Energy and Buildings 110 (2016) 353–361

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

The neural network predictive model for heat island intensity in Seoul

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ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form 4 November 2015
Accepted 4 November 2015
Available online 10 November 2015

Keywords:
Heat island
Heat island intensity
Neural network model
Automatic weather station
Seoul
Prediction model
Physical factor
Urban factor
Meteorological factor

ABSTRACT

The heat island effect in cities becomes intensified due to rapid urbanization and industrialization. This urban heat island has negative effects such as increase in cooling energy use and impairment of urban air quality. This study aims to develop a predictive model for heat island in Seoul, Korea using neural networks. To create the neural network predictive model, air temperatures of 28 locations in Seoul for a year have been collected from automatic weather stations operated by the Korea Meteorological Administration. The neural network model was created and tested for estimating the urban heat island intensity according to albedo, building coverage, green area, building area, water area, road area, temperature, humidity, wind speed and direction, and precipitation. Finally, prediction results from the neural network model were compared with the measured data. The coefficients of correlation of the developed models range from 0.95 to 0.99. The analysis also indicates that the neural network model has better predictive performance compared to the multiple regression model.

1. Introduction

People have moved to the city with the development of industry and transportation, and approximately 50% of the world's population currently lives in cities. Due to global warming, the surface temperature on the Earth has been increased by 0.76 K and many damages such as decreases in air quality, increases in infectious diseases, deterioration of health and increase in deaths have occurred in Europe and other countries since 1906 [1–4]. Thus, many studies on climate changes have been conducted in developed countries [1,2,5]. In particular, rapid urbanization and industrialization have deteriorated the urban environment [6]. Typical urban characteristics such as lack of vegetation, widespread use of impermeable surfaces, the urban form and structure that trap heat and slow wind speeds, increased human activity contribute to heat island formation [7]. Urban heat island phenomena is also influenced by the physical characteristics of the selected rural station [8]. The air and surface temperatures of urban areas are warmer than those of rural areas due to the urban characteristics. Consequently, urban areas consume more cooling energy than rural areas and people in urban areas suffer discomfort due to high temperatures and urban canyon effects [6]. A recent study [9] shows that a rise of urban air temperature increases the electricity demand of a building by up 8.5%. Thus, policies and studies on heat island have been actively conducted.

Many studies on the effects of urban climate on human health have been actively conducted. Excessive heat stress due to urban heat islands causes the damage of thermoregulatory system and the deterioration of physical well-being of urban population [10]. In 2003, about 50,000 people in Europe died due to heat waves [11]. Seoul, the capital of Korea, also experiences the changes in urban climate such as decrease in precipitation days, increase in cloudy and humid days and rise of the highest temperature [12]. Damages caused by heat islands are severe as about 1000 people in Seoul died due to abnormal high temperature in 1994 [13]. A study shows that heat-related deaths of older populations with the age of 65 and above are doubled with an increase of 1° in mean outdoor temperature [14]. It is expected that heat-related mortality increases significantly without the implementation of mitigation strategies [15]. Thus, it is indispensable to establish policies to mitigate urban heat islands and to conduct studies on heat islands to reduce negative impacts of urban heat islands [4,16,17].

The aim of this study is to develop accurate and reliable predictive models of heat island intensity of Seoul as a function of urban characteristics and weather conditions. To achieve this aim, this study investigates urban heat islands of Seoul with a population over 10 million using meteorological data obtained from 28 automatic weather stations operated by the Korea Meteorological

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http://dx.doi.org/10.1016/j.enbuild.2015.11.013
0378-7788/

Table 1
Physical factors affecting urban heat island.

Physical factor	Effect on urban heat island	Reference
Road area	Many parts of solar radiation spectrum are absorbed by the pavement in the city, because road is impervious surface, and its albedo is lower than those of trees and soil.	[24,25]
Water area	Reduction in water decreases heat loss by evaporation from urban surfaces.	[24,25]
Green area	Plants reduces the absorption of solar radiation with high albedo and reduces air temperatures with the process of evapotranspiration	[25–28]
Albedo	Albedo of urban physical factor is from 0.15 to 0.18 for plants, from 0.5 to 0.9 for white roof, from 0.05 to 0.35 for asphalt, and affects heat balance with the surrounding environment.	[24–27]
Building area	Buildings absorb solar radiation and convert it to heat and storing and releasing it to balance with the surrounding environment. High buildings with their facades participate in radiative and convective heat transfer with neighboring buildings.	[24,26]

Administration. After investigating patterns of urban air temperatures, this study develops and evaluates neural network predictive models for heat island intensities with urban morphological factors such as albedo, green area, building area, water area and road area and climatic variables including wind speed, direction, cloud amount, temperature and precipitation.

