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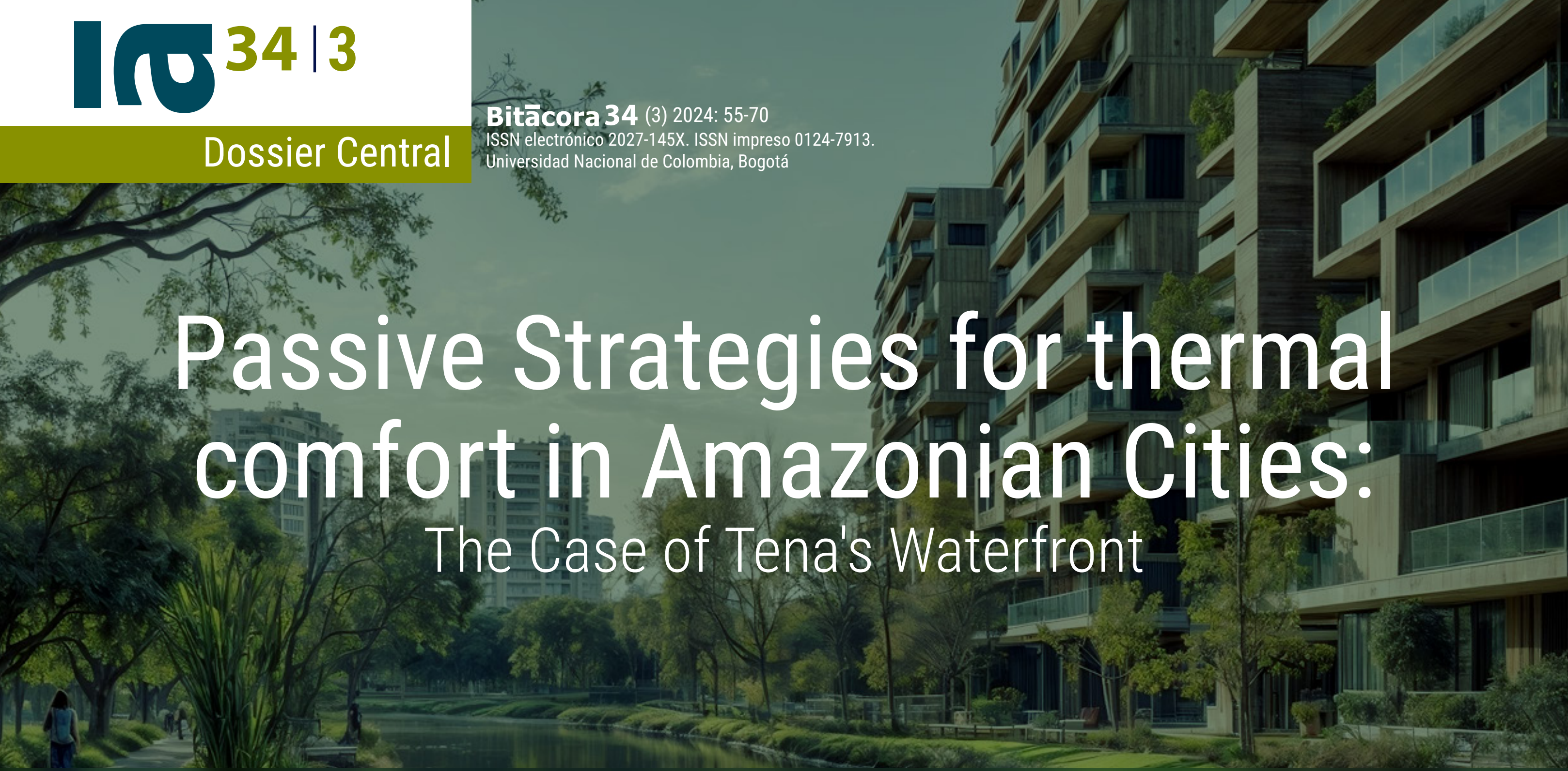

# Passive Strategies for thermal comfort in Amazonian Cities:
## The Case of Tena's Waterfront

## Estrategias pasivas para el confort térmico en ciudades amazónicas:
El caso del malecón del Tena

## Estratégias passivas para conforto térmico em cidades amazônicas:
O caso do malecón del Tena

## Stratégies passives pour le confort thermique dans les villes amazoniennes :
Le cas du malecon del Tena

**Fuente:** Autoría propia

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## Abstract

This study explores the application of passive strategies focused on reducing urban heat islands, with special attention to improving pedestrian thermal comfort in Amazonian cities. Based on climatic data such as temperature, humidity, solar radiation, and wind speed, the impact of urban morphology on public space, particularly on the Tena River waterfront, is analyzed. Using the Grasshopper and Ladybug simulation tools, two scenarios were compared: one current, with 2-3 story buildings, and one proposed, which includes buildings up to 6 stories integrated with native vegetation. The results demonstrate that the proposed scenario not only increases shading but also significantly contributes to the reduction of temperatures, confirming the viability of these strategies to enhance sustainable urban design and improve the quality of life in Amazonian environments. The evaluation of the results highlights aspects to improve in urban development and emphasizes the importance of integrating simulation tools to design urban proposals and open spaces, guaranteeing a comfort zone for the user, encouraging pedestrian routes and therefore increasing social relations in nearby public spaces.

Keywords: Climate action, Sustainability, Urban planning, Energy efficiency, Amazon cities.

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## Resumen

Este estudio explora la aplicación de estrategias pasivas, a nivel urbano y arquitectónico, enfocadas en reducir las islas de calor y mejorar el confort térmico de los peatones en las ciudades amazónicas. A partir de datos climáticos como temperatura, humedad, radiación solar y velocidad del viento, se analiza el impacto de la morfología urbano arquitectónico en el espacio público, particularmente en el malecón del río Tena. Utilizando las herramientas de simulación Grasshopper y Ladybug se compararon dos escenarios: uno actual, con edificaciones de 2-3 pisos, y otro propuesto, que incluye edificaciones de hasta 6 pisos integradas con vegetación nativa. Los resultados demuestran que el escenario propuesto no sólo aumenta la sombra, sino que también contribuye a la reducción de las islas de calor, confirmando la viabilidad de estas estrategias para potenciar el diseño urbano sostenible y mejorar la calidad de vida en ambientes amazónicos. La evaluación de los resultados destaca aspectos a mejorar en el desarrollo urbano y enfatiza la importancia de integrar herramientas de simulación para diseñar propuestas urbanas y espacios abiertos, garantizando una zona de confort para el usuario, fomentando los recorridos peatonales y aumentando las interacciones sociales en los espacios públicos.

Palabras clave: Acción climática, Sostenibilidad, Planificación urbana, Eficiencia energética, Ciudades amazónicas.

