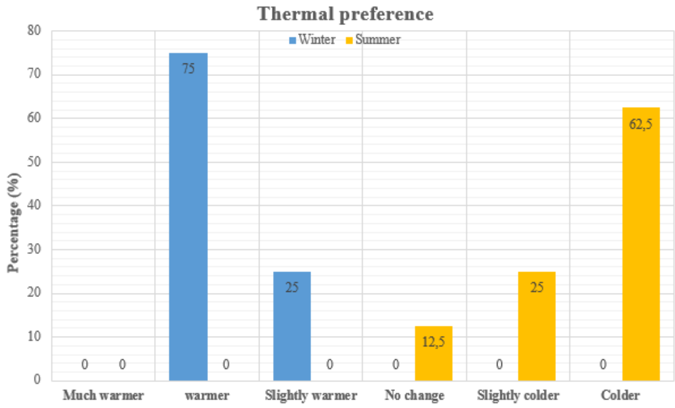


Figure VI.26. *Thermal preference of the respondents in the conference room "Pt.5".*

Source: Author 2025.

- **Thermal environment acceptability**

The thermal environment in winter is unacceptable, as 75% of participants find it totally unacceptable and 25% find it just unacceptable. In summer, 62.5% consider it totally unacceptable, 12.5% consider it just unacceptable, 12.5% find it just acceptable, and 12.5% find it acceptable.

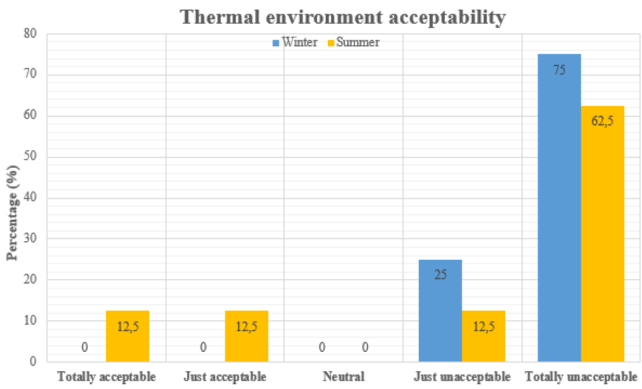


Figure VI.27. *Acceptability of the thermal environment by the respondents in the conference room "Pt.5".*

Source: Author 2025.

- **Thermal satisfaction**

In summer, 62.5% of survey participants are satisfied with the temperature in the conference room, whereas in winter, all respondents are dissatisfied with these conditions.

The conference room experiences thermal conditions that are somewhat comfortable during the summer, yet completely uncomfortable in the winter.

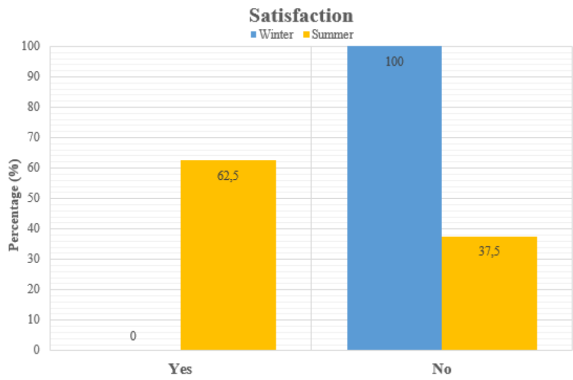


Figure VI.28. *Thermal satisfaction in the conference room "Pt.5".*

Source: Author 2025.

VI.3 Public Library of Constantine

VI.3.1 General information

To acquire reliable findings, the participants' gender and age have to be determined. According to the data, women account for 73% of respondents. In terms of age, 51.9% of the population is under 25, 33% are between 25 and 30, 13.2% are between 30 and 40, and just 1.9% are between 40 and 50.

Participants are dispersed as follows among the three study areas: The main reading room has 47.2% of the total, the secondary reading room has 46.2%, and the children's reading room has 6.6%.

Table VI.12. *Gender of the participants in the public library.*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	27	73

Table VI.13. *Age of the respondents in the public library.*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Percentage (%)	51.9	33	13.2	1.9	0	0

Table VI.14. *Emplacement of the respondents in the public reading room.*

Source: Author 2025.

Emplacement	Main reading room	Secondary reading room	Children's reading room
Percentage (%)	47.2	46.2	6.6

VI.3.2 The main reading room

VI.3.2.1 General information

The majority of responses in the main reading room (78%) are from women. 58% of the respondents are under 25 years old, 30% are in the 25–30 age range, and 12% are in the 30–40 age range.

Table VI.15. Gender of the respondents in the main reading room "Pt.4".

Source: Author 2025.

Gender	Male	Female
Percentage (%)	78	22

Table VI.16. *Gender of the respondents in the main reading room "Pt.4".*

Source: Author 2025.

	-25	25 - 30	30 – 40	40 - 50	50 - 60	+60
Male	10	8	4	0	0	0
Female	48	22	8	0	0	0
Total	58	30	12	0	0	0

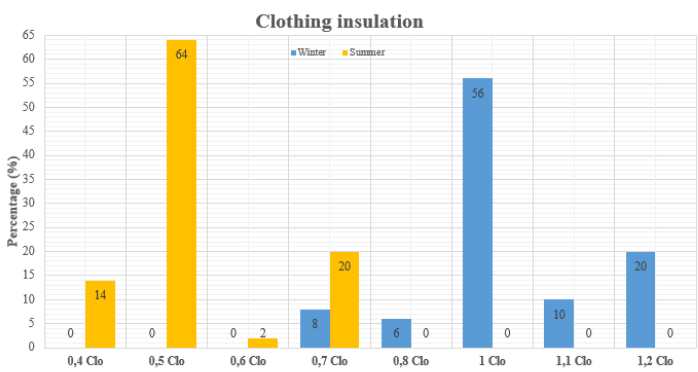


Figure VI.29. *Clothing insulation of respondents in the main reading room "Pt.4".*

Source: Author 2025.

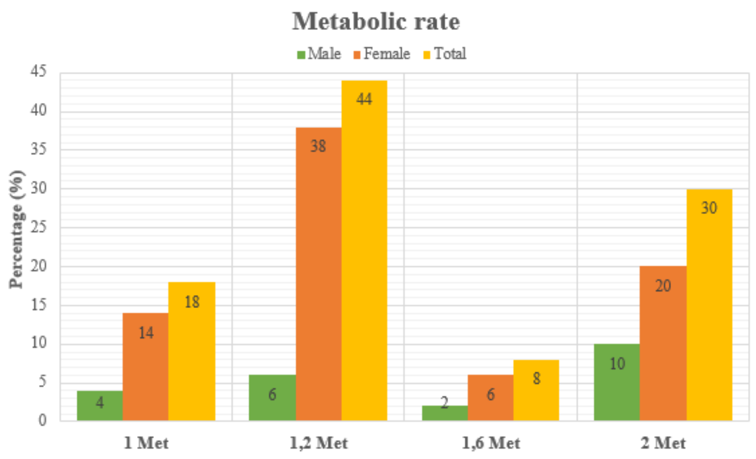


Figure VI.30. *Metabolic rate of respondents in the main reading room "Pt.4".*

Source: Author 2025.

VI.3.2.2 Thermal comfort evaluation

- **Thermal sensation**

As the Figure shows, 50% of people using the space in winter feel neutral (neither hot nor cold), 18% feel slightly cold, 14% feel slightly hot, and 6% feel cold. During the summer, 44% of users report feeling neutral, 16% slightly warm, 14% warm, 10% hot, and 8% very hot.

As a result, most respondents feel neither hot nor cold in the winter (50%) and are neutral or even a little hot (22%). In the summer, most users are more or less hot (48%) and neutral (44%).

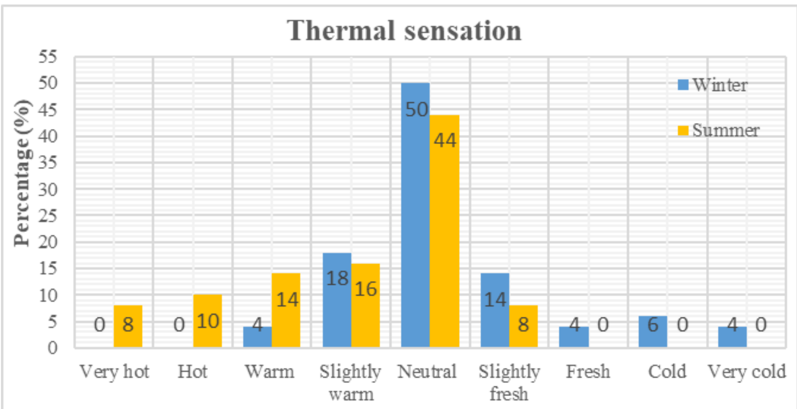


Figure VI.31*. Thermal sensation of respondents in the main reading room.*

Source: Author 2025.

- **Comfort**

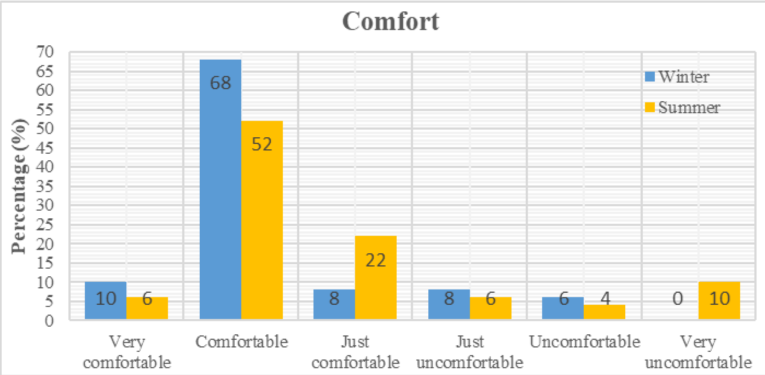


Figure VI.32. *Thermal comfort according to respondents in the main reading room.*

Source: Author 2025.

As illustrated in the figure above, a majority of users experience comfort during winter, with 68% expressing this sentiment. Following closely, 10% report feeling extremely comfortable, while 8% indicate they feel either just comfortable or just uncomfortable. A mere 6% of users report feeling uncomfortable. During the summer months, 52% of users claim to feel comfortable, with 22% stating they are just comfortable. Additionally, 10% feel very uncomfortable, 6% are just comfortable, and 4% express discomfort.

- **Thermal preference**

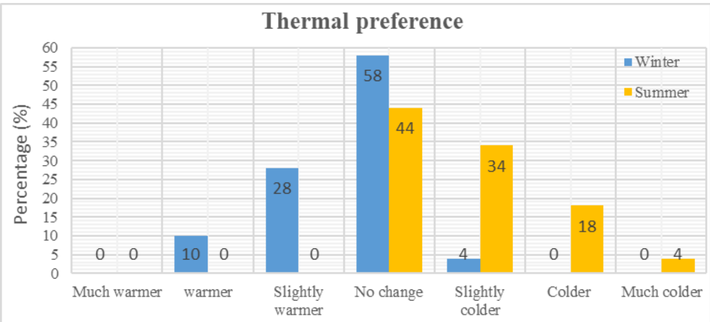


Figure VI.33. *Thermal preference of respondents in the main reading room.*

Source: Author 2025.

During the winter season, 58% of the users of this space prefer to maintain the existing thermal conditions, 28% opt for a slight increase in warmth, 10% desire a warmer environment, and 4% would like to experience slightly cooler temperatures. In the summer, 44% of users wish for no changes, 34% prefer a slight decrease in temperature, 18% favour a cooler atmosphere, and 4% seek a significantly cooler environment.

Thus, in winter, the majority of users favour maintaining the existing conditions, whereas in summer, a larger portion (56%) prefers a cooler environment compared to the 44% who wish for no changes.

- **Thermal environment acceptability**

In the winter, 44% of respondents find the thermal environment acceptable, 26% are neutral, 16% say it is completely acceptable, 12% find it unacceptable, and 2% find it absolutely unacceptable. In the summer, 40% find the temperature environment acceptable, 34% are neutral, 22% find it completely acceptable, and 4% find it unacceptable.

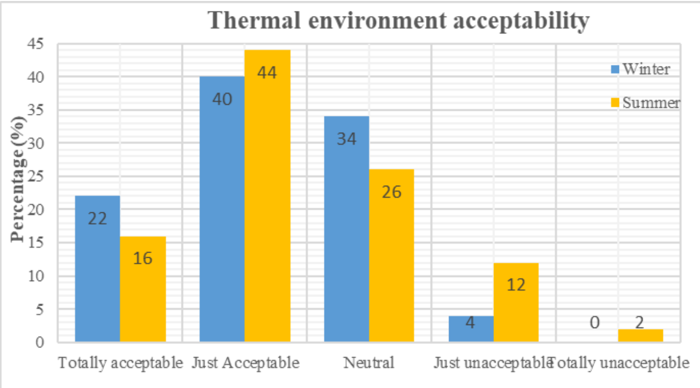


Figure VI.34. *Thermal environment acceptability by respondents in the main reading room.*

Source: Author 2025.

- **Satisfaction**

In both summer and winter, the data indicates that most users are typically satisfied with the thermal climate in the main reading room. The majority is represented by 88% in the winter and 78% in the summer. They are more satisfied in winter than in summer.

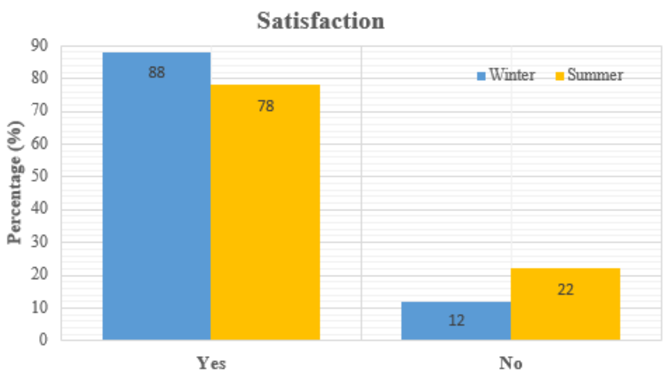


Figure VI.35. *Thermal satisfaction in the main reading room.*

Source: Author 2025.

VI.3.3 The secondary reading room

VI.3.3.1 General information

In this secondary reading room, 67% of the respondents are female, while 33% are male. Among those surveyed, 49% are below the age of 25, 37% fall within the 25–30 age bracket, and 14% are in the 30–40 age category.

