T.C.
İSTANBUL GEDİK ÜNİVERSİTESİ
INSTITUTE OF GRADUATE STUDIES

TOPIC OF THESIS: ASSESSMENT OF CONSTRUCTIONS STRUCTURES PROBLEMS IN HIGH TEMPERATURE IN NIGER

MASTER’S THESIS

Hamissou Oumarou YASSER

Civil Engineering Department

Civil Engineering Master in English Program

JUNE 2025
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Thesis Advisor: Assoc. Prof. Dr. Redvan GHASEMLOUNIA

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İSTANBUL GEDİK ÜNİVERSİTESİ
Lisansüstü Eğitim Enstitüsü Müdürlüğü

Jüri Tez Onay Formu

26.06.2025

LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜ

Bu çalışma 26.06.2025 tarihinde aşağıdaki jüri tarafından İnşaat Mühendisliği Anabilim Dalı, İnşaat Mühendisliği (Tezli Yüksek Lisans) Programı Yüksek Lisans Tezi olarak kabul edilmiştir.

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DECLARATION

I, Hamissou Oumarou YASSER, declare that this thesis titled “Assessment of Construction Structure Problems in High Temperature in Niger” is original work I did for the award of the master’s degree in Civil Engineering. I also declare that this thesis or any part of it has not been submitted and presented for any other degree or research paper in any other university or institution. (30/07/2025)

Hamissou Oumarou YASSER

DEDICATION

To my beloved mother and father, my brother and sisters, and all my friends You have always respected what I wanted to do and have given me full support and encouragement throughout my life.

FOREWORD

The construction industry in Niger faces unique and challenging conditions, particularly due to the extreme high temperatures that characterize much of the region. These environmental factors pose significant risks to the integrity and longevity of construction structures, necessitating a thorough understanding and assessment of the problems that arise under such conditions.

This report, "Assessment of Construction Structure Problems in High Temperature in Niger," seeks to address these critical issues by exploring the various ways in which high temperatures impact construction materials and techniques. It examines the physical and chemical changes that occur in building materials under prolonged exposure to heat, the structural deformations that may result, and the overall effect on the safety and durability of buildings.

The findings presented in this assessment are the result of comprehensive research, including field studies, laboratory experiments, and expert consultations. Our aim is to provide valuable insights and practical recommendations for engineers, architects, builders, and policymakers involved in the construction industry in Niger and other regions with similar climatic conditions.

By identifying and understanding the specific challenges posed by high temperatures, this report aims to contribute to the development of more resilient construction practices and materials. Ultimately, our goal is to enhance the quality and safety of construction projects, ensuring that structures can withstand the harsh environmental conditions of Niger and continue to serve their intended purposes for many years to come.

We extend our gratitude to all the researchers, field workers, and industry professionals who have contributed their expertise and efforts to this report. Their dedication and commitment have been instrumental in producing this comprehensive assessment.

We hope that this report will serve as a valuable resource for anyone involved in construction in high-temperature regions, and that it will inspire further research and innovation in the field.

June 2025 Hamissou Oumarou YASSER

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ABBREVIATIONS

FEA : Finite Element Analysis
RC : Reinforced concrete
DAF : The Dynamic Amplification Factor

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ASSESSMENT OF CONSTRUCTION STRUCTURES PROBLEMS IN HIGH TEMPERATURE IN NIGER

ABSTRACT

In high temperaturre, concrete begins to crack due to thermal expansion, which varies based on the type and quantity of sand, the type of gravel, and the proportions of cement and water in the mix. Additionally, the age of the concrete after the fire can influence its expansion. Within the first half hour, surface concrete tends to fall off, and thin surface layers fissure, especially under high temperatures. This phenomenon, known as fission precipitation, occurs when the concrete contains moisture. Another type of damage, called peeling, involves the gradual separation of surface layers, particularly in columns and bridges, where parallel cracks may cause these layers to detach.

After a fire, a condition assessment of the affected concrete structure is conducted to determine whether it needs repair or demolition. This assessment includes mapping visual damage and using measurement methods to detect the extent of the damage, which is crucial for safety and economic reasons. The assessment report has two parts: a literature review of common test methods and an experimental section comparing traditional methods (such as rebound hammer tests, ultrasound measurements, and microscopy) with a new methodology involving optical deformation measurement under pressure testing on drilled cylinders. This new method allows for continuous evaluation of damage across the fire-affected concrete cross-section.

Based on the study, two investigation levels are recommended. If the first level does not provide sufficient information, more complex methods are suggested. Visual examinations of the fire site, including the affected structure and other objects, as well as the fire's intensity, duration, and spread, are estimated. Damage such as splitting, deformations, and delaminations are documented. Delaminations and weak zones can be identified using a hammer and chisel. For complex scenarios, a classification system and tools like the rebound hammer and ultrasound measurements help quantify the damage but do not indicate its depth. When necessary, cores are drilled and evaluated using laboratory methods to determine the damage depth accurately.

Ultrasound measurements across different core depths provide a direct understanding of the damage's extent. In the laboratory, cracks and color changes are examined under a microscope to infer the maximum temperature the reinforcement experienced during the fire. Cracking patterns reveal information about the structure's durability, as high cracking intensity implies higher permeability and increased risk of reinforcement corrosion. To measure the fire's impact on the concrete's mechanical properties, cores are subjected to pressure tests while deformation is measured using a non-contact system, offering a comprehensive view of damage across the cross-section and leading to a more reliable assessment.

Keywords: *Potentail Air Temperature, Wind Speed, Relative humidity, Thermal resistance, Trees.*

NİJER'DE YÜKSEK SICAKLIKTA İNŞAAT YAPILARINDAKİ SORUNLARIN DEĞERLENDİRİLMESİ

ÖZET

Yüksek sıcaklıklarda beton, kumun türüne ve miktarına, çakıl türüne ve karışımdaki çimento ve su oranlarına bağlı olarak değişen termal genleşme nedeniyle çatlamaya başlar. Ayrıca, yangından sonra betonun yaşı genleşmesini etkileyebilir. İlk yarım saat içinde, yüzey betonu düşme eğilimindedir ve ince yüzey katmanları, özellikle yüksek sıcaklıklarda çatlar. Fisyon çökelmesi olarak bilinen bu fenomen, beton nem içerdiğinde meydana gelir. Soyulma adı verilen başka bir hasar türü, özellikle paralel çatlakların bu katmanların ayrılmasına neden olabileceği kolonlarda ve köprülerde yüzey katmanlarının kademeli olarak ayrılmasını içerir.

Yangından sonra, onarım mı yoksa yıkım mı gerektiğini belirlemek için etkilenen beton yapının bir durum değerlendirmesi yapılır. Bu değerlendirme, görsel hasarın haritalanmasını ve güvenlik ve ekonomik nedenlerden dolayı çok önemli olan hasarın kapsamını tespit etmek için ölçüm yöntemlerinin kullanılmasını içerir. Değerlendirme raporunun iki bölümü vardır: yaygın test yöntemlerinin literatür incelemesi ve geleneksel yöntemleri (geri tepme çekici testleri, ultrason ölçümleri ve mikroskopi gibi) delinmiş silindirlerde basınç testi altında optik deformasyon ölçümü içeren yeni bir metodolojiyle karşılaştıran deneysel bir bölüm. Bu yeni yöntem, yangından etkilenen beton kesitindeki hasarın sürekli değerlendirilmesine olanak tanır.

Çalışmaya dayanarak, iki araştırma seviyesi önerilir. İlk seviye yeterli bilgi sağlamazsa, daha karmaşık yöntemler önerilir. Etkilenen yapı ve diğer nesneler ile yangının yoğunluğu, süresi ve yayılımı dahil olmak üzere yangın yerinin görsel incelemeleri tahmin edilir. Bölünme, deformasyon ve delaminasyon gibi hasarlar belgelenir. Delaminasyonlar ve zayıf bölgeler bir çekiç ve keski kullanılarak tanımlanabilir. Karmaşık senaryolar için, bir sınıflandırma sistemi ve geri tepme çekici ve ultrason ölçümleri gibi araçlar hasarı ölçmeye yardımcı olur ancak derinliğini göstermez. Gerektiğinde, hasar derinliğini doğru bir şekilde belirlemek için karotlar delinir ve laboratuvar yöntemleri kullanılarak değerlendirilir.

Farklı karot derinliklerindeki ultrason ölçümleri, hasarın kapsamının doğrudan anlaşılmasını sağlar. Laboratuvarda, çatlaklar ve renk değişimleri, yangın sırasında donatının deneyimlediği maksimum sıcaklığı çıkarmak için mikroskop altında incelenir. Çatlama desenleri, yapının dayanıklılığı hakkında bilgi verir, çünkü yüksek çatlama yoğunluğu daha yüksek geçirgenlik ve donatı korozyonu riskinin artması anlamına gelir. Yangının betonun mekanik özellikleri üzerindeki etkisini ölçmek için, çekirdekler basınç testlerine tabi tutulurken deformasyon temassız bir sistem kullanılarak ölçülür, bu da kesit boyunca hasarın kapsamlı bir görünümünü sunar ve daha güvenilir bir değerlendirmeye yol açar.

Anahtar Kelimeler: *Potansiyel Hava Sıcaklığı, Rüzgâr Hızı, Bağıl nem, Isıl direnç, Ağaçlar*

1. INTRODUCTION

1.1 Background

The construction industry faces numerous challenges, with high temperatures posing significant risks to the integrity and durability of structures. As global temperatures rise due to climate change, understanding the impact of high temperatures on construction materials and structural performance becomes increasingly critical. High temperatures can affect the physical and chemical properties of construction materials, leading to a range of structural problems that can compromise safety and functionality.

Niger, characterized by its hot desert climate, experiences extreme temperatures that often exceed 45°C. This exacerbates the challenges associated with high-temperature construction, making it an ideal case study for understanding these issues. In regions like Niger, where resources and economic constraints limit the implementation of advanced construction technologies, addressing the effects of high temperatures on construction structures is vital for ensuring sustainable and resilient infrastructure.

1.2 Problem Statement

One of the most destructive disasters that can impact humanity is high temperature, and its uncontrolled in buildings can lead to extensive material losses and irreparable social harm. This is mainly because high temperatures can cause a structure to lose its load-bearing capacity within minutes, leading to rapid and catastrophic failure**.** In contrast, under normal conditions, these structures can last for decades. Effective firefighting and evacuation efforts will be insufficient if the fire resistance of the main load-bearing structures is not maintained for the required duration. Therefore, evaluating the fire resistance of building structures is an essential aspect of the design process. This becomes increasingly important with the rise in high-rise buildings, the growth of multifunctional facilities, and the heightened fire risks associated with potential terrorist attacks.

This article explores existing methods for enhancing the fire resistance of reinforced concrete structures and suggests directions for future development. The primary fire resistance criteria for building structures include:

- Loss of bearing capacity (R): collapse or unacceptable deformations of the structure.
- Loss of integrity (E): cracks or holes allowing flames or combustion products to penetrate the unheated surface.
- Loss of thermal insulation (I): the unheated surface reaching critical temperatures.

Empirical methods provide direct assessments but require significant resources, time, and effort. Additionally, physical experiments may not allow for easy modification of various parameters, loads, and other critical factors. Therefore, computational methods are generally preferred. These methods involve:

- Static analysis: assessing the bearing capacity of the structure, considering changes in the properties of concrete and reinforcement due to heating.

Addressing the issue of variable thermal conductivity involves determining the temperature at any point within the concrete element over time.

Maintenance is essential, and reinforcement is often necessary. In the past, not much attention was given to the durability of concrete. Concrete structures are susceptible to damage from frequent earthquakes or fires. Once a structure is damaged, its safety and durability are compromised. There is currently limited information on how structures are affected after repairing fire damage or strengthening in high-temperature environments or following earthquakes, underscoring the need for further research.

Construction structures in high-temperature environments face unique challenges, including thermal cracking, material degradation, and foundation instability. These issues not only increase maintenance costs but also pose serious safety risks. Despite growing recognition of these challenges, there is a lack of comprehensive studies addressing the specific problems faced by construction structures in extremely high-temperature environments, such as those in Niger.

The aiming of the study is to fill this gap by assessing the construction structure problems in high-temperature conditions. It seeks to identify the key issues, analyze their causes, and evaluate existing mitigation strategies to provide practical recommendations for improving construction practices in such environments.

1.3 Objectives of the Thesis

The main goals of this thesis are:

- To identify the common structural problems faced by construction structures in high-temperature environments.
- To analyze the impact of high temperatures on different construction materials used in Niger.
- To evaluate the effect of Using Trees to Reduce Temperature in Construction Areas.
- To make a simulation of an area using trees with the software Envi-met to observe the temperature, humidity and the velocity conditions.
- To make a simulation of an area using material construction with the software Envi-met to observe the temperature, humidity.

1.4 Research Questions

This study aims to address the following research questions:

- What are the most common structural problems encountered in high-temperature environments?
- How does the high temperature affect the physical and chemical properties of construction materials commonly used in Niger?
- What mitigation strategies are currently used to address high-temperature-induced structural problems, and how effective are they?
- What recommendations can be made to improve the design, material selection, and construction practices in high-temperature regions like Niger?

1.5 Structure of the Thesis

This thesis is organized into five chapters. The Chapter 1 entitled "Introduction," outlines the background, problem statement, objectives, research questions, and significance of the study. Chapter 2, "Literature Review," examines existing literature on the impact of high temperatures on construction structures, focusing on common problems, material properties, and mitigation strategies. Chapter 3, "Methodology," describes the research design, data collection methods, data analysis techniques, and ethical considerations. Chapter 4, "Results and Discussion," presents the findings from data collection and analysis, discussing their implications for construction practices in high-temperature environments. Finally, Chapter 5, "Conclusions and Recommendations," summarizes the key findings, provides recommendations for improving construction practices in high-temperature regions, and suggests areas for future research.

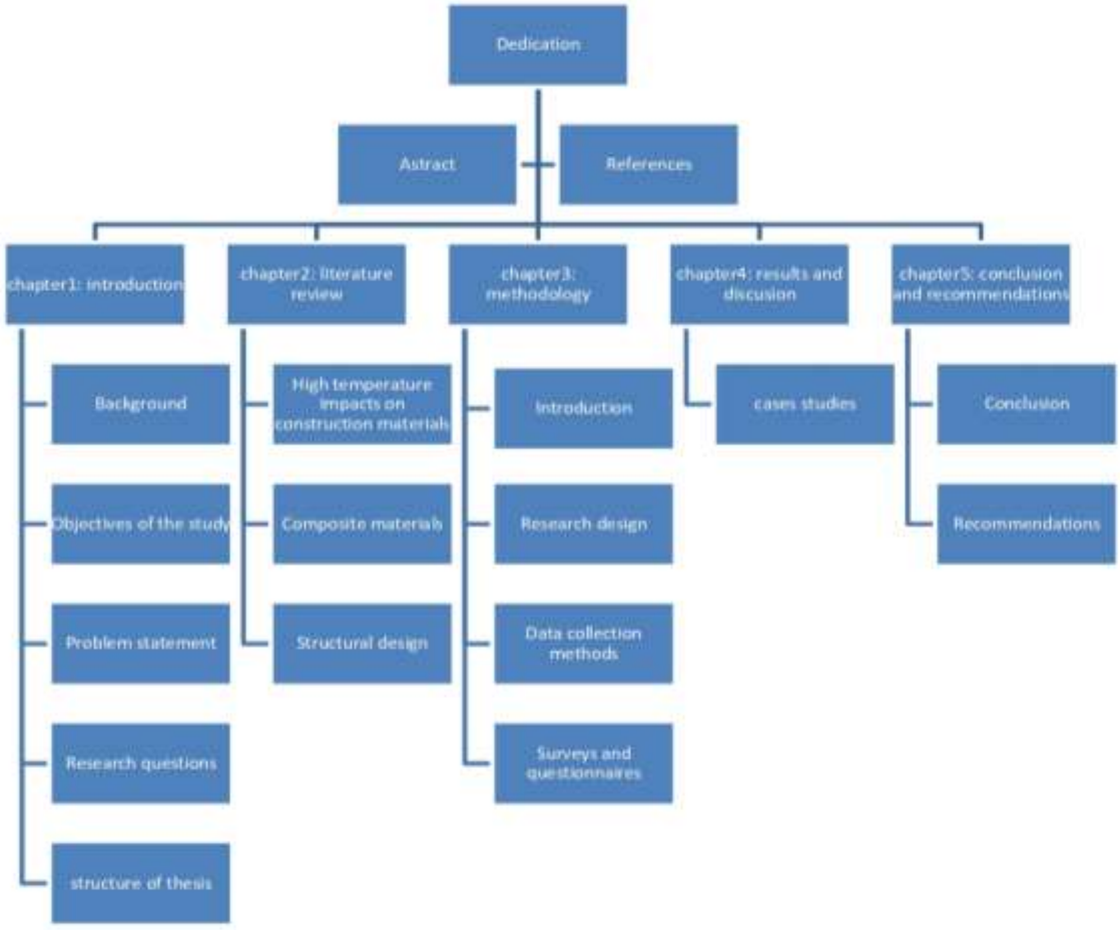


Figure 1. 1: Structure of Thesis

2. LITERATURE REVIEW

This chapter provides a comprehensive review of existing literature on the assessment of construction structure problems in high-temperature environments, with a specific focus on Niger. The literature review covers various aspects, including the impact of high temperatures on construction materials, common structural issues in high-temperature regions, mitigation strategies, and the specific challenges faced in Niger.

2.1 High-Temperature Impacts on Construction Materials

2.1.1 Concrete

Previous studies have provided essential insights into the fire properties of construction materials, the ability to assess structural behavior during a fire, and the selection of effective fire protection methods. The calculations to assess the strength and stability of buildings under fire conditions is included. The construction industry uses materials with diverse origins and properties, each varying in their capacity to maintain structural integrity under heat. elements such as concrete, brick, and reinforced concrete can withstand fire for tens of minutes to several hours before collapsing. Experience has shown that concrete offers good protection against high temperatures Because of its low thermal conductivity and high heat retention capacity.

This study aims to provide a current diagram of the behavior of concrete components under fire conditions and to address gaps in the standards. It also seeks to outline reliable verification procedures for assessing the fire resistance of structures based on current knowledge.

During a fire, concrete begins to crack as it expands, influenced by the type and quantity of sand, gravel, and the proportions of cement and water in the mix. The age of the concrete post-fire also affects this expansion. In the first half hour of a fire, surface concrete may spall, with thin surface layers peeling off due to high temperatures.

This phenomenon, known as spalling, is particularly prevalent in moisture-containing concrete. Another type of damage, called peeling, involves the gradual separation of surface layers, especially in columns and beams, where parallel cracks facilitate this separation. Due to concrete's low thermal diffusivity, the interior temperature of the concrete remains significantly lower than the surface temperature, confining cracks to the surface layers unless the fire persists for several hours, compromising the concrete's flexibility.

The modulus of elasticity of concrete decreases to 60% of its original value at temperatures up to 300°C and to 20% at higher temperatures. Similarly, the shear parameter of concrete declines, and the Poisson ratio, which measures the ratio between transverse and longitudinal strain under stress, decreases with rising temperatures. The differential thermal expansion between concrete and steel also causes surface cracks. The severity of heat's impact on concrete depends on factors such as maximum temperature, rate of temperature rise, duration of exposure, load-bearing status, aggregate quality, concrete grade, and the water-to-cement ratio.

