Published in: Proceedings of the ICSU2010, 1st International Conference on Sustainable Urbanisation. Hong Kong, China 15-17 December 2010.

LARGE SCALE INTEGRATION OF PHOTOVOLTAICS IN CITIES

Ursula Eicker, Aneta Strzalka, Claudia Schulte, Jürgen Bogdahn, Jürgen Schumacher, Volker Coors
Research Centre Sustainable Energy Technologies zafh.net, University of Applied Sciences Stuttgart
Schellingstr.24, 70174 Stuttgart, Germany
ursula.eicker@hft-stuttgart.de

ABSTRACT

For a large scale implementation of photovoltaics in the urban environment, building integration is a major issue. This includes installations on roof or facade surfaces with orientations that are not ideal for maximum energy production. Furthermore the building integration often leads to higher temperature levels, as the photovoltaic modules cannot always be ideally ventilated. These varying thermal situations can degrade the annual performance levels of photovoltaics.
To evaluate the performance of photovoltaics on an urban scale and determine the best integration possibilities, three dimensional town models were combined with accurate photovoltaic system simulations using the simulation environment INSEL. The developed urban planning tool SolarCity 3D is based on three dimensional CityGML data, where roof and facade surface polygons can be easily extracted for a selected town area. The data are transferred to the simulation environment INSEL, where hourly resolved irradiance data are calculated for each surface and a photovoltaic system simulation is then carried out. As an example the town of Stuttgart was used to calculate the potential of photovoltaic energy use using roof integrated modules only.

In cities, where a three dimensional town model is not yet available, laser scanning data can be used to extract roof surface areas, orientations and slopes. This method has been applied to a project area near Stuttgart, where detailed annual electricity consumption data were available for a city quarter of 10,000 inhabitants. It could be shown that 45% of the quarter´s electricity consumption can be covered by roof integrated photovoltaics.

KEYWORDS:

Urban photovoltaic potential, 3D CityModels, GIS systems

INTRODUCTION

Photovoltaic system are ideally suited for decentral electricity supply in urban structures. Integration in roofs or facades is supported in many countries by increased feed in tariffs for building integrated systems. In principle the roofs of buildings, which at present are practically not used for the generation of energy, represent large resources of areas for the conversion of solar energy (Wittmann, 1996). An assessment of the suitability of buildings for PV installation as a function of roof orientation and module efficiency was made by Fleming, 2005. Electricity produced by photovoltaic systems still is more expensive than other renewable energy resources. Therefore, for PV systems it is of special importance to lower energy losses and to get a high reliability and very long lifetime (Erge, 2001). Especially in case of the implementation of PV systems at city scale, the economical aspect should be considered. Some other requirements also have to be considered, like appropriate inclination and orientation of the installed PV systems. The effect of shading, which causes high losses in the performance of PV-systems is especially important in urban areas. The main reason for performance loss in one of the first larger PV implementation schemes, the German “1000-Roofs-Program” of the 1990ies, was shading (Quaschning, 1996).
The contribution of PV power to cover decentral energy consumption depends not only on building size but also on different consumer types. The estimation of solar potential and the evaluation of energy demand for specific end-use activities are the basic steps to determine the best policies for large-scale deployment of different solar energy applications (Voivontas, 1998). Regarding the different user behaviour, there is still lack of studies

regarding its impact. Several studies have shown that occupant behavior plays a prominent role in the variation in energy consumption in different households (Branco, 2004). In this paper, PV energy potential and user influenced consumption are compared. To simulate the contribution for urban electricity supply, automised simulations for a large number of buildings need to be carried out to accurately determine the urban photovoltaic energy potential.

METHODOLOGY

A good data basis for automatic detection of best fitting roof and facade surfaces for photovoltaics in terms of energy performance and integration possibilities is CityGML.

CityGML is an "OpenGIS Encoding Standard for the representation, storage and exchange of virtual 3D city and landscape models" (OGC WebSite). CityGML enables to describe 3D city and landscape models including geometry, semantic, topology and appearance. It is a multifunctional model which can be used for geospatial transactions, data storage, database modeling and provides a basis for 3D geospatial visualization, analyzing, simulation and exploration tools. It has a spatio-semantic model which specifies object modeling in different level of details. "Included are generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. This thematic information go beyond graphic exchange formats and allow to employ virtual 3D city models for sophisticated analysis tasks in different application domains like simulations, urban data mining, facility management, and thematic inquiries "(CITYGML WEBSITE).