Table VI.17. *Thermal satisfaction in the main reading room "Pt.3".*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	33	67

Table VI.18. *Age of respondents in the secondary reading room "Pt.3".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Male	18.3	8.2	6.1	0	0	0
Female	30.6	28.6	8.2	0	0	0
Total	48.9	36.8	14.3	0	0	0

VI.3.3.2 Thermal comfort evaluation

According to data, in winter, 45% of respondents are neutral, 21% feel fresh, 12% feel slightly fresh, while 14% have slightly warm and 8% feel warm. In summer, 39% are neutral, 16% have slightly warm, 16% feeling warm, 4% feel hot and 4% have very hot, while 14% have slightly fresh and 6% feel fresh.

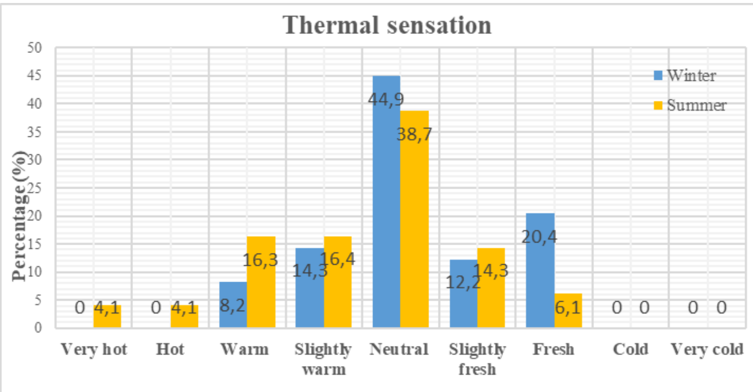


Figure VI.36. *Thermal sensation of respondents in the secondary reading room "Pt.3".*

Source: Author 2025.

- **Comfort**

During the winter, 63.3% of users consider the space to be comfortable, while 14.2% regard it as just comfortable. Additionally, 10.2% believe it to be very comfortable, 8.2% perceive it as just uncomfortable, and 4% find it uncomfortable. In the summer, 55.2% of users think the space is comfortable, 18.3% find it just comfortable, and 10.2% consider it very comfortable. Furthermore, 10.2% find it just uncomfortable, 4.1% are very uncomfortable, and 2% deem it uncomfortable.

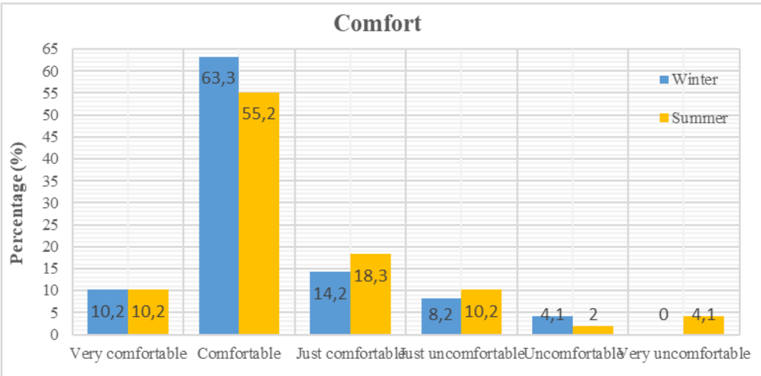


Figure VI.37. *Thermal comfort according respondents in the secondary reading room "Pt.3".*

Source: Author 2025.

- **Thermal preference**

During the winter, 45% of users express a desire for the thermal conditions of the space to remain constant, while 35% would prefer a slight increase in warmth. Additionally, 18% seek a warmer environment, and a mere 2% wish for a notable decrease in temperature. In the summer, 46.9% of users favour no alteration in temperature, 37% desire a slight chill, 8% would like it to be cooler, 2% prefer a significant drop in temperature, and 6% would opt for a slight increase in warmth .

Consequently, the majority of users indicate a preference for warmer temperature conditions throughout the winter season. During the summer, those who favour cooler temperatures and those who advocate for stable temperatures are equally represented.

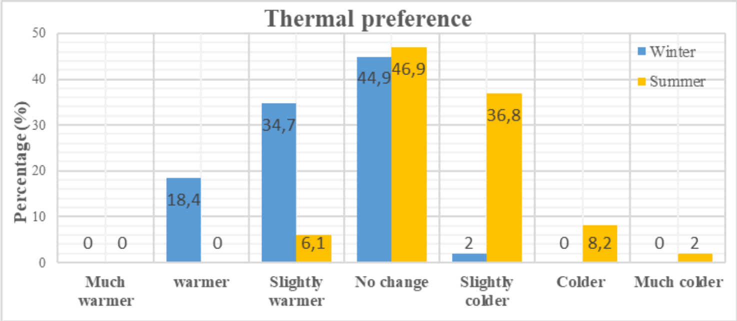


Figure VI.38. *Thermal preference respondents in the secondary reading room "Pt.3".*

Source: Author 2025.

- **Thermal environment acceptability**

According to the data, during the winter, 32.7% of respondents find the thermal environment just adequate, 30.6% find it very acceptable, 26.5% are neutral, and 10.2% find it just intolerable. In the summer, 34.8% find the thermal environment completely acceptable, 32.6% find it neutral, 22.4% find it barely tolerable, and 10.2% find it extremely undesirable.

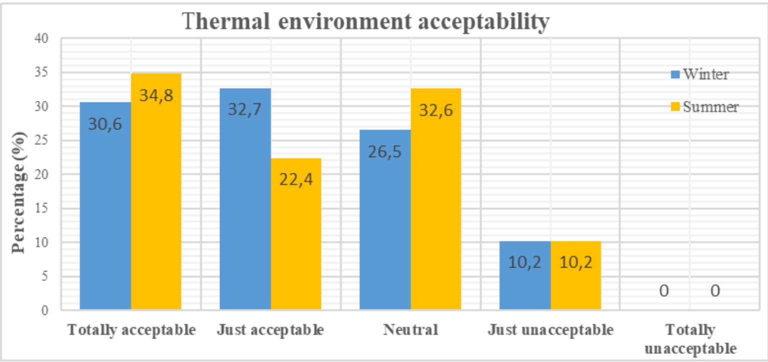


Figure VI.39. *Thermal environment acceptability by respondents in the secondary reading room "Pt.3".*

Source: Author 2025.

- **Satisfaction**

As shown in the graph, the thermal environment in this secondary reading room is deemed satisfactory by 80% of users during the winter season. Additionally, a significant majority (78%) express thermal satisfaction throughout the summer months.

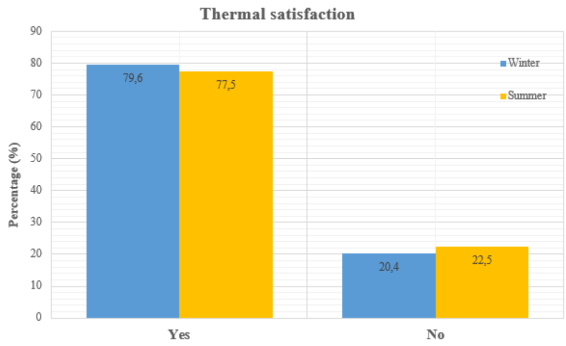


Figure VI.40. *Thermal satisfaction in the secondary reading room "Pt.3".*

Source: Author 2025.

VI.3.4 Children's reading room

VI.3.4.1 General information

In this space, designated as the children's reading room, the individuals surveyed were predominantly the companions of the children and those accountable for their care. According to the statistics, the majority of respondents (71%) were female. 28.5% of respondents were under 25, 28.6% were between 25 and 30, 14.3% were between 30 and 40, and 28.6% were between 40 and 50 years old.

Winter clothing insulation is 1.2 *Clo* for 57% of responders and 1 *Clo* for 43%. During the summer, 0.5 *Clo* accounts for 57%, 0.7 *Clo* for 28.5%, and 0.4 *Clo* for 14.5%. In addition, 71.4% of respondents reported a metabolic rate of 1.2 *MET*, whereas 28.6% reported a rate of 2 *MET*.

Table VI.19. *Gender of respondents in the children's reading room "Pt.1".*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	29	71

Table VI.20. *Age of respondents in the children's reading room "Pt.1".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Male	0	14.3	0	14.3	0	0
Female	28.5	14.3	14.3	14.3	0	0
Total	28.5	28.6	14.3	28.6	0	0

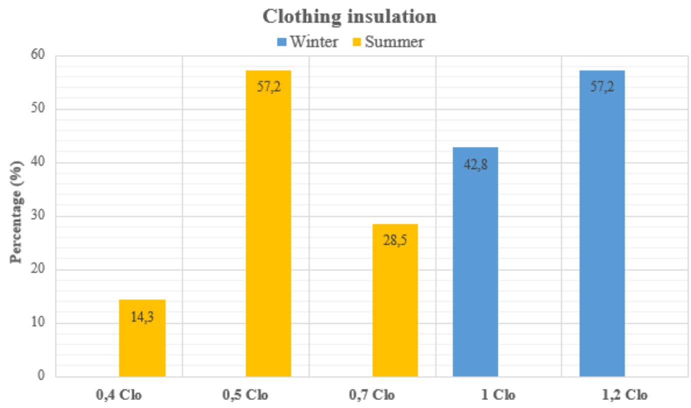


Figure VI.41. *Clothing insulation of respondents in the children's reading room "Pt.1".*

Source: Author 2025.

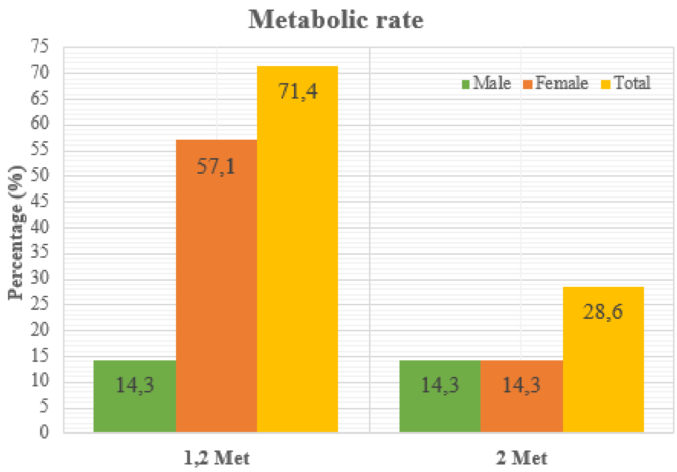


Figure VI.42. *Metabolic rate of respondents in the children's reading room "Pt.1".*

Source: Author 2025.

VI.3.4.2 Thermal comfort evaluation

- **Thermal sensation**

As seen in the figure, in the winter, 28.5% of respondents answer neutrally, with 28.5% feeling fresh, 14.3% feeling slightly fresh, 14.3% feeling very cold, and 14.3% feeling warm. In the summer, the majority (71.4%) are neither hot nor cold, while 28.6% feel warm.

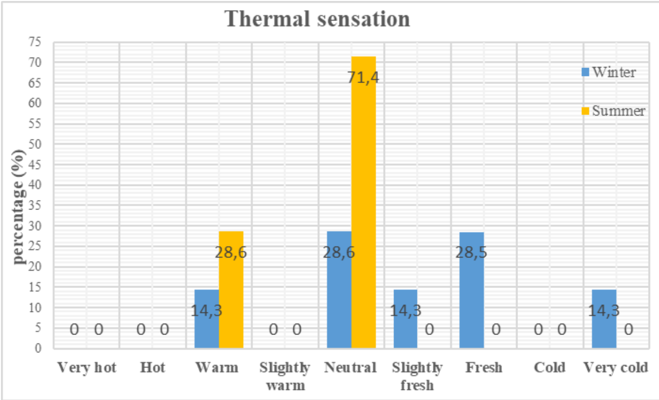


Figure VI.43. *Thermal sensation of respondents in the children's reading room "Pt.1".*

Source: Author 2025.

- **Comfort**

In the winter, 43% of respondents find the thermal environment comfortable, 28.5% find it just comfortable, and 28.6% find it extremely uncomfortable. 71.4% find the place thermally comfortable in the summer, 14.3% find it just comfortable, and 14.3% find it uncomfortable.

So, the space is thermally comfortable in summer more than in winter.

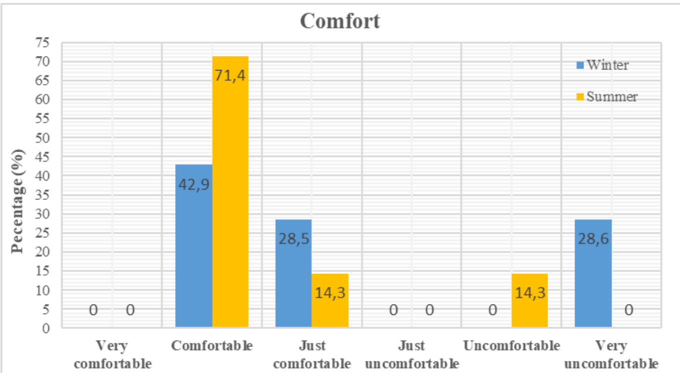


Figure VI.44. *Thermal comfort according to respondents in the children's reading room "Pt.1".*

Source: Author 2025.

- **Thermal preference**

A notable percentage of users (43%) prefer somewhat warmer conditions in winter; 29% want to maintain the current thermal environment; 14% favour warmer temperatures, and another 14% choose much warmer settings. During summer, most participants (57%) prefer a slightly cooler environment; 29% wish for no changes, while 14% desire a colder atmosphere.

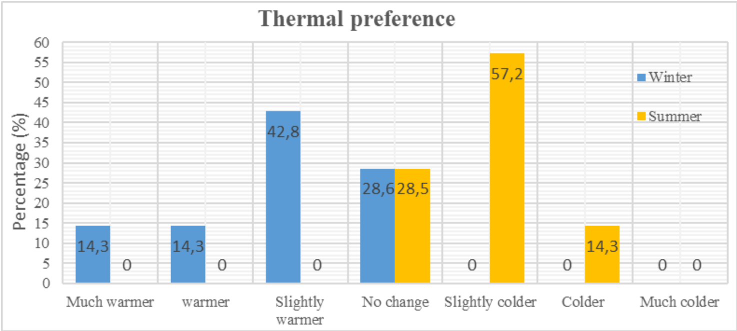


Figure VI.45. *Thermal preference of respondents in the children's reading room "Pt.1".*

Source: Author 2025.

- **Thermal environment acceptability**

According to the statistics, in winter, 43% of respondents say the thermal environment is just acceptable, 29% say it is completely unacceptable, 14% say it is just unacceptable, and 14% say it is entirely acceptable. During the summer, 43% think it is just fine, 29% think it is very acceptable, 14% are indifferent, and 14% think it is totally unacceptable.

The thermal environment in this space is more acceptable in summer than in winter.

