An Assessment of Vulnerable Areas in Urban Thermal Environments Based on Social and Economic Factors

B. Park, K. Oh, and H. Kim

***Abstract*—Intensification of urban thermal environments can threaten the survival of vulnerable groups including the elderly, infirmed, and children, due to rising temperatures. Therefore, this study suggests a system of assessment and classification of urban thermal environments by focusing on vulnerable, potentially high risk groups, identified by social and economic factors.**

In this study, assessment was based on the IPCC vulnerability assessment framework, and the results were classified as the following: *urgently needing improvement areas; potential risk areas*; *adaptive capacity enhancing areas*; and *sustainable current areas*. The vulnerability assessment results were analyzed to determine vulnerability by region with populations concentrated around the old downtown area and areas of unfavorable traffic conditions. Classification resulted in 19 dong of urgently needing improvement areas, 47 dong of potential risk areas, 17 dong of adaptive capacity enhancing areas, and 12 dong of sustainable current areas.

The results of this study can be used as a guideline to determine a basic direction for thermal environment improvement and for policy making.

***Index Terms*—Urban thermal environment, vulnerability assessment, vulnerable area, social and economic factors.**

I. Introduction

Recently, cities have been more frequently experiencing phenomena such as heat waves and tropical nights in the summer as a result of global climate change and higher concentrations of populations [1]. Urban areas consisting of high population density are intensifying the thermal environment through human activities.

Rosenzweig (2007) [2] claims that urban temperatures are higher by about 3°C than areas around urban areas in the U.S. The severity of the urban thermal environment can be seen in cases like Chicago, in which approximately 700 people reportedly perished as a result of drastic increases in urban temperature. Not surprisingly, the victims were found to be among the elderly and the infirm, those in socially and economically vulnerable groups. In fact, the NDMI (National Disaster Management Institute in Korea) presented analysis results of their research in which they applied a climate change scenario and estimated that about 10,000 people in vulnerable social groups will have perished from the heat wave phenomenon in Korea by 2020 [3]. Needless to say, research regarding improvement of the urban thermal environment is emerging as an important topic.

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This study focuses on ways to improve the urban thermal environment by first assessing the location of vulnerable groups based on social and economic factors in Incheon Metropolitan City in South Korea. Next, the relationship between potential impacts and the adaptive capacity of thermal environmental intensification is analyzed, based on the classification of the vulnerability assessment results. Finally, the causes of urban thermal environment intensification are analyzed.

The purpose of this study is to determine the urban thermal environment areas that are most affected and thus need the greatest improvement, and to suggest a planning and policy direction for the most socially and economically vulnerable groups based on the assessment results.

II. Literature Review

A general recurring phenomenon of the urban thermal environment is the heat wave, which can increase cardiovascular and infectious disease risks, and has been responsible for the highest death ratio in Europe over the past 10 years [4]. In fact, the IPCC's 4th report anticipated that high temperature events would continue to increase [5], [6]. Most vulnerable to heat waves are the elderly compared with their counterparts in other age groups, owing to their obviously different physiological characteristics [7].

Previous studies on heat waves have emphasized social and economic factors (climate, topography, heat island, income, and the elderly population ratio) in relation to the temperature and death ratio [8]. Namely, if the temperature increases about 0.5-2.0%, the annual death rate of the elderly and children increases in Europe [8]. Therefore, urban thermal environmental intensification poses a major risk for physically, socially, and economically vulnerable groups.

Vulnerable areas in the urban thermal environment is a concept in this study that refers those areas which houses significant populations of vulnerable groups. These areas are determined by analysis of climatic exposure, sensitivity, and adaptive capacity, which are the result of thermal stress in home or life zones. The United Nations Development Program (UNDP) (2005) has defined vulnerability in the urban thermal environment context [9].

This study assesses urban thermal environment vulnerable groups based on social and economic factors. It also classifies vulnerable areas in terms of the potential effects and adaptive capacity of urban residents in thermal environments.

III. Study Method

A. The Study Area

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The study s area is Incheon Metropolitan City in South Korea. The area of Incheon is 1,439.349km^3 and is home to approximately 2.9 million people. (Fig. 1) The city has a clear distinction of its new and old downtown areas which is the result of rapid urban growth. For this reason, Incheon also has distinct social and economic characteristics of its population distribution. Moreover, there are multi-spatial characteristics on Incheon due to its land area, beaches, islands, and basins.

