SOLURBAN Project

Solar Utilisation Potential of Urban Sites

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1 Introduction

In an effort to reduce fossil fuel emissions and associated climate change, there is an increasing desire to reduce the net energy consumption of buildings. This can be achieved both by reducing the demands for applied energy and by utilising renewable energy conversion technologies – the better utilisation of solar energy can contribute to both of these objectives.

Now in 2000, around 47% of the World's population lived in urban areas, with more developed countries being around 76% urban, and the trend is set to increase; consequently, around 60% of the global population is expected to be urbanised by 2030. Paradoxically, the potential for utilising solar resources is reduced in urban settings due to obstructions to the sky and sun (and city densities are rising). It is therefore important that the spatial availability of solar resources be studied to identify suitable utilisation strategies.

To this end the present study is concerned with the utilisation of daylight and solar radiation to reduce demands for lighting and heating and the conversion of solar radiation to provide electricity and heat for hot water. Called Solurban, this project investigates three Swiss districts within the cities of Basel, Geneva and Lausanne. This is based on simulations of solar and daylight quantities using Monte Carlo ray tracing methods (using the software RADIANCE), via the software tool PPF, which was extended in scope during this project.

2 Selected urban sites

At the beginning of the project, three national sites were chosen in collaboration with the Swiss Federal Office of Energy (SFOE), to cover the range of latitudes as well as a variety of building and morphological typologies. More specifically, we set out to choose sites of predominantly (i) pre-war residential buildings, (ii) post-war tenement social housing, and (iii) a relatively new multi-use district. This, together with the desire for sites with good refurbishment potential, resulted in the selection of the district of Matthaeus in Basel (north), Bellevaux in Lausanne (central) and Meyrin in Geneva (south)

2.1 MATTHAEUS DISTRICT: BASEL

Adjacent to the River Rhine, the district of Matthaeus has evolved from a mediaeval town at the frontier between Switzerland, France and Germany (Figure 1). Towards the end of the 19th century many of the town's walls were dismantled and its ditches filled, to make way for new construction. Public greens were also created on the site of the old fortifications, the main roads were improved and new streets were built, resulting in a predominantly orthogonal layout. A further concentrated period of development activity took place during the City's industrialisation period at the first half of the 20th Century to accommodate chemical, pharmaceutical and watch making firms. Matthaeus now has one of Switzerland's highest population densities, accommodating some 48% of the inhabitants of Basel within mainly 4-5 storey housing blocks. Around two-thirds of these are pre-war buildings which also accommodate small shops (Scartezzini et al, 2002).

An additional reason for choosing Matthaeus is that it has been selected by the Canton of Basel-Stadt as a pilot site for implementing the "2000W Society Programme". This is an ambitious program, devised by the Council of the Swiss Federal Institute of Technology (Kantons Basel-Stadt, 2001), aiming to reduce net mean energy use per capita from 6.5kW (the global average) to just 2kW. It is intended that a large proportion of this will be realised by reducing domestic energy consumption due to buildings and transport.

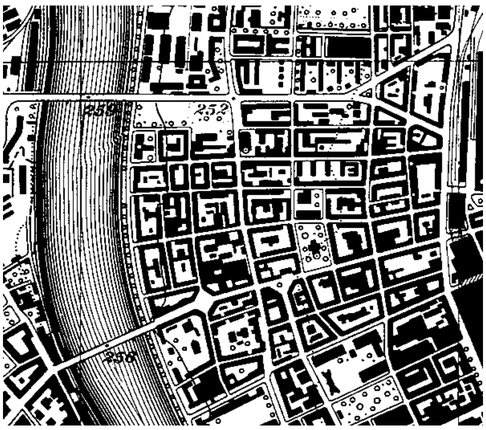


Figure 1: Matthaeus: site plan and illustrative photograph of a typical urban street

2.2 BELLEVAUX DISTRICT: LAUSANNE

The district of Bellevaux 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. Between the 12th and 20th Centuries the district included a Cistercian monastery, but the district is now almost exclusively residential. The site is composed of predominantly three to five storey tenement buildings, over three quarters of which were constructed during the post-war period1947-1970. The total 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 spaces could in principal support further densification without adverse environmental consequences, see Figure 2.

Figure 2: Bellevaux: site plan and illustrative photograph

2.3 MEYRIN DISTRICT: GENEVA

An agricultural village of fewer than 1000 inhabitants prior to World War One, the district of Meyrin, located 9 km from the centre of Geneva with an area of 998 hectares, was conceived as a satellite town for Geneva; representing one of the few examples of sixties functionalist town planning in Switzerland. Built at the edge of the city, between the airport and CERN (the European Centre for Nuclear Research) Meyrin accommodates a variety of industrial research centres, which represent 26 000 employment positions for a total population of 20 500 inhabitants.

