



Article

Street-Level Sensing for Assessing Urban Microclimate (UMC) and Urban Heat Island (UHI) Effects on Air Quality

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Abstract: During the intense heatwaves of late summer 2024, Washington, D.C.'s urban landscape revealed the powerful influence of urban morphology on microclimates and air quality. This study investigates the impact of building height-to-width (H/W) ratios on the urban heat island (UHI) effect, using a combination of field measurements and Computational Fluid Dynamics (CFD) simulations to understand the dynamics. Street-level data collected from late August to November 2024 across three sites in Washington, D.C., indicate that high H/W ratios (1.5–2.0) increased temperatures by approximately 2–3 °C and reduced wind speeds to around 0.8 m/s. These conditions led to elevated pollutant concentrations, with ozone (O₃) ranging from 1.8 to 7.3 ppb, nitrogen dioxide (NO₂) from 0.3 to 0.5 ppm, and carbon monoxide (CO) remaining relatively constant at approximately 2.1 ppm. PM_{2.5} concentrations fluctuated between 2.8 and 0.4 µg/m³. Meanwhile, lower H/W ratios (less than 1.5) demonstrated better air circulation and lower pollution levels. The CFD simulations are in agreement with the experimental data, yielding an RMSE of 0.75 for temperature, demonstrating its utility for forecasting UHI effects under varying urban layouts. These results demonstrate the potential of Computational Fluid Dynamics in not only modeling but also predicting UHI dynamics.

Keywords: urban heat island (UHI); urban microclimate (UMC); urban morphology; air quality; temperature distribution; wind speed; computational fluid dynamics (CFD); ENVI-met; mobile monitoring; sensor nodes



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1. Introduction

The Urban Heat Island (UHI) phenomenon occurs when urban areas exhibit higher temperatures than their rural surroundings, with temperature differences ranging from 1 °C to 7 °C [1,2]. This phenomenon arises from a combination of factors, including the absorption and retention of heat by urban infrastructure, anthropogenic heat release, and reduced vegetative cover [3,4].

Urban microclimates, shaped by localized climatic conditions, exacerbate UHI effects such as heat retention, reduced nighttime cooling, and pollutant buildup in street canyons [5]. Furthermore, the interaction between UHI and air quality has significant health implications. The elevated temperatures caused by UHI accelerate chemical reactions in the atmosphere, leading to increased concentrations of pollutants such as tropospheric ozone and fine particulate matter. These pollutants contribute to respiratory diseases, cardiovascular diseases, and heat stress, particularly in vulnerable populations [6,7]. In addition,

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The Urban Heat Island Iain D. Stewart, Gerald Mills, 2021-05-25 The Urban Heat Island UHI is an area of growing interest for many people studying the urban environment and local global climate change The UHI has been scientifically studied for 200 years and although it is an apparently simple phenomenon there is considerable confusion around the different types of UHI and their assessment The Urban Heat Island A Guidebook provides simple instructions for measuring and analysing the phenomenon as well as greater context for defining the UHI and the impacts it can have Readers will be empowered to work within a set of guidelines that enable direct comparison of UHI effects across diverse settings while informing a wide range of climate mitigation and adaptation programs to modify human behaviour and the built form This opens the door to true global assessments of local climate change in cities Urban planning and design strategies can then be evaluated for their effectiveness at mitigating these changes Covers both on surface and near surface or canopy measurements and impacts of Urban Heat Islands UHI Provides a set of best practices and guidelines for UHI observation and analysis Includes both conceptual overviews and practical instructions for a wide range of uses **Urban**

Microclimate Modelling for Comfort and Energy Studies Massimo Palme, Agnese Salvati, 2021-04-08 This book discusses urban microclimate and heat related risks in urban areas brought on by the combination of global climate change effects and local modification of climate determined by extensive urbanization such as the Urban heat island phenomenon This matter is relevant to almost all urbanized areas in the world where the increase of urban population and air temperature is expected to endanger both the overall health of the population and the energy supply for the functioning of urban systems The book details the inter relationship between urban morphology microclimate and building energy performance and presents a multidisciplinary approach that brings together Urban Climatology Engineering and Architectural knowledge to support the development of reliable models and tools for research and practice This book is a useful tool for architects and building energy modelers urban planners and geographers who need a practical guide to realize basic urban microclimate simulation for use in both academic research and planning practice Urban Form Influence on Microclimate and Building

Cooling Demand Daniela Maiullari, 2023 Urban form plays a critical role when planning city transitions toward decarbonization However in urban climate conditions the complex relationship between urban form and cooling demand remains understudied This thesis develops integrated approaches and knowledge in the transdisciplinary domain of urban morphology urban climatology and energy related fields while addressing the question How does urban form influence building cooling demand in urban microclimate conditions and how can the magnitude of the relationship be assessed By answering this main research question the thesis delivers a threefold contribution First it contributes to the conceptualization and understanding of both the intrinsic and the extrinsic role of urban form by identifying urban form characteristics that directly influence building cooling demand and indirectly contribute to shaping urban microclimate

conditions in buildings surroundings Second the thesis contributes to increasing the assessment accuracy of urban form related climate and energy performance It does so by developing a quantitative morphological method to identify Local Climate Types LCTs and by developing a modelling method that enhances the use of microclimate data as boundary conditions for energy demand assessments Finally for the city of Rotterdam the testing of these novel methods provides an understanding of how and to what extent the form of buildings and contexts influence building cooling demand

