ENHANCING THERMAL COMFORT FOR DIVERSE USERS IN THE PROPOSED DEVELOPMENT OF GEORGIA SQUARE MALL, ATHENS, GA: ASSESSING OUTDOOR ELEMENTS TO MITIGATE THERMAL DISCOMFORT IN MIXED-USE CONTEXT

by

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(Under the Direction of Ashley Steffans)

ABSTRACT

This thesis examines optimizing thermal comfort in the forthcoming Georgia Square Mall development in Athens, Georgia, with a focus on outdoor elements in a mixed-use context. Using advanced ENVI-met modeling, the project evaluates and enhances various environmental factors impacting thermal comfort, including site orientation, landscape design, shading, and natural features like plants and water. Prioritizing user needs, the design process emphasizes adaptability, flexibility, and inclusivity. By integrating microclimate solutions and sustainability principles, the thesis proposes a methodology to enhance thermal comfort. Simulations using ENVI-met will validate the effectiveness of the design interventions. Ultimately, the study contributes practical insights to landscape architecture and urban design, aiming to create inviting outdoor environments in similar projects.

INDEX WORDS: Thermal comfort, Georgia Square Mall, Environmental Modeling, Physiological environmental temperature, Vegetation, Paving material, Water bodies, Shading

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GLOSSERY

1. **Albedo**: The measure of a surface's reflectivity, indicating how much solar radiation it reflects back into the atmosphere. A higher albedo means more reflection, leading to cooler surface temperatures, while a lower albedo indicates more absorption of solar energy and warmer temperatures.

2. **ENVI-met**: A sophisticated microclimate simulation software used to model and analyze the thermal environment of outdoor spaces, incorporating factors such as terrain, vegetation, buildings, and atmospheric conditions.

3. **Microclimate**: The climate of a small, localized area, influenced by factors such as topography, vegetation, and human activities, which can differ from the broader regional climate.

4. **Mixed-Use Development**: A type of urban development that blends residential, commercial, cultural, institutional, or industrial uses, where those functions are physically and functionally integrated.

5. **Simulation-based Analysis**: An analytical approach that utilizes computer simulations or models to predict and analyze the behavior of complex systems, such as outdoor thermal environments, under different scenarios or conditions.

6. **Thermal Comfort**: The state of satisfaction or dissatisfaction of an individual with the thermal environment, influenced by factors such as temperature, humidity, air temperature, and radiant heat.

7. **Urban Heat Island Effect**: The phenomenon wherein urban areas experience higher temperatures than surrounding rural areas due to human activities, such as the concentration of buildings, roads, and other heat-absorbing infrastructurE

CHAPTER 1: INTRODUCTION

1.1 THESIS MOTIVATION

Urban growth is an ever-evolving tapestry, characterized by a complex interplay of historical context, environmental considerations, and the desires of diverse communities. With the redevelopment of Georgia Square Mall in Athens, Georgia, the opportunity of shaping the future of this community hub beckons us to delve into a realm of exploration, enlightenment, and change.

The history of Georgia Square Mall, from its inception to the present day, reflects not only the evolution of retail and commercial spaces but also resonates with the local community. This redevelopment, poised to reshape the spatial configuration of the mall, presents a providential moment to weave a narrative that merges the past, present, and the future. The significance of this attempt extends beyond architectural blueprints; it encapsulating the core values of community, belonging, and the quest of an urban landscape that aligns with the diverse needs and aspirations of the area's residents.

Embedded within this overarching narrative is the pressing issue of outdoor thermal comfort—an understated yet pivotal factor that can positively influence the way communities engage with their environment. The motivation to undertake this thesis is rooted in the recognition of a significant gap in our understanding of how the external spaces of mixed-use developments, such as the proposed Georgia Square Mall, can be optimized for thermal comfort. This gap isn't just theoretical; it represents a real challenge that, if unresolved, might undermine the potential of this redevelopment to cultivate a truly inclusive and fulfilling community experience.

The potential to deepen our understanding of the microclimate dynamics that shape outdoor spaces, and drawing insights from historical contexts and analogous projects, pushes this research forward. We are motivated by the desire to transcend conventional boundaries in urban design and landscape architecture, to not only meet but exceed the expectations of the community. The envisioned outcomes extend beyond the borders of Athens, offering a methodology and insights that can resonate with similar projects seeking to navigate the delicate balance between aesthetics, functionality, and user well-being.

This research is urgent because it underscores the commitment to creating outdoor spaces that are aesthetically pleasing, comfortable, adaptable, and welcoming. It goes beyond academic pursuit; it is a call to action and a demonstration of our responsibility as stewards of urban development to create outdoor spaces that are not only aesthetically pleasing but also comfortable, adaptable, and welcoming. As we embark on this journey, equipped with advanced modeling tools this research endeavors to contribute not just to the fields of landscape architecture and urban design but to the very fabric of community life in Athens and beyond.

1.2 PROBLEM STATEMENT

The redevelopment plans of Georgia Square Mall in Athens, Georgia, presents a significant challenge in optimizing thermal comfort within its mixed-use setting. Thermal Comfort refers to the state of satisfaction or dissatisfaction of an individual with the thermal environment, influenced by factors such as temperature, humidity, air temperature, and radiant heat. Despite the increasing emphasis on creating versatile spaces that cater to diverse user needs, there is a gap in understanding and addressing the intricate environmental factors influencing outdoor thermal comfort. Without a structured approach to evaluating and enhancing these factors poses a potential hindrance to the development's success in providing a pleasant and inclusive outdoor environment. Therefore, a thorough examination of how site layout, landscaping, shade, materials, and natural elements interact to regulate temperature is essential.

At present, there is a notable absence of a widely applicable approach within landscape architecture and urban design that is designed to effectively optimize outdoor thermal comfort in mixed-use projects. This study seeks to address this deficiency by utilizing sophisticated modeling methods, notably the ENVI-met software, to evaluate and improve thermal comfort within the Georgia Square Mall development.

By developing and simulating design interventions, this thesis seeks to not only contribute a valuable method for addressing the thermal comfort challenges specific to the external areas of Georgia Square Mall but also to offer insights and tactics that can be applied to similar projects with outdoor spaces.

Through this endeavor, the research aspires to make a substantial and focused contribution to advancing knowledge in the realms of landscape architecture and urban design, with a particular emphasis on the enhancement of outdoor thermal comfort in mixed-use settings.

1.3 RESEARCH QUESTIONS

1. What is the impact of microclimate conditions and other environmental elements on thermal discomfort in outdoor areas of the proposed Georgia Square Mall development?

2. In a mixed-use setting like the one for the proposed development, what design elements—such as water features, landscaping, shading, and material selection—can successfully reduce temperature discomfort?

1.4 RESEARCH OBJECTIVES

1.4.1 Comprehensive Assessment of Environmental Parameters

Investigate and analyze the environmental parameters influencing outdoor thermal comfort in the planned development of Georgia Square Mall. This encompasses a comprehensive assessment of factors such as site orientation, landscaping strategies, shading techniques, material selection, and the influence of natural elements on temperature control.

1.4.2 Development of Specialized Methodology

Develop and implement a structured and customized approach, specifically designed to enhance thermal comfort in the outdoor environments of mixed-use developments. This method seeks to tackle the distinct obstacles posed by the external spaces of the Georgia Square Mall.

1.4.3 Utilization of Advanced Modeling Techniques

Utilize sophisticated modeling methods, with a focus on utilizing the ENVI-met software, to comprehensively analyze the thermal dynamics of outdoor areas. This process will offer a foundational understanding of the current complexities and potentials.

1.4.4 Simulation of Design Interventions

Create and simulate specific design strategies to improve outdoor thermal comfort, using the ENVI-met software to forecast the effects of these modifications. These simulations will offer tangible evidence of the effectiveness of the proposed design interventions.

1.4.5 Transferable Insights for Similar Projects

Extract generalizable insights and tactics from the research findings that can be applied to similar projects with outdoor spaces in mixed-use developments. Provide a framework that transcends the specifics of Georgia Square Mall, contributing to the broader discourse in landscape architecture and urban design.

1.4.6 Validation of Methodology through Simulation Results

Validate the developed methodology by assessing the simulated results of the proposed design interventions. Demonstrate the expected gains in thermal comfort through quantitative and qualitative analysis, ensuring the reliability and effectiveness of the methodology.

1.4.7 Contribution to Knowledge in Landscape Architecture and Urban Design

Make a substantial contribution to the fields of landscape architecture and urban design by addressing the gap in knowledge specific to optimizing thermal comfort in the external spaces of mixed-use developments. Provide valuable insights that can inform future research and practical applications in similar contexts

1.5 SCOPE AND LIMITATIONS

1.5.1 Scope

- Outdoor Thermal Comfort in Mixed-Use Settings

  The primary focus of the thesis is to optimize outdoor thermal comfort within the mixed-use setting of the planned development of Georgia Square Mall. The scope extends to the external areas, encompassing open spaces, walkways, and gathering points.

- Environmental Parameters

  The research will comprehensively investigate and address environmental parameters that influence thermal comfort, including but not limited to site orientation, landscape design, shading, materials, and the impact of natural elements on temperature regulation.

- Advanced Modeling Techniques

  Advanced modeling techniques, particularly utilizing the ENVI-met software, will be employed to simulate the thermal conditions, propose design interventions, and assess the expected gains in thermal comfort.

- Transferable Insights

  The research aims to provide insights and tactics that are transferable to similar projects with outdoor spaces in mixed-use developments. The scope includes the development of a methodology that can be adapted to different contexts.

1.5.2 Limitations

- Site-Specific Context

  The findings and recommendations of this thesis are specific to the planned development of Georgia Square Mall in Athens, Georgia. While efforts will be made to extract transferable insights, the site-specific context may limit the generalizability of certain recommendations.

- Simulation-based Analysis

  The thesis heavily relies on simulation results generated through the ENVI-met software. While simulations provide valuable insights, they may not fully capture the real-world complexity of all variables, and actual implementation may yield different results.

- Resource Constraints

  The scope of the thesis may be constrained by resource limitations, influencing the depth and extent of data collection, modeling, and simulations. These constraints may impact the comprehensiveness of the study.

- Regulatory and Zoning Factors

  The research will consider environmental factors, but regulatory and zoning constraints may influence the feasibility of certain design interventions. The thesis will acknowledge thesis constraints but may not provide exhaustive solutions with regulatory frameworks.

- External Factors Impacting Thermal Comfort

  While the thesis considers a range of environmental parameters, it may not comprehensively cover all external factors (e.g., socio-economic factors, cultural preferences) that could influence thermal comfort in outdoor spaces.

- Single Software Utilization

  The exclusive use of ENVI-met software for simulations may limit the exploration of alternative modeling tools. While ENVI-met is a robust tool, the choice to focus on a single software application may restrict the diversity of simulation perspectives.

Acknowledging this scope and these limitations, the research aims to make a meaningful contribution to the understanding and enhancement of outdoor thermal comfort in mixed-use developments, particularly in the context of the Georgia Square Mall project

CHAPTER 2: BACKGROUND AND RESEARCH

2. BACKGROUND AND RESEARCH

2.1 Understanding Thermal Comfort

Thermal comfort is a subjective measure of satisfaction with the thermal environment, encompassing factors such as temperature, humidity, air velocity, radiant heat, and clothing choices. Achieving optimal thermal comfort is imperative for fostering a sense of well-being and community engagement within mixed-use developments. When the surrounding temperature is very hot or very cold, the human body regulates and maintains the body temperature to remain in the range between 36.5˚C and 37.5˚C, and this process is called thermoregulation. Around 60% of the energy produced through the ATP (adenosine triphosphate) process by the body cells is converted to heat to regulate and maintain the core body temperature.

The achievement of thermal comfort in mixed-use developments hinges on a nuanced understanding of temperature and microclimate dynamics. The ambient temperature, coupled with microclimate conditions, serves as a linchpin in determining the overall comfort of outdoor spaces. Proper regulation of and meticulous attention to these factors are paramount for creating environments that cater to the diverse thermal needs of community members. Equally crucial is the influence of design and land use on thermal conditions within mixed-use developments. The layout and architectural design play pivotal roles, with thoughtful integration of green spaces, water features, and diverse structural elements contributing significantly to the overall comfort of the environment. This underscores the importance of strategic planning and sustainable design practices in optimizing thermal conditions. Additionally, the adoption of user-centric design principles should be a fundamental consideration.

Acknowledging the varied preferences and needs of the community, user-centric design ensures that outdoor spaces are not only comfortable but also inclusive, adaptable, and responsive to the diverse thermal requirements of the residents. In amalgamating these factors, mixed-use developments can foster environments that prioritize thermal comfort, contributing to the overall well-being and satisfaction of the community.

The regulation of ambient temperature and microclimate conditions in mixed-use developments yields both positive and negative impacts on the overall thermal comfort of outdoor spaces. On the positive side, meticulous attention to these factors fosters environments that are conducive to comfort and well-being. The strategic integration of green spaces, water features, and diverse architectural elements plays a crucial role in enhancing overall comfort. These elements not only contribute to aesthetic appeal but also provide shaded areas, cooling effects, and optimal ventilation, creating outdoor spaces that cater to the diverse thermal preferences of the community. However, challenges arise in the form of potential negative impacts. High-density development may inadvertently contribute to the urban heat island effect, elevating temperatures and compromising thermal requirements. In navigating these dynamics, mixed-use developments can strike a balance, creating outdoor environments that are not only aesthetically pleasing but also prioritize the thermal comfort and satisfaction of the community.

2.2 History of Georgia Square Mall

According to the Anderson Independent newspaper published on 12th Feb 1981, the mall was inaugurated in 1981. This two-story mall was initially recognized for its design elements, such as the foil-copper look of the entrance leading to Belk. It stood out as one of the largest malls in a more rural setting when it was constructed. According to W&A Engineering's Master Planned Development Application Report, the mall debuted with anchor stores Belk, Davison's, Sears, and JCPenney, all of which had relocated from downtown Athens (W&A Engineering, 2022).

As per the Georgia Square Mall Website, the mall underwent renovations in 2007, updating both the exterior entrances and the interiors. However, despite two makeovers, the mall largely maintains its original character. The only change among the anchor stores was the transformation of Davison's to Macy's in 1986, followed by Rich's in 1988, then Rich's to Macy's in 2003, and back to Macy's in 2005. Macy's closed its doors in February 2017 (Online Athens, 2017). Kely Tokyo wrote on US Today that in August 2019, Sears announced its closure as part of a plan to shut down 26 stores. JCPenney also revealed its closure in June 2020, shutting its doors in October 2020. Subsequently, Belk became the sole remaining anchor store.

Additionally, Romeo in his article "SkyMall : Retail History and Abandoned Airports: Georgia Square Mall, Athens, GA" provides insights into the mall's history and renovations (Romeo, 2008).

In early 2022, a local construction company in Athens proposed a mixed-use development for the mall site. The plan included over 1000 residential apartments and nearly 100,000 square feet of new retail and restaurant space. While some existing retail spaces, including Belk, would be retained, the majority of the mall would be demolished.

2.2.1 Georgia Square Mall Development in Athens, Georgia

The Georgia Square Mall, situated in the west of Athens, Georgia, has long served as a prominent retail and social hub within the community (The Atlanta Journal, 1979). The origins of the Georgia Square Mall can be traced back to its establishment in 1981, marking a significant milestone in the local history of Athens, Georgia (Anderson Independent, 1981). Initially conceived as a retail destination, the mall emerged in response to the growing demand for centralized shopping experiences (Anderson Independent, 1981). Its strategic location in the west of Athens positioned it as a convenient and accessible hub for residents seeking a diverse range of goods and services (Anderson Independent, 1981). The mall is situated 5 miles to the west of downtown Athens, and the driving distance can be covered in about 10-15 minutes (Anderson Independent, 1981).

Over the years, the Georgia Square Mall has undergone several transformative phases, each reflective of broader societal and economic shifts (Masters, 2016). When the mall was opened in 1981, it functioned primarily as a retail destination, providing a centralized location for residents to fulfill their shopping needs (Anderson Independent, 1981). This initial phase mapped to the prevailing retail landscape at the time, characterized by standalone department stores and a focus on transactional commerce (Anderson Independent, 1981).

As societal and economic dynamics underwent significant shifts, so did the Georgia Square Mall (Masters, 2016). Recognizing the need to evolve beyond a traditional retail framework, the mall embarked on a transformative journey (Masters, 2016). Expansions, both in terms of physical space and offerings, became pivotal (Masters, 2016). The mall underwent structural modifications to accommodate a broader range of services and experiences beyond retail, marking a departure from its initial singular focus (Masters, 2016).

The mall's evolution was not confined to mere physical expansion; it was accompanied by a strategic integration of new features and amenities (Masters, 2016). The diversification of the retail mix involved attracting a broader array of stores, ranging from traditional department stores to boutique shops, reflecting changing consumer tastes (Masters, 2016). Entertainment venues, including cinemas and arcades, were introduced to create a more immersive and diversified leisure experience (Masters, 2016). The incorporation of entertainment facilities, such as cinemas, gaming arcades, and event spaces contributed to making the mall a one-stop destination for leisure and social activities (Masters, 2016). Dining establishments became integral components, transforming the mall into a destination not only for shopping but also for socializing and culinary exploration (Masters, 2016).

In response to the digital age, the Georgia Square Mall also embraced technological advancements to enhance the shopping experience (Masters, 2016). The integration of online connectivity, interactive displays, and digital interfaces became essential components of the mall's offerings (Masters, 2016). These technological innovations aimed to not only streamline transactions but also to create a more engaging and interactive environment for visitors (Masters, 2016).

The transformative phases were characterized by a community-centric approach, wherein the mall actively sought feedback from residents and adapted its offerings accordingly (Masters, 2016). This responsiveness to the evolving needs and preferences of the community reinforced the mall's role as a dynamic space that reflected the pulse of Athens, Georgia (Masters, 2016). The mall actively engaged with the community through surveys, focus groups, and events to gauge preferences, ensuring that the transformations resonated with the local population (Masters, 2016).

Beyond catering to changing consumer preferences, economic considerations played a crucial role in the mall's transformations (Masters, 2016). Adapting to shifts in the local and regional economy, the Georgia Square Mall strategically positioned itself to remain a viable and thriving entity (Masters, 2016). This adaptability showcased a proactive approach to economic fluctuations, ensuring the sustained relevance of the mall within the community (Masters, 2016). Strategic business decisions, market analysis, and economic forecasting were pivotal in guiding the mall's transformations, ensuring its sustainability in the face of economic changes (Masters, 2016).

2.2.2 Redevelopment of Georgia Square Mall

The Athens-Clarke County Commission, on March 7, 2023, granted unanimous approval to W&A Engineering's ambitious $650 million redevelopment plan for Georgia Square Mall, located on Atlanta Highway in west Athens, Georgia (Mather, 2023). Spanning 74.77 acres, this redevelopment is touted as the largest in the city's history (Mather, 2023).

W&A Engineering's Athens Director of Operations, Scott Haines, expressed elation at the overwhelming support received from Athens-Clarke County citizens, and the unanimous passage of both the site plan and the Community Benefits Agreement is recognized as a significant achievement after months of dedicated efforts (Mather, 2023).

In addition to the comprehensive site plan gaining unanimous approval, the Athens-Clarke County Commission also passed a Tax Allocation District (TAD)/ Community Benefits Agreement unanimously (Mather, 2023). The Georgia Square Mall Redevelopment TAD, a tool designed to finance development costs by reinvesting property tax revenue, will channel $189 million back into the project over the next 30 years (Mather, 2023). This marks the first instance of a Tax Allocation District being employed in Athens-Clarke County, promising avenues for affordable housing, green spaces, transportation infrastructure, and other community benefits outlined in the plan (Mather, 2023).

2.2.3 Significance of Development

Revitalization and Re- Imagination

The proposed development marks a new chapter in the history of the Georgia Square Mall. It represents a deliberate effort to revitalize and reimagine the space, aligning it with contemporary urban development principles. The aim is not only to meet the immediate needs of the consumers but also to create an enduring and adaptive environment that can accommodate the multifaceted demands of a diverse community.

Mixed-Use Vision

The emphasis on mixed-use development signals a departure from traditional retail-centric models. The vision for the Georgia Square Mall extends beyond being a shopping destination; it aspires to be a dynamic blend of commercial, recreational, and communal spaces. This forward-thinking approach aligns with a growing awareness of the importance of creating integrated environments that cater to various aspects of community life.

Addressing Evolving Community Needs

In the context of Athens' evolving demographic and cultural landscape, the redevelopment of the Georgia Square Mall acknowledges the need to stay attuned to changing community needs. By embracing a mixed-use model, the development aims to create a destination that appeals to the broad spectrum of users, and ensuring that the space remains relevant and vibrant over time.

2.2.4 Specific Challenges and Opportunities in the Proposed Development

Integrating Nature and Urban Design:

The integration of outdoor spaces within a mixed-use development offers a unique opportunity to harmonize nature with urban design. However, it also presents challenges related to microclimate dynamics. Balancing green spaces, water features, and architectural elements to enhance aesthetics while mitigating thermal discomfort requires a thoughtful and integrated approach.