Benefiting from the evolution of the economic attractiveness of Geneva, Meyrin has experienced intensive growth for more than a decade and comprises industrial estates, malls and tenement buildings, more that 70% of which have been developed since the 1960s. Furthermore, owing to local development pressure and a lack of available land, the urban density of Meyrin (Figure 3) is set to further increase.

Figure 3: Meyrin: site plan and illustrative photograph

The key statistics characterising these three districts are summarised in Table 1.

Characteristics	**Matthaeus, BS**	**Bellevaux, VD**	**Meyrin, GE**
Ground surface area, Ha	59.1	35.6	998
Population, people	15 300	4 600	20 500
Topography	light slope	sloping	slightly undulating
Key development phase	66% pre 1945	75% in period 1947-1970	70% post 1960

Table 1: Characteristics of the three different urban districts

3 Calculation methodology

Early work on the subject of solar energy planning involved the use of approximate manual calculation methods, to advise on site layout for solar access. With improved computing power and interface design many of these methods were developed in software form, though the basis of the underlying calculations remained fairly approximate. Spawned predominantly by the gaming and movie industries however, considerably more sophisticated "Numerical Simulation" methods have recently been developed within the computer graphics domain. These numerical simulation programs provide a basis for representing a realistic sky brightness distribution as well as the sun and the effects of multiple reflections (both diffuse and specular) from urban obstructions of arbitrary complexity.

There are two approaches to numerical simulation of radiation exchange: radiosity and ray tracing. The former essentially involves discretising the surfaces within the computational domain and solving initially for exchanges between light source(s) and receiving cells and then for successive exchanges between these cells, assuming diffuse reflection characteristics (see Cohen and Wallace (1993) for a detailed explanation). The latter may be either forward or backward, but for the backwards case rays are spawned from surfaces within an observer's visual field (the image to be rendered) initially towards light sources and subsequently within the ambient environment, based on monte carlo sampling. This is a recursive process, so that once a reflecting surface is encountered, this too spawns rays. The process continues according to pre-defined image quality settings (such as minimum distance between sample points (affecting interpolation) and number of ambient bounces) have been reached (see Ward Larsen and Shakespeare (1997) for a detailed explanation). Numerous software tools have evolved which utilise radiosity and ray-tracing algorithms as well as hybrids between them. Several studies have compared the methods on the basis of accuracy (Mardaljevic, 1995) and usability (Ashmore and Richens, 2001), but the freeware ray tracing program RADIANCE (Ward Larsen and Shakespeare, 1997), and interfaces to it, consistently outperforms competing tools and is commonly used to produce high quality renderings (and associated quantitative results) for snapshots in time.

The power of numerical simulation has recently been exploited to excellent effect in the current context to predict solar irradiation. In one early study this was based on performing hourly simulations (Kovach and Schmid, 1996). Subsequent work focussed on ways of reducing the computational expense of this useful form of analysis. For example, Mardaljevic (2000, 2003) used image processing techniques to construct long time series (e.g. annual) results from a statistical subset of hourly simulations. Resultant falsecoloured images then help with visual diagnosis, such as identifying potential for the use of solar energy conversion technologies. An alternative method, introduced by Compagnon (2000, 2004), involves the rather quicker statistical pre-processing of the sky radiance distribution, as opposed to the post-processing of simulation results. The resultant synthetic sky can also be used to produce falsecoloured images, but the main aim is to produce results for a set of grid points, slightly offset from the normal of the set of built surfaces in an urban scene. Although this involves a large number of hourly simulations (potentially more than the technique due to Mardaljevic, depending on the size and complexity of the urban scene), the results from this set of 'virtual pyranometers' can be processed, for example to produce solar irradiation and daylighting illuminance histograms (c.f. Figures 5-7). These solar-morphology fingerprints provide *a priori* information regarding the relative effectiveness of alternative designs. Furthermore, they may be combined with energy thresholds to quantify the proportions of built surface that exhibit potential for passive and active solar or daylight utilisation. Falsecoloured images can also be thresholded (c.f. Figure 8) to identify where this potential exists (Compagnon 2004, Robinson 2004). It is for these reasons that this cumulative sky based modelling of irradiation and illumination was employed within this project to study the three case study sites, using the software tool due to Compagnon, called PPF.

3.1 PPF SOFTWARE

The 3D geometry of some neighbourhood, once defined using a 3D modelling tool such as AutoCAD, is imported into PPF in DXF format and translated into its native ASCII format. Some basic computations are carried out in this format, for example to deduce total built floor area (using specified or deduced numbers of storeys). A further translation is then performed to produce a model in the format required by the extensively validated (e.g. Mardaljevic, 1995) ray tracing program RADIANCE (Ward-Larson and Shakespeare, 1997) to which the sky model is also parsed.