Concrete can regain much of its strength if the temperature does not exceed 700°C during cooling, with steel regaining its lost resistance and cracks closing. However, marbling and dents remain. Standard tests have shown that reinforced concrete columns can achieve durability times surpassing international code requirements, as actual fire conditions are often less severe than those in standard tests. Concrete's widespread use in construction makes understanding its behavior under high temperatures critical, as research indicates significant impacts on its properties.

High temperatures can significantly affect concrete properties; for example, temperatures above 50°C may reduce its compressive strength through thermal cracking and diminished load-bearing capacity (Neville, 2011), while differential thermal expansion can induce internal stresses, leading to micro-cracks and potential structural failure (Mehta & Monteiro, 2014).

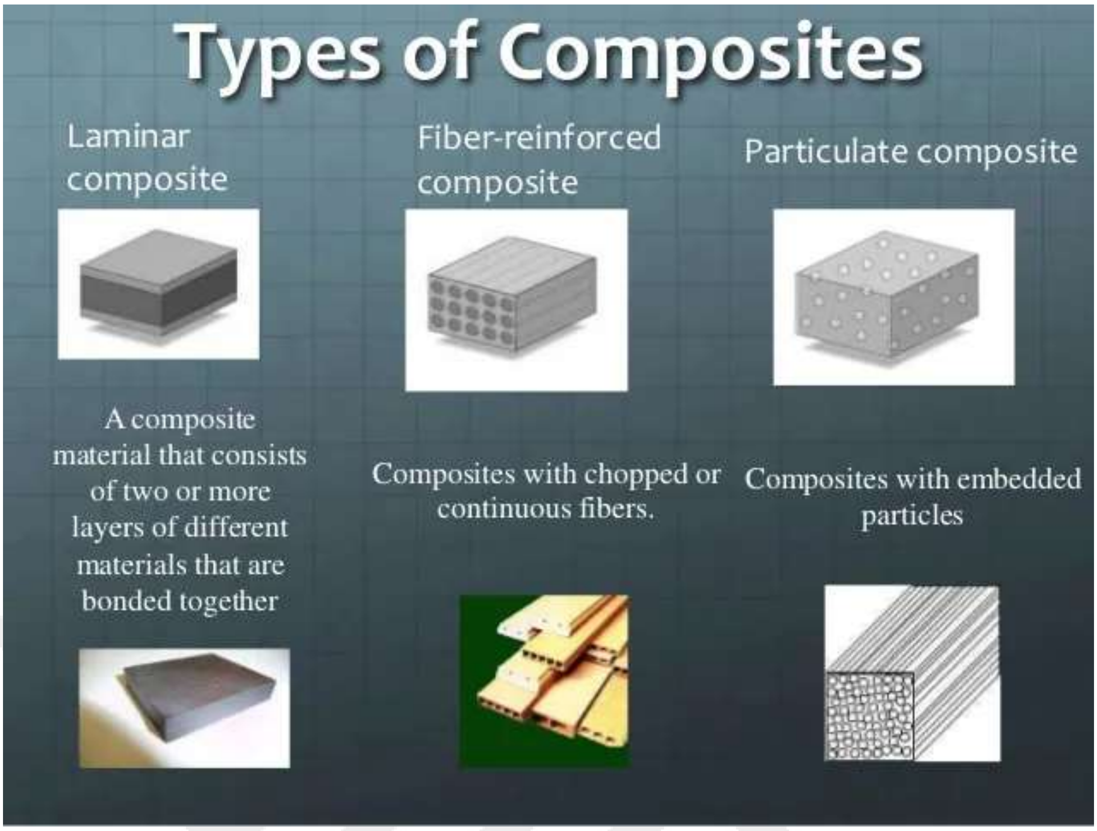
2.1.2 Steel

Steel structures in buildings initially provide some resistance to burning and contain the fire for a brief period. However, as the temperature rises beyond 500°C, the yield stress of the steel significantly diminishes, dropping to between 50% and 70% of its original value at temperatures below 550°C, and to just 20% to 30% of its original value at temperatures above 700°C. Additionally, the modulus of elasticity of reinforcing steel decreases to about 80% of its original value at 480°C, and deteriorates rapidly with sustained high temperatures. This deterioration can lead to severe damage, including dents and delamination in both concrete and steel elements..

Steel structures are also vulnerable to high temperatures, which can significantly affect their performance and safety. At elevated temperatures, steel experiences a loss of strength and stiffness, potentially compromising the structural integrity of the system (Kodur, 2005). Additionally, steel undergoes thermal expansion when exposed to heat, similar to concrete. This expansion can cause buckling and structural deformation, further endangering the stability of the structure (Kirby & Preston, 1988).

2.1.3 Composite materials

Composite materials, while engineered to endure diverse environmental conditions, encounter significant challenges in high-temperature environments. One primary issue is degradation, as elevated temperatures can hasten the breakdown of polymer matrices within the composites, leading to a reduction in their mechanical properties (Hollaway & Head, 2001). Another challenge is thermal cycling, where repeated exposure to heating and cooling cycles can induce delamination and other forms of structural damage. These factors collectively undermine the long-term performance and reliability of composite materials in extreme thermal conditions.



Types of Composites

Laminar composite

A composite material that consists of two or more layers of different materials that are bonded together

Fiber-reinforced composite

Composites with chopped or continuous fibers.

Particulate composite

Composites with embedded particles

Figure 2.1: Composite material

2.2 Common Structural Issues in High-Temperature Regions

Thermal cracking, material degradation, and foundation problems are significant challenges in high-temperature regions. Thermal cracking arises from the differential expansion and contraction of materials, leading to structural cracks that compromise integrity (Bai & Zhao, 2003). Additionally, high temperatures accelerate chemical reactions like steel oxidation and concrete hydration, causing material degradation that reduces structural lifespan and increases maintenance costs (Lee & Mindess, 2018). Furthermore, temperature fluctuations affect soil properties, destabilizing foundations, especially in regions with expansive soils such as Niger, where heaving and settlement issues are common (Nelson & Miller, 1992).

2.2.1 Structural design (Construction techniques)

Design modifications, such as providing adequate expansion joints and using shading techniques, can help reduce the impact of thermal stresses (ACI Committee 305, 2009).

Implementing construction techniques that account for high temperatures, such as curing concrete in cooler parts of the day and using reflective coatings, can improve the durability of structures.

Construction practices in Niger are shaped by a combination of traditional techniques, modernization efforts, economic constraints, and environmental considerations. As the country continues to urbanize and develop, there is a growing need to balance modern construction methods with traditional practices that are well-suited to the local climate and context. Collaboration between government agencies, international organizations, NGOs, and local communities is essential for addressing infrastructure challenges and promoting sustainable development in Niger, undergoing rapid urbanization, leading to increased demand for infrastructure such as buildings, roads, and bridges. Constructing these structures to withstand high temperatures is essential for the country's development and resilience against climate change impacts.

Adobe and Mud Brick Construction is a traditional building material such as adobe, mud bricks, and thatch roofs are commonly used due to their availability and thermal properties suitable for the climate and Flat Roofs is traditional dwellings often feature flat roofs, which help to deflect heat and collect rainwater during the brief rainy season.

In urban areas, modern construction techniques involving concrete, masonry, and steel are becoming more prevalent, especially for commercial and public buildings.

2.3 Challenges in Niger

2.3.1 Limited resources

The availability of high-quality construction materials and advanced construction technologies is limited in Niger, making it difficult to implement some of the mitigation strategies (USAID, 2019).

2.3.2 Economic constraints

High temperatures can accelerate the degradation of construction materials, leading to increased maintenance costs over the lifespan of structures. Studying how to mitigate these effects can help reduce long-term maintenance expenses and preserve infrastructure investments.

Niger is one of the poorest countries in the world, with limited financial resources for large-scale infrastructure development.

The construction sector relies heavily on foreign aid and investment for major projects, including road construction, water infrastructure, and public buildings.

Economic constraints limit the ability to invest in advanced materials and construction techniques, leading to reliance on traditional methods that may not be well-suited for high-temperature conditions (IMF, 2021).

3. METHODOLOGY

3.1 Introduction

This chapter outlines the methodology used to assess the problems faced by construction structures in high-temperature environments. It covers the research design, data collection methods and data analysis techniques.

3.2 Study Area

Niamey experiences a hot and arid climate, characterized by high temperatures, low humidity, and minimal rainfall, especially in the northern regions.

There are significant seasonal variations, with hot, dry seasons lasting from October to May, and a short rainy season from June to September, primarily affecting the southern regions**.**

The study utilizes a mixed-methods approach, integrating both quantitative and qualitative research techniques. This methodology provides a thorough and nuanced understanding of the issues faced by construction structures under high-temperature conditions.

Figure 3.1: Nniamey Map

3.3 Data Collection Methods

3.3.1 Review

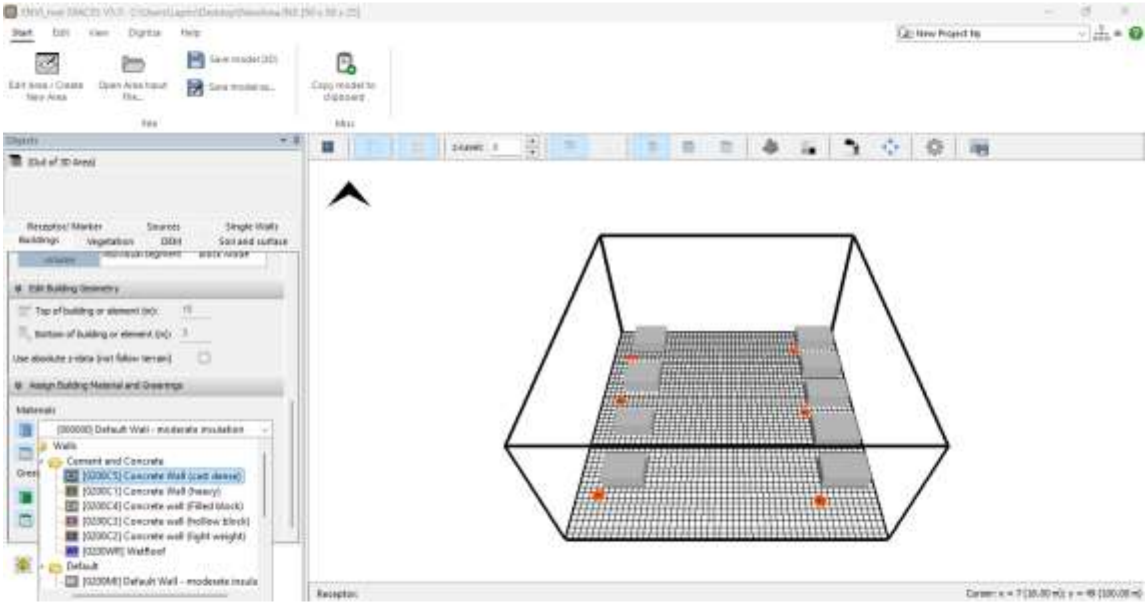
A thorough literature review was conducted to gather existing knowledge on the impact of high temperatures on construction materials and structures. Academic journals, industry reports, and previous research studies were reviewed to identify common problems and potential solutions.

3.3.2 Simulation with envi met using construction material

Scenario 1: concrete wall (cast dense)

We decide to use a cast dense concrete wall for Scenario 1, ensuring enhanced durability and structural integrity.

Figure 3.2: Concrete Wall (Cast Dense)



Edit Building Geometry

Top of building or element (m): 15

Bottom of building or element (m): 3

Use absolute z-data (not follow terrain) ☐

Assign Building Material and Greenings

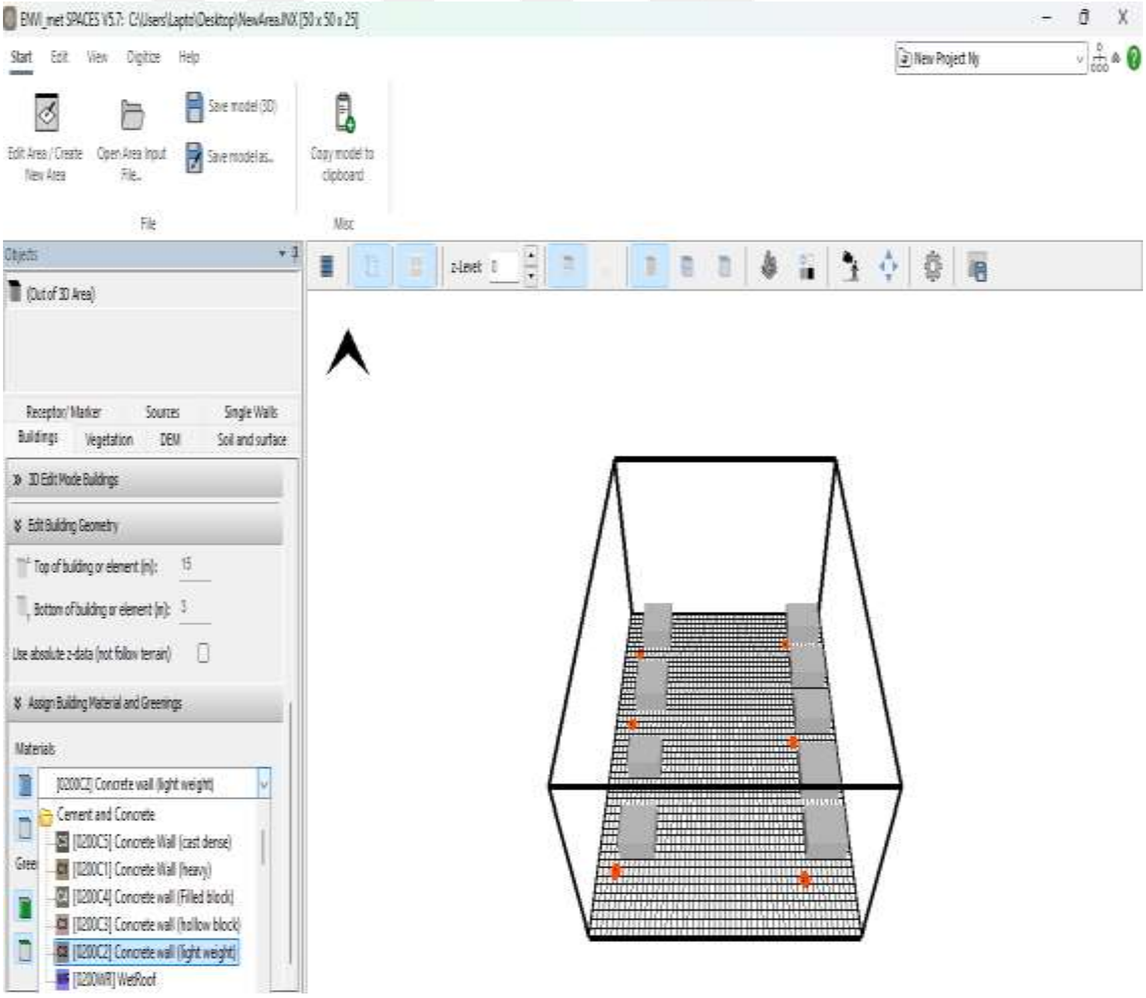
Materials: [000000] Default Wall - moderate insulation

Figure 3.3: Material Modeling By Envi Met

Scenario 2 : concrete wall(leigt weight)

In Scenario 2, a lightweight concrete wall is implemented to optimize structural efficiency while maintaining durability.

Figure 3.4: Concrete Wall (Leight Weight)



Top of building or element (m): 15

Bottom of building or element (m): 3

Use absolute z-data (not follow terrain) ☐

Materials: [0200C2] Concrete wall (light weight)

Figure 3.5: Material Modelling By Envi Met

3.3.3 Formula of analysis of construction structures

Thermal stresses can be calculated using this formula:

$$\sigma = E * \alpha * \Delta T \quad (3.1)$$

Equation 1 Thermal stresses

Thermal stress (σ) is the internal stress induced in a material when it undergoes a change in temperature. It is determined by the material's Young's modulus (E), which measures its stiffness or resistance to deformation, and the coefficient of thermal expansion (α), which describes how much the material expands or contracts with temperature changes. The thermal stress is directly proportional to the temperature change (ΔT). When a material is constrained and experiences a significant ΔT, the resulting thermal expansion or contraction can lead to internal stresses, which, if large enough, may cause deformation or failure of the material.

When a steel beam is exposed to a temperature rise, it undergoes thermal expansion, which is the increase in the length of the material due to the increase in temperature. The amount by which the length of the beam increases can be calculated using the formula for linear thermal expansion:

$$\Delta L = \alpha * \mathrm{L0} * \Delta \mathrm{T} \quad (3.2)$$

Equation 2: Thermal stress

3.3.4 Formulation of reducing temperature through construction materials

The thermal resistance (R) of a material layer can be calculated using the formula:

$$R = \frac{d}{\kappa} \quad (3.3)$$

Equation 3: thermal resistance

Thermal resistance, denoted as R, is a measure of a material's ability to resist the flow of heat and is expressed in square meters degree Celsius per watt (m²·°C/W). It depends on the thickness of the material layer, dd, measured in meters (m), and the material's thermal conductivity, κ, which is given in watts per meter degree Celsius (W/m·°C). The relationship between these quantities is that thermal resistance increases with the thickness of the layer, d, and decreases with higher thermal conductivity, κ, meaning materials with high thermal conductivity allow heat to pass through more easily.For multiple layers, the thermal resistances to get the total thermal resistance (R_{total}): R_{total}=R1+R2+R3+…

The temperature drop (ΔT) through the material can be found using the heat transfer equation:

$$\Delta T = Q \cdot Rtotal \; / \; A \tag{3.4}$$

Equation 4: Temperature

The heat transfer rate, denoted as Q and measured in watts (W), represents the amount of heat energy transferred per unit of time. The total thermal resistance, RtotalRtotal, is a measure of how resistant a material or system is to heat flow, with units of square meters times degrees Celsius per watt (m^2·°C/W). Heat transfer also depends on the surface area, AA, through which the heat is being transferred, measured in square meters (m^2). Together, these variables determine the efficiency and rate at which heat is conducted or resisted in a thermal system.

3.3.5 Formula of effect of using trees to reduce temperature in construction areas

The cooling effect due to evapotranspiration can be significant, especially in areas with substantial vegetation and water availability. To calculate the cooling effect due to evapotranspiration, we need to understand a few key concepts and gather relevant data. Here’s a step-by-step guide to performing such a calculation:

The cooling effect can be calculated using the formula:

$$Q = ET \times A \times \rho \times L \tag{3.5}$$

Equation 5 cooling effect

The total cooling effect (Q), measured in either megajoules (MJ) or calories, can be calculated using the relationship between evapotranspiration (ET), area (A), the density of water (ρ), and the latent heat of vaporization (L). Evapotranspiration (ET), expressed in millimeters per day, represents the rate at which water is transferred from the land to the atmosphere. The area (A) refers to the surface area in square meters (m^2) over which this process occurs. Water, having a density (ρ) of 1000 kg/m^3 at a temperature of 40°C, requires a significant amount of energy for phase change, characterized by the latent heat of vaporization (L).