Microclimate Considerations:

The Georgia Square Mall's outdoor areas are subject to a range of environmental factors that influence thermal comfort. These include sunlight exposure, wind patterns, and the impact of surrounding structures. Understanding and addressing these microclimate conditions are crucial for creating outdoor spaces that are enjoyable year-round.

Sustainability and Resilience:

In the face of global climate concerns, the development must embody sustainable and resilient design principles. This involves selecting materials, landscaping, and architectural features that not only enhance thermal comfort but also contribute to the ecological well-being of the surrounding environment.

2.3 Environmental Factors Affecting Thermal Comfort

2.3.1 Role of Green Space in Enhancing Thermal Comfort:

Green areas have become useful instruments in urban settings for reducing the effects of rising temperatures and enhancing local residents' thermal comfort. Built-up green spaces have the capacity to affect both the local temperature and its immediate surroundings, which is known as their "cooling effect". The need to investigate sustainable solutions has intensified due to the trend of rising global temperatures, which is attributable to higher quantities of greenhouse gases in the Earth's atmosphere (Miller, 2008).

Research has regularly shown how effective green infrastructure is at lowering the urban heat island (UHI) impact. Examples of this infrastructure include parks, trees, forests, and green roofs (Lai, 2019). Green areas, especially urban woods and large parks, provide better thermal comfort; during the day, temperatures can drop by up to 0.94˚C (Bowler, 2010). The extent and arrangement of urban green spaces (UGS), where vegetation cover and tree shade areas are critical factors in defining their cooling effect and UHI reduction, are directly related to this beneficial effect (Jamei, 2016).

Thermal comfort is improved and ambient temperatures are lowered considerably when trees and other plants are present. The ground and air are actively cooled by evapotranspiration, or the release of water vapor through plant leaves, and shade. According to research, shaded locations might have temperatures that are 12 to 26°C colder than those that are not. Urban surfaces receive less direct solar radiation when trees and other plants provide shade. Buildings can also benefit from this shading effect, which lowers energy consumption by minimizing the need for air conditioning. This is in line with the ideas of improving thermal comfort in urban areas and leads to lowered pollution and greenhouse gas emissions as well as improved environmental sustainability (Aram, 2019).

Green areas play a crucial role in urban environments not only by reducing the effects of rising temperatures but also by contributing to environmental sustainability throughout the seasons. The seasonal changes of trees, particularly their shedding of leaves during winter, further enhance their environmental benefits. During the colder months, deciduous trees lose their leaves, allowing more sunlight to reach the ground and warm the surrounding areas, thus providing natural heating benefits.

2.3.2 Role of Water Bodies in Enhancing Thermal Comfort

It is imperative to ensure maximum thermal comfort in urban settings, considering the difficulties that come with high temperatures. By taking advantage of their natural cooling qualities, water features contribute significantly to the creation of a pleasant outdoor atmosphere.

These water features are considered fixed elements in urban environments that naturally moderate local temperatures. Water's higher specific heat capacity causes it to warm more slowly, which keeps the temperature down all day. One way to characterize the 'cooling oasis' effect produced by these water features is that their evaporation adds to their cooling effect.

The cooling capability of water features in urban settings is maximized by optimizing the surface area of fountains. These water features absorb and release extra heat, acting as effective heat sinks. The ability of water to evaporate continuously adds to a long-lasting cooling effect. Furthermore, evaporation modifies the energy dynamics by dissipating sensible heat and stored energy, which results in a noticeable drop in the immediate ambient air temperature.

Research employing remote sensing and computer modeling continually shows how effective water sources are at lowering temperature. Urban spaces that include well-planned fountains exhibit a cooling effect that reduces energy use and greatly improves outdoor thermal comfort.

In conclusion, water features—especially fountains—are essential for creating a more comfortable outdoor space because of their inherent cooling mechanisms. They also offer a sustainable, natural approach to temperature control.

2.3.3 Role of Albedo in Enhancing Thermal Comfort

Understanding how building materials affect thermal comfort requires an understanding of albedo, which is measured on a scale of 0 to 1. Albedo values indicate a material's reflectivity; a value of 0 denotes total solar absorption, while a value of 1 denotes 100% reflection. For example, new asphalt has an albedo of approximately 0.04; it barely reflects 4% of light, absorbing the other 96% and producing heat.

The light energy that materials take from the sun is transformed into heat energy, which raises the temperature of the material. This behavior is noticeable on warm

days, for example, when strolling across a heated asphalt parking lot. High albedo values play a crucial role in construction materials when it comes to thermal comfort.

The effects of albedo are more noticeable in highly populated regions because residents and buildings can work together to create an urban heat island effect, which is a localized rise in temperature. Lower surface temperatures are mostly maintained by materials with higher albedo, or more reflectivity. This characteristic can prove to be a useful tactic to lessen temperature discomfort, particularly in crowded areas.

By their very nature, reflective surfaces reflect a large percentage of incident solar radiation back, limiting the absorption that raises temperatures. The strategic consideration of albedo becomes important when aiming to maximize thermal comfort since it affects the choice of building materials and helps to create outdoor environments that are more comfortable.

CHAPTER 3: METHODOLOGY

3.1.1 Case Study 1: Redmond Tower Center, Washington, USA

Overview

Figure 1: Aerial View of Rendmod Tower Centre post Redevelopment

Originally developed as a traditional shopping mall in the late twentieth century, Redmond Town Center underwent a transformative journey in response to changing urban dynamics and community needs. Established in 1997, the mall played a significant role in the retail landscape of Redmond, providing a centralized location for shopping and socializing.

However, as consumer preferences evolved, the need for a more dynamic and community-oriented space became evident. In 2013, recognizing the potential for adaptive reuse, the visionaries behind Redmond Town Center embarked on a comprehensive redevelopment project. The aim was not only to revitalize the physical infrastructure but also to redefine the center's purpose, turning it into a mixed-use destination that embraced sustainability, connectivity, and enhanced outdoor experiences.

Design Considerations for Thermal Comfort

I. Green Spaces and Shading

The redevelopment introduced expansive central parks and landscaped areas, transforming the once-concrete landscape into a green oasis. The addition of native trees and vegetation not only provided shade but also paid homage to the region's natural beauty. The incorporation of central greenery and strategically placed trees is grounded in the need to mitigate the urban heat island effect, enhance visual appeal, and provide shade for visitors.

II. Water Features and Cooling Strategies

Reflecting a commitment to creating a comfortable microclimate, water fountains were strategically placed throughout the development. These features were not just functional but also served as artistic expressions, blending the practical with the aesthetic. Water features contribute to a cooling effect through evaporation, enhancing the overall microclimate and creating aesthetically pleasing focal points.

III. Sustainable Technologies

As part of the redevelopment, the inclusion of solar panels became a symbol of Redmond Town Center's commitment to sustainable practices. The adoption of renewable energy technologies reflected an understanding of the impact of traditional energy sources on local climates.

IV. User-Centric Approach

The redesign prioritized inclusivity and user comfort. Adaptable outdoor furniture arrangements were introduced to create flexible gathering spaces, which, along with accessible pathways cater to diverse user needs and preferences, promoting a sense of community.

Conclusion

Redmond Town Center's evolution from a traditional shopping mall to a vibrant mixed-use development is not just a story of physical transformation but also one of adapting to the evolving narrative of urban life. The historical context enriches the narrative, emphasizing how the center's legacy laid the foundation for a forward-thinking approach that prioritizes thermal comfort, sustainability, and community well-being in the heart of Redmond, Washington.

3.1.2 Case Study 2: Eastland, Victoria, Australia

Overview

Figure 2:View of Eastland Victoria, Australia post Redevelopment

Originally established as a traditional shopping center, Eastland in Ringwood served as a local retail hub for decades. However, recognizing the changing dynamics of urban living, the need for sustainable development, and a desire to create a vibrant community space, Eastland underwent a comprehensive redevelopment. The aim was to transform the site into a modern, mixed-use destination that prioritizes not only shopping but also an enhanced quality of life for visitors.

Design Considerations for Thermal Comfort

I. Green Spaces and Shading

   Eastland introduced a central open-air park with native Australian trees and plants, creating a shaded oasis for shoppers. The carefully selected vegetation not only provides visual appeal but also contributes to cooling the surrounding areas, making outdoor spaces more comfortable.

II. Building Materials and Orientation

   The rooftop of Eastland features cool roofing materials that reflect sunlight and reduce heat absorption. Additionally, the orientation of newly constructed buildings is designed to maximize natural shading, with taller structures strategically placed to cast shadows over outdoor gathering spaces during peak sun hours.

III. Water Features and Cooling Strategies

   A prominent water feature—a central fountain surrounded by seating areas—serves as a focal point within Eastland. The continuous flow of water not only enhances the aesthetic experience but also introduces a cooling effect, creating a comfortable microclimate around the feature.

IV. Sustainable Technologies

   Solar panels are integrated into the design, covering portions of the parking structures and providing a renewable energy source. Additionally, energy-efficient LED lighting throughout the development reduces heat generation and contributes to the overall sustainability of Eastland.

V. User-Centric Approach

Eastland’s outdoor spaces are furnished with adaptable seating arrangements, such as movable benches and chairs. Accessible pathways and ramps are strategically placed to ensure that visitors of all abilities can navigate the complex easily, promoting inclusivity and user satisfaction.

VI. Microclimate Monitoring and Adaptability

Weather stations installed on the rooftops continuously monitor temperature, humidity, and wind patterns. In response to particularly hot days, automated misting systems in outdoor seating areas are activated, providing instant relief and adapting to the changing microclimate.

Conclusion:

The redevelopment of Eastland in Ringwood exemplifies a holistic approach to enhancing thermal comfort within a mixed-use urban environment. By integrating green spaces, sustainable building materials, water features, and advanced technologies, Eastland has successfully created a vibrant and comfortable destination for visitors. The user-centric design approach ensures inclusivity and satisfaction for all, while microclimate monitoring and adaptability mechanisms ensure ongoing optimization of thermal conditions. Overall, Eastland serves as a model for sustainable and comfortable urban development, setting a benchmark for future projects aiming to prioritize the well-being of their communities.

3.1.3 Case Study 3: CityPalace, Toronto, Ontario, Canada

Overview

Figure 3: Development proposal of CityPalace

CityPalace in Toronto represents a visionary redevelopment project that aims to transform a central area of the city into a mixed-use destination. The historical significance of the site, combined with the need for sustainable urban living, has driven the project's commitment to enhancing thermal comfort and overall livability for its residents and visitors.

Design Considerations for Thermal Comfort

I. Green Spaces and Shading

   CityPalace integrates a central park with a diverse selection of trees such as native maples and oaks, providing shade and contributing to the reduction of the urban heat island effect. The use of permeable pavements and green roofs further enhances the cooling effect.

II. Building Materials and Orientation

The buildings in CityPalace feature cool roofing materials, like reflective membranes, to minimize heat absorption. The orientation of structures is optimized to maximize natural shading, with the placement of high-performance glazing and external shading devices to control solar gain.

III. Water Features and Cooling Strategies

A water feature, perhaps a reflective pool or cascading fountain, is strategically placed within CityPalace. This feature not only adds aesthetic value but also contributes to cooling through evaporative processes. Recirculation systems ensure water sustainability.

IV. Sustainable Technologies

CityPalace incorporates advanced building systems, including solar panels on rooftops, to harness renewable energy. Energy-efficient HVAC systems are utilized, with materials such as low-emissivity glass promoting insulation and reducing heat transfer.

V. User-Centric Approach

Adaptable outdoor spaces in CityPalace feature modular and ergonomic furniture made from recycled materials. Accessibility is ensured through ramps, smooth pathways, and inclusive seating arrangements, promoting a comfortable and welcoming environment for everyone.

VI. Microclimate Monitoring and Adaptability

The rooftops of CityPalace host weather stations and sensors that continuously monitor temperature, humidity, and wind patterns. Responsive technologies, like automated louvers and shading systems, adapt to changing weather conditions to maintain optimal thermal comfort

Conclusion:

The CityPalace redevelopment project in Toronto embodies a forward-thinking approach to urban development, integrating sustainability and thermal comfort into its design principles. By prioritizing green spaces, utilizing sustainable building materials, and implementing user-centric design elements, CityPalace demonstrates a commitment to creating a livable and enjoyable environment for both residents and visitors. The incorporation of advanced technologies for microclimate monitoring and adaptability further enhances the project's ability to maintain optimal thermal comfort throughout changing weather conditions Overall, CityPalace sets a precedent for future urban developments, showcasing the potential to harmonize historical significance, sustainability, and human centric design in modern cityscapes.

3.2 COMPARATIVE ANALYSIS

a. Temperature Distribution

The approaches to temperature distribution in Eastland, Redmond Tower Center, and CityPalace illustrate diverse strategies for mitigating thermal discomfort. Eastland's reliance on native vegetation, Redmond Town Center's strategic building orientation, and CityPalace's emphasis on adaptable outdoor spaces suggest unique and promising approaches to temperature control.

b. Solar Exposure

Insights into distinct solar exposure strategies emphasize how Eastland's cool roofing materials, Redmond Town Center's optimized building orientation, and CityPalace's diverse shading elements address solar radiation. The potential effectiveness of these strategies showcases the importance of tailored, solar-conscious design based on the local context.

c. Wind Patterns

Nuanced wind patterns in Eastland, Redmond Town Center, and CityPalace highlight the theoretical benefits of natural windbreaks, strategic building orientations, and responsive technologies. These conceptual approaches underscore the importance of optimizing wind comfort based on the specific urban context.

d. Vegetation Impact

The potential role of vegetation in microclimate regulation is underscored. Eastland's native Australian trees, Redmond Town Center's incorporation of local flora, and City Palace's diverse tree selection suggest the significant impact of vegetation on shade provision and evapotranspiration, contributing to potential thermal comfort.

e. Water Features and Evaporation

Illustrating the potential cooling effects of water features in Eastland, Redmond Town Center, and CityPalace, the recirculation systems in Eastland, diverse water elements in Redmond Town Center, and integrated water feature in CityPalace showcase promising strategies for harnessing evaporation and enhancing microclimate comfort.

f. Building Thermal Effects

The theoretical influence of building design on microclimates is highlighted. Eastland's cool roofing materials, Redmond Town Center's optimized orientation, and City Palace's strategic building design suggest tailored approaches to minimize heat absorption and regulate thermal effects in outdoor spaces.

g. Adaptive Strategies

The potential efficacy of adaptive strategies in Eastland, Redmond Town Center, and CityPalace is emphasized. Misting systems in Eastland, automated shading in

Redmond Town Center, and responsive technologies in CityPalace highlight dynamic approaches to maintaining optimal thermal conditions in changing weather scenarios.

h. User-Centric Comfort

Emphasizing the importance of user-centric design for outdoor comfort, the adaptable outdoor furniture in Eastland, inclusive pathways in Redmond Town Center, and ergonomic design in CityPalace suggest diverse yet intentional approaches to enhancing the overall experience and comfort of users.

i. Rainwater Absorption

Illustrating the potential impact of rainwater absorption strategies in Eastland, Redmond Town Center, and CityPalace, the permeable pavements in Eastland, green roofs in Redmond Town Center, and water feature in CityPalace showcase varied approaches to managing rainwater and contributing to sustainable design.

j. Microclimate Variability

The consideration of microclimate variability across different periods in Eastland, Redmond Town Center, and CityPalace underscores the potential need for adaptable design solutions, emphasizing the importance of temporal factors in optimizing thermal comfort.

In conclusion, the comparative analysis of temperature distribution, solar exposure, wind patterns, vegetation impact, water features and evaporation, building thermal effects, adaptive strategies, user-centric comfort, rainwater absorption, sustainability metrics, and microclimate variability across the case studies has provided valuable insights into diverse design strategies for optimizing outdoor thermal comfort. To further refine and validate these insights, the focus will now shift to selecting key factors, such as temperature distribution, solar exposure, and adaptive strategies, for in-depth analysis through advanced modeling tools. The utilization of tools like ENVI-met will allow for a more granular examination of these chosen factors providing a comprehensive understanding of their impact on the microclimate and aiding in the development of targeted design interventions for the Georgia Square Mall redevelopment.

Aspect	Eastland, Victoria, Australia	Redmond Tower Centre, WA,USA	CityPalace, Toronto, Canada
Temperature Distribution	Relies on native vegetation for cooling effect	Strategic building orientation for shade	Diverse tree selection for shade provision
Solar Exposure	Cool roofing materials to reduce heat absorption	Optimized building orientation for solar gain control	Reflective membranes on buildings for reduced heat absorption
Wind Patterns	Utilizes strategic building placement for windbreaks	Responsive technologies for wind comfort	Optimized building design for wind flow
Vegetation Impact	Relies on native Australian trees for shade and evapotranspiration	Incorporates local flora for shade provision	Diverse tree selection for shade and cooling
Water Features and Evaporation	Includes water fountains for cooling effect	Utilizes diverse water elements for evaporation	Integrated water features for cooling and aesthetics
Building Thermal Effects	Features cool roofing	Optimized building design to reduce	Reflective membranes on

	materials to minimize heat absorption	heat transfer	buildings for heat reduction
Adaptive Strategies	Employs misting systems for instant relief	Utilizes automated shading for temperature control	Implements responsive technologies for optimal thermal conditions
User-Centric Comfort	Furnished with adaptable seating for user satisfaction	Offers inclusive pathways for accessibility	Features ergonomic design for user comfort
Rainwater Absorption	Utilizes permeable pavements for rainwater management	Incorporates green roofs for rainwater absorption	Includes water features for rainwater utilization
Sustainability Metrics	Integrates solar panels for renewable energy	Incorporates renewable energy technologies	Utilizes solar panels for sustainable energy
Microclimate Variability	Monitors temperature, humidity, and wind patterns for adaptability	Utilizes weather stations for real-time data	Implements weather sensors for dynamic adjustments

Table 1: Comparative Analysis table for Case Studies

3.3 ABOUT ENVI-MET

The ENVI-met software is publicly accessible on the internet (www.envi-met.com). The "Student Version" was employed in this thesis. In order to portray urban structure, ENVI-met layers the DEM, surface structures, vehicles, and vegetation to build a 3D model region input file. The same important characteristics present in semantic 3D models are reflected in these elements.

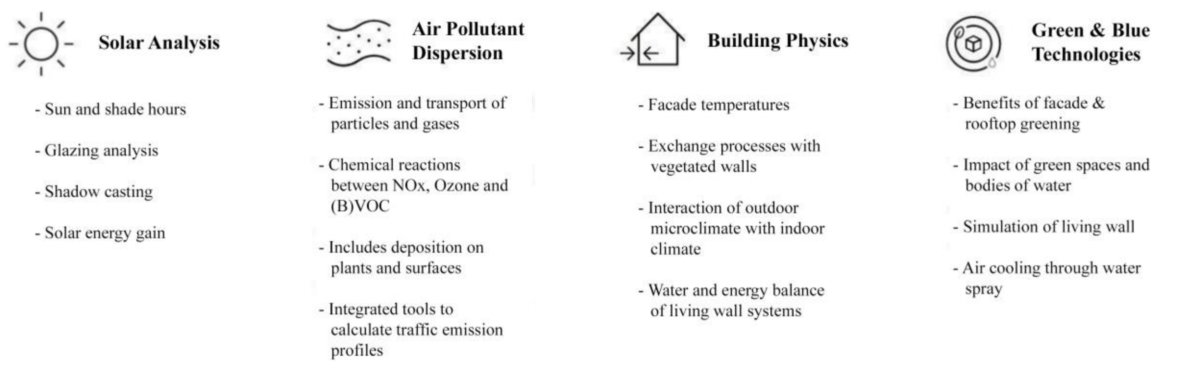

Figure 4: Features of ENVI-met

Environmental research, architecture, landscape architecture, and urban planning all make extensive use of ENVI-met, a sophisticated microclimate modeling program. ENVI-met, created by the Danish Meteorological Institute (DMI), enables users to model and examine the intricate relationships that exist between different environmental elements in both urban and rural areas.

The capacity of ENVI-met to model microclimate at a high degree of detail, accounting for variables including solar radiation, wind patterns, temperature distribution, and vegetation cover, is one of its primary characteristics. Users may precisely evaluate air quality, thermal comfort, and other environmental aspects with ENVI-met since it provides an accurate representation of the physical properties of a given site.

ENVI-met simulates the effects of various design interventions or urban layouts on the local microclimate using sophisticated computational techniques and numerical simulations. This makes it possible for researchers, landscape architects, and urban planners to examine different situations and optimize designs for both the best possible environmental performance and human comfort.

The software is equipped with a user-friendly interface that supports visualization of simulation results through interactive 3D graphics and heat maps. This makes it easier for users to interpret and communicate the findings of their simulations to stakeholders and decision-makers.

Overall, ENVI-met plays a crucial role in supporting sustainable urban design and planning by providing valuable insights into the complex dynamics of urban microclimates. Its versatility and accuracy make it a powerful tool for addressing contemporary challenges related to climate change, urbanization, and the built environment.

