Solar Energy Utilisation Potential of three different Swiss Urban Sites

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Abstract

Besides providing a more efficient energy use, a large scale application of solar energy technologies in the urban context will be required in the upcoming decades to achieve a drastic reduction of greenhouse gas emissions in the biosphere. Three different urban sites, representative of three of the largest Swiss cities (Basel, Geneva and Lausanne), were examined in order to assess their respective solar potential. Spatial distributions of solar irradiation and daylight fluxes over the overall building facades and roofs were calculated using ray-tracing simulation techniques to determine the appropriate placement of different solar technologies (passive and active solar, photovoltaic and daylighting). Several performance indicators were used to assess the solar utilisation potential of these urban sites (e.g. statistics of sky view factors and daylight factors). A comparison of the results observed for the three urban sites is presented in this paper. It has been observed in the three cases that the building surface areas appropriate to solar technologies are very significant.

Zusammenfassung

Um die Emission von Treibhausgasen in die Atmosphäre deutlich einzuschränken, wird in der nahen Zukunft neben einer effizienteren Energienutzung ein weitverbreiteter Einsatz von Sonnenenergie unerlässlich sein. Drei urbane Standorte, repräsentativ für drei grosse Schweizer Städte (Basel, Genf und Lausanne), wurden vor diesem Hintergrund hinsichtlich ihre Potentials für Sonnenenergie untersucht. Die räumliche Verteilung der Sonnen- und Tageslichteinstrahlung auf Gebäudefassaden und -dächer wurden mithilfe von Ray-Tracing Methoden simuliert, um die bestgeeignetste Anordnung verschiedener Sonnenenergietechnologien zu ermitteln (passive und aktive thermische Sonnenenergie, Photovoltaik und Tageslichtnutzung). Bestimmte Indikatoren erlaubten die Beurteilung der drei Standorte hinsichtlich ihres Potentials für Sonnenenergie, wie z.B. die statistische Verteilung der Sky View Factors und der Tageslichtquotient. Die diesbezüglichen Resultate für die drei Standorte werden in unserer Studie verglichen. Hierbei zeigt es sich, dass in allen drei Fällen die für Sonnenenergie nutzbare Fläche sehr erheblich ist.

1. Introduction

Based on an evaluation of the potential use of solar energy in three representative districts of Swiss cities, the present research [1], supported by the Swiss Federal Office of Energy (SFOE), aims to promote sustainable urban architecture by allowing a better direct use of solar energy in the urban environment: passive and active solar energy, daylighting and photovoltaics.

The innovative energy policy adopted by the canton of Basel-Stadt since 2001 earned it the selection as a pilot site for the implementation of a "2000 Watt Society" programme, representing a clear objective within the framework of the "Strategy for Sustainable Development" of the Council of the Swiss Federal Institute of Technology [2]. The pilot site of Matthaeus in Basel, as well as the mixed use area of Meyrin in Geneva and Bellevaux in Lausanne, were investigated as a consequence in this study regarding their solar energy utilisation potential.

2. Selected urban sites

2.1 Matthaeus-Basel / Meyrin-Geneva / Bellevaux-Lausanne

The first urban site considered, "Klein Basel – Matthaeus", is located near the city centre of Basel along the Rhine river. The old medieval city, bought in 1392 by Grossbasel, presents a checkerboard plan orientated along a north-south/east-west axis; its streets are parallel to the Rhine. Of the overall cantonal population of 402 000 inhabitants, 190 800 (48%) live in this town whose surface area equals 37 km^2. Owing to its restricted area, the Matthaeus district's potential development is very limited. Consequently, every refurbishing project is subject to careful consideration and optimisation. With an area of approximately 59 hectares for an overall population of 15 300 inhabitants, this urban site is characterised by one of highest population densities of Swiss cities (Fig. 1).

The "city of Meyrin", located 9 km from the centre of Geneva with an area of 998 hectares, was conceived as a satellite town for Geneva; it is one of the rare examples of the architecture and functionalist town planning of the sixties in Switzerland. Built at the edge of the city, Meyrin accommodates various internationally renown research centres, which represent 26 000 employment positions for a total population of 20 500 inhabitants. The urban concepts of the modern city [3] dictated the principles of the Meyrin block plan. The urban settlement of this site shows clearly defined zones with regard to both morphology as well as functionality (Fig. 2).