Based on CityGML models attribute extraction such as geographical position and orientation of building surfaces, calculation of roof area and pitch as well as shadow effects based on roof structures and neighborhoods are possible.

ARCHITECTURE

In order to be able to perform large scale urban simulations like photovoltaic potential analysis, energy demand forecasts etc., it is necessary to link an urban three-dimensional dataset to the specific required simulation tool. This input data does not only need to represent the geometrical aspect of urban features, but also semantic information to serve simulation tools appropriately. CityGML, as outlined above, is a good candidate for such a data model. Nevertheless, the data also needs to be managed, processed and transformed in order to be used for simulations. A management framework for urban 3D data is necessary providing data on a city scale not only to one specific simulation tool, but to different tools for different scenarios. It should be easily extendable and adaptable to new scenarios.

At the University of Applied Sciences Stuttgart (HFT) a 3D management framework has been developed which can be used in different scenarios, e.g. urban planning (Knapp et al. 2007). This framework is also used to provide data to the SolarCity3D engine in the photovoltaic potential analysis scenario.

For the task of evaluating the performance of photovoltaics on an urban scale and determine the best integration possibilities a system architecture (see Figure 1) was developed combining:

- A graphical 2D map based user interface for selection of the urban area to be analyzed
- The CityModel Administration Toolkit (CAT3D)[1]: a framework for handling CityGML models including data connection tools, internal data representation, specific utility tools and data format creation tools for conversion of the 3D data to various visualization and output formats.
- A SOLARCity3D calculation engine for extraction of the attributes relevant for photovoltaic simulation (geographical position and orientation, roof area and pitch)
- An Interface to the simulation engine
- INSEL[2]: photovoltaic system simulation environment
- CATsEye[3]: a 3D Viewer for the classified visualization of the results

---

[1, 3] The **C**itymodel **A**dministration **T**oolkit and CATsEye - 3D Viewer - developed at HFT Stuttgart

[2] INSEL developed by doppelintegral GmbH

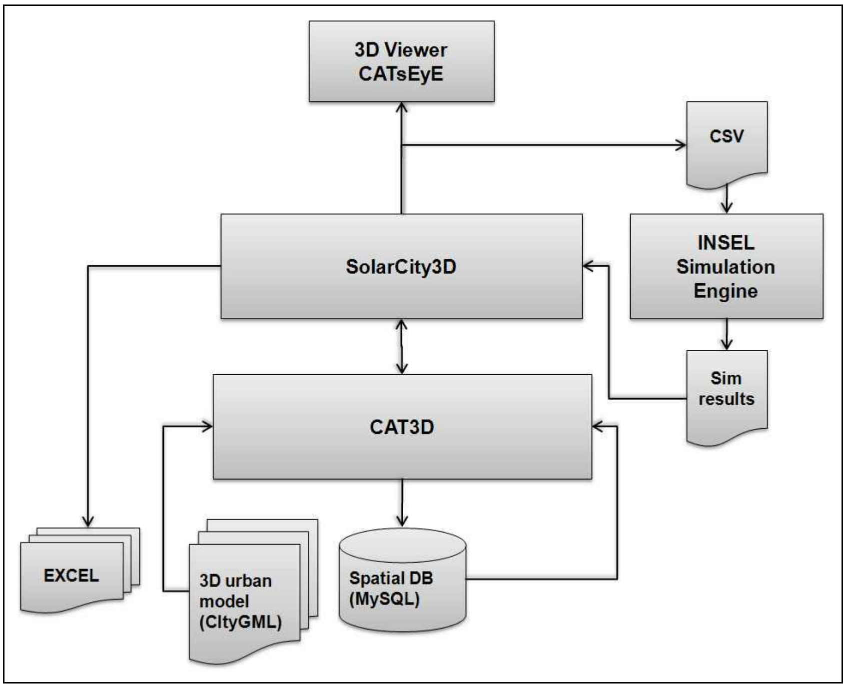


Figure 1: System Architecture

In the SolarCity3D scenario it is necessary to select a specific area of the urban model and to perform the analysis for the selected extent. The CAT3D framework provides several modules implementing capabilities, which can be used by other tools/applications. Mainly three major parts of the framework can be differentiated: connection to data sources, feature/geometry mapping and output data creation. There are also several toolkits, which provide functionality in order to transform and process data on mapping level. This functionality includes coordinate reference system transformation, geometry transformations, intersection, merging of data from different sources, etc. The SolarCity3D engine makes use of several modules of the framework in order to perform its task of photovoltaic potential analysis; in simple words it uses CAT3D and the spatial database as an urban information repository in order to retrieve information, which is fed to the simulation tool.