3.3.1 The Methodological Use of Envi-Met

The evaluation and optimization of microclimatic conditions are critical steps in the creation of sustainable and livable urban settings. I use the complex microclimate modeling program ENVI-met to explore the details of thermal comfort in the proposed development as part of my thesis.

With the use of ENVI-met, a potent instrument in my research technique, I am able to model and examine the intricate relationships between environmental elements in the mixed-use Georgia Square Mall setting. My goal is to evaluate outdoor features and their effect on thermal discomfort by utilizing ENVI-met capabilities, which will provide evidence-based insights to the design process.

3.3.2 How ENVI-met Supports the Thesis

ENVI-met offers a streamlined approach to creating intricate microclimate models that accurately depict the physical characteristics of the Georgia Square Mall location. Its capability to model terrain, vegetation, buildings, and other environmental features in detail facilitates a comprehensive understanding of the site's microclimatic conditions.

Dynamic Simulation: Dynamic simulations conducted through ENVI-met allow for the exploration of how different environmental factors and design alterations influence thermal comfort over time. By simulating various scenarios, such as changes in vegetation, building shading, or orientation, the effectiveness of different strategies in addressing thermal discomfort among customers can be assessed.

Thermal Comfort Assessment: ENVI-met facilitates the evaluation of multiple thermal comfort parameters at different locations within the proposed development, including humidity, air temperature, and wind speed. Utilizing established metrics like Physiological Equivalent Temperature (PET) and Predicted Mean Vote (PMV), thermal comfort levels can be accurately assessed, pinpointing areas of potential discomfort and guiding necessary design adjustments.

Visualization and Communication: Leveraging ENVI-met's visualization capabilities, user-friendly 3D visualizations and heat maps can be generated to aid in the interpretation and communication of simulation results. These visualizations are invaluable tools for stakeholders and decision-makers, providing clear insights into design strategies that optimize thermal comfort for all users.

