METEOROLOGICAL APPLICATIONS
*Meteorol. Appl.* **14**: 61–67 (2007)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/met.6

# Weather and cycling – a first approach to the effects of weather conditions on cycling

Christiane Brandenburg,[1]* Andreas Matzarakis[2] and Arne Arnberger[1]
[1] *Institute for Landscape Development, Recreation and Environmental Planning, Department of Spatial, Landscape and Infrastructure Sciences, University of Natural Resources and Applied Life Sciences, Peter Jordan Str. 82, 1190 Vienna, Austria*
[2] *Meteorological Institute, University of Freiburg, Werderring 10, 79085 Freiburg, Germany*

**ABSTRACT:** In urban and suburban recreation areas, walking and cycling constitute an important part of leisure activities. Both activities involving motion, are not only carried out for recreation but also for commuting to and from work. The mixture of recreation and commuting cycling is a challenge for park management. Conflicts between user groups, such as walkers and cyclists, exist due to the different movement speeds and also different user profiles: walkers, leisure cyclists and cyclists who commute have distinctive degrees of acceptance towards other user groups. Another challenge for park management is the damage caused by the bicycles. There is damage to the surface of gravel trails due to the frequency of use and there is damage to the vegetation next to the trails as a result of evasive manoeuvres by the cyclists. Paved trails are preferred by cyclists as this results in increased speed.

Important issues associated with park management are: degradation of the soil surface in general, and trails in particular, as well as conflicts between different recreational users, such as walkers and cyclists caused by their different user profiles including different speeds and acceptance of social carrying capacities.

To shed some light on bicycling activities in Vienna, an analysis of the pattern of the temporal use of daily frequency of recreational and commuting cyclists was carried out, taking weather conditions into consideration. The results show that, principally, cycling is an activity performed during fine weather. This is especially the case for recreational use. Fine weather is interpreted as generally sunny weather with an ambient temperature of more than 5 °C, few clouds and no precipitation for a period of 1 year. In this study, the temperature, precipitation and cloud cover, as well as the thermal index 'physiologically equivalent temperature' (PET), were used as parameters to describe more precisely the dependence of both cyclist groups on the local weather conditions. 

KEY WORDS bioclimate; physiologically equivalent temperature; cycling; recreation; commuting; recreation area management; visitor monitoring

*Received 6 January 2006; Revised 12 December 2006; Accepted 12 December 2006*

## 1. Introduction

Landscape-related leisure-time activities are manifold and have a major influence on fragile ecosystems and rural landscapes. In urban and suburban recreation areas, walking and cycling represent a major leisure activity (Gobster, 1991; Arnberger and Brandenburg, 2002). However, cycling and walking not only play a role in leisure-time activities in recreational areas, they are also means of commuting. High frequencies and the spatial and temporal distribution of these activities lead to conflicts with environmental protection on the one hand, and between the individual user groups on the other. These conflicts have resulted in an increase in the demand for visitor management measures in an increasing number of areas (Lindsey, 1999; Cessford, 2002; Arnberger, 2003).

This study describes the different effects of varying weather conditions on recreational and commuting cycling in an area of Vienna. Variations in the effects of weather on cycling patterns can be empirically related to different user characteristics in order to allow a better understanding of the determinants of the day-to-day variations in bicycle usage in the study area.

As Auer *et al*. (1990) noted, the dependence of the human senses on weather and climate was discovered a long time ago (e.g. Büttner, 1938). However, the question of how weather affects leisure and recreational activities has received little attention within the framework of meteorological and climate studies. Emphasis has always been on thermal comfort (Becker, 1972; Hammer *et al*., 1986; Jendritzky *et al*., 1990). Nevertheless, numerous studies exist on large-scale climatic evaluations of the interrelation between climate and travel decisions (Harlfinger, 1985) and on recreation from a health, or purely medical, point of view (Licht, 1964; Becker, 1972; Harlfinger, 1978; Bullrich, 1981; Rotton *et al*., 1990; Trenkle, 1992; Matzarakis and de Freitas, 2001).