A set of performance related quantities are calculated by PPF in order determine the potential of urban sites to utilise different radiation-based technologies (passive and active solar and daylighting), for which different sky types are required.

Firstly, to assist with results interpretation and potentially to inform judgements regarding longwave radiation exchange potential (e.g. for radiant cooling of buildings) a uniform overcast sky is described. Integrating the energy received per unit sky over the hemisphere we have an irradiance I ($W.m^{-2}$)of πR, for radiance R ($W.m^{-2}.Sr^{-1}$). For a unit radiance sky we can therefore calculate a **sky view factor** as I/ . In contrast to this continuous treatment of sky brightness, to determine **annual solar irradiation** the sky is represented as a set of 145 sky zones, each represented as a discrete but relatively large light source (i.e. of solid angle not much less than $2\pi/145$). The radiance of each sky zone is the cumulative radiance over the period of interest, so that the units are $Wh.m^{-2}.Sr^{-1}$. When calculated over the duration of the heating season we describe the sky required to calculate the **heating season solar irradiation**. Furthermore, in multiplying the former values by a relevant luminous efficacy and dividing the corresponding results by the number of daylight hours, we have the sky required to calculate **annual mean illuminance**.

When used in conjunction with various thresholds, results from calculations performed using these skies contain all of the information required by the present project. For example, results can be processed to determine the area and proportion of built surface for which solar photovoltaic panels, solar thermal collectors, passive solar systems and photoresponsive artificial lighting are viable (the basis upon which these judgements are made is discussed in section 4).

However, several modifications needed to be made to PPF to handle the large scale of the urban districts under examination within this project (up to almost 1000Ha) as well as different 3D model formats and combinations of building and site topography models. Furthermore, a separate easily programmable post-processor has been developed at EPFL to provide greater flexibility for results analysis, rather than relying upon continuous modification and re-compilation of PPF.

3.2 DESCRIPTION OF 3D DIGITAL MODELS

The Land Register and Surveying Office of Canton Basel-Stadt (Grundbuch und Vermessungsamt) has a digital model of the entire Canton at its disposal, derived from aerial photogrammetry. From this the vertex coordinates of surfaces with a minimum dimension exceeding 3m are defined, along with the order in which they are connected as an homogeneous solid. A computational routine was written to modify the data files relating to the district of Matthaeus which contain this information, so that individual surfaces could be distinguish from one another. In other words the model was re-configured into 3D-FACE format. This was needed so that results from PPF could be interpreted in a way that would relate the received energy to the orientation and tilt of a specific surface plane. See Figure 4 top.

The City of Lausanne does not have a relevant 3D digital model at its disposal, so that it was necessary to construct a new 3D model for this project. Using data recorded on microfilm by the Archives de la Construction Moderne (ACM) of EPFL, as well as written records from the City of Lausanne, sloped and flat roof surfaces were defined. These surfaces were then extruded vertically down and intersected with a 3D topography model, based on digital data provided by the Swiss Federal Office of Topography (SWISSTOPO) in the form of digitised 1:25 000 maps. This required some modifications to the PPF software. The results were stored in such a way that each building could be individually identified, supporting standalone building analyses if required. See Figure 4 middle.

The appropriate office of the Canton of Geneva (Service d'Information du Territoire Genevois) provided a digital model in MNT25 (Modèle Numérique du Terrain, derived from 1:25 000 digitised maps) format of the ground surface. A separate file GRID-MNS (Modèle Numérique du Surface) describes the entire terranean / superterranean (built only) surface. Algebraic subtraction of GRID-MNS from MNT25 therefore leaves the built surfaces. Unfortunately however, the GRID-MNS model is somewhat crude, so that sloped surfaces of buildings are not defined. As such, the 3D model used in this project suffers from the same drawback. Fortunately however, the majority of buildings have flat roofs. See Figure 4 bottom.

