Towards quantifying forest recreation: exploring outdoor thermal physiology and human well-being along exemplary pathways in a central European urban forest (Augsburg, SE-Germany)

Joachim Rathmann, Christoph Beck, Simon Flutura, Andreas Seiderer, Ilhan Aslan, Elisabeth André

Angaben zur Veröffentlichung / Publication details:

Rathmann, Joachim, Christoph Beck, Simon Flutura, Andreas Seiderer, Ilhan Aslan, and Elisabeth André. 2020. "Towards quantifying forest recreation: exploring outdoor thermal physiology and human well-being along exemplary pathways in a central European urban forest (Augsburg, SE-Germany)." *Urban Forestry & Urban Greening* 49: 126622. https://doi.org/10.1016/j.ufug.2020.126622.

Towards quantifying forest recreation: Exploring outdoor thermal physiology and human well-being along exemplary pathways in a central European urban forest (Augsburg, SE-Germany)

Joachim Rathmann[a,*], Christoph Beck[b], Simon Flutura[c], Andreas Seiderer[c], Ilhan Aslan[c], Elisabeth André[c]

[a] Geography, University of Würzburg, Germany
[b] Geography, University of Augsburg, Germany
[c] Human Centered Multimedia, University of Augsburg, Germany

A R T I C L E I N F O

Handling Editor: Matilda van den Bosch

Keywords:
Ecosystem services
Forest recreation
Local climate zones
Machine learning

A B S T R A C T

Contact with nature can help to reduce stress, enhance stress resilience, promote mental and physical health and has a positive impact on people's mood. Beside urban park and residential green, recreation in urban forests can act as therapeutic means. From a climatological point of view, urban and periurban forests and green spaces provide a number of benefits particularly including air temperature and humidity control as well as air pollution reduction. Due to their compensating thermal effects urban green and urban forests may help to counteract potentially health relevant effects of urban warming. The main objective of our study is to explore the quantification of forest recreation based on measurement campaigns for the combined simultaneous recording of relevant features along routes comprising varying urban structural types (ranging from built up to densely forested areas). Combining data on subjective well-being and objective data on human physiology can help to quantify health effects of varying environments. The study area is the urban forest of Augsburg, in the German Federal State of Bavaria, Southern Germany.

Our results substantiate clear cut and statistically significant climatic differences among varying urban environments (i.e. local climate zone categories) and prove the potential positive effects of urban forests/urban green on bioclimatic conditions (e.g. via a reduction in maximum air temperatures during summer). Moreover, the beneficial effects of urban green structures on human physiological parameters (e.g. reductions in heart rate) could be verified.

1. Introduction and state of research

Globally, more people live in urban than in rural areas and as urbanization is rapidly increasing, 66 % of the world´s population will live in urban areas by the year 2050 (UNPD, 2014). Beside positive health aspects of urbanization, modern life styles have led to increased physical challenges, for example obesity, and mental stress for people. Contact with nature can help to reduce stress, enhance stress resilience, promote mental and physical health and has a positive impact on people's mood (Ulrich et al., 1991). Beside urban park and residential green, recreation in urban forests can act as therapeutic means. There is strong evidence, underlined by a plethora of studies worldwide, that green spaces can positively affect human health, well-being, the quality of life and public health (van den Berg et al., 2010; Sandifer et al., 2015; Donovan, 2017; Rathmann and Brumann, 2017). Focusing on forests, shinrin-yoku, forest bathing, is a traditional Japanese practice in nature by mindfully using all five senses as a kind of nature therapy, triggering positive health benefits for the human physiological and psychological systems, that involves simply wandering along forest trails and spending time in forests (Park et al., 2009; Song et al., 2015, 2016; Hansen et al., 2017). On the other hand, health hazards (e.g. animals, pollen, subjective fears in dark forests) should not be neglected when discussing forest-health relations. By now, many cause–effect relationships between forests and human health have already been established (Colfer, 2008).