Shading effect

$$SE = SR * TC * RSR \tag{3.6}$$

Equation 6: shading effect

Evapotranspiration Effect

$$EE = Total\ water * LHV \tag{3.7}$$

Equation 7:EE

3.3.6 Case study (Kalt casten street)

The street Kalt Casten is amongst the main street of Niamey. It is in the downtown of Niamey city, linking the plateau neighborhood and president avenue highway from the south and between, the Niamey Mall, and SoniBank from the north. Along the street there is many government building offices and stores.

- The Street was built with a length of 950 m and a width of 24 m. It contains pedestrian
- Paths with a width of 5.5 m on both sides. The street does not provide any thermal comfort
- Requirements for pedestrians, such as shading and vegetation.
- Which are shown in figures (6) and (7).

Figure 3.6: Kalt Casten Street (Google Maps)

Figure 3.7: Klat Casten Street (Pedestrian)

Case studies of existing construction projects in high-temperature regions were analyzed. This involved the examination of project documents, structural assessments, and failure reports. key cases included an in-depth Analysis of Construction Structures in High Temperatures in Niger, exploring how extreme heat impacts structural integrity. Research focused on Reducing Temperature through Construction Materials in Nigeremphasized innovative material choices to enhance thermal regulation. Additionally, the Effect of Using Trees to Reduce Temperature in Construction Areas in Niger was assessed using the advanced environmental modeling software Envi-met, highlighting the cooling benefits of integrating vegetation. Studies on Structural Dynamics provided insights into the behavior of structures under dynamic loads, while Fire Damage Assessment of Reinforced Concrete Structures examined the resilience and recovery strategies for fire-affected buildings.

3.3.7 Wind speed

Niamey is experiencing partly cloudy conditions with a temperature of 66°F (19°C). Winds are blowing from the northeast at speeds ranging from 6.7 to 11.2 mph (10.8 to 18 km/h), with gusts up to 15.6 mph (25 km/h).

Figure 3.8: wind speed

Source: (climate.com)

3.3.8 Temperatures

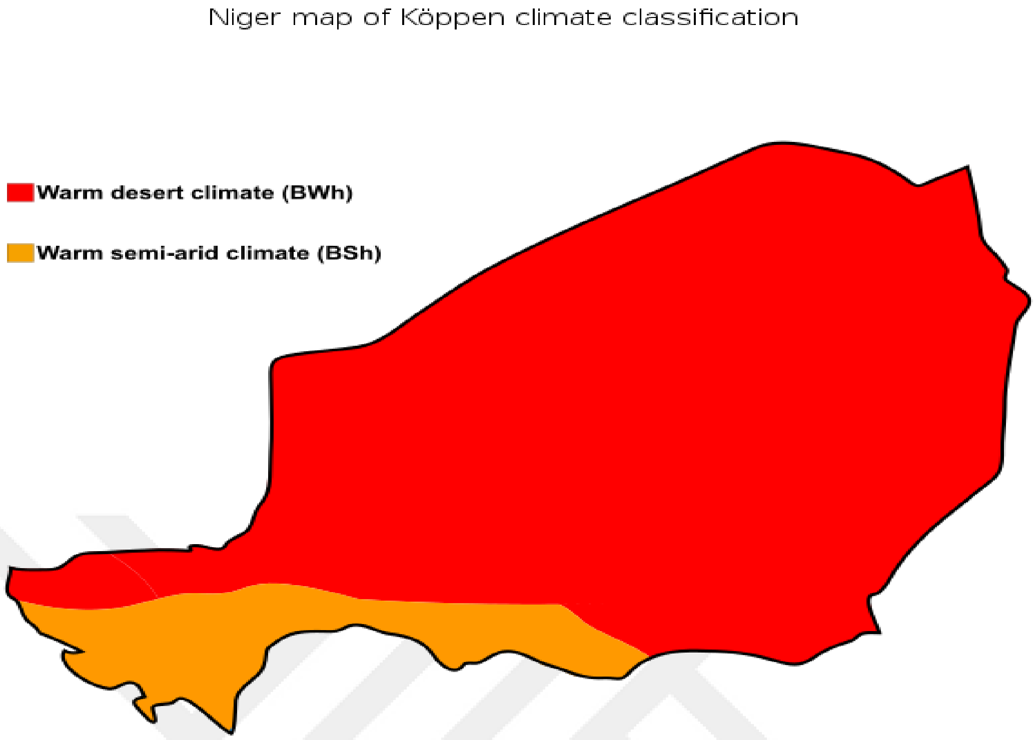


Figure 3.9: Niger map

Source: (source:google)

Niger, defined by its hot desert climate, faces unique challenges in construction.

In terms of temperature experiences, it is some of the highest one in the world, with temperature frequently exceeding 40°C during the hot season. Understanding how structures perform and degrade in such extreme conditions is crucial for ensuring their durability and safety.

Often exceeding 45°C, which exacerbates the problems associated with high-temperature environments (World Bank, 2020).

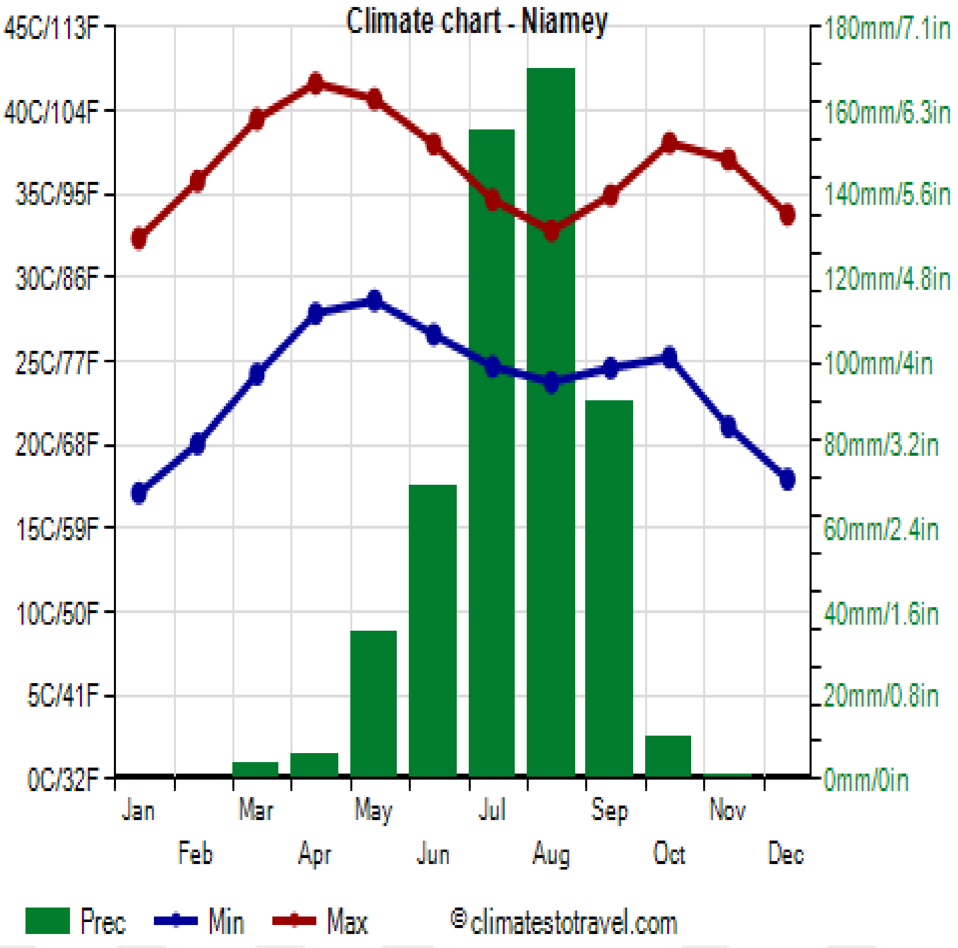


Figure 3.10: Temperature

Source: (climate.com)

3.3.9 Humidity

The average annual relative humidity is approximately 49,5 %, with notable monthly variations. March typically experiences the lowest humidity at around 19%, while August sees the highest, averaging 80%.

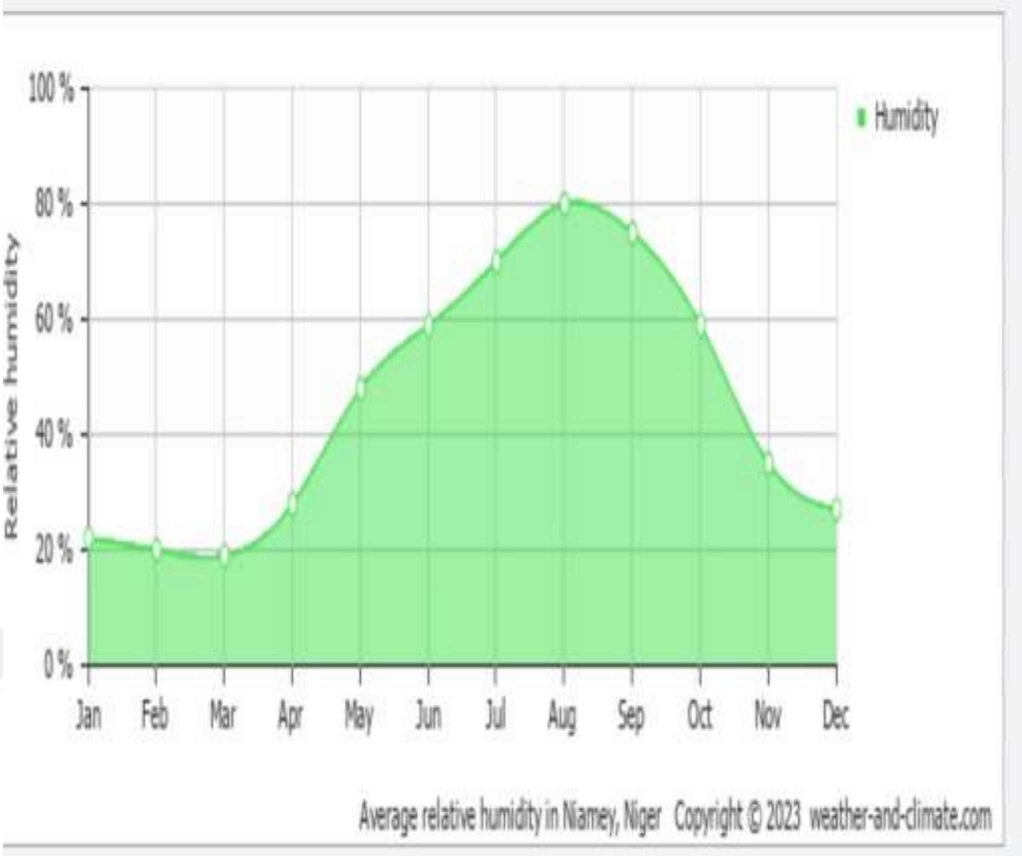


Figure 3.11: Average Humidity in Niamey

3.4 Surveys and Questionnaires

Surveys and questionnaires were distributed to engineers, architects, and construction managers working in high-temperature environments. The survey aimed to collect data on:

- Types of structural problems encountered.
- Frequency and severity of these problems
- Mitigation strategies currently in use.

3.5 Data Analysis

The case studies and statistical analyses provide valuable insights into the impact of high temperatures on construction structures and the effectiveness of various mitigation strategies. The use of Envi-met software has further validated the findings, demonstrating that thoughtful selection of materials and environmental planning can significantly improve structural resilience and comfort in hot climates like Niger.

3.5.1 Quantitative data analysis

Quantitative data from surveys and case studies were made using statistical methods. The following case studies have been exanimated: Analysis of Construction Structures in High Temperature in Niger, Reducing Temperature through Construction Materials in Niger, Effect of Using Trees to Reduce Temperature in Construction Areas in Niger and Damage assessment of reinforced concrete structures. studies were made to summarize the data, while software like Envi-met were used to determine the significance of the findings.

3.5.2 Qualitative data analysis

Qualitative data from interviews and open-ended survey responses were analyzed using thematic analysis. This involved collecting the data, identifying patterns and themes, and interpreting the findings to provide context and depth to the quantitative results.

Quantitative data collected from surveys and case studies were meticulously analyzed using advanced statistical methods. The case studies under examination include a comprehensive analysis of construction structures exposed to high temperatures in Niger, an investigation into the potential of construction materials to mitigate heat, an evaluation of the impact of incorporating trees to lower temperatures in construction areas, and a damage assessment of reinforced concrete structures. Each study aimed to provide a detailed summary of the data collected. To enhance the accuracy and relevance of the findings, specialized software such as Envi-met was utilized to simulate and assess the significance of the results. This multifaceted approach ensured a robust and nuanced understanding of the effects of temperature and material use in construction practices.

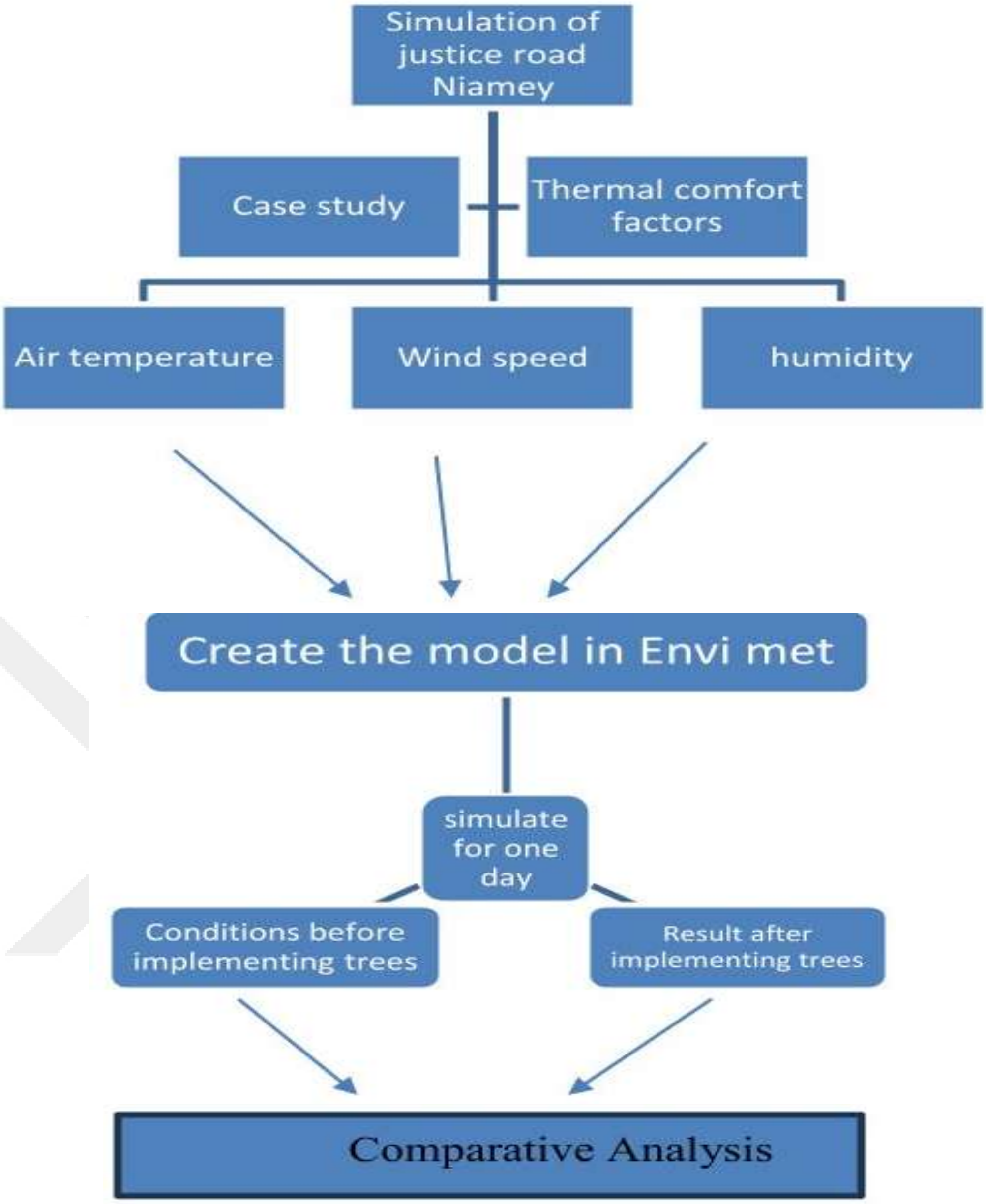


Figure 3.12: Methodology Flow Chart

4. RESULTS AND DISCUSSIONS

Niger is known for its extreme temperatures, particularly in the arid northern regions. The temperatures often exceeding (44 Degree Celsius) during the peak of summer. These conditions present unique challenges for construction and infrastructure development.

This extreme heat poses significant challenges for the inhabitants, affecting their health, productivity, and overall quality of life. Traditional construction materials and methods have proven insufficient in mitigating these temperatures. These cases studies explore how modern construction materials can be used to reduce indoor temperatures, enhancing living conditions and promoting sustainable development.

The primary aim is to analyze the impact of high temperatures on construction structures in Niger, examining both the challenges and the strategies employed to mitigate these effects.

4.1 Analysis of Construction Structures in High Temperature in Niger

Structural analysis methods used in building construction include various techniques designed to understand, predict, and optimize structural behavior under different loading conditions. These methods enable engineers to design buildings that meet safety standards, endure environmental challenges, and ensure long-term durability for occupants and communities. They are essential for guaranteeing the safety, stability, and efficiency of building construction projects.

The use of heat-resistant materials, such as specially formulated concrete has been crucial. Moreover, the incorporation of ventilation systems and reflective roofing has helped to mitigate the heat buildup within the market premises, ensuring a more comfortable environment for both vendors and customers. Engineers employed a reinforced concrete to enhance durability. Additionally, regular maintenance schedules were established to address any damage caused by the high temperatures, ensuring the road remains safe and functional year-round.

The Strategies for Mitigating High-Temperature Effects is to use Heat-Resistant Materials.

One effective strategy to combat the effects of high temperatures is the use of heat-resistant materials. Advanced polymers and composite materials are increasingly being utilized for their superior thermal stability. These materials can withstand high temperatures without significant degradation, ensuring the longevity and integrity of the structures.

Incorporating innovative design solutions, such as reflective surfaces and adequate ventilation, can significantly reduce heat absorption and buildup in structures. Reflective coatings on roofs and walls can deflect a substantial portion of solar radiation, thereby reducing the internal temperature. Similarly, designing buildings with natural ventilation systems can facilitate airflow, helping to cool the interior spaces.

Regular maintenance and monitoring are essential to ensure the durability of structures in high-temperature environments. Scheduled inspections can identify early signs of material degradation or structural weaknesses, allowing for timely repairs. Additionally, the use of modern monitoring technologies, such as thermal imaging, can help detect hotspots and areas of concern that may not be visible to the naked eye. Many materials lose significant strength at high temperatures.

When a steel beam length $L_o=10\,m$ is exposed to a temperature rise of $\Delta T=500^{\circ}c$.

The change in length of a beam, denoted as ΔL, represents how much the beam expands or contracts due to temperature changes. This change in length is determined by several factors. One key factor is the coefficient of linear thermal expansion, α, which varies depending on the material; for steel, it is approximately $12\times10^{-6}\ °C^{-1}$. Another important factor is the original length of the beam, L_0, which sets the starting point for any thermal expansion. Finally, the temperature change, ΔT, plays a critical role, as it dictates how much the material will expand or contract. The relationship between these variables is often used to predict structural changes in materials exposed to varying temperatures.

