Modeling Technology for Assessment of Summer Thermal Comfort Conditions of Arctic City on Microscale: Application for City of Apatity

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Abstract. Arctic warming changes not only natural landscapes in polar latitudes but also brings relatively warm summer episodes in cities. In this study the results of the modeling research of the thermal comfort of Apatity town with population about 57 000 inhabitants (the fifth among the biggest cities, located to the North from the Arctic circle), situated in Murmansk region of Russian Federeration are considered. Here, directly in city center were performed first constant measurements of UHI (Urban Heat Island)'s intensity by automatic weather stations during winter 2015–spring 2017 (UHIARC measuring campaign). Received data of this measurements network were assimilated by Rayman model to simulate thermal comfort conditions in «Apatity's science campus» - central district of city. This model calculates the radiation temperature, average radiation fluxes and biometeorological indices (PET, PMV, SET) at a particular point at a particular time. The main goal of this investigation was to test the technology for thermal comfort assessment at microscale for city of Arctic region. Also preliminary analysis of spatial and temporal characteristics of PET (Physiological Equivalent Temperature) for 500 m^2 populated area in central part of Kola Peninsula during short Arctic summer was performed.

Simulated results showed significant spatial diversity of PET-values during contrast weather conditions. In night hours as during hottest day in summer of 2016 modeling points located in different local conditions differs to each other due to non-uniform wind speed and radiation shield conditions.

Keywords: Urban climate · Thermal comfort · PET · Rayman model · Arctic region

1 Introduction

In view of climate change that is affecting the Arctic ecosystems, it is also interesting to assess the changes that occur in anthropogenic systems. Since the UCCRN report [1] does not contain any information about Arctic cities, such information can only be obtained by direct measurement. Such network has already been installed within the

V. Vasenev et al. (Eds.): SMSC 2018, Springer Geography, pp. 66–75, 2020.
https://doi.org/10.1007/978-3-030-16091-3_10

Eastern Arctic [2] and in the territory of European Russia (the Kola Peninsula), data is available after winter 2015. It is important that the automatic station in the city of Apatity (main site of UHIARC network) is installed directly in the urban landscape (the most densely built-up area), which distinguishes it from the WMO station located in the background green zone outside the city limits [3].

This position of the station allows receiving data directly about the weather and climate of the Arctic city, as well as assessing the total impact of weather factors on the health of the population.

Traditionally, this influence was assessed in the winter [4] and had as its goal the prediction of a work and rest regime for shift workers in the fields [5]. However, due to the warming of the regional climate [6], the question of the conditions of summer comfort is no less acute [7]. This is also due to the fact that the population of the northern regions is poorly adapted to hot periods.

One of the main modern approaches is the use of models of human heat balance [8], assessing the effect of meteorological factors on the body's thermoregulation [9]. Moreover, this calculation of a model of the Rayman [10] type can produce both at a point and at a microscale, taking into account the microclimatic heterogeneity of, say, a city microdistrict.

A similar task within the framework of the Rayman environment is solved by modeling the inhomogeneity of the arrival of solar radiation, its reflection and inhomogeneity of the wind regime in the surface layer of the urban atmosphere. In this study, an attempt was made to simulate thermal comfort conditions on the KSC campus in the city center during the summer period of 2016 in 9 different locations of the urban landscape. The technology of preparing data on the urban relief is described in detail as part of the technological process.

2 Materials and Methods

For PET index calculation different initial data files are needed that would show meteorological and geographical characteristics of the region [11]. The main components of processing are shown on Fig. 1.

The most important is the one containing meteorological measurements. In our case, it is a .txt file presented as table with 10 columns. The source of meteorological data is Davis Vantage Pro 2, located in Apatity town in the campus of Kola Scientific Center (KSC). This AWS model was chosen for UHIARC network due to it relatively low cost and high accuracy of air temperature (0,5°C) [2]. For current study there were taken meteorological measurements during the whole summer period of year 2016 (from June 1st to August 31st) with five minutes frequency period. Thus, in total there was collected 288 values of each meteorological characteristic per day. For each one date and time were fixed. Every five minutes 4 parameters are measured – air temperature, relative humidity (%), wind velocity (meters per second). Cloud cover level (points) was measured on WMO station of Apatity.

