# A REVIEW ON OBSERVATION OF URBAN HEAT ISLAND IN THERMAL REMOTE SENSING

[1] Illyani Ibrahim, [2] Azizan Abu Samah and [3] Rosmadi Fauzi
[1, 2, 3] *Department of Urban and Regional Planning, Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia*

## ABSTRACT
The climate experts have proposed various approaches and strategies to understand the causes of Urban Heat Island (UHI) phenomenon. The aim of this paper is to review the details concerning the themes of urban climate study and its measurement over a variety of cities. The paper discusses several approaches of thermal remote sensing study of different spatial resolution as well as satellite images. The researchers conclude with the development of an observation framework of the thermal remote sensing.

**Keywords:** Remote sensing, thermal, urban heat island

## INTRODUCTION
Surface temperature provides essential input to a range of remote sensing applications, including the biophysical properties in ecosystems and offers a potential for understanding the real scenario on the urban environment. The prime parameter in the algorithm is the land surface temperature whereby it is crucial for the estimation of heat balance that covers sensible, latent and ground heat flux. Related studies can be referred to Oke (1981); Oke (1982); Voogt and Oke (1997); Weng et al. (2006) ; and Weng et al. (2008). A complex structure of urban atmosphere as measured in cities is difficult to be conducted (Voogt and Oke 1997), as the combination of urban climate factors is different at different scales. This paper will review and discuss various studies concerning the themes and measurements of the urban heat island as well as thermal remote sensing.

## THEMES OF URBAN HEAT ISLAND
With the integration of advanced technology and scientific knowledge nowadays, it is hoped that the urban climate problem, especially in Urban Heat Island (UHI) can be beneficial to understanding the behaviour of the specific environmental issue. In urban heat study, there are elements of themes that receive great concern, which is divided by variables used for each particular theme. UHI has been brought to attention by researchers from various fields, including climatological, architecture and planning.

From climatological aspects, UHI intensity depends on the size, population and industrial factors (Oke 1973), by calculating the differences of urban and rural sites. Streutker (2003) had confirmed the relationship between surface temperature with population density and the modelling of both variables are defined by Oke (1973); Weng et al. (2006). Johnson and Wilson (2009) had measured the surface urban heat island with the socioeconomic indicator for measuring the risk of extreme heat events.

From meteorological aspects, UHI depends on the meteorological parameter such as wind, the vertical temperature lapse rate, weather condition, cloud and surface property. Such research have been carried out by Bornstein (1968); Nkemdirim (1980); Voogt and Oke (1997); Liang (2007); Taha (2008); Kustas and Anderson (2009). Extensive work in meteorology showed that the surface inversions were less intense and far frequent in the

surrounding region Bornstein (1968). Jauregui (1992) also concluded that the UHI is highest during the dry season and decreasing in the rainy season.

From planning aspects, land cover information was the primary parameter for urban heat island mapping (Arnis Asmat et al. 2003). Stathopoulou and Cartalis (2007) had derived the relationship between the UHI and land cover changes using statistical analysis. Xiao et al. (2006) had analysed the factors of urban expansion and land use change and found that the population, traffic conditions, industrialisation and policy are the important ones.

Some researchers identified the relationship between the intensity of urban heat island with specific geophysical factors such as the normalized difference vegetation index ( NDVI) (Yuan and Bauer 2007; Knight and Voth 2010), roads, green areas and urban structure (Hu 2009; Yamazaki et al. 2009; Onishi et al. 2010) and land cover/land use (Yang et al. 2003; Chen et al. 2006; Xian and Crane 2006; He et al. 2007; Cheng et al. 2008; Huang et al. 2008; Wen et al. 2008; Xu et al. 2008; Amiri et al. 2009; Dan et al. 2009; Nonomura et al. 2009).

The growing concern in this studies is on temporal characteristics and spatial pattern of urban heat island by integration of several remote sensing images. It is also to study the changes of heat investigation and its relation to urban expansion (Klysik and Fortuniak 1999; Kim and Baik 2005; Khaikine et al. 2006; Kong and Nakagoshi 2006; Zurita-Milla 2008; Du et al. 2009; Dai et al. 2010).

