



Effective monitoring and warning of Urban Heat Island effect on the indoor thermal risk in Bucharest (Romania)



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ABSTRACT

Extreme hot events and heat waves occur frequently in Bucharest during the warm season, triggering significant heat stress and thermal risks, especially in buildings with inappropriate ventilation, while climate change scenarios agree upon the warming trend along the next decades. This study investigates the impact of the Urban Heat Island (UHI) on the thermal regime of buildings, in order to develop a warning system capable to issue early warnings when the thermal risk reaches high levels in Bucharest. The warnings should be accurate regarding the intensity of the risk, the temporal fit and location, and complex information is compiled (e.g. air and land surface temperature, land cover, buildings and flat characteristics). Ground-based meteorological data and satellite products were used for computing the ambient temperature over several test areas for the summer months, and the indoor climate was dynamically modelled with an hourly resolution. The thermal risk was determined using standardized comfort indices, e.g. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), and the specific thermal and functional characteristics of the buildings.

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1. Overview

Intervals characterised by high outdoor temperatures and heat waves occur frequently in Bucharest during the warm season, triggering significant thermal risks, especially in buildings with inappropriate energy configuration. On the other hand, climate change scenarios agree upon the warming trend along the next decades. This study investigates the impact of the Urban Heat Island (UHI) on the thermal regime of buildings, in order to develop a warning system capable to issue early warnings to prevent the thermal risk effects on persons who live in housing units in Bucharest. The events which generated more than 52,400 victims in Western European countries [1,2], and the USA victims from the East Coast (August 2003), provide convincing reference on the consequences of inadequate technical solutions for buildings, and on the lack of intervention procedures for such emergency situations, on the other hand.

Garcia Herrera et al. [2] presented in a large study the EHW 03 analysis (Extreme Heat Wave 2003) and certain conclusions to support this approach: a large share of deaths (35%) included elderly

persons living in buildings with few rooms (a situation which is specific for most apartments in the blocks built in Romania in the period of 1950–1985); more than 45% of the victims died in hospitals due to the lack of or malfunctioning air conditioning systems and to the poor health condition of the patients.

The study of the Urban Heat Island is an important challenge, and there is significant literature on the topic [3–11]. The Urban Heat Island (UHI) is defined as the temperature difference between urban and rural areas. Several studies which tackled this topic [12–17] present a direct correlation between UHI effects and solutions focused on the Energy Performance (EP) of urban settlements. Increased EP seems to be a future solution for sustainable housing. The analysis and the energy audit of urban settlements represent a means of geometrical [18] and structural reconfiguration [19] with the purpose to minimise the UHI impact on the urban microclimate.

The justification of approaching this subject in Romania's capital, Bucharest, is given by the alarming forecast issued by the European Environmental Agency [20], and by the consequences on the thermal regime of inhabited areas, especially in the southern and western Romania in the summer of 2015. The climatic stress affecting the buildings is hereby considered as an *area-specific urban climate hazard*, characterised by two thermodynamic parameters, namely the outdoor air temperature (intensive parameter) and

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Nomenclature

V	Vulnerability of housing unit [%]
$R_{j,k}$	Excessive Thermal Risk [–]
R	Pearson correlation coefficient [–]
R^2	Determination coefficient [–]
p, q, r, w	Numerical coefficients of the two dimension polynomial interpolation of risk matrix [–]
$v_{1,2,3}$	Vulnerability-persons classes [–]
A	the outdoor temperature variation during a day [°C]
U	Overall heat transfer coefficient [W/m ² K]
ϑ	Temperature [°C]
τ	Time [h]
α –	Surface absorption of solar radiation

Subscript

j	Index of housing unit
k	Index of experimental urban area
o	Outside
M	Maximum
m	Minimum
COR	Corrected
s	Sunny hours
n	Night time hours
l	Summing index
$Cerv$	Cervantes high school area
$ins.$	Renovated housing unit
CF	Current floor
LL	Last level
T	Terrace
w	Wall

Superscript

COR	Corrected
FOR	Forecast
l	Summing exponent
$min. warning$	Maximum acceptable value of the excessive thermal regime risk

solar radiation intensity in a sunny summer day (extensive parameter).

