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Research on strategies to mitigate the impact of Urban Heat Islands using the ENVI-met Model applied to the Van Phu urban area, Hanoi

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Abstract

Under the extreme development of climate change, the issue of urban heat islands (UHI) is an increasingly widespread concern in many countries worldwide, including Vietnam. In sustainable urban development, climate and environmental information are the most important factors, helping forecast climate change according to planning scenarios and providing recommendations and strategic directions in adjusting planning to minimize climate change. A practical method to study the complex mechanisms of urban climate formation at the urban planning stage is numerical simulation modeling, which assesses the impact of the UHI in relation to the area and evaluates the effectiveness of mitigation measures under different scenarios for that area. In this study, the authors evaluated the effectiveness of measures to minimize the impact of UHI, applied to the Van Phu urban area, Ha Dong Disc., using scenarios of positive change of green infrastructure improvement and increase in greenery in the area. Recommendations have been made to mitigate the UHI. Based on the heat regime simulation results, the solution of changing infrastructure and increasing green areas effectively minimizes the UHI phenomenon and ensures human thermal comfort in urban environments. Future research will focus on developing multivariate correlation regression models to evaluate the effectiveness of UHI mitigation through green infrastructure improvements.

Keywords: *Urban planning; urban heat island; green space; thermal comfort; microclimate;*

1. Introduce

The urban environment is where the radiative, thermal, dynamic, and hydraulic processes change climate. One characteristic distinguishing urban areas from rural areas is their ability to dissipate heat less well at night. Cities accumulate heat energy during the day and only partially release it into the surrounding space at night [1], [2]. The structure of the urban environment is characterized by high-rise buildings with high construction density combined with a large thermal mass of construction materials, leading to reduced wind speeds [3]. In current conditions, when there is a need to minimize the consequences of urbanization, knowledge of modeling various physical phenomena in the city becomes important. Monitoring urban energy consumption, characterizing and quantifying the impact of urban heat islands (UHI), and studying thermal comfort inside and outside the homes of urban residents are widely relevant to the development of knowledge of the interactions between planning, climate, and energy. Urban surface heating is one of the most discussed phenomena in the scientific literature in recent years, contributing to global warming and leading to the need to reconsider planning policies for sustainable urban areas [4]. In addition to the urban heat island problem, climatic conditions and air quality in urban areas are also important for human health and are factors that affect flora and fauna as well as agricultural systems. Urban climate can be described at the micro, meso, and macro levels to identify and analyze relevant climate information. Microclimate can refer to areas or structures with detailed image resolution over distances of up to several meters (e.g., building complexes or trees). Microclimate mainly affects the health of humans, as well as plants and animals. The relevant meteorological indices are (i) temperature, (ii) wind direction and speed, (iii) evaporation, relative humidity, and (iv) solar radiation. For example, impermeable surfaces in urban areas have a negative impact on the microclimate, having scorching heat during the day and gradually cooling down at night [5]. Additionally, these surfaces have little to no filtering ability for air pollutants and dust particles. Negative impacts on the microclimate are mainly due to emissions as well as obstacles to air exchange (such as construction sites), and a reduction in the number of open areas and green spaces is essential for a healthy microclimate [6].

Vietnam is a country strongly affected by climate change, with a significant increase in extreme heat. Vietnam's urban areas are all in the process of expansion and development, making the heat island phenomenon in large cities in Vietnam increasingly severe. One of the most effective ways to improve the comfort and safety of the city environment is to improve green infrastructure. Developing green infrastructure is important in forming urban planning strategies to reduce the urban heat island effect and improve the urban ecosystem. Proposed measures include green spaces, fountains, artificial water surfaces, the greening of roofs, and building facades. Research has proven that the total amount of heat transferred into a building with a green roof can be reduced by 50-60% compared to a conventional roof [10]. In hot, dry climates, increasing air humidity through landscaping can reduce temperatures by up to 5 degrees, thereby increasing thermal comfort in summer [11]. Trees and vegetation are most effective at climate mitigation when planted in "strategic" locations around buildings or to shade sidewalks or streets. These measures are becoming increasingly popular in the fight against rising temperatures in megacities in summer [7]. The connection between ecosystems and urban areas must be the foundation for the sustainable development of urban areas. On the other hand, the lack of open and green spaces, high construction density, urban compaction, poor air quality, and constant traffic congestion can lead to urban environmental degradation [8][9].