Table 4.1: Temperature

Lo	ΔT	α	$\boldsymbol{\Delta L}$
10m	500°C	12×10-^{6}°C^{-1}	**0.06m**

So, the steel beam would expand by 6 cm when exposed to a temperature rise of 500°C.

This thermal expansion occurs because the atoms in the steel vibrate more vigorously as the temperature increases, pushing each other apart and causing the material to expand. This is a fundamental property of most materials when subjected to heating.

In practical terms, if the beam is constrained (fixed at both ends), the expansion can lead to significant internal stresses, potentially causing deformation or even structural failure if the expansion isn't accommodated. If the beam is free to expand, it simply becomes longer by 6 cm.

4.1.1 Analysis of Damage of reinforced concrete structures due to the high temperature

Reinforced concrete (RC) buildings possess significant inherent fire resistance, meaning high temperatures do not necessarily lead to destruction. However, a thorough post-fire evaluation is essential due to the variable condition of the concrete. Concrete in buildings exposed to fire often exhibits non-uniform characteristics across its cross-section, with the surface layer typically suffering the most severe deterioration. Despite these challenges, RC structures typically maintain stability after a fire, albeit requiring repairs to address residual damage and deformations.

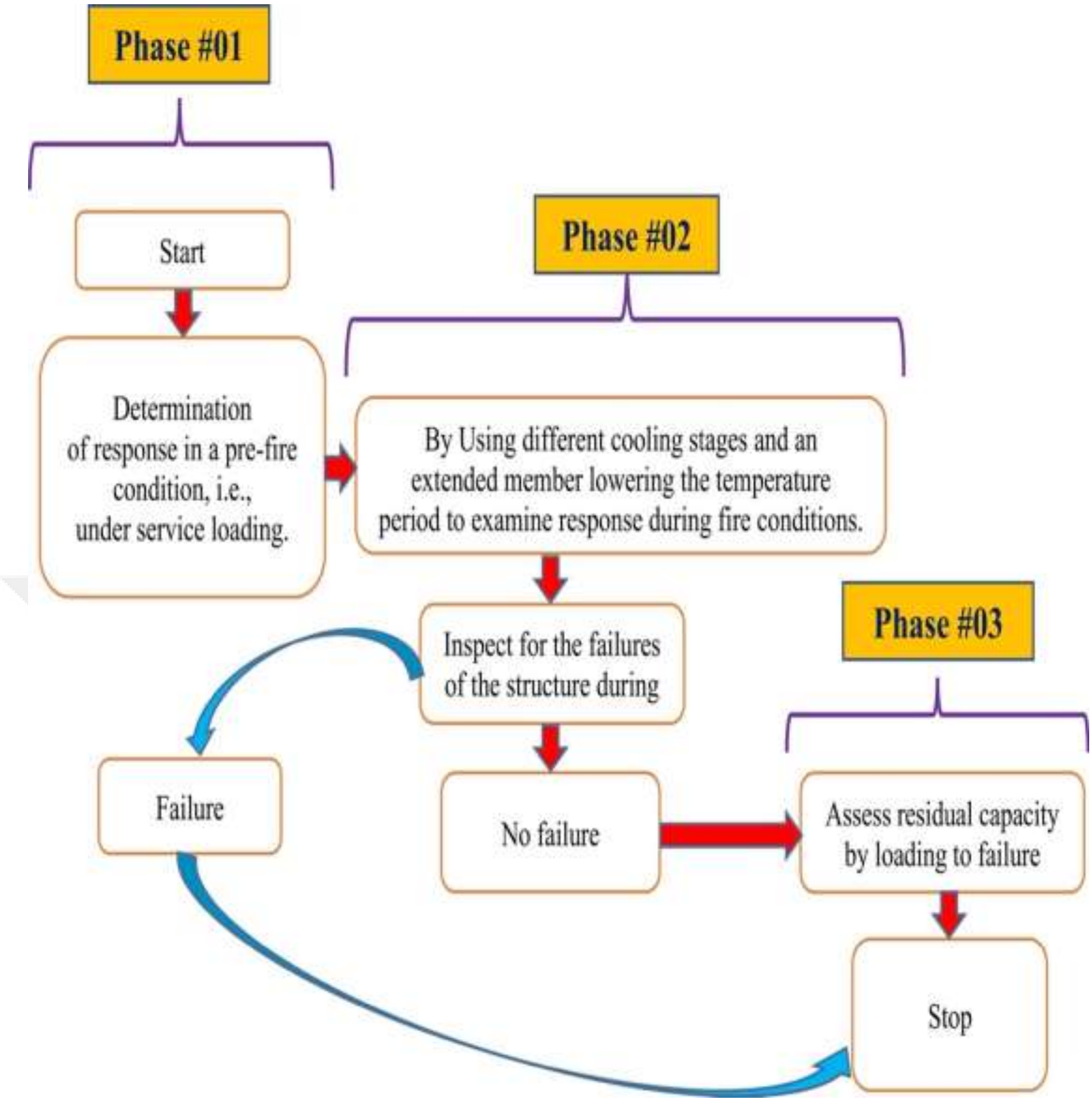


Figure 4.1: Assessment for Residual Capacity of RC Structural Elements

4.2 Reducing Temperature through Construction Materials in Niger

The primary objective of this case study is to identify and evaluate construction materials that can effectively reduce indoor temperatures in Niger. By focusing on materials with superior thermal insulation properties, this study aims to provide sustainable and affordable solutions for local communities.

The construction materials with proven thermal insulation properties and field surveys conducted to understand the current construction practices and the challenges faced by local communities.

Model houses with reflective roofing materials demonstrated a reduction in roof surface temperatures by up to 30%, leading to a noticeable decrease in indoor temperatures. These materials are particularly effective in regions with high solar radiation.

AAC blocks performed well in reducing indoor temperatures. Their high thermal resistance and low thermal conductivity make them an excellent choice for hot climates. Additionally, AAC is lightweight and easy to handle, making construction faster and less labor-intensive.

Green roofs showed the most significant reduction in roof surface temperatures, with some test sites recording reductions of up to 35%. However, the implementation of green roofs requires careful planning and maintenance, which may pose challenges in Niger's arid climate.

The integration of PCMs into wall panels demonstrated potential in stabilizing indoor temperatures. However, the high cost of PCMs and the need for advanced installation techniques may limit their widespread adoption in Niger.

To Identify the Properties of the Materials First, you need to know the thermal conductivity (κ) of the materials involved. Thermal conductivity is a material property that indicates how well a material conducts heat. It is typically measured in watts per meter per degree Celsius (W/m·°C).

Next, determine the thickness (d) of each material layer in the construction. Thickness is usually measured in meters (m).

4.2.1 Result of thermal resistance of each layer

Table 4.2: Thermal

Brick layer		
d_{brick}	κ_{brick}	**R**$\mathbf{R_{brick}}$
0.72	**0.1**	**0.132 m^2 °C/W**

Table 4.3: Thermal Resistance

Insulation layer		
$d_{insulation}$	$\kappa_{insulation}$	$\mathbf{R_{insulation}}$
0.050	0.4	**1.25 m2·°C/W**

Table 4.4: Thermal Differnce

Q	Rtotal	A	**ΔT**
500	1.389	10	**69.45 °C**

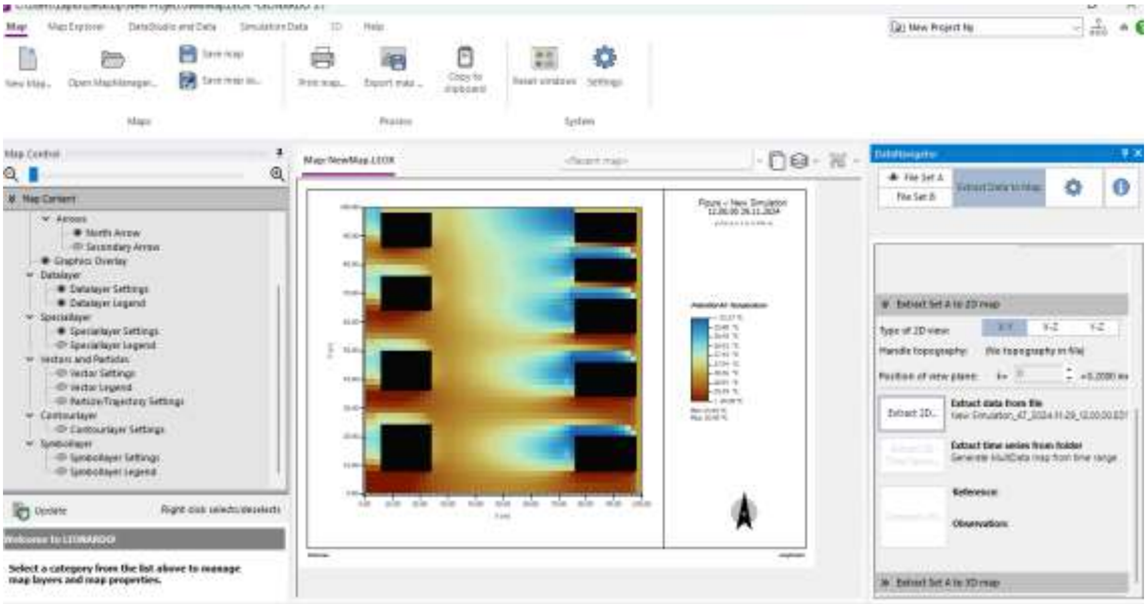
So, the temperature drop across the wall would be approximately 69.45°C given the specified conditions.

4.3 Result of Envi-Met Simulation Using Material to Reduce Temperature and Improve Humidity

The Simulation was set to summertime, immersing its participants in a vibrant, sun-drenched environment. The virtual air was warm and carried the faint scent of blooming flowers, while digital birds chirped in the background, creating an idyllic ambiance. Long shadows stretched across simulated streets as golden light bathed the scenery, and the hum of outdoor activity filled the atmosphere with life. It was a season of endless potential, where the world within the Simulation seemed to slow down, inviting moments of leisure and exploration under an ever-blue sky.

4.3.1 Result for the Scenario 1: Tempature & humidity

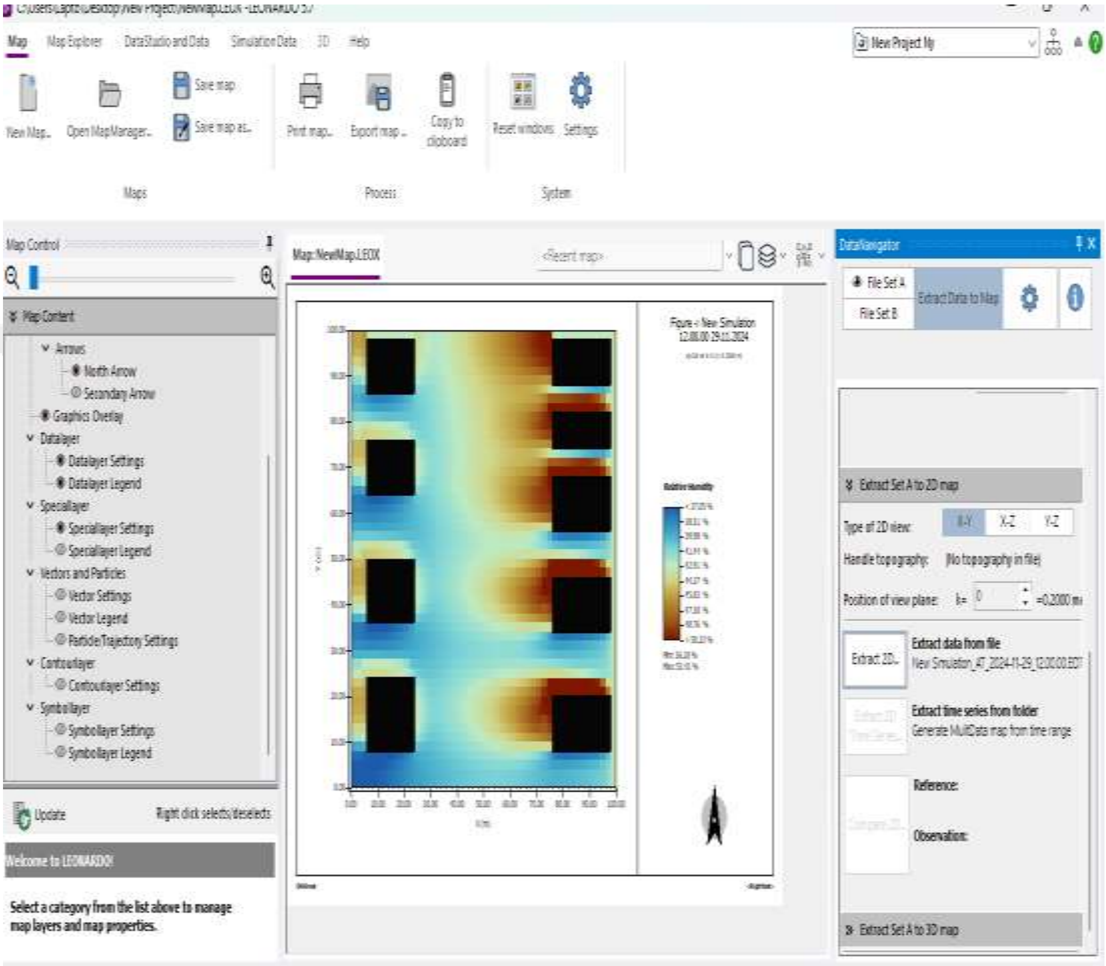
The temperature readings showed a significant increase, likely due to its enclosed environment, characterized by concrete structures, sparse greenery, and extensive asphalt roadways. On that day, the maximum temperature (PAT) reached 24.95 ºC, while the minimum (PAT) was 30.90 ºC.



Select a category from the list above to manage map layers and map properties.

Figure 4.2: PAT Simulated By Envi Met

Humidity levels significantly impact meteorological phenomena such as thunderstorms and storms. When humidity hits 100%, the air becomes completely saturated with water vapor, resulting in dew formation or precipitation. Analyzing the relative humidity map from the model used that day reveals a maximum relative humidity of 36.18 % and a minimum of 53.41 %.

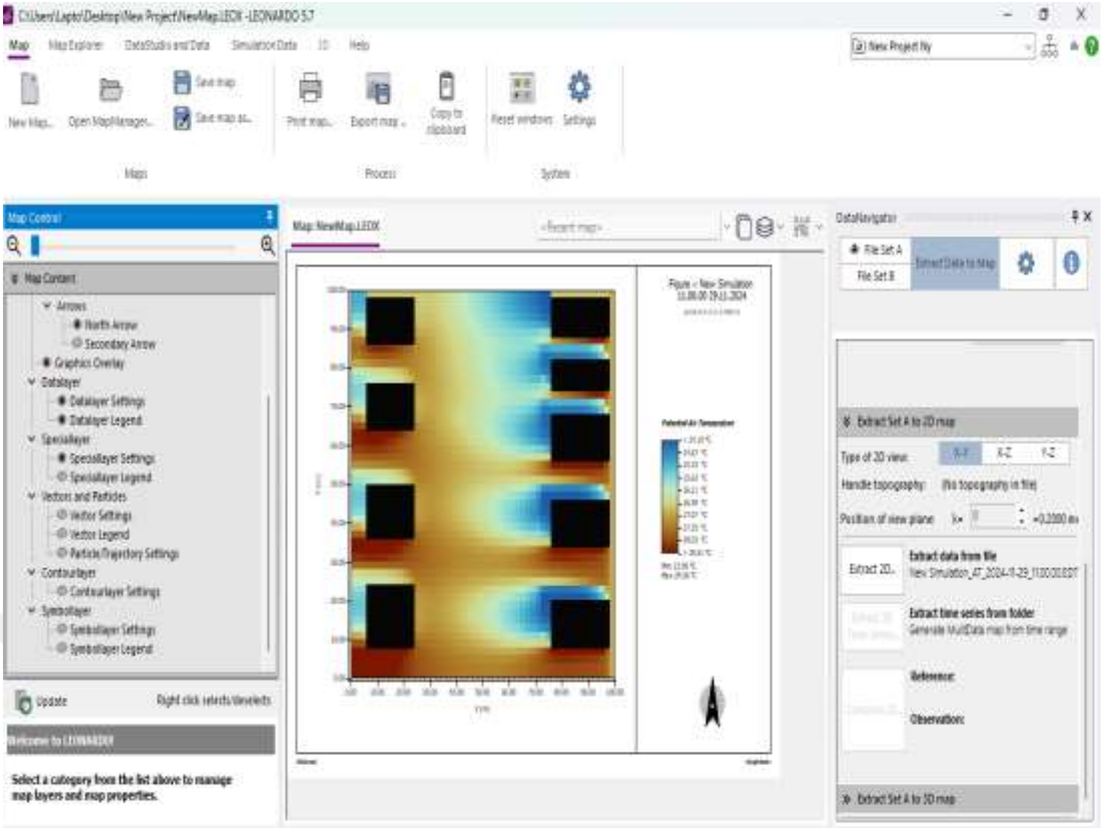


Select a category from the list above to manage map layers and map properties.

Figure 4.3: Relative Humdity Simulated By Envi Met

4.3.2 Result for the scenario 2: Temperature and humidity

The temperature readings indicated a notable rise, likely attributed to its enclosed environment, dominated by concrete structures, limited greenery, and expansive asphalt roadways. On that day, the maximum temperature (PAT) reached 23.96 ºC, while the minimum (PAT) was 29.36 ºC.



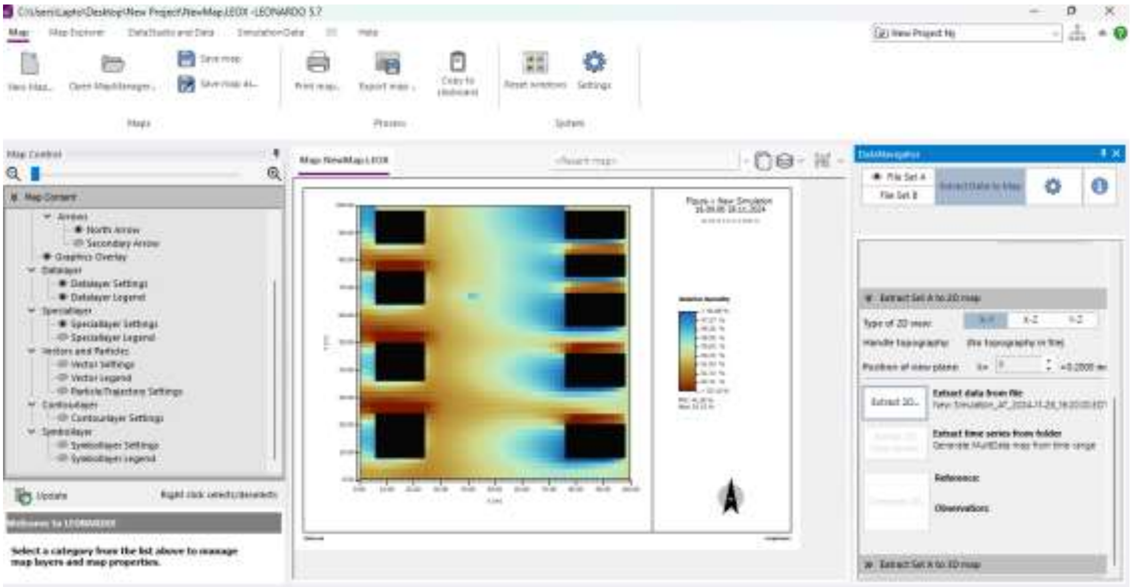
Select a category from the list above to manage map layers and map properties.