However, a detailed clarification of the relations between human

* Corresponding author.
E-mail addresses: joachim.rathmann@uni-wuerzburg.de (J. Rathmann), christoph.beck@geo.uni-augsburg.de (C. Beck), Simon.Flutura@informatik.uni-augsburg.de (S. Flutura), andreas.seiderer@informatik.uni-augsburg.de (A. Seiderer), ilhan.aslan@informatik.uni-augsburg.de (I. Aslan), andre@informatik.uni-augsburg.de (E. André).

health and forests is necessary in order to quantify this cultural ecosystem services provided forests. In a recent study about preferred forest characteristics, Stigsdotter et al. (2017) found that a balance between enclosed dense growth and open views is most beneficial for restoration. Hunter et al. (2019) describe the relationship between the duration of a nature experience and changes in salivary cortisol and alpha-amylase used as two physiological biomarkers of stress. They show that the efficiency of a “nature pill” per time expended was greatest between 20 and 30 min.

From a climatological point of view, urban and periurban forests and green spaces provide a number of benefits particularly including air temperature and humidity control as well as air pollution reduction (e.g. Demuzere et al., 2014). Due to their compensating thermal effects urban green and urban forests may help to counteract potentially health relevant effects of urban warming – including as most prominent the so called urban heat island (UHI, Oke, 1967). As urban overheating is expected to further increase under probable future climate change conditions (e.g. McCarthy et al., 2010) urban green and urban forests gain additional importance with respect to adaptation strategies for climate change in the urban environment (e.g. Emmanuel and Loconsole, 2015).

The field of Human-Computer Interaction (HCI) has witnessed multiple waves and turns (Rogers, 2012), including a "turn to the wild" and a "turn to embodiment", which put emphasis on the importance of in-the-wild (Hutchins, 1995) and in-situ (Rogers, 2011) research methods to study couplings between the environment, user behavior and technology. It is therefore not surprising that in particularly over the last decade, the technology for physiological measurements in field experiments developed rapidly (Song et al., 2015, 2016). Thereupon several studies on the physiological effects of the natural environment in field conditions have been performed recently (Hartig et al., 2003; Park et al., 2008, 2009; Tsunetsugu et al., 2007; Tyrvainen et al., 2014). Mobile observations can record the spatial and temporal variability of both the microclimate and the physiological states along the pathways of the sensor carriers if the measurement system permits, thereby providing richer micro-environmental information, including thermal histories. Wearables, apps, and other sensor-based or “smart” devices are becoming mainstream and have the potential to transform healthcare through real-time, continuous data collection (Nakayoshi et al., 2015). Remarkably, by precisely examining the daily, weekly, and seasonal patterns it is possible to gather insights into the different factors influencing human behavior and health (Cornet and Holden, 2017). Two studies employed people-based monitoring of environmental variables to investigate diurnal variability in heat exposure (Kuras et al., 2015) and human-physiological response (Nakayoshi et al., 2015). Nakayoshi et al. (2015) analyze outdoor thermal physiology. They have looked at demographic or anthropometric variations in the thermophysiological condition of people during transient outdoor activity. Therefore, they developed wearable sensors to record individual microclimate (temperature, humidity, wind speed and radiation) and physiological states (skin temperature, heart rate). Park et al. (2009) use heart rate variability (HRV), blood pressure, and pulse rate as physiological indices in their study on recreation in the Conifer Forest in Hinokage Town, Japan. Data from 12 male students clearly show that positive emotions are higher in the forest, compared to the city and pulse rate and diastolic blood pressure were significant lower in the forest area.

Despite many individual studies a clear quantification of cause-effect relationships of health effects from forest visits is still missing so far. Thus, the main objective of our study is to explore the quantification of health effects of forest recreation. As our explorative study cannot present final results we aim to stimulate further detailed research.

Moreover, we aim to address the following research questions:

- How can the effects of varying urban environments on climatic/bioclimatic conditions and human physiology be quantified through the use of sensor technologies?
- And is it feasible to use machine learning to model the relations between type of urban environment and human well-being?

To this end we perform measurement campaigns for the combined simultaneous recording of relevant features along routes comprising varying urban structural types (ranging from built up to densely forested areas). Combining data on subjective well-being and objective data on human physiology can help to quantify health effects of varying environments, including urban forests.

Thus, the study follows a holistic approach in contrast to previous studies on thermal comfort and thermal physiology, which often focus on meteorological variables and derived indices representing objective thermal conditions (Epstein and Moran, 2006). The physiological equivalent temperature (PET), as a frequently applied human-biometeorological index, measures the thermal comfort based on the energy balance of the human being (Mayer and Höppe, 1987). However, the way urban citizens experience thermal comfort depends on a complex interweaving of cultural, behavioral, physical and psychological factors (Yang et al., 2013).