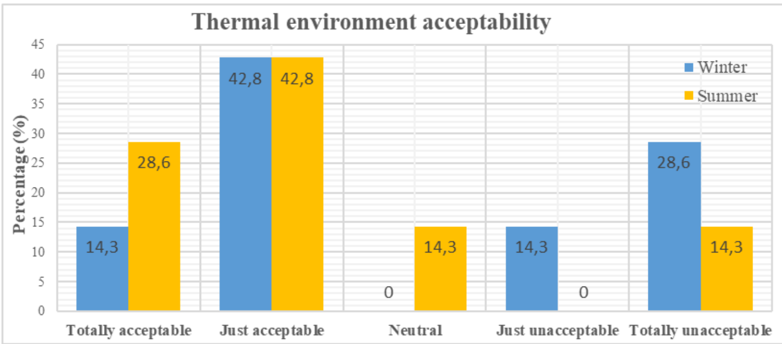


Figure VI.46. *Thermal environment acceptability by respondents in the children's reading room.*

Source: Author 2025.

- **Satisfaction**

In the winter, 57% of those surveyed are content with the temperature conditions, whereas in the summer, 86% are typically satisfied.

The respondents are more satisfied with the thermal environment in the summer than in the winter.

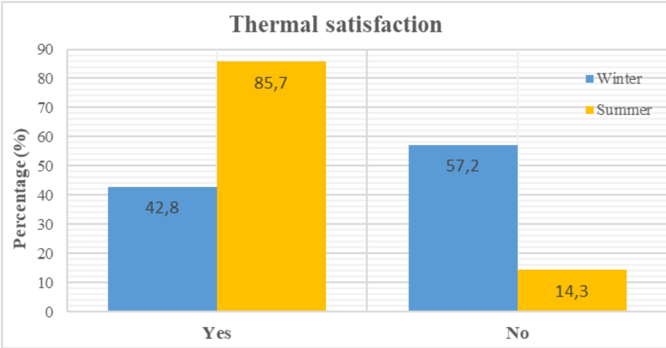


Figure VI.47. *Thermal satisfaction in the children's reading room.*

Source: Author 2025.

VI.4 The performance hall "Zenith Constantine"

VI.4.1.1 General information

The assessment for the third structure, the performance venue "Zenith Constantine", was exclusively carried out in the different levels of the primary hall throughout the summer months, as there were no events taking place during the winter period when the questionnaire was administered.

According to statistics, 61% of survey participants are women. 31% were aged between 30 and 40, 20% were under 25, 15% were aged between 25 and 30, 14% were aged between 50 and 60, 11% were over 60, and 9% were aged between 40 and 50.

54% of the participants were situated on the middle level of the hall (1st level), 35% were positioned on the second level, and 11% were located on the ground floor (VIP level).

Table VI.21. *Gender of respondents in the performance hall.*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	39	61

Table VI.22. *Age of respondents in the performance hall.*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Percentage (%)	20	15	31	9	14	11

Table VI.23. *Emplacement of respondents in the performance hall.*

Source: Author 2025.

Emplacement	**Level 0 (VIP) "Pt.1"**	**Level 1 "Pt.2"**	**Level 2 "Pt.3"**
Percentage (%)	11	54	35

VI.4.2 The ground floor of the performance hall

VI.4.2.1 General information

In the VIP level on the ground floor, 67% of respondents were women. 34% of respondents were aged between 30 and 40, 22% between 25 and 30, 22% between 50 and 60, and 22% were over 60 years old.

Clothing insulation was 0.4 *Clo* for 78% of respondents, 0.3 *Clo* for 11%, and 0.6 *Clo* for 11%. And the metabolic rate was 1.2 *Met* for 44.4%, 1 *Met* for 33.3%, and 1.6 *Met* for 22.3%.

Table VI.24. *Gender of respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

Gender	**Male**	**Female**
Percentage (%)	33	67

Table VI.25. *Age of respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

	-25	**25 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**+60**
Male	0	0	12	0	11	11
Female	0	22	22	0	11	11
Total	0	22	34	0	22	22

Figure VI.48. *Clothing insulation of respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

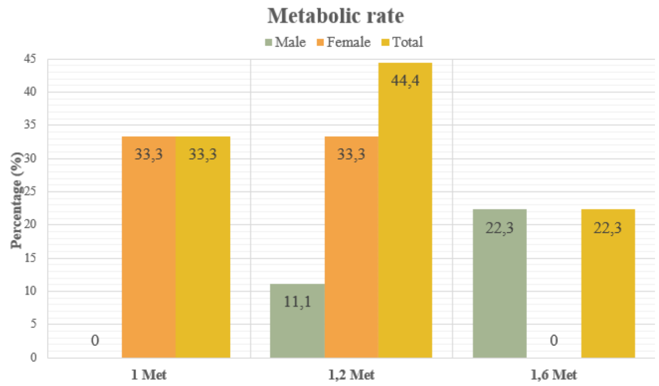


Figure VI.49. *Metabolic rate of respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

VI.4.2.2 Thermal comfort evaluation

- **Thermal sensation**

According to the figure below, the space is slightly fresh for 44.4% of the participants, and it is fresh for 11.2%, while 44.4% are neutral.

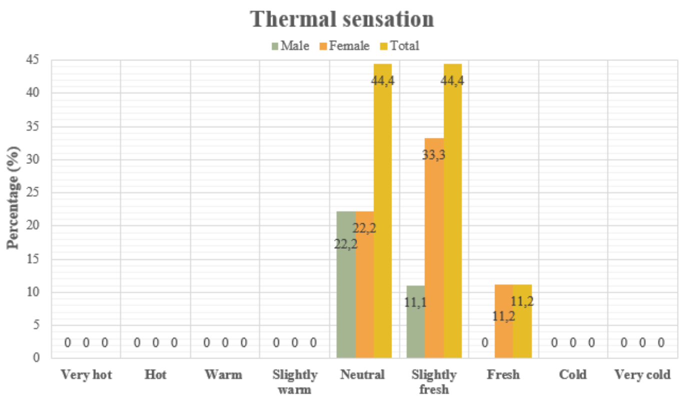


Figure VI.50. *Thermal sensation of respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

- **Comfort**

The space is considered comfortable by 67% of respondents and just comfortable by 33%. Therefore, this space is thermally comfortable in summer.

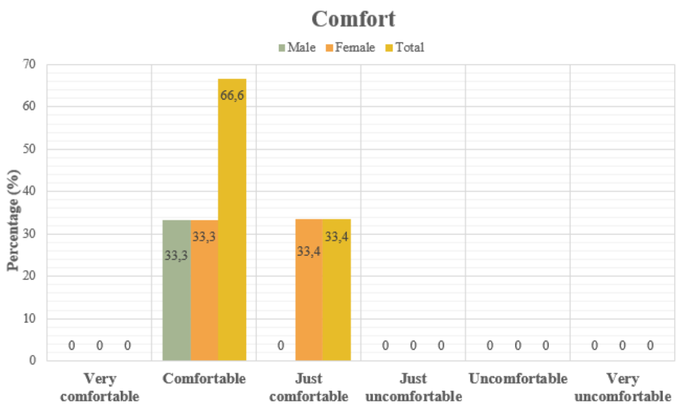


Figure VI.51. *Thermal comfort according to respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

- **Thermal preference**

The majority of the respondents (67%) prefer that the thermal conditions in summer in this space remain unchanged, while 33% prefer having slightly warmer temperatures.

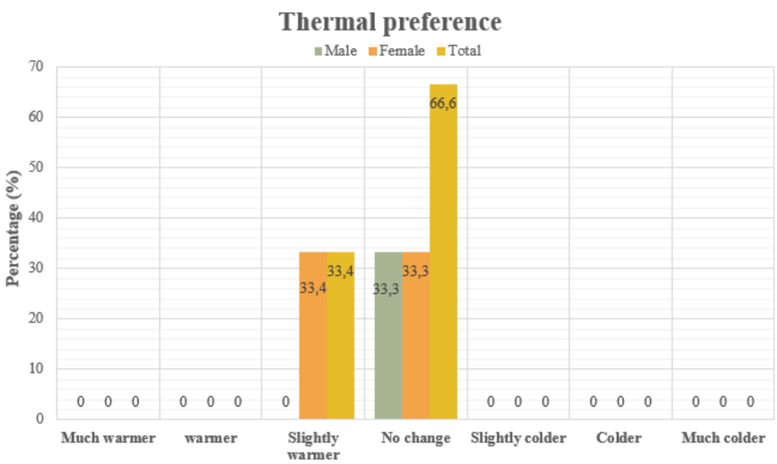


Figure VI.52. *Thermal preference of respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

- **Thermal environment acceptability**

The thermal environment in the VIP level (level 0) is considered just acceptable by 56% of participants and totally acceptable by 11%, while 33% of them are neutral.

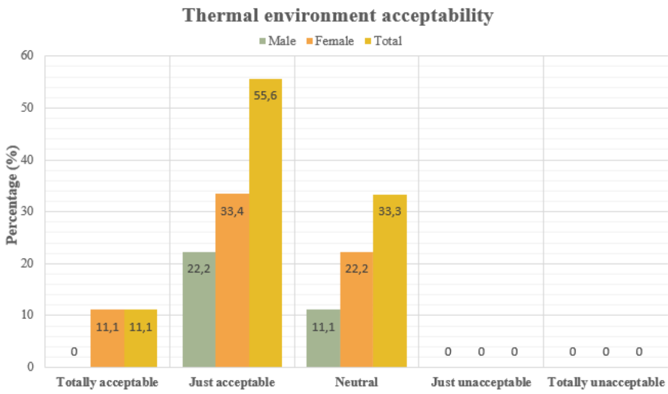


Figure VI.53. *Thermal environment acceptability by respondents in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

- **Thermal satisfaction**

The totality of the surveyed individuals is satisfied with the thermal conditions in this space.

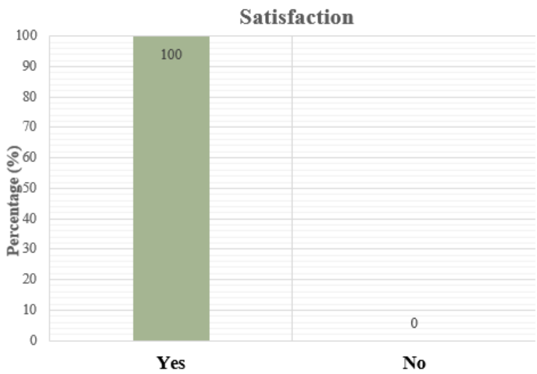


Figure VI.54. *Thermal satisfaction in the ground level of the performance hall "Pt.1".*

Source: Author 2025.

VI.4.3 The first floor of the performance hall

VI.4.3.1 General information

In the first level of the performance hall, 67.4% of the attendees are women. 32.6% of the respondents are under 25 years old, 25.5% fall within the age range of 30 to 40 years, 11.6% are aged between 50 and 60 years, 11.6% are over 60 years old, 9.4% are between 40 and 50 years old, and 9.3% are between 25 and 30 years old.

44.2% of the participants have a clothing insulation value of 0.4 *Clo*, while 25.6% have 0.6 *Clo*, 18.6% have 0.5 *Clo*, and 11.6% are at 0.3 *Clo*. In terms of metabolic rate, 60.5% are at 1 *Met*, 28% at 1.2 *Met*, 9% at 1.4 *Met*, and 2.5% at 2 *Met*.

Table VI.26. *Gender of respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	32.6	67.4

Table VI.27. *Age of respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 - 60	+60
Male	9.3	0	9.3	4.7	4.7	4.7
Female	23.3	9.3	16.2	4.7	6.9	6.9
Total	32.6	9.3	25.5	9.4	11.6	11.6

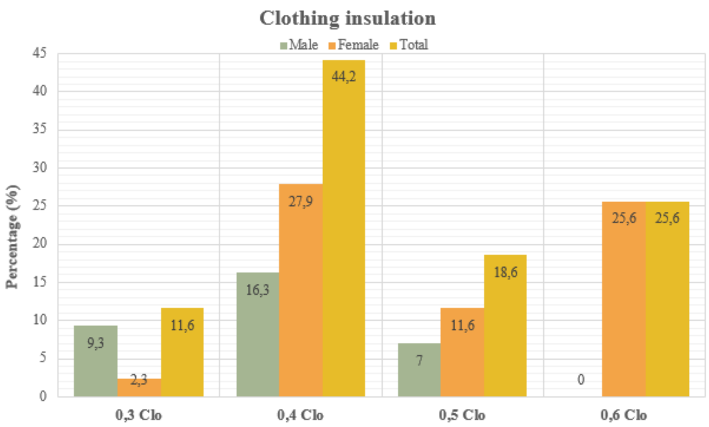


Figure VI.55. *Clothing insulation of respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

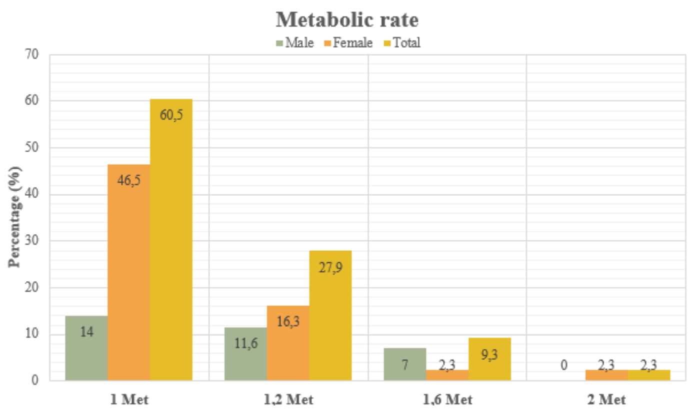


Figure VI.56. *Metabolic rate of respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

VI.4.3.2 Thermal comfort evaluation

- **Thermal sensation**

21% of participants at the first level feel that it is slightly fresh, 14% report that it is slightly warm, 9.4% indicate that it is warm, 2.3% feel hot, and another 2.3% find it fresh, while 51% of the participants remain neutral.

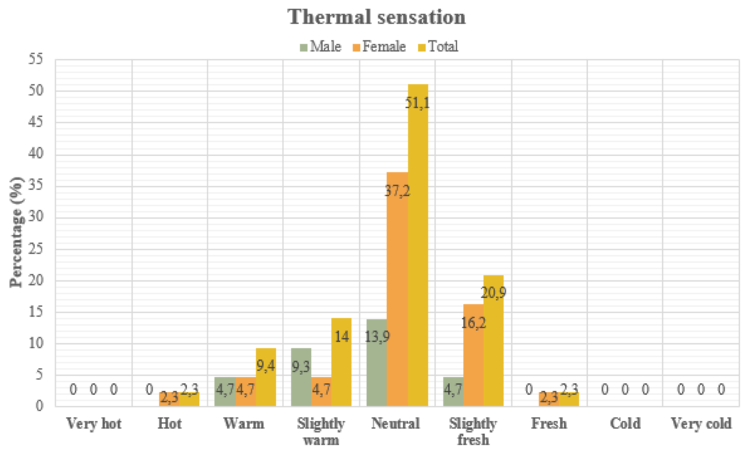


Figure VI.57. *Thermal sensation of respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

- **Comfort**

60.5% of the respondents find the space thermally comfortable, 21% consider it very comfortable, 9.3% regard it as just comfortable, and 9.2% perceive it as just uncomfortable.