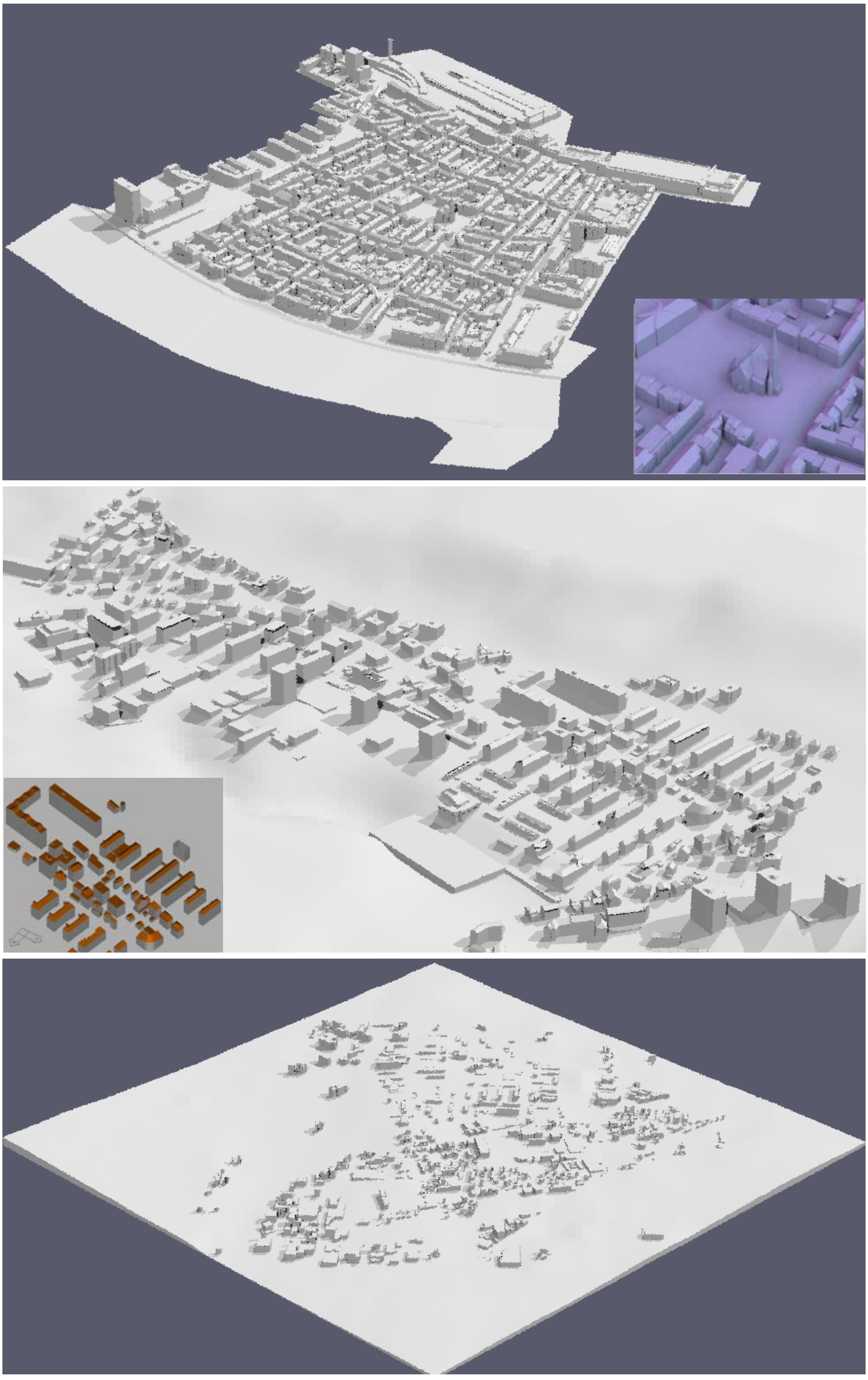


Figure 4: 3D models for Matthaeus (upper), Bellevaux (middle) and Meyrin (lower)

4 Results

4.1 IRRADIATION AVAILABILITY AND SKY ACCESS

The key output from PPF is the solar irradiation histogram. Shown in Figure 5 for example, is that for Matthaeus, with black areas relating to façades and grey to roofs. Façade irradiation here is reasonably normally distributed around 400kWh.m^{-2}, but with an annual global solar irradiation on the horizontal plane exceeding 1 200kWh.m^{-2}, this is rather low. In contrast with the facades, the roofs of Matthaeus are relatively unobstructed, with the highest frequency of surfaces receiving 1 100 kWh.m^{-2}. However the distribution has a long tail towards the low end of the irradiation scale, suggesting that some low roofs are heavily obstructed. From the view factor corrected surface area rose, it is evident that there is a slight bias towards N/S aligned buildings (i.e. with longer façades facing E/W).