To date, many studies focus on environmental psychology while cause-effect relations of biophysical benefits in forests are still poorly understood as large-scale studies with reliable data are lacking. Thus, our explorative study contributes to a holistic understanding of human-environment connections. We bridge environmental data with surveys to cover different models of wellbeing. Therefore, we recorded data via a wide range of sensors such as professional and low cost temperature and humidity sensors, gas and dust sensors, audio recording and physiological data acquiring heart rate and skin conductance, as well as synchronized self-assessment regarding environment related wellbeing. Additionally, surveys where applied to countercheck objective recordings. Finally, machine learning has been applied in order to examine our data for complex interactions between environment classes and physiology.

2. Study area

The study area is the urban forest of Augsburg, in the German Federal State of Bavaria, Southern Germany. The urban forest area amounts to approximately 2.000 ha and it is within the boundaries of the city of Augsburg (> 292.000 inhabitants (2017) (City of Augsburg, 2019; LfStat, 2017).

The urban forest is situated on an alluvial floodplain. Compared to potential natural vegetation the forest tree composition is altered by historical deforestations and embankments for flood protection led to 30 % spruce trees (Picea abies spp.) modifying the original riparian tree species composition, showing a mixture of forest types with several rare orchids growing on pine-heath and open forest structures, which are crossed by many canals and framed on the eastern side by the river Lech. Forest management aims at mixed, structured and uneven-aged forests with selective harvesting. Forest roads sum to 220 km (~110 m ha^{-1}) in the urban forest area, which is an old nature conservation area and for most of its parts a drinking water protection area (Meyer et al., 2019).

The long-term (1981–2010) mean annual air temperature in Augsburg is 8.5 °C, the warmest month is July (18.1 °C), the coldest month is January (-0.8 °C), the mean annual rainfall is 767 mm (DWD - Deutscher Wetterdienst, 2018a). The main wind direction is southwest and the mean wind speed is 2.9 m/s (DWD - Deutscher Wetterdienst, 2018b). The local scale study area of the analyses presented in this contribution considers different local climate zones (Stewart and Oke, 2012) determined for the Augsburg urban area (Beck et al., 2018) including the categories “Open Mid Rise”, “Scattered Trees” and “Dense Trees” (Fig. 1). The study area thus allows for the investigation of differences and transitions between the varying structural types with