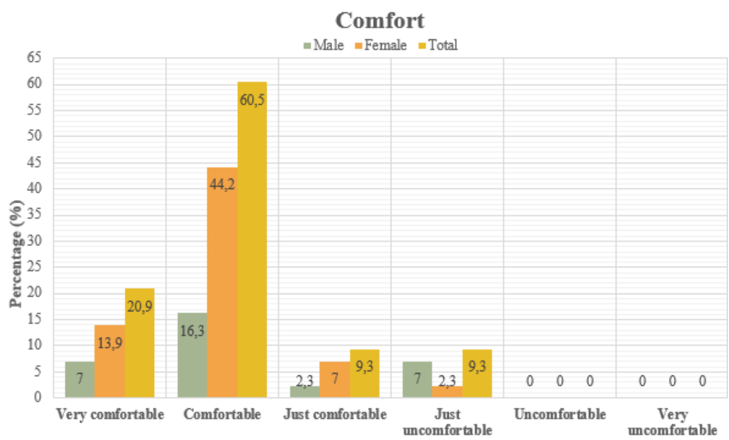


Figure VI.58. *Thermal comfort according to respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

- **Thermal preference**

According to data, 30% of participants prefer slightly cooler temperatures, 14% prefer colder temperatures, and 5% prefer slightly warmer temperatures, while 51% prefer the temperature conditions to remain unchanged.

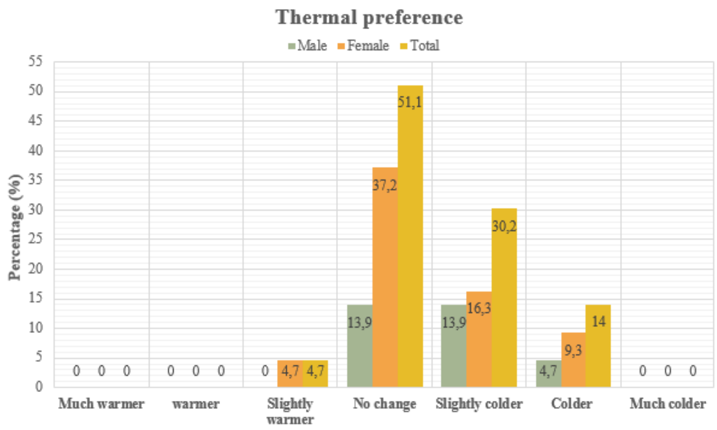


Figure VI.59. *Thermal preference of respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

- **Thermal environment acceptability**

The thermal environment of this space is considered just acceptable by 46.6% of the participants, completely acceptable by 35%, and just unacceptable by 4.6%, and approximately 14% of the respondents are neutral.

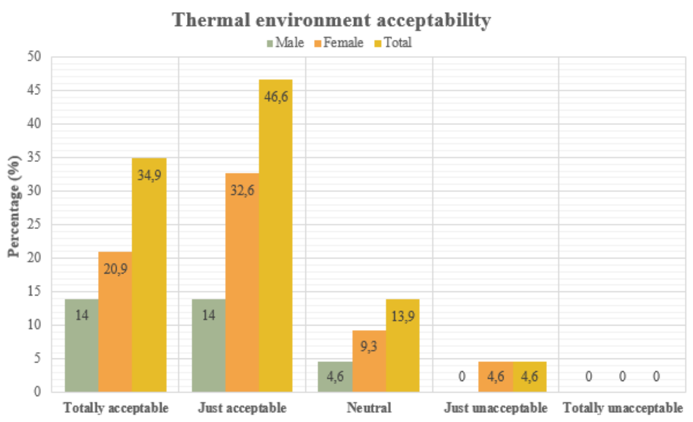


Figure VI.60. *Thermal environment acceptability by respondents in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

- **Thermal satisfaction**

The majority of the participants (98%) are satisfied with the thermal environment and the thermal conditions in the first level of the performance hall.

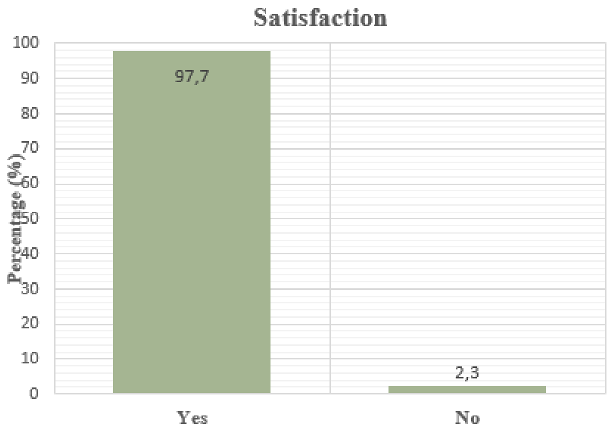


Figure VI.61. *Thermal satisfaction in the first floor of the performance hall "Pt.2".*

Source: Author 2025.

VI.4.4 The second floor of the performance hall

VI.4.4.1 General information

On the second level of the auditorium, half of the survey participants are men and the other half are women. 39.4% of these participants are between 30 and 40 years old, 21.4% are between 25 and 30 years old, 14.3% are between 50 and 60 years old, 7.1% are under 25 years old, and 7.1% are over 60 years old.

According to the statistics, clothing insulation is at 0.4 Clo for 36% of respondents, 0.5 Clo for 28%, 0.6 Clo for 18%, 0.3 Clo for 11%, and 0.7 Clo for 7%. Additionally, the metabolic rate is at 1 Met for 50% of respondents, 1.2 Met for 39%, 1.6 Met for 7%, and 2 Met for 4%.

Table VI.28. *Gender of respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

Gender	Male	Female
Percentage (%)	50	50

Table VI.29. *Age of respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

	-25	25 - 30	30 - 40	40 - 50	50 -60	+60
Male (%)	0	7.1	17.9	7.1	10.7	7.1
Female (%)	7.1	14.3	21.5	3.6	3.6	0
Total (%)	7.1	21.4	39.4	10.7	14.3	7.1

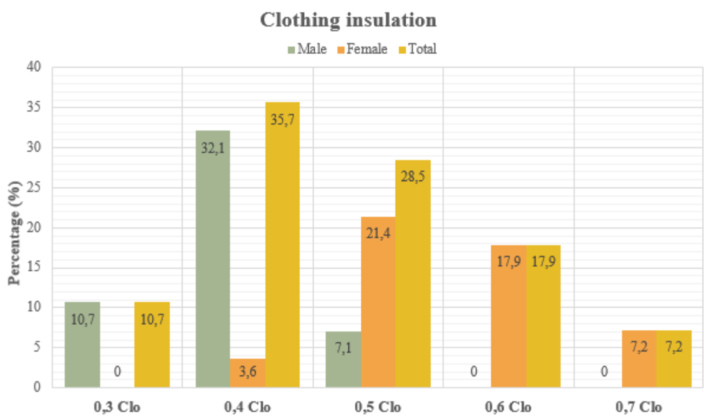


Figure VI.62. *Clothing insulation of respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

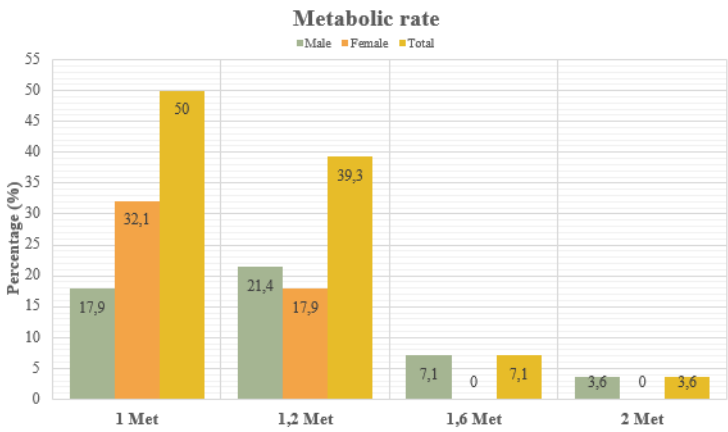


Figure VI.63. *Metabolic rate of respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

VI.4.4.2 Thermal comfort evaluation

- **Thermal sensation**

According to the responses regarding thermal sensation, 53.5% of respondents reported feeling neutral, 32.2% felt slightly fresh, 10.7% felt a little warm, and 3.6% reported feeling warm.

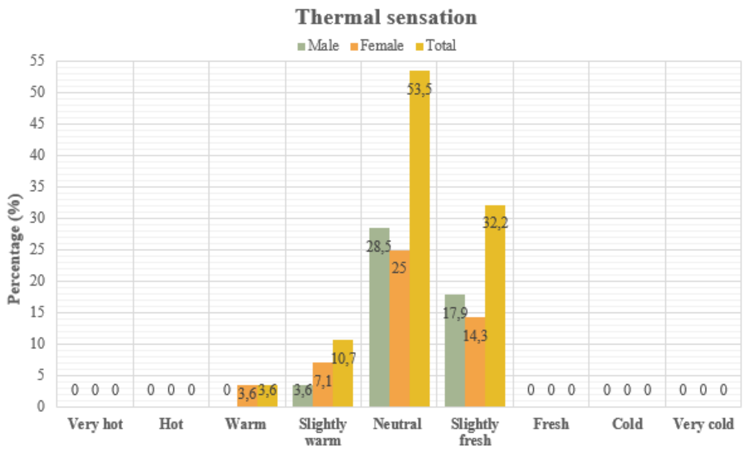


Figure VI.64. *Thermal sensation of respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

- **Comfort**

As shown in the graph below, 71.4% of participants find the space comfortable, 21.4% find it very comfortable, and 7.2% find it just comfortable. Therefore, according to all participants, this space is comfortable.

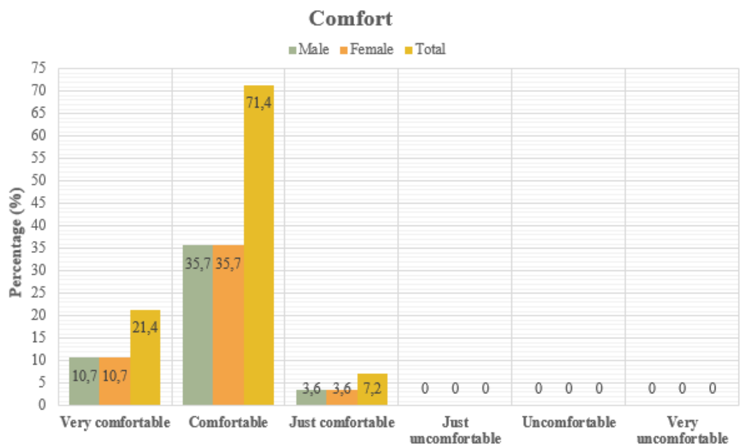


Figure VI.65. *Thermal comfort according to respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

- **Thermal preference**

As seen, 57% of respondents prefer that the thermal conditions in this place remain without changes, 39% prefer that it be slightly colder, and 4% prefer that it be a little warmer.

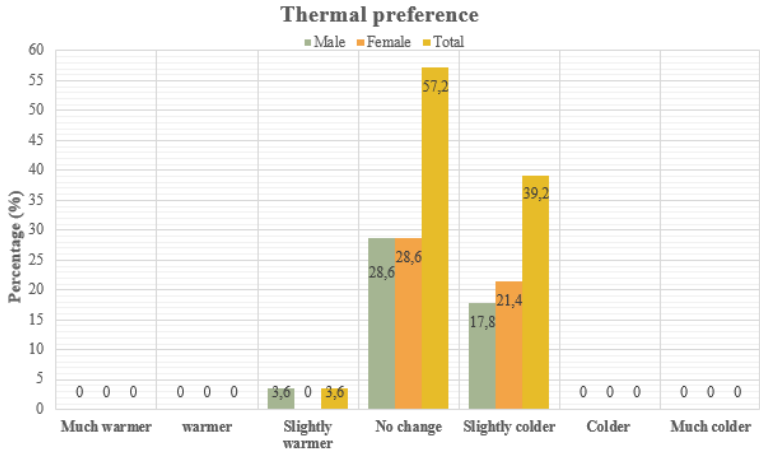


Figure VI.66. *Thermal preference of respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

- **Thermal environment acceptability**

The thermal environment is totally acceptable according to 50% of the contributors, it is just acceptable by 36%, and 14% of them are neutral.

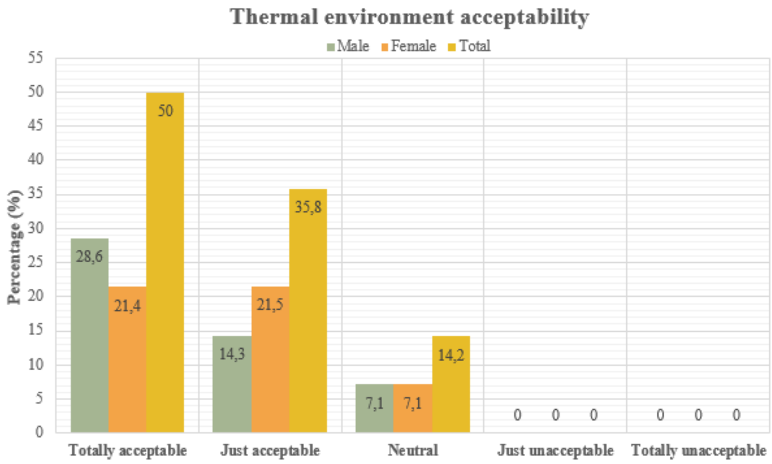


Figure VI.67. *Thermal environment acceptability by respondents in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

- **Thermal satisfaction**

The majority of respondents who participated in the survey, represented by 96.4%, are satisfied with the thermal environment in the second level of the performance hall.

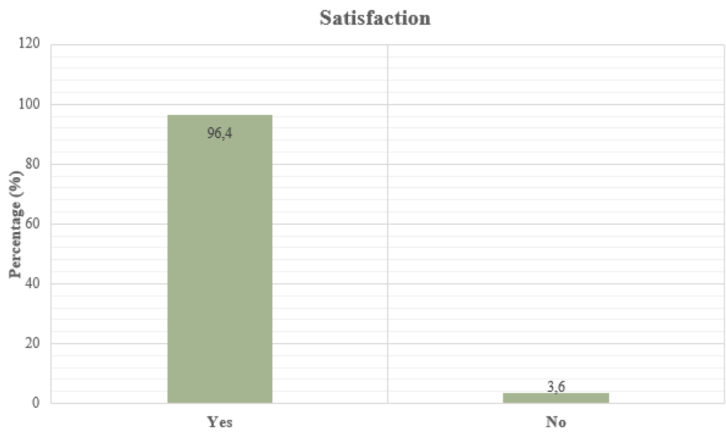


Figure VI.68. *Thermal satisfaction in the second floor of the performance hall "Pt.3".*

Source: Author 2025.