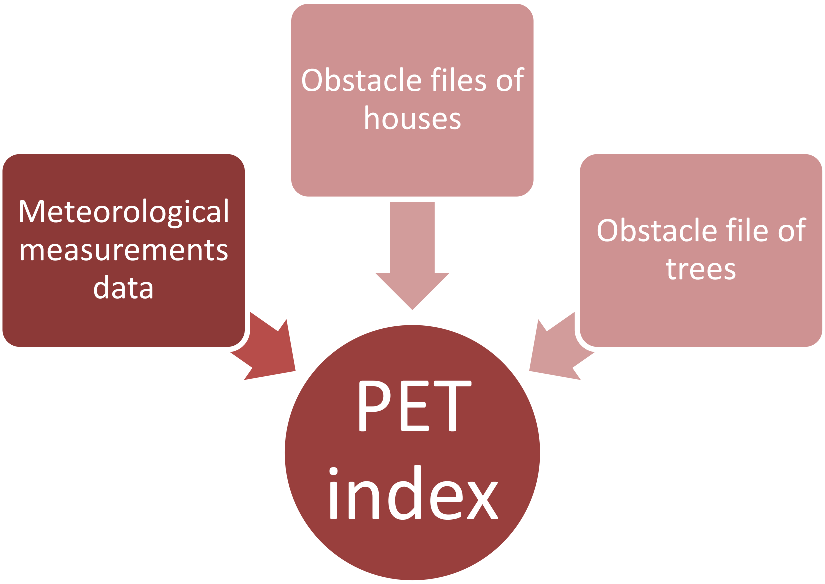

Fig. 1. Initial data for PET calculation by Rayman model.

Also additional data is needed for RayMan calculations. This information shows the geographical location of meteorological station, for example, time zone (UTC+3 for Apatity), height above sea level (178 m) and coordinates (67°34′N, 33°23′E). Station location is shown on Fig. 2.

In total, 26497 measurements for each of 4 characteristics were made. All of them were composed into a .txt file for further processing in RayMan model [10]. Apart from .txt file, additional files are needed, such as 3 shapefiles reflecting landscape and human impact on this territory. The first file contains polygons of buildings in Apatity. The second one contains the information about central points for each building.

For correct index calculations vegetation and relief also need to be considered. Apatity's relief in central part of city can be characterized as flat and no significant height difference was noticed. Thus, there was no need in using DEM (digital elevation model) for calculations. On the contrary, vegetation is widely spread and is crucial for town, especially for its microclimate. Another shapefile needs to be used for adding vegetation information into Rayman.

All shapefiles mentioned need to be converted into .obs files for further RayMan calculations. Thus, one .txt measurements file and three obs files are considered as initial data.