The "Bellevaux district" is situated in the north of Lausanne, at about 1.5 km from the city centre. It is bounded in the east and the west by two woods: the Bois de Sauvabelin and the Bois Mermet. The area of the Bellevaux district equals 35.6 hectares for 4 601 inhabitants. From the 12th Century on, the district included a Cistercian monastery, but its effective development originates from the beginning of the 20th century. The total number of 240 buildings cover a built area of 81 880 m2, corresponding to a land occupation coefficient equal to 0.23. This relatively low value allows for interesting green spaces but it also includes residual spaces with low environmental value. These latter spaces could accommodate an increase in built area without environmental consequences (Fig. 3).

***Figure 1:** Matthaeus district (Basel city) [4].*

***Figure 2:** Meyrin district (Geneva) [5].*

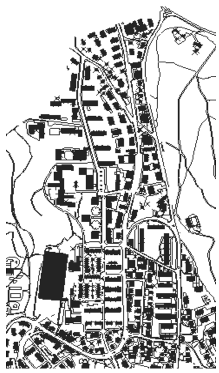
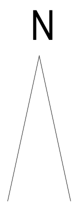


***Figure 3:** Bellevaux district (Lausanne) [6].*



2.2 Comparison of urban sites

The following tables and figures give a comparison of the principal statistical data of Matthaeus, Meyrin and Bellevaux districts, as well as a typical view. The three city morphologies differ in terms of their access to solar irradiation and daylight, which is limited both by physical and socio-economical factors. Solar irradiation and daylight access were examined through computer simulations of the three urban sites.

Features	
Altitude	254 meters a.s.l.
District area	59.1 hectares
Population	15 300 ihhabitants
Population density	259.1 ihhab./hect.
Inhabitants/Household	1.96
Habitable area/Inhabitants	32 m2
Buildings history	66% before 1945
Topography	light slope

Table 1: *General statistics of Matthaeus (Basel).*

Figure 4: *Typical street view of "Matthaeus" district (Basel).*

Features	
Altitude	464 meters a.s.l.
District area	998 hectares
Population	20 500 ihhabitants
Population density	20.6 ihhab./hect.
Inhabitants/Household	2.3
Habitable area/Inhabitants	35 m2
Buildings history	70% after 1960
Topography	slightly undulating

Table 2: *General statistics of Meyrin (Geneva).*

Figure 5: *Typical view of "Meyrin" district (Geneva).*

Features	
Altitude	565-578 meters a.s.l.
District area	35.6 hectares
Population	4 601 ihhabitants
Population density	129.3 ihhab./hect.
Inhabitants/Household	1.94
Habitable area/Inhabitants	36.5 m2
Buildings history	76% between 1947-70
Topography	sloping

Table 3: *General statistics of Bellevaux (Lausanne).*

Figure 6: *Typical areal view of "Bellevaux" district (Lausanne).*

3. Simulation Methodology

The general approach consists of estimating the available and useful solar radiation and daylight flux in each urban environment. Several techniques of direct use of solar energy for heating, daylighting and/or electricity production are taken into account. The computer methodology used to assess the solar energy utilisation potential of "Matthaeus" [7-8], "Meyrin" [8] and "Bellevaux", is based on the original method developed by R. Compagnon within the framework of the PRECis european project [9].

The overall procedure, based on the Radiance ray-tracing program [10], was modified, however, to take into account the larger area of the considered urban sites (59 hectares for Matthaeus, 998 hectares for Meyrin and 36 hectares for Bellevaux), as well as the higher model complexity of the districts (detailed building shapes and typology, higher urban density).

The utilization potential of different solar technologies applicable to these urban sites (passive and active solar use, photovoltaic and daylighting) was assessed in several steps:

- Climate data of all sites were obtained from the Meteonorm database. They were processed statistically in order to build up representative average radiometric and photometric sky models [11];
- A site ground relief, as well as additional building features (surface reflectance), were incorporated in a 3D digital model of the urban sites;
- The models were processed by computer simulation (ray-tracing techniques) in order to determine the solar irradiation and daylight illuminance distributions on the buildings envelopes (facades and roofs);
- Finally, several performance indicators were calculated according to these distributions in order to determine the optimal solar energy utilisation strategy for urban sites (relative fraction of building areas appropriate to a solar technology, appropriate surface locations).