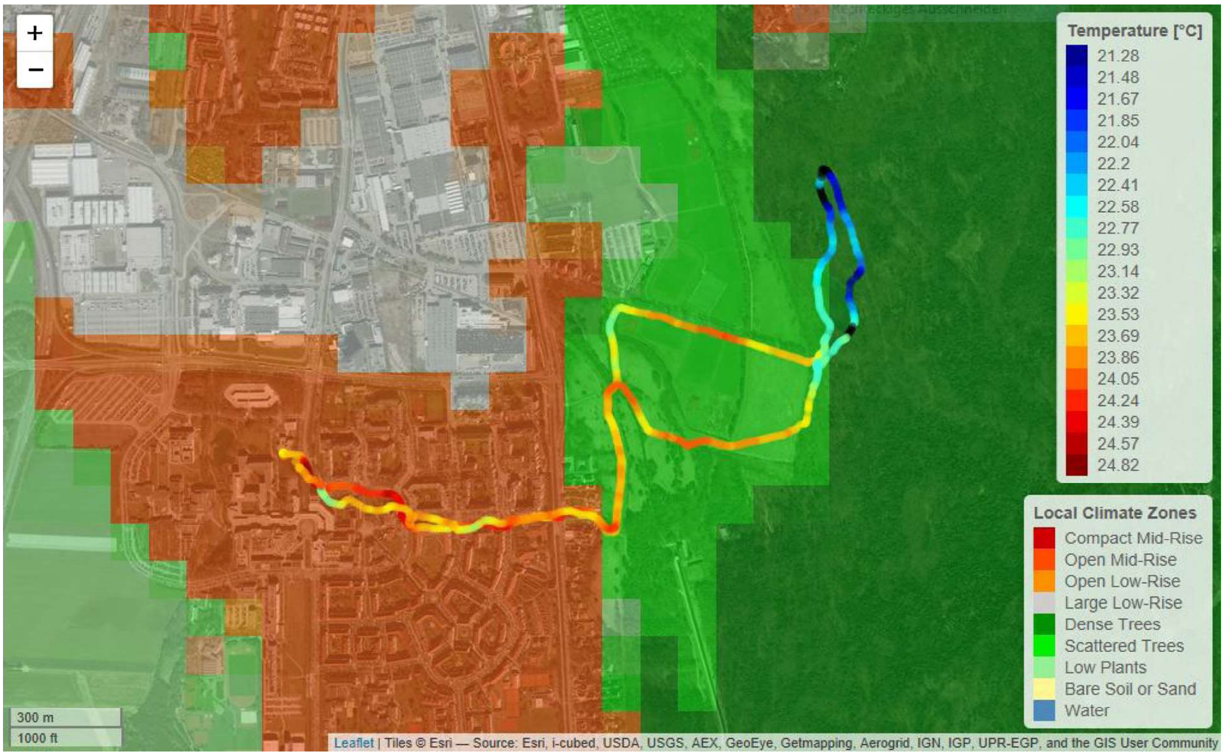


Fig. 1. Map of the study area. Indicated are the distribution of local climate zones and the track of fixed measurement routes. Colors of the measurement track indicate measured air temperatures for one selected measurement campaign (09/06/2017, 12:21-13:42 UTC + 2).

respect to bioclimate, human physiology and subjective well-being.

3. Methods

We carried out measurement campaigns along fixed approx. 5 km long routes (Fig. 1), recording the climatic conditions, the human physiology and the subjective wellbeing simultaneously. The measurement campaigns in the present study are designed to consider variations in the thermoregulatory response of subjects under transient thermophysiological state (walking), in different outdoor conditions. Eleven male and ten female students participated in the study. Insights on physiology relies on 20 recordings during summer, while another 20 where conducted during winter, without showing any significant seasonal differences.

Ambient air temperature and derived humidity metrics have been recorded utilizing a digital aspiration psychrometer ALMEMO FNAD 46 from Ahlborn (Ahlborn, 2018a) and a data logger ALMEMO 2590A (Ahlborn, 2018b). According to the manufacturer the accuracy of the temperature sensor is ± 0.2 K at 0–60 °C and the accuracy of the derived relative humidity (RH) is ± 1 % at + 25 °C ± 3 K, 1013 mbar and 50 % RH.

The sensor has been mounted on a wearable unit allowing measurements at approximately 1.8–2.1 m above ground, thereby avoiding thermal or hygric disturbances from the carrying person. Measurements have been logged every two seconds and have been merged with simultaneously recorded GPS coordinates.

Mobile human physiology measurements were conducted using Microsoft Band 2 wrist bands. The Heart Rate (HR) was sampled at 1 Hz, the Inter-Beat-Interval (IBI) and Galvanic Skin Conductance at 5 Hz. Recording was done synchronized to GPS and a range of environment-sensors, capturing amongst others temperature and humidity.

Next to logging sensors, participants were asked to assess their wellbeing regularly, to lay foundation for a model of subjective wellbeing generated using supervised machine learning.

Logging was done on a smartphone (Samsung Galaxy S3). The overall setup explores sensors that can be used in an every-day setting using consumer grade hardware. such as a Microsoft Band 2. It served as optical sensor for Blood Volume Pressure (BVP) from which Heart Rate (HR) and Inter Beat Interval (IBI) were recorded.

Subjective wellbeing was logged synchronized to sensor data, mentioned in the previous paragraph. Therefore, a smartphone and smartwatch interface was developed using web-technologies (Tizen Web-App on the smartwatch, Samsung Gear S2 and a website hosted on the smartphone). The input of user-assessments via the webbased interfaces was sent to the program during? the synchronized sensor signal recording. The annotations consist of a 5-point scale on valence (Is the moment good / bad?), and 9-point scales for temperature (are you feeling hot / cold?) and air-quality (is the air-quality good / bad?). Participants were asked to annotate every time their sensation changed. This resulted in an average of 75 annotations per recorded session. Based on the HR and IBI, that reflect the body's load, we infer on the Local Climate Zone the data were recorded in. Via GPS the recording area is assigned to the data as label, which is used as ground truth for the learning algorithm. The employed algorithm, a Support Vector Machine (SVM), searches a possibility to separate the data with different labels into according classes. To evaluate the achieved quality, data are divided into training and validation set.