## Résumé

Cette étude examine les stratégies passives pour réduire les îlots de chaleur urbains et améliorer le confort thermique des piétons dans les villes amazoniennes. En utilisant des données climatiques telles que la température, l'humidité, le rayonnement solaire et la vitesse du vent, l'impact de la morphologie urbaine sur l'espace public, notamment le front de mer de la rivière Tena, est analysé. Grâce aux outils de simulation Grasshopper et Ladybug, deux scénarios sont comparés : un scénario actuel avec des bâtiments de 2 à 3 étages et un scénario proposé avec des bâtiments jusqu'à 6 étages intégrés à la végétation indigène. Les résultats montrent que le scénario proposé augmente l'ombrage et réduit significativement les températures, confirmant l'efficacité de ces stratégies pour améliorer la conception urbaine durable et la qualité de vie dans les environnements amazoniens. L'évaluation souligne les points à améliorer dans le développement urbain et l'importance d'intégrer des outils de simulation pour concevoir des espaces urbains et ouverts, garantissant une zone de confort pour l'utilisateur, favorisant les itinéraires piétonniers et renforçant les interactions sociales dans les espaces publics adjacents.

## Resumo

Este estudo examina estratégias passivas para reduzir ilhas de calor urbanas e melhorar o conforto térmico dos pedestres nas cidades amazônicas. Utilizando dados climáticos como temperatura, umidade, radiação solar e velocidade do vento, é analisado o impacto da morfologia urbana no espaço público, incluindo a orla do rio Tena. Utilizando as ferramentas de simulação Grasshopper e Ladybug são comparados dois cenários: um cenário atual com edificações de 2 a 3 pavimentos e um cenário proposto com edificações de até 6 pavimentos integradas à vegetação nativa. Os resultados mostram que o cenário proposto aumenta o sombreamento e reduz significativamente as temperaturas, confirmando a eficácia dessas estratégias para melhorar o desenho urbano sustentável e a qualidade de vida nos ambientes amazônicos. A avaliação destaca áreas para melhoria no desenvolvimento urbano e a importância de integrar ferramentas de simulação para projetar espaços urbanos e abertos, garantindo uma zona de conforto para o usuário, favorecendo percursos pedestres e fortalecendo as interações sociais em espaços públicos adjacentes.

Palavras-chave: Ação climática, Sustentabilidade, Planejamento urbano, Eficiência energética, Cidades amazônicas.

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**Passive Strategies for thermal comfort in Amazonian Cities:**
The Case of Tena's Waterfront

Mots-clés : Confort Urbain, Villes Amazoniennes, Rayonnement Solaire, Îlots de Chaleur, Stratégies de Refroidissement Passif

## Introduction

In the Amazonian regions, urbanization threatens the ecosystem integrity and makes population growth control challenging. According to Da Silva et al. (2023), urban expansion has drastically altered the Amazon biome. This is mostly due to the urban infrastructure, such as buildings and highways, quickly replacing the biome's natural habitat (Albert et al., 2023). This change has caused a drastic reduction in vegetation, thus affecting urban microclimates.

Cities' microclimates are directly impacted by changes in the surrounding landscape. This transformation is largely responsible for the phenomena known as urban heat islands, which Filho et al. (2021) characterized because of rising temperatures. Furthermore, Santamouris et al. (2015) have looked closely at these microclimatic changes caused by alterations in urban surfaces. The evidence on the relationship between urban expansion and the increase in surface temperatures highlights the urgent need to integrate urban planning approaches that promote both environmental sustainability and improved quality of life in Amazonian regions.

*The evidence on the relationship between urban expan sion and the increase in surface temperatures highlights the urgent need to integrate urban planning approaches that promote both environmental sustainability and improved quality of life in Amazonian regions.*

In the Amazon, urbanization often overlooks the biological and cultural potential of these local ecosystems, even though these phenomena are closely related. In such cases, they are just seen as resources to be used for financial gain, claims Trindade Júnior (2015). Research like that done by Erlwein and Pauleit (2021) has clearly shown a correlation between urban densification, a dearth of green space, and the intensity of heat islands. This perspective has significant implications since the local population experiences thermal discomfort because of the ensuing urban climate event, which lowers their quality of life and makes it more difficult for them to enjoy public places.

Despite these challenges, experience shows that cities have the potential to improve thermal comfort by harmoniously integrating buildings with the natural environment. This involves carefully considering local climate parameters and taking advantage of available natural resources, such as natural ventilation and lighting. A crucial element in this strategy is urban morphology, as it can significantly influence climatic responses. As Mohajer (2022) pointed out, urban configuration can favor wind circulation, modifying its speed and, therefore, affecting temperature variations in the urban environment.

The intensity of urban heat islands and particular meteorological variables, like wind speed and cloud cover, are examined in the Al-Obaidi et al. (2021) paper. This study offers a deeper comprehension of the ways in which a city's microclimate might be impacted by its urban configuration. Specifically, it emphasizes the significant influence that taller buildings can have on the dynamics of the city by enhancing how people interact with their surroundings. In addition to increasing densification rates, this rise in building height offers valuable guidelines on how urban profile growth can actively affect microclimate behavior. These guidelines can be used in urban design strategies that aim to mitigate heat islands and create a more sustainable, energy-efficient, and comfortable environment for the city's residents (Simbaña et al, 2020).

Amazonian cities must therefore combine urban expansion with the preservation of their natural environment, as they are surrounded by biodiverse habitats. This article highlights the need to implement sustainable urban planning techniques that respect the specific ecological environment of the Amazon. These strategies therefore include the creation of urban environments that encourage minimal intervention and ensure sufficient ventilation, which can help to diminish the adverse effects of increasing urbanization. Furthermore, the appropriate placement of architectural buildings that permit sufficient light penetration and offer ideal pedestrian-level areas must be the foundation of these urban layouts (Natanian & Auer., 2019).

This article highlights the importance of the Tena River in the Ecuadorian Amazon and has chosen the Tena's Pier as the study location. This area has evolved into a hierarchical public space that is the preferred gathering place for social, cultural, and political events by the inhabitants, in addition to being a natural link with the river. Additionally, walkways and pedestrian connections link the sector's main attractions to the surrounding natural environment (Carrión et al., 2023).

Considering this, the proximity of water bodies to the research region highlights the need of creating urban microclimates and integrating rivers as structural elements that support thermal comfort in urban environments. However, despite the existence of a research base on thermal comfort strategies, a notable gap is identified in studies applied specifically to Amazonian cities, which underlines the need to validate specific approaches that adapt to the unique conditions of these regions.

To improve thermal comfort without depending on mechanical systems, this essay puts out the notion that the Tena's Pier might benefit greatly from the application of urban design concepts focused on architectural buildings that incorporate natural light and ventilation. These strategies promote social cohesion and thermal comfort in public areas while simultaneously supporting environmental sustainability, allowing for a smooth transition from the urban to natural ecosystems along the river. It should be emphasized that this hypothesis ensures sustainable expansion on the site with a minimum heat island effect by implementing specific building growth guidelines along this waterfront, rather than implying any significant financial commitment by the Municipality of Tena.

The aim of this study is to maximize the relationship between thermal comfort and public space occupancy by implementing strategies that enhance users' interactions with their surroundings. Natanian (2019) lists some of the most successful methods as providing shade through parametric optimization of new building heights and orientation that maximizes natural illumination and minimizes heat absorption at pedestrian level. These strategies complement a sustainable growth model that incorporates natural elements and gives priority to passive solutions, providing practical and financially viable ways to manage solar radiation and air currents.