VI.5 Discussion and observation

Based on the questionnaire survey, the thermal environment in winter is satisfactory for the majority of respondents in the main reading room and secondary reading room of the public library. However, in the palace of culture, the majority of respondents in the various spaces are dissatisfied with the thermal environment.

Participants are generally pleased with the summer temperature conditions in the cultural palace's different spaces, the public library's children's reading room, and the performance hall.

According to the survey findings, respondents are most satisfied in the summer in the small exhibition hall (distribution hall), the entrance hall of the *VIP* lounge of the cultural palace, the children's reading room of the public library, and the 3,000-seat performance hall.

During the winter period, spaces with double-skin façades that have a high percentage of openings are the most comfortable. Also, spaces with *DSF* with a south-facing curtain wall are the most comfortable.

In summer, spaces with double-skin facades that are completely closed or have few openings are considered more comfortable than others. Furthermore, spaces with a north-facing curtain wall facade are comfortable, while those facing south or east are less comfortable.

VI.6 Conclusion

This chapter focused on the second approach utilized, which was a questionnaire survey. The findings were processed in Microsoft Excel and displayed as graphs and tables. First, there was a presentation and discussion of the survey participants' results and replies in the various regions of each building, followed by observations based on the reported data and a conclusion.

Based on the replies and outcomes of this questionnaire survey, it was determined that:

- Spaces with DSFs that have few openings are comfortable in summer and uncomfortable in winter, such as the children's reading room and the exhibition hall of the cultural palace.
- In the summer, areas with DSFs that are fully closed and have no openings, like the performance hall, are comfortable.
- Spaces featuring a combination of DSF and north-facing curtain walls are more comfortable in the summer than in the winter. When facing south, they are more pleasant in the winter than in the summer.

General conclusion

1. General conclusion

Innovative façade technologies are emerging as a result of growing awareness of the need for energy-efficient and ecologically conscious building. Double-skin facades, or DSFs, are frequently cited by designers as effective ways to meet contemporary design goals. This is due to DSFs' ability to satisfy the requirements of comfort, energy efficiency, and visual appeal for building exteriors.

The double-skin facade is not a new idea, but designers are starting to incorporate it into their designs. Its complexity and ability to react to a range of environmental conditions necessitate a comprehensive design.

The double skin facade of a building serves as a 'filter' between the internal and external surroundings, emphasizing its importance in reducing overall energy consumption. However, poorly constructed façades can present considerable issues with energy usage.

The first part of the study, focuses on the double skin facade system, begins with a definition of the system and then goes on to provide a historical review of its history. The components of the double skin were then discussed, followed by the way of operation for this sort of façade. We also reviewed the factors that determine double skin performance, as well as the system's pros and downsides.

Thermal comfort has been defined as a state of mind and a feeling of environmental thermal satisfaction, making it a highly subjective concept that is complex to assess and achieve. The state of thermal discomfort leads space users to try to cope and achieve thermal comfort through the use of energy by HVAC systems. Excessive use of HVAC systems, which is very common especially in regions with difficult and extreme climatic conditions, negatively affects the energy performance of the building and makes it look energy-intensive. A global orientation towards energy-efficient buildings has emerged to ensure thermal comfort for the building user and a low-energy building through the adoption of different energy efficiency programmes and the application of different strategies on the building envelope to meet the challenge of a climatically integrated and energy-efficient architecture.

Thermal comfort is a very subjective term that is difficult to measure and attain. It has been characterized as a state of mind and a sensation of ambient thermal contentment. Users of the facility attempt to cope with the pain caused by the heat by using energy to run HVAC systems. Overuse of HVAC systems, which is highly prevalent, particularly in areas with challenging and harsh climates, has a detrimental impact on the building's energy efficiency and gives the impression that it uses a lot of energy.

In order to achieve the main objective of our study, which is to analyse the impact of double skin on thermal comfort in public buildings and to verify the proposed hypotheses, we studied (03) three public buildings with cultural references in Constantine, a city in the North-East of Algeria, characterized by a semi-arid climate, all of these buildings have double skin facades built with different materials and construction techniques. Four interior spaces of each building were studied, and each of these spaces has a DSF built with different materials and a different orientation. In-situ measurements and a questionnaire survey were carried out using appropriate materials, in two periods (underheating period and overheating period), during three typical days on each period.

From the results obtained from the in-situ measurements and the questionnaire survey several conclusions can be drawn.

- In our study, the double-skin façade significantly increased the temperature difference between the interior and exterior by more than 16°C in winter and approximately 22°C in summer.
- The type of construction material and the orientation of the DSF have an impact on its performance.
- A material does not perform the same if the orientation is different.
- Double skin facade combined with a large percentage of double-glazed curtain wall are very efficient in winter because they provide thermal comfort without the need of using the heating system. While they provide a greenhouse effect in summer because of inadequate ventilation caused by users closing all the openings to switch on the air conditioning.
- The DSF combined with double glazed curtain wall is more effective in winter when facing South than North or West.
- Spaces featuring a DSF with a high proportion of double-glazed curtain walls are more comfortable in winter, with a difference of nearly 15°C compared to other spaces.
- The spaces with less opening have a more comfortable temperature than the others, especially in summer, with a difference about 9°C compared with the other spaces.
- Double skin facades with terracotta panels, are more effective than others in summer.

- The way the space is used significantly affects the effectiveness of the "DSF", because it influences the ventilation, which is an essential point in the "DSF's" functioning.
- Double-skin façades offer significant energy savings, as they provide thermal comfort without the need for heating or air conditioning systems.

We can therefore conclude that our main hypothesis is confirmed: DSF acts as a filter between the internal and external environment and decreases the difference between indoor and outdoor temperature.

As with the secondary hypotheses, the combination of different DSFs in terms of construction techniques and materials is more effective.

It is therefore an effective strategy for optimising thermal comfort in buildings in the climate of the city of Constantine.

2. Study limitation

This research faced several limitations and constraints that were beyond our control, such as the following:

The research laboratory associated with the parent faculty (LGCH civil and hydraulic engineering laboratory) lacked the essential measuring instruments required to commence measurement campaigns. To address this issue, we utilized thermo-hygrometers and multimeters from the ABE (Bioclimatic Architecture and Environment) laboratory and the EE (Energy and Environment) laboratory at the University of Constantine 3.

The scarcity of resources is regarded as a significant limitation, which resulted in the reduction of the case studies to merely three buildings. Ideally, at least one building without DSFs should have been included, as such an addition would have facilitated a more pertinent comparative analysis and yielded more comprehensive results regarding the influence of DSFs on thermal comfort in public buildings.

The field research was initiated in 2019, but lockdown (COVID-19) prevented it from being finished. We repeated the study in 2021, but because of the partial lockdown, cultural events were limited, which resulted in fewer performances and fewer visits to buildings.

During interviews with users of the selected spaces, it proved to be exceedingly challenging to elicit responses, as individuals expressed that they had come to enjoy the performances rather than to respond to inquiries, which consequently led to a decline in the number of participants.

The lack of simulation software in the faculty's laboratory rendered its acquisition unfeasible. Therefore, to fulfil the objectives of this study, we replaced simulation with a questionnaire survey.

3. Future perspectives

This study, which focused on double-skin facade systems, considerably improved our understanding of the subject and provided a more in-depth look at this type of façade and construction system that has grown in popularity throughout the world in recent years. Nonetheless, it focuses on the impact of DSF on thermal comfort in public buildings located in a semiarid region.

This research issue is far from exhausted, and new questions regarding it are constantly emerging and expanding. From this point of view, different perspectives and aspects pertinent to this research may be addressed, and new disciplines might be developed, including:

Our study focuses on the impact of DSF on thermal comfort in public buildings in the semi-arid climate of Constantine. A study of different climatic contexts is recommended in order to propose guidelines for each type of climate.

As shown, various factors impact the DSF's performance, including building materials and processes, as well as orientation. To better understand the influence of building materials, it is recommended to investigate the effects of various materials and novel materials.

The DSF is a good solution because of its thermal performance, but a well-ventilated building will increase thermal comfort by releasing trapped heat and preventing the greenhouse effect in spaces with glazed facades. It is essential to study the appropriate ventilation rate using modelling and simulation tools.

Also, it is suggested that putting removable sunshades to the glazed facades in the summer would be an interesting approach to study the performance of "DSF".

Bibliographic References

A Double Skin Facade System: Transparency in the Age of Building Energy Use Reduction | William Rawn Associates Architects [WWW Document], n.d. URL https://www.rawnarch.com/ (accessed 12.2.24).
Adcha, 2008. Cartes postales anciennes de Constantine: La Halle aux Grains. Cartes postales anciennes de Constantine. URL http://adcha-cartes-postales-constantine.blogspot.com/2008/09/la-halle-aux-grains.html (accessed 9.16.24).
Ahmed, M.M.S., Abel-Rahman, A.K., Ali, A.H.H., Suzuki, M., 2015. Double Skin Façade: The State of Art on Building Energy Efficiency. JOCET 4, 84–89. https://doi.org/10.7763/JOCET.2016.V4.258
Ahriz, A., Mesloub, A., Djeffal, L., Alsolami, B.M., Ghosh, A., Abdelhafez, M.H.H., 2022. The Use of Double-Skin Façades to Improve the Energy Consumption of High-Rise Office Buildings in a Mediterranean Climate (Csa). Sustainability 14, 6004. https://doi.org/10.3390/su14106004
Alannah, 2024. Greening Data Centres [WWW Document]. Green Walls. URL https://green-walls.co.uk/blog/greening-data-centres/ (accessed 12.27.24).
Al-awag, E.A.N., Wahab, I.A., 2022. Perspectives in double-skin façade (DSF) advantages and disadvantages. IOP Conf. Ser.: Earth Environ. Sci. 1022, 012003. https://doi.org/10.1088/1755-1315/1022/1/012003
Alberto, A., Ramos, N.M.M., Almeida, R.M.S.F., 2017a. Parametric study of double-skin facades performance in mild climate countries. Journal of Building Engineering 12, 87–98. https://doi.org/10.1016/j.jobe.2017.05.013
Alberto, A., Ramos, N.M.M., Almeida, R.M.S.F., 2017b. Parametric study of double-skin facades performance in mild climate countries. Journal of Building Engineering 12, 87–98. https://doi.org/10.1016/j.jobe.2017.05.013
Amr, H.A.E.-A., Zekry, A.A., 2025. Comparative analysis of static and dynamic double skin façade to Achieve indoor thermal comfort and daylighting.
ANSI/ASHRAE Standard 55-, 2013.
APERCU HISTORIQUE : DE CIRTA A CONSTANTINE. [WWW Document], n.d. URL https://interieur.gov.dz/Monographie/article_detail.php?lien=1563&wilaya=25 (accessed 7.16.25).
Arendt, K., 2012. Influence of external walls' thermal capacitance on indoor thermal comfort. Gdańsk University of Technology.
Aruta, G., Ascione, F., Iovane, T., Mastellone, M., 2025. Double-skin façades for the refurbishment of historic buildings: Energy-economic feasibility for different types of glazing and ventilation rates. Journal of Building Engineering 103, 112125. https://doi.org/10.1016/j.jobe.2025.112125
ASHRAE Standard 55, 2022. Thermal environmental conditions for human occupancy.
Bahrar, M., 2018. Contribution au développement et à l'analyse d'une enveloppe de bâtiment multifonctionnelle dans le cadre de l'optimisation du confort dans l'habitat.
Baldinelli, G., 2009. Double skin façades for warm climate regions: Analysis of a solution with an integrated movable shading system. Building and Environment 44, 1107–1118. https://doi.org/10.1016/j.buildenv.2008.08.005
Bao, S., Zou, S., Li, B., Chen, Q., Zhao, M., 2023. Summer thermal comparative experimental study of double plant-skin façades and double skin façades. Journal of Building Engineering 72, 106641. https://doi.org/10.1016/j.jobe.2023.106641
Barbosa, S., Ip, K., Southall, R., 2015. Thermal comfort in naturally ventilated buildings with double skin façade under tropical climate conditions: The influence of key design parameters. Energy and Buildings 109, 397–406. https://doi.org/10.1016/j.enbuild.2015.10.029
Barnaś, J., 2014. Double-skin façades – the shaping of modern elevations – technology and materials. Technical transactions architecture.
Barone, G., Vardopoulos, I., Attia, S., Vassiliades, C., 2024. Optimizing energy-efficient building renovation: Integrating double-skin façades with solar systems in the Mediterranean landscape. Energy Reports 12, 2933–2945. https://doi.org/10.1016/j.egyr.2024.08.032
Batier, C., 2016. Confort thermique et énergie dans l'habitat social en milieu méditerranéen 291.
BENDAOUD, T., 2016. Constantine Cité de l'air et des passions. ATOUCHA édition.