Other studies of thermal remote sensing have established a variety of methods of land surface temperature extraction by numerous investigations (Dousset and Gourmelon 2003; Jensen 2007; Rong-bo et al. 2007; Ifatimehin and Adeyemi 2008; Zhang et al. 2008; Kon Joon and Seok-Soon 2009; Zhong et al. 2009).

A model can be developed using remote sensing; such as the study done by Hu and Weng (2010) where they had evaluated the impervious surfaces by using linear spectral mixture analysis (LSMA). Unger et al. (2004) had discussed the remote sensing while Dan et al. (2009) had constructed a quadratic polynomial model equation to simulate the relationship between temperature and NDVI. The regression model of land surface temperature with the built-up land, vegetation and water developed by Xu (2008). Wienert and Kuttler(2009) had analysed the maximum of urban heat island with latitude by using the multiple regression analysis. Another regression equation used to predict surface temperatures from known NDVI values was developed by Hardegree(2006). Additionally, Liang (2007) modelled the anthropogenic factor as one of the primary elements of UHI.

## MEASUREMENT OF URBAN HEAT ISLAND STUDY

The study starts with collecting temperature routines that are mostly descriptive. Howard (1818), who is known as a pioneer in urban climate study, had observed a difference of temperature between the city and the surrounding areas and found out maximum differences of 2.2˚ F in fall month and 0.5˚ F during the spring month. This study leads to extensive work by various scholars such as Kratzer (1956) who compared the daily variation of temperature, and Chandler (1965) who analysed the city-countryside temperature differences with a mean, maximum and minimum temperature.

Initially, urban heat island was measured using the atmospheric temperatures, and this type of measurement can be gathered from a meteorological station (Bornstein 1968; Kumanan 1970; Schmidlin 1989). This type of studies are often applied to the daily

maximum and minimum temperatures at the selected sites of the rural and urban areas to determine the magnitude and seasonal variability of the urban heat island. The selection of urban and rural sites and the method of calculating urban heat island intensity need to be determined cautiously.

Instead of analysing published meteorological data, the automobile traverses have also been used by (Whyte 1970; Oke 1973; Oke and Maxwell 1975; Park 1986; Bottyán and Unger 2003; Kardinal Jusuf, Wong et al. 2007). Oke (1973) conducted mobile traverses to study the relationship between the size of cities with the magnitude of urban heat island. Treska (1973) used a thermistor that can be mounted on the mobile for the temperature measurement, while Saaroni et al. (2000) and Ben-Dor et al. (2001) had used a car that is equipped with thermocouples with a data logger. Wong and Yu (2005) did mobile surveys for understanding the relationship between the land use and the ambient conditions. Saaroni et al. (2000) had combined a fixed station and airborne thermal video radiometer (TVR) to study spatial assessment of the urban heat island and its thermal characteristics.

The potential application in urban climate study is using remote sensing technology to understand the behaviour of urban heat island in depth. There are growth in popularity of utilizing the satellite observations of land surface temperature, that are also implemented in engineering and technology Al-Khateeb (2008), landscape and urban planning (Kardinal et al. 2007; Kim 2009; Onishi et al. 2010) and meteorology study (Bornstein 1968; Suckling 1981; Colacino and Lavagnini 1982; Gallo and Owen 1999; Kassomenos and Katsoulis 2006; Taha 2008). This suggests that satellite observations are mostly acceptable to be used in various research fields. The advantages of satellite observations are its availability of historical datasets and an excellent spatial resolution which covers broad areas. However, the limitation of this type of measurement is due to its radiometric resolution whereby the pixel size is limited into 60 meter (Landsat image), 30 meter (ASTER), unless hyperspectral image but it is very costly.

Most studies before the 1980s used only one source of data and improvements are shown in the later studies that most of them are three or four integration of data as for verification and validation. The selected data and measurement tools should be studied due to the expensive cost, such as airborne tools. The use of satellite images would be beneficial for a global scale instead of using the limited point of meteorological station, as this will reduce the cost and manpower. There is a growing innovation of using remote sensing in urban climate; thus an implementation of research needs is a significant concern which is essential for understanding the urban heat island real behaviour. From the literature review, there are 14 types of method available in UHI research, as shown in Table 3.1.