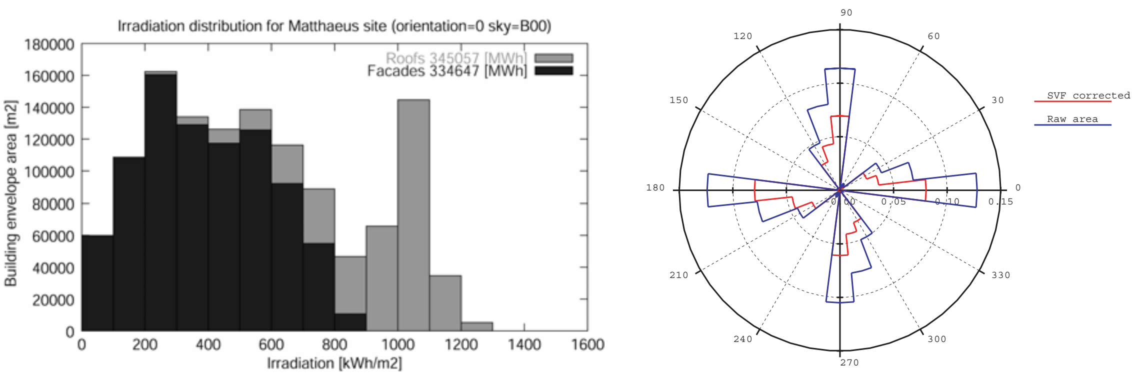


Figure 5: Matthaeus: Irradiation histogram and cumulative irradiation / sky view factor rose

For the Bellevaux district the dominance of the N/S road axis is similar. However, with a lower site density and buildings of relatively few storeys, the sky views, solar access and as such the annual irradiation are relatively higher. A dampened tail for the roof irradiation distribution indicates a reduced tendency for relatively low and overshaded roofs.

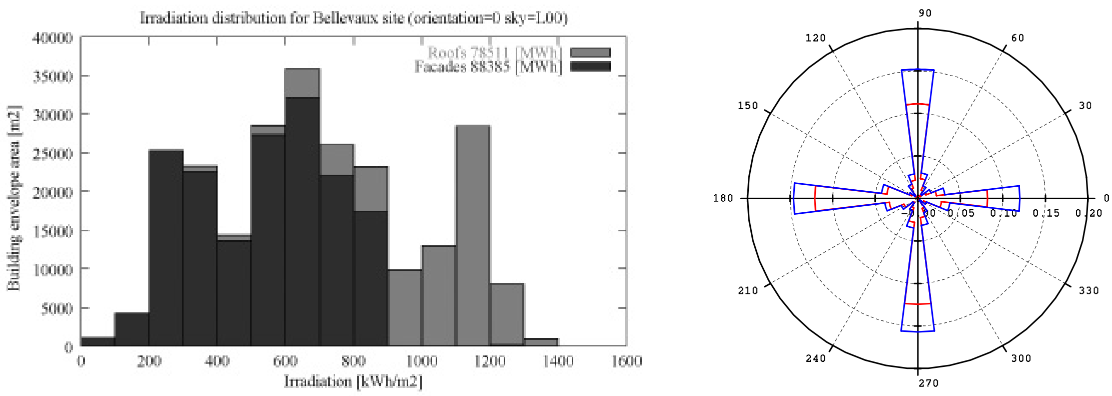


Figure 6: Bellevaux: Irradiation histogram and cumulative irradiation / sky view factor rose

For Meyrin the trend in results is rather different (Figure 7). The buildings are oriented along the North East, South West axis. Interestingly, the orientation of long façades varies with some of the larger buildings arranged in groups at right angles to one another. Furthermore, these large buildings are relatively high at nine storeys, so that despite the relatively generous spacing there remains reasonable overshading. A bi-modal distribution is clearly distinguishable, with peaks in the ranges 300-400 kWh.m^{-2} and 700-800 kWh.m^{-2}, reflecting the dominance of long surfaces oriented within 45° of South and North respectively. The same is also true, to a lesser degree, for Bellevaux reflecting the distinction between South and East/West collecting surfaces. The low density of the site is reflected in a uniformly high view factor for the range of orientations.

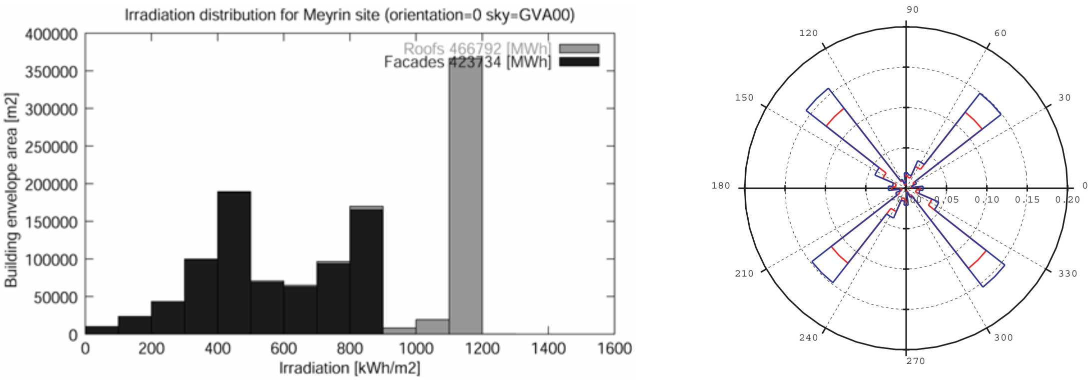


Figure 7: Meyrin: radiation histogram and cumulative irradiation / sky view factor rose