4. Results

From the numerous measurement campaigns that have been performed variations in climatic and physiological parameters and subjective wellbeing depending on varying surface types can be determined In more detail, our preliminary results substantiate clear cut and statistically significant climatic differences among varying urban environments (i.e. local climate zone categories) and show the potential positive effects of urban forests/urban green on bioclimatic conditions (e.g. via a reduction in maximum air temperatures during summer). Moreover, the beneficial effects of urban green structures on human physiological parameters (e.g. reductions in heart rate) could be

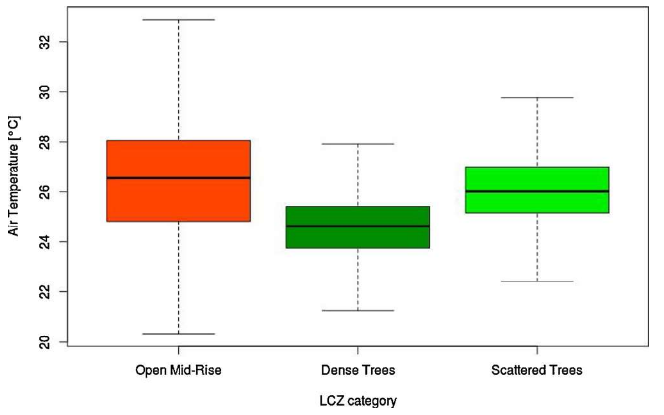


Fig. 2. Boxplots of air temperatures (°C) linked to local climate zones Open Mid Rise, Dense Trees and Scattered Trees respectively. Boxplots include data from 22 measurement campaigns that have been performed during summer (June, July, August) 2017, between noon and 3 pm, along the route displayed in Fig. 1, under synoptic boundary conditions characterized by wind speed / cloud cover not exceeding 4 m/s / 4 octas.

verified.

Distinct air temperature variations along the measurement routes could be documented (Fig. 1) and the statistical significance of the effects of surface type characteristics on air temperatures could be verified via non-parametric Kruskal-Wallis tests (Kruskal and Wallis, 1952) and pairwise Wilcoxon tests (e.g. Crichtlow and Fligner, 1991). From Fig. 2 most clear cut differences in air temperatures become apparent between built up (local climate zone “Open Mid Rise”) and densely forested (local climate zone “Dense Trees”) areas. In general, these differences are most pronounced during calm and clear synoptic conditions. However, distinct differences also appear when considering rather “disturbed” weather situations (see Fig. 2, including synoptic situations with wind speeds up to 4 m/s and cloud cover up to 4 octas), thus supporting respective findings reported elsewhere (Beck et al., 2018; Straub et al., 2019).

Boxplots include the median, the 1 st and 3rd quartile; whiskers indicate the highest/lowest value inside the interval defined by ± the 1.5-fold interquartile range. A Kruskal-Wallis test and pairwise Wilcoxon tests reveal statistical significance (alpha = 0.01) of the grouping according to local climate zones and moreover statistical significant differences between all pairwise combinations of local climate zone categories.

Less clear effects could be determined with respect to physiological parameters, using an aggregation of all recordings (bottom) (Fig. 3).

However, a tendency towards more comfortable conditions in natural surroundings and in particular in forested environments can be deduced (Fig. 3). Indicators are a slightly lower heart rate in the forest and consequently a higher inter-beat-interval.

Since an environment's influence on wellbeing could be a valuable information for mobile applications to suggest routes for restress reduction or recreation, we design our machine learning models in a way, they could be used for classification in real-time.

To evaluate the data regarding their use within a mobile health application, we use a Support Vector Machine (SVM) model for online prediction (Bennett and Demiriz, 1999). A sliding window of 10 s with 240 s of overlap is used to classify the environment class based on heart rate and inter-beat-interval with the help of a range of overall 22 statistical features combined with 64 features based on Galvanic Skin Response (GSR) Table 1.

With an overall accuracy of 88.33 % classes “Scattered Trees”, “Open Mid Rise” and “Dense Trees” can be classified well, The overall results can be achieved fusing GSR and BVP, where as the individual modalities score 14 (GSR) and 36 (HR/IBI) percent points lower.

The model’s evaluation suggests that the individual local climate zones have strong and characteristic influence on our physiology which canbe measured with an off-the-shelf wearable and that the impact can in turn be used as context information in a mobile application.