* Correspondence to: Christiane Brandenburg, Institute for Landscape Development, Recreation and Environmental Planning, Department of Spatial, Landscape and Infrastructure Sciences, University of Natural Resources and Applied Life Sciences, Peter Jordan Str. 82, 1190 Vienna, Austria. E-mail: christiane.brandenburg@boku.ac.at

Published studies dealing with local weather conditions and the circumstances of recreational activities have so far been closely related to research on thermal comfort (Gerth, 1986, 1987; Hammer *et al*., 1986; Höppe and Mayer, 1987; Auer *et al*., 1990; Jendritzky *et al*., 1990; Höppe, 1999). The explicit relationship between weather and visitor frequencies, as well as the identification of a climate threshold for specific types of recreational activities, has attracted little attention from the scientific community. McCalla *et al*. (1987) made the assumption that the relationship between leisure-time activity and weather could be defined by threshold values for cold and warm periods. The threshold values are either relative or defined in accordance with the season and the respective local weather. According to McCalla *et al*. (1987) a close relationship exists between recreational activity and air temperature.

Considering that several causal relations between weather and human behaviour remain unknown, some studies have used stochastic models to quantify the relations (Taubenheim, 1969, cited in Bucher, 1993). According to the individual studies or problems, various meteorological parameters, i.e. air temperature or air humidity, or the synergetic effect of meteorological parameters, have been included in the models (Bucher, 1993).

In the following sections, the relationship between current local weather conditions and the behaviour of those using their bicycles for recreation or to commute will be investigated. The main focus will be on using the methods of human energy balance to investigate the extent to which leisure-time cyclists and commuting cyclists differ with regard to their dependence on weather conditions. The methods of visitor registration, human-biometeorological evaluation, as well as the amalgamation of the respective results, will be introduced. The results will be discussed taking into account the correlation between the evaluated current weather conditions and observed visitor frequencies.

## 2. Study area and study period

Data were collected in a suburban recreation area called the 'Wienerberg' in the south of Vienna, the capital of Austria (Figure 1). The park is managed by the municipal forest department. Forested patches dominate the 120 hectares of the park. The recreation area, Wienerberg, provides about 14 km of gravel trails and a great number of paths, but only two trails are open for cycling.

The park, established in the late 1980s, is surrounded by residential and commercial areas, a hospital and garden allotments. The park management has observed constantly increasing levels of recreational use, primarily due to recent housing developments in the surrounding area. Additional residential high-rise buildings are currently under construction, and will further increase the pressure on the park due to recreation and commuting.

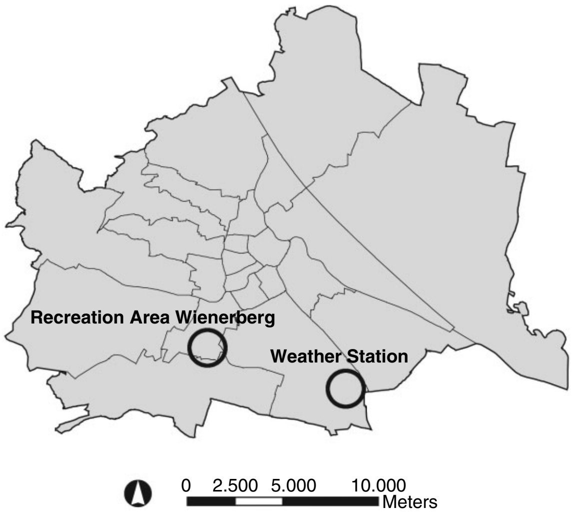


Figure 1. Map of Vienna, location of the investigation area and the weather station.

From the meteorological viewpoint, the weather conditions in 2002, the year of the study, were typical of the last 20 years.

## 3. Methods

The motivation for cyclists visiting the recreation area was identified using on-site interviews at the main access points. In the investigation area, visitors were intercepted at access points along the main trail section between April and October 2002. The interviews took place on five randomly selected working days and five randomly selected Sundays between 0800 and 1900 CET (0700 and 1800 UTC). For the estimation of the total annual number of visitors and user types to the forests, the results of long-term permanent video monitoring at selected sites and temporally selective counting by human observers were combined.

Hidden observations with a video recording system were used to identify working day and weekend cycling patterns. These data were used to classify recreation and commuting cyclists. A permanent time-lapse video recording system was installed at the access points to the Wienerberg recreation area from January 2002 to December 2002 to monitor recreational activities between dawn and dusk (Leatherberry and Lime, 1981; Brandenburg, 2001; Arnberger, 2003). (The type of video system installed made it impossible to identify individual persons, thus guaranteeing anonymity.) The following data were assembled when analysing the video tapes: date, day of the week, time, video station, number of persons in a group, direction of movement, the type of user group (for example, cyclists, walkers, joggers). The meteorological data: air temperature, precipitation, sunshine and humidity were obtained from a nearby meteorological station of the Austrian Central Institute for Meteorology and Geodynamics, located six km to the southeast of the study area. The available data cover the above mentioned time frame of the research period.