3.4 ABOUT SITE

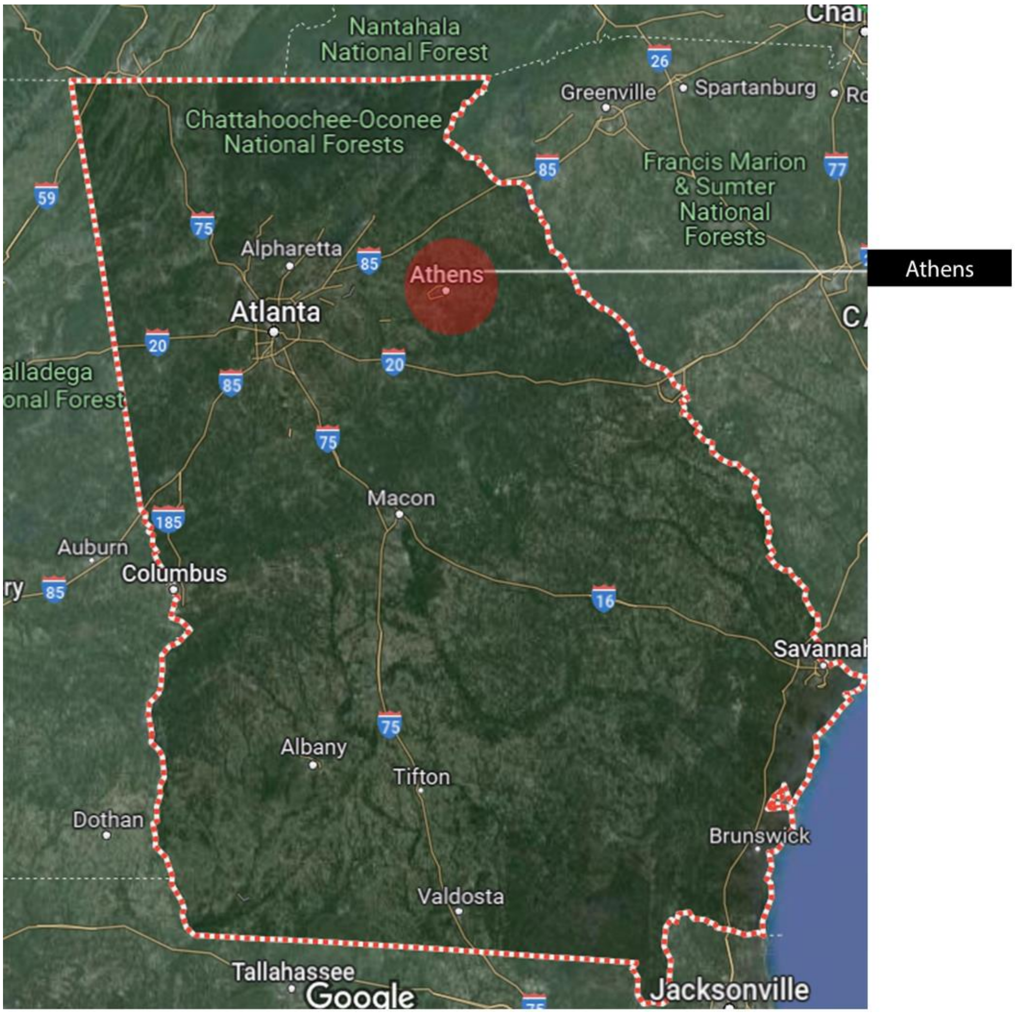

Figure 5: Aerial View of Georgia State

Figure 6: Aerial view of Athens area

Figure 7: Proposed area, Georgia Square Mall, aerial shot

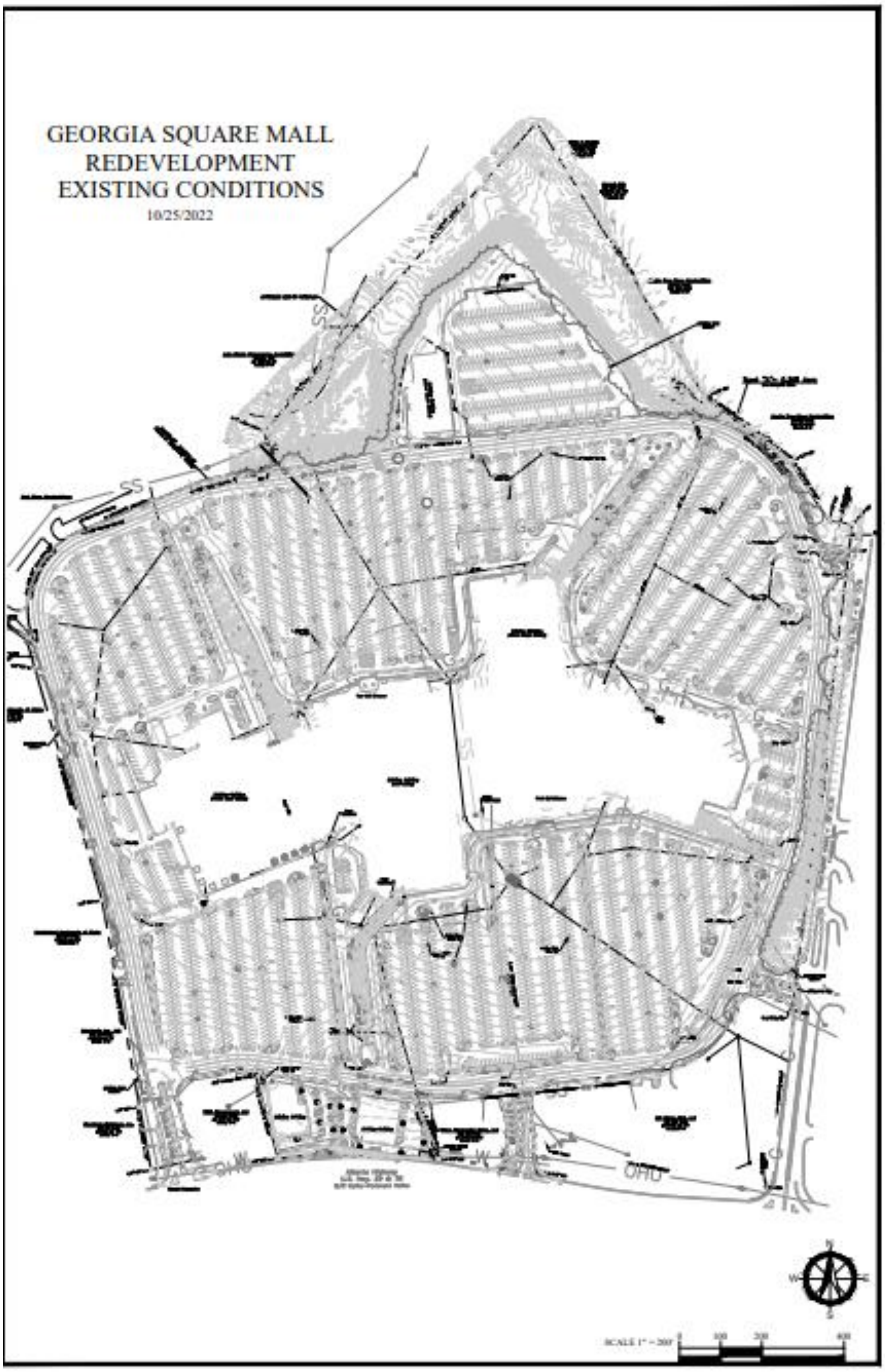

Figure 8: Existing site conditions

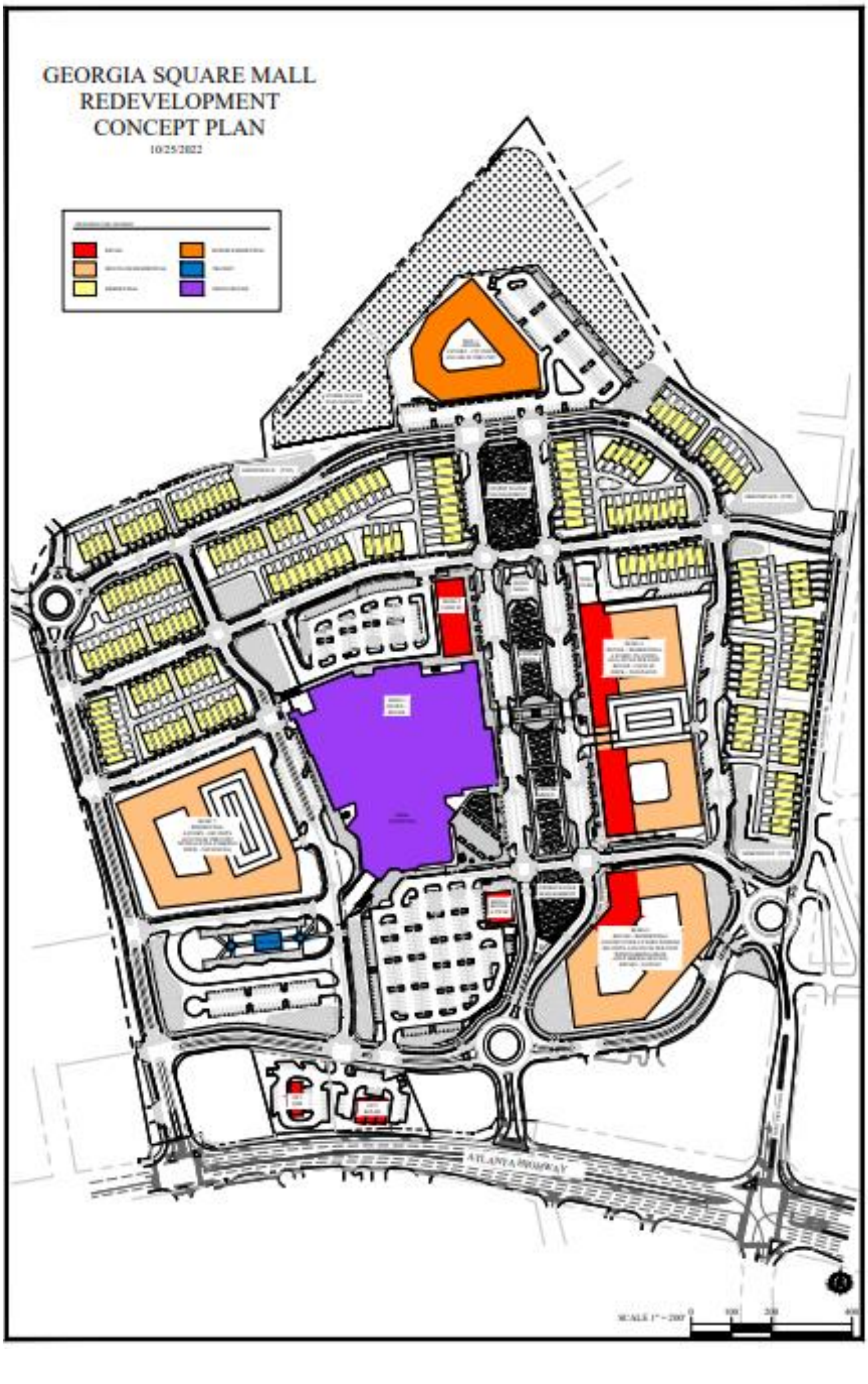

Figure 9: Proposed development plan

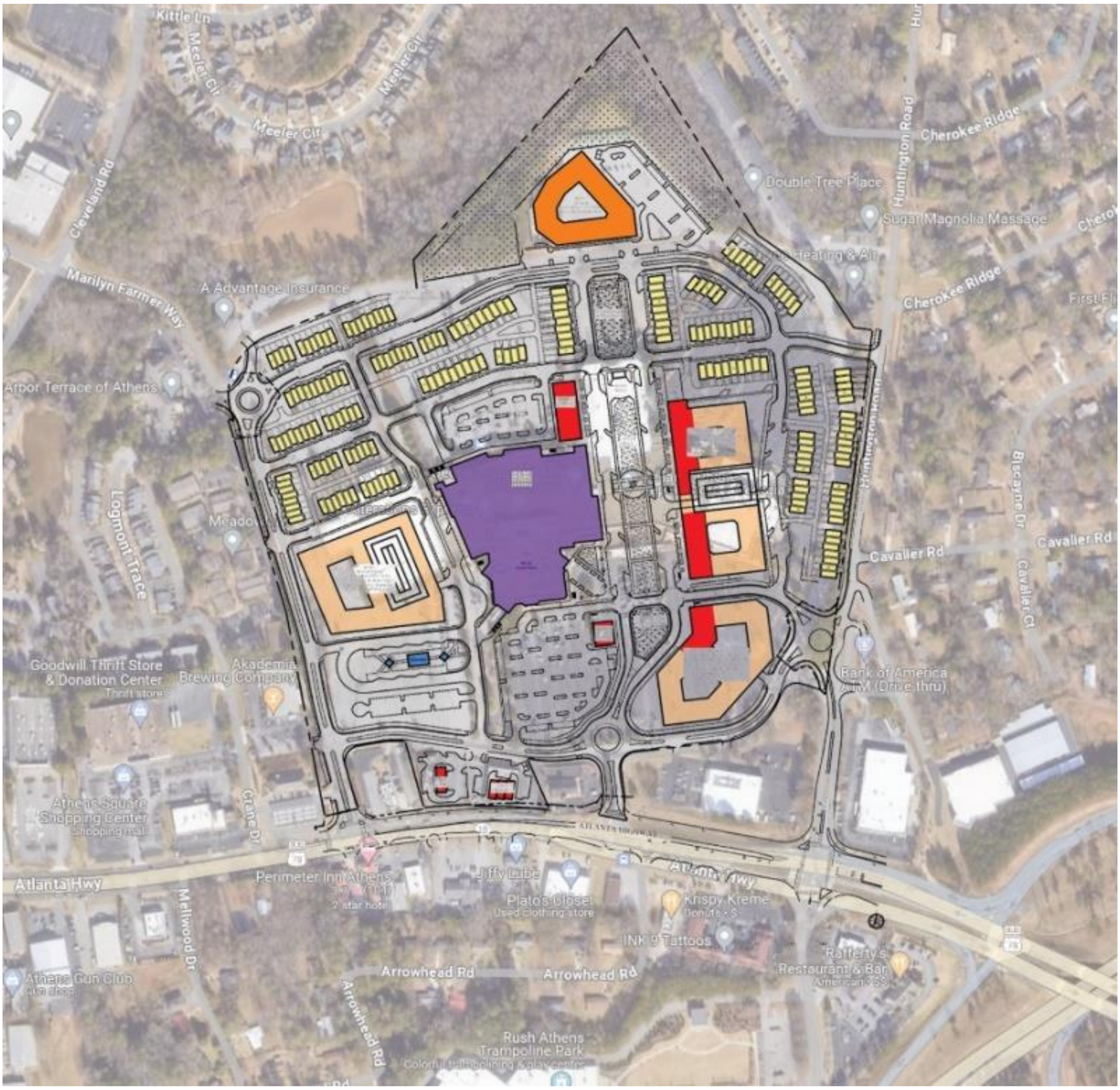

Figure 10: Context map

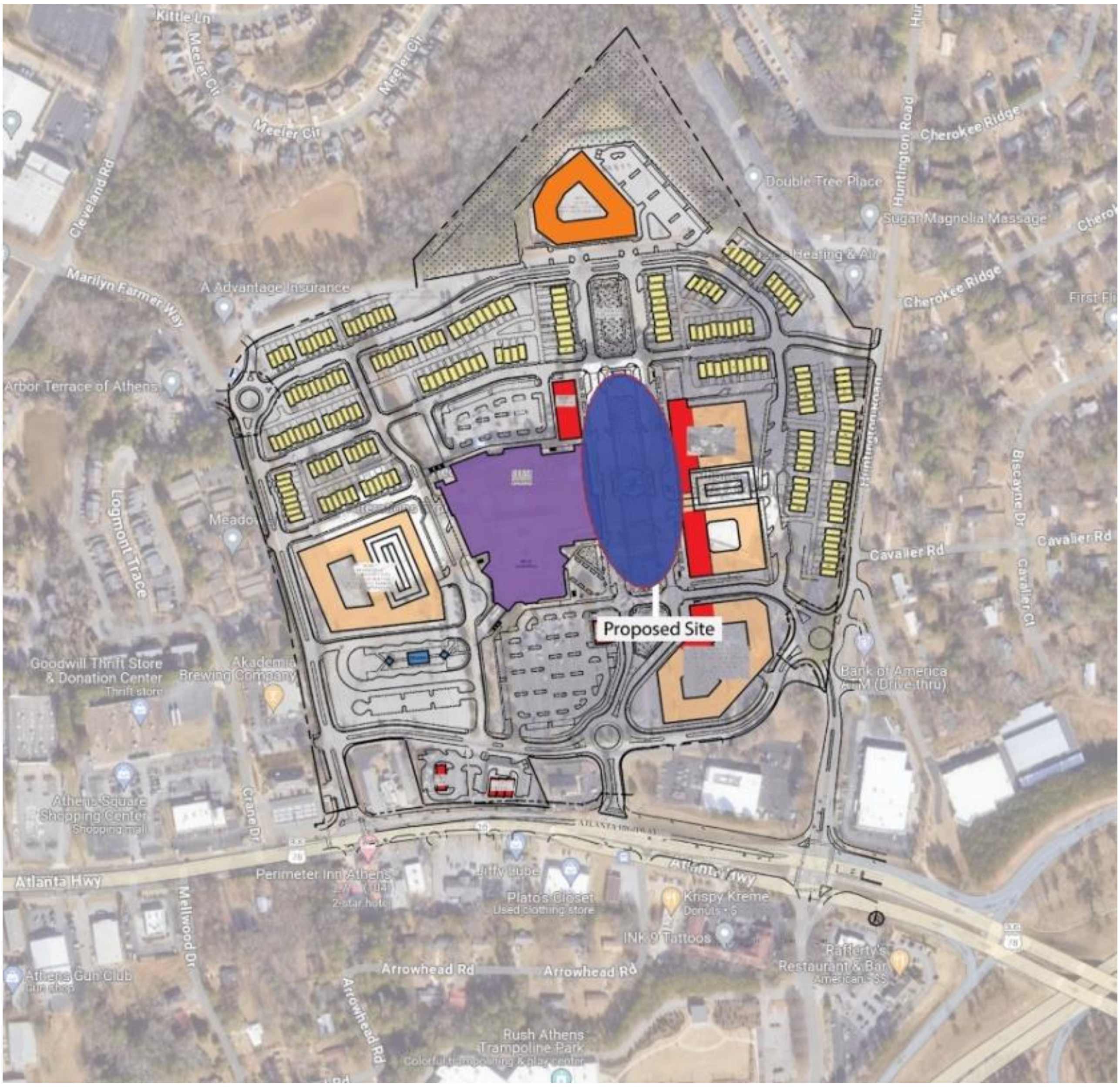

Figure 11: Proposed site marking on the map

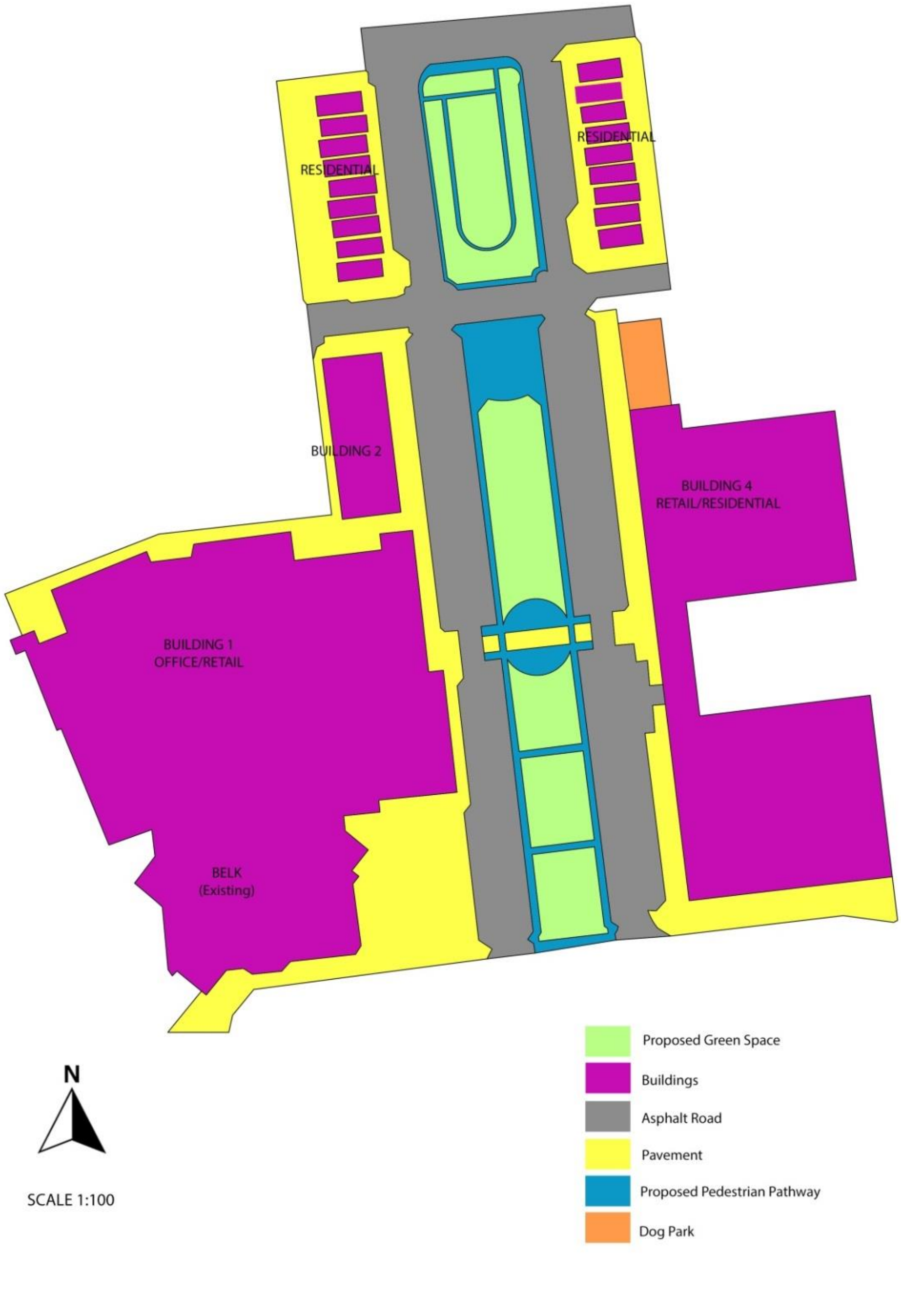

Figure 12: Floor plan with legends for base model

CHAPTER 4: DESIGN PROPOSAL AND SIMULATION

4.1 NUMERICAL ANALYSIS USING ENVI-MET

A portion of Georgia Square Mall was modelled in three dimensions using ENVI-met, a microclimatic simulation application with a focus on computational fluid dynamics (CFD). In contrast to other models that concentrate on particular microclimate characteristics, ENVI-met thoroughly assesses a variety of parameters to produce a broad range of outcomes.

Layers represent surfaces, trees, and buildings in the model, and ENVI-met produces a large volume of hourly data that is kept in several folders. XML-enclosed metadata and binary (EDX, EDT) or ASCII formats are the most used formats for output files, which contain topics including soil, flora, buildings, radiation, contaminants, atmosphere, and solar access.

ENVI-met has drawbacks despite its advantages. It is computationally demanding due to its thorough parameter estimate of the environment, particularly for high-resolution structures in district-scale modeling. Furthermore, the intricacy of the software's 3D INX format and the paucity of documentation can make it difficult to create a complete 3D representation.

The thesis presents a coupling structure for four 3D models. The first depicts the base case, showing current environmental conditions. The second focuses solely on green aspects while maintaining other factors constant. The final proposed model integrates key environmental factors like plants, pavement materials, soil, and profiles.

Understanding ENVI-met's capabilities and input files is crucial for determining its data specifications. The software aims to provide a detailed representation of weather parameters on a district scale, considering atmospheric layers and energy transfers between soil, water, plants, and building materials. Meteorological parameters and urban climate composition play significant roles in ENVI-met simulations, influencing meso-scale processes in the lower tropospheric layers.

Three types of vertical grids are available in ENVI-met.

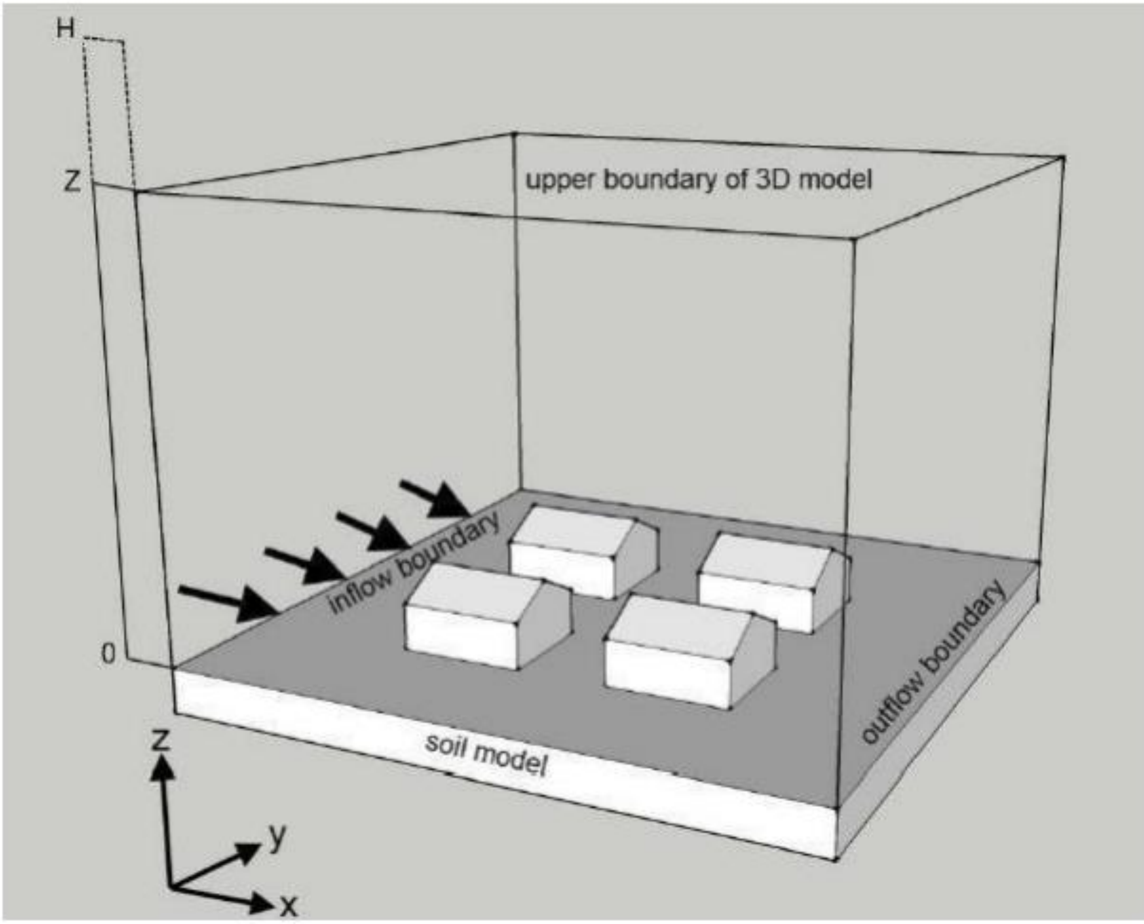

Figure 13: The three different grids used by ENVI-met, area input file is depicted on the 3D model (Huttner, 2012)

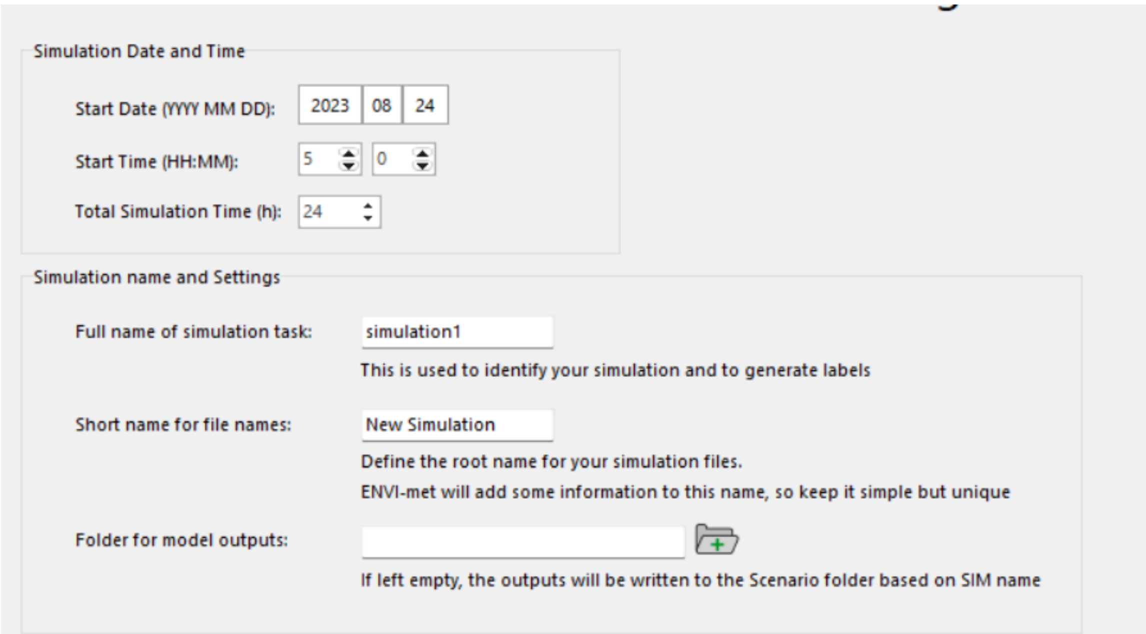

Figure 14: Selection of basic parameters in ENVI-met

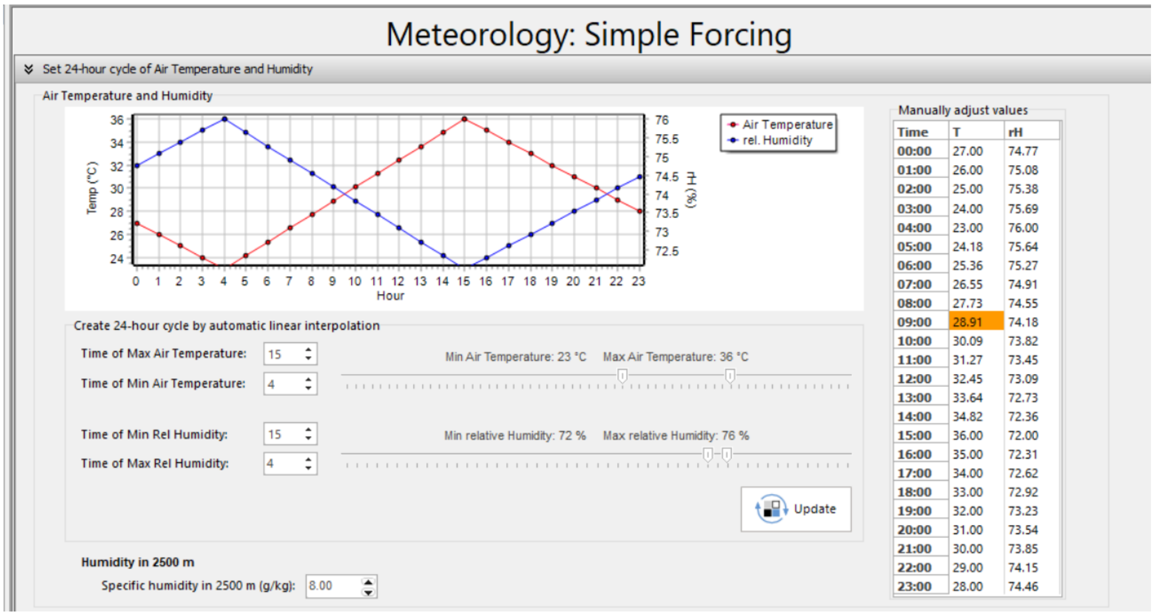

Figure 15: Setting of meteorological conditions

ENVI-met relies on meteorological parameters at its boundaries, known as boundary conditions, to establish connections with the three-dimensional area model and initialize the vertical weather model. Essential weather data includes air temperature, relative humidity, and wind speed near the surface, as well as wind direction and humidity at 2500 meters above the surface.

Additionally, specifying the date to be simulated, along with the start time, simulation duration, and roughness value, is necessary. ENVI-met initializes the sun path using latitude and longitude information from the region input file. Temperature parameters and other settings can be adjusted during the setup process.

There are three methods for inputting temperature parameters. The first method involves adjusting upper and lower temperature bounds while keeping wind speed and relative humidity constant. The second method, called simple forcing, enables users to create a graph of hourly temperatures and relative humidity values to incorporate into the simulation file.

ENVI-met has a variety of relational databases built in that are included in the region input file. Soil, water, grass, tree foliage, and building construction materials are examples of these materials. This is one of ENVI-met's most critical features, since they provide an identifier, such as an albedo value or a leaf area distribution (LAD) value for trees.

Vegetation is represented as a basic plant entity in another key segment. A collection of vertically occupied voxels constitutes a simple plant. The vegetation object's height is proportional to the number of voxels. Albedo, transmittance, leaf type, leaf occupancy, and other plant foliage parameters are used in the voxels. ENVI-met uses simple plants as the first and most basic depiction of vegetation.

4.2 METHODOLOGY APPLICATION AND SIMULATION RESULTS

The simulations were carried out for 3 July 2023 between 7 a.m. and 9 p.m. For this case, building materials like dark-colored concrete pavements, asphalt, heavy-weight concrete, and low albedo surfaces with little vegetation were used. The final results are generated in Leonardo using the area input simulation files.

The intensity of heat islands is color-coded, with blue indicating the least influence and red representing the largest. The intensity scale is seen in the legends map, generated by Leonardo

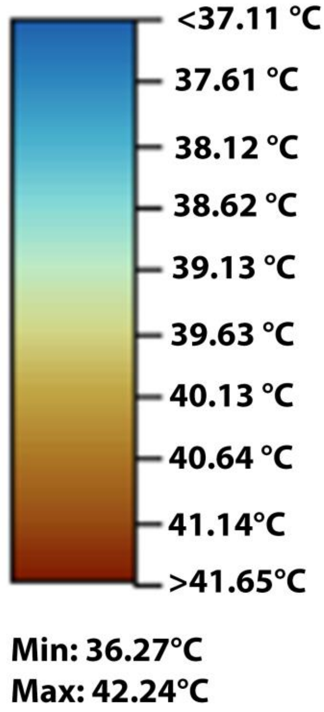

Figure 16: Legends for ENVI-met models

4.2.1 ENVI-MET BASE MODEL SIMULATION RESULTS

The ENVI-met base model depicts the proposed site without any vegetation, featuring concrete structures and dark-colored concrete pavers for pedestrian walks, along with sandy soil covering the designated green space. The simulation is set for 24 August 2023, which coincides with one of the hottest days in Athens, GA. On this day, temperatures soared to 38˚C, with a minimum of 23˚C recorded across most parts of Georgia.

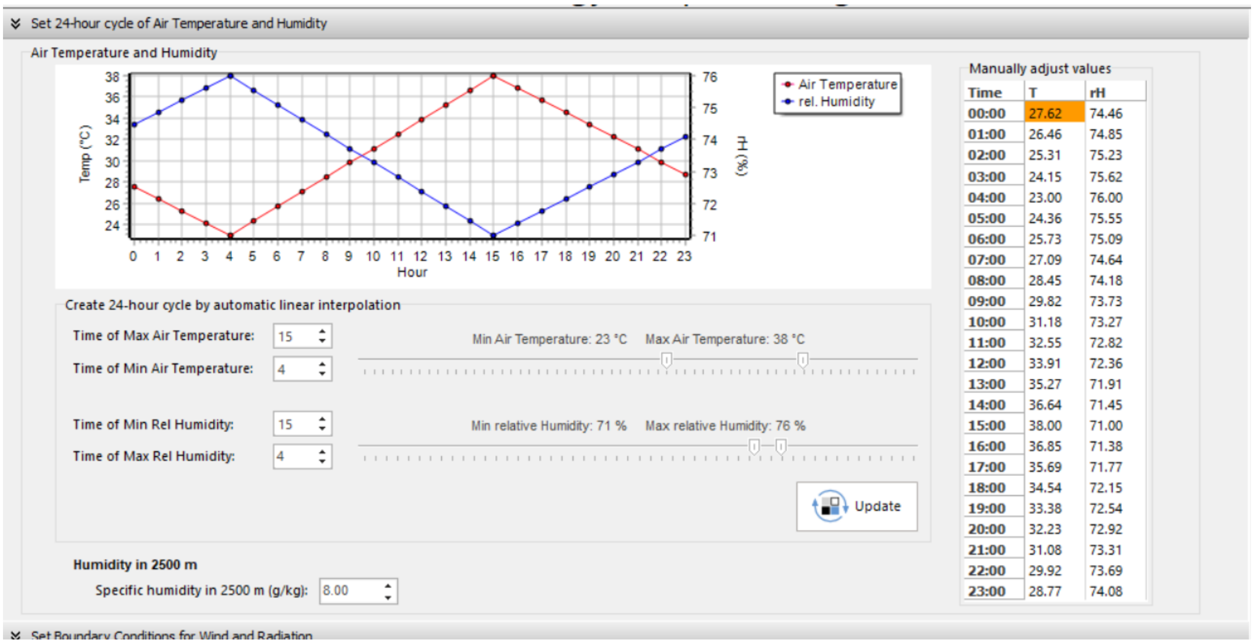

Figure 17: Graph showing the 24-hour interpretation of air temperature and relative humidity

The base case model simulations show the following results:

- Relative humidity
- Mean radiant temperature
- Solar radiation
- Potential air temperature

RELATIVE HUMIDITY

Relative humidity is a measure of the amount of moisture present in the air compared to the maximum amount of moisture present in the air, compared to the maximum amount of moisture the air can hold at a specific temperature. It is expressed as a percentage and indicates how close the air is to saturation. High relative humidity levels can contribute to discomfort by making the air feel warmer and stickier, especially during hot weather. Conversely, low relative humidity can lead to dryness and discomfort, particularly in cold climates.

Inference:

- As we can spot from the image generated by Leonardo, we can see that most part of the open space faces low relative humidity which can lead to dryness and discomfort during cold climate.
- Limited green cover causes low evapotranspiration and reduced shading, which results in low relative humidity and high air temperature.