5. Summary

Urban forests as visible landscapes affect human beings in many ways, including recreation, aesthetic appreciation and health effects. The present study shows the bioclimatic conditions within the urban forest of Augsburg in SE-Germany and links these to human wellbeing, based on interviews on subjective wellbeing and on measurements of heart rate. Additionally, machine learning was applied in order to tackle the complex relationships between environment and affect and to make this context information more accessible for future applications and forest management strategies.

When it comes to detecting environment-classes by their influence on a human’s physiology, “Dense Trees” is well distinguishable from other local climate zone categories “Scattered Trees” and “Open Mid Rise”. The difference between classes “Open Mid Rise” and “Scattered Trees” are not discriminable well, in contrast. A look at the aggregated, underlying data (HR and IBI) makes this seem plausible.

Against the background of the detected differences among environment-classes – local climate zones – with respect to climatic, physiological and subjective parameters, it appears to be feasible to strive for an extension of the local climate zones concept towards a concept of “local wellbeing zones”.

Based on environment-classification and user ratings a model predicting an environment-classes influence on a user’s wellbeing can be developed in future.

Thus, we focus on the one hand sensing for malicious influences in everyday-routines, on the other hand for routing applications avoiding spots of personal dislike.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

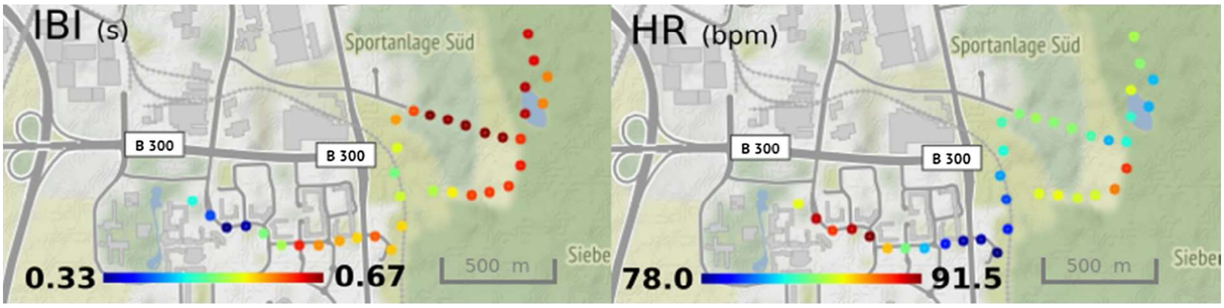


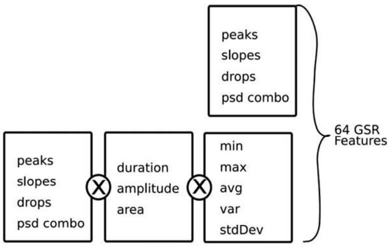
Fig. 3. Aggregated data of all recording-sessions. IBI (left) and HR (right) in 36 points.

Table 1

Classification Accuracy and evaluation of a SVM-model for three Local Climate Zones (bottom) based on statistical features on IBI and HR (left) and GSR-Features (right), 86 features in total. HR/IBI-Features are sorted according to their rank within the Sequential Feature Selection. The model is evaluated on 480 samples using ten-fold crossvalidation.

rank	feature	score	rank	feature	score
1	IBI_MAXPOS	0.40	12	HR_ZEROS	0.50
2	HR_MAXPOS	0.43	13	IBI_PEAKS	0.50
3	IBI_MIN	0.43	14	IBI_MINPOS	0.49
4	IBI_STD	0.43	15	HR_STD	0.41
5	HR_PEAKS	0.43	16	HR_RANGE	0.35
6	IBI_ZEROS	0.43	17	IBI_LEN	0.34
7	IBI_MAX	0.42	18	HR_LEN	0.34
8	IBI_ENERGY	0.45	19	HR_MEAN	0.33
9	HR_MINPOS	0.50	20	HR_ENERGY	0.33
10	IBI_MEAN	0.48	21	HR_MAX	0.34
11	IBI_RANGE	0.50	22	HR_MIN	0.31

22 HR/IBI Features ranked using SFS



Environment Fusion (SVM)

	dense trees	scattered trees	open midrise	Acc. %
dense trees:	129	10	21	80.62 %
scattered trees:	9	148	3	92.50 %
open midrise:	9	4	147	91.88 %
Average				**88.33 %**

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ufug.2020.126622.