DOI: 10.1002/met

The observed visitor monitoring data were analysed using an objective human-biometeorological evaluation methodology. Not only elementary meteorological parameters, such as air temperature and precipitation, were taken into account, but also the physiologically equivalent temperature (PET), which incorporates both meteorological and thermo-physiological parameters (VDI, 1998; Höppe, 1999; Matzarakis *et al*., 1999). The values of the thermal index were calculated using the radiation and the bioclimate model 'RayMan' (Matzarakis *et al*., 2000). The input values for the RayMan model are air temperature (°C), vapour pressure (hPa), wind speed ($ms^{-1}$), and cloud cover (in octas) or global radiation ($Wm^{-2}$), clothing insulation (clo) and physical activity. In accordance with VDI (1998), the thermo-physiological parameters are set up for typical clothing (0.9 clo) and light activity (80 $Wm^{-2}$).

The concept of the quantification of the thermal environment by the physiologically equivalent temperature works as follows. In order to consider the thermal environment of humans in an appropriate way, it is necessary to use evaluation methods that deal with the atmospheric environment as a whole and not with single meteorological parameters, and which have thermo-physiological importance.

In order to substantiate the obtained results statistically, simple and multiple linear regression models were used (Table II). Attention was paid to the interaction between recreational and commuting cyclists and weather conditions. The activities of all cyclists, recreational cyclists (Rcbikers) and commuting cyclists (Wbikers) were correlated with the meteorological parameters and human-biometeorological factors.

An univariate analysis of variance was used to investigate the weather-dependence of commuting and recreational cyclists. Using the meteorological parameter 'precipitation' and the thermal index, the influence of weather conditions is included in the regression model as independent variables. A classification of two precipitation categories – with and without precipitation – is used in this analysis. A day with precipitation is defined, in accordance with Wakonigg (1981) and Harrison *et al*. (1999), as any day with at least 1 mm of rainfall. Lower levels of precipitation (less than 1 mm per day) are noticed by the visitors, but are not seen as having a major influence on the decision-making process regarding recreational activity. It is intended to include the duration and intensity of precipitation in future analyses.

The categorization of the PET is carried out according to the evaluation steps of Matzarakis and Mayer (1996). Table I gives the ranges of the PET for different levels of thermal perception.

## 4. Results

In the following sections, the results obtained will be introduced and discussed. Only those results of visitor questioning and video monitoring which are of relevance to the discussion will be dealt with.

Table I. Levels of physiologically equivalent temperature (PET) in °C for different levels of thermal perception by human beings according to Matzarakis and Mayer (1996).

| PET | Thermal perception |
|---|---|
| <4 | Very cold |
| 4–8 | Cold |
| 8–13 | Cool |
| 13–18 | Slightly cool |
| 18–23 | Comfortable |
| 23–29 | Slightly warm |
| 29–35 | Warm |
| 35–41 | Hot |
| >41 | Very hot |

### 4.1. Interviews

Eight hundred and ninety completed questionnaires obtained in the Wienerberg recreational area were evaluated. Among the reasons given for visiting the area were: recreation, walking the dog, sport, as well as going to work and to school.

### 4.2. Video monitoring

Visitor counting resulted in an annual use estimate of around 1.24 million visits. Remarkable differences were observed, depending on the day of the week. Averages of 4300 daily visits on weekends and about 3000 on workdays were recorded. Video interpreters identified four main activity types: walkers, cyclists, dog walkers and joggers. A total of 55 824 cyclists were registered: 34 938 on workdays and 20 886 on weekends.

### 4.3. Categorization of cyclists

One first analysing step in this study is the identification and categorization of recreational and commuting cyclists. The results of the on-site interviews show that one of the cyclist's reasons for visiting the recreation area is commuting (Arnberger, 2003). A classification of both types of cyclists, those cycling for recreation and for commuting, was carried out, distinguishing between workday and weekend cycling patterns. A distinct peak in the mornings on workdays, as opposed to weekends, is apparent (Figure 2). Therefore, the 4896 cyclists monitored during the time between 0700 and 0900 CET on workdays were classified as commuting cyclists, and the 30 579 cyclists monitored after 0900 CET on workdays as recreational cyclists.