To assess the effectiveness of these urban and architectural design strategies aimed at reducing heat islands, climate simulations are performed in two scenarios: one reflecting current condition and one projecting future modifications. The comparison of the digitally evaluated experimental models at full scale completes the empirical validation process. In addition, computer programs like Ladybug and Grasshopper are used, which allow the uploading of EPW climate files and the simulation of the site's climatic conditions and their effects on the projected and current architectural volumetric scale. Using these applications, designers easily investigate the direct connection between environmental data and architectural design development, allowing for graphical data results that are closely integrated with the building geometry (Toutou et al., 2018, Natanian et al., 2019).

This methodological approach not only provides a robust framework for evaluating bioclimatic urban design solutions, but also establishes standards that could serve as a basis for future urban planning projects in Amazonian cities that maximize thermal comfort and environmental sustainability.

## Conceptual Framework

### *Sustainable Architecture*

It considers design techniques that produce spaces and buildings with the least amount of carbon footprint, thereby achieving environmentally responsible architecture. This article explores only passive sustainable strategies, or those that incorporate cost-free natural elements and just focus on ensuring that the sun and wind are managed properly. In this sense, depending on whether gain or control of these elements is necessary, comfortable urban environments are suggested through the appropriate management of the sun and wind.

### Urban Comfort

It refers to the range of temperatures at which a person feels anatomically normal, meaning that neither extremely high (hot) nor extremely low (cold) temperatures would cause stress to their bodily or mental structures. The accepted range for a human being to feel comfortable

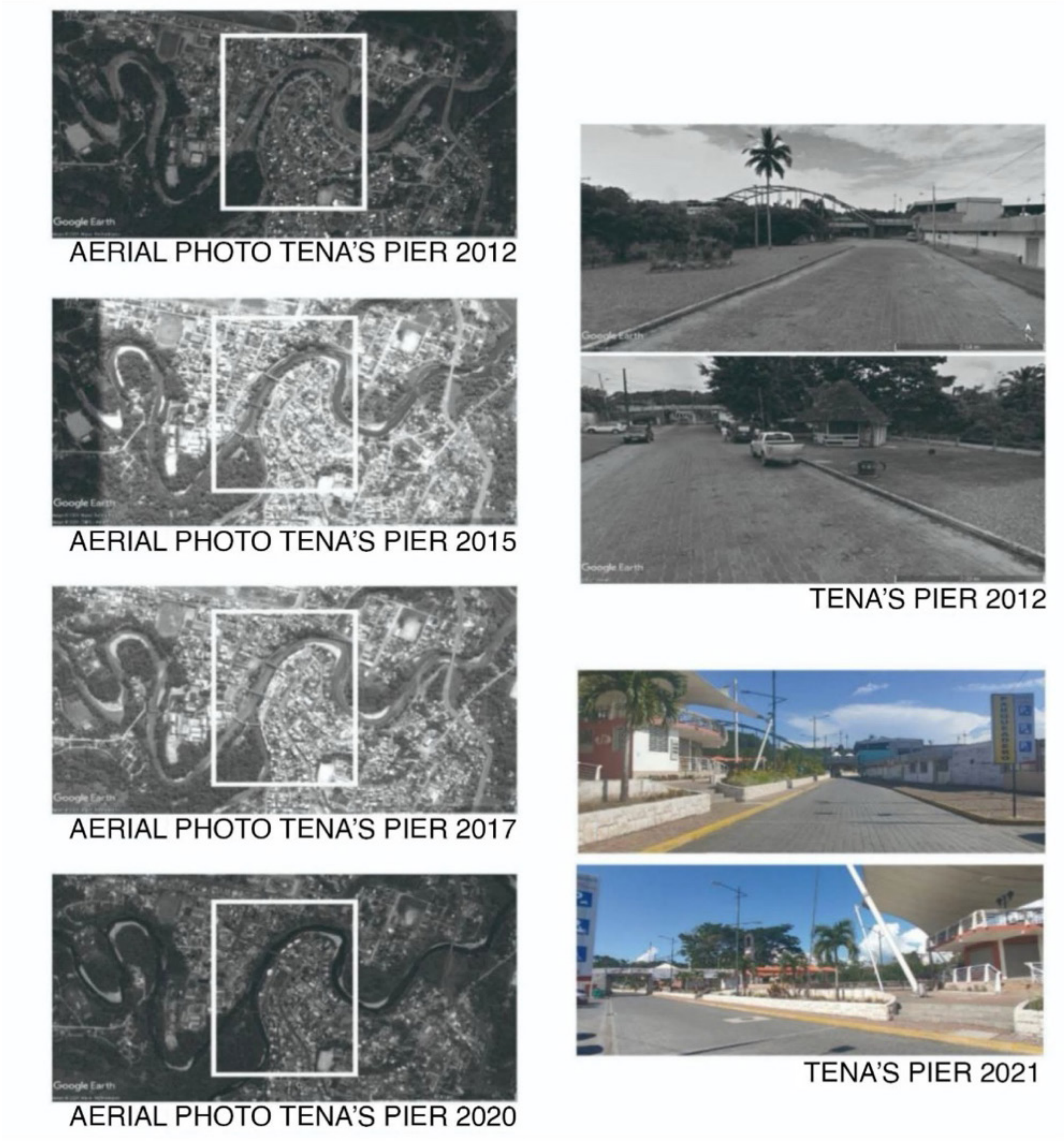



**Image 1.** *Orthophotograph's and photographs of the Tena´s Pier.*
**Source:** Own elaboration, Google Earth and own resources.

and be able to perform their physical or mental activities without any distraction is between 18 and 25 degrees Celsius. AHSRAE 55, and (NEC, 2018).

### Heat Islands

Are the thermal byproduct of the interaction between solar radiation and natural ventilation at pedestrian level, which determines whether a space is comfortable or not. Heat islands are those variations in temperature that have values more than 28 degrees Celsius; cold islands are those with values lower than 8 degrees Celsius. Because of Tena's unique climate, we will refer to spaces that are uncomfortable for pedestrians and have temperatures above 28 degrees Celsius in this piece.

### Urban Regeneration/Architectural scale

It considers several strategies aimed at enhancing the interaction between the user and the urban environment. This article focuses on enhancing spaces by guaranteeing a comfort zone at the pedestrian level that promotes social, cultural, and economic dynamics. Therefore, improving the appropriation of the spaces of the city by its inhabitants, transforming various transition spaces into spaces of permanence. (Rocchio, et al., 2023).

## Metothology

### Study Site

The city of Tena, located in the Amazon region of Ecuador, is characterized by a warm and humid climate, with temperatures frequently above 30°C. This place has experienced a remarkable recent development, driven by its strategic location in eastern Ecuador, its connection to the capital, Quito, and the significant influence of tourism. The specific study area is located along Avenida 15 de Noviembre, which connects the historic center with the commercial area of the city.