Type of 2D view: X-Y

Handle topography: (No topography in file)

Figure 4.4: PAT Simulated By Envi Met

Humidity plays a crucial role in meteorological events like thunderstorms and storms. At 100% humidity, the air becomes fully saturated with water vapor, leading to the formation of dew or precipitation. Analysis of the relative humidity map from the model used that day shows a maximum value of 54.33 % and a minimum of 46.38 %.



Select a category from the list above to manage map layers and map properties.

Type of 2D view: X-Y

Handle topography: (No topography in file)

Figure 4.5: Humidity Simulated By Envi Met

Table 4.5: Scenario Comparison

	Potential Air Temperarture	Humidity
Scenario 1: Concrete wall (cast dense)	**Min:24.95** ºC **Max:30.90** ºC	**Min:36.18%** **Max:53.41%**
Scenario 2: Concrete wall (light weight)	**Min:23.96** ºC **Max:29.36** ºC	**Min:46.38%** **Max:54.33%**

4.4 Result of Effect of Using Trees to Reduce Temperature in Construction Areas

One of the most immediate benefits of trees is their ability to provide shade. By casting shadows on surfaces like pavement and buildings, trees reduce the amount of solar radiation absorbed, thus lowering surface temperatures. This cooling effect can significantly mitigate the urban heat island effect, making outdoor spaces more comfortable for workers and residents alike.

Trees release moisture through a process called evapotranspiration, where water evaporates from their leaves and surrounding soil. This process cools the air in their vicinity, similar to how sweat cools the human body. In construction areas, where large expanses of bare ground and building materials contribute to heat retention, trees can help balance the local climate by increasing humidity and cooling the air.

Trees act as natural air filters, trapping dust, pollutants, and particulate matter from the air. In construction zones, where activities like demolition and excavation can release pollutants into the atmosphere, trees play a crucial role in improving air quality. Cleaner air not only benefits construction workers but also enhances the overall environmental health of the area.

Urban construction often disrupts natural drainage patterns, leading to increased runoff and potential flooding. Trees help mitigate these issues by absorbing rainwater through their roots and reducing stormwater runoff. This natural water management system is especially valuable in urban areas prone to heavy rainfall and flash floods.

Beyond their environmental advantages, trees also contribute to the aesthetic appeal of construction areas. They soften the harsh lines of buildings and machinery, creating a more pleasant visual environment. Moreover, numerous studies have shown that exposure to green spaces and nature improves mental well-being and reduces stress levels among individuals, including construction workers.

Implementing a tree planting strategy in construction areas requires careful planning and consideration of factors such as species selection, maintenance needs, and spatial constraints. Choosing native tree species adapted to local climate conditions ensures better survival rates and ecosystem integration. Additionally, providing adequate irrigation during the establishment phase and regular maintenance thereafter are critical for the long-term success of urban forestry initiatives.

Despite the numerous benefits of integrating trees into construction areas, several challenges remain. Limited space, competing infrastructure demands, and initial costs can pose barriers to widespread adoption. However, advancements in urban planning and sustainable design practices offer opportunities to overcome these challenges. Innovative approaches such as green roofs, vertical gardens, and community involvement in tree planting initiatives can further enhance the cooling and environmental benefits of trees in construction zones.

4.4.1 The cooling effect

Assuming the following data collected from the study which has been conducted in the area:

Table 4.6: Cooling Effect

Q	ET	A	ρ	L
122,500 MJ/day	5mm/day	10,000 m² (1 hectare)	1000 (kg/m³)	(2.45 MJ/kg) or (585 cal/g)

So, the cooling effect due to evapotranspiration over an area of 1 hectare for one day is 122,500 MJ.

If you need the cooling effect in other units, you can convert the energy accordingly.

Would you like to perform a calculation with specific data? If so, please provide the necessary details such as the ET rate, area, and time period.

4.4.2 Combine shading and evapotranspiration effects

Combining shading and evapotranspiration effects can significantly enhance cooling and water efficiency in various environments. Shading, typically achieved through the use of trees, canopies, or other structures, reduces direct sunlight exposure, thus lowering ambient temperatures and minimizing heat gain in buildings and open spaces. When these two mechanisms are integrated, they create a synergistic effect: shading decreases the demand for water by reducing evaporation rates, while the plants’ evapotranspiration provides a natural cooling effect, further enhancing the microclimate. This combination can lead to more sustainable urban planning, improved agricultural practices, and better-designed green spaces that contribute to overall environmental health and human comfort.

Total cooling effect = Shade cooling effect + Evapotranspiration cooling effect

We have a 1-acre construction site and we plant 100 mature trees with the following properties. Each tree provides a canopy area of 50 square meters, offering significant environmental benefits. By shading the ground beneath it, the tree reduces solar radiation by 70%, helping to lower surrounding temperatures and decrease the urban heat island effect. The tree also plays a crucial role in water management through evapotranspiration, releasing 100 liters of water per day into the atmosphere. This process absorbs energy in the form of latent heat, with 2260 joules required to vaporize each gram of water. As a result, the tree helps cool the air, promoting a more comfortable microclimate.

4.4.3 Shading effect

Table 4.7: Shading Effect

Shade cooling effect	solar radiation	Total canopy area	Reduction in solar radiation	Canopy area per tree
3.5 MW (3500 kW)	1 kW/m² (1000 W/m²)	100 trees * 50 m²/tree = 5000 m²	70%	50 m²

The total canopy area of 100 trees, each covering 50 m², amounts to 5000 m². On a sunny day, assuming the solar radiation is 1 kW/m² (or 1000 W/m²), the trees provide significant shade that contributes to cooling. Considering the cooling effect of the shade at 70% efficiency, this can be calculated as 5000 m² * 0.7 * 1000 W/m², resulting in a total cooling effect of 3.5 MW (or 3500 kW). This demonstrates the substantial impact trees have on reducing heat in their surroundings through shading.

4.4.4 Evapotranspiration effect

Table 4.8: Evapotranspiration Effect

EE	**Total water**	**LHV**
22.6 GJ/day (22,600,000 kJ/day)	10000 liters/day	2260 J/g

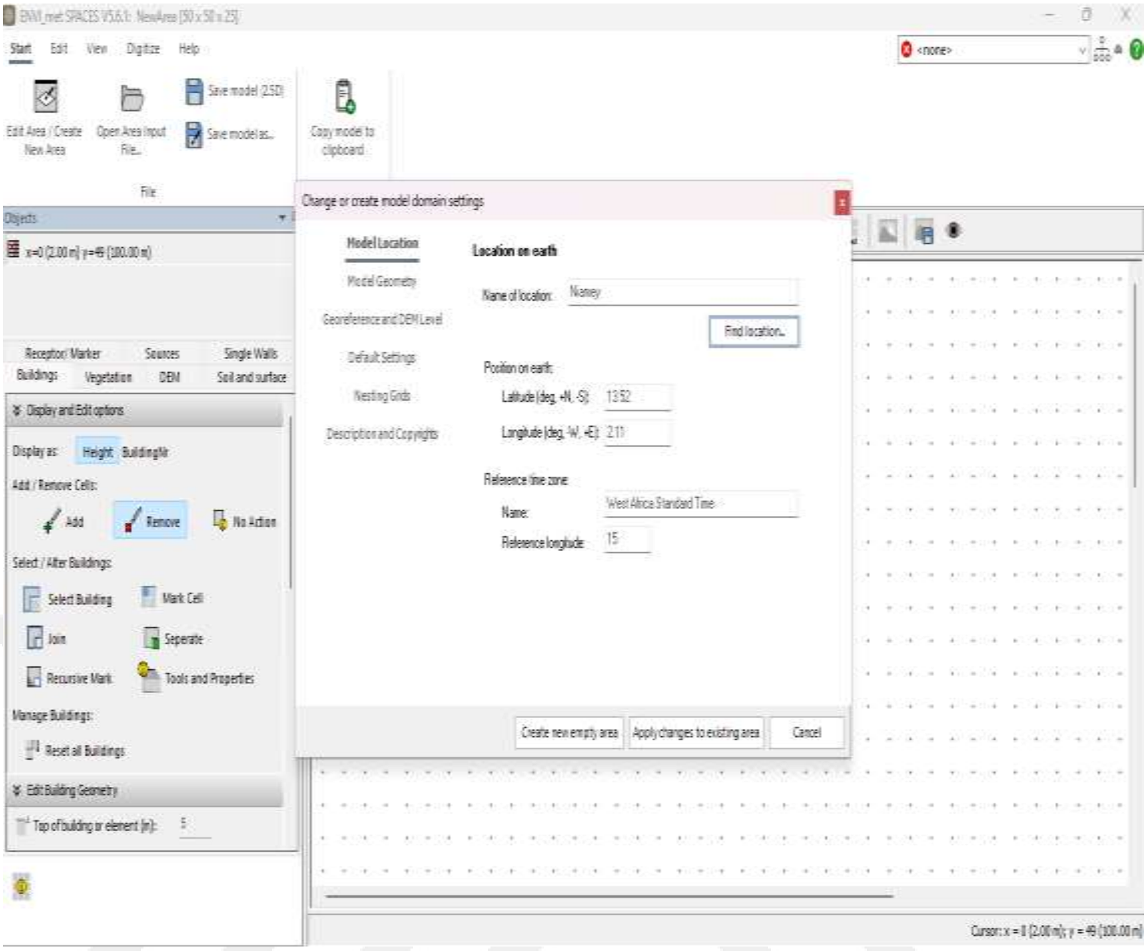
A group of 100 trees releases a total of 10,000 liters of water vapor per day, which is equivalent to 10,000,000 grams of water vapor. The cooling effect generated by this water vapor can be calculated using the heat of vaporization of water, which is 2260 joules per gram. Therefore, the total cooling effect produced by these trees is 22.6 gigajoules per day, or 22,600,000 kilojoules per day.

4.5 Envi Met Model Set Up Before Implanting Trees

The construction area has been defined which is in north of Niger where the datas have been collected from a survey, including buildings, surfaces, and existing vegetation.

The simulation duration was along 6 months, the soil was Predominantly sandy and low in organic matter, affecting water retention. Generally low, but higher during the rainy season. Accurate initial moisture levels are crucial for simulating tree growth. The simulation was to analyze the microclimatic impact of the trees.

One of the notable features of the ENVI-met program is its ability to identify the selected area's location and automatically determine its latitude and longitude, enabling accurate predictions of air temperature, wind speed, and relative humidity.



Location on earth

Name of location: Niamey

Position on earth:

Latitude (deg. +N, -S): 13.52

Longitude (deg. -W, +E): 2.11

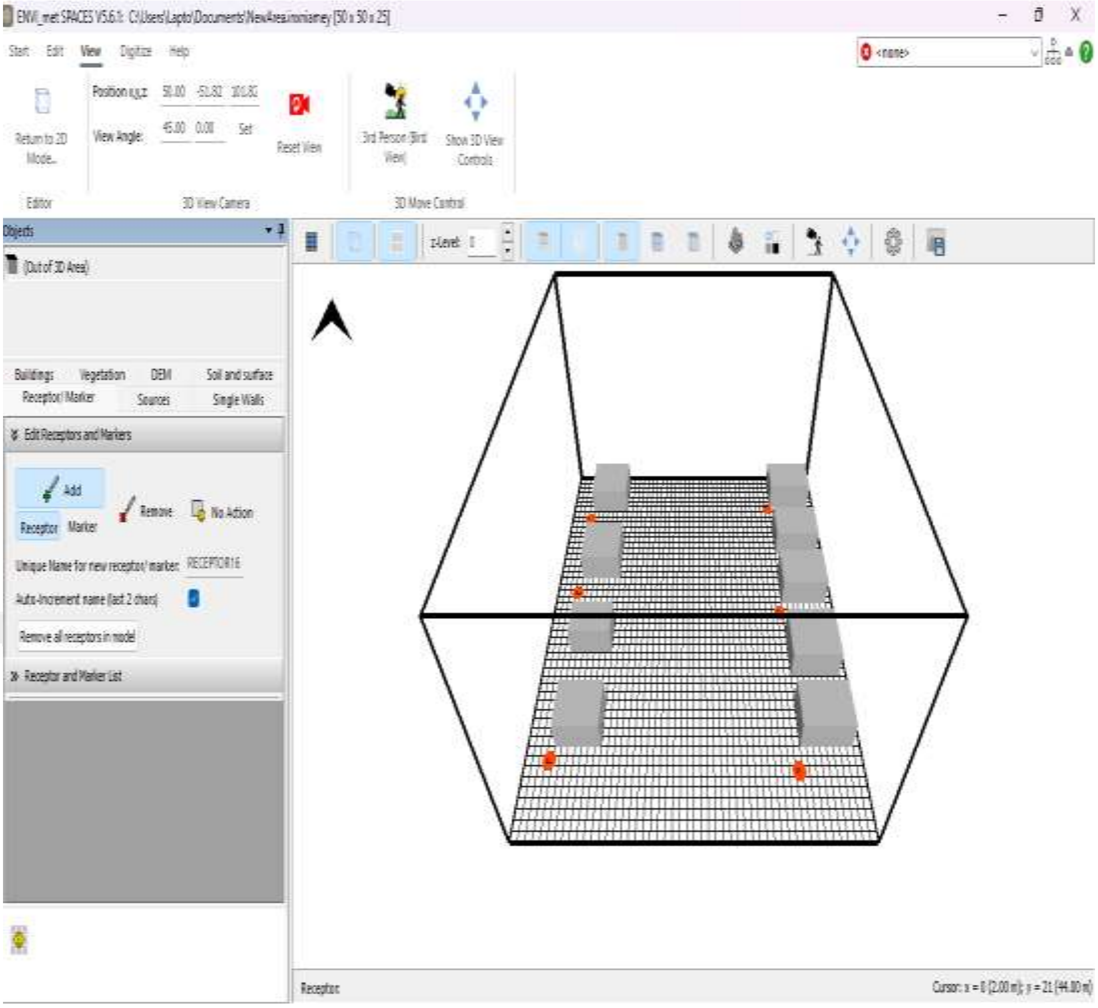
Reference time zone:

Name: West Africa Standard Time

Reference longitude: 15

Figure 4.6: Location Determination

The characteristics of the main road, paved with bitumen, and the interior road, paved with concrete, along with the materials used for the building's walls and roofing must be accurately accounted for. Additionally, determining the building's true north is crucial for proper orientation to sunlight and thermal radiation. These factors must be precisely incorporated into the model design to ensure accurate and effective results, enhancing thermal comfort for both the environment and the building's occupants.



Position x,y,z: 50.00 -51.82 101.82

View Angle: 45.00 0.00

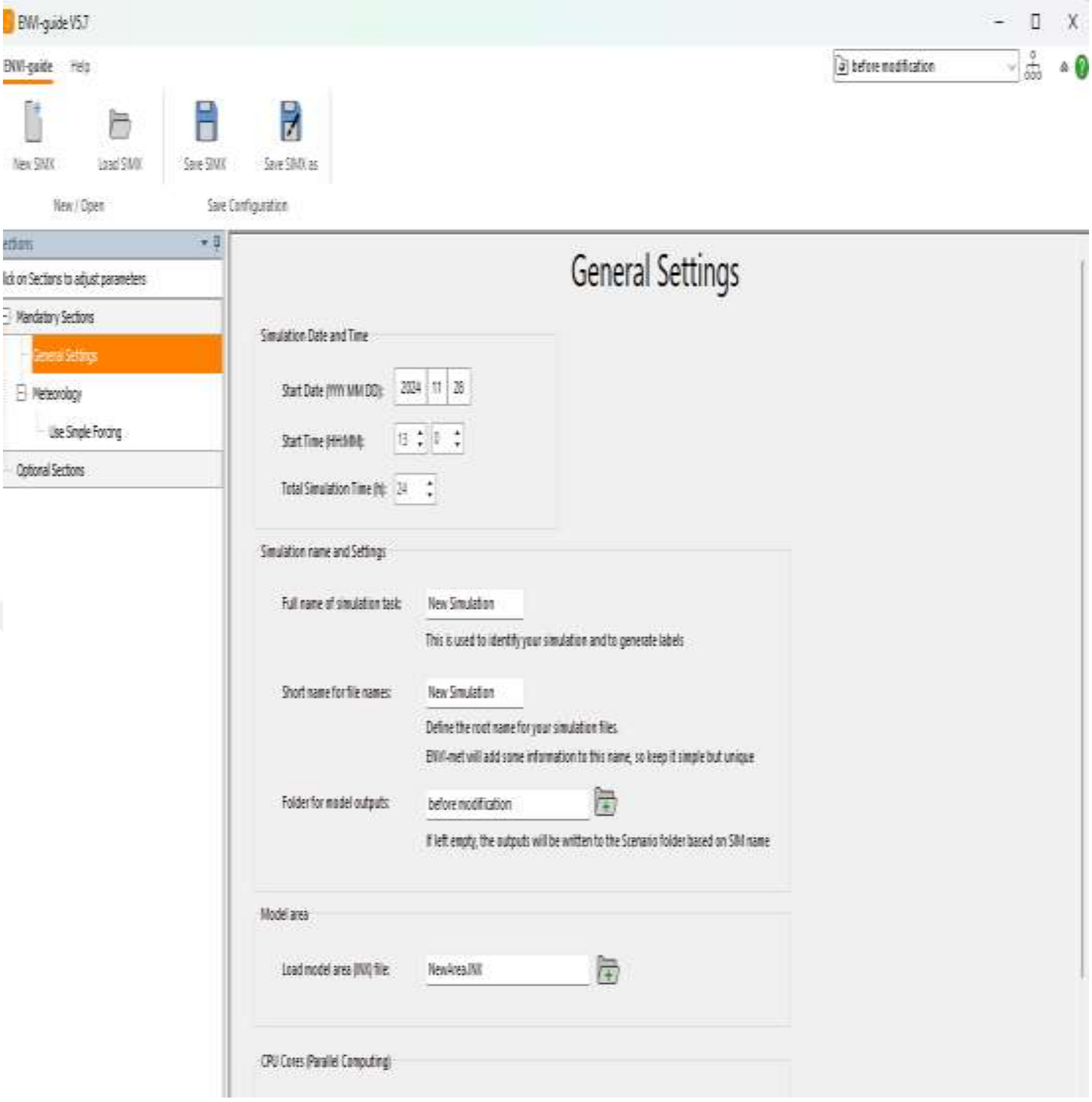
z-Level: 0

Unique Name for new receptor/ marker: RECEPTOR16

Cursor: x = 0 (2.00 m); y = 21 (44.00 m)

Figure 4.7: View of the Design Simulated By Eniv-Met

Establishing the day's maximum and minimum temperatures along with the relative humidity.



General Settings

Simulation Date and Time

Start Date (YYYY MM DD): 2024 11 26

Start Time (HH:MM): 13 0

Total Simulation Time (h): 24

Simulation name and Settings

Full name of simulation task: New Simulation

This is used to identify your simulation and to generate labels

Short name for file names: New Simulation

Define the root name for your simulation files.