The relationship between the time of day and the number of cyclists is the same in summer and winter and is not shown in the diagram. The number of commuting cyclists in summer is not as high as the number of commuting cyclists in winter. This is an effect of the school holidays and also general to vacation time.



DOI: 10.1002/met

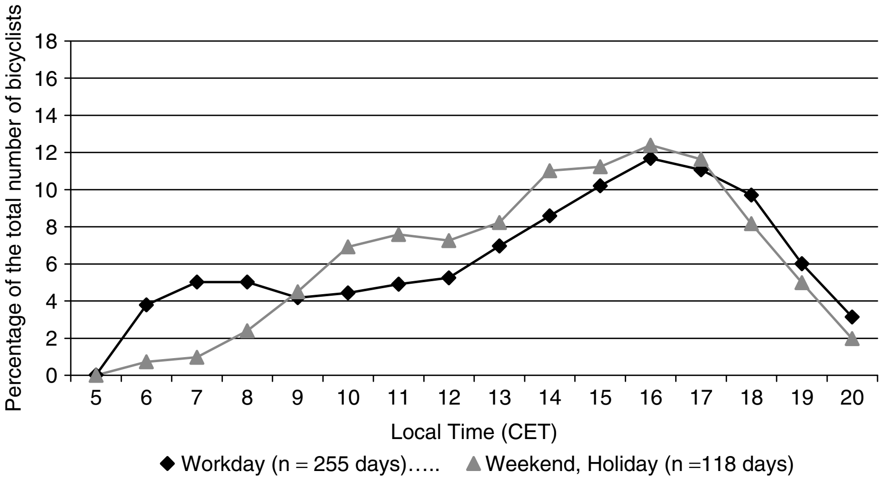


Figure 2. Daily patterns of cyclists in the recreation area differentiated by workdays and weekend (total number of cyclists 55 824).

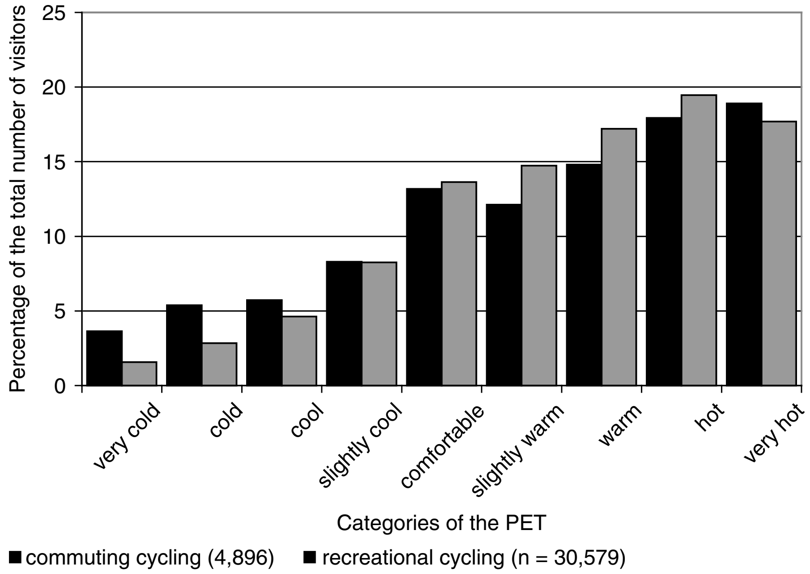


Figure 3. Relationship between the PET and two types of cyclists (only workdays are considered).

## 4.4. The dependence of cyclists on the weather

Analysing only workdays during the survey period, Figure 3 shows the relationship between the thermal index PET, precipitation and the total number of cyclists. It reveals the strong dependence of both recreational and commuting cyclists on the weather. Frequencies of both types are high during fine weather conditions: the PET categories of comfortable and warmer (above 23 °C according to Table I). However, it is apparent that in cooler weather – the PET categories of slightly cool to very cool – commuting by cycle occurs more often than recreational cycling. The differences in the warmer weather period can be traced back to other external influences, such as school and public holidays.

Analyses of the differences in the influence of precipitation on the behaviour of the two cyclist categories show that about 10% more commuting cyclists than recreational cyclists are on the move during rainfall (shown in Figure 4).