The developed SolarCity3D calculation engine is built on top of the CAT3D framework. It uses the data management and data mapping functionality of CAT3D in order to perform 'data mining' functions to preprocess urban information for the photovoltaic potential analysis (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

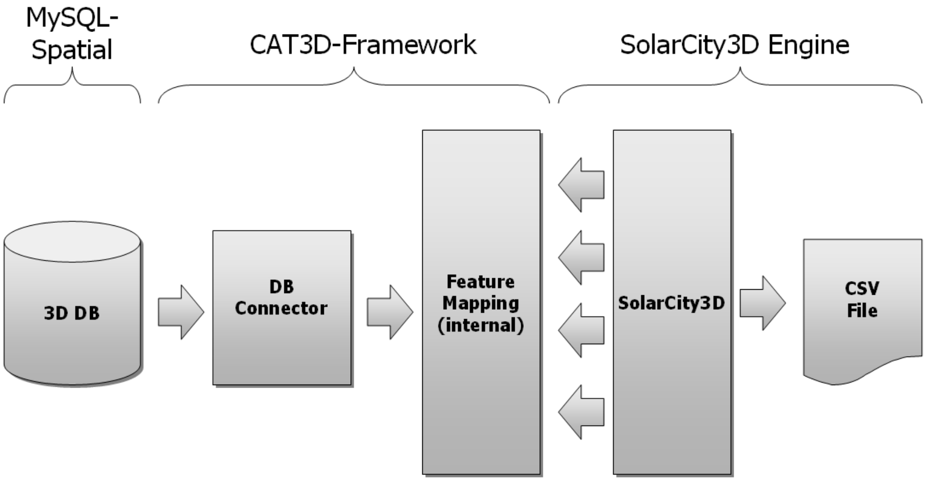
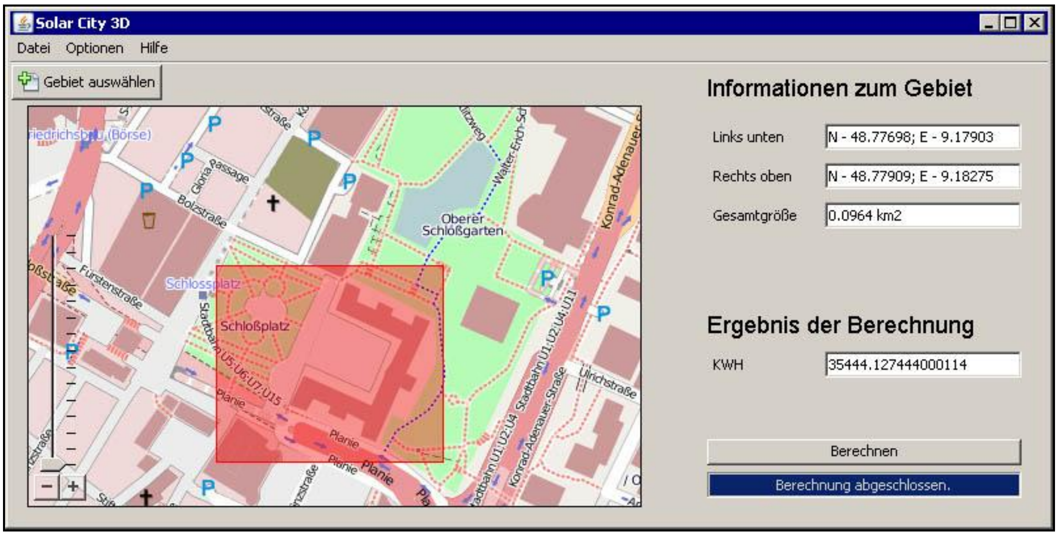


Figure 2: SolarCity3D workflow – data extraction from DB and SolarCity3D processing

The actual process can be divided into distinct steps. First of all the SolarCity3D engine receives the spatial extent for which the analysis of the rooftops should be performed. This extent can be selected by the user via the graphical interface (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). This spatial bounding box is used by the CAT3D framework DB-Connector module in order to query the 3D features from the database. The features are then mapped into the internal data representation and provided in a list structure. This list can be accessed by the SolarCity3D engine in order to perform necessary calculations and transformations.