The analysis scale is the "*dong*" which is the smallest unit of management for residential areas in Korea. The urban thermal environmental vulnerability assessment analysis includes 107 *dong* units that are used for the climate change data (of a total of 120 *dong* units). The excluded 13 *dong* units that are security areas (military zones) and thus collection of climate change basic data is inaccessible.

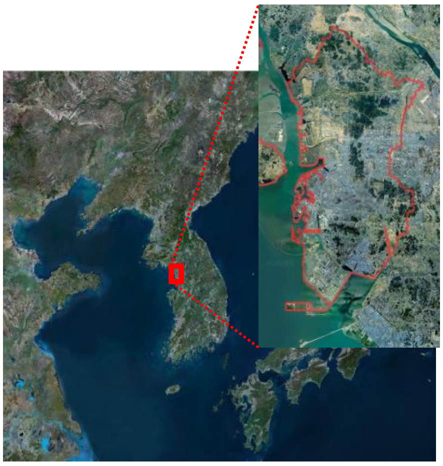

Fig. 1. The study area (Incheon metropolitan city).

B. Urban Thermal Environment Vulnerable Area Assessment

1) Vulnerability assessment

The analysis process of this study was divided into 2 steps. First, an urban thermal vulnerable assessment was conducted following the IPCC's climate vulnerability equation using the vulnerability framework shown in (Fig. 2).

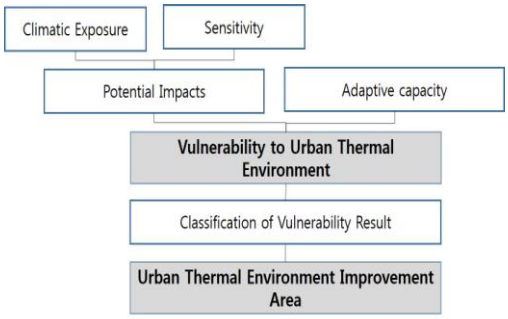

Fig. 2. Assessment framework.

Then, assessment factors were determined to identify inherent characteristics and various measurement units, and to minimize correlation inter-variables [10]. The assessment factors were then ready to use (Equation 1)

$$\text{The standard Value} = (\text{Actual Value} - \text{Minimum Value}) / (\text{Max Value} - \text{Minimum Value}) \quad (1)$$

Climate exposure was used to determine the mean value of the final factors that had a positive correlation. Sensitivity and adaptive capacity factors were found to have both positive and negative correlation factors. Next, climatic exposure, sensitivity, and adaptive capacity factors were re-normalized and the potential effects and vulnerability were calculated (Equation 2, 3). However, climatic exposure, sensitivity, and adaptive capacity were weighted the same. This is because when the factors were evaluated each other, they were found to have each factor influence and distortion.

$$\text{The potential effect} = \text{Climatic exposure} + \text{Sensitivity} \quad (2)$$

$$\text{The vulnerability} = \text{Potential effect} - \text{Adaptive capacity} \quad (3)$$

2) Selection factors

TABLE I: THE URBAN THERMAL ENVIRONMENT VULNERABILITY ASSESSMENT FACTORS

Division		Assessment factors	Previous studies	Note
Climatic exposure		Mean days value of 33 ℃ heat wave in the past 10 years	[10], [11]	Intensification of and exposure to the Urban Thermal Environment
Sensitivity	Social factors (A)	The elderly ratio of over 65 years	[11], [12]	Physiological characteristics
		The children ratio of below 5 years		
		Disable persons		
		Recipient of national basic livelihood guarantees	[10], [13]	Social welfare
		Low income, one-parent families	[10], [13]	
		Thermal – related illness	[10], [11]	Health
	Physical factors	Residential buildings deterioration (over 30 year old)	Additional	Environment of residential
		Unlicensed buildings	Additional	
Adaptive capacity	Economic factors	GDP	[14], [15]	Productivity per person
		Local taxes	[11]	Income level per dong
		Taxes per person	Additional	Income level per person
	Social factors (B)	Medical beds per thousand persons	[10], [16]	Infra service
		Elderly welfare facilities	Additional	

Factors of the urban thermal environment vulnerable assessment were selected on the basis of previous studies, and additional factors were required (Table I). The vulnerability framework includes mean temperature, precipitation, and extreme weather hazard events such as climatic exposure, social vulnerability as sensitivity and adaptive capacity.

Finally, the selected factors were divided into groups of physical, social (A), (B) and economic factors. The physical factors were determined directly, the extent of poor living environments as the basis for redevelopment and reconstruction projects carried out within the law and by institutions in Korea.