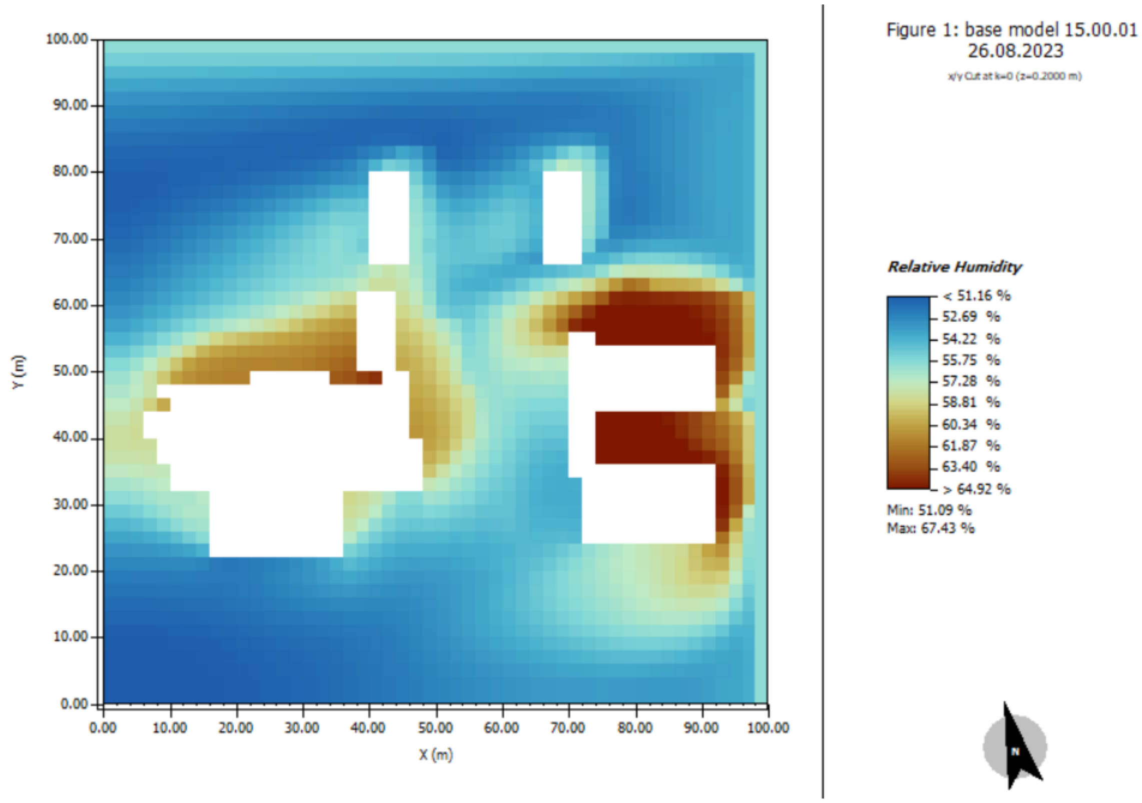

Figure 18: Relative humidity of base model, produced by Leonardo

MEAN RADIANT TEMPERATURE

Mean radiant temperature (MRT) is the average temperature of all the surfaces surrounding an individual, including walls, floors, ceilings, and objects. It represents the combined effect of radiant heat exchange between a person's body and the surrounding surfaces. MRT influences thermal comfort by impacting the rate at which heat is gained or lost by an individual through radiation.

Inference:

- The MRT of various surfaces along the pathway, such as pavement and buildings, have significantly influenced the temperature and comfort levels of an individual.

- Asphalt roads and concrete pavements, when exposed to direct sunlight, have contributed to higher perceived temperatures and discomfort, especially during hot weather conditions.
- In shaded areas, mean radiant temperature is up to 13˚C higher than air temperature, while in sunlit areas, mean radiant temperature higher than air temperature.

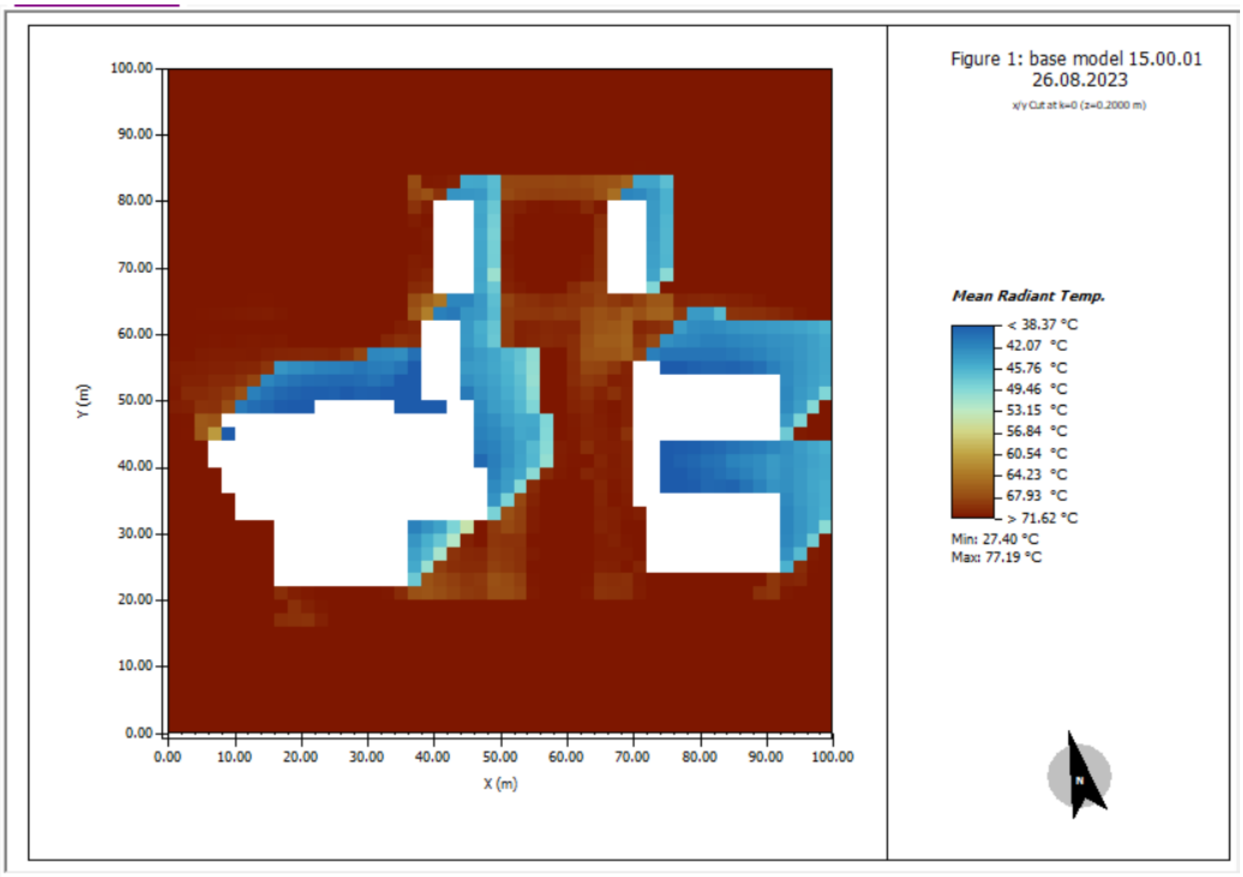

Figure 19: Mean radiant temperature of base model, produced by Leonardo

SOLAR RADIATION (DIRECT, DIFFUSED, AND REFLECTED)

Solar radiation refers to the electromagnetic energy emitted by the sun, which includes direct, diffused, and reflected components:

- Direct Solar Radiation: This is the solar energy that reaches the Earth’s surface directly from the sun without any scattering or absorption by the atmosphere.

It represents the portion of solar radiation that travels in a straight line and is not diffused by clouds or atmospheric particles. Direct solar radiation is typically highest when the sun is at its zenith or highest point in the sky.

- Diffused Solar Radiation: Diffused solar radiation is the solar energy that has been scattered or diffused by particles in the Earth's atmosphere, such as water vapor, dust, or air molecules. Unlike direct solar radiation, diffused radiation does not follow a direct path from the sun to the Earth's surface but instead scatters in multiple directions. Diffused radiation contributes to daylight illumination even on cloudy days when direct sunlight is obscured.
- Reflected Solar Radiation: Reflected solar radiation refers to the portion of solar energy that is reflected off surfaces such as the earth's surface, buildings, vegetation, or water bodies. This reflected radiation can contribute to the overall solar heat gain experienced in outdoor environments.

Inference:

- Direct solar radiation, diffuse sky radiation reflected by buildings and sidewalks, and shortwave energy received by typical urban systems are all part of a model that aim to mimic urban absorption of solar radiation. Under cloudless conditions, buildings absorb more solar radiation than flat surfaces.
- The retail structures provide shading, which reduces the amount of solar radiation absorbed by the surfaces underneath. This might also lead to heat being trapped in certain areas, which in turn contributes to heat islands.

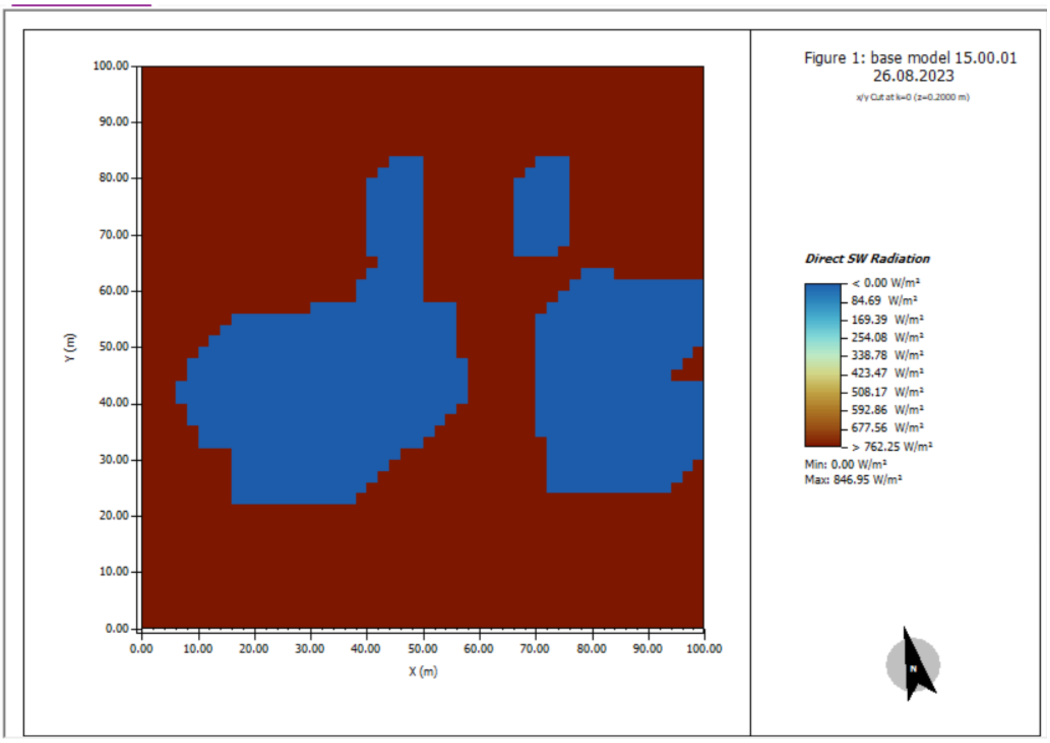

Figure 20: Direct solar radiation, produced by Leonardo

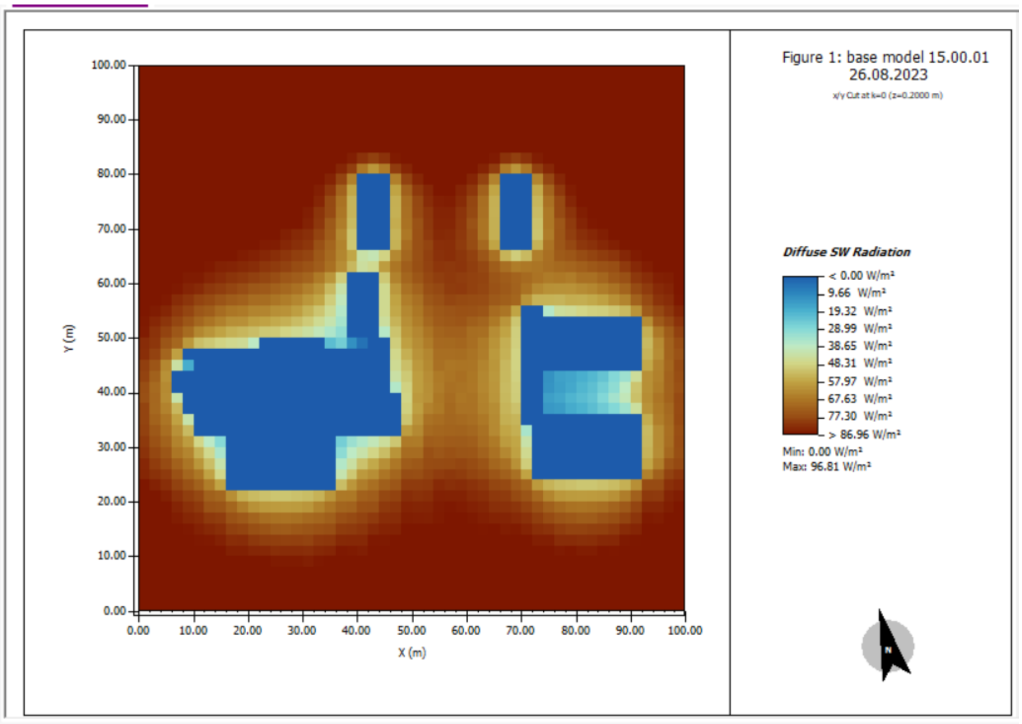

Figure 21: Diffused solar radiation, produced by Leonardo

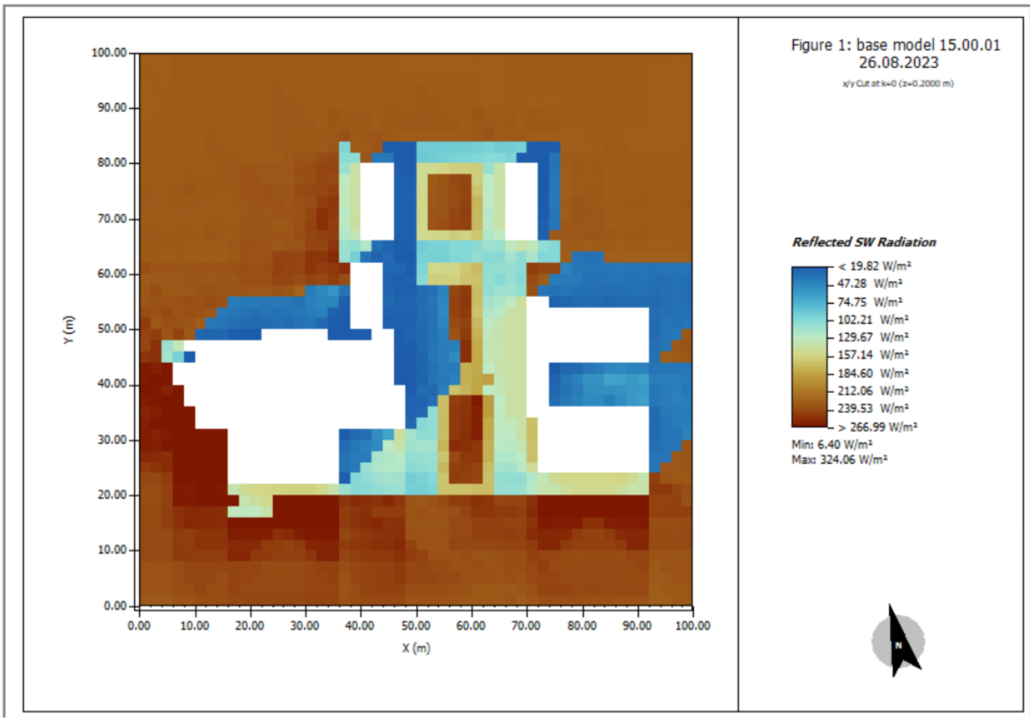

Figure 22: Reflected solar radiation, produced by Leonardo

POTENTIAL AIR TEMPERATURE

Potential air temperature refers to the temperature that air would have if it were brought adiabatically to a standard reference pressure level, typically at the Earth's surface. It is calculated based on the actual air temperature at a given altitude, taking into account the decrease in temperature with increasing altitude due to adiabatic cooling.

Inference:

- Increased impervious surfaces result in higher global temperatures due to increased heat absorption.
- Shade and evapotranspiration are two ways that trees and other plants lower air and surface temperature.

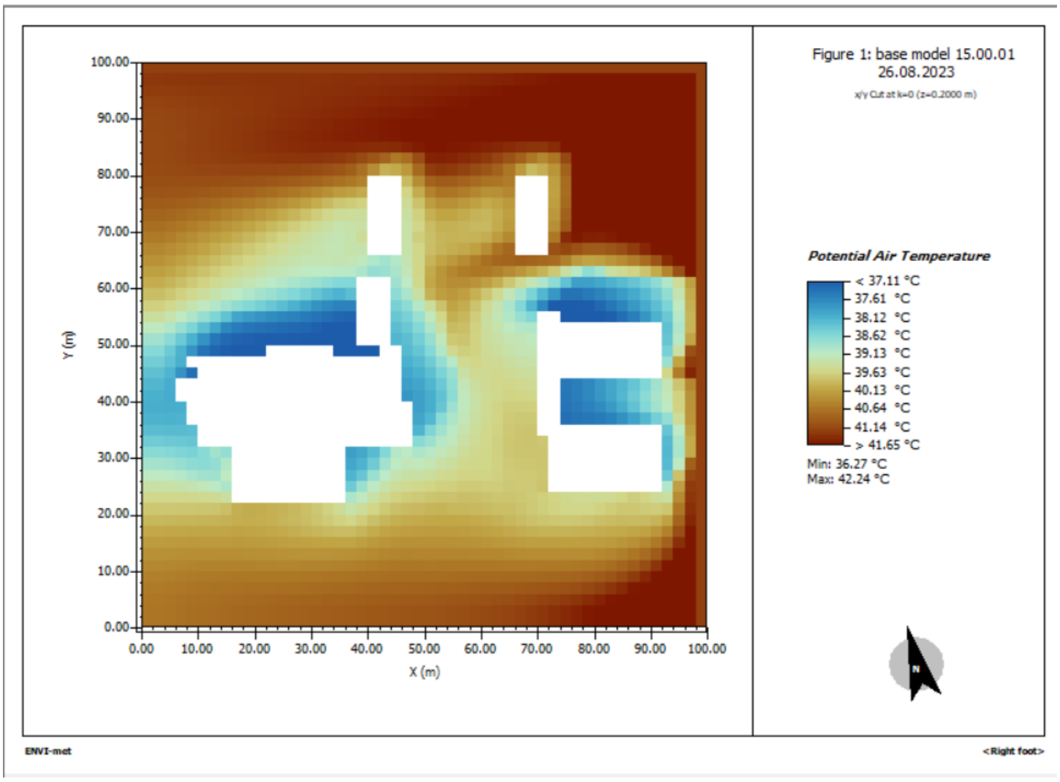

Figure 23: Leonardo inference, visualization of potential air temperature for the base model

4.2.2 ENVI-MET PROPOSED DESIGN MODEL 1 (ONE LINE OF TREES)

For this simulation, a single line of red oak trees with medium coverage has been strategically placed in the center to evaluate its effect on thermal comfort within the area on August 24, 2023. Red oak trees were selected due to their native presence in Georgia and their suitability as street trees.