The study area starts at La Isla Park, where a pedestrian bridge links the waterfront and the central park, and it goes all the way to the north, to the bend of the Tena River, where the stated avenue starts. Since 2012, the Tena Pier has been the subject of an intensive spatial recovery process, motivated by the recurrent flooding of the river during the rainy seasons. Over time, many facilities have been built in this area connecting the city center.

The urban morphology of Tena has evolved around the micro-basins of the Tena and Pano rivers, which converge in the city center to form the Tena River. Due to the extensive network of estuaries in the area, there are many opportunities for environmental tourism. Because of the many accessible attractions, there has been an increase in pedestrian routes since the ground floor land use in this region of the waterfront was modified, especially in the afternoons and evenings.

Urban and rural activities typical of the Amazon have developed along the waterfront, including sport fishing, recreational usage of the river, and on occasion, use of the river for transportation. This region stands out for having a pedestrian zone with huts and a vegetal landscaped edge. At a higher level of the platform, areas covered with tensile membrane structures have been installed that serve various purposes, including bars, sales of crafts, and restaurants. This route also includes sanitary service areas and parking lots.

Tena also stands out for having strong urban-rural ties, which are evident in the city's physical layout as well as in the ethnic groups' cultural manifestations. This highlights the vital role that tourism plays in the city's urban dynamics.

## Climate Simulation Scenarios

Due to the importance of this Tena River axis, a scientific framework organized into two primary phases of climate study has been developed with the aim of promoting sustainable development and enhancing urban comfort on the Tena waterfront and its surroundings. The first phase evaluates the current climate conditions of the area, while the second phase projects future scenarios considering potential urban developments, including the reuse or renovation of vacant spaces and existing buildings.

Making a three-dimensional model of the study region is the first step in the methodological approach. Advanced tools for climate analysis, such as climate antennas and the examination of PDF files with historical and current data, are incorporated with this model. This analysis is essential to identify existing patterns and establish preliminary guidelines for improving urban heat through efficient management of the local climate.

Subsequently, a data-driven approach is employed to investigate and validate passive architectural design strategies. The strategies include properly orienting buildings, promoting natural ventilation, and strategically using vegetation to enhance thermal comfort in urban environments and regulate temperature by providing shade—elements that local communities recognize and appreciate (Alvarado-Arias et al., 2023). The analysis is

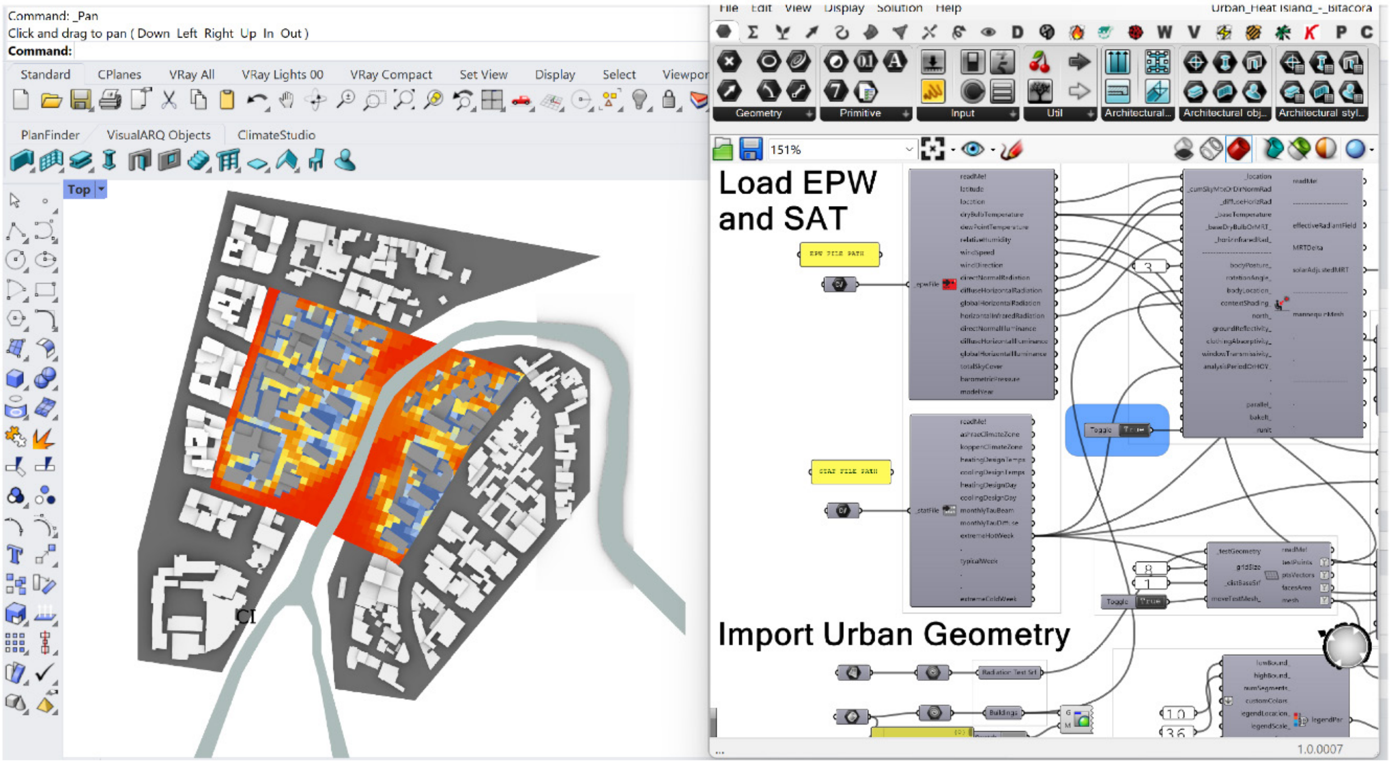



**Image 2.**3d model to the left and grasshopper ladybug definition at the right
**Source:** Own elaboration, 3d model Rhinoceros, Grasshopper, Ladybug

enriched by comparison with experimental models and previous studies (Zhang et al., 2016), which have explored the relationship between architectural configuration and climatic performance.

Grasshopper3D, a "graphical algorithm editor" built within the 3D modeling program Rhino, is used to run these simulations. With Grasshopper, designers can investigate in real time how environmental data and design generation interact. Using free and open-source parametric simulation plugins, such Ladybug Tools (Honeybee), natural light and other climatic operations are optimized with this visual programming platform for generative algorithms. By minimizing computing resources and enabling quick and efficient iterations, these plugins help handle the necessary calculations in an accurate and efficient manner. The dynamic 3D model and its grasshopper definition are shown in image 02 below.

By simulating urban buildings and their natural and built context, aiming for a lower carbon footprint, it is ensured that the suggested design options are not only practically feasible from an environmental and social point of view, but also adapted to the requirements and the distinctive environment of the Tena coast, thus achieving a sustainable model that can be replicated in other Amazonian cities.