Urban Microclimate Evyatar Erell, David Pearlmutter, Terence Williamson, 2012-06-25 The quality of life of millions of people living in cities could be improved if the form of the city were to evolve in a manner appropriate to its climatic context Climatically responsive urban design is vital to any notion of sustainability it enables individual buildings to make use of renewable energy sources for passive heating and cooling it enhances pedestrian comfort and activity in outdoor spaces and it may even encourage city dwellers to moderate their dependence on private vehicles Urban Microclimate bridges the gap between climatology research and applied urban design It provides architects and urban design professionals with an understanding of how the structure of the built environment at all scales affects microclimatic conditions in the space between buildings and analyzes the interaction between microclimate and each of the elements of the urban landscape In the first two sections of the book the extensive body of work on this subject by climatologists and geographers is presented in the language of architecture and planning professionals The third section follows each step in the design process and in part four a critical analysis of selected case study projects provides a demonstration of the complexity of applied urban design Practitioners will find in this book a useful guide to consult as they address these key environmental issues in their own work

Global Urban Heat Island Mitigation Ansar Khan, Hashem Akbari, Francesco Fiorito, Sk Mithun, Dev Niyogi, 2022-06-15 Global Urban Heat Island Mitigation provides a comprehensive picture of global UHI micro thermal interaction in different built environments The book explains physical principles and how to moderate undesirable consequences of swift and haphazard urban development to create more sustainable and resilient cities Sections provide extensive discussion on numerous UHI mitigation technologies and their effectiveness in cities around the globe In addition the book proposes novel UHI mitigation technologies and strategies while also assessing the effectiveness and suitability of UHI mitigation interventions in various climates and urban forms Adopts a multidisciplinary approach bridging theoretical and applied urban climatology with urban heat mitigation Compiles disparate urban climate research concepts and technologies into a coherent framework Includes contributions from leaders in fields from around the globe

[The Urban Microclimate as Artifact](#) Sascha Roesler, Madlen Kobi, 2018 Urban microclimates cannot be explained solely on the basis of scientific phenomena but are also affected materially and spatially by the city's local architecture The layout design and facade construction of buildings have a major impact on wind and temperature conditions For this reason architecture and urban design that have an effect on microclimates must be investigated in their social and cultural contexts The publication uses international case studies to

explain these relationships The focus is on manifestations of urban microclimates in an architectural and urban design context The places investigated are located in France Italy the USA New Zealand the Philippines Taiwan and Burkina Faso

Urban Microclimate, a Study of Energy Balance and Fluid Dynamics Neda Yaghoobian, 2013 Improvements in building energy use air quality in urban canyons and in general urban microclimates requires understanding of the complex interaction between urban morphology materials and climate as well as their interaction with the flow dynamics in urban canyons The review of the literature indicates that despite a long history of valuable urban microclimate studies more comprehensive approaches of investigating energy heat and flow in urban areas are needed In this research an indoor outdoor dynamically coupled urban model the Temperature of Urban Facets Indoor Outdoor Building Energy Simulator TUF IOBES has been developed and carefully validated It is a building to canopy model that simulates indoor and outdoor building surface temperatures and heat fluxes in an urban area to estimate cooling heating loads and energy use in buildings The effects of a large number of parameters such as different ground surface albedo building condition window size and type seasonal climate and canopy aspect ratio on building thermal loads were investigated The results presented in this dissertation highlight the fact that the interaction of urban materials e g reflective pavements with surrounding buildings must be considered in the energy analysis of urban areas Although reflective pavements have been proposed as a mitigation measure for urban heat island since they reduce urban air temperatures the increased solar reflectivity which transports solar radiation into through fenestrations and onto adjacent buildings increases building energy use To investigate a more comprehensive and realistic simulation of the diurnally varying street canyon flow and associated heat transport TUF IOBES three dimensional surface heat flux distribution were used as thermal boundary conditions in large eddy simulation LES Compared to previous analyses which used uniformly distributed thermal forcing on urban surfaces the present analysis shows that non uniform thermal forcing can result in complex local air flow patterns Strong horizontal pressure gradients were detected in streamwise and spanwise canyons throughout the daytime which motivate larger turbulent velocity fluctuations in the horizontal directions rather than in the vertical direction This dissertation demonstrates that only local simulations for specific neighborhoods and urban climates can elucidate specific effects of urban mitigation measures with often surprising outcomes

Whispering the Strategies of Language: An Psychological Journey through **Assessing The Urban Microclimate Erg Ucd**

In a digitally-driven world wherever screens reign great and immediate connection drowns out the subtleties of language, the profound strategies and mental nuances hidden within words frequently get unheard. However, located within the pages of **Assessing The Urban Microclimate Erg Ucd** a fascinating fictional treasure blinking with raw thoughts, lies an exceptional quest waiting to be undertaken. Composed by an experienced wordsmith, that charming opus invites readers on an introspective trip, delicately unraveling the veiled truths and profound impact resonating within ab muscles fabric of each and every word. Within the emotional depths of this emotional review, we will embark upon a sincere exploration of the book is core styles, dissect their charming writing style, and yield to the powerful resonance it evokes deep within the recesses of readers hearts.

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