Benterki, S., 2016. Entrer à Constantine, paysage et projet urbain. Université Constantine 3.
Berkouk, D., 2017. Étude comparative entre le social et le promotionnel, dans la ville de Biskra.
Bibliothèque principale de la lecture publique à Constantine : La lecture en fête, n.d. . El watan.
Bilan énergétique mondial, édition 2024: statistiques énergétiques consolidées et tendances mondiales [WWW Document], 2024. URL https://www.enerdata.fr/publications/analyses-energetiques/bilan-mondial-energie.html (accessed 2.15.25).
Boulebbina, C., 2022. Etude du confort thermique avec optimisation de la consommation energétique en zone semi-aride : site à batna.
C. O. Souza, L., A. Souza, H., F. Rodrigues, E., 2018. Experimental and numerical analysis of a naturally ventilated double-skin façade. Energy and Buildings 165, 328–339. https://doi.org/10.1016/j.enbuild.2018.01.048
Chappells, H., Shove, E., 2004. A review of philosophies and paradigms.
Charron, R., Athienitis, A.K., 2006. Optimization of the performance of double-façades with integrated photovoltaic panels and motorized blinds. Solar Energy 80, 482–491. https://doi.org/10.1016/j.solener.2005.05.004
Climate Consultant 6.0, n.d.
comfort noun - Definition, [WWW Document], 2025. . OxfordLearnersDictionaries.com. URL https://www.oxfordlearnersdictionaries.com/definition/english/comfort_1 (accessed 2.15.25).
confort [WWW Document], 2025. . dictionary.cambridge. URL https://dictionary.cambridge.org/dictionary/french-english/confort (accessed 2.15.25).
Constantine | PDF [WWW Document], n.d. . Scribd. URL https://fr.scribd.com/document/685449139/constantine (accessed 7.16.25).
Constantine - Bibliothèque urbaine de Bab El Kantara «Une bouffée d'oxygène» culturelle pour la ville [WWW Document], n.d. . vitaminedz.com. URL https://www.vitaminedz.com/fr/Algerie/constantine-bibliotheque-urbaine-de-bab-6254136-Articles-0-0-1.html (accessed 9.18.24).
courrier, 2015a. Palais de la culture Al Khalifa : un haut lieu culturel au cœur de Constantine | lecourrier-dalgerie.com. URL https://lecourrier-dalgerie.com/palais-de-la-culture-al-khalifa-un-haut-lieu-culturel-au-coeur-de-constantine/ (accessed 9.16.24).
courrier, 2015b. La salle Zénith de Constantine : une prouesse architecturale pour un rayonnement culturel | lecourrier-dalgerie.com. URL https://lecourrier-dalgerie.com/la-salle-zenith-de-constantine-une-prouesse-architecturale-pour-un-rayonnement-culturel/ (accessed 9.20.24).
CSCEC, 2013. Descriptif Générale du projet. DEP.
Daneshkadeh, S., 2013. The impact of the middle east technical university.
Daverat, C., 2012. Etude expérimentale de la convection naturelle en canal vertical à flux de chaleur imposé: application au rafraîchissement passif de composants actifs de l'enveloppe des bâtiments.
Descriptif générale du projet, 2013.
Die Steiff Story [WWW Document], n.d. . Margarete Steiff GmbH. URL https://corporate.steiff.com/de/unternehmen/historie/ (accessed 11.27.24).
Ding, W., Hasemi, Y., Yamada, T., 2005. Natural ventilation performance of a double-skin façade with a solar chimney. Energy and Buildings 37, 411–418. https://doi.org/10.1016/j.enbuild.2004.08.002
Dopudi, M., 2018. Naturally ventilated double skin façade: cfd and simplified model for parametric energy simulation.
Double skin facade [WWW Document], 2021. . SlideShare. URL https://www.slideshare.net/slideshow/double-skin-facade-247928402/247928402 (accessed 12.18.24).
Double-Skin Facades: Characteristics and Challenges for an Advanced Building Skin | glassonweb.com [WWW Document], n.d. URL http://www.glassonweb.com/article/double-skin-facades-characteristics-and-challenges-advanced-building-skin (accessed 11.30.24).
Double-Skin Facades: Characteristics and Challenges for an Advanced Building Skin [WWW Document], 2019. URL https://swiat-szkla.pl/article/15310-double-skin-facades-characteristics-and-challenges-for-an-advanced-building-skin (accessed 12.18.24).
DTR/Document Technique Règlementaire. Réglementation thermique du bâtiment, 2016.

durable, C. général au développement, n.d. International [WWW Document]. Chiffres clés de l'énergie - Édition 2024. URL https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-energie-2024/11-international.php (accessed 2.15.25).
E-learning [WWW Document], n.d. URL https://www.biffsa.com/e-learning (accessed 4.28.25).
Eslamirad, N., Sanei, A., 2016. Double Skin Facades in Use, A Study of Configuration and Performance of Double Skin Façade, Case Studies some Office Buildings. RSTCONF.
Façade double peau — Ekopedia [WWW Document], n.d. URL http://www.ekopedia.fr/wiki/Fa%C3%A7ade_double_peau (accessed 10.20.24).
façade [WWW Document], 2024. URL https://dictionary.cambridge.org/dictionary/english/facade (accessed 10.27.24).
Fallahi, A., Haghighat, F., Elsadi, H., 2010. Energy performance assessment of double-skin façade with thermal mass. Energy and Buildings 42, 1499–1509. https://doi.org/10.1016/j.enbuild.2010.03.020
FANTAZI, I., 2021. Le management des operations de conservation du patrimoine bati en algerie dans un contexte evenementiel : cas de la vielle ville de constantine capitale de la culture arabe 2015. Université SALAH BOUBNIDER Constantine 3, Constantine, Algérie.
Fissabre, A., Niethammer, B., 2009. The Invention of Glazed Curtain Wall in 1903 - The Steiff Toy Factory.
Flores Larsen, S., Rengifo, L., Filippín, C., 2015. Double skin glazed façades in sunny Mediterranean climates. Energy and Buildings 102, 18–31. https://doi.org/10.1016/j.enbuild.2015.05.019
Fung, T.Y.Y., Yang, H., 2008. Study on thermal performance of semi-transparent building-integrated photovoltaic glazings. Energy and Buildings 40, 341–350. https://doi.org/10.1016/j.enbuild.2007.03.002
Gallery of Bund Finance Centre / Foster + Partners + Heatherwick Studio - 5 [WWW Document], n.d. . ArchDaily. URL https://www.archdaily.com/881511/bund-finance-centre-foster-plus-partners-plus-heatherwick-studio/59dfadedb22e3805c30000b9-bund-finance-centre-foster-plus-partners-plus-heatherwick-studio-photo (accessed 12.27.24).
Gallery of Gensler Tops Out on World's Second Tallest Skyscraper: Shanghai Tower - 29 [WWW Document], n.d. . ArchDaily. URL https://www.archdaily.com/413793/gensler-tops-out-on-world-s-second-tallest-skyscraper-shanghai-tower/520406f7e8e44e949b00018b-gensler-tops-out-on-world-s-second-tallest-skyscraper-shanghai-tower-image (accessed 11.27.24).
Ghaffarianhoseini, Ali, Ghaffarianhoseini, Amirhosein, Berardi, U., Tookey, J., Li, D.H.W., Kariminia, S., 2016. Exploring the advantages and challenges of double-skin façades (DSFs). Renewable and Sustainable Energy Reviews 60, 1052–1065. https://doi.org/10.1016/j.rser.2016.01.130
Givoni, B., 1992. Comfort, climate analysis and building design guidelines. Energy and Buildings 18, 11–23. https://doi.org/10.1016/0378-7788(92)90047-K
Google Maps [WWW Document], n.d. . Google Maps. URL https://www.google.com/maps/@28.1497079,-3.1804359,2573030m/data=!3m1!1e3?entry=ttu&g_ep=EgoyMDI1MDcwOS4wIKXMDSoASAFQAw%3D%3D (accessed 7.15.25a).
Google Maps [WWW Document], n.d. . Google Maps. URL https://www.google.com/maps/place/Wilaya+de+Constantine/@27.9735846,5.2123455,5.48z/data=!4m6!3m5!1s0x12f10cb470246509:0x5e2ae1969309f737!8m2!3d36.3373911!4d6.663812!16zL20vMDl2cl9m?entry=ttu&g_ep=EgoyMDI0MDkxOC4xIKXMDSoASAFQAw%3D%3D (accessed 9.22.24b).
Gratia, E., De Herde, A., 2007a. Greenhouse effect in double-skin facade. Energy and Buildings 39, 199–211. https://doi.org/10.1016/j.enbuild.2006.06.004
Gratia, E., De Herde, A., 2007b. The most efficient position of shading devices in a double-skin facade. Energy and Buildings 39, 364–373. https://doi.org/10.1016/j.enbuild.2006.09.001
Gratia, E., De Herde, A., 2004. Natural cooling strategies efficiency in an office building with a double-skin façade. Energy and Buildings 36, 1139–1152. https://doi.org/10.1016/j.enbuild.2004.05.004
Haase, M., Marques Da Silva, F., Amato, A., 2009a. Simulation of ventilated facades in hot and humid climates. Energy and Buildings 41, 361–373. https://doi.org/10.1016/j.enbuild.2008.11.008
Haase, M., Marques Da Silva, F., Amato, A., 2009b. Simulation of ventilated facades in hot and humid climates. Energy and Buildings 41, 361–373. https://doi.org/10.1016/j.enbuild.2008.11.008
Haddad, M., 1966. Une Clé pour Cirta. Annasr.

Hazem, A., 2018. Méthodologie d'Optimisation Énergétique d'un Bâtiment Equipé d'une Double Façade Ventilée. Université de Batna -2-, Batna, Algérie.

Hazem, A., Ameghchouche, M., Bougriou, C., 2015. A numerical analysis of the air ventilation management and assessment of the behavior of double skin facades. Energy and Buildings 102, 225–236. https://doi.org/10.1016/j.enbuild.2015.05.057

HEBBAL, B., 2022. Optimisation de la consommation énergétique d'un habitat saharien par des techniques passives. Université Kasdi Merbah Ouargla.

Heimrath, R., Hengsberger, H., Mach, T., Streicher, W., Waldner, R., Flamant, G., Guarracino, G., Erhorn, H., Erhorn-Kluttig, H., Santamouris, M., Farou, I., Duarte, R., Blomsterberg, A., Sjöberg, L., Blomquist, C., 2005. Best facade best practice for double skin façades (No. EIE/04/135/S07.38652).

Heimrath, W.S.R., Hengsberger, H., Mach, T., Waldner, R., Flamant, G., Loncour, X., Guarracino, G., Erhorn, H., Erhorn-Kluttig, H., Santamouris, M., Farou, I., Duarte, R., Blomsterberg, Å., Sjöberg, L., Blomquist, C., 2005. State of the Art of Double Skin Facades in Europe The results of WP1 of the BESTFACADE Project.

Hien, W.N., Liping, W., Chandra, A.N., Pandey, A.R., Xiaolin, W., 2005. Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. Energy and Buildings 37, 563–572. https://doi.org/10.1016/j.enbuild.2004.08.004

Histoire de Constantine et de ses communautés [WWW Document], n.d. URL http://www.constantine-hier-aujourdhui.fr/LaVille/histoire.htm (accessed 9.16.24).

Hou, K., Li, S., Wang, H., 2021. Simulation and experimental verification of energy saving effect of passive preheating natural ventilation double skin façade. Energy Exploration & Exploitation 39, 464–487. https://doi.org/10.1177/0144598720956288

Hou, Y.-C., Timmins, F., Zhou, Q., Wang, J.-Z., 2021. A conceptual analysis of the meaning of comfort at the end-of-life using the Walker and Avant (2014) Framework. Frontiers of Nursing 8, 91–97. https://doi.org/10.2478/fon-2021-0011

How Do Double-Skin Façades Work? [WWW Document], 2024. . ArchDaily. URL https://www.archdaily.com/922897/how-do-double-skin-facades-work (accessed 12.5.24).

http://revue.enstp.edu.dz/files/article/28/article%208.pdf [WWW Document], n.d. URL http://revue.enstp.edu.dz/files/article/28/article%208.pdf (accessed 4.17.25).

https://www.bksv.com/media/doc/BO0016.pdf [WWW Document], n.d. URL https://www.bksv.com/media/doc/BO0016.pdf (accessed 4.16.25).

Hu, Z., Maxit, L., Cheng, L., 2021. Acoustic design and analyses of a double Skin Façade system. Applied Acoustics 173, 107727. https://doi.org/10.1016/j.apacoust.2020.107727

Huckemann, V., Kuchen, E., Leão, M., Leão, É.F.T.B., 2010. Empirical thermal comfort evaluation of single and double skin façades. Building and Environment 45, 976–982. https://doi.org/10.1016/j.buildenv.2009.10.006

Inan, T., Basaran, T., 2019. Experimental and numerical investigation of forced convection in a double skin façade by using nodal network approach for Istanbul. Solar Energy 183, 441–452. https://doi.org/10.1016/j.solener.2019.03.030

Jankovic, A., Goia, F., 2021. Impact of double skin facade constructional features on heat transfer and fluid dynamic behaviour. Building and Environment 196, 107796. https://doi.org/10.1016/j.buildenv.2021.107796

Jenkins, M., 2019. Thermal Comfort Basics: What is ASHRAE 55? | SimScale Blog [WWW Document]. SimScale. URL https://www.simscale.com/blog/what-is-ashrae-55-thermal-comfort/ (accessed 4.4.25).

Joe, J., Choi, W., Kwak, Y., Huh, J.-H., 2014. Optimal design of a multi-story double skin facade. Energy and Buildings 76, 143–150. https://doi.org/10.1016/j.enbuild.2014.03.002

Joe, J., Choi, W., Kwon, H., Huh, J.-H., 2013. Load characteristics and operation strategies of building integrated with multi-story double skin facade. Energy and Buildings 60, 185–198. https://doi.org/10.1016/j.enbuild.2013.01.015

Kermiche, S., 2015. Quand L'histoire Nourrit Une Vision D'avenir... Synergies Monde Méditerranéen, GERFLINT 121–130.

Kim, D., Cox, S.J., Cho, H., Yoon, J., 2018. Comparative investigation on building energy performance of double skin façade (DSF) with interior or exterior slat blinds. Journal of Building Engineering 20, 411–423. https://doi.org/10.1016/j.jobe.2018.08.012

Kumar, P., 2019. Role of CFD in evaluating occupant thermal comfort | simulationHub Blog [WWW Document]. simulationHub. URL https://www.simulationhub.com/blog/role-of-cfd-in-evaluating-occupant-thermal-comfort (accessed 3.22.25).

Le Corbusier, Centrosoyus, Moscou, Russie, 1928 [WWW Document], n.d. . Fondation Le Corbusier. URL https://www.fondationlecorbusier.fr/en/work-architecture/achievements-centrosoyus-moscow-russie-1928-1935/ (accessed 11.27.24).

Le petit larousse, 2010. . LAROUSSE.

LIEBARD, A., de HERDE, A., 2005. Traite D'architecture Et D'urbanisme Bioclimatique.

Lim, Y., Ismail, M.R., 2022. Aptitudes of Double Skin Façade Toward Green Building within Built Environment. ARFMTS 100, 146–170. https://doi.org/10.37934/arfmts.100.3.146170

Lin, Y., Zhou, Y., Chen, C., 2023. Interventions and practices using Comfort Theory of Kolcaba to promote adults' comfort: an evidence and gap map protocol of international effectiveness studies. Syst Rev 12, 33. https://doi.org/10.1186/s13643-023-02202-8

Lin, Z., Song, Y., Chu, Y., 2022. Summer performance of a naturally ventilated double-skin facade with adjustable glazed louvers for building energy retrofitting. Energy and Buildings 267, 112163. https://doi.org/10.1016/j.enbuild.2022.112163

Loncour, X., Deneyer, A., Blasco, M., Flament, G., Wouters, P., 2005. Ventilated Double Skin Façades - Classification & illustration of façade concepts (No. 3).