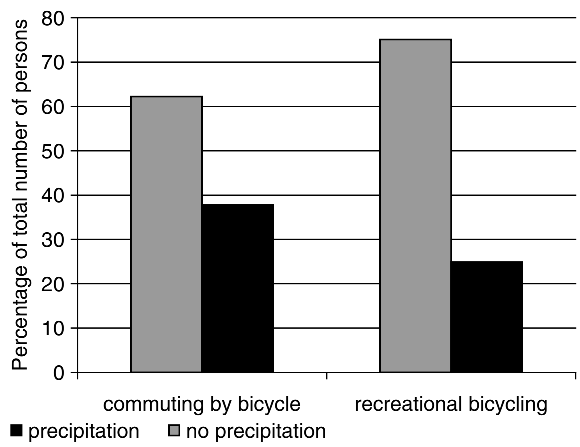


Figure 4. Relationship between precipitation and the number of commuting and recreational cyclists (n = 30, 579) (only workdays are considered).

### 4.5. Annual patterns of cyclists and dependence on weather

In this stage, the daily number of cyclists and the precipitation, as well as the thermal index, PET, is interpreted to provide a more precise determination of the relationship between the weather and cyclists. A direct relationship can be identified between the visitor frequencies and the meteorological and human-biometeorological factors.

Figure 5 shows the annual pattern of recreational cyclists in the Wienerberg area with the corresponding PET and precipitation values. The number of recreational cyclists has been multiplied by two to increase clarity, and it demonstrates that there is a close relationship between the number of recreational cyclists, the existing PET values (calculated for 1400 CET) and the total amount of daily precipitation. The curves for the PET and recreational cyclists follow the same trend; a difference can only be observed for the last days of the year (around Christmas).

A somewhat different picture is observed for the commuting cyclists. Figure 5 shows that activities of commuting cyclists are obviously less affected by weather. In general, thermal conditions tend to be more important than rainfall for the commuters' decision making. At the end of July, the annual courses of commuting cyclists and the meteorological conditions are not correlated. This is possibly on account of the summer school holiday period, which is not classified as a typical public holiday and is therefore included in the sample.

In order to substantiate the obtained results statistically (as well as the evidence from Figure 5 mentioned earlier), the results were investigated using simple and multiple linear regression models (Table II). Attention was paid to the interaction between recreational and commuting cyclists and the weather conditions. The activities of all cyclists (Rcbikers) and commuting cyclists (Wbikers) are correlated with the meteorological parameters and human-biometeorological factors.

### 4.6. Quantification of the dependence of cycling on weather

For a more precise determination of the relationship between the weather and cycling, the number of cyclists is correlated with the air temperature and precipitation as well as the PET. A direct relationship can be identified between the visitor frequencies and the meteorological and human-biometeorological factors.

Table II. For the recreation area, the coefficient *a* (for RN, $T_a$ and PET) and constant *b* included in the multiple regression model of visitors (recreational cyclists, commuting cyclists and all cyclists as dependent variables) and the physiologically equivalent temperature, PET, precipitation (RN), air temperature $T_a$; as dependent variable $R^2$ (single and multiple coefficient of determination at a significance level of 95%, $n = 223$) are listed for workdays in 2002.

| | $a$(RN) | $a(T_a)$ | $a$(PET) | $b$ | $R^2$ |
|---|---|---|---|---|---|
| Rcbiker | −0.58 | | | 134.0 | 0.05 |
| | | 9.96 | | −24.5 | 0.71 |
| | −0.39 | 9.80 | | −15.6 | 0.74 |
| | | | 6.84 | 24.4 | 0.78 |
| | −0.34 | | 6.73 | 31.7 | 0.79 |
| Wbiker | −0.07 | | | 21.8 | 0.04 |
| | | 1.23 | | 2.1 | 0.52 |
| | −0.05 | 1.28 | | 3.2 | 0.54 |
| | | | 0.84 | 8.4 | 0.55 |
| | −0.04 | | 0.82 | 9.4 | 0.56 |
| All bikers | −0.61 | | | 155.8 | 0.05 |
| | | 11.2 | | −22.4 | 0.72 |
| | −0.44 | 11.0 | | −12.3 | 0.75 |
| | | | 7.67 | 32.9 | 0.78 |
| | −0.38 | | 7.55 | 41.1 | 0.80 |