References

AHLBORN, 2018a. Technical Data - Hand-held Digital Psychrometer FNAD 46. https://www.ahlborn.com/download/pdfs/kap08/eng/psychroe.pdf.

AHLBORN, 2018b. Technical Data – ALMEMO 2590A Series. https://www.ahlborn.com/download/pdfs/kap01/eng/2590Ae.pdf.

Beck, C., Straub, A., Breitner, S., Cyrys, J., Philipp, A., Rathmann, J., Schneider, A., Wolf, K., Jacobeit, J., 2018. Air temperature characteristics of Local Climate Zones in the Augsburg urban area (Bavaria, Southern Germany) under varying synoptic conditions. Urban Clim. 25, 152–166.

Bennett, P., Demiriz, A., 1999. Semi-supervised support vector machines. Adv. Neural Inf. Process. Syst. 11, 368–374.

City of Augsburg, 2019. Stadtwald Augsburg – Erholung rund um Lech und Wertach. Accessed June 25th 2019. http://www.augsburg.de/freizeit/ausflugsziele/stadtwald/.

Colfer, C.J.P., 2008. Human Health and Forests: Global Overview of Issues, Practice and Policy. Earthscan, London, UK.

Cornet, V.P., Holden, R.J., 2017. Systematic review of smartphone-based passive sensing for health and wellbeing. J. Biomed. Inform. 77, 120–132.

Crichtlow, D.E., Fligner, M.A., 1991. On distribution-free multiple comparisons in the one-way analysis of variance. Commun. Stat.— Theory Methods 20, 127–139.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., et al., 2014. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manage. 146, 107–115.

Donovan, G.H., 2017. Including public-health benefits of trees in urban-forestry decision making. Urban For. Urban Green. 22, 120–123.

DWD - Deutscher Wetterdienst, 2018a. Long-term (1981–2010) Averages of Temperature and Precipitation for Augsburg-Mühlhausen. Accessed date: 9 January 2018. http://www.dwd.de.

Deutscher Wetterdienst, D.W.D.-, 2018b. Monthly Mean Values of Wind Speed and Wind Direction for Augsburg-Mühlhausen. http://www.dwd.de, Accessed date: 9 January 2018. .

Emmanuel, R., Loconsole, A., 2015. Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK. Landsc. Urban Plan. 138, 71–86.

Epstein, Y., Moran, D.S., 2006. Thermal comfort and heat stress indices. Indust. Health 44, 388–398.

Hansen, M.M., Jones, R., Tocchini, K., 2017. Shinrin-Yoku (Forest bathing) and nature therapy: a state-of-the-Art review. Int. J. Environ. Res. Public Health 14 (8), 851.

Hartig, T., Evans, G.W., Jamner, L.D., Davis, D.S., Gärling, T., 2003. Tracking restoration in natural and urban field settings. J. Environ. Psychol. 23, 109–123.

Hunter, M.C.R., Gillespie, B.W., Yu-Pu Chen, S., 2019. Urban nature experiences reduce stress in the context of daily life based on salivary biomarkers. Front. Psychol. https://doi.org/10.3389/fpsyg.2019.00722.

Hutchins, E., 1995. Cognition in the Wild. MIT Press, Cambridge, MA.

Kruskal, W.H., Wallis, W.A., 1952. Use of ranks in one-criterion variance analysis. J. Am. Stat. Assoc. 47, 583–621.

LfStat, 2017. Bevölkerung: Kreise, Geschlecht. Nationalität, Stichtag (12411-005r). https://www.statistikdaten.bayern.de/genesis/online?language=de&sequenz=Tabelle Ergebnis&selectionname=12411-005r. Accessed 25 June 2019.

Mayer, H., Höppe, P., 1987. Thermal comfort of man in different urban environments. Theor. Appl. Climatol. 38, 43–49.

McCarthy, M.P., Best, M.J., Betts, R.A., 2010. Climate change in cities due to global warming and urban effects. Geophys. Res. Lett. 37, L09705. https://doi.org/10.1029/2010GL042845. 2010.

Meyer, M., Rathmann, J., Schulz, C., 2019. Spatially-explicit mapping of forest benefits and analysis of motivations for everyday-life's visitors on forest pathways in urban and rural contexts. Landsc. Urban Plan. 185, 83–95.