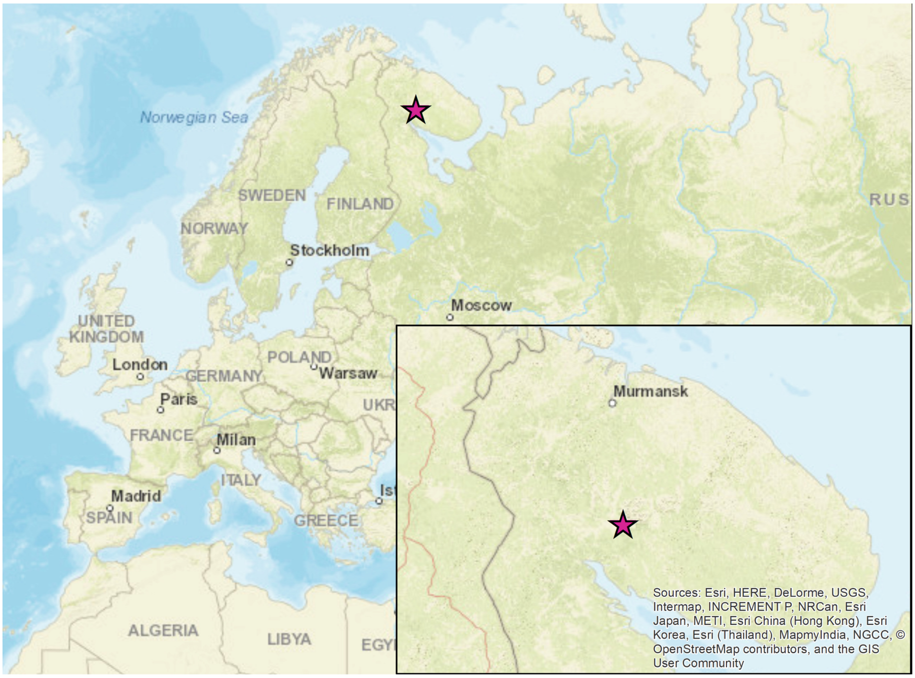

Fig. 2. Geographical map of study area (Apatity-city location)

3 Methods

The main aim of RayMan is to calculate different thermal indices for the quantification of thermal conditions [10]. So it is supposed to get Physiological Equivalent Temperature using different types of files. Measurement file should be converted to text file where all the empty gaps should be omitted, all the columns should be in right consequence (as in RayMan). After correcting it, this file was uploaded to RayMan model.

After that files with information about houses and trees should be uploaded. For doing that all these files should be converted to obstacle format (.obs). But, first of all, shape files should have appropriate attribute information.

Shape file containing polygons of houses was created using Open Street Map sources (building polygon for Murmansk region). However, not all the buildings were presented there, so some of them were created manually by dint of space images (Landsat) and panoramas (Google). Also it is necessary for this shape file to have information about height of each building in meters. To calculate it, the floor number information and the average height of one floor were used. The height calculation was made using ArcMap operation “field calculator”. The building polygons based on OSM contain information about floor number. If the building is not captured in OSM, its height is calculated manually.

Second shape file should contain centroid of each building captured in the previous file. Centroid number should be equal to the number of buildings. For creating this file ArcMap 10.3 operation “Feature to Point” (Data Management tools) was used. All the central points should have attribute information about its height above sea level. So for every building appropriate value was written according to topographic maps.

Third shape file needed is point shape file containing information about trees. Every point in this file means a single tree, which can be deciduous or coniferous. Vegetation polygon from OSM data was firstly converted into points. For that some operations in ArcMap were made – Create Fishnet, Create label points, intersect. After completing operations, according to Landsat images and other services, only trees were chosen, omitting bushes and grass cover. For converting these points into appropriate format, some additional information is needed, in particular tree height, trunk radius. The height of each tree and its radius are averaged per natural region.

After preparing these files it should be converted into obstacle files. For doing that a specific plugin exists (“shptoobs”). It is adapted only for QGIS application. On Fig. 3 the main interface is shown. There are three layers that have to be combined into one obstacle file.