ENVI-met will add some information to this name, so keep it simple but unique

Folder for model outputs: before modification

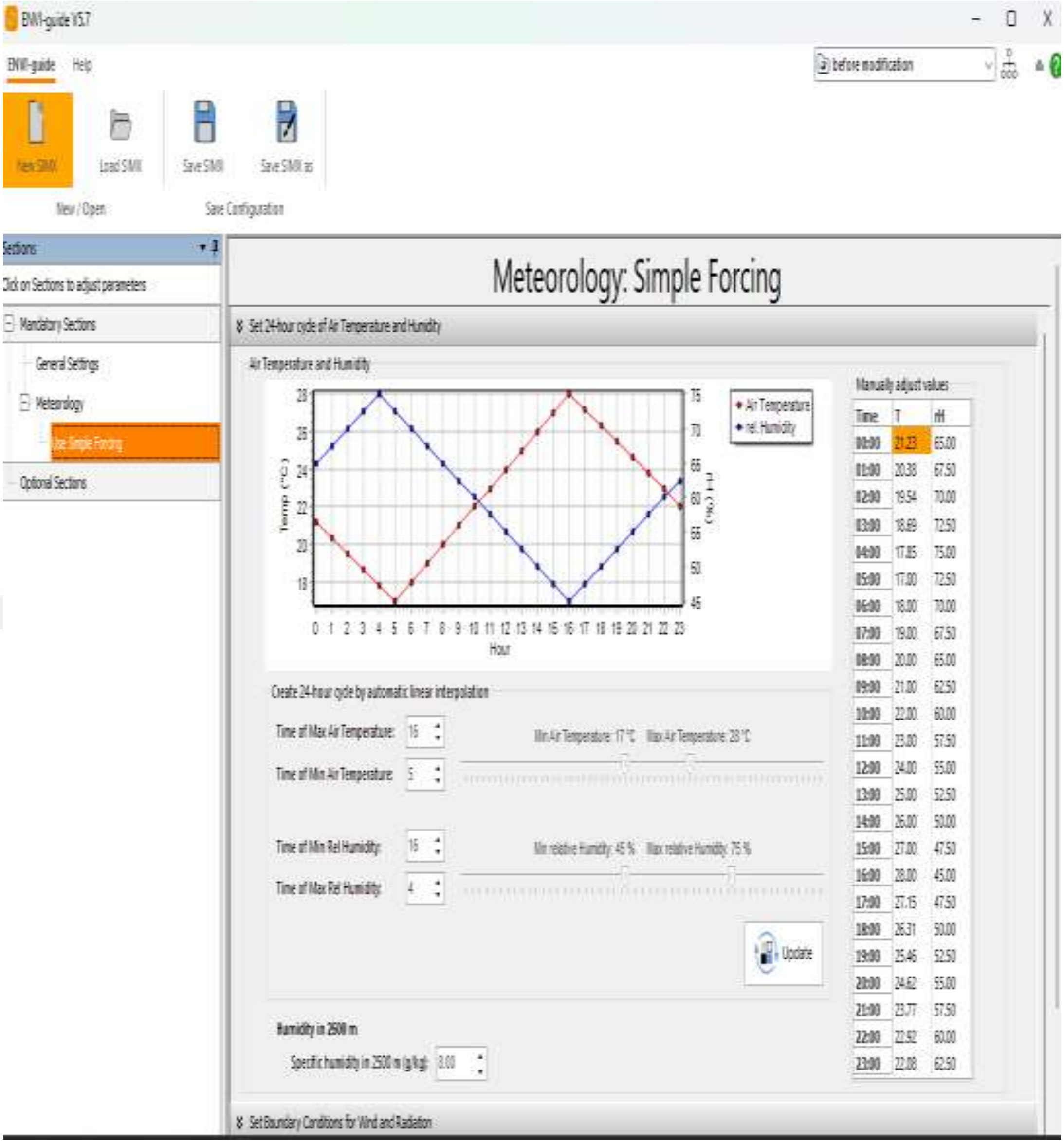
If left empty, the outputs will be written to the Scenario folder based on SIM name

Model area

Load model area (INX) file: NewArea.INX

CPU Cores (Parallel Computing)

Figure 4.8: General Settings



Create 24-hour cycle by automatic linear interpolation

Time of Max Air Temperature: 15

Time of Min Air Temperature: 5

Min Air Temperature: 17 °C Max Air Temperature: 28 °C

Time of Min Rel Humidity: 15

Time of Max Rel Humidity: 4

Min relative Humidity: 45 % Max relative Humidity: 75 %

Humidity in 2500 m

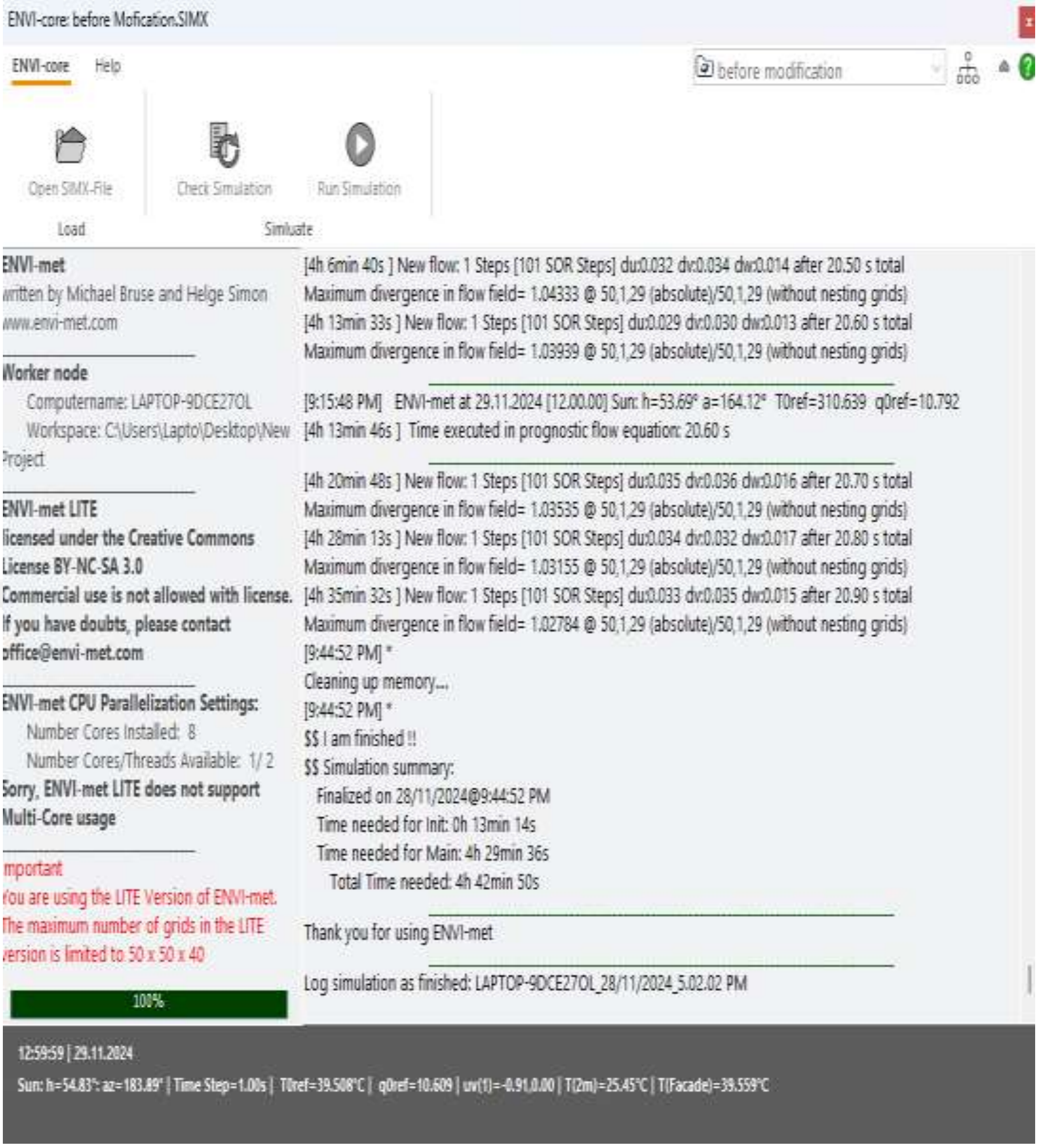
Specific humidity in 2500 m (g/kg): 3.00

Manually adjust values

Time	T	rH
00:00	21.23	65.00
01:00	20.38	67.50
02:00	19.54	70.00
03:00	18.69	72.50
04:00	17.85	75.00
05:00	17.00	72.50
06:00	18.00	70.00
07:00	19.00	67.50
08:00	20.00	65.00
09:00	21.00	62.50
10:00	22.00	60.00
11:00	23.00	57.50
12:00	24.00	55.00
13:00	25.00	52.50
14:00	26.00	50.00
15:00	27.00	47.50
16:00	28.00	45.00
17:00	27.15	47.50
18:00	26.31	50.00
19:00	25.46	52.50
20:00	24.62	55.00
21:00	23.77	57.50
22:00	22.92	60.00
23:00	22.08	62.50

Figure 4.9: Setting the Temperature and Humidity by Envi-Met

Running the specified model continuously for 24 hours to obtain results.



```
ENVI-met
written by Michael Bruse and Helge Simon
www.envi-met.com

Worker node
    Computername: LAPTOP-9DCE27OL
    Workspace: C:\Users\Lapto\Desktop\New
Project

ENVI-met LITE
licensed under the Creative Commons
License BY-NC-SA 3.0
Commercial use is not allowed with license.
If you have doubts, please contact
office@envi-met.com

ENVI-met CPU Parallelization Settings:
    Number Cores Installed: 8
    Number Cores/Threads Available: 1/ 2
Sorry, ENVI-met LITE does not support
Multi-Core usage

mportant
ou are using the LITE Version of ENVI-met.
The maximum number of grids in the LITE
ersion is limited to 50 x 50 x 40
```

```
[4h 6min 40s ] New flow: 1 Steps [101 SOR Steps] du:0.032 dv:0.034 dw:0.014 after 20.50 s total
Maximum divergence in flow field= 1.04333 @ 50,1,29 (absolute)/50,1,29 (without nesting grids)
[4h 13min 33s ] New flow: 1 Steps [101 SOR Steps] du:0.029 dv:0.030 dw:0.013 after 20.60 s total
Maximum divergence in flow field= 1.03939 @ 50,1,29 (absolute)/50,1,29 (without nesting grids)

[9:15:48 PM]   ENVI-met at 29.11.2024 [12.00.00] Sun: h=53.69° a=164.12°  T0ref=310.639  q0ref=10.792
[4h 13min 46s ]  Time executed in prognostic flow equation: 20.60 s

[4h 20min 48s ] New flow: 1 Steps [101 SOR Steps] du:0.035 dv:0.036 dw:0.016 after 20.70 s total
Maximum divergence in flow field= 1.03535 @ 50,1,29 (absolute)/50,1,29 (without nesting grids)
[4h 28min 13s ] New flow: 1 Steps [101 SOR Steps] du:0.034 dv:0.032 dw:0.017 after 20.80 s total
Maximum divergence in flow field= 1.03155 @ 50,1,29 (absolute)/50,1,29 (without nesting grids)
[4h 35min 32s ] New flow: 1 Steps [101 SOR Steps] du:0.033 dv:0.035 dw:0.015 after 20.90 s total
Maximum divergence in flow field= 1.02784 @ 50,1,29 (absolute)/50,1,29 (without nesting grids)
[9:44:52 PM] *
Cleaning up memory...
[9:44:52 PM] *
$$ I am finished !!
$$ Simulation summary:
  Finalized on 28/11/2024@9:44:52 PM
  Time needed for Init: 0h 13min 14s
  Time needed for Main: 4h 29min 36s
    Total Time needed: 4h 42min 50s

Thank you for using ENVI-met

Log simulation as finished: LAPTOP-9DCE27OL_28/11/2024_5.02.02 PM
```

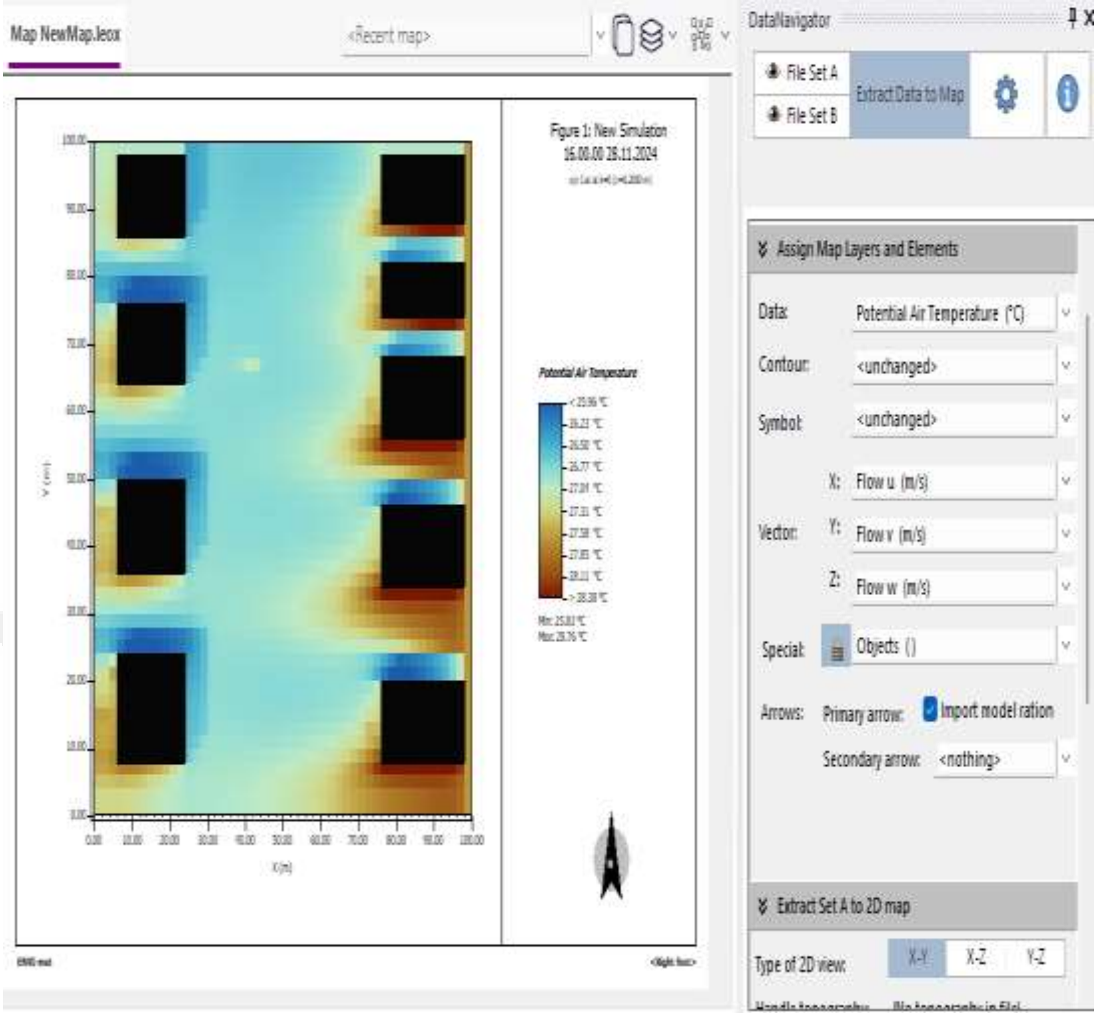
```
12:59:59 | 29.11.2024
Sun: h=54.83°: az=183.89° | Time Step=1.00s | T0ref=39.508°C | q0ref=10.609 | uv(1)=-0.91,0.00 | T(2m)=25.45°C | T(Facade)=39.559°C
```

Figure 4.10: Running Simulation for 24 Hours

4.6 The Results of Data Analysis before Modifying Model

4.6.1 Potential air temperature

The temperature readings across the facility have risen significantly, likely due to the area's confined nature, surrounded by concrete structures, a lack of greenery, and the extensive use of asphalt on the roadways. On that particular day, the maximum temperature (PAT) recorded was 28.76 ºC, while the minimum (PAT) was 25.83 ºC.

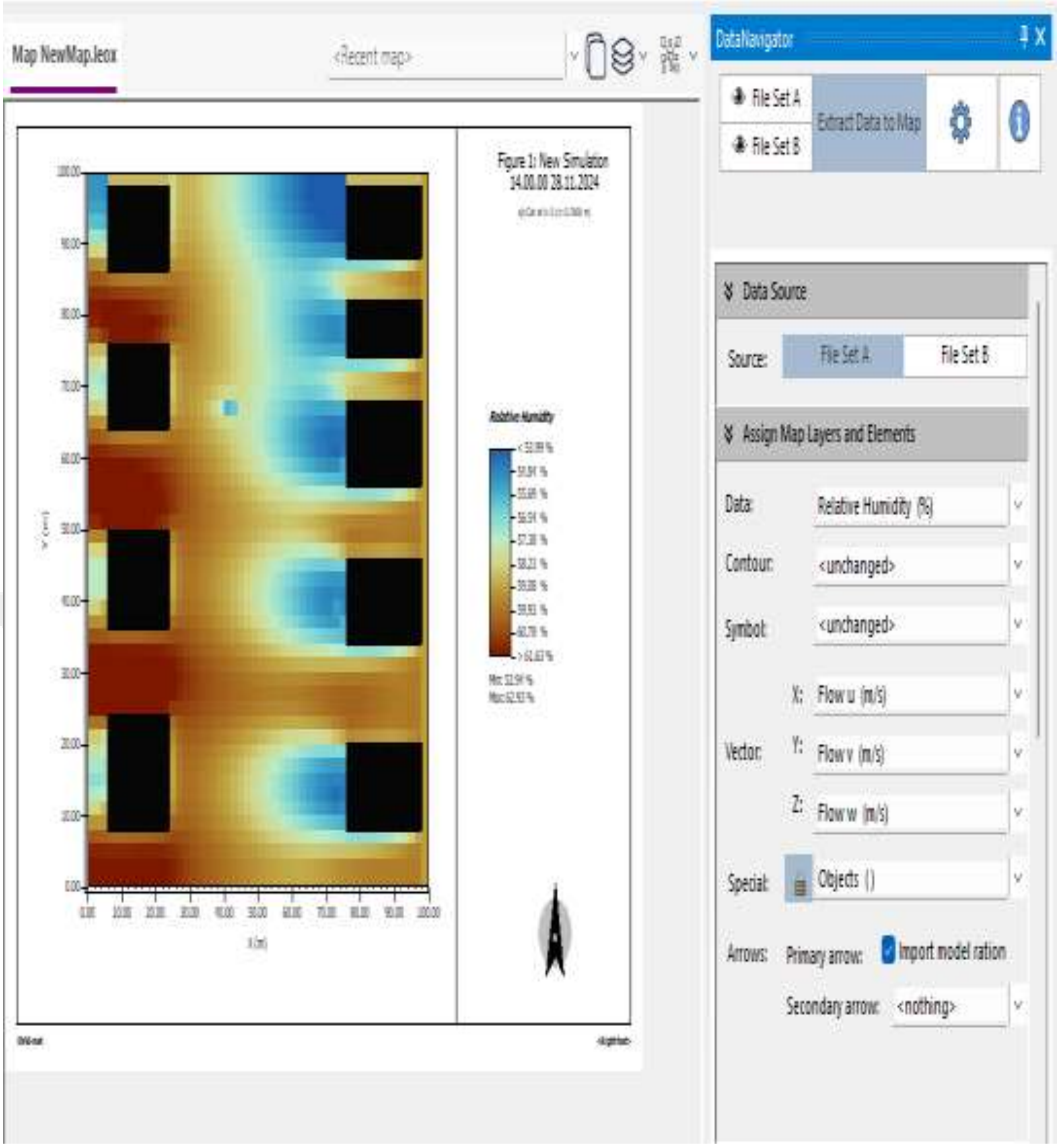


Data: Potential Air Temperature (°C)
Contour: <unchanged>
Symbol: <unchanged>
Vector: X: Flow u (m/s)
Y: Flow v (m/s)
Z: Flow w (m/s)
Special: Objects ()
Arrows: Primary arrow: ☑ Import model ration
Secondary arrow: <nothing>
Type of 2D view: X-Y

Figure 4.11: Air Temperature Developed Model Simulated By Eniv Met

4.6.2 Humdity

Various meteorological phenomena, including the formation of thunderstorms and storms, are influenced by humidity levels. When humidity reaches 100%, the air becomes fully saturated with water vapor, leading to dew formation or precipitation. Analyzing the relative humidity map for the model used that day shows that the highest recorded relative humidity was 62.93%, while the lowest was 52.94%.