Table 3.1: The types of study and its related scholars in the urban heat island study.

| Types of study | Scholars |
|---|---|
| Downscaling LST image | Stathopoulou, M. And Cartalis, C. (2009) |
| LST and heat balance | Kato, S. Yamaguchi, Y., Liu, C. C., Sun, C. Y. (2008); Jiahua, Z. And Fengmei, Y. (2009) |
| LST and land cover | Xian, G. and Crane, M. (2006); Stathopoulou, M. And Cartalis, C. (2007); Van, T. T. (n.y) |
| LST landuse | Haishan, C. And Lexiang, Q. (2010); Buyantuyev, A., Wu, J. (2010); Nonomura, A., Kitahara, M., Masuda, T. (2009) |
| LST method | Peng, H., Li, H., (2009); Van, T. T., Trung, L. V., Lan, H. T. (2009); Ifatimehin, O. O. And Adeyemi, S. (1998); Sun, Q., Tan, J. Xu, Y., (2010); Adinna, E.N., Christian, E. I., Okolie, T. |

| | |
|---|---|
| | (2009); Takeuchi, W., Hashim, N. And Thet, K. M. (2010) |
| Nighttime study | Fung, W. Y., Lam, K. S., Nichol, J. And Wong, M. S. (2009); Zhou, J., Chen, Y., Wang, J. and Zhan W. (2010) |
| Nocturnal study | Xu, H., Dan, B., Dan, S., Lu, Z. (2009) |
| Pattern study | Alonso, M. S., Labajo, J. L. And Fidalgo, M. R. (2003) |
| Regression study | Dan, S., Gao, Y., Xu, H., Dan, B. (2009) |
| Sensible heat flux | Kato, S. and Yamaguchi, Y. (2005) |
| Spatial study | Saaroni, H., Ben-Dor, E. Bitan, A. and Potchter, O. (2000); Kolokotsa, D., Psomas, A., Karapidakis, E. (2009); Kubota, T. And Ossen, D. R. (2010); Dan, S., Dan, B., Li, H.,Xu, H., Xue, W., Chen, G. (2009) |
| Spatial study and factors | He, Z., Gao, Y., Bai, Y., and Yang, S. (2010); Imhoff, M. L., Zhang, P., Wolfe,R. E., Bounoua, L. (2010) |
| Temporal study | Liu, W., Zhong, J. Jiang, X., Zheng, Z. (2006); Dai, X., Guo, Z., Zhang, L., Li, D. (2010); Amiri, R., Weng, Q., Alimohammadi, A., Alavipanah, S. K. (2009); Sheng, H. L., Lin, S. and Ting, W. Y. (2009) |
| UHI pattern | Xiao, R. Ouyang, Z., Wang, X. Li, W. (n.y) |

## THERMAL REMOTE SENSING STUDY

The thermal measurement used in urban climate study by Rao (1972) was the first to demonstrate the use of remote sensing for analyses of urban areas. After the 1980s, most of the researchers started to have a better understanding of the use of remote sensing in the urban study. Later, the studies of land surface temperatures and thermal remote sensing in the urban area have been conducted by NOAA AVHRR (Hafner and Kidder 1999; Dousset and Gourmelon 2003; Stathopoulou and Cartalis 2009). Dousset and Gourmelon (2003) derived parameters on the surface heat fluxes by using NOAA AVHRR and GIS to combine landcover classification from SPOT HRV with in-situ data. Streutker (2003) conducted a study to investigate the correlation between urban heat island and rural magnitude. Hafner and Kidder (1999) conducted a modelling of urban heat island using NOAA AHVRR to retrieve the surface parameters; albedo, soil thermal and moisture properties. In addition, Jin et al. (2005) conducted a study by using MODIS to provide a global analysis of the zonal average of properties such as surface temperatures, emissivity and albedo were measured over urban areas versus neighbouring non-urban areas.