2. Research background

2.1. Urban heat island

The climate varies with latitude, altitude and other locally specific geographical and environmental factors. Air and surface temperatures of urban areas are higher than the temperature of surrounding areas. This heat island is easily found in urban areas because of low surface albedo, urban forms and structures contributing to an increase in heat storage and a decrease in long wave heat loss by radiation and anthropogenic heat from human activities [1,18].

The urban heat island intensity, which is the air temperature difference between rural and urban areas, is commonly used to measure the heat island effect and is calculated by Eq. (1) [7,19]. It is generally considered that the heat island effect exists when the maximum urban heat island intensity is over 2 K [12]:

$$\text{UHI} = T_{\text{Urban}} - T_{\text{Rural}} \tag{1}$$

UHI is the urban heat island intensity (K); T_{Urban} is the temperature of urban; T_{Rural} is the temperature of rural.

Various studies on heat island were conducted from perspectives of climate and energy [5,12,20–24]. Kolokotroni et al. [24] analyzed the heat island intensity in London during summer as a function of urban and building characteristics and Kolokotroni et al. [5] investigated the use of building energy in London considering heat island effects. Kim and Baik [12] examined the heat island intensity in Seoul using climatological data from weather stations from 1973 to 1996. The rural area chosen to calculate heat island intensity for Seoul was Neunggok where was rural and had the same latitude as the central area of Seoul. Mihalakakou et al. [23] developed the artificial neural network based predictive model and analyzed the characteristics by using the climate data collected in Athens for 2 years. There are still lack of reliable models to predict heat island intensity in Seoul which considers the urban morphology of Seoul. Thus, the aim of this study is to establish the neural network based predictive model with consideration of physical factors in Seoul.

2.2. Physical factors relevant for the UHI

This study selected urban physical factors for the development of a predictive model. Following previous studies on predictive models for urban heat island, data on selected factors were collected as follows: road area, water area, green area, albedo, and building area of 28 locations in Seoul. These factors were considered as key elements influence the occurrence of urban heat island as explained in Table 1 [24–28].

2.3. Predictive model for estimating UHI

For the development of a predictive model to estimate UHI, this study analyzed methodological approaches adopted by previous studies [12,26,28] on prediction models for the estimation of UHI. The predictive models in previous studies used maximum UHI, wind speed, cloudiness, relative humidity, surface albedo, altitude, floor area ratio as independent variables to estimate UHI. Modeling approaches to develop the predictive model can be categorized into neural network and multiple regression methods. The multiple regression analysis uses statistical techniques to analyze a relationship between the independent variables and dependent variable. One limitation of this method is that the regression method should not be applied when a relationship between independent and dependent variables is non-linear:

$$y_i = \beta_0 + \beta_i x_i + \alpha_i \tag{2}$$

β is the regression coefficient; x is the dependent variable; α is the constant term; y is the output value.

A neural network has been widely used in studies to both regress and classify weather variables such as air temperature, humidity, and precipitation [29,30]. The model of a neural network resembles that of a black-box, so it is easy to predict nonlinear factors such as weather variables. The neural network consists of a number of interconnect processing elements or neurons, as shown in Eq. (3) [31]. Previous studies [28,32,33] have shown that the prediction performance of neural networks for UHI forecast is reliable. Consequently, this study utilizes the neural network to develop a predictive model for UHI prediction:

$$y_k = \bar{f}\left[\sum_{j=1}^{M} \omega_{kj} \cdot f\left(\sum_{i=1}^{d} \omega_{ji} x_i + \omega_{jo}\right) + \omega_{ko}\right] \tag{3}$$

ω is the an weight; x is the dependent variable; α is the constant term; f is the activation function; y is the output value.

2.4. Neural network

A neural network is based on nervous system of an organism, such as a neuron. A network system provides a dynamic state in response to the value of knowledge or information of the external input for deduction of the required output. This network system is separated into three steps as shown in Fig. 1 as follows: step 1. Entering input data, step 2. Conducting the learning or training process, and step 3. Diagnostic checking, and drawing a conclusion.