4. Solar performances indicators of urban sites

The density of urban areas largely affect the Sky View Factor (SVF), from which depend their cooling and daylighting potential. In a first analysis, the façade and roof corresponding values were calculated for the three sites. The urban feature of Matthaeus is responsible for a significant reduction of the sky fraction viewed by the buildings facades; most of the building facades (and roofs) are subject to rather unfavourable conditions. Consequently, SVF values lie between 20-50% for the facades and 80-100% for the roofs of Matthaeus. SVF values lie between 45-55% for the facades and 95-100% for the roofs of Meyrin and between 40-45% for the facades and 95-100% for the roofs of Bellevaux. This results show that Meyrin and Bellevaux definitely have more favourable conditions than Matthaeus.

The orientation rose [9] appearance is mostly reflecting the rectangular shape of buildings and their regular arrangement on the three sites. This graph shows the facades oriented in each direction: areas are aggregated into several azimuth sectors (15° wide each). The diagram takes into account that some facades may be highly obstructed and therefore fail to perform as potential solar collectors: it includes the SVF corrected area of the building facades and roofs. The Matthaeus and Bellevaux roses indicate that these sites are slightly more influenced by North-South/East-West azimuths (Fig. 7 and 11). For Meyrin, which is mainly occupied by long building rows, the orientation rose is clearly dominated by North-West South-East / North-East South-West directions (Fig. 9).

This is confirmed by the statistical distributions of the solar irradiation of the building facades and roofs (Fig. 8, 10 and 12). Minimal irradiation threshold was fixed at 800 kWh/m2 per year for PV facade systems (1000 kWh/m2 per year for roofs); these statistics show on the three sites that very significant fractions of building facades and roofs benefit from yearly irradiation and illuminance values are suitable for operating different solar technologies. Similar figures were drawn for the daylight illuminance distribution.

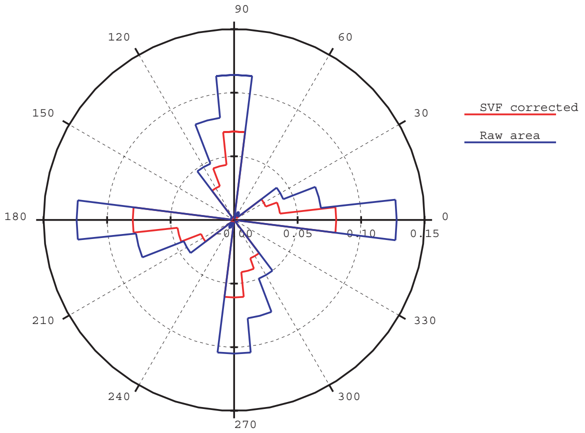


Figure 7: *Orientation rose of the overall building facades of Matthaeus (Raw area and Sky View Factor corrected).*

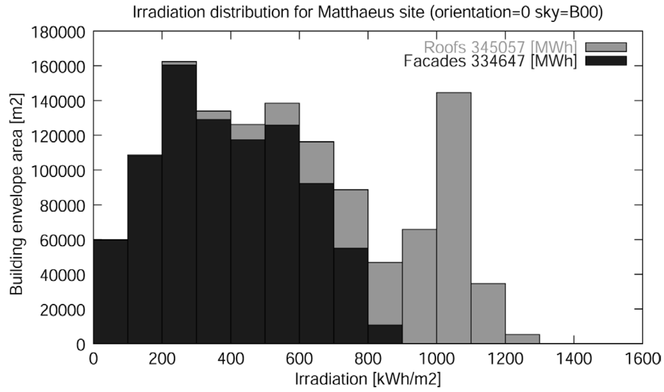


Figure 8: *Statistical distribution of yearly irradiation on the building facades and roofs of Matthaeus.*

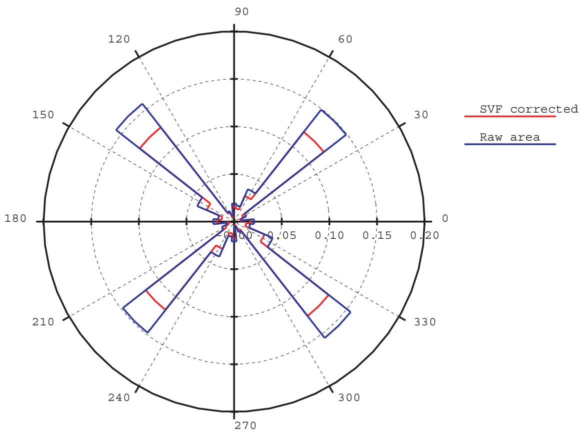


Figure 9: *Orientation rose of the overall building facades of Meyrin (Raw area and Sky View Factor corrected).*