Medium resolution thermal infrared data such as Landsat TM/ETM, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Moderate Resolution Imaging Spectroradiometer (MODIS), have been employed in various research on the land surface temperature in relation to land cover and parameters studied. Fung et al. (2009) derived the night time urban air temperatures using ASTER as thermal satellite image integrated with a mobile survey as a ground measurement. Weng (2001) and Shaharuddin Ahmad and Noorazuan Md Hashim (2007) detected urban growth and assessed its impact on surface temperature in the region by using multitemporal Landsat Thematic Mapper (TM) data, in the Zhuang Delta, China and Selangor, Malaysia, respectively. Adinna et al. (2009) investigated the level of urban heat island effect based on Landsat ETM+ with relation to environmental parameters. Van et al. (2009) determined the surface temperature of urban areas in Ho Chi Minh City by using Landsat and ASTER satellite images and found out the average bias of land surface temperature calculation, about 2˚ Celcius compared with in situ measurement. The author mentioned that the advantage of new technology and traditional measurement was achieved in this study. Many surface urban heat island studies have been conducted using thermal data from satellites (Quattrochi 2003; Streutker 2003). Takeuchi et

al. (2010) mentioned that surface urban heat islands in Kuala Lumpur are present day and night, but are most influential during the day.

The high-resolution imagery has the benefit of a dense grid of temperature data over a whole city and distinctive features for individual buildings (Nichol, 1996). There are studies that used a high spatial resolution (10 meters) ATLAS (Advanced Thermal and Land Applications Sensor data (channel 13: 9.6-10.2 µm) (Ben-Dor et al. 2001; Gluch 2003; Gluch et al. 2006). Gluch (2003) examined the surface thermal pattern using the thermal land cover response for the Salt Lake City, Utah. Another study was conducted using hyperspectral was carried out by Jung et al. (2005) to detect the urban effect on vegetation in a less built-up Hungarian city. There are only fewer studies conducted by using hyperspectral images, might be due to its expensive cost.

Some studies intended to improve the accuracy of the spatial resolution and develop an appropriate approach in a correction of remote sensing image. Al-Khateeb (2008) improved the accuracy of spatial resolution of thermal band TM 6 from 120 meters to 30 meters which known as image fusion techniques. In term of macro level of an image, the study carried out by (Stathopoulou and Cartalis 2009) had downscaled of NOAA AVHRR spatial resolution to be more accurate by using different scaling factor. Hu (2009) developed an established new technique which can tackle these problems to obtain a better estimation of impervious surfaces.

## FRAMEWORK FOR UHI AND REMOTE SENSING

Reviews of environmental problem study using remote sensing show that there is growing attention given to UHI studies. The ability of remote sensing to extract the information with the algorithm exploration has made it possible to be applied for environmental investigation. According to this review, the framework of UHI studies using remote sensing is summarized as below;

