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Urban area thermal monitoring: Liepaja case study using satellite and aerial thermal data

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ABSTRACT

The aim of this study is to explore large (60 m/pixel) and small scale (individual building level) temperature distribution patterns from thermal remote sensing data and to conclude what kind of information could be extracted from thermal remote sensing on regular basis. Landsat program provides frequent large scale thermal images useful for analysis of city temperature patterns. During the study correlation between temperature patterns and vegetation content based on NDVI and building coverage based on OpenStreetMap data was studied. Landsat based temperature patterns were independent from the season, negatively correlated with vegetation content and positively correlated with building coverage.

Small scale analysis included spatial and raster descriptor analysis for polygons corresponding to roofs of individual buildings for evaluating insulation of roofs. Remote sensing and spatial descriptors are poorly related to heat consumption data, however, thermal aerial data median and entropy can help to identify poorly insulated roofs. Automated quantitative roof analysis has high potential for acquiring city wide information about roof insulation, but quality is limited by reference data quality and information on building types, and roof materials would be crucial for further studies.

1. Introduction

Urbanized environment strongly affects global climate by overconsumption of the resources and production of waste and pollution. Heating of buildings is an important component in urban energy consumption and production of greenhouse gas (GHG) emissions. Buildings represent more than 45% of final energy consumption in Latvia and more than 70% of final energy consumption is for residential buildings (Commission, 2015). Application of modern technologies helps to reduce energy consumption for heating even for existing buildings, e.g. for private buildings it is possible to reduce energy consumption for 50–75% and for apartment houses for 80–90% (Harvey, 2013).

Thermal aerial remote sensing offers a chance to acquire city wide, detailed information about thermal characteristics of the materials and objects lying on the ground like roofs of the buildings, heating mains, asphalted surfaces and so on while satellite thermal data provide frequent data on general temperature distribution in the city. This data set may complement for efficient thermal planning in urban environment by helping to identify not only heat islands but also specific problematic buildings and regions in the city.

The aim of this study is to explore large (60 m/pixel) and small scale (individual building level) temperature distribution patterns from thermal remote sensing data and to conclude what kind of information could be extracted from thermal remote sensing on regular basis.

A lot of effort has been put to explain thermal satellite data over urban environment (Voogt and Oke, 2003), however, many studies focus on metropolis (Li et al., 2012; Melaas et al., 2016; Tran et al., 2006), instead of small cities. Analysis of small cities can provide detailed explanation on phenomenon observed due to easier ancillary data acquisition over smaller area. Temperature patterns in urban environment are affected by physical, properties of urban surfaces, sky view factor, street geometry, traffic loads, anthropogenic activities, land use/land cover, especially vegetation distribution (Weng, 2009; Chudnovsky et al., 2004). Landsat programme offers free of charge thermal daytime data for more than three decades enabling extended research of temperature patterns. Frequently used satellite thermal images include also ASTER and MODIS data. Landsat data deliver relatively high spatial resolution, but temporal resolution is 16 days. Weng et al. (2014) proposed a data fusion model to blend MODIS and Landsat TM data to enhance both temporal and spatial details. Geletič et al. (2016) compared Landsat 8 and ASTER data for analysis of the relationships between surface temperatures and local climate zone and noticed certain differences related to different LST retrieval algorithms. Vegetation abundance and distribution of impervious surfaces are often

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Table 1
Descriptors calculated for each roof polygon for which heat consumption data were available.

Vector (shape descriptors based on OSM data)	Ancillary data	Raster (thermal and visible light descriptors)
1. Area of polygon 2. Number of polygon vertices 3. Perimeter of the polygon 4. Number of concave vertices 5. Number of convex vertices 6. Eccentricity (Zhang and Lu, 2004; Morse, 1998) 7. Eccentricity (Zhang and Lu, 2004; Morse, 1998) 8. Circularity (Zhang and Lu, 2004; Morse, 1998)	1. Heat consumption for selected buildings (Mwh) for November, December, January, February and March 2011 2. Normalized heat consumption changes like $HC_{nov,dec} = (H_{dec} - H_{nov})/H_{nov}$, where H — heat consumption in specific month	1. Mean raster value of the polygon 2. Median raster value of the polygon 3. Minimum raster value 4. Maximum raster value 5. Standard deviation of raster values 6. Entropy of raster values (Gonzalez and Woods, 2004) 7. Otsu's threshold for raster values (Otsu, 1975) 8. Otsu's thresholding effectiveness metric (Otsu, 1975)