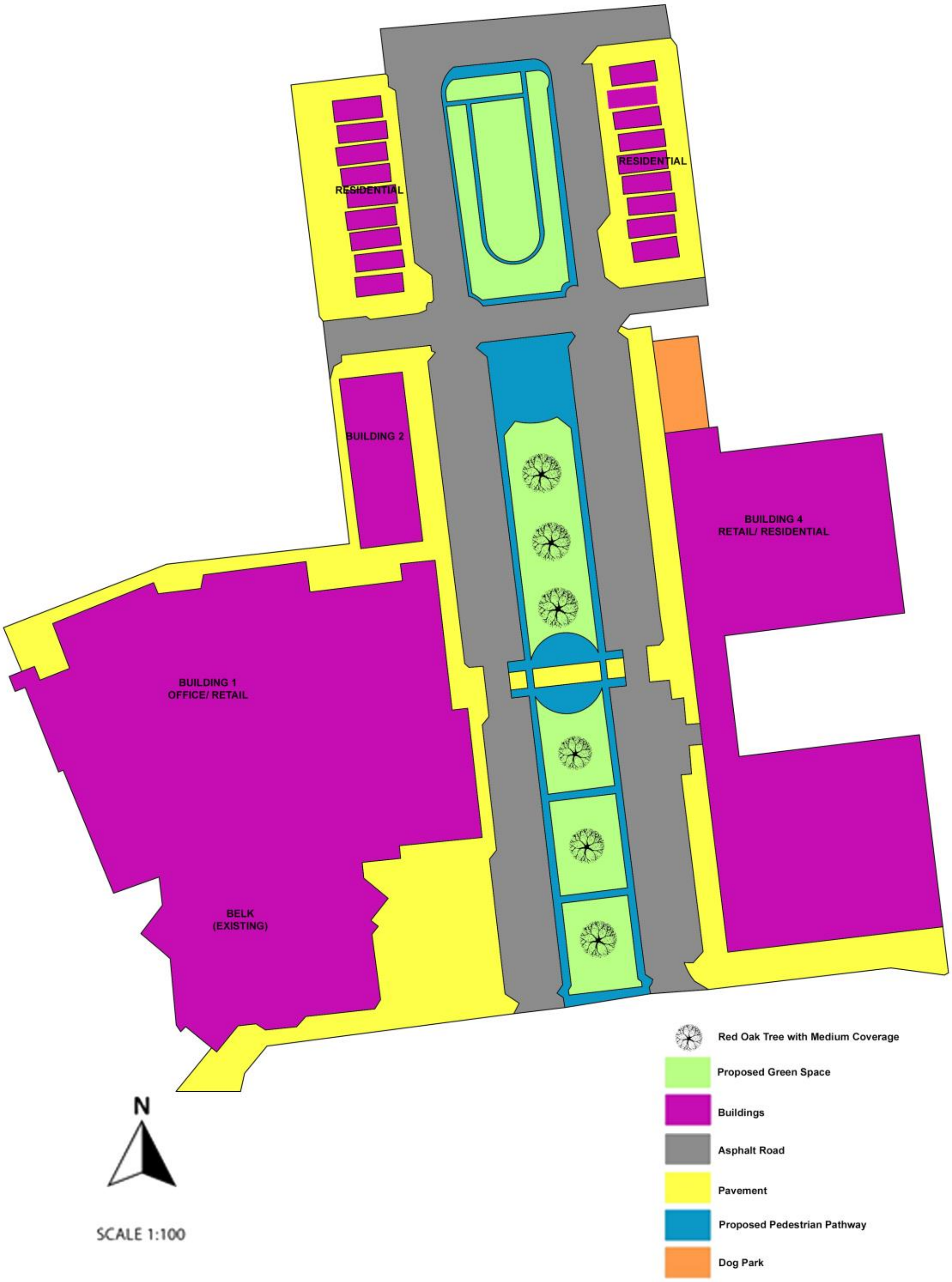

Figure 24: Site plan for proposed design model 1 (one line of trees)

RELATIVE HUMIDITY

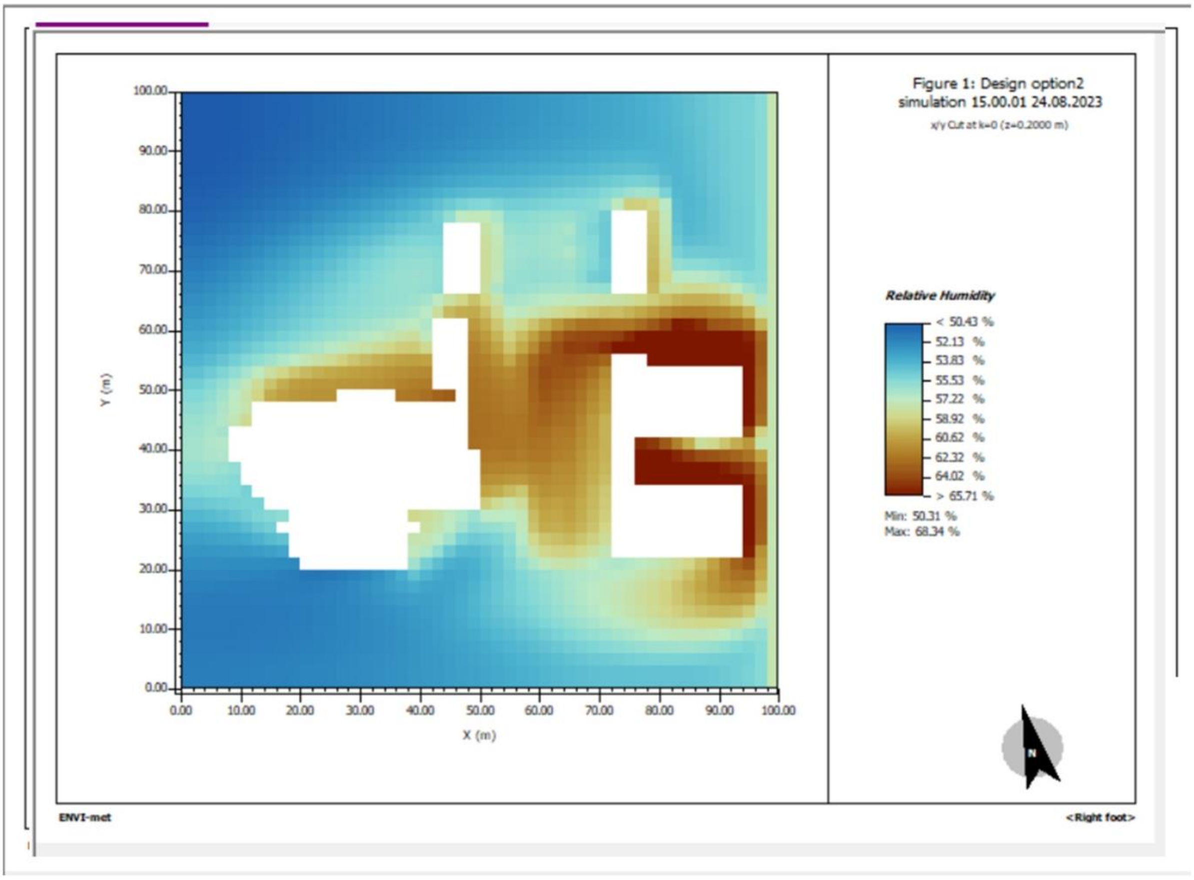

Figure 25: Relative humidity of model with single line of trees

Inference:

- The relative humidity is the lowest during the hottest hours of the day. But even after positioning the red oak trees with medium coverage in a single line, the result shows that the relative humidity is ranging from 58% to 62% at 3 p.m., which makes it not very thermally comfortable for the users.

MEAN RADIANT TEMPERATURE

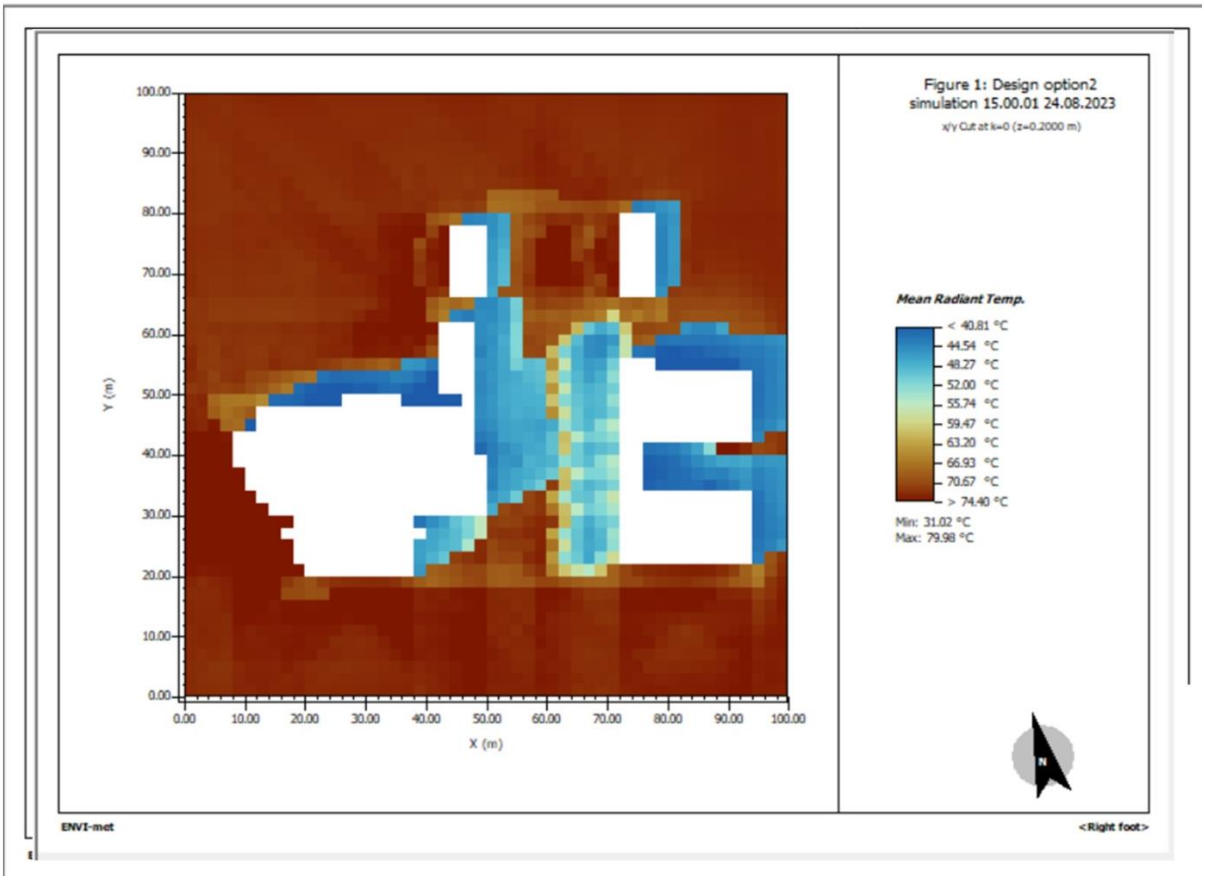

Figure 26: Mean radiant temperature of base model

Inference:

- In shaded regions, the mean radiant temperature surpasses the air temperature by up to 6˚C, which makes the space thermally comfortable, whereas in sunlit areas, it exceeds the air temperature by up to 30˚C.

SOLAR RADIATION

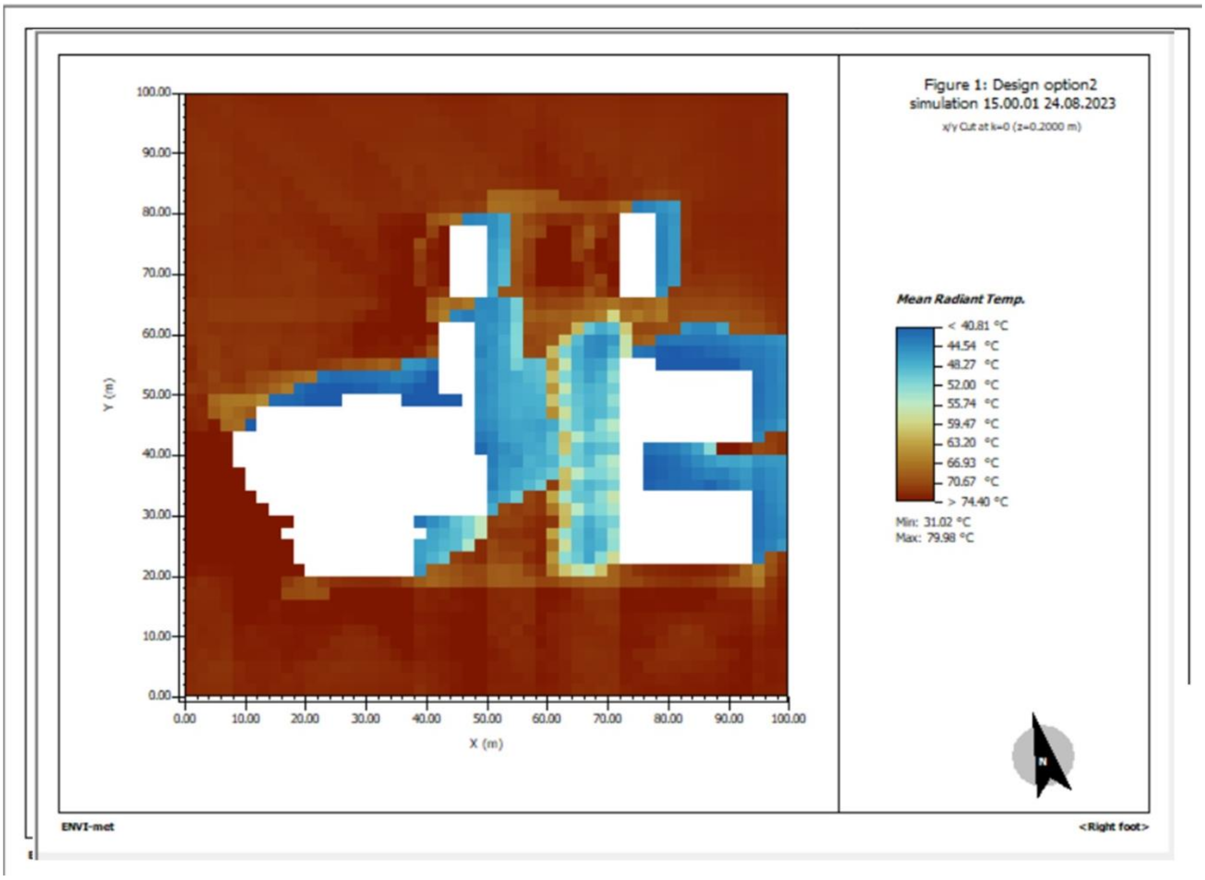

Figure 27: Direct solar radiation, produced by Leonardo

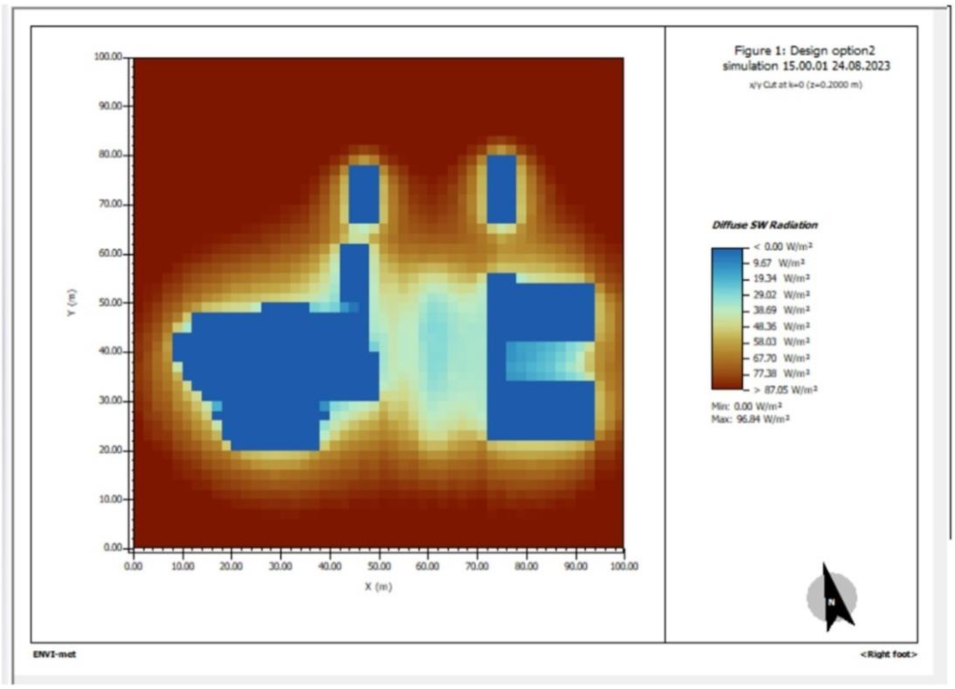

Figure 28: Diffused solar radiation, produced by Leonardo

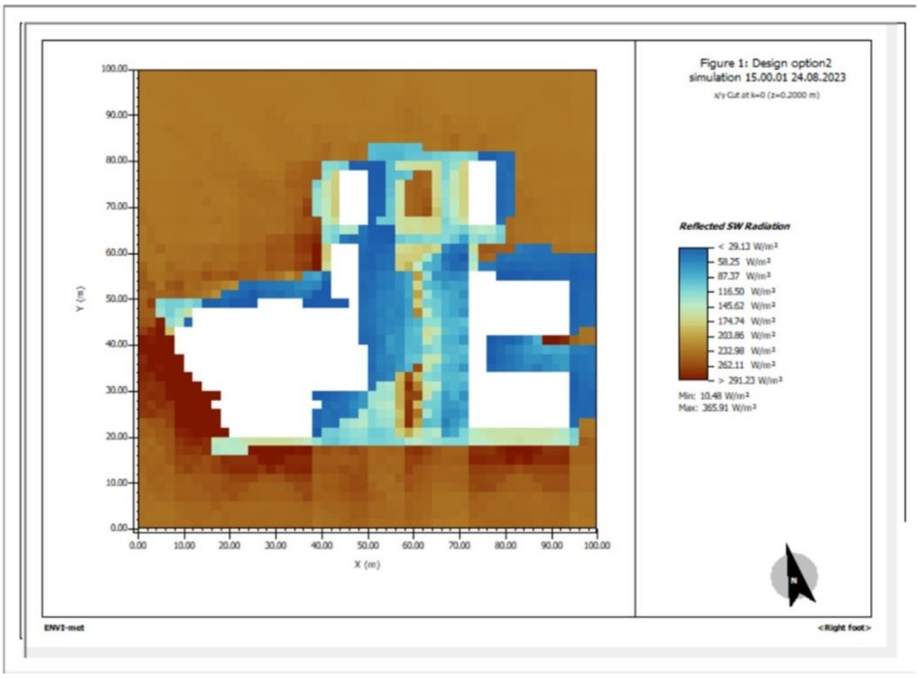

Figure 29: Reflected solar radiation, produced by Leonardo

Inference:

- The area where trees are situated experiences reduced direct solar radiation, ranging from 84 W/m^2 to 507 W/m^2. The reduced direct solar radiation contributes to improved thermal comfort by minimizing heat absorption and reducing the overall temperature of the area.
- The area where trees are situated experiences reduced diffused solar radiation, ranging from 19 W/m^2 to 60 W/m^2. The reduced diffused solar radiation's effect on thermal comfort results in slightly lower temperature due to less solar heat gain.
- Reduced reflected solar radiation has both positive and negative impacts on thermal comfort. The reduced reflected solar radiation contributes to lower surface temperatures and decreased heat absorption in environments with impervious surfaces such as asphalt and concrete. This results in cooler microclimates and improved thermal comfort for pedestrians.

POTENTIAL AIR TEMPERATURE

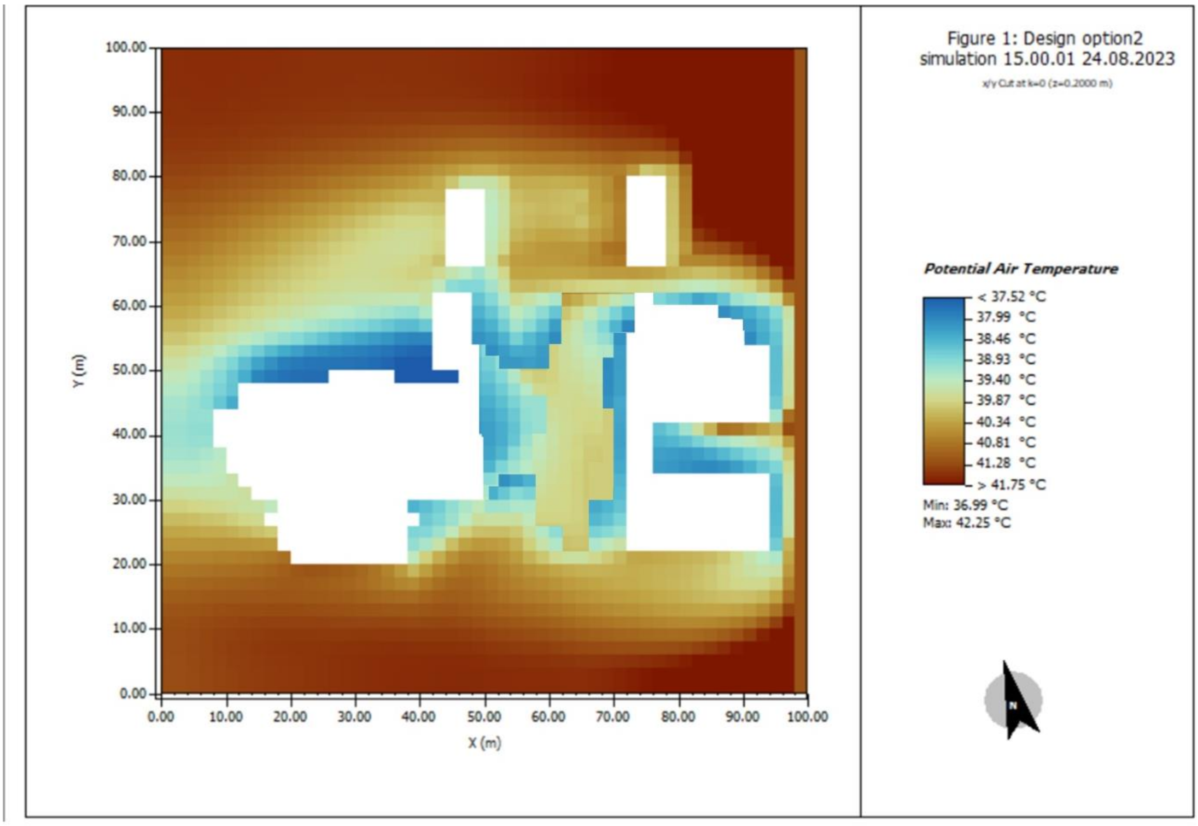

Figure 30: Potential air temperature of model with single line of trees

Inference:

- Increased impervious surfaces result in higher temperatures due to increased heat absorption, even with a single line of red oak trees with medium coverage; the potential air temperature is relatively high for the pedestrians to feel thermally comfortable.