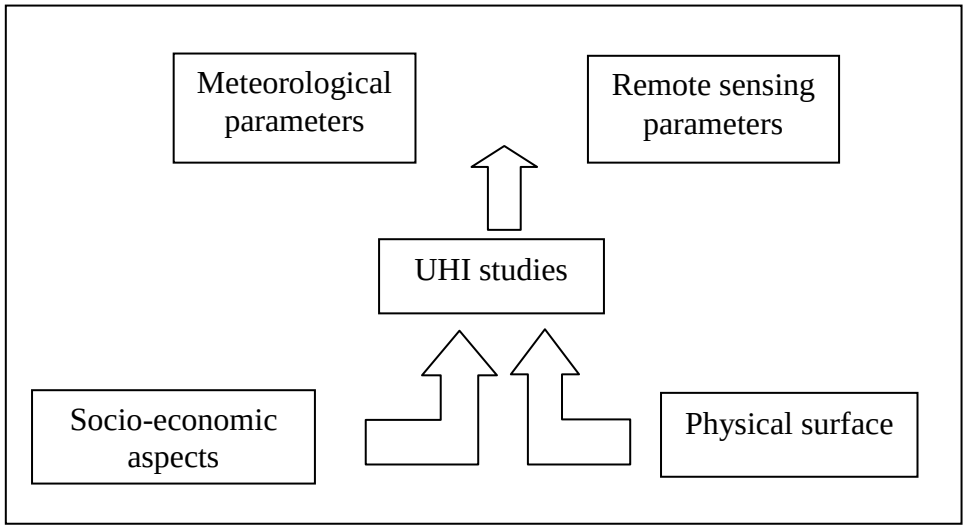


Fig. 1: The framework for the types of measurements in UHI studies

## CONCLUSIONS

This review intends to summarize the elements of urban heat island study as well as the research method chronologically for the understanding of the development of techniques of this study. It can be seen that various methods have been developed to assist in the understanding of the formation of this phenomenon. This review suggests that there has been a progressive improvement of a variety of techniques for documentation of the various parameters in the urban heat island studies.

## REFERENCES

Adinna, E. N., E. I. Christian, et al. (2009). "Assessment of urban heat island and possible adaptations in Enugu urban using Landsat-ETM." Journal of Geography and Regional Planning **2**(2): 30-36.

Al-Khateeb, T. A. (2008). "Land use classification utilizing Landsat thermal band - based on Wavelet Transform." Eng.&Tech **26**(11).

Amiri, R., Q. Weng, et al. (2009). "Spatial-temporal dynamics of land surface temperature about fractional vegetation cover and land use/cover in the Tabriz urban area, Iran." Remote Sensing of Environment **113**: 2606-2617.

Arnis Asmat, Shattri Mansor, et al. (2003). Rule-based classification for urban heat island mapping. FIG Regional Conference. Marrakech, Morocco.

Asmala Ahmad and Noorazuan Hashim (n.y.). "A remote sensing-GIS evaluation of urban growth-land surface temperature relationships in Selangor, Malaysia." GIS Development.

Ben-Dor, E., R. Lugassi, et al. (2001). A quantitative approach for monitoring the urban heat island effects, using hyperspectral remote sensing. Geoscience and Remote Sensing Symposium, 2001. IGARSS '01. IEEE 2001 International.

Bornstein, R. (1968). "Observations of the urban heat island effect in New York City." Journal of Applied Meteorology **7**(4): 575-582.

Bottyán, Z. and J. Unger (2003). "A multiple linear statistical models for estimating the mean maximum urban heat island." Theoretical and Applied Climatology **75**(3): 233-243.

Chen, X.-L., H.-M. Zhao, et al. (2006). "Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes." Remote Sensing of Environment **104**(2): 133-146.

Cheng, K.-S., Y.-F. Su, et al. (2008). "Assessing the effect of landcover changes on air temperature using remote sensing images—A pilot study in northern Taiwan." Landscape and Urban Planning **85**: 85-96.

Colacino, M. and A. Lavagnini (1982). "Evidence of the urban heat island in Rome by climatological analyses." Archives for Meteorology Geophysics and Bioclimatology Series B-Theoretical and Applied Climatology **31**(1-2): 87-97.

Dai, X., Z. Guo, et al. (2010). "Spatio-temporal exploratory analysis of urban surface temperature field in Shanghai, China." Stoch Environ Res Risk Assess **24**: 247-257.

Dan, M., G. Huili, et al. (2009). Study of urban heat island based on remote sensing in Beijing-capital zone. Urban Remote Sensing Event, 2009 Joint.

Dan, S., Y. Gao, et al. (2009). Regression analysis of urban heat island temperature and vegetation index on complex terrain. International Conference on Information Engineering and Computer Science, Wuhan.

Dousset, B. and F. Gourmelon (2003). "Satellite multi-sensor data analysis of urban surface temperatures and landcover." ISPRS Journal of Photogrammetry & Remote Sensing **58**: 43-54.

Du, M., Q. Wang, et al. (2009). Temporal and spatial variations of Urban Heat Island effect in Beijing using ASTER and TM data. Urban Remote Sensing Joint Event.

Fung, W. Y., K. S. Lam, et al. (2009). "Derivation of nighttime urban air temperatures using a satellite thermal image." American Meteorological Society **48**: 863-872.

Gallo, K. and T. Owen (1999). "Satellite-based adjustments for the urban heat island temperature bias." Journal of Applied Meteorology **38**(6): 806-813.