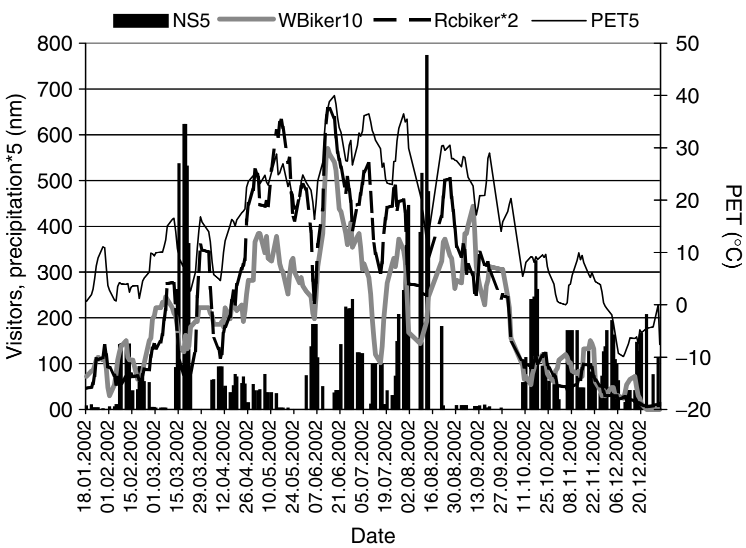


Figure 5. Annual patterns of recreational cyclists (multiplied by 2, Rcbiker × 2), working bikers (multiplied by 10, Wbiker × 10), precipitation (multiplied by 5, NS × 5) and physiologically equivalent temperature (PET, 5 × 5) in the Wienerberg for the year 2002 (only working days are included).



DOI: 10.1002/met

### 4.7. Simple correlations

The simple linear regression of any type of cyclists and precipitation reveals that no statistical relationship is identifiable. In each of the three regressions, $R^2$ is 0.05. On the other hand, the relationship between the number of cyclists and the air temperature is significant and much more meaningful. More precisely, the relationship between air temperature and recreational cyclists is stronger ($R^2 = 0.71$) than with commuting cyclists ($R^2 = 0.52$).

### 4.8. Multiple correlations

The multiple linear regression between the cyclists and the independent variable air temperature (1400 CET) and the categories of precipitation ('yes and no') demonstrates a higher regression coefficient (for recreational bikers 0.74) than the regression with air temperature alone. The regression coefficients between the cyclists and PET alone, as well as PET and precipitation, reveal strong correlations between these variables, as indicated by high $R^2$ values; for PET alone this is 0.78, for PET in combination with precipitation, $R^2$, it is 0.80. In general, however, the regression coefficients for the commuting cyclists are lower than for the recreational cyclists.

This leads to the conclusion that commuting cyclists are less dependent on the weather since they pay less regard to meteorological and biometeorological conditions (Figures 3, 4 and 5). For all cyclists, the results show the same trend as for recreational cyclists, but with higher $R^2$ values. In this case, the $R^2$ value for PET and precipitation is 0.80. An additional analysis, fitting the 10 data with a moving average of five days, shows an identical pattern for $R^2$ but this time, with higher values. For example, the $R^2$ for precipitation and PET was 0.07 higher for commuting cyclists and 0.19 higher for recreational cyclists than the $R^2$ without the five-day moving averages.

## 5. Conclusions

The analysis shows that a relationship exists between weather conditions and both cycling for recreational and commuting purposes. The frequency of use of recreation areas, however, depends not only on actual meteorological variables such as air temperature and precipitation. It also depends on the thermal perception by people and the motivation for using the areas for recreation or commuting.

The perception of thermal and precipitation conditions which includes recent experience (about the previous six days) of the conditions of thermal perception and the current conditions, will probably explain the statistical correlation between the amount of different cyclist types and the combination of bioclimatic conditions and precipitation with a higher significance level. The combination of bioclimatic conditions must include air temperature, short- and long-wave radiation, air humidity and wind speed, as well thermo-physiological parameters (clothing and activity).

Therefore, the present study encourages further investigations into the relationships between the actual bioclimatic and meteorological conditions and the memory of the thermal perception of the last few days, and the impact of these on various kinds of outdoor activities such as cycling, jogging, walking and dog walking.