Source: File Set A

Data: Relative Humidity (%)

Contour: <unchanged>

Symbol: <unchanged>

Vector: X: Flow u (m/s)

Y: Flow v (m/s)

Z: Flow w (m/s)

Special: Objects ()

Arrows: Primary arrow: ☑ Import model ration

Secondary arrow: <nothing>

Figure 4.12: The Humidity Simulated by Envi-Met

4.6.3 Wind velocity

After completing the simulation for the study region and analyzing the wind speed data, which significantly influences the climate, the researcher concludes that the maximum wind speed recorded on that day was 2.73 m/s, while the minimum was 0.04 m/s. This limitation adversely affects thermal comfort.

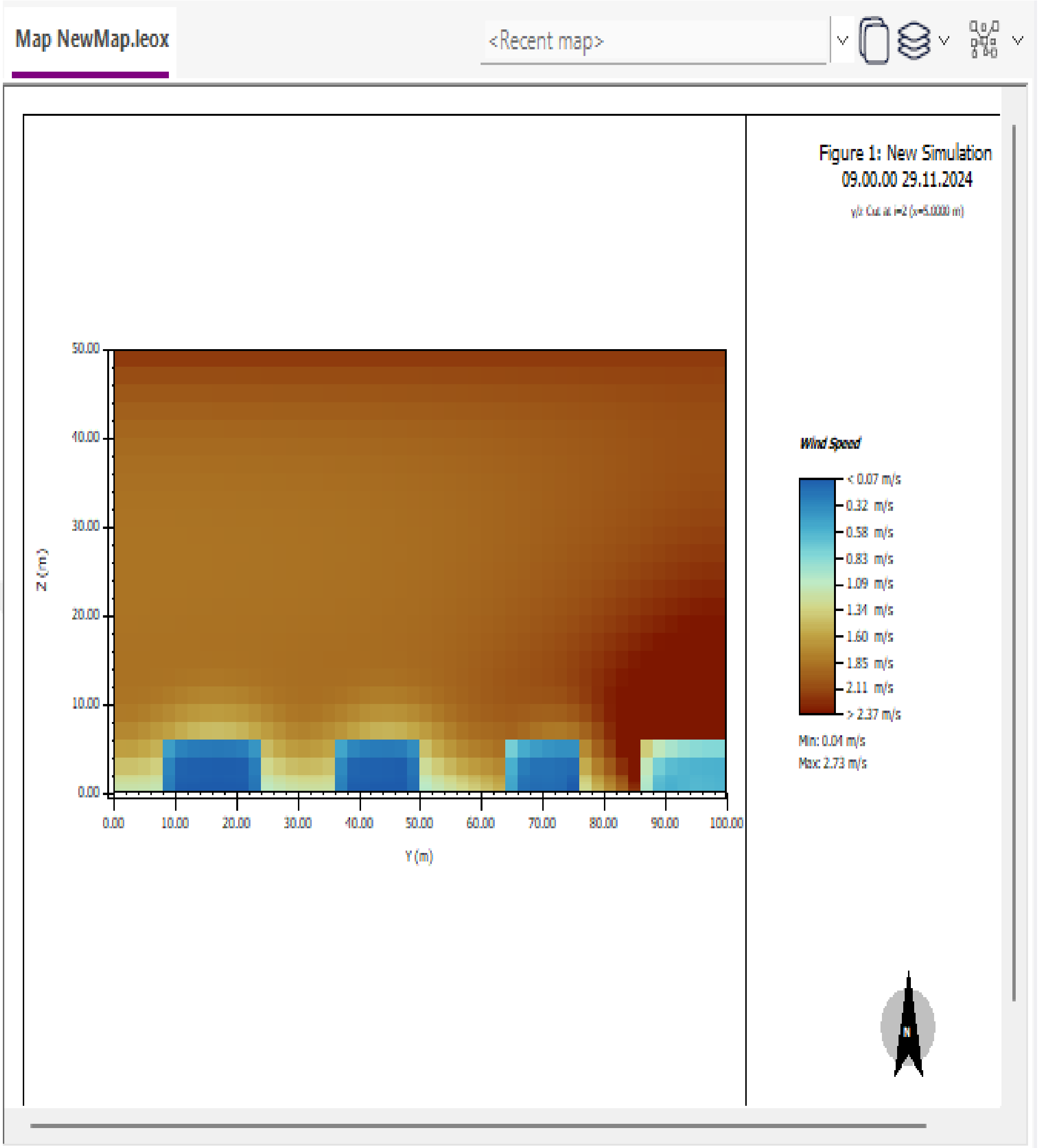


Figure 4.13: Wind Velocity Simulated By Envi Met Before

4.7 Model Setup after Implanting the Trees

Implement the following modifications to enhance thermal comfort by implanting trees around the building, insulate the walls and roofs using isolating materials such as Isogam, apply heat-reflective red-coated asphalt, and install aluminum shades around the building.

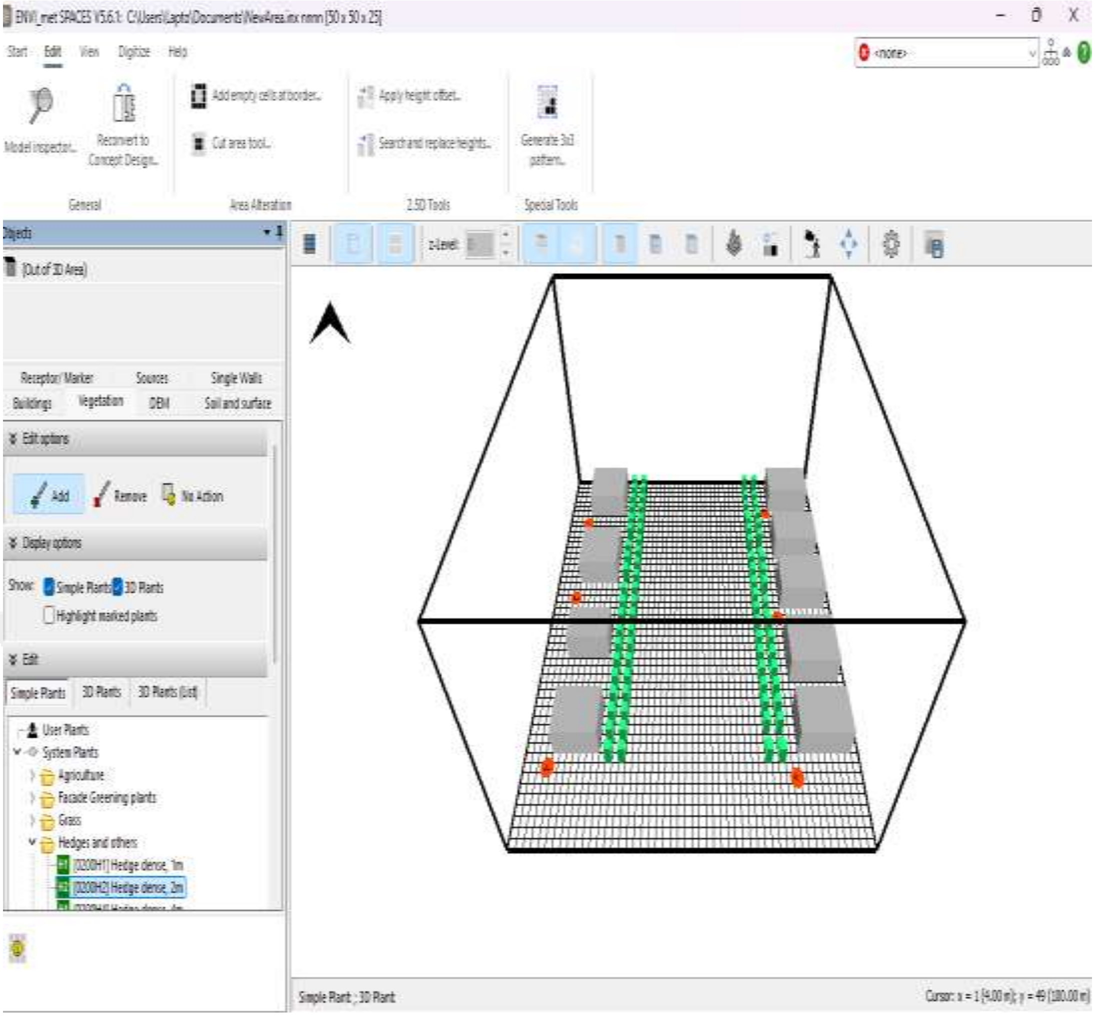


Figure 4.14: View of 3D Developed Model Simulated By Envi Met

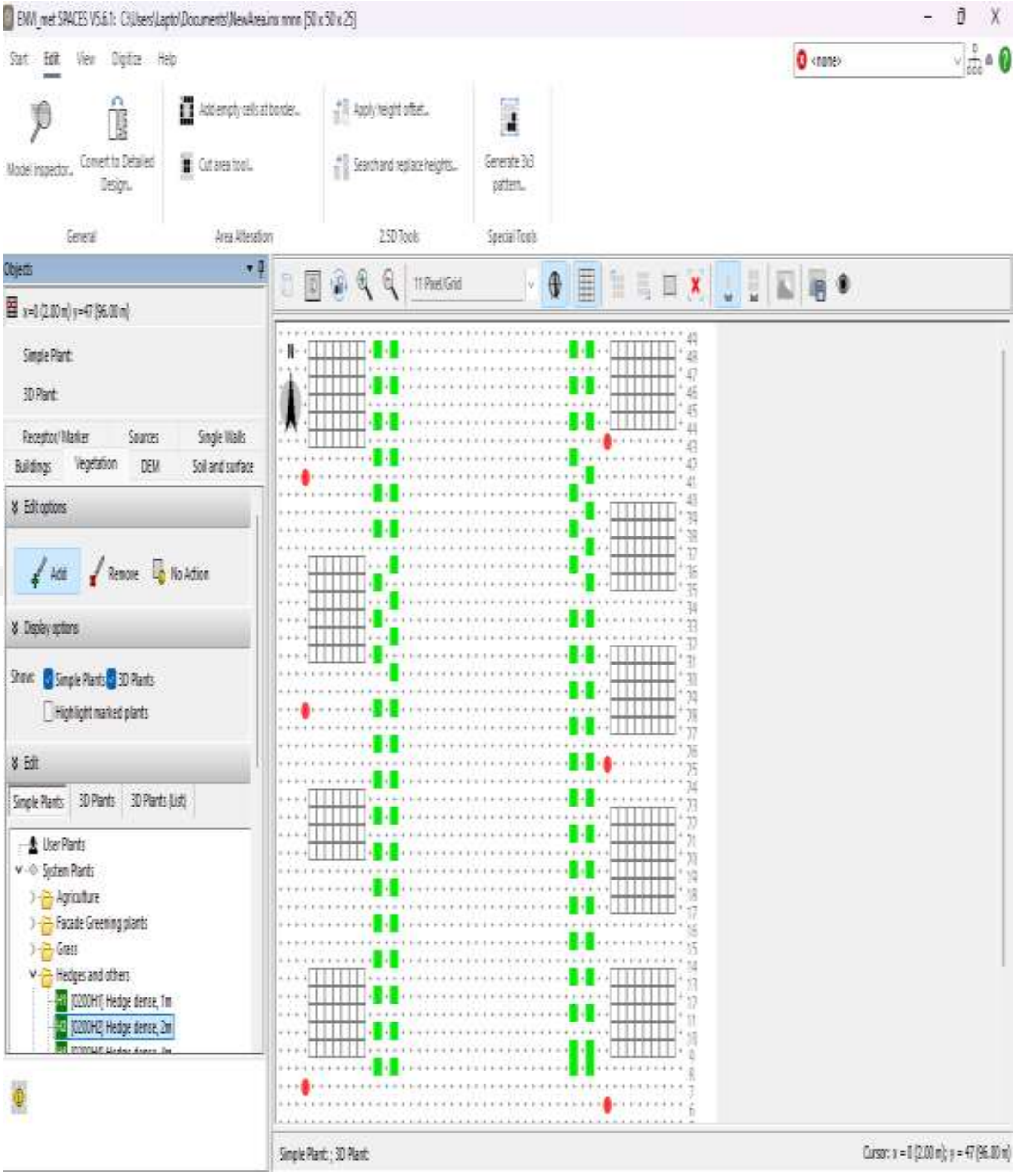
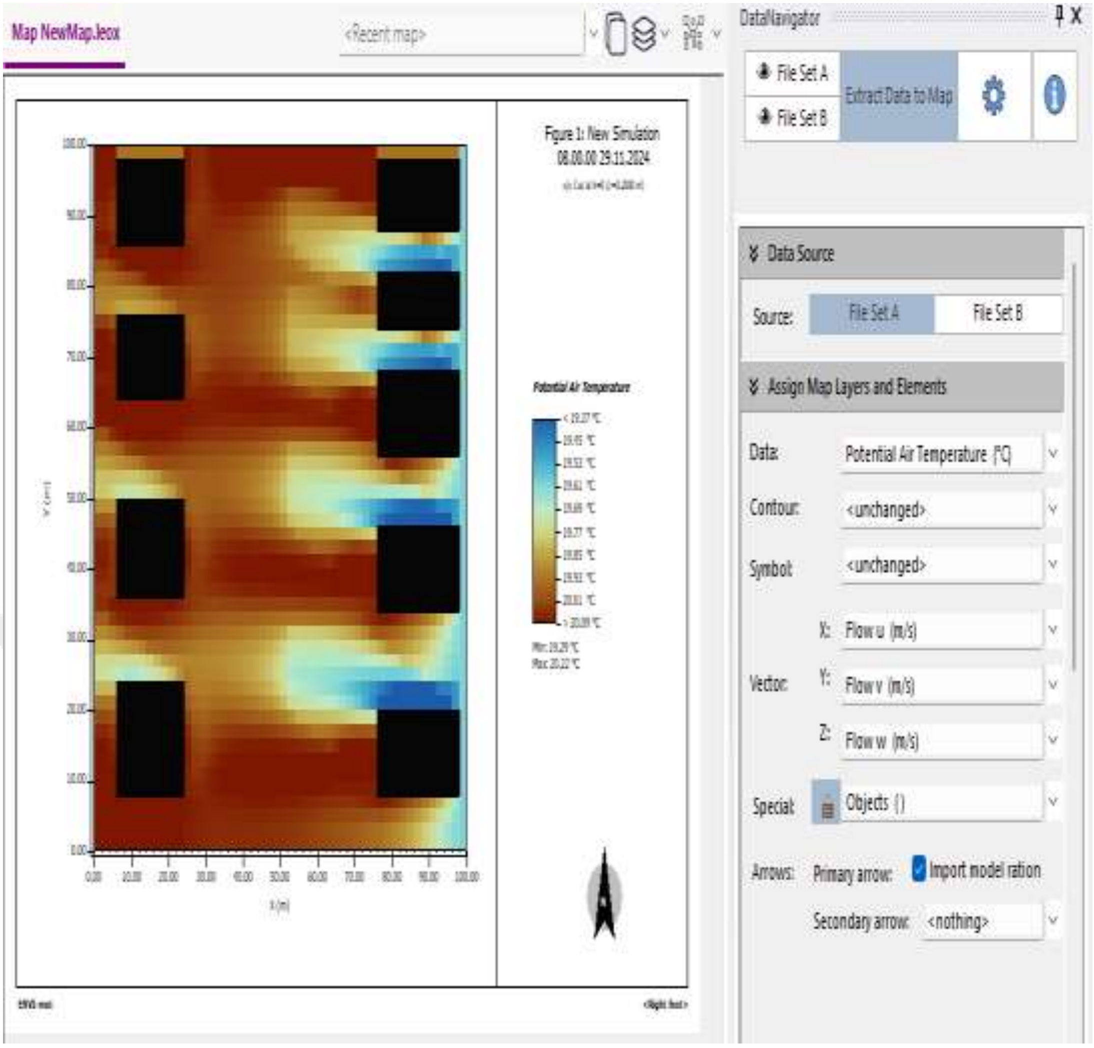


Figure 4.15: View of Design Vegetation on Envi Met

4.8 The Results of Data Analysis after Modifying Model

4.8.1 Potential air temperature

A relative decrease in temperature was observed after applying the modifications to the model. On that day, the maximum PAT was recorded at 20.22 ºC, while the minimum PAT was 19.29 ºC.



