

빅데이터 기반 건축 · 도시 공간 폭염 취약성 분석 방안

Big Data Based Approaches to Heatwave Vulnerability Assessment of the Built and Urban Environment

허한결 Heo, Hankyul

변기영 Byun, Giyoung

송유미 Song, Yumi

남기천 Nam, Kichoen

(a u r i

Summary

Big Data Based Approaches to Heatwave Vulnerability Assessment of the Built and Urban Environment

Heo, Hankyul Byun, Giyoung Song, Yumi Nam, Kichoen

Introduction

■ Research Background and Purpose

As the global average temperature recorded an all-time high in 2023, warnings have emerged that the climate crisis has moved beyond simple Global Warming and entered the stage of Global Boiling. In Korea, the upward trend in temperature is evident, with the number of heatwave days and tropical nights in the summer of 2024 ranking among the highest on record, leading to increased casualties such as heat-related illnesses and deaths. The increase in heatwave days in Seoul is steep even by global standards, and this climate change is leading to physical damage such as surging demand for cooling energy in buildings and fires in air conditioner outdoor units. Existing heatwave responses were mainly based on macroscopic meteorological data, which had limitations in reflecting local thermal environment differences within the city.

Accordingly, this study aims to analyze microscopic heatwave vulnerability at the building and block level by utilizing public data and big data technologies. Specifically, the study aims to develop an effective process for identifying heatwave-risk buildings and spaces by linking scattered public data to construct big data, classifying Seoul's Local Climate Zones (LCZ) based on machine learning, and combining this with Land Surface Temperature (LST) and microclimate simulations (ENVI-met).

Novelty of the Study

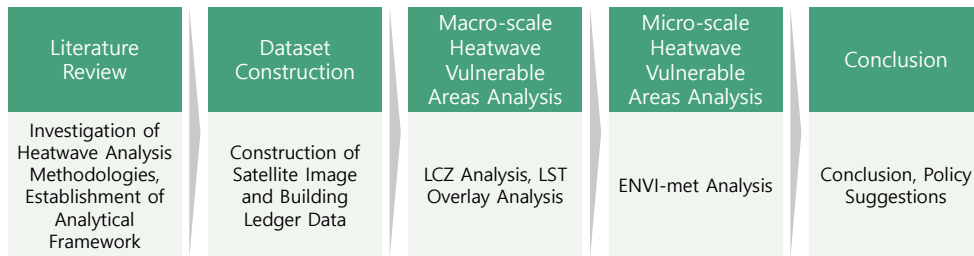
The Novelty of this study lies in improving the limitations of existing macro-scale analysis techniques by 1) performing LCZ analysis to primarily screen heatwave-vulnerable areas, and 2) analyzing heatwave vulnerability at the individual building level using microclimate simulation (ENVI-met) for these vulnerable areas.

■ Research Scope

The spatial scope of this study covers the entire area of Seoul, where the heat island phenomenon due to urbanization is distinct and public data is well-established. Seoul is a representative area with a high risk of heatwave damage due to high-density buildings and insufficient green space. The content scope consists of data construction, derivation of heatwave-vulnerable space types based on LCZ, microclimate simulation analysis for these types, vulnerability analysis by space, and proposals for heatwave response measures.

■ Research Method and Flow

The research proceeds in a five-step flow: establishing an analytical framework through literature review, constructing data for analysis, analyzing LCZ and macro-scale heatwave vulnerable areas, analyzing micro-scale heatwave vulnerable areas through ENVI-met simulation, and deriving results and policy suggestions. First, the framework and necessary data list were derived through literature review. Second, a dataset for analysis was constructed by collecting and preprocessing administrative information such as satellite images and building ledgers. Third, LCZ in Seoul is classified using deep learning (CNN) techniques, and Land Surface Temperature is analyzed using the thermal bands of satellite images. Fourth, ENVI-met simulations are performed on the derived heatwave-risk LCZ types to analyze detailed thermal environments such as Potential Air Temperature (PAT), Mean Radiant Temperature (MRT), and Physiological Equivalent Temperature (PET), and vulnerable building types are derived by combining this with attribute information such as building age and usage. Finally, based on this, legal and institutional improvement plans for heatwave response at the building and spatial unit are proposed.