The weather forecast issued by National Meteorological Administration (NMA) targets the daytime values of the air temperature and the clouding level on a regional scale. The method for processing climate data necessary to issue timely Excessive Thermal Regime Warnings starts with establishing a significant correlation ($R > 0.80$) between the climate parameters which are object to the current (regional) weather forecast and the climate parameters specific to the urban micro-zones.

The use of forecasting models such as Weather Research and Forecasting (WRF) [21] coupled with the Noah land-surface model and a modified urban canopy model (WRF-UCM2D) [22] does not seem to be enough for getting the outdoor hourly air temperature necessary for modelling the dynamic thermal regime within the inhabited areas. The limiting conditions of the mathematical model WRF (imposed values of certain parameters such as urban fraction or anthropic thermal flow) impact on the accuracy of air temperature modelling within urban micro-zones and, implicitly, on the results related to the microclimate in the housing units.

Consequently, for the purpose of issuing climate warning in different urban micro-zones, we chose to use two intensive thermodynamic parameters, namely outdoor air temperature measured at the ground level weather stations and the Land Surface

Temperature (LST) obtained by satellite remote sensing at a 1-km space resolution.

The underlying assumption of the method used to determine the climate parameters at the level of urban micro-zone consists in the fact that the correlation relationships between the values of the outdoor air temperature and between the land surface temperatures (LST), in the form of linear regression functions determined at the level of NMA weather stations and of the urban areas of Bucharest Municipality, have an objective phenomenological nature. This paper presents the outcomes of the current stage of empirical validation of the above-mentioned assumption, based on the measurements performed at the level of ground weather stations in the *peri*-urban and urban areas of the Bucharest Municipality.

2. Goal and objectives

The main goal of this paper is to present a procedure for issuing the Warning on the Excessive Natural Thermal Regime of housing units within buildings placed in various urban areas of the Bucharest Municipality. The warning is issued based on data derived from the weather forecast submitted by the National Meteorological Administration and on data obtained by satellite remote sensing, associated with the estimation of the Excessive Thermal Regime Risk derived from the dynamic simulation of the indoor thermal regime under forecasted weather conditions.

The paper presents representative results for housing units placed in condominium-type buildings.

3. Defining the vulnerability of inhabited areas and the excessive thermal regime risk when no air conditioning equipment and systems are used

According to IPCC [23], the vulnerability of a system is defined by the extent to which a system is sensitive to or even unable to cope with the adverse effects of climate change, including climate and extreme values variations. The vulnerability of an inhabited area depends on the climate change intensity, on the climate parameters variation and on the characteristics of the energy configuration of the inhabited area. In this paper, vulnerability is defined as a function:

$$V_{j,k} = f_j(\overline{PPD}_{j,k}(\bar{\vartheta}_{o,k}, A_k)) \quad [\%] \quad (1)$$

where the climate parameters defining the intensity of the Urban Climate Hazard (UCH) are:

$\bar{\vartheta}_{o,k}$ —Daily average outdoor temperature during a sunny summer day characteristic for the Experimental Urban Area k (EUA_k) where the inhabited area is placed [°C].

The daily average outdoor temperature is determined using the relationship:

$$\bar{\vartheta}_{o,k} = 0.50 \times (\vartheta_{o,M,k} + \vartheta_{o,m,k}) \quad (2)$$

A_k —Outdoor temperature variation during a sunny summer day, characteristic for the Experimental Urban Area k , where the inhabited area is placed [°C]

The outdoor temperature variation during a day is determined using the relationship:

$$A_k = 0.50 \times (\vartheta_{o,M,k} - \vartheta_{o,m,k}) \quad (3)$$

$\overline{PPD}_{j,k}$ —Daily average value of the thermal comfort indicator *Predicted Percentage Dissatisfied* [24], associated with the housing unit j located in the urban area k [%].

The values of the climate parameters defining the intensity of the Climate Hazard are related to *sunny summer days in June, July*

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