Source: File Set A

Data: Potential Air Temperature (°C)

Contour: <unchanged>

Symbol: <unchanged>

Vector: X: Flow u (m/s)

Y: Flow v (m/s)

Z: Flow w (m/s)

Special: Objects ()

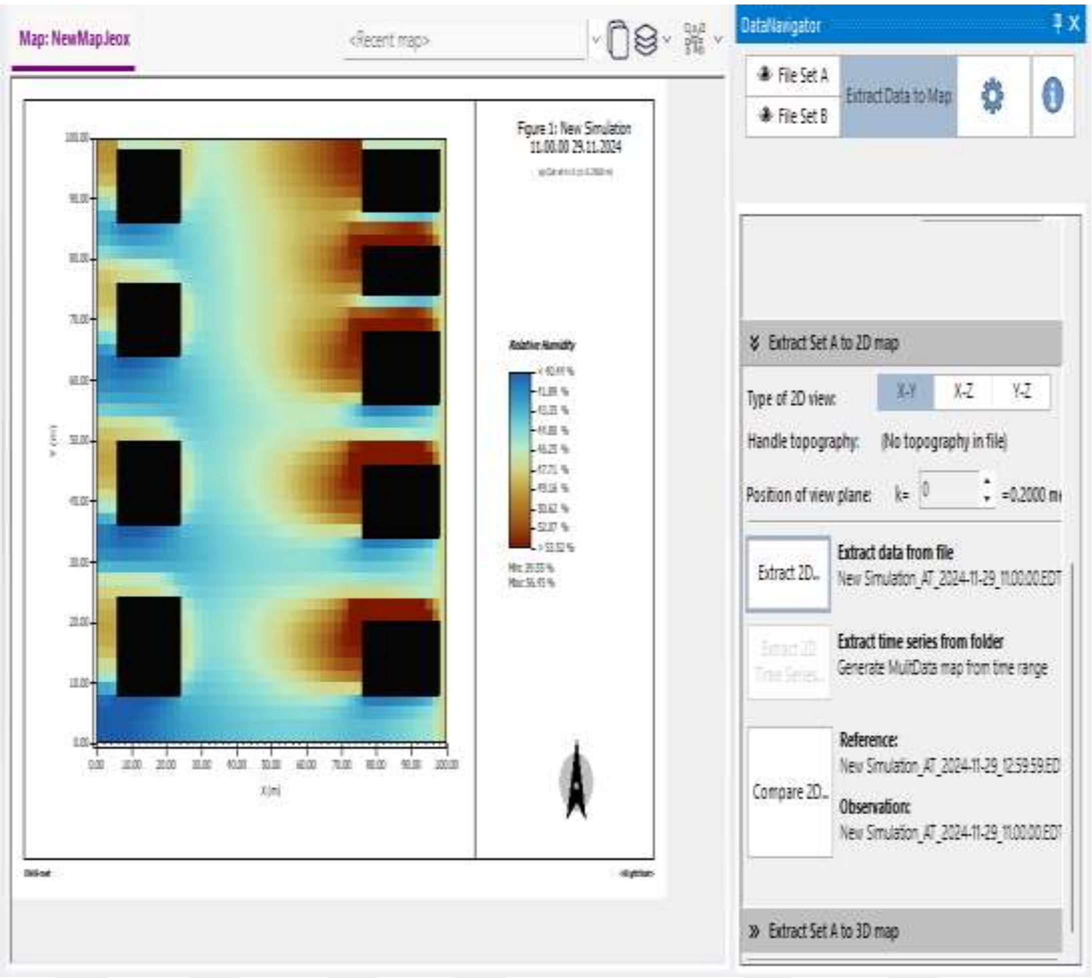
Arrows: Primary arrow: ☑ Import model ration

Secondary arrow: <nothing>

Figure 4.16: Air Temperature Developed Model Simulated By Eniv Met

4.8.2 The humidity

The result findings after modifying the model revealed that the relative humidity levels varied throughout the day. The maximum recorded relative humidity was 56.45%, while the minimum was 39.55%.



Type of 2D view: X-Y

Handle topography: (No topography in file)

Position of view plane: k= 0 =0.2000 m

Extract data from file
New Simulation_AT_2024-11-29_11.00.00.EDT

Extract time series from folder
Generate MultiData map from time range

Reference:
New Simulation_AT_2024-11-29_12.59.59.ED

Observation:
New Simulation_AT_2024-11-29_11.00.00.EDT

Figure 4.17: Humidity Simulated By Envi Met

4.8.3 The wind velocity

After modifying the model and simulating it using ENVI-met software, the results showed an improvement in thermal comfort. The maximum recorded wind speed on that day was 2.67 m/s, while the minimum wind speed was 0.03 m/s.

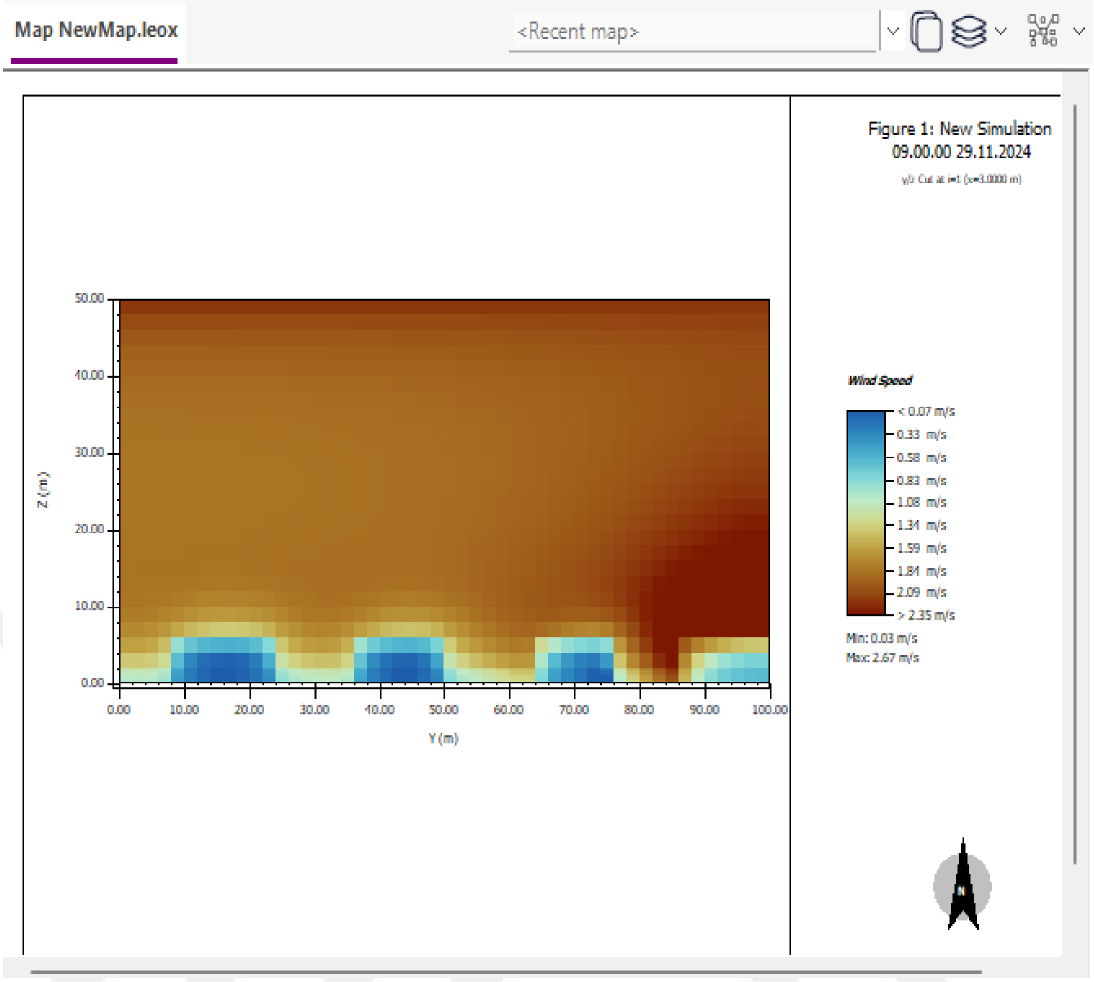


Figure 4.18: Wind Velocity Simulated By Envi Met

4.9 Comparing Results Gained Before and After Modification

The data analysis revealed several positive environmental changes. This cooling effect was followed by an increase in humidity levels, contributing to a more comfortable atmosphere. Additionally, air quality improved considerablely, with a notable reduction in dust levels, indicating a cleaner and healthier environment. Was, while the minimum (PAT) was.

Table 4.9: Comparing Results

	Before modification	After modification
1	Maximum potential air temperature = 28.76 ºC Minimum potential air temperature = 25.83 ºC	Maximum potential air temperature = 20.22 °C Minimum potential air temperature = 19.29°C
2	Maximum relative humidity = 62.93% Minimum relative humidity = 52.94 %	Maximum relative humidity = 56.45 % Minimum relative humidity = 39.55%
3	Maximum wind velocity = 2.73 m\s Minimum wind velocity = 0.04 m\s	Maximum wind velocity = 2.67 m\s Minimum wind velocity = 0.03 m\s

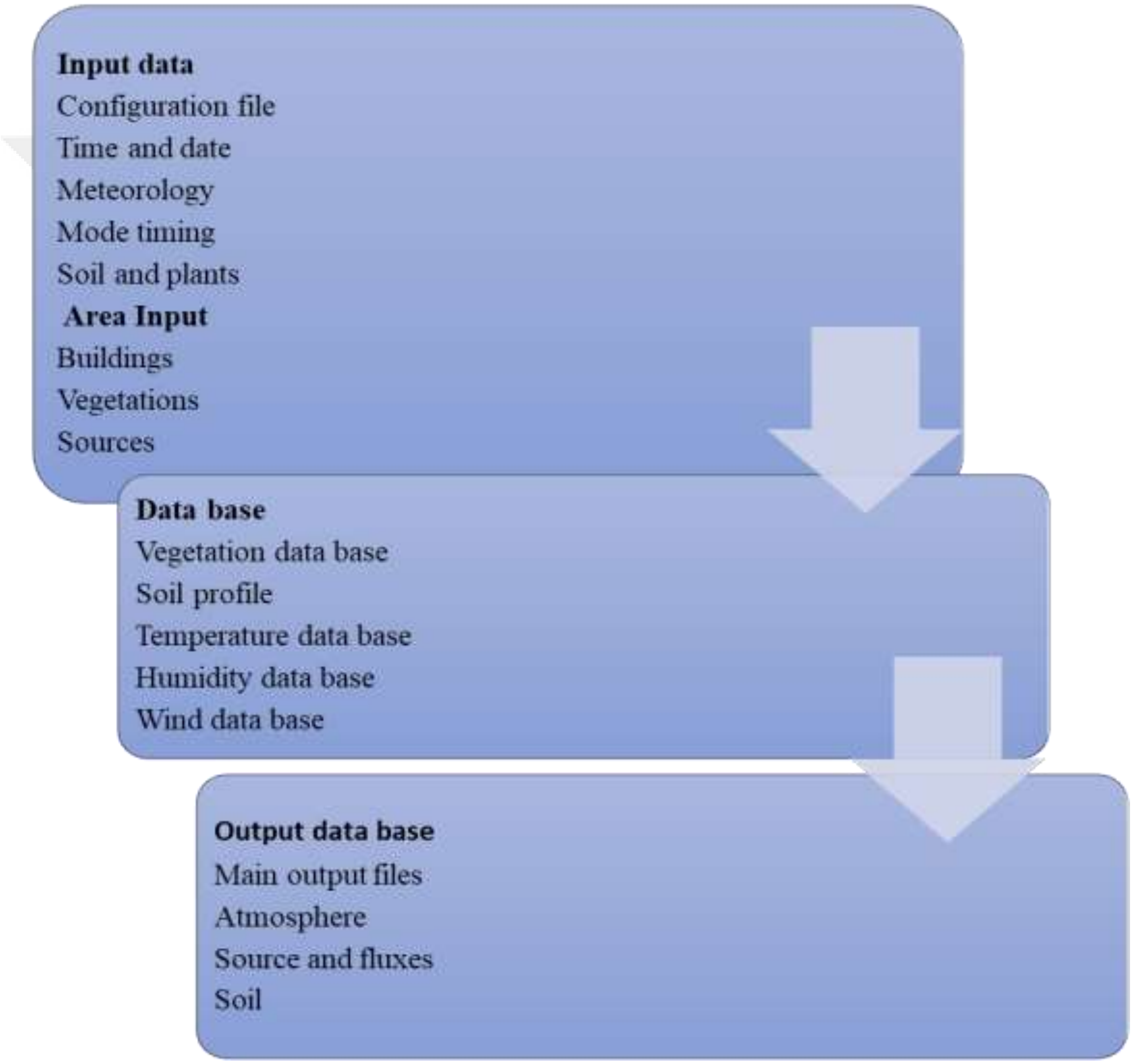


Figure 4.19: Envi-Met Workflow Chart

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Incorporating trees into construction areas is a multifaceted strategy with far-reaching benefits. From mitigating the urban heat island effect and improving air quality to enhancing aesthetics and promoting mental well-being, trees play a crucial role in creating sustainable and resilient urban environments. As cities continue to expand and face climate change challenges, investing in urban forestry not only contributes to environmental stewardship but also fosters healthier and more livable communities for generations to come. By recognizing the importance of trees in construction areas, we can pave the way towards a greener and more sustainable future.

However, using heat-resistant materials, innovative design solutions, and rigorous maintenance protocols, it is possible to construct and maintain durable structures capable of withstanding these harsh conditions. As climate change continues to exacerbate extreme weather conditions globally, the lessons learned from Niger’s approach to high-temperature construction can serve as valuable guidelines for other regions facing similar challenges.

the potential of modern construction materials to reduce indoor temperatures in Niger, offering sustainable and practical solutions for improving living conditions. Insulating Concrete Forms, reflective roofing materials, and Autoclaved Aerated Concrete are particularly promising due to their effectiveness and feasibility for local implementation. While green roofs and Phase Change Materials also show great potential, their application may be more challenging due to maintenance requirements and costs.

The data analysis of structures in high temperatures underscores the significant impact of extreme heat on building materials and infrastructure. The findings highlight the need for improved construction techniques, materials, and maintenance practices to enhance the resilience of structures in this challenging climate.

This case study serves as a critical reminder of the importance of adapting construction practices to local climate conditions, ensuring sustainability and durability in an era of increasing global temperatures.

In this study, we have systematically assessed the problems associated with construction structures exposed to high temperatures. The key findings from the research can be summarized as follows:

5.1.1 Material degradation

High temperatures significantly accelerate the degradation of construction materials such as concrete and steel.

Concrete experiences thermal expansion, cracking, and spalling, leading to reduced structural integrity.

Steel structures exhibit loss of strength and stiffness, becoming more prone to buckling and deformation under load.

5.1.2 Thermal expansion and contraction

Repeated cycles of heating and cooling cause thermal fatigue in construction materials.

Differential expansion and contraction rates between different materials lead to joint failures, warping, and misalignment in composite structures.

5.1.3 Research responses

What are the most common structural problems encountered in high-temperature environments?

- High temperatures can significantly impact the structural integrity of construction materials through various mechanisms. Thermal expansion causes materials to expand, often resulting in cracks, deformation, and joint failures in structures as components shift beyond their design tolerances. Additionally, loss of strength in materials such as concrete and steel at elevated temperatures compromises their ability to bear loads, increasing the risk of failure. In extreme heat, dehydration of concrete occurs, with moisture loss leading to shrinkage, cracking, and reduced long-term durability. Furthermore, material degradation accelerates in high-temperature environments, promoting chemical reactions such as steel corrosion and the deterioration of adhesives and protective coatings, which can undermine structural performance over time. These challenges necessitate careful material selection and design considerations in high-temperature regions.

How does the high temperature affect the physical and chemical properties of construction materials commonly used in Niger?

- High temperatures significantly impact various construction materials, compromising their structural performance and durability. Concrete experiences moisture loss under heat, leading to reduced strength and an increased risk of cracking, with prolonged exposure breaking down the cement paste. Steel reinforcement weakens under high temperatures, losing yield strength and elongation capacity, which jeopardizes its load-bearing ability. Masonry materials like clay bricks undergo thermal expansion, often resulting in cracks and structural instability. Wood suffers from dehydration, leading to warping, splitting, and a diminished capacity to bear loads. Similarly, asphalt pavements soften in the heat, reducing their load-bearing capacity and making them prone to rutting and deformation. These effects underscore the necessity for tailored material selection and protective measures in high-temperature environments**.**

What mitigation strategies are currently used to address high-temperature-induced structural problems, and how effective are they?

- The use of heat-resistant materials, such as specially formulated concrete mixes with supplementary elements like fly ash, silica fume, or slag, plays a crucial role in enhancing structural durability in high-temperature environments. Thermal insulation through methods like applying insulative coatings, reflective paints, and adding insulating layers effectively shields structures from direct heat exposure, minimizing thermal stress. Expansion joints, when properly designed, allow for controlled thermal movement, significantly reducing the risk of cracking caused by temperature fluctuations. Additionally, incorporating shading structures and optimizing natural ventilation systems help mitigate heat buildup, improving both indoor comfort and the resilience of the building. Furthermore, protective measures, including the application of anti-corrosion treatments and heat-resistant paints, safeguard materials like steel from degradation, extending their service life and ensuring structural integrity**.**

What recommendations can be made to improve the design, material selection, and construction practices in high-temperature regions like Niger?

- To ensure resilience in high-temperature environments, a comprehensive approach to construction is essential. Material selection should prioritize options like geopolymer concrete and fiber-reinforced composites, which are specifically designed to withstand extreme heat. Adapted design features, such as overhangs, shaded windows, and ventilated facades, can minimize heat impact on buildings. Innovative technologies, including the use of phase-change materials, offer advanced solutions for regulating thermal loads. Additionally, optimizing local materials that are naturally heat-resistant and cost-effective can enhance sustainability while reducing expenses. Effective construction practices, such as scheduling work during cooler periods, ensuring proper curing of concrete, and applying heat-resistant coatings, further bolster structural integrity. Finally, regular inspection and maintenance plans are critical for promptly addressing heat-induced damages and prolonging the lifespan of structures.

5.2 Recommendations

To further enhance the resilience of construction structures to high temperatures, future research should focus on:

5.2.1 Development of New Materials:

- Research into new materials with enhanced high-temperature performance is crucial.

- Investigating the long-term behavior of these materials under cyclic thermal loads.

The assessment of construction structure problems in high-temperature environments highlights the critical need for innovative approaches in material science, design practices, and construction techniques. By addressing the challenges identified in this study, the construction industry can improve the safety, durability, and resilience of structures, ensuring they can withstand the adverse effects of high temperatures. The findings underscore the importance of ongoing research, interdisciplinary collaboration, and the implementation of stringent construction standards to safeguard infrastructure in the face of rising global temperatures and increasing fire risks.

5.2.2 Improved design models

- Developing more accurate predictive models for material behavior under high temperatures.
- Incorporating real-world data from fire incidents and extreme temperature events to validate these models.

5.2.3 Field studies and monitoring

- Conducting field studies to monitor the performance of structures in high-temperature environments.
- Implementing sensor technologies to provide real-time data on structural health and temperature effects.

5.2.4 Interdisciplinary approaches

- Collaborating with fire safety engineers, materials scientists, and climate experts to develop holistic solutions.
- Exploring the integration of smart technologies, such as automated fire suppression systems and adaptive insulation.
- Provide continuous training for engineers, architects, and construction personnel on the latest techniques and materials for high-temperature construction.

- Promote awareness of the challenges and solutions related to construction in high-temperature environments through workshops, seminars, and publications.
- Implementing these recommendations will help mitigate the adverse effects of high temperatures on construction structures, enhancing their safety, durability, and performance.

5.3 Limitation of the Thesis

While this study provides valuable insights into the impact of high temperatures on construction structures in Niger, it is important to acknowledge its limitations, which may influence the scope, depth, and generalizability of its findings. Firstly, there is limited data availability on the specific effects of high temperatures on construction materials and structures in Niger, stemming from a lack of comprehensive local research, minimal records of structural failures, and insufficient climatic data capturing regional variations. Secondly, the study may overgeneralize findings due to Niger's diverse climatic zones, where desert and semi-arid regions experience different temperature extremes. Additionally, the focus on existing materials and traditional practices excludes innovative materials and modern construction techniques that could offer alternative solutions. Temporal constraints further restrict the study, as long-term structural degradation caused by heat is difficult to assess within the study’s time frame, and there is a lack of longitudinal studies to predict cumulative effects. Experimental limitations, such as limited access to advanced facilities and challenges in replicating real-world conditions, also reduce the comprehensiveness of the findings. Furthermore, economic and socio-cultural factors, including cost constraints and local traditions, are not fully integrated, potentially limiting the practicality of proposed strategies. Comparative analysis with regions facing similar conditions is minimal, which could have provided valuable context or alternative approaches. Lastly, while the study suggests mitigation strategies, it does not deeply explore the policy and implementation challenges within Niger’s infrastructural and governance context, leaving a gap in actionable recommendations

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RESUME

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