Research flow

Trends in Building and Urban Heatwave Analysis Methodologies

■ Urban Heatwave Research Trends

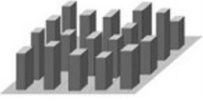
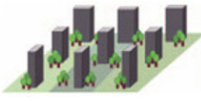


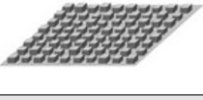
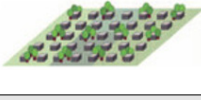
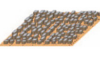





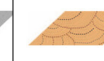

Urban heatwave analysis is largely divided into air temperature (AWS, etc.) data analysis, Land Surface Temperature (LST) data analysis, and microclimate simulation (ENVI-met). While studies using AWS data are useful for understanding the heat island intensity and spatiotemporal distribution of the entire city, they are limited in local analysis due to the limitations of observation points. On the other hand, LST research based on satellite images can grasp the detailed temperature distribution across the city, making it widely used for hotspot analysis. Furthermore, CFD (Computational Fluid Dynamics) simulation models like ENVI-met are being actively introduced to analyze the impact of microscopic spatial elements such as building layout, vegetation, and pavement materials on the thermal environment. Such simulation studies demonstrate effectiveness in quantitatively predicting thermal environment improvement effects resulting from urban redevelopment or green space creation. This study adopted a multi-layered approach utilizing LCZ and LST for wide-area analysis and ENVI-met for detailed analysis, reflecting these trends.

■ Local Climate Zone (LCZ) Research Trends

The Local Climate Zone (LCZ) system, devised by Stewart and Oke (2012) to objectively compare and analyze urban heat island phenomena, is a classification system widely used worldwide. LCZ classifies urban spaces into 17 standard types (10 building types, 7 land cover types) based on building height, density, and land cover status. Previous studies have classified LCZ using the WUDAPT protocol or, more recently, by introducing deep learning techniques to improve accuracy. In particular,

CNN (Convolutional Neural Network) based studies are deriving more precise classification results than existing methods by learning the spatial characteristics of satellite images. Additionally, multiple studies have proven that distinct differences in land surface temperature or air temperature appear by LCZ type, confirming that high-density building areas (LCZ 1~3) and industrial areas (LCZ 8, 10) are particularly vulnerable to the heat island phenomenon.

Examples of LCZ type and definition

LCZ Type	Definition	LCZ Type	Definition				
1. Compact high-rise 	Dense mix of tall buildings (dozens of stories). Few or no trees. Land cover is mostly paved	4. Open high-rise 	Open arrangement of tall buildings (dozens of stories). Highly permeable land cover				
2. Compact midrise 	Dense mix of mid-rise buildings (3-9 stories). Few or no trees. Land cover is mostly paved	5. Open midrise 	Open arrangement of mid-rise buildings (3-9 stories). Highly permeable land cover				
3. Compact low-rise 	Dense mix of low-rise buildings (1-3 stories). Few or no trees. Land cover is mostly paved	6. Open low-rise 	Open arrangement of low-rise buildings (1-3 stories). Highly permeable land cover				
LCZ Type (Refer to Table 2-1 for detailed definitions)							
7	8	9	10	D	E	F	G
							

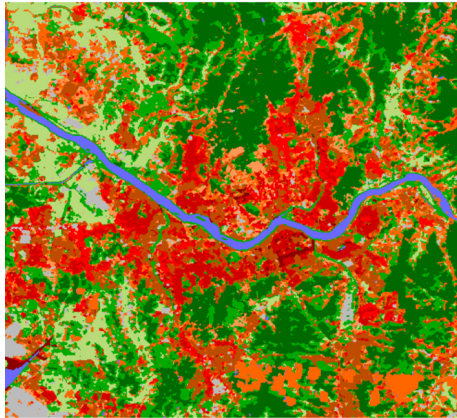
Source: Stewart, I.D. & Oke, T.R.. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*. 93. p.1,885