Informationen zum Gebiet

Links unten: N - 48.77698; E - 9.17903

Rechts oben: N - 48.77909; E - 9.18275

Gesamtgröße: 0.0964 km2

Ergebnis der Berechnung

KWH: 35444.127444000114

Berechnung abgeschlossen.

Figure 3: User interface for selection of spatial area

Based on the retrieved building geometries, the geographical position and orientation of the roof surfaces, its area and pitch are calculated.

In CityGML, as well as the internal CAT3D representation, the geometry of a building is modeled by its boundary representation. The boundary surface of the building geometry is described by polygons as a piecewise linear complex. Each polygon belong either to a roof, ground or wall surface. Only polygons that belong to roof surfaces are extracted from the building model. For each of these polygons, its area is calculated by triangulating the polygon and summing up the triangle areas. Orientation of the roof surface is derived from the normal vector of the polygon (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

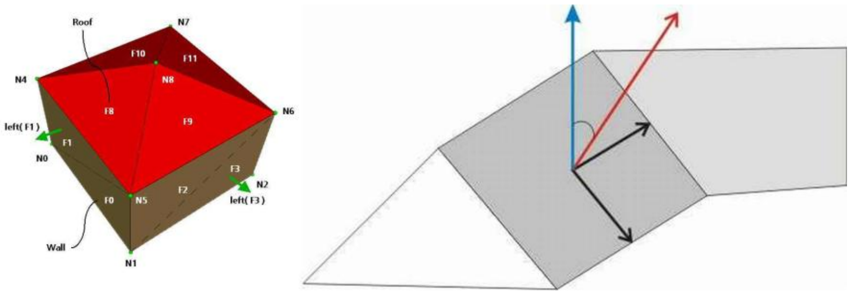


Figure 4: Surface orientation in CityGML

The SolarCity3D component writes the information retrieved from the calculation into a CSV text file that can be read by the simulation model. Within the CSV file the FeatureID and PolygonID of the CITYGML objects are listed combined with the attributes inclination, azimuth and area needed for the photovoltaic potential calculation. Because these two IDs are maintained throughout the simulation process the result values can be linked to the corresponding geometries in the 3D model.

The PV system simulations use the surface area and orientation as an input to a photovoltaic system model. This contains a model for different photovoltaic module and inverter technologies including an MPP tracker for optimum yield production. The photovoltaic module can be chosen from a database of over 5000 modules produced worldwide. In the inverter database, more than 1000 inverters are available. From a meteorological database with 2000 locations worldwide, monthly mean values of irradiance and ambient temperature for the chosen location are selected. The well validated models of Gordon-Reddy for daily values and Aguiar / Collares-Pereira for hourly irradiance generation are used.

The photovoltaic potential results received from the INSEL simulation tool are integrated in the 3D CityModel by adapting the color of the building roofs according to the classification of the photovoltaic potential. Finally the result are visualized within the CATsEYE 3D Viewer (see Figure 8). The CATsEye viewer is a component that uses data from the CAT3D data mapping layer to visualize urban models and data via 3D rendering.