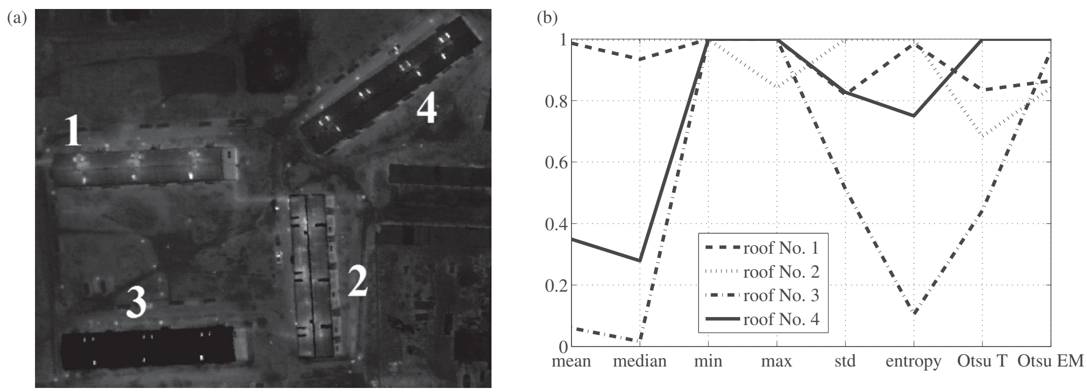

Fig. 1. (a) Examples of well (Nos. 3 and 4) and poorly (Nos. 1 and 2) insulated roofs in thermal aerial image. (b) Thermal image descriptor plot for well and poorly insulated roofs.

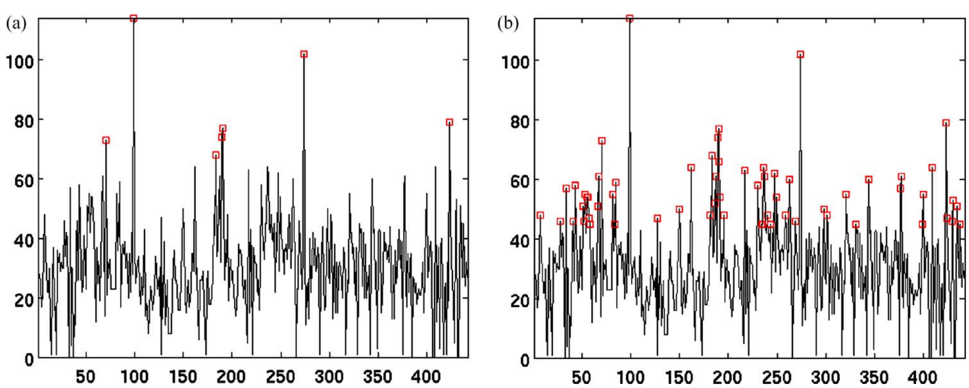

Fig. 2. Thermal median values for building polygons. (a) Strongest outliers preserve 10% of total energy. (b) Strongest outliers preserve 40% of total energy.

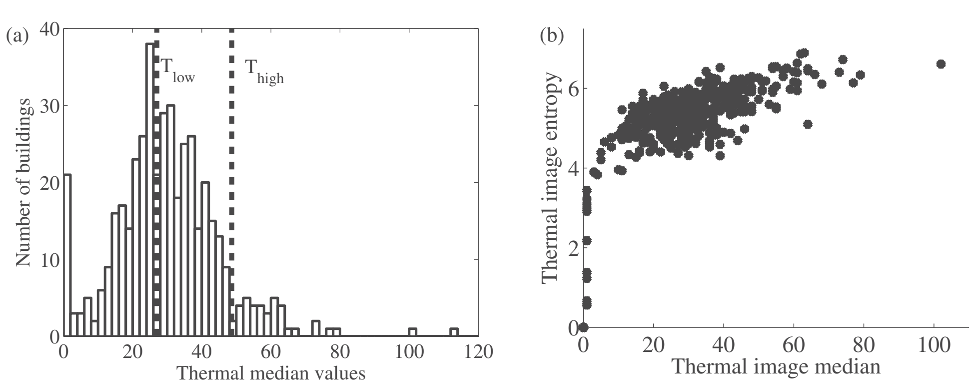

Fig. 3. (a) Histogram of thermal image median values for roof in subset with heat consumption data available. (b) Relationships between thermal image entropy and median.

researched in context of temperature patterns. Vegetation coverage has a cooling effect on surface temperature. Negative correlation is typical between daytime land surface temperature (LST) and vegetation index, like NDVI obtained from summer images (Dousset and Gourmelon, 2003; Yuan and Bauer, 2007). However, LST – NDVI scatter plots tend to have a triangular shape which has been tried to explain using soil–vegetation–atmosphere transfer model and using field and remote sensing based measurements (Weng et al., 2004). Between LST and