Garcia-Cueto, O. R., E. Jauregui-Ostos, et al. (2007). "Detection of the urban heat island in Mexicali, B. C., México and its relationship with land use." Atmósfera **20**(2): 111-131.

Gluch, R., D. A. Quattrochi, et al. (2006). "A multi-scale approach to urban thermal analysis." Remote Sensing of Environment **104**: 123-132.

Gluch, R. M. (2003). Mapping the urban thermal pattern of the Salt Lake Valley using advanced thermal land applications sensor airborne data. United States -- Utah, The University of Utah. **PhD:** 85.

Hafner, J. and S. Q. Kidder (1999). "Urban Heat Island Modeling in Conjunction with Satellite-Derived Surface/Soil Parameters." Journal of Applied Meteorology **38**: 448-465.

Hardegree, L. C. (2006). Spatial characteristics of the remotely-sensed surface urban heat island in Baton Rouge, Louisiana: 1988-2003. United States -- Louisiana, Louisiana State University and Agricultural & Mechanical College. **PhD:** 128.

He, J. F., J. Y. Liu, et al. (2007). "Assessing the effect of land use=land cover change on the change of urban heat island intensity." Theor. Appl. Climatol. **90**(217-226).

Hu, X. (2009). Impervious surface estimation from remote sensing imagery using sub-pixel and object-based classifications in Indianapolis, USA. United States -- Indiana, Indiana State University. **PhD:** 134.

Hu, X. and Q. Weng (2010). "Estimation of impervious surfaces of Beijing, China, with spectral normalized images using linear spectral mixture analysis and artificial neural network." Geocarto International **25**(3): 231-253.

Huang, L., D. Zhao, et al. (2008). "Scale impacts of land cover and vegetation corridors on urban thermal behaviour in Nanjing, China." Theor. Appl. Climatol. **94**: 241-257.

Ifatimehin, O. O. and S. Adeyemi (2008). "A satellite remote sensing-based land surface temperature retrieval from Landsat TM data." Ethiopian Journal of Environmental Studies and Management **1**(3): 63-70.

Jensen, A. (2007). Remote sensing analysis of surface temperature and landscape feature dynamics. United States -- Arkansas, University of Arkansas. **M.A.:** 119.

Johnson, D. P. and J. S. Wilson (2009). "The socio-spatial dynamics of extreme urban heat events: The case of heat-related deaths in Philadelphia." Applied Geography **29**(3): 419-434.

Kardinal J. S., N. H. Wong, et al. (2007). "The influence of land use on the urban heat island in Singapore." Habitat International **31**(2): 232-242.

Kassomenos, P. A. and B. D. Katsoulis (2006). "Mesoscale and macroscale aspects of the morning Urban Heat Island around Athens, Greece." Meteorology and Atmospheric Physics **94**: 209-218.

Khaikine, M. N., N. Kuznetsova, et al. (2006). "Investigation of temporal-spatial parameters of an urban heat island by passive microwave remote sensing." Theoretical and Applied Climatology **84**: 161-149.

Kim, J. (2009). Land-use planning and the urban heat island effect. United States -- Ohio, The Ohio State University. **PhD:** 338.

Kim, Y. H. and J. J. Baik (2005). "Spatial and temporal structure of the urban heat island in Seoul." Journal of Applied Meteorology **44**: 591-605.

Klysik, K. and K. Fortuniak (1999). "Temporal and spatial characteristics of the urban heat island of Lódz, Poland." Atmospheric Environment **33**(24-25): 3885-3895.

Knight, J. and M. Voth (2010). "Mapping impervious cover using multi-temporal MODIS NDVI data." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing: 1-7.

Kon Joon, B. and P. Seok-Soon (2009). "Evaluation of the surface temperature variation with surface settings on the urban heat island in Seoul, Korea, using Landsat-7 ETM+ and SPOT." Geoscience and Remote Sensing Letters, IEEE **6**(4): 708-712.

Kong, F. and N. Nakagoshi (2006). "Spatial-temporal gradient analysis of urban green spaces in Jinan, China." Landscape and Urban Planning **78**: 147-164.