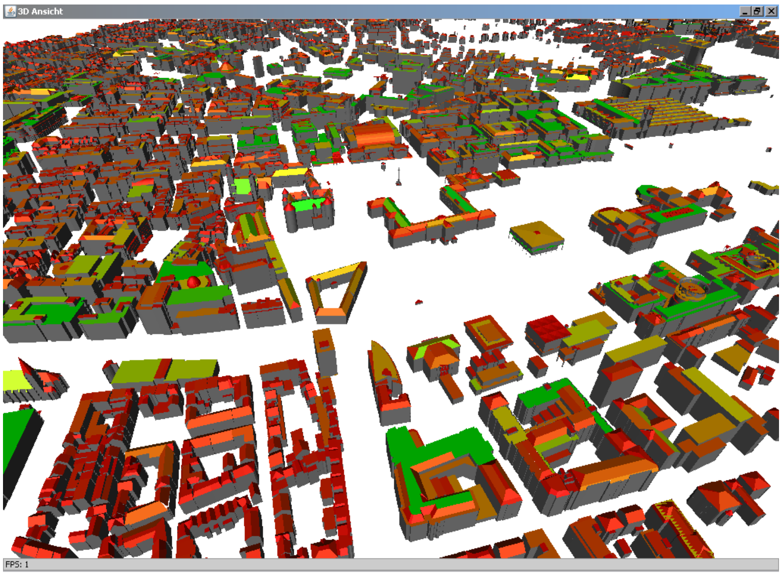


Figure 5: Results of photovoltaic potential analyze visualized in 3D Viewer

In case, where three dimensional town models are not yet available, laser scanner data can be used to extract roof surface orientations and slopes. This method has been applied to a project area near Stuttgart, where detailed electricity consumption data were available for a city quarter of 10,000 inhabitants. The program GeoMedia Professional and its application GeoMedia Grid were used as a tool to estimate suitable roof areas for the PV-installation (Strzalka et al, 2009).

All households residing in row houses and multi-family houses were considered as potential users of PV-systems for electricity production. This solar roof potential was then restricted by space availability, area available on the building's roofs and number of buildings, which have already installed PV-systems.

The analysis of the roof type within the laser scanner data showed that almost 80% of the building's roofs are of flat type. Taking into consideration this fact, the extraction of the roof orientation and slope was not needed anymore. Most inclined roofs occurred not to be suitable for the PV- installation because of chimneys, dormer windows and windows.

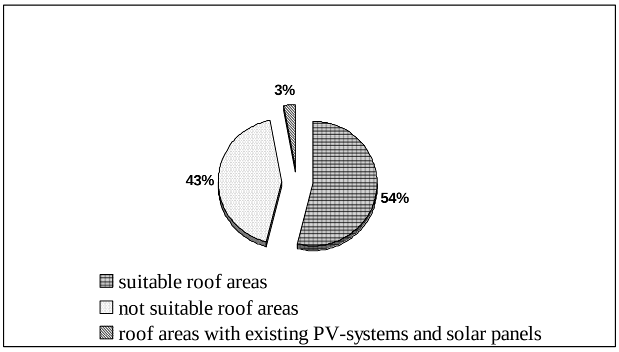


Figure 6: Classification of the roofs in the new town Scharnhauser Park

The energy needs for the electricity for each household was provided by the Utility Company as annual electricity consumption values of the year 2005, which were stored in the Access database. The total electricity consumption for all residential buildings for the year 2005 has a value of 10700 MWh.
The average value of all buildings related to the gross surface area is 40 kWh/(m²a). Related to the number of persons the consumption is 1600 kWh/(Person a).

As individual consumption cannot be published on the Internet due to data protection issue, the web published results are averaged for similar building types.

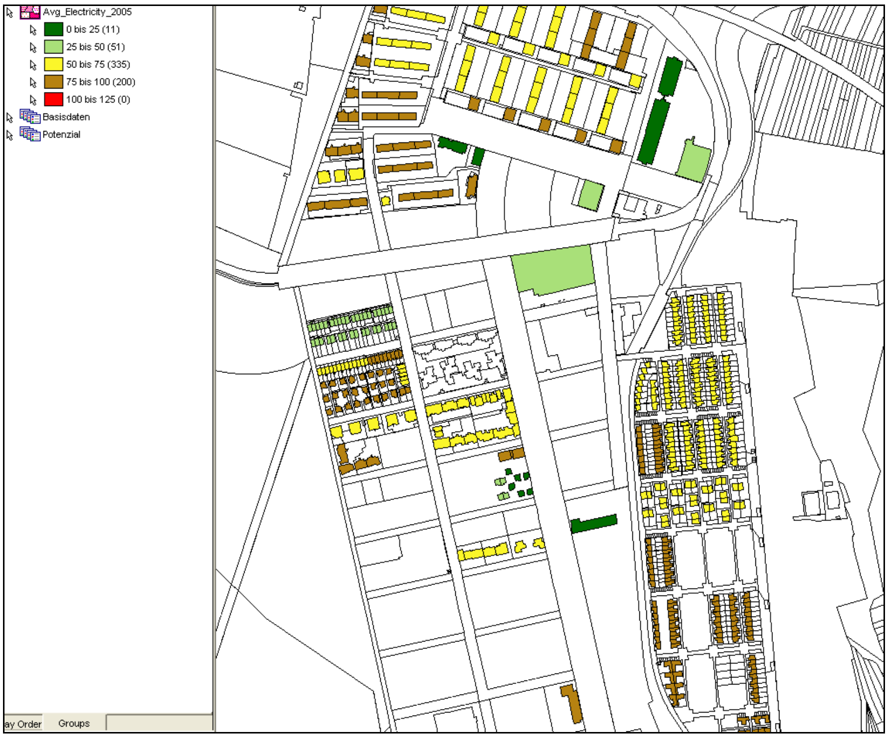


Figure 7: Average measured electricity consumption per building group.