4.2 ACTIVE SOLAR TECHNOLOGIES

Following consultations with experts in the field of solar collector installation, a series of thresholds of annual irradiation incident on façades and roofs have been identified, beyond which a given technology is likely to become economically viable for that type of location. Regarding photovoltaics (PV), thresholds of 800 and 1000 $kWhm^{-2}$ were adopted for vertical façades and roofs respectively. The lower figure for façades reflects the economic advantages of utilising the PV panels as a form of cladding and also the relative ease of services integration in this location. For solar thermal collectors the lower figures of 400 and 600 $kWhm^{-2}$ were adopted for façades and roofs respectively, owing to the generally reduced cost of this type of collector. The rationale behind the differential between façades and roofs is similar to that for PV.

Based on these, for Matthaeus just 1.3% and 49% of the façade and roof surfaces respectively are viable for the integration of PV, though this increases to around 47% and 92% of the associated surfaces in respect of solar thermal collectors. At Bellevaux the façades receive considerably more irradiation, so that the fractions of PV viable surfaces are 11.7% and 65% respectively, increasing to 68% and 96% in the case of solar thermal technologies. At Meyrin the fraction of PV viable surface areas corresponds to 22% and 95% for façades and roofs – this latter reflects both the uniformity of building heights and the low density of the site. For solar thermal collectors this increases to 77% and 99%.

By using a Boolean filter, so that only pixels exceeding a given value are coloured, surfaces of the building envelope which are viable for a given solar technology can be visually identify *a-priori*, ensuring that installations respond correctly to the available energy. Figure 8 for example presents thresholded images of this type, together with a falsecolour irradiation image, for all three districts.

A full set of falsecolour and thresholded images is available from LESO-PB. As an example, see further results relating to Matthaeus in the Appendix.