ENVI-MET PROPOSED DESIGN MODEL 2 (WATER BODY)

For this simulation four 5’× 5’ water bodies have been strategically placed in the center to evaluate their effect on thermal comfort within the area on August 24, 2023

Figure 31: Site plan of proposed model 2 (with just water bodies)

RELATIVE HUMIDITY

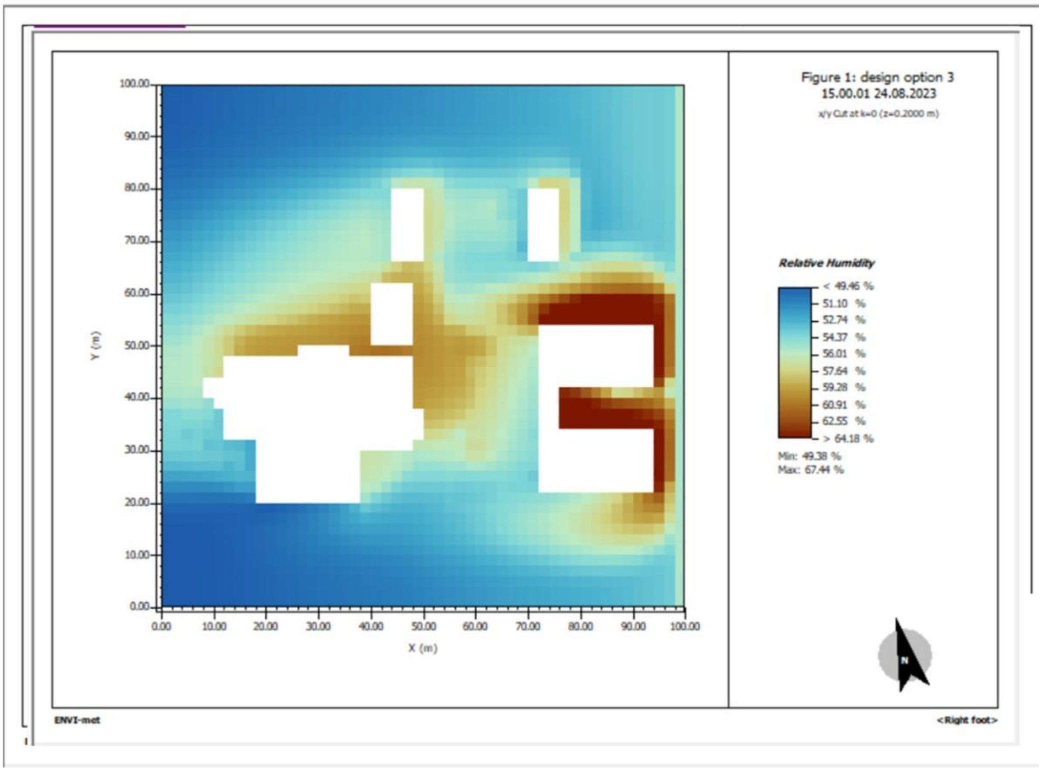

Figure 32: Relative humidity produced by Leonardo for model with just water bodies

Inference:

- Even after incorporating a single line of water bodies, the relative humidity during the hottest hours of the day remains relatively low. At 3 p.m., the relative humidity fluctuates between 52% and 59%. While this indicates an improvement compared to the previous model featuring red oak trees with medium coverage in a single line, the thermal comfort for users is still suboptimal.

MEAN RADIANT TEMPERATURE

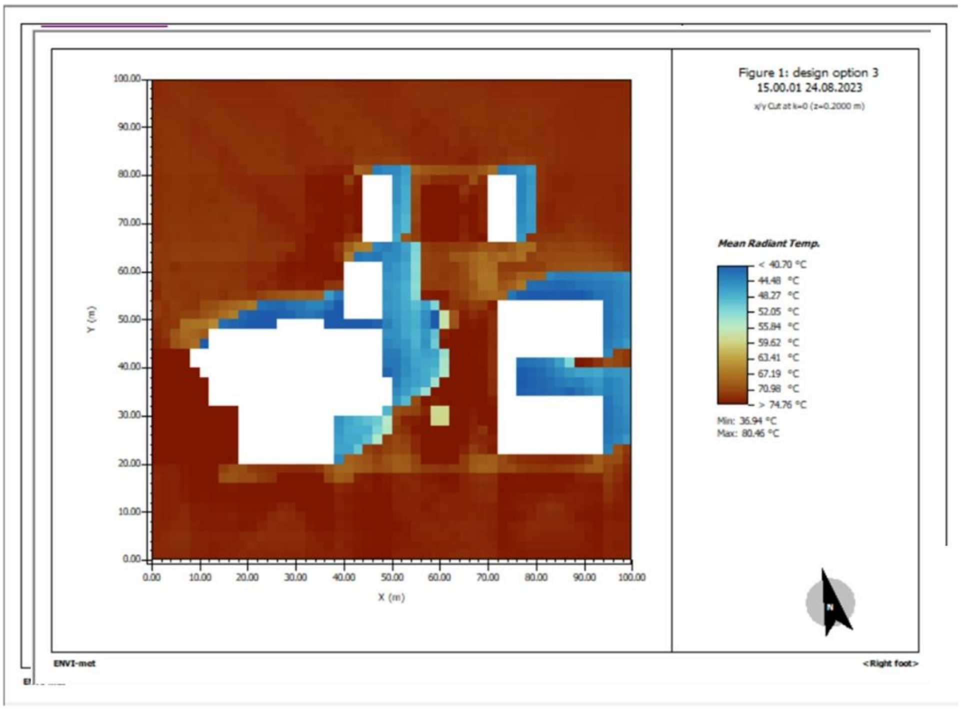

Figure 33: Mean radiant temperature produced by Leonardo for model with just water bodies

Inference:

- Due to the absence of trees or artificial shading on the site, the mean radiant temperature in this simulation remains considerably high compared to the previous scenario. Consequently, the presence of water bodies alone does not significantly reduce the mean radiant temperature, resulting in a lack of thermal comfort in the space.

SOLAR RADIATION

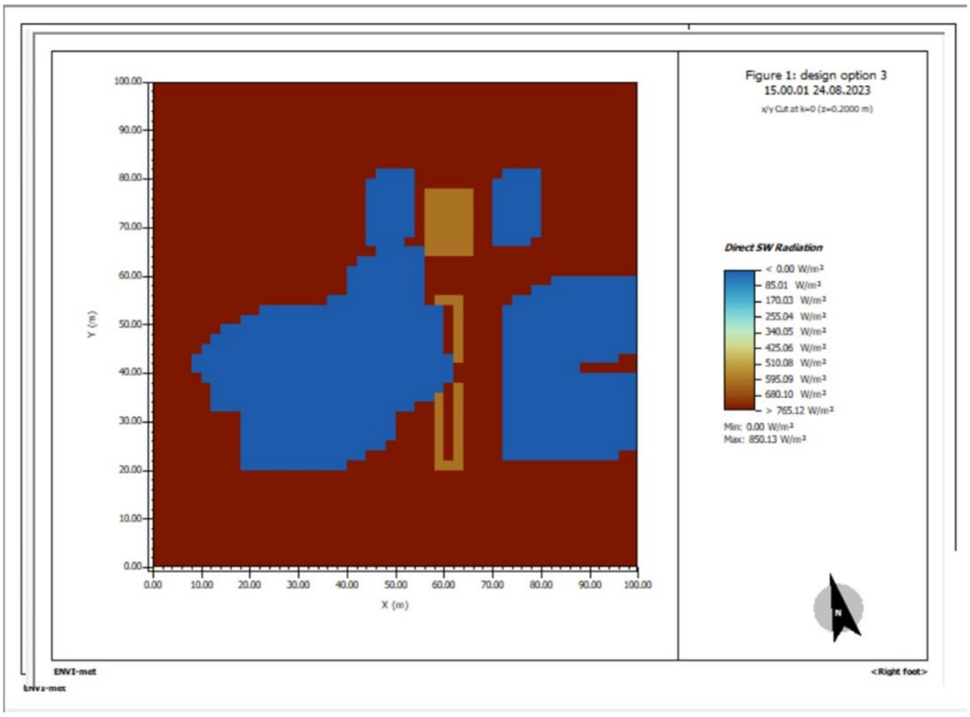

Figure 34: Direct solar radiation produced by Leonardo for model with just water bodies

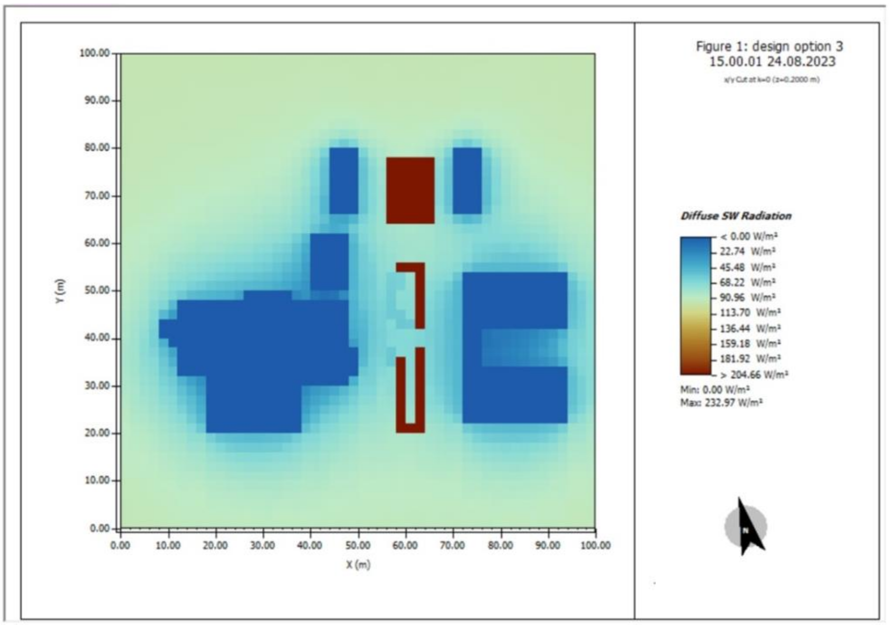

Figure 35: Diffused solar radiation produced by Leonardo for model with just water bodies

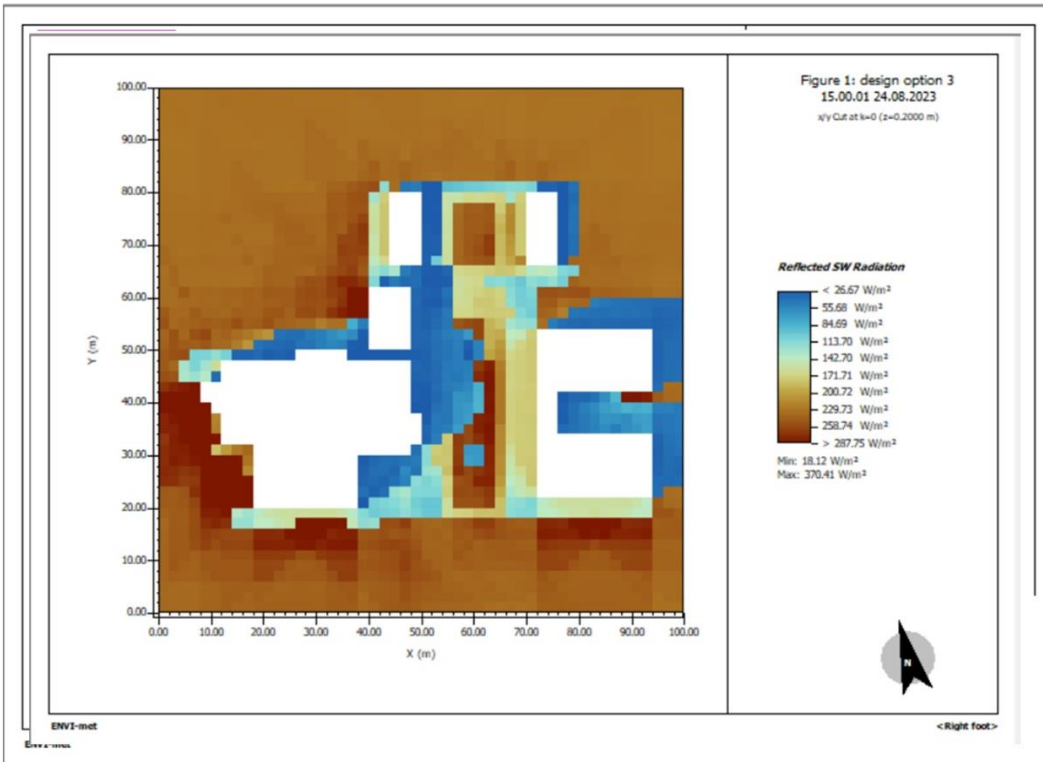

Figure 36: Reflected solar radiation produced by Leonardo for model with just water bodies

Inference:

- The absence of shading results in maximum direct solar radiation exposure. In comparison, the previous scenario with shading provided a better option, contributing to improved thermal comfort.
- Water bodies contribute to lower levels of diffused solar radiation. When sunlight hits the surface of the water body, some of the solar energy is reflected, while the rest is absorbed and scattered. This scattering effect reduces the intensity of sunlight reaching surrounding areas, including the ground and nearby surfaces. As a result, the presence of water bodies helps to mitigate the impact of direct sunlight and lowers the levels of diffused solar radiation in the surrounding environment.
- The surrounding area still shows a high level of reflected solar radiation, indicating continued heat accumulation despite the presence of water bodies in this simulation.

POTENTIAL AIR TEMPERATURE

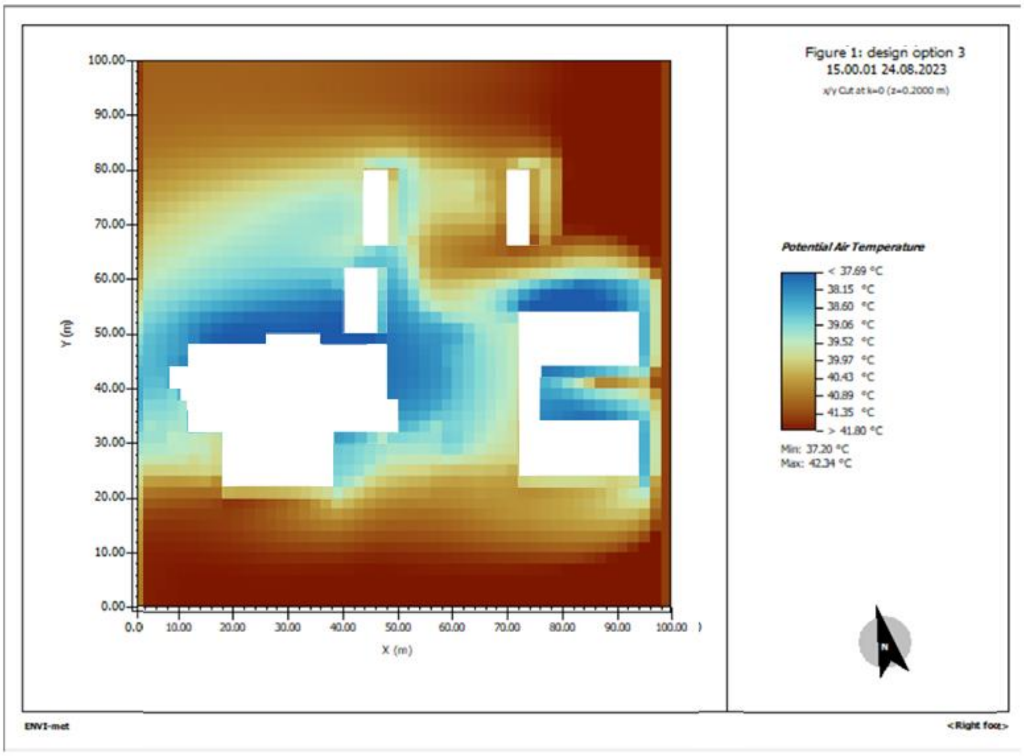

Figure 37: Potential air temperature produced by Leonardo for model with just water bodies

Inference:

Higher temperatures are the result of increased heat absorption from more impermeable surfaces. Because water bodies absorb heat from their surroundings and release it through evaporation, they have a cooling influence on potential air temperature. This procedure helps to create a more comfortable thermal environment by bringing down the air temperature near the body of water.

4.2.4 ENVI-MET PROPOSED DESIGN MODEL (FINAL DESIGN) SIMULATION RESULTS

In order to optimize pedestrian thermal comfort, water features and red oak trees are thoughtfully included in the final design simulation. In order to maximize their combined cooling effects and produce a more comfortable microclimate inside the defined region, water bodies and trees are placed with great care. Through evaporation, the water bodies lower the surrounding temperature, and the trees shade the area and further lessen the absorption of solar radiation. This well-considered arrangement attempts to reduce heat stress and improve people' general comfort in the area.

Figure 38: Site plan for the proposed design (final model)

RELATIVE HUMIDITY

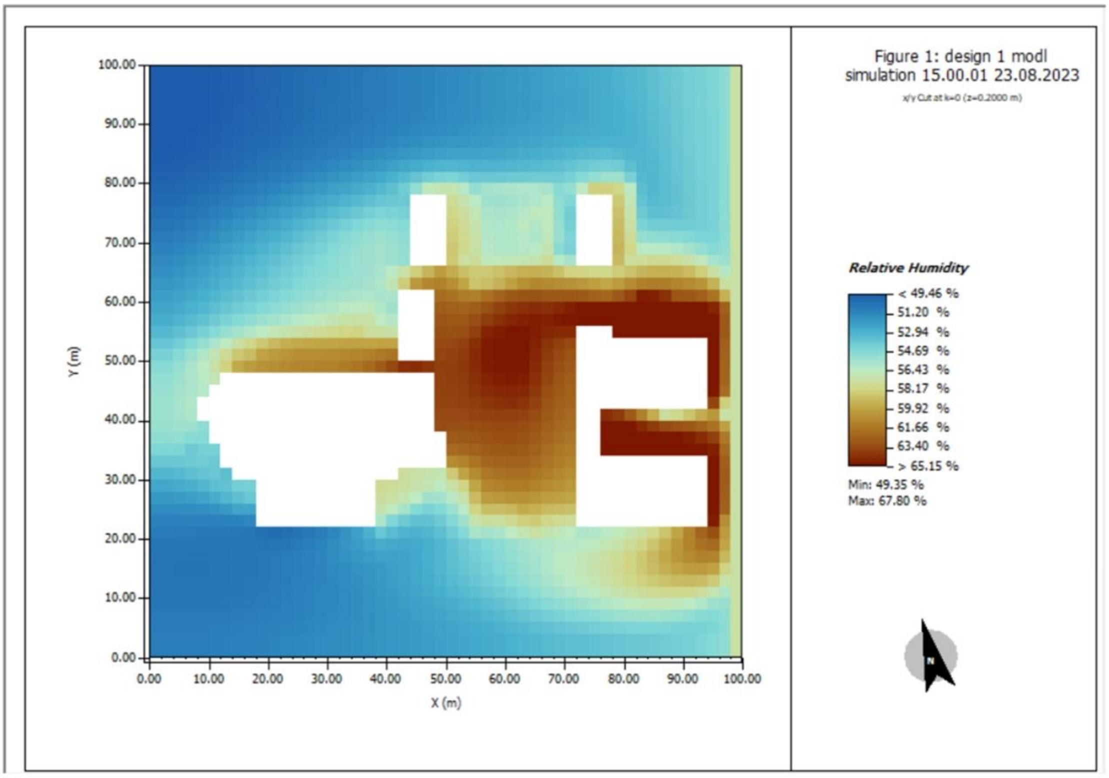

Figure 39: Relative humidity produced by Leonardo for final design model

Inference:

After employing diverse tactics to augment thermal comfort, there was a noticeable amelioration in the relative humidity levels recorded during the hours of maximum heat. Relative humidity at 3 p.m. ranged from 46% to 50%, suggesting a suitable temperature for pedestrians. Thanks to their ability to lower temperatures, provide humidity, and provide shade, trees were a major factor in this increase in terms of overall comfort. Furthermore, the thoughtful arrangement of bodies of water had a further beneficial effect on relative humidity levels. A more agreeable microclimate was created because the presence of water bodies promoted evaporation, which raised the moisture content in the air and raised relative humidity.