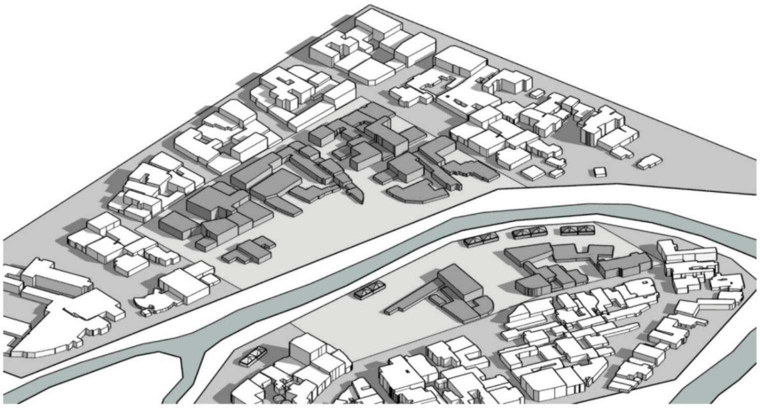
### Scenario #1: Current situation.

This scenario focuses on the current climate analysis of Tena, including temperature, winds and solar radiation. The results allow guidelines to be established on building height, orientation and views, aligning these elements with urban comfort criteria.

### Scenario #2: Projected Situation.

This scenario offers a vision of densification and revitalization for the area being studied. The inclusion of buildings no taller than six floors is taken into consideration, which would contribute to improving thermal comfort by reducing solar radiation gain at pedestrian levels. By generating wind tunnels and projecting shade, the plan aims to maximize building interior comfort zones and enhance urban comfort. Furthermore, using native plants and permeable areas is suggested as countermeasures to reduce heat islands. This simulation includes new buildings with a height of up to six stories so that they can harmoniously dialogue with the existing context and guarantee real sustainable growth.

The data obtained from the simulation are analyzed under the following three climatic parameters, providing a solid basis for urban and architectural planning looking forward a sustainable development.



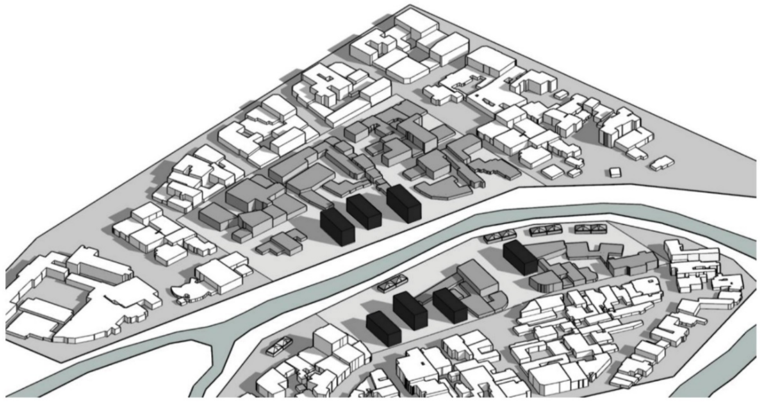




**Image 3.** *Scenarios proposed for this research*
**Source:** Own elaboration, 3d model Sketch Up.

## Climate Data

- This article considers three main parameters to be analyzed in each scenario.
- Shadow projection: this analysis establishes comfort zones generated by the shadows of buildings and surrounding surfaces. To achieve this, the climatic information from the antenna closest to Tena is processed in the Grasshopper / Ladybug program. This EPW file contains the meteorological data of the sector such as temperature, humidity, wind rose, radiation rose and precipitation. Once the temperature is determined, the need for access or solar control in the study area is established.
- Solar radiation: this parameter determines the availability of sunlight both in buildings and at street level. Too much or too little direct radiation will directly affect the comfort of any space, making it a necessary parameter to consider allowing adequate sunlight inside and outside a space.
- Ventilation: this indicator determines the wind flow and speed, as well as the area's capacity to allow cross ventilation, necessary to maintain thermal comfort both at street level and indoors.

## Analysis

- Shadow projection. – These graphs are obtained using the daily sun path, where the sun's rays are outlined in the geometries from sunrise to sunset, casting shadows on the surrounding buildings as well as on the street level (Sari et al, 2021). With this analysis, microclimates are identified at the pedestrian level to understand pedestrian comfort. For this article, the sun is placed on December 21 (winter solstice) at 5:00 pm determining the azimuth and angle of the sun at that specific time, everything in gray at street level is the shadow projection, while other gray-colored surfaces are shaded areas. Furthermore, the combined shadows of every structure are projected onto a shadow range analysis map, which shows the gray areas that are shadowed during the day on a given day from sunrise to sunset.
- Solar Radiation. - These graphs represent the amount of sun that a surface is exposed to on a monthly or yearly basis. To determine this, the software used divides each surface of the volume into pixels and then colors them based on the amount of sun they receive monthly or year-

ly. The data collected is measured in kilowatts per square meter ($kw/m^2$). This result is graphically represented using a red-yellow-blue gradient scale in which the areas with the highest kw/m2 are colored red and then range to the lowest kw/m2 areas that are colored blue.

- The Ecuadorian National Electricity Council states that the average value of solar radiation per day is between 4700 to 4920 $kw/m^2$ for Tena. (Conelec, 2008). Understanding the differences in radiation in each scenario and deciding whether solar gain strategies are necessary depend heavily on this value. By varying the geometry, floor height, or the use of solar control devices like overhangs or other sun protection systems, buildings can be made to perform better in relation to solar access needs. These graphics, therefore, didactically depict cold or heat islands at pedestrian level as well as surfaces that receive a lot of sun and those that do not.
- Ventilation. These graphs consider the direction, speed and frequency of the wind, which is hosted by the wind rose. At the urban scale, wind direction is utilized to designate proper cross ventilation between buildings, prevent wind tunnels at street level, and minimize wind shadows caused by the difference in pressure created when air strikes a building's façade.
- Additionally, a wind profile graph is produced, showing the symmetrically proportional relationship between air speed and building height—that is, the quicker the wind blows, the higher the building (Li & Donn, 2017). This is crucial to identify potential modifications to a building's geometry that could result in an aerodynamic form or the creation of openings on particular levels to lessen wind force acting on the structure and the wind shadow effect, which causes turbulence at the rear of the building.
- All these factors need to be considered to create well-ventilated, comfortable areas both inside and outside of structures, as well as to lessen the force of the wind and its effects. The NEC 2018 (Ecuadorian Construction Code) states that air velocity recommendations are as high as 5 m/s for outdoor spaces and as high as 2 m/s for inside spaces. These values will be used to analyze the variance in height and air intake and decide whether air velocity reduction techniques are required.

## Results

The data from scenario #1 shows Tena's current state, while scenario # 2 presents an outlook for the area under study's growth and urban regeneration with the addition of specific buildings up to six stories tall, which will result in thermal comfort by lowering the solar radiation gain at the pedestrian level. Every scenario examines the sun's path and radiation, comprehending both its present and potential states of expansion before concluding with a wind study of both scenarios.

### Scenario # 1. Current Situation.

Image 3 shows that two- and three-story buildings predominate, except for two buildings that are taller than eight meters. The area subjected to the radiation and wind analysis is represented by the dark gray buildings. The abundance of solar radiation captured by each building is evident since there aren't any tall structures to obstruct the sun's rays. Tena's high temperatures make it more difficult to make use of shading mechanisms or lower the number of windows to block sun radiation.