Nakayoshi, M., Kanda, M., Shi, R., de Dear, R., 2015. Outdoor thermal physiology along human pathways: a study using a wearable measurement system. Int. J. Biometeorol. 59 (5), 503–515.

Oke, T.R., 1967. City size and the urban heat island. Atmos. Environ. 7, 769–779.

Park, B.J., Tsunetsugu, Y., Kasetani, T., Hirano, H., Kagawa, T., Sato, M., Park, B.J., Tsunetsugu, Y., Ishii, H., Furuhashi, S., Hirano, H., Kagawa, T., Miyazaki, Y., 2008. Physiological effects of Shinrin-yoku (taking in the atmosphere of the forest) in a mixed forest in Shinano Town, Japan. Scand. J. For. Res. 23, 278–283.

Park, B.J., Tsunetsugu, Y., Kasetani, T., Morikawa, T., Kagawa, T., Miyazaki, Y., 2009. Physiological effects of forest recreation in a young conifer forest in Hinokage Town, Japan. Silva Fennica 43 (2), 291–301.

Rathmann, J., Brumann, S., 2017. Therapeutische landschaften in der psychoonkologie. Gaia 26/3, 254–258.

Rogers, Y., 2011. Interaction design gone wild: striving for wild theory. Interactions 18 (4), 58–62.

Rogers, Y., 2012. HCI theory: classical, modern, and contemporary. Synth. Lect. Hum. Inform. 5 (2), 1–129.

Sandifer, P.A., Sutton-Grier, A.E., Ward, B.P., 2015. Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: opportunities to enhance health and biodiversity conservation. Ecosyst. Serv. 12, 1–15.

Song, C., Ikei, H., Kobayashi, M., Miura, T., Taue, M., Kagawa, T., Li, Q., Kumeda, S., Imai, M., Miyazaki, Y., 2015. Effect of forest walking on autonomic nervous system activity in middle-aged hypertensive individuals: a pilot study. Int. J. Environ. Res. Public Health 12 (3), 2687–2699.

Song, C., Ikei, H., Miyazaki, Y., 2016. Physiological effects of nature therapy: a review of the research in Japan. Int. J. Environ. Res. Public Health 13 (8), 781.

Stewart, I.D., Oke, T.R., 2012. Local climate zones for urban temperature studies. Bull. Am. Meteorol. Soc. 93, 1879–1900.

Stigsdotter, U.K., Corazon, S.S., Sidenius, U., Refshauge, A.D., Grahn, P., 2017. Forest design for mental health promotion—using perceived sensory dimensions to elicit restorative responses. Landsc. Urban Plan. 160, 1–15.

Straub, A., Berger, K., Breitner, S., Cyrys, J., Geruschkat, U., Jacobeit, J., Kühlbach, B., Kusch, T., Philipp, A., Schneider, A., Umminger, R., Wolf, K., Beck, C., 2019. Statistical modelling of spatial patterns of the urban heat island intensity in the urban environment of Augsburg, Germany. Urban Clim. 29. https://doi.org/10.1016/j.uclim.2019.100491.

Tsunetsugu, Y., Park, B.J., Ishii, H., Hirano, H., Kagawa, T., Miyazaki, Y., 2007. Physiological effects of Shinrin-yoku (taking in the atmosphere of the forest) in an old-growth broadleaf forest in Yamagata prefecture, Japan. J. Physiol. Anthropol. 26 (2), 135–142.

Tyrvainen, L., Ojala, A., Korpela, K., Lanki, T., Tsunetsugu, Y., Kagawa, T., 2014. The influence of urban green environments on stress relief measures: a field experiment. J. Environ. Psychol. 38, 1–9.

Ulrich, R.S., Simons, R.F., Losito, B.D., Fiorito, E., Miles, M.A., Zelson, M., 1991. Stress recovery during exposure to natural and urban environments. J. Environ. Psychol. 11, 201–230.

UNPD, 2014. World Urbanization Prospects 2014: The 2014 Revision. New York: United Nations Population 512 Division.

van den Berg, A.E., Maas, J., Verheij, R.A., Groenewegen, P.P., 2010. Green space as a buffer between stressful life events and health. Soc. Sci. Med. 70, 1203–1210.

Yang, W., Wong, N.H., Jusuf, S.K., 2013. Thermal comfort in outdoor urban spaces in Singapore. Build. Environ. 59, 426–435.