Big Data-Based Local Climate Zone Analysis

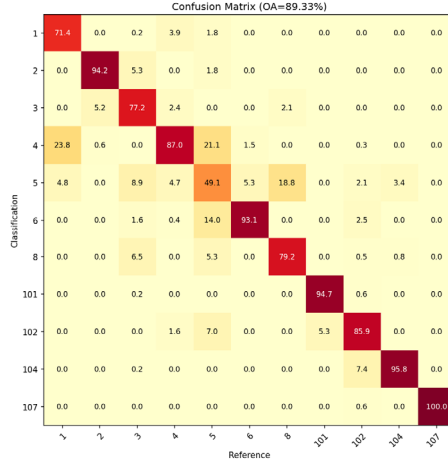
■ Derivation of Seoul LCZ

Landsat 8 satellite images and a CNN model were utilized for LCZ classification in Seoul. The dataset was constructed by resampling to 100m and 10m resolutions, and LCZ sample data for training and testing were generated through visual reading using Google Earth, etc.. As a result of CNN model training, the Overall Accuracy was approximately 89.33%, securing high reliability. Looking at the classified Seoul LCZ map, major commercial areas such as the city center and Gangnam were clearly

distinguished as high-rise and mid-rise high-density areas (LCZ 1, 2), residential areas as low-rise and mid-rise dense areas (LCZ 2, 3), and outer forest areas as dense tree areas (LCZ A, B). However, due to the limitation of the 100m grid resolution, limitations were also identified where some minute spatial characteristics (e.g., small streams) were ignored or noise occurred between adjacent pixels.



[Seoul LCZ Prediction Map]



[Confusion Matrix of Classification Results]

LCZ classification result

■ Derivation of Heatwave-Risk LCZ Types

The thermal environment characteristics by LCZ type were identified by overlaying the derived Seoul LCZ map with Land Surface Temperature (LST) data calculated through the thermal infrared band of Landsat 8 satellite images taken on August 29, 2024. The analysis showed that the type with the highest average temperature was LCZ 8 (Large low-rise), where large low-rise buildings are concentrated, recording an average of 45.35°C. This reflects the characteristics of areas with large floor areas and a lack of vegetation, such as factories or warehouses. This was followed by LCZ 3 (Compact low-rise, 43.56°C) and LCZ 2 (Compact mid-rise, 43.38°C), where buildings are densely arranged. Conversely, LCZ A (Dense trees, 32.35°C) and LCZ G (Water, 31.55°C) recorded the lowest temperatures, confirming the heat island mitigation function within the city. Notably, LCZ 1 (Compact high-rise), where high-rise buildings are concentrated, showed an average of 39.71°C, appearing relatively lower than the low-rise dense areas. This suggests that the shadows and wind paths formed by high-rise buildings have an effect of partially suppressing the

rise in land surface temperature. In conclusion, in Seoul, low-rise and industrial areas with high impervious surface ratios, lack of vegetation, and dense buildings were identified as the spatial types most vulnerable to heatwaves.

Average Temperature by LCZ Type

LCZ Type	Average Temperature (°C)	Rank	LCZ Type	Average Temperature (°C)	Rank
LCZ 1 (Compact high-rise)	39.71	7	LCZ 8 (Large low-rise)	45.35	1
LCZ 2 (Compact mid-rise)	43.38	3	LCZ A (Dense trees)	32.35	10
LCZ 3 (Compact low-rise)	43.56	2	LCZ B (Scattered trees)	36.22	9
LCZ 4 (Open high-rise)	40.79	4	LCZ D (Low plants)	39.47	8
LCZ 5 (Open mid-rise)	39.96	6	LCZ G (Water)	31.55	11
LCZ 6 (Open low-rise)	40.59	5	※Overall average temperature: 39.35°C		

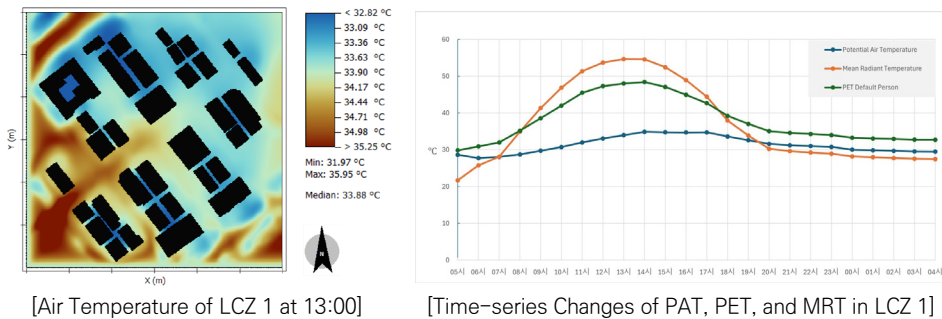
Derivation of Heatwave-Vulnerable Building and Spatial Types