The annual percentage of energy needs for electricity covered by the PV-system is calculated with the assumption that all household with the suitable roof area and with no available PV-system, will install it. Inputs for this calculation are the average annual solar radiation on the surface with 40° slope for the year 2005 (1299 kWh/m²a) and the efficiency of the PV systems of 12%. The simulations showed that almost 45% (without consideration of shading) of the annual electricity consumption (10700 MWh) of this area could be covered by the solar power from PV-systems. On an individual building level, the percentage strongly depends on the user behaviour and energy consumption. For similar building types, the ratio of PV production to own consumption can vary by a factor 2.

Figure 8: Representation of suitable roof areas and percentage of PV coverage per building.

Additionally, the program GeoMedia WebMap Professional was used to visualize the results of this analysis. On this web page every citizen of the analyzed residential area has a possibility to view the value of the suitable roof area for PV-installation.

CONCLUSIONS

The paper presents a method development and implementation of a fully automated process to extract roof surfaces and orientations based on 3D urban model or airborne laser scan. The results are used to determine the photovoltaic potential on a city level. The quality of the results strongly depends on the input data model. While CityGML allows very high details of building geometry, a typical city model contains accurate but less detailed building geometry. Roof features such as antennas are usually not included.

To analyse a single building, a more detailed model of the building geometry is necessary. However, the developed data management structure and the coupling to the simulation tool can handle this as well.

The case study showed that 45% of measured electricity consumption in an urban district with medium density could be covered by roof integrated photovoltaics. The data can be made available to the city quarter inhabitants using a Web based GIS system.

REFERENCES:

Branco, G., Lachal. B., Gallinelli, P., Weber, W., 2004, Predicted versus observed heat consumption of a low energy multifamily complex in Switzerland based in long-term experimentail data, Energy and Building 36, p. 543-555

CITYGML WebSite, Exchange and Storage of Virtual 3D CityModels, URL: http://www.citygml.org/1523/ (access 28th April 2010)

Erge, T., Hoffmann, V. U., Kiefer., K., (2001). „The German experience with grid-connected PV-systems“. Solar Energy, Vol. 70, Issue 6, Pages 479-487.

Fleming, P.D., Brownsword, R. A., Pearsall, N., Powell, J. C., (2005), “ Sustainable cities – modelling urban energy supply and demand. Applied Energy, 82 (2), pp. 167-180.

Knapp, S., Bogdahn, J., Coors, V. (2007): “Improve public participation in planning processes by using web-based 3D-models for communication platforms”; REAL CORP 2007 Proceedings / Tagungsband ISBN: 978-39502139-3-5 (Print) Editors: Schrenk,v. Popovich, Benedikt

OGC Standards Website: OpenGIS® City Geography Markup Language (CityGML) Encoding Standard, URL: http://www.opengeospatial.org/standards/citygml (access 28th April 2010)

Quaschning, V., (1996). “Simulation der Abschattingsverluste bei solarelektrischen Systemen”. ISBN 3-89574-191-4, Verlag Dr, Köster Berlin.

Strzalka, A., Md. Zahid Hasan, S., Eicker, U., (2009). „Potential of Roof Top PV-systems for Supplying Electricity in Residential Area Scharnhauser Park“, Proceedings of ICDRET ’09 in Dhaka, Bangladesh, 83-86, ISBN 978-984-33-0616-6.

Voivontas, D., Tsiligiridis, G., Assimacopoulos, D., (1998). „Solar Potential for Water Heating Explored by GIS”, Solar Energy Vol.62, No.6, p. 419-427.

Wittmann, H., Bajons, P., Doneus M., Friesinger, H., (1997), „Identification of Roof Areas Suited for Solar Energy Conversion Systems“, Renewable Energy, Vol. 11, No. 1, pp. 25-36.