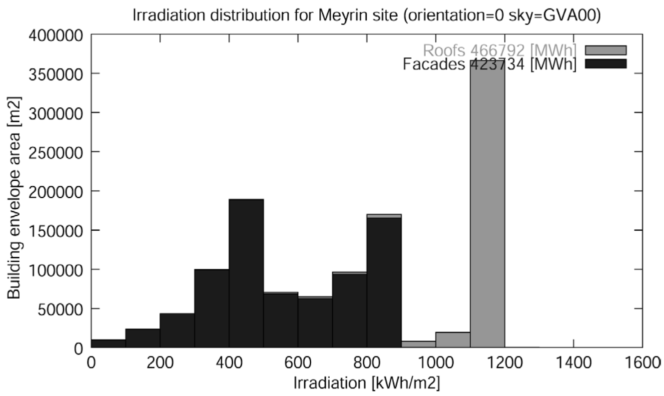


Figure 10: *Statistical distribution of yearly irradiation on the building facades and roofs of Meyrin.*

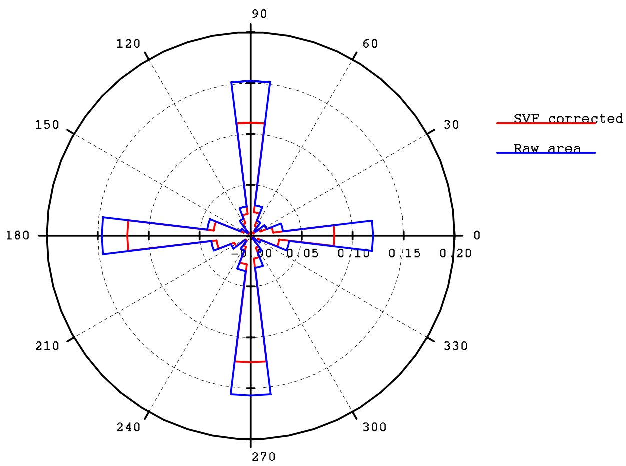


Figure 11: *Orientation rose of the overall building facades of Bellevaux (Raw area and Sky View Factor corrected).*

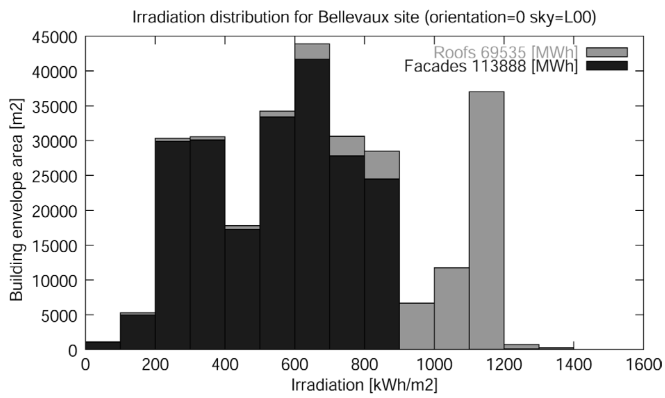


Figure 12: *Statistical distribution of yearly irradiation on the building facades and roofs of Bellevaux.*

Yearly thresholds themselves were determined according to procedures presented in detail in [10], based on the following assumptions:

- The minimal vertical irradiation required for passive solar leads to a positive energy balance for state-of-the-art glazings in the Basel (167 [kWh/m^2] for a heating season), in the Geneva (187 [kWh/m^2] for a heating season) and in the Lausanne climate (182 [kWh/m^2] for a heating season.
- The values required for active solar and photovoltaics, which differ for facades and roofs, correspond to the edge of normal operating conditions (e.g. 800 [kWh/m^{2}year] for PV in vertical facades and 400 [kWh/m^2 year] for active solar energy use).
- The mean illuminance required for side daylighting techniques on vertical openings (utilisation coefficient of 0.05) leads to a 500 Lux illuminance on a workplane (10 [kLux]) average illuminance required over the whole year).