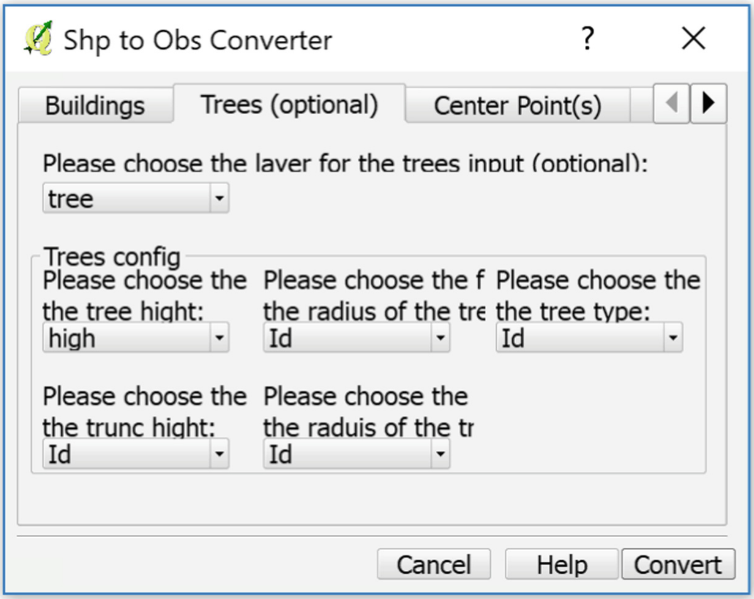

Fig. 3. Shp to obs converter window

As soon as all the files are converted and corrected, it can be loaded into RayMan application and points for PET calculations may be chosen. Window showing the location of buildings and trees can be seen on Fig. 4.

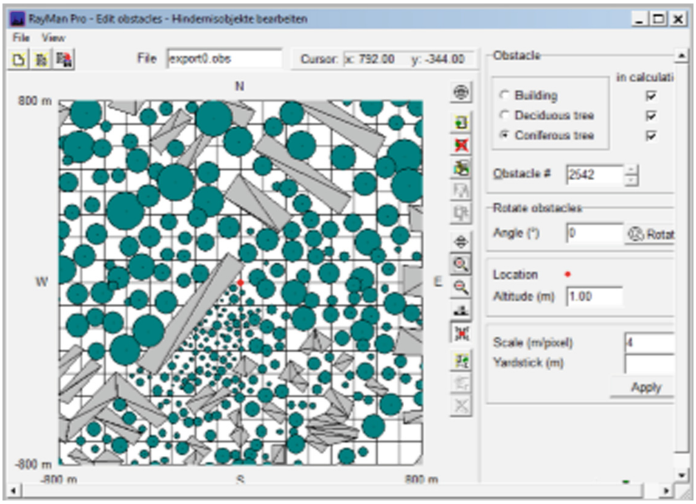

Fig. 4. Buildings and trees in RayMan application.

According to data available, 9 points of measurements are chosen, all of them are different depending on closeness to roads, buildings and vegetation areas, relative height, etc. For each point PET index was calculated. Also PET index was counted for Imandra lake and this point can be considered as a base point due to its minimal anthropogenic effect. For all points universal personal data, clothing data and activity characteristics are set in RayMan application. After calculations all PET indexes for each point are divided into 9 groups according to climate comfort (from PET less than 4 to PET more than 41). Based on this information pie diagrams are made to show general climate comfort level.

During summer 2016 a period with a minimum cloud cover can be extracted and PET is calculated separately. For this time minimum index values can be seen. Also PET indexes were calculated for the hottest day (July, 4th of 2016).

4 Results and Discussion

All PET index calculations for each point and its division to groups according to comfort level are shown on Fig. 5.

Despite the fact that Apatity is located on 67°N, it can be noticed that almost for each point there are PET indexes higher than 29. It means that there are periods of time when climate comfort level can be considered as warm, hot and sometimes very hot. Almost for all points prevailing comfort levels are warm (PET from 29 to 35) and moderately warm (PET from 23 to 29). For Imandra lake predominant comfort level is very cold (PET from 4 to 8). It can be an evidence of urban heat island influence: urban area is more heated than the area without significant anthropogenic activity. PET difference in calculation points can be explained by local features. For example, places located on the top of buildings (#2 and #9) are generally colder than ones located on the ground, especially near vegetation areas i.e. parks and squares due to wind influence.