Kumanan, I. (1970). Towards an understanding of the urban heat island in the Detroit-Windsor area. Canada, University of Windsor (Canada). **M.A.:** 85.

Kustas, W. and M. Anderson (2009). "Advances in thermal infrared remote sensing for land surface modelling." Agricultural and Forest Meteorology **149**(12): 2071-2081.

Liang, J. (2007). A modelling study of the heat island formation and its potential effects on air pollution and meteorology. Canada, York University (Canada). **M.Sc.:** 177.

Lu, D., Q. Weng, et al. (2006). "Residential population estimation using a remote sensing derived impervious surface approach." International Journal of Remote Sensing **27**(16): 3553-3570.

Nkemdirim, L. C. (1980). "A test of a lapse rate wind speed model for estimating heat island magnitude in an urban airshed." Journal of Applied Meteorology **19**(6): 748-756.

Nonomura, A., M. Kitahara, et al. (2009). "Impact of land use and land cover changes on the ambient temperature in a middle scale city, Takamatsu, in Southwest Japan." Journal of Environmental Management **90**: 3297-3304.

Oke, T. R. (1973). "City size and the urban heat island." Atmospheric Environment (1967) **7**(8): 769-779.

Oke, T. R. (1981). "Canyon Geometry and the nocturnal urban heat island - Comparison of scale model and field observation." Journal of Climatology **1**(3): 237-&.

Oke, T. R. (1982). "The energetic basis of the urban heat island." Quarterly Journal of the Royal Meteorological Society **108**(455): 1-24.

Oke, T. R. and G. B. Maxwell (1975). "Urban heat island dynamics in Montreal and Vancouver." Atmospheric Environment (1967) **9**(2): 191-200.

Onishi, A., X. Cao, et al. (2010). "Evaluating the potential for urban heat-island mitigation by greening parking lots." Urban Forestry & Urban Greening.

Park, H.-S. (1986). "Features of the heat island in Seoul and its surrounding cities." Atmospheric Environment (1967) **20**(10): 1859-1866.

Quattrochi, C. P. L. a. D. A. (2003). "Land-Use and Land-Cover Change, Urban Heat Island Phenomenon, and Health Implications: A Remote Sensing Approach." Photogrammetric Engineering & Remote Sensing **69**(9): 1053-1063.

Rong-bo, X., O. Zhi-yun, et al. (2007). "Spatial pattern of impervious surfaces and their impacts on land surface temperature in Beijing, China." Journal of Environmental Sciences **19**: 250-256.

Saaroni, H., E. Ben-Dor, et al. (2000). "Spatial distribution and microscale characteristics of the urban heat island in Tel-Aviv, Israel." Landscape and Urban Planning **48**(1-2): 1-18.

Schmidlin, T. (1989). "The urban heat island at Toledo, Ohio." The Ohio Journal of Science **89**(3): 38-41.

Shaharuddin Ahmad and Noorazuan Md Hashim (2007). "Effects of Soil Moisture on Urban Heat Island Occurrences: Case of Selangor, Malaysia." Humanity & Social Sciences Journal **2**(2): 132-138.

Stathopoulou, M. and C. Cartalis (2007). "Daytime urban heat islands from Landsat ETM+ and Corine land cover data: An application to major cities in Greece." Solar Energy **81**(3): 358-368.

Stathopoulou, M. and C. Cartalis (2009). "Downscaling AVHRR land surface temperatures for improved surface urban heat island intensity estimation." Remote Sensing of Environment **113**(12): 2592-2605.

Streutker, D. R. (2003). A study of the urban heat island of Houston, Texas. United States -- Texas, Rice University. **PhD:** 146.

Suckling, P. W. (1981). "Nocturnal observations of incoming longwave radiation and the urban heat-island for a small Prairie City." Archives for Meteorology Geophysics and Bioclimatology Series B-Theoretical and Applied Climatology **29**(1-2): 23-27.

Taha, H. (2008). "Meso-urban meteorological and photochemical modelling of heat island mitigation." Atmospheric Environment **42**(38): 8795-8809.