Social factors (A) were identified, with emphasis on population characteristics, as increasingly socially vulnerable. Social factors (B) were ascertained with emphasis on healthy infra-structures as decreasingly socially vulnerable. Economic factors were determined by income level in the case areas (each *dong*) as increasingly having adaptive capacity.

Groups of these factors were recognized in the urban thermal environment context based on the vulnerable social and economic groups who are most affected by urban heat.

A. *Classification*

The results of the urban thermal environmental vulnerability assessment revealed classification of the relationship between adaptive capacity (X axis) and potential capacity (Y axis) by quadrant analysis, based on the research by Downing (2003) [17]. This classification suggests improvement methods of the urban thermal environment through analysis between social and economic characteristics.

If these areas had a potential effect > 0, and adaptive capacity < 0, they are *urgently needing improvement areas.*

If these areas had a potential effect > 0, and adaptive capacity > 0, they are potential risk areas.

If these areas had a potential effect < 0, and adaptive capacity < 0, they are enhance adaptive capacity required areas.

If these areas had a potential effect < 0, and adaptive capacity > 0, they were sustainable in current state areas.

IV. Result of Analysis

A. *Results of the Urban Thermal Vulnerability Assessment*

In the results of the climate exposure assessment, the total number of days of heat waves over the past 10 years were 322. For each *dong*, heat waves days were a mean of 4.64. Climate exposure vulnerability was higher in the northeast *dong* of the study area than for others. These *dong* have high population density and are composed of new and old downtown areas.

For the results of the sensitivity assessment, social factors (A) were analyzed and revealed a mean of 0.187 and a minimum of 0.010. Physical factors were analyzed and showed a mean of 0.191 and a minimum of 0.009. The total sensitivity assessment found a mean of 0.245 and a minimum of 0.034. This was proportional to the population density. Furthermore, sensitivity vulnerability was higher in the southwest *dong* than in others. These *dong* were the old town areas that have a high density of older residents (over 30 years old) and unlicensed buildings.

In the results of adaptive capacity, economic factors were analyzed and showed a mean of 0.297 and a minimum of 0.002. Social factors (B) were analyzed and revealed a mean of 0.603 and a minimum of 0.562. The total adaptive capacity assessment was analyzed and showed a mean of 0.278 and a minimum of 0.011. This was higher in new town areas than in the old ones. Moreover, it is known that there is a large income gap among urban residents in each *dong*.

For the results of the urban thermal environmental vulnerability assessment in consideration to exposure assessment, sensitivity and adaptive capacity were analyzed and found a mean of 0.477 and a minimum of 0.001. This revealed a big variation value for vulnerability, which was higher in the *dong* of the old towns than in others. They were located in the northeast *dong* which are nearby highways and have high population densities. This reveals that high population density and income are related to high temperature and vulnerability.

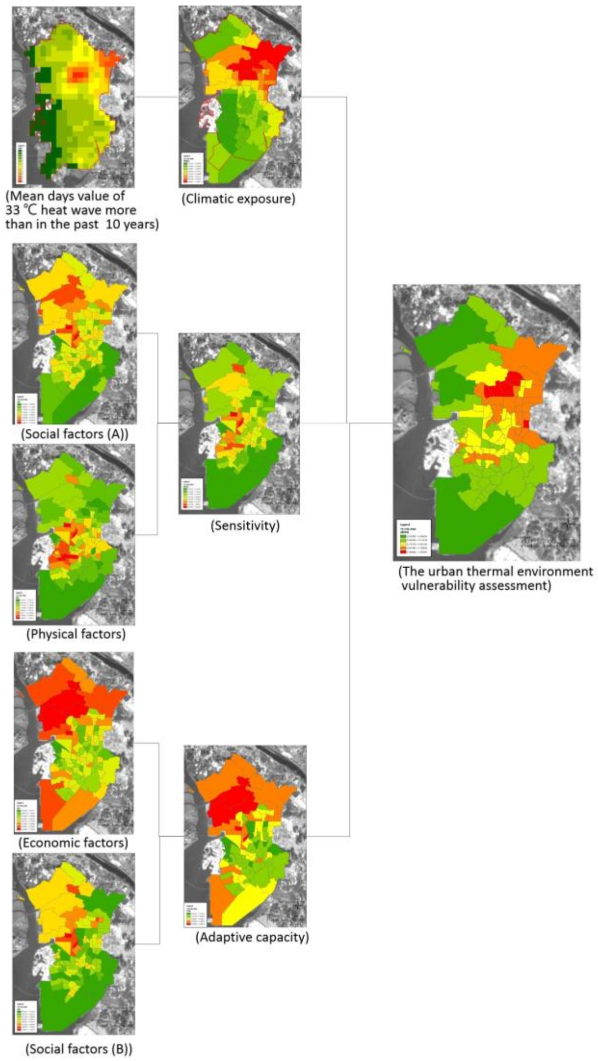

Fig. 3. The results of vulnerability assessment.