Tables 4, 5 and 6 show that there is not much difference between Matthaeus, Meyrin and Bellevaux as regards the use of passive solar techniques. Values related to PV systems on facades differ in a very significant way: the potential is weak for Matthaeus facades (1.3%) and rises to 21.9% for Meyrin. These values remain relatively low compared with PV roofs which reach 49.4% for Matthaeus and 94.9% for Meyrin: Bellevaux' values are in-between those of Matthaeus and Meyrin.

The values observed for Meyrin are not surprising: daylighting figures reach 78.5% for Meyrin, while it amounts to 70.2% for Bellevaux only 51.1% for Matthaeus: Meyrin's roofs are particularly free from shadows from surrounding buildings.

These values confirm what was mentioned on Meyrin's construction bases (modern city theory [3]): this settlement is definitely more favorable to solar and daylight utilization than Bellevaux and the Matthaeus medieval fabric.

Considering however the very large facade and roof areas of these urban areas; a very significant part of the surfaces remains appropriate for solar technology. This is true in spite of Matthaeus' urban character, which is less favourable than Meyrin in all the stated points (Table 7).

5. Conclusion

Preliminary assessments of the overall utilisation potential of solar energy in urban contexts are necessary to achieve a sound and reasonable implementation of these technologies in large cities. Such an evaluation has been undertaken in Switzerland for three different urban sites:

- Matthaeus/Basel-Stadt
- Meyrin/Geneva
- Bellevaux/Lausanne

The solar potential of the three sites differs, though not drastically: the smallest difference appears for passive solar techniques level (+ =14,6%), the largest concerns the PV facades (+ =45%).

The differences are explained partly by the morphological fabric of these three districts. That of Matthaeus consists of imperfectly formed island sites with gardens of often large surfaces in the center. This checkerboard plan is organized with variably dimensioned streets of which some are rather narrow (urban canyons), while in Meyrin and Bellevaux urban bars are surrounded by green parks directed by long broad avenues.

A very significant part of the building facades and roofs is appropriate for various solar technologies (excepting PV systems on facades in Matthaeus). A drastic reduction of non-renewable energy consumption of these urban sites, as targeted within the framework of the "2000 Watt Society" project, can reasonably be envisaged as a consequence.

Solar technology	Passive*	Active	PV	Daylighting**
Relative fraction				
Facade area	31.9%***	46.7%	1.3%	51.1%
Roof area	-	92.2%	49.4%	-
Required minimal treshold				
Facade	167 [kWh/m2]	400 [kWh/m2]	800 [kWh/m2]	10 [kLux]
Roof	-	600 [kWh/m2]	1000 [kWh/m2]	-

Table 4: *Relative fraction of building facade/roof areas appropriate for a given solar technology in Matthaeus.*

Solar technology	Passive*	Active	PV	Daylighting**
Relative fraction				
Facade area	46.5%***	76.7%	21.9%	78.5%
Roof area	-	99.2%	94.9%	-
Required minimal treshold				
Facade	187 [kWh/m2]	400 [kWh/m2]	800 [kWh/m2]	10 [kLux]
Roof	-	600 [kWh/m2]	1000 [kWh/m2]	-

Table 5: *Relative fraction of building facade/roof areas appropriate for a given solar technology in Meyrin.*

Solar technology	Passive*	Active	PV	Daylighting**
Relative fraction				
Facade area	58.2%***	68.7%	11.7%	70.2%
Roof area	-	96.1%	73.1%	-
Required minimal treshold				
Facade	182 [kWh/m2]	400 [kWh/m2]	800 [kWh/m2]	10 [kLux]
Roof	-	600 [kWh/m2]	1000 [kWh/m2]	-

Table 6: *Relative fraction of building facade/roof areas appropriate for a given solar technology in Bellevaux.*

* *Calculation over the heating season*

** *Yearly calculation for a 8h00 to 18h00 daylight period*

*** *η = 0,7 Utilisation Factor of Solar Energy*

Surfaces	Matthaeus (Basel)	Meyrin (Geneva)	Bellevaux (Lausanne)
District area	59.1 hectares	998 hectares	35,6 hectares
Total vertical area	858’030 [m2]	754’944 [m2]	210’858 [m2]
Irradiation facades	334'647 [MWh]	423'734 [MWh]	113’888 [MWh]
Horizontal roof area	373’365 [m2]	406’765 [m2]	67’803 [m2]
Irradiation roofs	345'057 [MWh]	466'792 [MWh]	69’535 [MWh]

Table 7: *Districts, facade and roof areas and yearly irradiation.*

6. Literature / References

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