In management, urban environmental monitoring using meteorological monitoring data does not always provide the ability to find urban heat islands quickly. Numerical modeling is an effective method to study the complex mechanisms of urban climate formation at the urban planning stage. Over the past two decades, numerical modeling methods have received strong development. They are implemented in modern computer systems and software. Numerical models help to study complex nonlinear heat and mass transfer processes in heterogeneous media, which is especially important when studying urban climate problems. Thanks to the advent of new information technology, digital models are constantly being improved. Through the application of numerical modeling, it is possible to evaluate the effectiveness of urban climate mitigation strategies using different experimental forecasting scenarios. Thus, it is definitely effective in solving and resolving planning issues to ensure the sustainable development of territories.

Energy balance methods (Energy Balance Model, EBM) and computational fluid dynamics (Computational et al.) are used to model heat and thermal mass transfer processes in urban environments. Among them, the CFD method is a powerful tool for modeling the microclimate of the urban environment, allowing the calculation of heat fields, velocities, and radiation, as well as in the assessment of external thermal comfort [12].

The ability to create three-dimensional computer models that simulate urban environments, taking into account climatic influences at different scales, both within the city and within the boundaries of the surrounding area, is a significant advantage of the software and computing complex under consideration. ENVI-met allows for calculating the dynamic characteristics of the air environment, thermodynamic properties, and radiation flows, considering heat transfer processes and thermal mass occurring on the ground surface, walls, and roofs of buildings. Houses as well as green areas. ENVI-met is a 3D microclimate model designed to simulate the interaction of surfaces, vegetation, and air in urban environments based on the fundamental laws of thermodynamics and dynamics liquid. By modeling, it is possible to identify and analyze shortwave and longwave radiation fluxes, considering shading, reflection, and re-radiation from a combination of buildings and vegetation. The main variables the ENVI program responds to are air temperature, humidity, wind speed and direction, environmental turbulence and dispersion levels, radiation fluxes, bioclimatic characteristics, etc. [13]. In this study, the authors used the climate model in the Envi-met program to simulate and calculate the intensity of thermal radiation to evaluate the effectiveness of different mitigation measures, thereby helping to provide a vision. Recognition and decisions related to urban space design, such as the Van Phu urban area and Ha Dong district, were chosen for the case study. This study aims to evaluate the urban heat island phenomenon for urban areas in Hanoi city and determine the effectiveness of mitigation measures on air temperature and thermal comfort of residents.

2. Research data and methods

2.1. Research and data collection area

This study aims to evaluate the influence of high-density urban construction areas on urban microclimate. To achieve this goal, the study considers changing temperature conditions depending on the density of trees in residential areas, thereby evaluating the impact on the thermal comfort of residents in the area. Van Phu urban area in central Ha Dong was studied with a population of 20.000 people and an area of 94,1 hectares and was designed considering the requirements for modern architectural space and infrastructure. The road network accounts for 34,4% of the total area. The Van Phu urban area was chosen because it has the characteristics of a typical metropolitan area with a busy street system and many types of establishments: office buildings with 36-40 floors, adjacent villas, and residential areas with low-rise housing with 4-5 floors. In general, this area is characterized by little vegetation and narrow streets adjacent to high-density highways - sources of pollution.

Microclimate data from the nearest weather station in Ha Dong (VNM_NVN_Ha.Dong.488250) were used for modeling. The purpose of the model is to study how urban microclimate develops from existing environmental conditions and how vegetation and trees influence thermal comfort. Based on climate data from Climate.onebuilding.org, the analysis considered relevant meteorological parameters: temperature variation over time, relative humidity, wind speed, and direction on a sunny day typical hot.

2.2. Urban microclimate modeling

ENVI-met software uses parameters of the building, vegetation, ground, climate, and soil conditions to simulate microclimate changes depending on the shape of the building and additional shading. , etc. ENVI-met is a three-dimensional computer model that analyzes microscopic-scale thermal interactions in urban environments.

ENVI-met models the dynamic changes of several thermodynamic parameters at the macroscopic level, creating a three-dimensional (2×2×2 meter grid), building-air interaction model atmosphere - vegetation - water surface [14]. With a foundation based on the principles of fluid mechanics, thermodynamics, and the laws of atmospheric physics, ENVI-met is capable of calculating three-dimensional fields of wind, turbulence, temperature, air humidity, gases, radiation fluxes, and pollutant dispersion [13]. High-resolution spatial model data, combined with detailed vegetation models, can help calculate photosynthetic rates, air temperature and humidity, wind speed, CO2 concentration, and many other information [13].