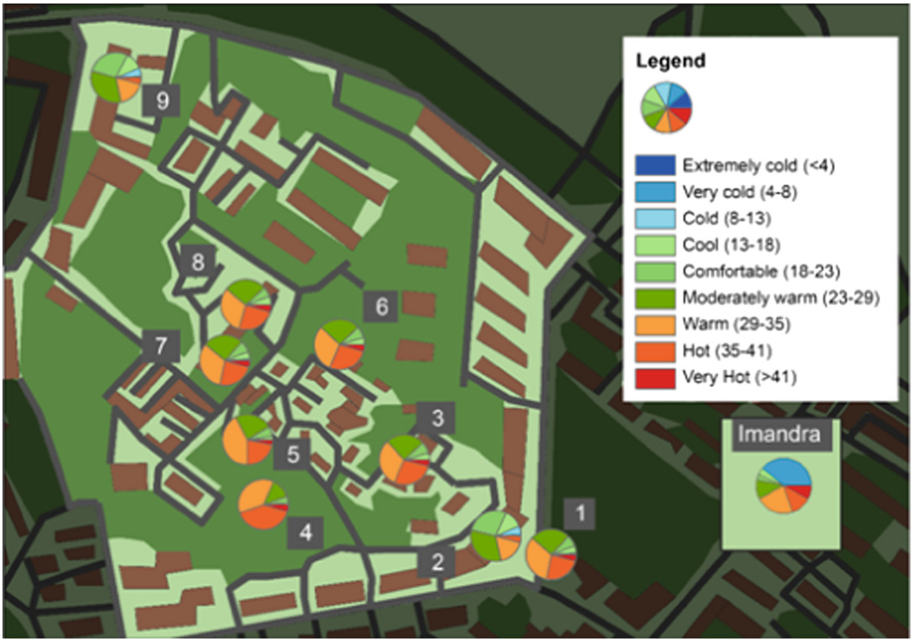

Fig. 5. Time distribution of summer PET index values for Apatity points (1–9) and Imandra lake (nearest WMO station).

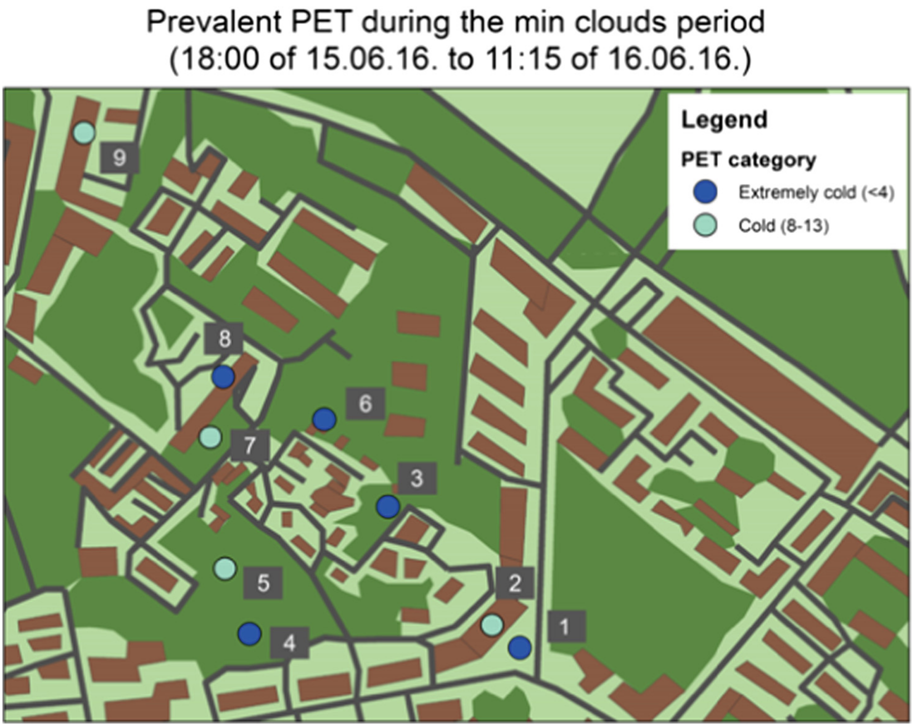

Fig. 6. PET for min cloud period.