As a result, social factors (A) and (B) of the main factors in the sensitivity and adaptive capacity assessments tended to be widely distributed in the relatively old downtown areas. And economic factors of the main factors in the adaptive capacity assessment had a greater vulnerability deviation than the other factors. This shows economic level deviation in each *dong* between the old and new downtown areas. Finally, the vulnerability assessment results that consider social and economic factors were analyzed to determine vulnerability by region with populations concentrated around the old downtown area and unfavorable traffic conditions areas (Fig. 3).

B. Classification Results

The results of the urban thermal environmental vulnerability assessment were grouped using quartile classification for potential effect and adaptive capacity. The quartile types were *urgently needing improvement areas, adaptive capacity enhancing areas, potential risk areas, and sustainable current areas.* (Fig. 4)

The classification results were 19 *dong* of *urgently needing improvement areas*, 47 *dong* of *potential risk areas*, 17 *dong* of *adaptive capacity enhancing areas*, and 12 *dong* of *sustainable current areas*. (Table II)

Urgently needing improvement areas showed a high potential effect and small adaptive capacity. These *dong* were home to economically and socially vulnerable groups and showed high temperatures. These areas are in need of housing repair, hospitals, welfare facilities, financial support, cool and green roof installations, and parks.

Potential risk areas had a high potential effect and big adaptive capacity. These *dong* were found to have an elevated level of economic life, but separated by heat-sensitivity. These areas are in need of a reduction of the potential effect, and require housing repair, and welfare and medical services.

Adaptive capacity enhancing areas were found to have a low potential effect and small adaptive capacity. If these *dong* are not managed well, they are likely to be future *urgently needing improvement areas* and will need to increase the potential effect. They also are in need of housing repairs and welfare services. *Sustainable current areas* were found to have a low potential effect and big adaptive capacity, and do not require improvements. The results of these classifications can be used to suggest an improvement direction for urban thermal environmental vulnerability assessment when considering social and economic factors.

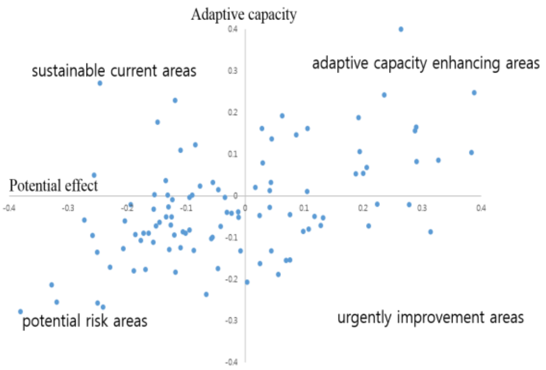

Fig. 4. Classification resorts.

TABLE II: CLASSIFICATION RESORTS

Categories	Dong	
	Value	Ratio (%)
Total	107	100.0
urgently improvement areas	19	17.8
potential risk areas	17	15.9
adaptive capacity enhancing areas	47	43.9
sustainable current areas	12	11.2

V. RESULTS AND DISCUSSION

This study assessed urban thermal environmental vulnerability based on consideration to social and economic factors, and on the IPCC's climate vulnerability framework. The classification of the assessment results revealed the characteristics of thermal vulnerable areas and can be used as an improvement direction by employing social and economic factors. The vulnerability assessment results that consider social and economic factors were analyzed to determine vulnerability by region with populations concentrated around the old downtown area and unfavorable traffic conditions areas. Also, the results of the classification determined 19 dong of urgently needing improvement areas, 47 dong of potential risk areas, 17 dong of adaptive capacity enhancing areas, and 12 dong of sustainable current areas.

Although previous studies used the city unit for assessment, this study narrowed the scale to the *dong*. This is significant for vulnerability assessment considering that *dong* is the smallest living area of a city. Moreover, variable sensitivity and adaptive capacity assessments factors were considered real vulnerable group characteristics, and the results of the vulnerable areas were classified using quartile classification.

This study determined a relationship between social and economic factors and suggests an improvement direction. In terms of limitations, the factors of variable fields were not considered, and this study did not suggest variable fields methods for urban thermal environment improvement.

Nevertheless, the results of this study are can be used as the basis for policy decision making for the urban thermal environment improvement. Also, thermal area classification by quartile classification can be used as basis of improvement direction.

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