Mansouri, K., 2023. Optimisation du confort thermique et de l'efficacité énergétique dans les établissements scolaires : cas d'un climat chaud et aride. (thèse de doctorat). Université de Biskra.

Manubawa, A.E., Purwanto, L., Ardiyanto, A., 2020. Measuring The Quality of Natural Lighting in A Building with Double Skin Façade (DSF). IJAUD 10. https://doi.org/10.30495/ijaud.2020.15845

Manzano-Agugliaro, F., Montoya, F.G., Sabio-Ortega, A., García-Cruz, A., 2015. Review of bioclimatic architecture strategies for achieving thermal comfort. Renewable and Sustainable Energy Reviews 49, 736–755. https://doi.org/10.1016/j.rser.2015.04.095

MAZARI, M., 2012. Etude et évaluation du confort thermique des bâtiments à caractère public : Cas du département d'Architecture de Tamda (Tizi-Ouzou).

Memari, A.M., Solnosky, R., Hu, C., 2022. Multi-Disciplinary Characteristics of Double-Skin Facades for Computational Modeling Perspective and Practical Design Considerations. Buildings 12, 1576. https://doi.org/10.3390/buildings12101576

Merdaci, 2015. Constantine: City of Eagles, The Thousand And One Names. Zaki Bouzid editions.

Meteonorm 8, n.d.

Moniteur, L., 2013. Une double peau de métal suspendue à la toiture.

N. Al-Azri, Y. Zurigat, N. Al-Rawahi, N. Al-Rawahi, 2012. Development of Bioclimatic Chart for Passive Building Design in Muscat-Oman. RE&PQJ 10. https://doi.org/10.24084/repqj10.841

Naddaf, M.S., Baper, S.Y., 2023. The role of double-skin facade configurations in optimizing building energy performance in Erbil city. Sci Rep 13, 8394. https://doi.org/10.1038/s41598-023-35555-0

Notre Wilaya - Direction du Tourisme et de l'Artisanat Constantine, 2021. URL https://constantine.mta.gov.dz/fr/notre-wilaya/ (accessed 7.16.25).

Omoya, T., 2023. Thermal comfort in buildings: evaluation and semi-empirical modeling of occupant adaptation to environmental stimuli.

Palais de la culture Mohamed Laïd Al Khalifa à Constantine : Bientôt un statut officiel pour l'établissement [WWW Document], n.d. . El watan. URL https://elwatan-dz.com/palais-de-la-culture-mohamed-laid-al-khalifa-a-constantine-bientot-un-statut-officiel-pour-letablissement (accessed 9.13.24).

Parement de façade métallique et parement de facade résille, n.d. . France Résille. URL https://france-resille.com/facades/ (accessed 12.27.24).

Pelletier, K., Wood, C., Calautit, J., Wu, Y., 2023. The viability of double-skin façade systems in the 21st century: A systematic review and meta-analysis of the nexus of factors affecting ventilation and thermal performance, and building integration. Building and Environment 228, 109870. https://doi.org/10.1016/j.buildenv.2022.109870

Pilotage façade double peau [WWW Document], n.d. . Souchier Boullet. URL http://www.souchier-boullet.com/gestion-energetique/systeme-pilotage-intelligent/pilotage-facade-double-peau (accessed 12.5.24).

Poirazis, H., 2004. Double Skin Façades for Office Buildings (Literature review No. EBD-R--04/3). Lund University, Lund, Sweden., Department of Construction and Architecture.

Pomponi, F., Piroozfar, P.A.E., Southall, R., Ashton, P., Farr, Eric.R.P., 2016. Energy performance of Double-Skin Façades in temperate climates: A systematic review and meta-analysis. Renewable and Sustainable Energy Reviews 54, 1525–1536. https://doi.org/10.1016/j.rser.2015.10.075

Proyecto arquitectónico Hospital QuirónSalud Córdoba, n.d. . Enero Arquitectura. URL https://www.eneroarquitectura.com/portfolio-item/hospital-quironsalud-cordoba/ (accessed 12.27.24).

Qahtan, A.M., 2019. Thermal performance of a double-skin façade exposed to direct solar radiation in the tropical climate of Malaysia: A case study. Case Studies in Thermal Engineering 14, 100419. https://doi.org/10.1016/j.csite.2019.100419

Quentin (Webmaster), 2020. Façade ventilée double peau pour un bâtiment commercial "intelligent" à Berlin [WWW Document]. Verre & protections.com. URL https://www.verreetprotections.com/facade-ventilee-double-peau-pour-un-batiment-commercial-intelligent-a-berlin/ (accessed 12.27.24).

Rahmani, B., Kandar, M.Z., Rahmani, P., 2012. How Double Skin Façade's Air-Gap Sizes Effect on Lowering Solar Heat Gain in Tropical Climate?

Redjel, T., Benssedik-Bdeir, S., 2015. يحكى عن مدينة اسمها قسنطينة, L'Algérie d'hier à demain. Araja editions, Constantine, Algérie.

Regnier, C., 2012. Guide to Setting Thermal Comfort Criteria and Minimizing Energy Use in Delivering Thermal Comfort (No. LBNL--6131E, 1169480). https://doi.org/10.2172/1169480

Rijal, H.B., Humphreys, M.A., Nicol, J.F., 2019. Adaptive model and the adaptive mechanisms for thermal comfort in Japanese dwellings. Energy and Buildings 202, 109371. https://doi.org/10.1016/j.enbuild.2019.109371

Roberts, F., Yang, S., Du, H., Yang, R., 2023. Effect of semi-transparent a-Si PV glazing within double-skin façades on visual and energy performances under the UK climate condition. Renewable Energy 207, 601–610. https://doi.org/10.1016/j.renene.2023.03.023

Roulet, C.-A., 2008. CONDITIONS DE CONFORT ET DE LOGEMENT SAIN.

Saelens, D., Hens, H., 2020. Comparison of the energy demand of multiple-skin facades, in: Carmeliet, J., Hens, H., Vermeir, G. (Eds.), Research in Building Physics. CRC Press, pp. 503–511. https://doi.org/10.1201/9781003078852-69

SAFER, N., 2006. Modélisation des façades de type double-peau équipées de protections solaires : approches multi-échelles 316.

Safer, N., Woloszyn, M., Roux, J.J., 2005. Three-dimensional simulation with a CFD tool of the airflow phenomena in single floor double-skin facade equipped with a venetian blind. Solar Energy 79, 193–203. https://doi.org/10.1016/j.solener.2004.09.016

Sanchez, E., Rolando, A., Sant, R., Ayuso, L., 2016. Influence of natural ventilation due to buoyancy and heat transfer in the energy efficiency of a double skin facade building. Energy for Sustainable Development 33, 139–148. https://doi.org/10.1016/j.esd.2016.02.002

Stec, W.J., Van Paassen, A.H.C., Maziarz, A., 2005. Modelling the double skin façade with plants. Energy and Buildings 37, 419–427. https://doi.org/10.1016/j.enbuild.2004.08.008

Straube, J.F., van Straaten, R., 2001. The Technical Merit of Double Facades for Office Buildings in Cool Humid Climates.

Stüdle, R., 2015. Bâtiments à façades double-peau.

Su, Z., Li, X., Xue, F., 2017. Double-skin façade optimization design for different climate zones in China. Solar Energy 155, 281–290. https://doi.org/10.1016/j.solener.2017.06.042

Szokolay, S.V., 1986. Climate analysis based on the psychrometric chart. International Journal of Ambient Energy 7, 171–182.

Tao, Y., Fang, X., Setunge, S., Tu, J., Liu, J., Shi, L., 2021a. Naturally ventilated double-skin façade with adjustable louvers. Solar Energy 225, 33–43. https://doi.org/10.1016/j.solener.2021.07.013

Tao, Y., Zhang, H., Huang, D., Fan, C., Tu, J., Shi, L., 2021b. Ventilation performance of a naturally ventilated double skin façade with low-e glazing. Energy 229, 120706. https://doi.org/10.1016/j.energy.2021.120706

Tao, Y., Zhang, H., Zhang, L., Zhang, G., Tu, J., Shi, L., 2021c. Ventilation performance of a naturally ventilated double-skin façade in buildings. Renewable Energy 167, 184–198. https://doi.org/10.1016/j.renene.2020.11.073

The Green Pine Garden / Scenic Architecture [WWW Document], 2013. . ArchDaily. URL https://www.archdaily.com/360605/the-green-pine-garden-scenic-architecture (accessed 12.27.24).

Tout savoir sur la façade double peau : définition, exemples, performance [WWW Document], n.d. URL https://www.acodi.fr/fr/blog/tout-savoir-sur-la-facade-double-peau (accessed 5.3.25).

Viard, V.M., 2015. Colomiers. Le complexe sportif Capitany monte sur la première marche du podium de Midi-Pyrénées Bois [WWW Document]. ToulÉco. URL https://www.touleco-green.fr/Colomiers-Le-complexe-sportif-Capitany-monte-sur-la-premiere,18026 (accessed 12.27.24).

Visiter Médina de Constantine - Préparez son voyage en Algérie [WWW Document], n.d. URL https://www.theoutsiders.travel/inspiration/lieu/medina-de-constantine/ (accessed 7.16.25).

Wang, C., Yang, H., Ji, J., 2024. Design, fabrication, and performance assessment of a novel PV/T double skin facade. Building and Environment 261, 111750. https://doi.org/10.1016/j.buildenv.2024.111750

Wang, Y., He, F., Lv, Z., Yang, W., Wang, Q., 2022a. Experimental investigations on thermal performance of spray cooling double skin façade in hot humid climate region. Energy and Buildings 277, 112605. https://doi.org/10.1016/j.enbuild.2022.112605

Wang, Y., He, F., Lv, Z., Yang, W., Wang, Q., 2022b. Experimental investigations on thermal performance of spray cooling double skin façade in hot humid climate region. Energy and Buildings 277, 112605. https://doi.org/10.1016/j.enbuild.2022.112605

What is thermal comfort? | Underfloor Insulation Experts [WWW Document], 2023. URL https://www.underfloorinsulationaustralia.com.au/what-is-thermal-comfort/ (accessed 4.5.25).

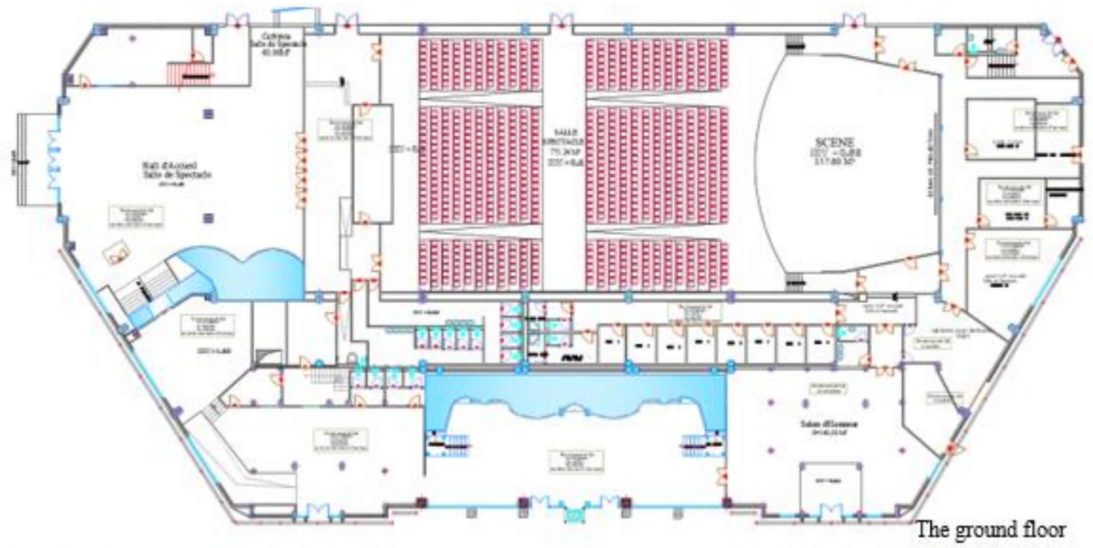
Wong, P.C.J., 2008. Natural ventilation in double-skin façade design for office buildings in hot and humid climate. UNSW Sydney. https://doi.org/10.26190/UNSWORKS/18713

Yılmaz, Z., Çetintaş, F., 2005. Double skin façade's effects on heat losses of office buildings in Istanbul. Energy and Buildings 37, 691–697. https://doi.org/10.1016/j.enbuild.2004.07.010

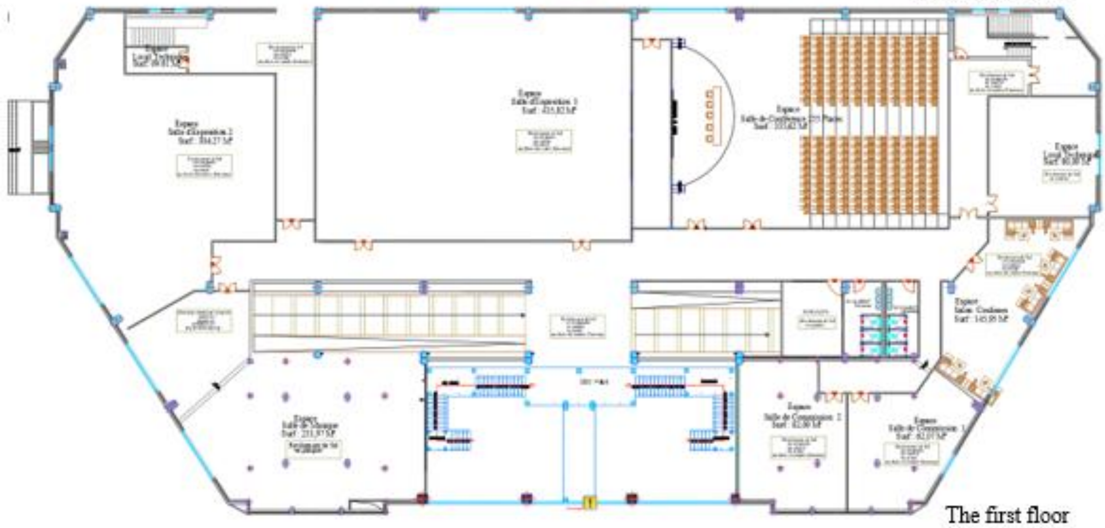
APPENDICES

Appendix 1: Different architectural plans of the three public buildings studied.