There are two main steps to take before modeling in ENVI-met:

- Edit input data of the urban area that needs to be checked. This task requires the built environment's geometric dimensions and the urban infrastructure's specific design characteristics, such as land cover lines, vegetation size, and area. The model is designed in a three-dimensional space where buildings, trees/vegetation, and various surfaces are present. These elements are represented by grid cells of different sizes. The smaller the cell, the better the resolution.

- The second step is to edit the urban climate configuration file, which contains information about the object's location, temperature, wind speed, humidity, and PMV parameters, as well as a database of soil types and vegetation. The simulation is then computed using both the input file and the configuration file.

Visualizations are customized to show the urban environment at the desired data layer: horizontally (plan view), vertically (section view), or in 3D axonometric view. This data separation allows for the analysis of small-scale interactions between buildings, surfaces, and individual sources for different scenarios over a 24-hour period.

Through typical meteorological data during the period 2007-2021, one of the hottest days was selected to simulate microclimatic conditions in the region and evaluate scenarios to minimize the recorded impacts. Received on July 3 was 40,4 °C at 17:00 hours in summer (Table 1).

Table 1. Initial data of the study area in ENVI-met

Simulation model size (m)	1440 × 1488 ×240
Model size (number of grid points in xyz direction)	181×187×31
Grid size (meters) dx, dy, dz	8×8×8
Geographic location (latitude, longitude)	20,96 –N; 105,76 -E
Nested grid	8
Method for creating a vertical grid	Equidistant
Time zone	GMT +7
Main parameters of the model	
Simulation date	July 3
Simulation start time	00:00, continuous 24 hours
Wind speed at 10 м	2,26
Wind direction	Southeast

Initial air temperature	33,17 ℃ = 306,17°K
Minimum temperature (simulated day)	31,25℃
Maximum temperature (simulated day)	40,4℃
Average daily specific humidity (g/kg)	19,78
Minimum humidity (simulated day) (g/kg)	17,97 at 5:00 p.m
Maximum humidity (simulated day) (g/kg)	22,5 at 2h

Table 2. Scenarios for Van Phu area

Scenario	**Characteristics**
Scenario 1	Current status of the urban area Van Phu
Scenario 2	The amount of green trees has increased by 30%, increasing lawns, and renovating roofs and walls in the area into green wall and green roof systems for building, accounting for about 70% of the area.
Scenario 3	The amount of new trees in urban areas increased by 50%

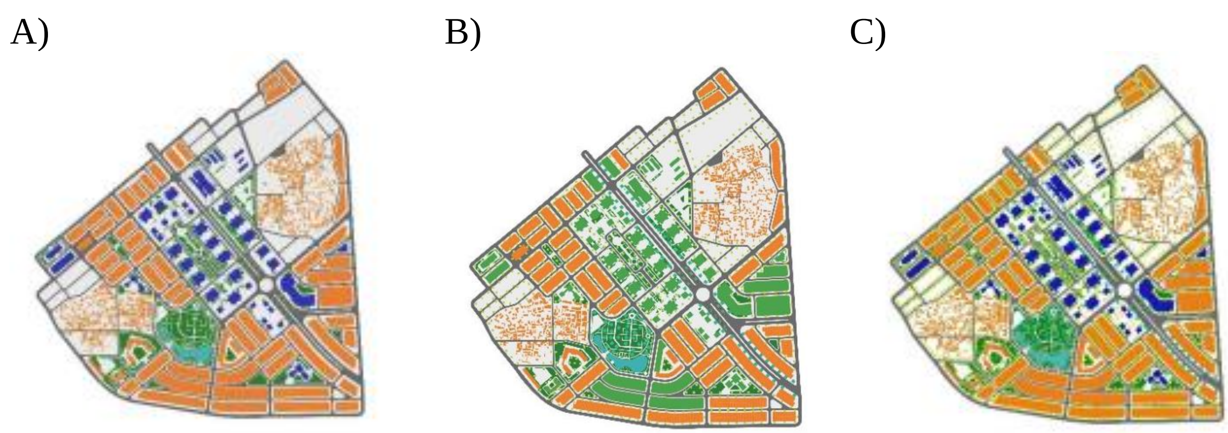

Figure 1. Simulation scenario for Van Phu urban area according to: (A) Scenario 1*; *(B) Scenario and (C) Scenario 3.

proposed mitigation solutions" code B2022-MDA-12 according to decision No. 2190/QD-BGDDT dated June 30, 2021.

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