### Scenario # 2. Potential Urban Regeneration and Growth

In this scenario, seven buildings are proposed with a height of up to 6 floors. These buildings are mainly distributed in empty spaces or in certain areas with existing buildings that can be replaced since they are single-story volumes. It is important to note that the dimensions of the proposed buildings are arbitrary and respond more to generating shadows in the surrounding spaces without causing excessive contrast with the existing context. These seven new buildings have dimensions of 12 x 32 m and a height of 6 floors, typical proportions of bar-type buildings throughout the country. Furthermore, it is worth mentioning that these new structures are situated in front of and alongside the Tena River, heading toward the pier. These buildings are proposed as mixed-use structures, with commercial space at the pedestrian level and residential or office spaces on the upper levels. The shaded areas on the ground floor seek to improve the social dynamics in this sector.

### Shading. Scenario #1.

The shadows cast by the sun at a particular time on December 21 in the sector are shown in Image 4 (upper part). It should be mentioned that because to the relatively low density of buildings in the area, shadows are rare even at low sun angles. Moreover, Image 4 (upper part) depicts the shading caused by the structures from 6 a.m. to 6 p.m. The region surrounding the waterfront is undoubtedly overheated due to the lack of shadow projection.

### Shading. Scenario #2

In this scenario, the variation in shaded spaces compared to scenario 1 can be clearly seen. The new buildings, whose height does not exceed 6 floors, allow solar

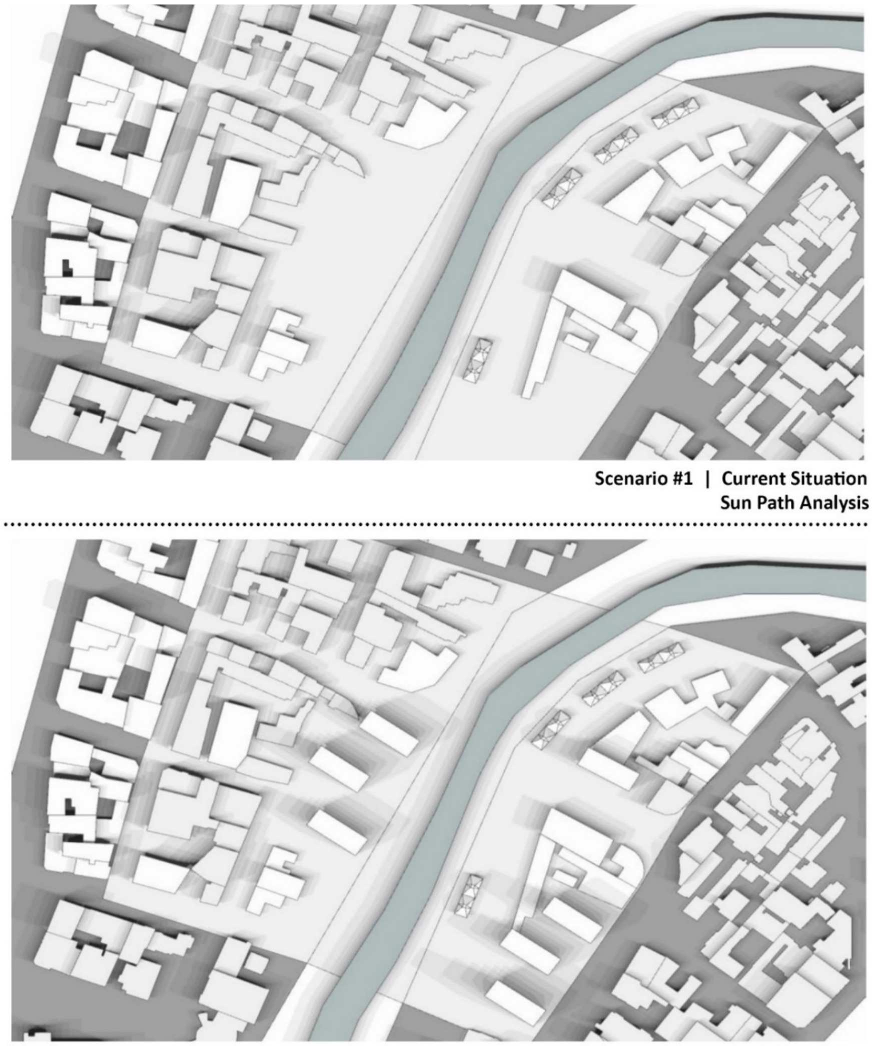



**Image 4.** Shading simulations of scenarios proposed for this research

**Source:** Own elaboration, Rhinoceros, Climate Studio.

access to the surrounding buildings, but also generate shade at the pedestrian level. Additionally, they have a parallel rotation towards the Napo River, which expands the shade strip and guarantees solar capture throughout the day, both in the morning and in the afternoon. Image 4 (bottom part) shows the solar positioning at 8am on December 21, the shadow projection occupies a good portion of the space at the pedestrian level.

Image 4 (bottom part) also shows gradual shading, considering the solar path from 6 am to 6 pm. As can be seen, large thermal comfort zones are ensured since shade covers 3/4 of the empty space. The benefit of adding the suggested additional buildings is evident when contrasted with the current situation, in which hardly more than 1/4 of the land was covered. In contrast to scenario 1, when some of these spaces were strictly residual areas, it is also crucial to note that most of these shaded spaces are accessible and can be plazas or public places within the building where various social dynamics are conformed.

## Solar Radiation. Scenario #1

The majority of the examined areas in Image 5 (upper part), which corresponds to the heat islands in the sector, is red, indicating that it experiences temperatures higher than thirty degrees Celsius. Considering that the thermal comfort zone is between 18 and 25 degrees, it can be said that individuals find these temperatures uncomfortable and unintentionally convert these locations from living spaces to transitional spaces. In addition, some of the blue zones had a 21-degree temperature. The buildings surrounding these places give shade, which is why these areas appear blue. Most of these rooms are setbacks or residual spaces, thus even though they are within a safe temperature range, they aren't always dynamic or used.

## Solar Radiation. Scenario #2

In this option, Image 5 (bottom part), it can be clearly seen how the red zones that indicate a high incidence