Palace of culture “AL KHALIFA”



The ground floor



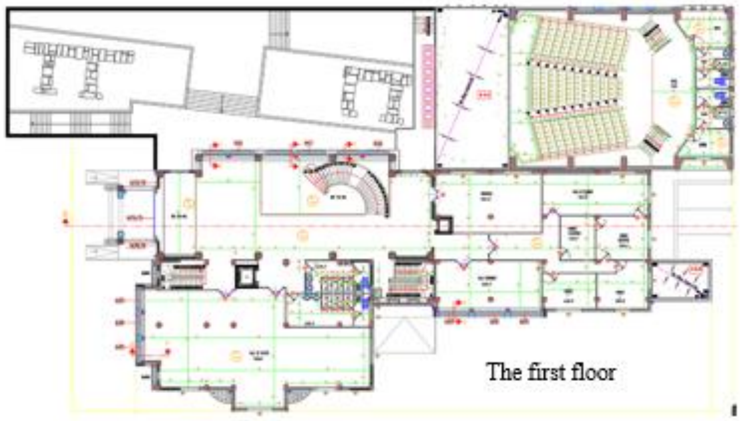
The first floor

The second floor

Public library of Constantine

The underground

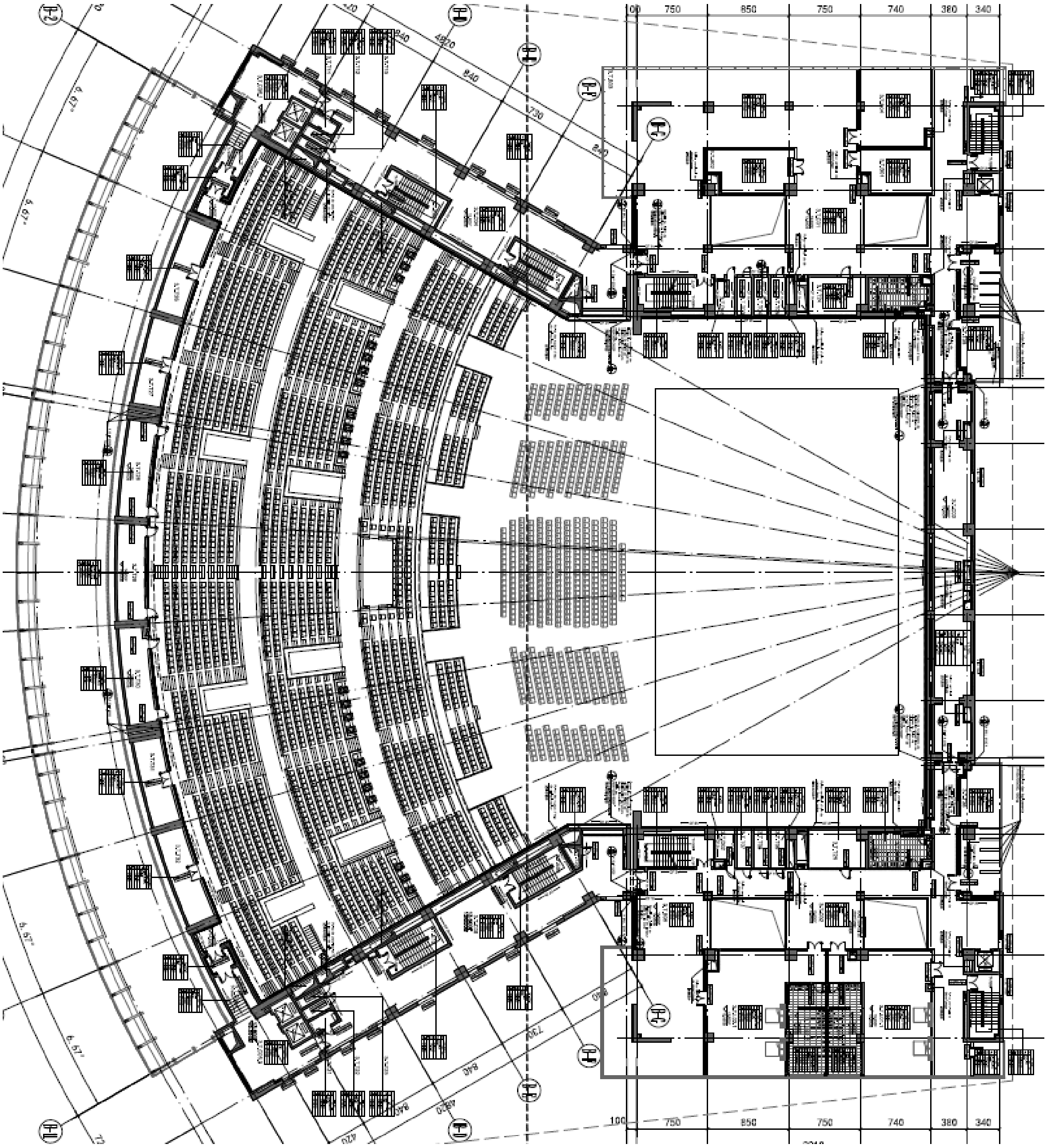
The ground floor



The first floor

The second floor

Performance Hall “AHMED BEY, Zenith Constantine”



Appendix 2: Questionnaires used in the survey in the case of the Palace of Culture "Al Kalifa"

Enquête sur le confort thermique dans le bâtiment

- **Information générale :**

Age : -25 ☐ 25-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ +60 ☐

Sexe : Homme ☐ Femme ☐

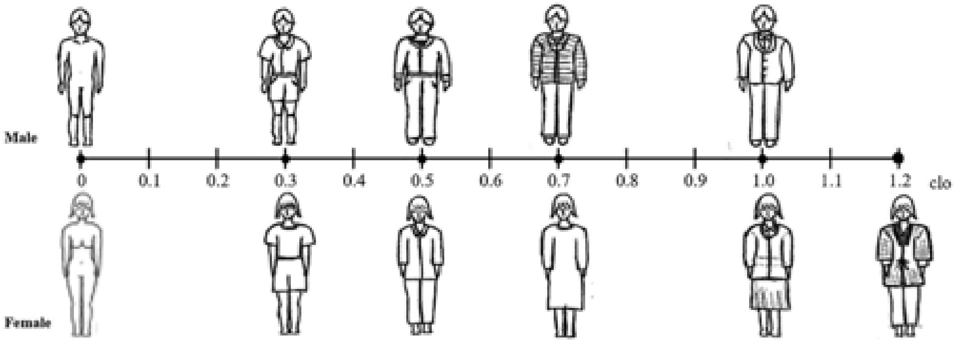
Etes-vous : Personnel ☐ Vendeur ☐ visiteur ☐

Votre localisation : Hall Sud-Est ☐ Hall Est ☐ Hall Nord-Est ☐

Votre position dans la salle :

A l'entrée ☐ Au centre ☐ Au fond ☐

- **Information sur le niveau habillement et le niveau d'activité :**
  - Pouvez-vous indiquer le niveau d'habillement : (marquer votre réponse sur l'axe)



  - Voulez-vous indiquez votre niveau d'activité

Coucher, inactif	
Assis, inactif	
Activité légère, assis	
Debout détendu	
Activité légère, debout	
Activité moyenne, debout	
Activité soutenue (travail lourd : danse)	

- **Confort thermique :**

  - Comment vous sentez vous ?

Extrêmement chaud	Très chaud	Chaud	Légèrement chaud	Neutre	Légèrement froid	Froid	Très froid	Extrêmement froid

  - Comment trouver-vous cela ?

Très Confortable	Confortable	Peu confortable	Peu inconfortable	Inconfortable	Très inconfortable

  - Pouvez-vous indiquer comment vous préfériez être.

Beaucoup plus chaud	Plus Chaud	Un peu chaud	Sans changement	Un peu plus froid	Plus froid	Beaucoup plus froid

  - Comment juger vous cet environnement ?

Tout à fait acceptable	Tout juste acceptable	Neutre	Tout juste inacceptable	Tout à fait inacceptable

  - Comment jugez-vous le niveau de l'humidité

Humide ☐ Naturel ☐ Sec ☐

  - Utilisez-vous un système d'appoint ?

Oui ☐ Non ☐

- Lequel ? :

  - Etes-vous généralement satisfait de l'environnement thermique ?

Oui ☐ Non ☐

Commentaires :

Appendix 3 Questionnaires used in the survey in the case of the public library

Enquête sur le confort thermique dans le bâtiment

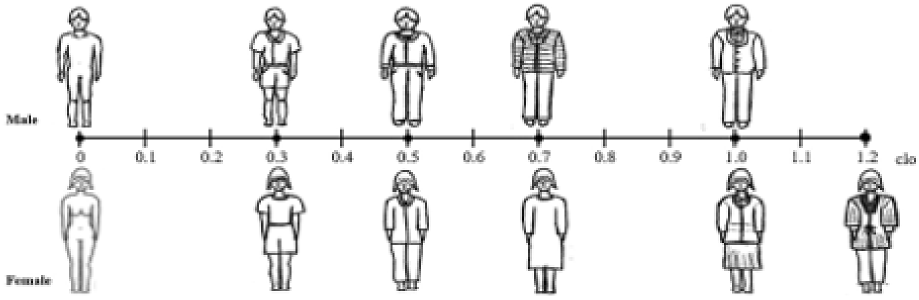
- **Information générale :**

Age : -25 ☐ 25-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ +60 ☐

Sexe : Homme ☐ Femme ☐

Votre localisation : S. de lecture 2e ☐ S. de lecture 1e ☐ S. des chercheurs ☐

- **Information sur le niveau habillement et le niveau d'activité :**
  - Pouvez-vous indiquer le niveau d'habillement : (marquer votre réponse sur l'axe)



  - Voulez-vous indiquez votre niveau d'activité

Coucher, inactif	
Assis, inactif	
Activité légère, assis	
Debout détendu	
Activité légère, debout	
Activité moyenne, debout	
Activité soutenue (travail lourd : danse)	

- **Confort thermique :**

1- En hiver :

- Comment vous sentez vous ?

Extrêmement chaud	Très chaud	Chaud	Légèrement chaud	Neutre	Légèrement froid	Froid	Très froid	Extrêmement froid

- Comment trouver-vous cela ?

Très Confortable	Confortable	Peu confortable	Peu inconfortable	Inconfortable	Très inconfortable

- Pouvez-vous indiquer comment vous préfériez être.

Beaucoup plus chaud	Plus Chaud	Un peu chaud	Sans changement	Un peu plus froid	Plus froid	Beaucoup plus froid

- Comment juger vous cet environnement ?

Tout à fait acceptable	Tout juste acceptable	Neutre	Tout juste inacceptable	Tout à fait inacceptable

- Comment jugez-vous le niveau de l'humidité

Humide ☐ Naturel ☐ Sec ☐

- Etes-vous généralement satisfait de l'environnement thermique en hiver ?

Oui ☐ Non ☐

Commentaires :

2- En été

- Comment vous sentez vous ?

Extrêmement chaud	Très chaud	Chaud	Légèrement chaud	Neutre	Légèrement froid	Froid	Très froid	Extrêmement froid

- Comment trouver-vous cela ?

Très Confortable	Confortable	Peu confortable	Peu inconfortable	Inconfortable	Très inconfortable

- Pouvez-vous indiquer comment vous préfériez être.

Beaucoup plus chaud	Plus Chaud	Un peu chaud	Sans changement	Un peu plus froid	Plus froid	Beaucoup plus froid

- Comment juger vous cet environnement ?

Tout à fait acceptable	Tout juste acceptable	Neutre	Tout juste inacceptable	Tout à fait inacceptable

- Comment jugez-vous le niveau de l'humidité

Humide ☐ Naturel ☐ Sec ☐

- Etes-vous généralement satisfait de l'environnement thermique en été ?

Oui ☐ Non ☐

Commentaires :

Appendix 4: Questionnaires used in the survey in the case of the performance hall "Zenith Constantine"

Enquête sur le confort thermique dans un bâtiment public

- **Information générale :**

Age : -25 ☐ 25-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ +60 ☐

Sexe : Homme ☐ Femme ☐

Etes-vous : Personnel ☐ Spectateur ☐

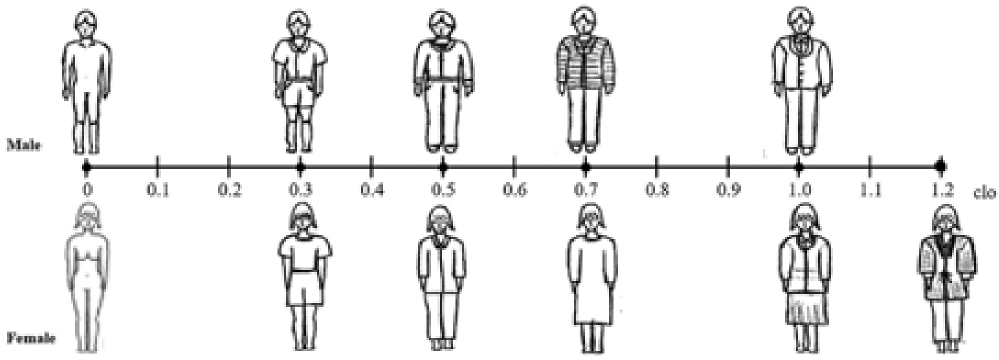
Votre localisation : Salle de spectacle ☐ Couloir D'accueil vitré ☐

Votre position dans la salle :

Niveau 0 ☐ Niveau 1 ☐ Niveau 2 ☐ Place VIP ☐ Coulisses ☐

- **Information sur le niveau habillement et le niveau d'activité :**

- Pouvez-vous indiquer le niveau d'habillement : (marquer votre réponse sur l'axe)



- Voulez-vous indiquez votre niveau d'activité

Couché, inactif	
Assis, inactif	
Activité légère, assis	
Debout détendu	
Activité légère, debout	
Activité moyenne, debout	
Activité soutenue (travail lourd : danse)	

- **Confort thermique :**

  - Comment vous sentez vous ?

Extrêmement chaud	Très chaud	Chaud	Légèrement chaud	Neutre	Légèrement froid	Froid	Très froid	Extrêmement froid

  - Comment trouver-vous cela ?

Très Confortable	Confortable	Peu confortable	Peu inconfortable	Inconfortable	Très inconfortable

  - Pouvez-vous indiquer comment vous préfériez être.

Beaucoup plus chaud	Plus Chaud	Un peu chaud	Sans changement	Un peu plus froid	Plus froid	Beaucoup plus froid

  - Comment juger vous cet environnement ?

Tout à fait acceptable	Tout juste acceptable	Neutre	Tout juste inacceptable	Tout à fait inacceptable

  - Comment vous percevez la température ?

Très chaude	Chaude	Un peu chaude	Neutre	Un peu froide	Froide	Très froide

  - Pouvez-vous indiquer comment vous souhaitiez qu'elle soit ?

Plus chaude ☐ Sans changement ☐ Plus fraiche ☐

  - Comment jugez-vous le niveau de l'humidité

Humide ☐ Naturel ☐ Sec ☐

  - Etes-vous généralement satisfait de l'environnement thermique ?

Oui ☐ Non ☐

Commentaires :