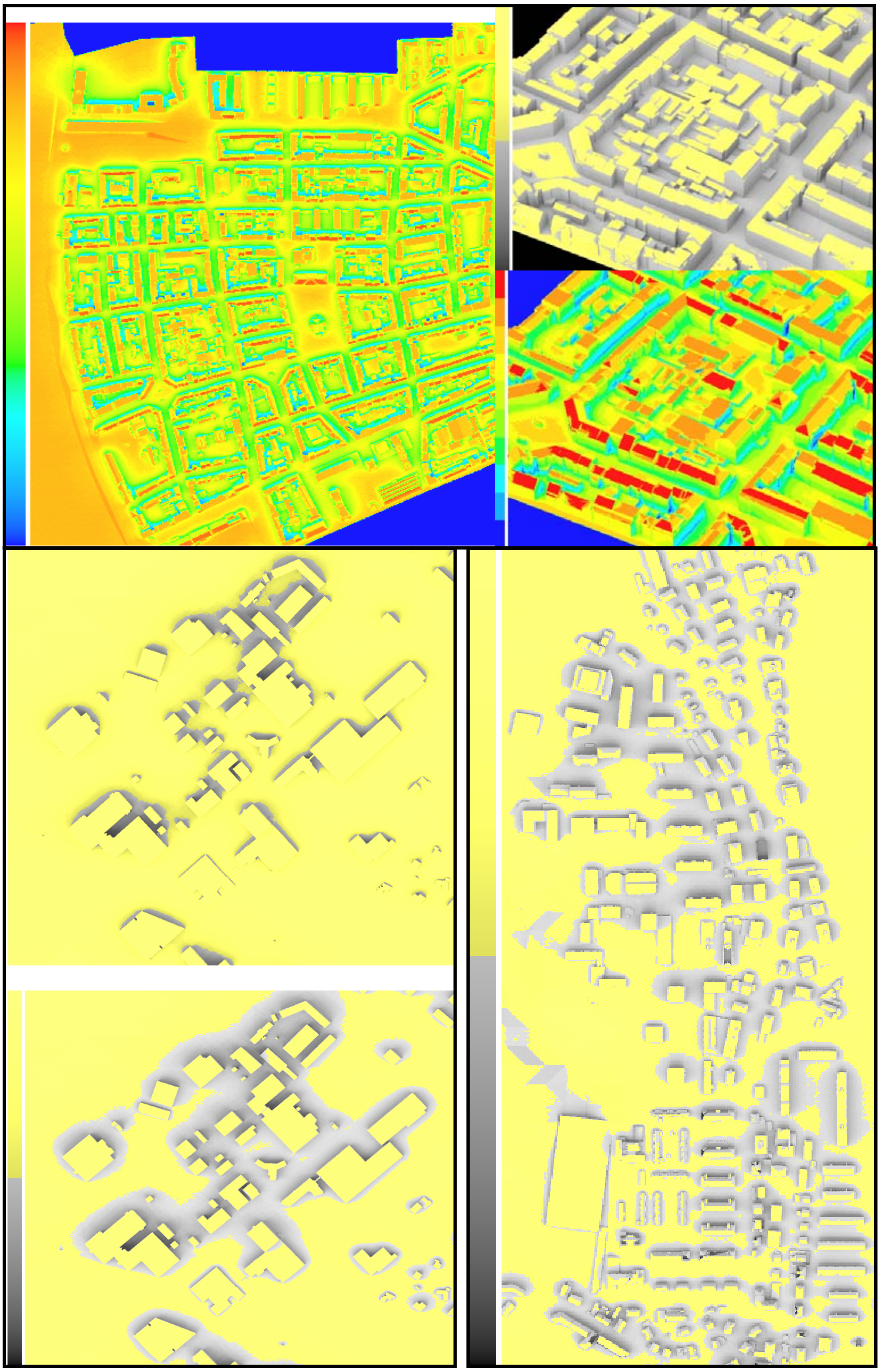


Figure 8: Falsecolour images and thresholded images using a Boolean filter. Top: Continuous falsecolour, discretised falsecolour (with 100kWh.m^{-2} subdivisions) and threshold image relating to façade-integrated PV. Lower left: Plan view illustrating areas solar thermal (above) and PV (below) collector viability for horizontal surfaces at Meyrin. Lower right: Roof-mounted PV threshold image for the entire Bellevaux site.

4.3 DAYLIGHTING AND PASSIVE SOLAR GAIN

Provided that the total useful solar irradiation transmitted through a glazed element into a heated space exceeds the heat lost through this element, then it will be viable in energy terms to utilise passive solar gain, so long as this does not lead to unwanted cooling loads. Ignoring infiltration losses, this passive solar threshold may be determine from the expression: $PST = 0.024DD \cdot U/g\eta$ (kWh.m^{-2}), for heating degree days *DD* (d°C), glazing thermal transmittance *U* (Wm^{-2}K^{-1}), glazing total solar transmittance *g* (-) and solar utilisation coefficient (-), to account for the fraction of solar gains which are not useful in reducing heat energy demands (i.e., this leads to temperatures exceeding the set-point or a space is deliberately ventilated to prevent this from happening), after Compagnon (2004).

U and *g* values of 1.3 and 0.75, typical of efficient double glazing, and a solar utilisation coefficient of 0.7, corresponding to a thermally massive building and LTHW radiators, are assumed. Using heating season degree days of 2 810 for Matthaeus, 3 063 for Bellevaux and 3 146 d °C for Meyrin, the corresponding thresholds are 167kWh.m^{-2}, 187kWh.m^{-2} and 182kWh.m^{-2} respectively, based on irradiation simulated for the heating season only. This leads to percentages of façade area for which passive solar gain is viable of 32%, 55% and 47% for Matthaeus, Bellevaux and Meyrin.

It is not considered necessary to define an upper threshold beyond which passive solar gains constitute a significant risk of overheating, subsequently leading to a cooling energy demand. This is because, especially in the temperature climate of Switzerland, such a risk may be abated by appropriate façade and solar shading design. In other words glazing which is promoted during winter to offset heating demands can be protected during summer to avoid unwanted overheating / cooling demands.

Finally, one may calculate a vertical illuminance threshold (IT), for example to judge the viability of a given daylighting design and / or of utilising daylight responsive lighting controls. If the performance of a given daylighting design is expressed in terms of a daylight utilisation coefficient, expressed as the mean fraction of vertical illumination (Fi) which is received on the internal working plane, then our illuminance threshold may be expressed as the quotient of a design internal illuminance Ei and Fi (IT= Ei /Fi). Assuming an internal design illuminance of 500Lux and a utilisation coefficient of 0.05 (typical for a vertical opening) the external illuminance threshold is 10 000 Lux. On this basis, with external illuminance calculated based on a mean anisotropic sky luminance distribution using the model due to Perez et al (1993), we find that 51% (Matthaeus), 70% (Bellevaux) and 78% (Meyrin) of façades have good daylight potential.