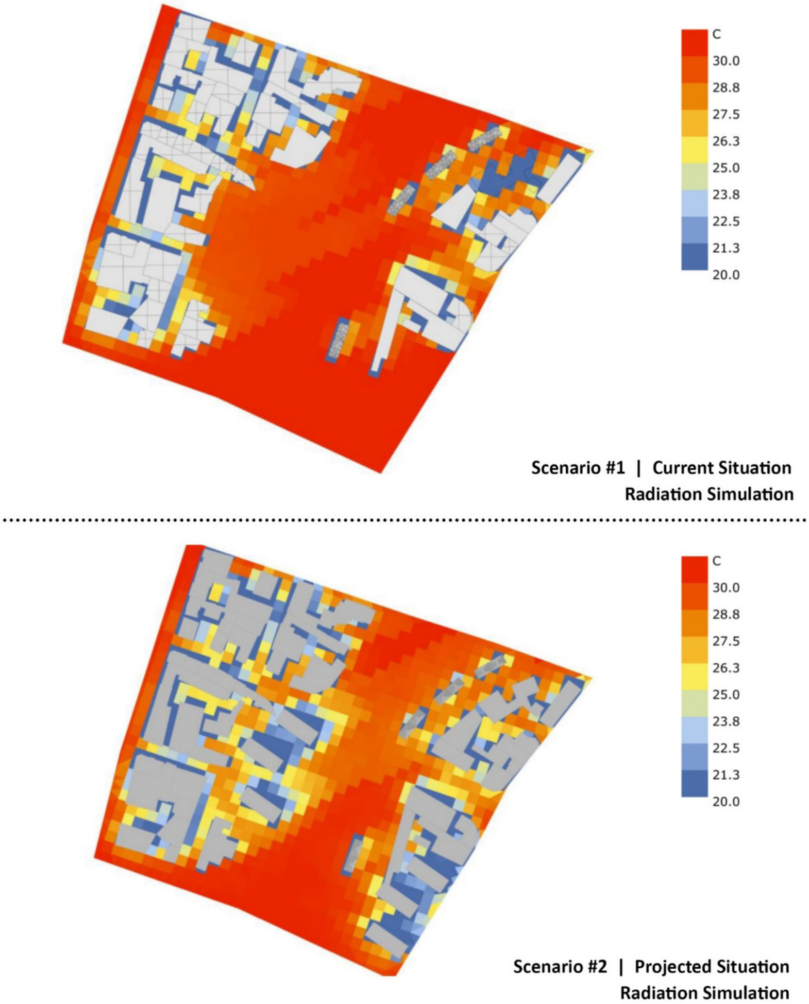
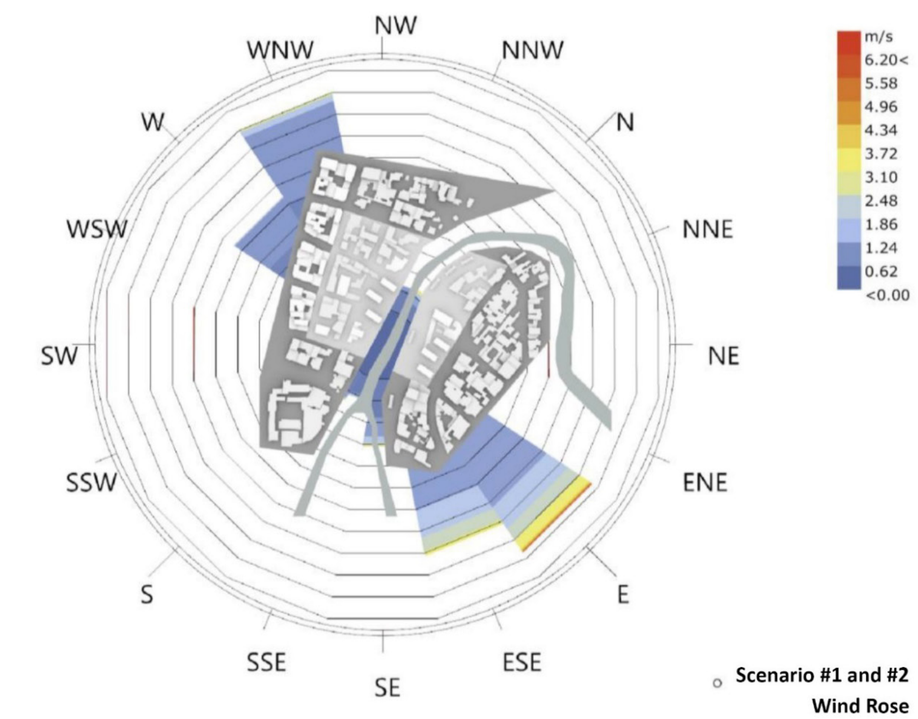



**Image 5.** Solar Radiation simulations of scenarios proposed for this research
**Source:** Own elaboration, Rhinoceros, Ladybug.

of solar radiation, with temperatures around 30 degrees, have decreased considerably. Regions designated in blue and orange, which denote adequate solar radiation within the comfort zone—that is, temperatures between 20 and 25 degrees Celsius—now make up nearly ¾ of the chosen area. Therefore, it can be concluded that the heat islands have been significantly decreased, allowing for larger shaded spaces in which users feel comfortable and carry out different activities, thus encouraging all these spaces to no longer be transitional but to become dynamic and livable spaces.

## Wind and Natural Ventilation.

The wind rose, Image 6 (upper part), of the designated location is the first point of reference for the wind analysis. Due to the original intended scope, this analysis does not include wind simulations on the buildings. However, several of the applicable aspects in the simulation can be understood starting from the wind rose, which are the following: the predominant wind directions are from the North-West and South-East, with winds that can reach up to 2 m/s from the North-West direction, and 6 m/s from the South-East direction. According to the NEC, the acceptable wind speed for outdoors is up to 5 m/s, which means that certain mechanisms would be required to reduce wind speed in this direction. Adding vegetation to the area is one way to mitigate wind speed while enhancing shade protection. Image 6, bottom part, shows the wind profile, or the speed at which the wind moves through a particular height. In this case, for the chosen area and on the proposed 6-story buildings, the wind speed is only 0.71 m/s, which means that wind acceleration strategies are required since the NEC recommends speeds of 2 m/s for internal spaces. Part of the wind acceleration strategies are managed through the size of the



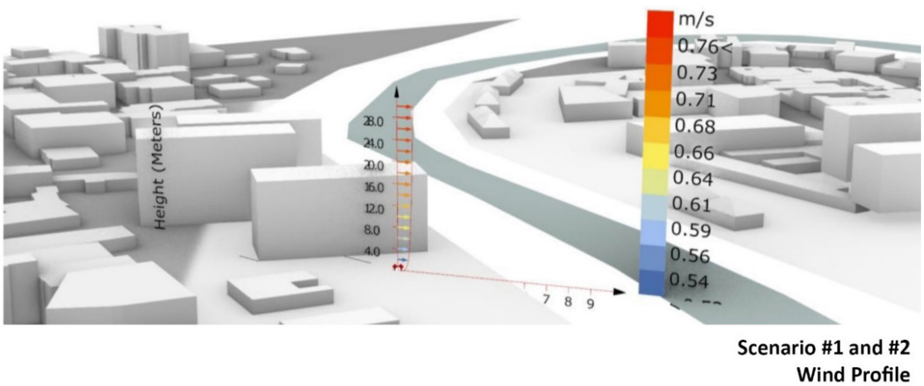




**Image 6.** Wind rose and profile of the existing area of this research
**Source:** Own elaboration, Rhinoceros, Ladybug.

perforations in the façade, which are smaller while those in the back are larger, thus increasing the air pressure and ultimately its speed.

## Conclusions.

As a growing Amazonian city, Tena has become a reference for urban phenomena that take on unique characteristics of its physical, social, and natural environments; therefore, it's imperative to suggest strategies that support the city's sustainable development architectural scale buildings. In this regard, the analysis of the projected urban growth in the vicinity of this pier contributes to the enhancement of the city's public space.