It is assumed that recreational cyclists obtain information on the local weather conditions beforehand, and, consequently, avoid periods of intense and/or extensive precipitation. In order to obtain more precise datasets and, subsequently, more reliable results, an analysis of hourly data will be conducted in future studies.

In a further step towards producing a very useful planning tool, a regression model will be used for calculations. This will be used to predict the number of recreational and commuting cyclists for each day based on the previous day's weather forecast. Another important view into the future is the analysis of comparable recreation areas with a similar composition of user types in order to evaluate the presented models. The same analysing methods, such as long-term visitor monitoring, as well as thermal perception, must be used.

In the current study, methods of long-term monitoring of recreational activities, human-biometeorological assessment of thermal perception, and actual weather conditions are used. Therefore, these results exceed the scope of the studies mentioned in the introduction. The existing results from McCalla *et al.* (1987) do not rely on advanced scientific methods including the human energy balance.

The use of a cycle for commuting, even under inclement weather conditions, has a major influence on the management of recreation areas. Therefore, it is important to shed some light on the preferred type of path or trail used by commuting cyclists and the dependence of this decision on rainfall. In rainy conditions, riding on un-tarred paths can lead to increased erosion of the trail surface. Repairing these trails leads to a non-budgeted strain on management resources.

Considering that cycling for commuting is also carried out during fine weather, one must expect an increasing conflict between the groups using their bicycles for commuting and those who are recreational cyclists. The different travelling speeds of these two groups will lead to yet another clash of interests.

## Acknowledgements

Our thanks go to Nikola Sander for proofreading the manuscript. The Institute for Landscape Development, Recreation and Conservation Planning was commissioned by the Vienna City Council, Forest Department, to collect data on public use of the Wienerberg suburban area.

## References


Arnberger A. 2003. Modellierung sozialer Tragfähigkeitsgrenzen von Erholungsgebieten, Doctoral dissertation, BOKU – University of Natural Resources and Applied Life Sciences, Vienna.

Arnberger A, Brandenburg C. 2002. Visitor structure of a heavily used conservation area: the Danube floodplains National Park, Lower Austria. *Monitoring and Management of Visitor Flows in Recreational and Protected Areas*. Proceedings; published by Institute for Landscape Architecture and Landscape Management, BOKU – University of Natural Resources and Applied Life Sciences: Vienna; 7–13.

Auer I, Bogner M, Hammer N, Koch E, Rudel E, Svabik O, Vielhaber C. 1990. *Das Bioklima von Gmunden*. Zentralanstalt für Meteorologie und Geodynamik: Vienna.

Becker F. 1972. Bioklimatische Reizstufen für eine Raumbeurteilung zur Erholung. *Forschungs- und Sitzungsberichte der Akademie für Raumforschung und Landesplanung Hannover* **76**: 45–61.

Brandenburg C. 2001. Erfassung und Modellierung von Besuchsfrequenzen in Erholungs- und Schutzgebieten – Anwendungsbeispiel Nationalpark Donau-Auen, Teilgebiet Lobau, Doctoral dissertation, BOKU – University of Natural Resources and Applied Life Sciences, Vienna.

Bucher K. 1993. Ein Verfahren zur objektiven Klassifikation des Wetters unter biosynoptischen Gesichtspunkten. *Berichte des Deutschen Wetterdienstes*. Deutscher Wetterdienst: Offenbach am Main.

Bullrich K. 1981. *Atmosphäre und Mensch*. Umschau Verlag: Frankfurt.

Buttner K. 1938. *Physikalische Bioklimatologie*. Akademische Verklagsgesellschaft: Leipzig.

Cessford G. 2002. Perception and Reality of Conflicts: Walkers and Mountain Bikes on the Queen Charlotte Track in New Zealand. *Monitoring and Management of Visitor Flows in Recreational and Protected Areas*. Proceedings; published by Institute for Landscape Architecture and Landscape Management, BOKU – University of Natural Resources and Applied Life Sciences: Vienna; 102–108.

Gerth W-P. 1986. Klimatische Wechselwirkungen in der Raumplanung bei Nutzungsänderungen. *Berichte des Deutschen Wetterdienstes*, Vol. 171. Selbstverlag des Deutschen Wetterdienstes: Offenbach.

Gerth W-P. 1987. Anwendungsorientierte Erstellung großräumiger Klimaeignungskarten für die Regionalplanung. *Berichte des Deutschen Wetterdienstes*, Vol. 173. Selbstverlag des Deutschen Wetterdienstes: Offenbach.