Takeuchi, W., Noorazuan Hashim, et al. (2010). Application of remote sensing and GIS for monitoring urban heat island in Kuala Lumpur Metropolitan area. MapAsia 2010 and ISG 2010. Kuala Lumpur, Malaysia.

Treska, E. (1973). The nocturnal urban heat island in Laramie, Wyoming. United States -- Wyoming, University of Wyoming. **M.A.:** 60.

Unger, J., Z. Bottyan, et al. (2004). "Connections between urban heat island and surface parameters: measurements and modelling." Quarterly Journal of the Hungarian Meteorological Service **108**(3): 173-194.

Van, T. T., L. V. Trung, et al. (2009). "Application of Thermal Remote Sensing in Study on Surface Temperature Distribution of Ho Chi Minh City." Remote Sensing for Sustainable Development.

Voogt, J. and T. Oke (1997). "Complete urban surface temperatures." Journal of Applied Meteorology **36**(9): 1117-1132.

Wen, X., G. Hu, et al. (2008). An investigation of the relationship between land cover ratio and urban heat island. Image and Signal Processing, 2008. CISP '08. Congress on.

Weng, Q. (2001). "A remote sensing–GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China." International Journal of Remote Sensing **22**(10): 1999-2014.

Weng, Q., H. Liu, et al. (2008). "The Spatial Variations of Urban Land Surface Temperatures: Pertinent Factors, Zoning Effect, and Seasonal Variability." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **1**(2): 154-166.

Weng, Q., D. Lu, et al. (2006). "Urban Surface Biophysical Descriptors and Land Surface Temperature Variations." Photogrammetric Engineering & Remote Sensing **72**(11): 1275-1286.

Whyte, R. A. P. (1970). "A spatial model of urban heat island." Journal of Applied Meteorology **9**: 571-573.

Wienert, U. and W. Kuttler (2009). Statistical analysis of the dependence of urban heat island intensity on latitude.

Wong, N. H. and C. Yu (2005). "Study of green areas and urban heat island in a tropical city." Habitat International **29**: 547-558.

Xian, G. and M. Crane (2006). "An analysis of urban thermal characteristics and associated land cover in Tampa Bay and Las Vegas using Landsat satellite data." Remote Sensing of Environment **104**: 147-156.

Xiao, J., Y. Shen, et al. (2006). "Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing." Landscape and Urban Planning **75**: 69-80.

Xu, H. (2008). Remote Sensing of Urban Expansion and Heat Island Effect in Jinjiang Estuary Area of Fujian, China. International Workshop on Earth Observation and Remote Sensing Applications.

Xu, Y., Z. Qin, et al. (2008). Comparative analysis of urban heat island and associated land cover change based in Suzhou city using LANDSAT data.

Yamazaki, F., A. Murakoshi, et al. (2009). Observation of urban heat island using airborne thermal sensors. Urban Remote Sensing Event, 2009 Joint.

Yang, H. and Y. Liu (n.y.). "A satellite remote sensing based assessment of urban heat island in Lanzhou city , northwest China."

Yang, L., G. Xian, et al. (2003). "Urban Land-Cover Change Detection through Sub-Pixel Imperviousness Mapping Using Remotely Sensed Data." Photogrammetric Engineering & Remote Sensing **69**(9): 1003-1010.

Yuan, F. and M. E. Bauer (2007). "Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery." Remote Sensing of Environment **106**(3): 375-386.

Zhang, Z., J. S. M. Ji, et al. (2008). Surface urban heat island in Shanghai, China: Examining the relationship between land surface temperature and impervious surface fractions derived from LANDSAT ETM+ imagery.

Zhong, L., Y. M. A, et al. (2009). "Estimation of Land Surface Temperature over the Tibetan Plateau using AVHRR and MODIS Data." Advances in Atmospheric Science **27**: 1110-1118.

Zurita-Milla, R. (2008). Mapping and monitoring heterogeneous landscapes: spatial, spectral and temporal unmixing of MERIS data. Hoogleraar Geo-informatiekunde mbav Remote Sensing, Wageningen Universiteit (Nederland). **PhD**.