MEAN RADIANT TEMPERATURE

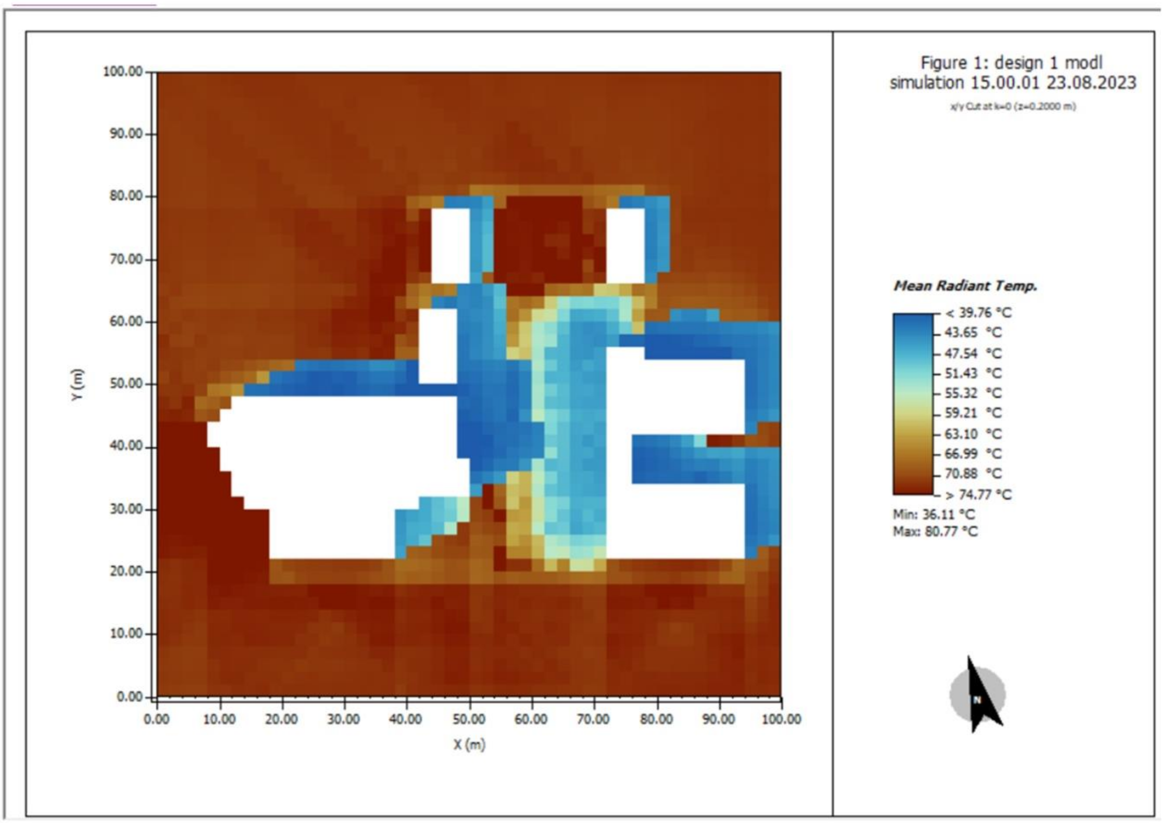

Figure 40: Mean radiant temperature produced by Leonardo for final design model

Inference:

The simulated environment's mean radiative temperature has been positively impacted by the strategic placement of three water bodies and red oak trees with medium coverage. Because of the trees' abundant shade, the mean radiative temperature has decreased due to a decrease in direct solar radiation. Furthermore, the evaporation of the water bodies has helped to lower the mean radiative temperature by minimizing the amount of heat absorbed by the surrounding surfaces. This combined effect highlights how effectively plants and water elements can be incorporated into urban architecture to improve thermal comfort and create more aesthetically pleasing outdoor spaces.

SOLAR RADIATION

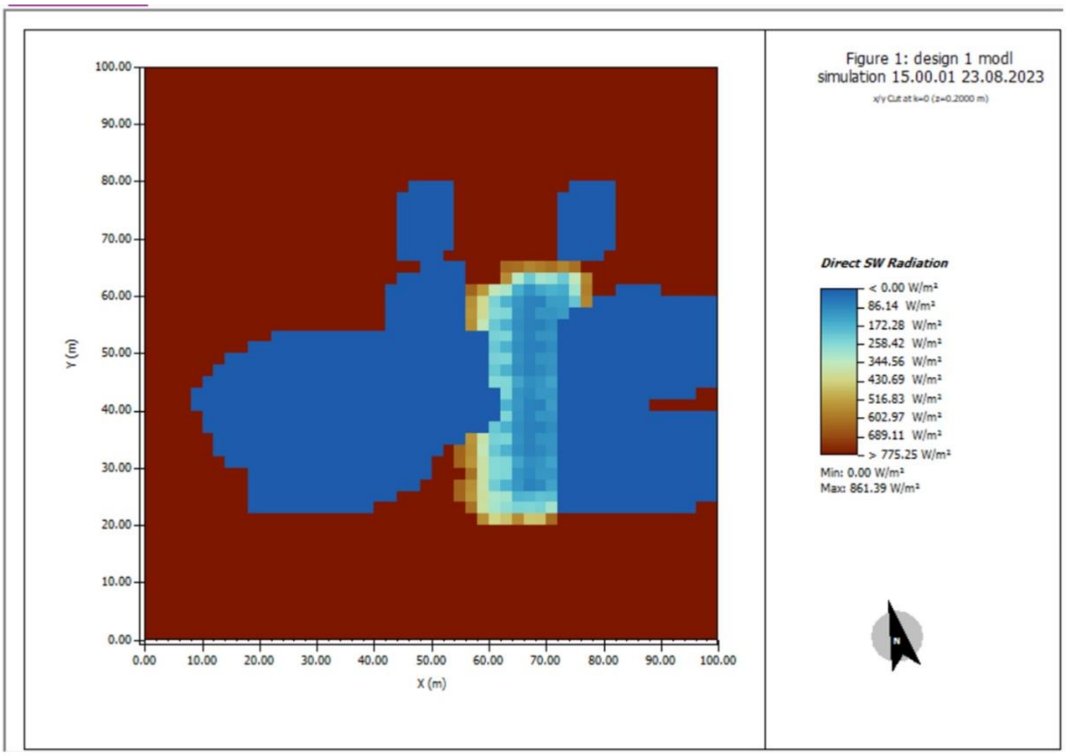

Figure 41: Direct solar radiation produced by Leonardo for final design model

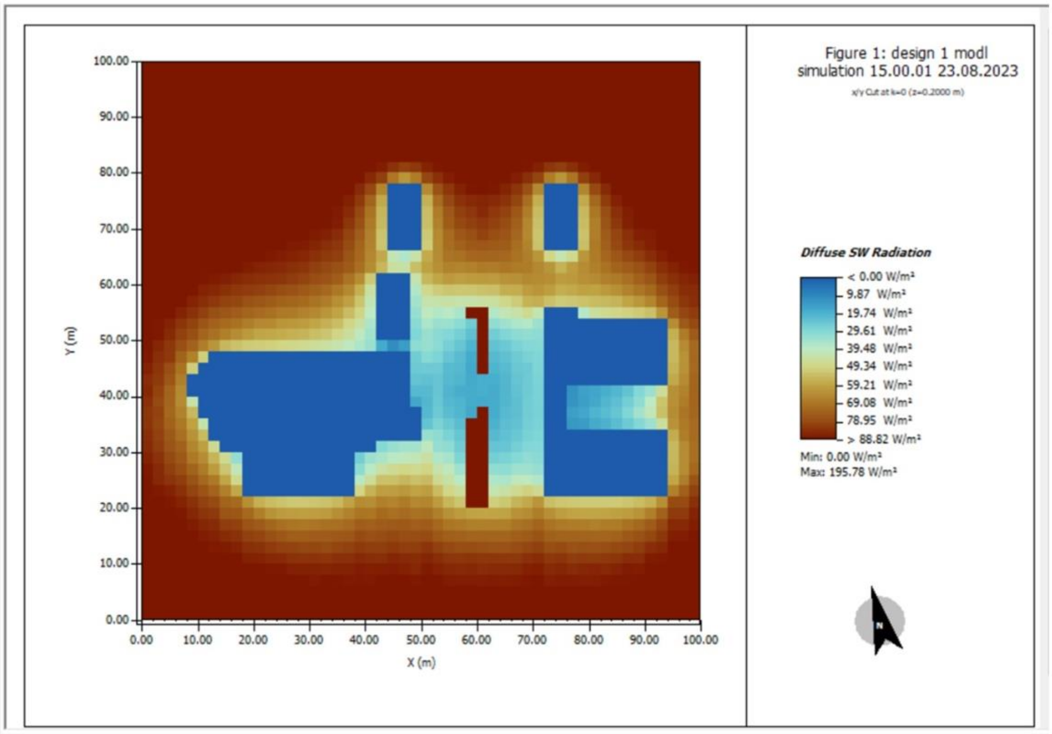

Figure 42: Diffused solar radiation produced by Leonardo for final design model

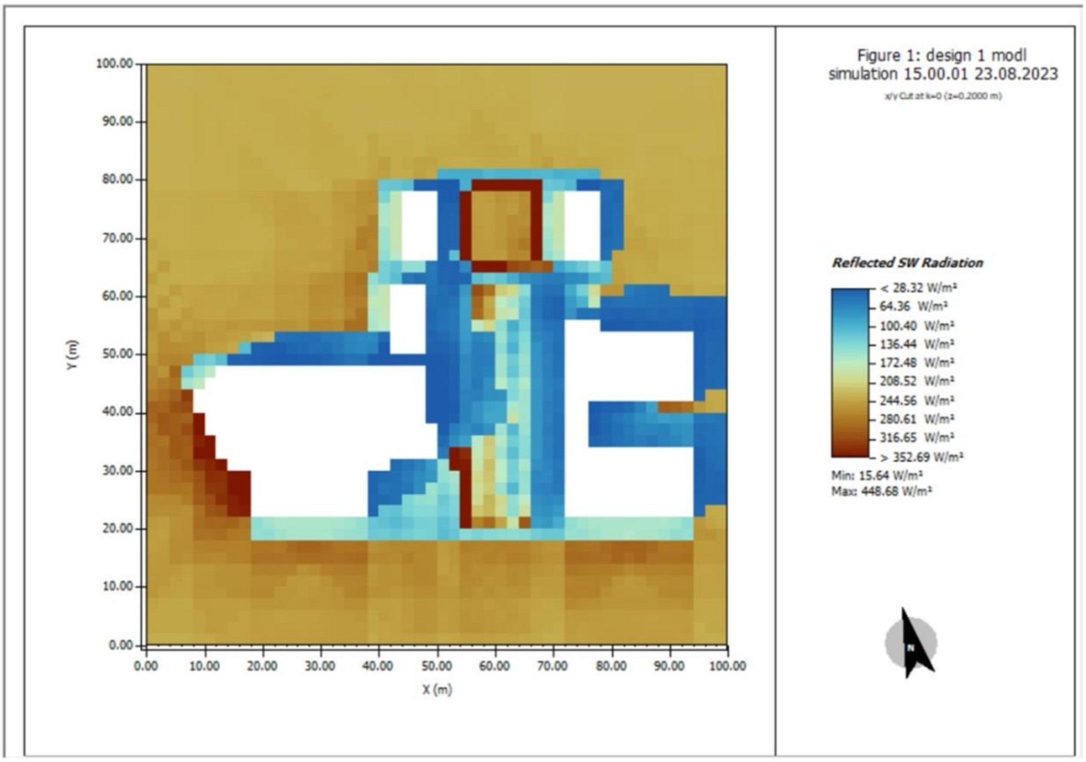

Figure 43: Reflected solar radiation produced by Leonardo for final design model

Inference:

- The amount of direct solar energy absorbed is reduced when there are trees and waterbodies. The remaining area receives the most direct sun radiation, with the exception of the areas with trees and bodies of water. The simulation maintains a suitable temperature in the space.
- In this simulation, the combined presence of water bodies and trees effectively reduces solar radiation levels, ensuring thermal comfort. The scattering effect of water bodies and shading provided by trees contribute to a pleasant microclimate without high levels of reflected solar radiation

POTENTIAL AIR TEMPERATURE

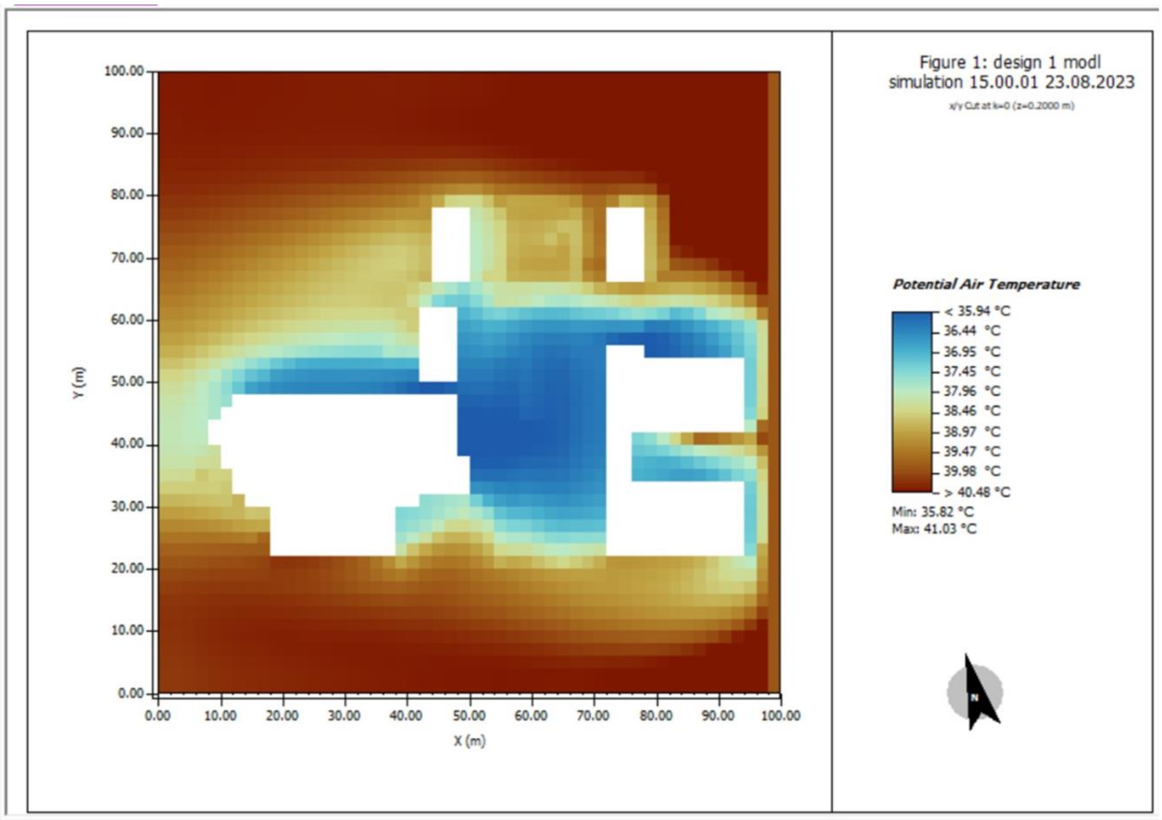

Figure 44: Potential air temperature produced by Leonardo for final design model

Inference:

Trees play a pivotal role in regulating temperatures within urban environments by employing various cooling mechanisms simultaneously, including evapotranspiration, solar radiation reflection, and shading. Through evapotranspiration, trees utilize incoming energy to transform water vapor, leading to lower air temperatures as energy is diverted towards the vaporization process rather than contributing to sensible heat. This helps to mitigate the overall heat experienced in the surrounding area.

During the measurement period, air temperatures fluctuated from 17˚C in the morning to 38˚C during the peak of the day. In the base case scenario, temperatures ranged between 25 and 61˚C, while in the proposed case with the strategic placement of trees and water bodies, temperatures were notably lower, ranging from 10 to 24˚C.

Furthermore, the cooling impact has been further amplified by the presence of aquatic bodies. By evaporating, the water bodies help to lower temperatures, dispersing heat and establishing a more agreeable environment. This method of combining water features and trees shows how they work together to regulate temperature, emphasizing how important it is to include natural components in urban planning to improve thermal comfort and lessen the influence of the urban heat island effect.

CHAPTER 5: CONCLUSIONS AND FINDINGS

5.1 CONCLUSIONS FROM SIMULATION RESULTS

The comprehensive analysis and modeling carried out with ENVI-met yielded important information about the microclimatic dynamics of the Georgia Square Mall region. By building and assessing multiple design models with varying combinations of water features and vegetation, the research sought to maximize thermal comfort while reducing the negative impacts of urban heat islands. The results highlight how important it is for urban design interventions to improve environmental quality and advance people's well-being in urban environments.

The base model simulations demonstrated the serious difficulties caused by the current weather, which is marked by high temperatures, low relative humidity, and strong sun radiation. These circumstances are made worse by the lack of foliage and impermeable pavements, which puts pedestrians' comfort and health at danger. Analyses of mean radiant temperature showed how surface materials affect thermal comfort and emphasized the necessity of deliberate actions to reduce heat radiation and absorption.

The suggested design models investigated the efficacy of combining vegetation and water features to improve microclimatic conditions in response to these difficulties. The first model, which just had one row of trees, showed some improvement in mean radiant temperature and relative humidity but not enough to provide maximum thermal comfort. Due to the lack of shading, Model 2, which included water bodies, showed slight improvements in relative humidity but was unable to considerably lower mean radiant temperature.

The ultimate design model proved to be the most successful in improving thermal comfort and reducing the effects of urban heat islands by strategically including both trees and water bodies. The final design model significantly reduced air and surface temperatures and improved relative humidity by utilizing the cooling qualities of vegetation and the evaporative cooling effect of water bodies. These results highlight the value of a multimodal approach to urban planning, utilizing water features and green infrastructure's synergistic effects to build resilient and habitable cities.

The study also emphasizes how useful ENVI-met is as a potent tool for modeling microclimatic conditions and assessing the effectiveness of design modifications. Informed decision-making in urban planning and design is made possible by ENVI-met's significant insights into the interactions between natural and constructed elements, despite its computational complexity and intensity. Notwithstanding, it is imperative to recognize the constraints of ENVI-met, including the difficulties linked to model calibration and validation, in addition to the requirement for comprehensive input data and proficiency in model interpretation.

In conclusion, the findings of this study emphasize the importance of sustainable urban design practices in addressing contemporary challenges related to climate change and urbanization. By prioritizing the integration of green infrastructure and water-sensitive design principles, cities can enhance resilience, promote public health, and create more equitable and enjoyable urban environments for current and future generations. Moving forward, continued research and interdisciplinary collaboration will be essential to advance our understanding of urban microclimates and develop innovative solutions for building climate-resilient cities.

Furthermore, this thesis lays the groundwork for further expansion and exploration, particularly concerning the winter season. While the focus has primarily been on addressing thermal comfort challenges associated with high temperatures and solar radiation, extending the research to consider winter conditions presents an opportunity to comprehensively address year-round comfort and environmental sustainability. By investigating how design interventions such as the strategic placement of evergreen trees, windbreaks, and thermal insulation can mitigate cold temperatures and enhance comfort during colder months, this research can offer valuable insights into creating resilient and adaptable urban spaces capable of providing optimal thermal comfort across all seasons. Additionally, examining the interplay between winter design strategies and their impact on microclimatic dynamics will contribute to a more holistic understanding of urban climate resilience and inform future urban planning and design efforts.

5.2 CHALLENGES AND CONSIDERATIONS FOR REAL-WORLD APPLICATION

It is crucial to recognize the difficulties and factors involved in converting theoretical frameworks and simulation-based insights into practical applications as we look to the future of urban design and planning. While sophisticated tools like ENVI-met provide useful capabilities for assessing design modifications and modeling microclimatic conditions, their successful application in real-world urban contexts necessitates careful handling of a number of issues.

5.2.1 Data Limitations and Uncertainties:

The inherent constraints and uncertainties related to input data and modeling assumptions are a major source of difficulty in real-world applications. The quality of input data, such as meteorological parameters, land use characteristics, and building layouts, has a significant impact on the accuracy and reliability of simulation results, even if ENVI-met offers a full platform for simulating microclimatic phenomena. Errors in data gathering and modeling presumptions can induce biases and uncertainties, which may result in incorrect interpretation of simulation results and less-than-ideal design choices. To overcome data restrictions and increase the precision and dependability of simulation results, strong validation procedures, sensitivity studies, and ongoing modeling technique improvement are needed.

5.2.2 Scale and Complexity of Urban Systems:

Complex interdependencies and nonlinear feedback mechanisms that are characteristic of urban environments present formidable modeling and simulation problems. Capturing the intricate interplay of many land uses, socioeconomic activities, and environmental processes that affect microclimatic conditions is made more difficult by the size and complexity of urban systems. High-resolution modeling at the district or city size is difficult to accomplish using ENVI-met because of its increasing computational and memory demands as the simulation grows. Additionally, due to the dynamic character of urban systems, which are impacted by variables including population dynamics, land-use changes, and climate variability, adaptive modeling techniques that can account for temporal and spatial heterogeneity while preserving computational efficiency are required.

5.2.3 Integration with Planning and Decision-making Processes

In order to bridge the gap between research and practice, interdisciplinary collaboration and stakeholder involvement are necessary for the effective integration of simulation-based insights into urban planning and decision-making processes.

5.2.4 Cost and Resource Constraints

Financial and resource limitations frequently prevent the application of simulation-based design methodologies in actual urban projects. Large computational resources, specialist knowledge, and time-consuming data processing are needed for advanced simulation tools like ENVI-met, which may be beyond the means of smaller towns, neighborhood associations, or universities with limited funding. Furthermore, compared to traditional methods, adopting sustainable design principles like low-impact development and green infrastructure may come with greater upfront expenditures, which presents difficulties for projects with little funding. Innovative finance strategies, capacity-building programs, and strategic alliances are needed to overcome budget and resource limitations in order to encourage the broad adoption of sustainable design principles in a variety of urban environments and democratize access to simulation tools.

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