■ Microclimate Analysis of Heatwave Risk Areas

Actual areas representing high-risk types derived through LCZ analysis (Yeouido-dong, Songpa-dong, Mullae-dong, Sadang-dong, etc.) were selected to perform ENVI-met simulations. To elaborately implement the physical environment of the analysis sites on the computer, three criteria were applied. 1) Uniform size of all analysis sites to 300m × 300m squares, 2) application of a high-resolution grid of 1m × 1m to detect minute thermal environment changes, and 3) reflection of actual building height and terrain (DEM) from the building ledger. Potential Air Temperature (PAT), Mean Radiant Temperature (MRT), and Physiological Equivalent Temperature (PET) were utilized as analysis indicators to precisely analyze thermal environment changes by time (09:00, 13:00, 15:00, 21:00).

The analysis results showed that high-density areas such as LCZ 1 (Yeouido-dong) and LCZ 2 (Songpa-dong) exhibited 'urban heat storage' characteristics, where radiant heat accumulation is large during the day and accumulated heat does not easily escape at night, leading to sustained nighttime heat loads such as tropical nights. On the other hand, low-rise residential areas such as LCZ 3 (Mullae-dong) and

LCZ 6 (Junggye-dong) showed a rapid temperature rise during the day due to narrow alleys and high pavement ratios, and pedestrian heat stress (PET) appeared very high. In comparison, areas where buildings are openly arranged and green space is secured, such as LCZ 4 (Sadang-dong) or LCZ 5 (Sinchon-dong), showed characteristics where heat is quickly dispersed or mitigated due to ventilation and shading effects. The waterfront area, LCZ G (Sincheon-dong), showed distinct cooling effects in both day and night, confirming its role as a buffer zone for the urban thermal environment.



Example of ENVI-met analysis result

■ Derivation of Heatwave-Vulnerable Building and Space by Spatial Type

Based on the ENVI-met analysis results, thermal vulnerability according to building attributes (height, year of construction, usage) was quantitatively evaluated. The analysis confirmed a tendency for surrounding thermal vulnerability to increase as building height increases. This is because the 'canyon effect,' which increases radiant heat reflection and re-radiation and hinders ventilation, is strengthened as the building becomes higher and the envelope area increases. Also, buildings with older construction years (before 1999) showed higher thermal vulnerability due to lack of insulation performance and deterioration, while new buildings since 2011 showed relatively favorable results thanks to strengthened energy standards. By usage, educational research facilities and neighborhood living facilities showed the highest vulnerability due to large paved areas and lack of green space, while apartment complexes and office facilities with secured landscaping appeared relatively low. This suggests that customized management considering the physical characteristics of buildings, not just the temperature of the space, is necessary for heatwave response.

Conclusion

This study multidimensionally identified the heatwave vulnerability of building and urban spaces in Seoul using big data and advanced analysis technologies. The results confirmed that the physical structure of the city (LCZ) has a decisive influence on the thermal environment, and in particular, high-density, low-rise, and industrial areas are most vulnerable to heatwaves. It was also quantitatively proven through microscopic simulation that building height, deterioration, and usage are major factors worsening the surrounding thermal environment.

Based on these research results, the following policy implications are proposed. First, deregulation of the opening and use of data linked to personal information (health, death, etc.) is necessary to advance heatwave damage prediction models. Second, a system to constantly monitor buildings at risk of various disasters, including heatwaves, should be established by linking disaster data to the building life cycle information system under the 'Building Management Act'. Third, it is necessary to revise the 'Building Act' and related enforcement rules to check the heatwave risk of the site in advance at the building permit stage and to mandate or recommend preventive measures such as the use of heat-shielding paint and securing green space when building in risk areas. Finally, the current heatwave risk map service should be upgraded to an intelligent service capable of practical heatwave risk management by combining the building/spatial unit vulnerability analysis results of this study with socio-demographic factors (sensitivity, adaptive capacity). This will contribute to enhancing the efficiency of urban heatwave adaptation policies, such as the placement of cooling centers and support for vulnerable groups.

Keywords :

Heatwave, Local Climate Zone, Remote Sensing, Vulnerability Analysis, ENVI-met