For min cloud cover period (July 15–16) it can be seen that PET index is much lower than in usual conditions, it can be considered as cold (PET from 8 to 13) and extremely cold (PET less than 4), it is shown on Fig. 6. This can be explained by the fact that this period includes mostly night hours when there is less solar radiation during polar night. But in roof points (in clear sky conditions and low wind speed) these period is relatively more comfortable than at pedestrian level due to possible influence of near surface temperature inversions in atmospheric boundary layer.

Also PET indice for the hottest day were calculated (shown on Fig. 7). As it can be seen, warm and cool PET values are prevalent. Again it demonstrates the influence of urban heat island on city microclimate and position of modeling point in building area.

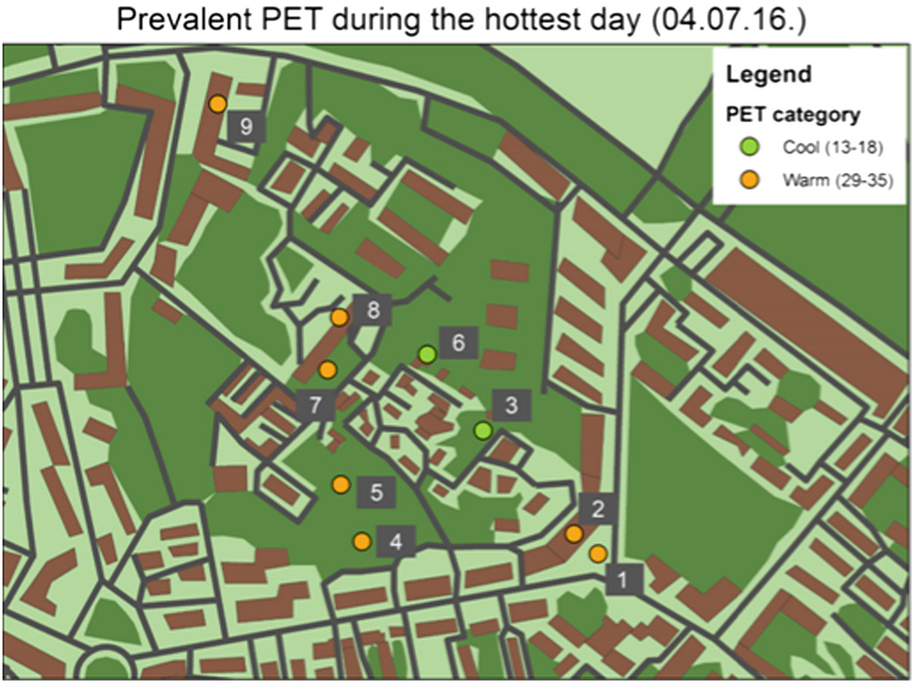

Fig. 7. PET during the hottest day during summer of 2016

5 Conclusion

Based on the results of this study, it is necessary to allow that this pilot experience of using the technology of calculating thermal comfort conditions for small Arctic city with a high spatial resolution is quite successful. The inhomogeneity of thermal comfort conditions in urban development was reproduced according to the PET-index simulation data. It was also convincingly shown that in the background areas (in the suburbs on the board of Imandra lake) in summer the frequency of cold stress conditions is much higher. Inside the campus of the KSC region most warmer points in clear sky periods are the roofs of tall buildings.

In general, simulated results showed significant spatial diversity of PET-values during contrast weather conditions. In night hours as during hottest day in summer of 2016 modeling points located in different local conditions differs to each other due to non-uniform wind speed and radiation shield conditions.

Nevertheless, this technology can be improved in future modeling runs.

Acknowledgments. The research has been supported by the grant programme from the Russian Science Foundation (Project № 17-77-20070 "An initial assessment and projection of the bioclimatic comfort in Russian cities in XXI century against the context of climate change"). The work of Pavel Konstatinov (AWS data quality control) was partially supported by RFBR project № 18-05-60146_Arctica.

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