Gobster PH. 1991. Urban park trail use: an observational approach. Proceedings of the 1991 Northeastern Recreation Research Symposium. (General Technical Report NE-160). USDA Forest Service, Northeastern Forest Experiment Station: Saratoga Springs, 215–221.

Hammer N, Koch E, Rudel E. 1986. Die Beurteilung der thermisch-hygrischen Befindlichkeit des Menschen nach verschiedenen Modellen. *Archives for Meteorology, Geophysics and Bioclimatology* **36**: 343–355.

Harlfinger O. 1978. Thermisches Empfinden im Hinblick auf den Einfluß der Adaption. *Archives for Meteorology, Geophysics and Bioclimatology* **26**: 365–371.

Harlfinger O. 1985. *Bioklimatischer Ratgeber für Urlaub und Erholung*. Gustav Fischer Verlag; Stuttgart.

Harrison SJ, Winterbottom SJ, Sheppard C. 1999. The potential effects of climate change on the Scottish tourist industry. *Tourism Management* **20**: 203–211.

Höppe P. 1999. The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology* **43**: 71–75.

Höppe P, Mayer H. 1987. Planungsrelevante Bewertung der thermischen Komponente des Stadtklimas. *Stadt und Landschaft* **19**: 22–30.

Jendritzky G, Menz G, Schirmer H, Schmidt-Kessen W. 1990. Methodik zur raum-bezogenen Bewertung der thermischen Komponente im Bioklima des Menschen (Fortgeschriebenes Klima-Michel-Modell). *Beitr Akad Raumforsch Landesplan* **114**: 1–80.

Leatherberry EC, Lime D. 1981. *Unstaffed Trail Registration Compliance in a Backcountry Area*, Research Paper NC-214. North Central Forest Experiment Station: St Paul.

Licht S. 1964. *Medical Climatology*. Elizabeth Licht Publisher, Waverly Press: Maryland, MD.

Lindsey G. 1999. Use of urban greenways: insights from Indianapolis. *Landscape and Urban Planning* **45**: 145–157.

Matzarakis A, Mayer H. 1996. Another kind of environmental stress: thermal stress. *WHO Newsletter* **18**: 7–10.

Matzarakis A, de Freitas C (eds). 2001. Proceedings of the first international workshop on climate, tourism and recreation. *Commission on Climate Tourism and Recreation*. International Society of Biometeorology: Freiburg.

Matzarakis A, Mayer H, Iziomon M. 1999. Applications of a universal thermal index: physiological equivalent temperature. *International Journal of Biometeorology* **43**: 76–84.

Matzarakis A, Rutz R, Mayer H. 2000. Estimation and calculation of the mean radiant temperature within urban structures. In *Biometeorology and Urban Climatology at the Turn of the Millennium*, de Dear RJ, Kalma JD, Oke TR, Auliciems A (eds). Selected Papers from the Conference ICB-ICUC'99, WCASP-50: WMO/TD No. 1026: Sydney; 273–278.

McCalla RJ, Day EED, Millward HA. 1987. The relative concept of warm and cold spells of temperature: methodology and application. *Archives for Meteorology, Geophysics and Bioclimatology* **25**: 323–336.

Rotton J, Shats M, Stander R. 1990. Temperature and pedestrian tempo: walking without awareness. *Environment and Behavior* **22**: 650–674.

Taubenheim J. 1969. *Statistische Auswertung Geophysikalischer und Meteorologischer Daten*. Akademischer Verlag. Geest & Portig; Leipzig.

Trenkle H. 1992. *Klima und Krankheit*. Wissenschaftlicher Buchverlag Darmstadt; Darmstadt.

VDI. 1998. *Methods for the Human-biometeorological Assessment of Climate and Air Quality for Urban and Regional Planning at Regional Level*, Part I: Climate, *VDI guideline 3787*. Part 2. Beuth, Berlin.

Wakonigg H. 1981. Wetter und Witterung als komplexe Erscheinung. (Ein Vorschlag zur Darstellung der örtlichen Witterung durch Mehrfachkombination im Sinne echter Witterungsklimatologie) Teil 1 und 2. *Wetter und Leben Zeitschrift für angewandte Meteorologie* **33**: 1–16, 69–93.




DOI: 10.1002/met