The strategies proposed from this article take on importance in the urban edge of the pier in search of becoming a transition zone from the urban to the natural environment, considering the potential of the parallel waterfront as a natural and biological cordon in the city.

Considering the effects of new construction within the Tena sector allows for the development of solutions where new buildings serve as catalysts for local social dynamics, rather than being built as is often the case without considering the effects on the comfort zones of surrounding places. As a result, one of the suggested techniques is the creation of urban comfort zones within cities, which can provide pedestrian-level areas that fall within the accepted temperatures of 18 to 25 degrees without requiring mechanical components.

One of the article's main conclusions is that heat islands can be minimized by assessing the current environment, considering the buildings that are already in place, and using these inputs to generate a projection that accounts for vacant spaces or buildings that could be replaced with new constructions that would not only increase the area's density but also create comfortable urban spaces by projecting shade. Additionally, properly managing ventilation allows these spaces not to be residual spaces as has normally been done in most cities. Finally, by connecting the growth of these structures to the improvement of the waterfront by linking the river, the existing environment and the comfort of pedestrians, sustainable growth strategies can be established that serve as reference for other amazonian cities.

Apart from the strategies that have been discussed above regarding building height and urban growth, it is crucial to stress that the river and the green edge in the Amazonian city are natural elements that enhance urban comfort because pedestrian spaces have been designed with these elements in mind at ground level. In this case, the improvement of public spaces associated with the river and its unique features will be indicated by additional activities that successfully foster social interactions. As a result, the Tena boardwalk is transformed into a place that, because of the river, can be improved as a green belt by including areas in its layout where the native flora and trees provide shade and places for people to hang out. This is because, apart from increasing the study area's urban comfort, creating a natural space at the river's end presents an important opportunity for Amazonian cities.

This comprehensive approach, which combines ecology with urban design, highlights the importance of waterfronts not only as aesthetic or recreational components, but as vital elements in promoting urban sustainability.

In summary, this study has demonstrated that urban heat island effects can be successfully reduced using thoughtful design urban solutions and permeable areas. Building layout and architectural design have a significant impact on how solar radiation is absorbed and how air circulation is enabled, both of which directly affect local temperatures. Incorporating green spaces is also crucial since it enhances the general environmental conditions and increases the energy efficiency of buildings. Heat island effects can be significantly reduced by methodically incorporating these principles into urban design, which helps to create more sustainable and habitable urban environments.

Furthermore, verification of natural lighting performance has established itself as an indispensable practice in contemporary architectural design. This process not only optimizes the use of natural light in built spaces, but also plays an essential role in promoting sustainability and occupant well-being. (Rostami et al, 2024). Using advanced modeling and simulation techniques, designers and architects can anticipate and adjust the distribution of natural light, ensuring energy-efficient and comfortable indoor environments. Integrating this type of verification into the design phase not only meets current environmental demands, but also sets a standard for the future development of sustainable construction and environmentally conscious design. (Nicholson et al, 2024).

Finally, the results obtained confirm that the implementation of climate simulation scenarios is an effective tool to assess the impact of urban design in reducing the heat island effect. It has been shown that strategic adjustments in buildings, including the orientation of buildings and the incorporation of natural elements, can significantly reduce this phenomenon without compromising internal thermal comfort. This validates the hypothesis that meticulously planned interventions in the urban structure can offer sustainable solutions that benefit both the urban environment and the quality of life of its residents.

## Recommendations

This article started from the premise of understanding the growth and urban fabric that has developed along the Tena River, specifically in the area where the Tena waterfront is located. The analysis of heat islands and solar radiation at the pedestrian level was limited to the existing buildings in the area, with the possibility of future projections based on vacant lots. As such, this is a specific study aimed at raising awareness of how comfortable spaces can be created through sustainable architecture by analyzing the effects of each building on its immediate surroundings. However, a more in-depth study is recommended that includes other complementary aspects such as the use of vegetation in the area, as well as land use regulations for these sectors where the minimum heights indicated in this article are used to ensure the comfort zone at pedestrian level, reducing heat islands to a minimum.

Therefore, the following recommendations are proposed as complementary strategies that will allow for the creation of dynamic and comfortable spaces in Tena, guaranteeing a comfort zone for pedestrians not only in the study sector but in any space in the city of Tena.

Buildings must have a minimum height of 4 stories (12 m high) to ensure shade around the building throughout the day. Width and depth dimensions are variable and may be determined based on the configuration of the lot.

The integration of native vegetation and landscape design into various public space scales is deemed crucial in Amazonian cities. This not only enhances air quality but also offers users shade at a human scale, fosters connection, and facilitates the transition from undeveloped to more constructed areas. Depending on the size of the areas and how they are designed, these trees may be timber ones with broad canopies, such bamboo, palm, yutzo, and balsa, whose foliage varies in diameter from one to three meters, providing pedestrians with shade from the sun. The Amazon, with its predominantly greenery, has the challenge of urban regeneration framed in the dialogue between the natural and the urban, which becomes an opportunity in the design of walkable spaces in the city taking into consideration its climatic conditions that must guarantee a quality of life of users.

Additionally, there is a need to implement cross- and induced ventilation strategies within buildings to ensure a comfort zone not only at the pedestrian level but also within the building. To ensure this ventilation, the minimum proportions required by the rooms must be considered, such as ratios of 1 to 2 and 1 to 3 based on their height and depth proportions (Baker and Steemers, 2000).

However, it is suggested that the GAD of Tena requires studies of the sustainable impact of a building before granting the construction license. These studies may include the analysis of solar radiation, heat islands and natural ventilation, seeking to ensure adequate lighting and ventilation and a reduction of heat islands at the pedestrian level. It is worth mentioning that a pedestrian comfort zone encourages the growth of various economic and social activities, promoting the emergence of new social dynamics and, ultimately, a better city.

Finally, to reduce Tena's carbon footprint, it is suggested that the sustainable ways that the GAD has been developing in this city be reviewed and that the strategies and recommendations outlined in this article be added to the current measures. Because there are less cars on the road than in larger cities like Quito, Guayaquil, or Cuenca, $CO^2$ pollution in this city is reportedly lower than in those areas. Nevertheless, the usage of air conditioning has been steadily rising, which has increased the need for electricity. Therefore, by implementing natural strategies that require little to no energy use and so contribute to reducing the carbon footprint, these sustainable strategies, both at the pedestrian level and at the internal level of spaces, can guarantee a comfort zone, helping to combat climate change.

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**ABBREVIATIONS**

**ASHRAE.** The American Society of Heating, Refrigerating and Air Conditioning Engineers

**3D.** Three Dimensional.

**°C.** Celsius Degrees.

**CO².** Carbon Dioxide.

**CONELEC.** Ecuadorian National Electricity Council. (Consejo Nacional de Electricidad) by its acronym in Spanish.

**EPW.** Energy Plus Weather Format.

**GAD.** Decentralized Autonomous Government. (Gobierno Autónomo Descentralizado) by its acronym in Spanish.

**KW/M²** Kilowatts per square meters.

**M/S** Meters per second.

**NEC.** Ecuadorian Construction Code. (Norma Ecuatoriana de Construcción) by its acronym in Spanish.