4.4 DISCUSSION OF RESULTS

Impact of thresholds

The thresholds used in this project have been defined on a pragmatic basis. For daylight we define a required external illuminance based on standard figures for required internal illuminance and daylighting utilisation. For direct solar gain we are able to calculate a heating season irradiation required to achieve a gains loss ratio greater than unity for a reasonable performing window, so that the glazing tends towards a net source of thermal energy. The thresholds for active solar collectors contain an element of subjectivity – based on consultations with experts we have identified a safe quantity of irradiation beyond which the collectors will be economically viable. The values for horizontal surfaces reflect the cost of the technology and the value of the energy produced (thermal or electric). For both technologies the thresholds are lower for façades, reflecting the cost saving due to façade integration (reduced cladding and piping / cabling costs). However, to provide the reader the option of testing alternative thresholds, a full set of curves have been produced relating threshold to viable proportion of surface area (Figure 9).

A 10% variation in the threshold for façade integrated solar thermal and photovoltaic collectors leads to a changes of approx. 5% and 10% respectively in applicable surface. Roof integrated solar thermal collectors are essentially insensitive to this threshold. However, the viability of roof-integrated photovoltaics is very sensitive to the same change in this threshold, depending upon the site density, with Matthaeus being the most sensitive.

The thresholds discussed thus far relate to a theoretical potential. In reality protrusions from roofs such as chimneys or glazing in façades and roofs reduces the amount of usable area for active solar collectors. For roofs a reasonable estimate for the useable fraction is 0.8 (as used during the European PRECis Project) whereas this might be as low as 0.6 for façades (assuming a glazing ratio of 30-40% for domestic properties). Multiplying the theoretical percentage areas obtained from using the relevant thresholds by this usable fraction then defines a practical potential percentage area. However, the figures quoted assume that the active solar technologies will be directly embedded within the surface of interest. Whilst this is reasonable for façades, many roofs offer the prospect of inclining / orienting the panels towards the optimal tilt and orientation. In this way both the yield and viable surface area will increase, typically by 20-25% (Robinson, 2003), compensating for losses in area due to practical constraints. As a consequence, the theoretical threshold results may therefore be taken as they are for roofs, whereas those for façades should be adjusted to account for practical constraints.

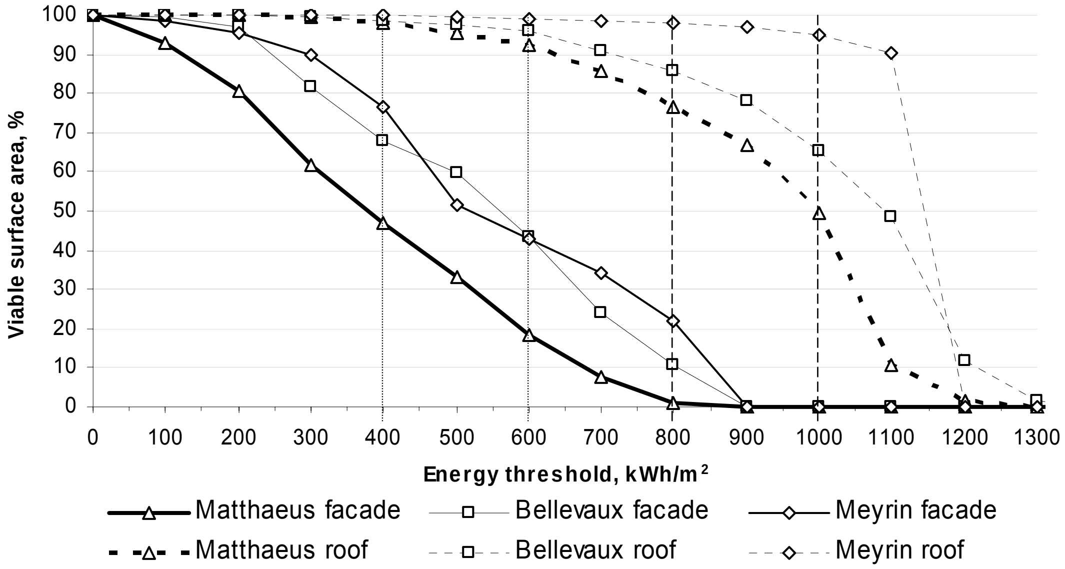


Figure 9: Viable surface area as a function of active solar technology energy threshold, showing threshold (dotted (thermal) and dashed (PV) vertical lines)

Impact of site density

To curb urban sprawl there is an increasing demand for further densification of urban areas. There have also been numerous controversial debates arguing for further densification on the basis of (net) energy consumption. It is interesting therefore to explore the results in relation to site density to identify whether any interesting relationships emerge. For this a common measure of site density is the plot ratio: "the ratio between the floor area or areas of a building or buildings and the site area upon which such development is to take place".

The mean vertical irradiation is essentially linearly related to plot ratio (Figure 10) and curves for both daylight and solar thermal collector viability follow a similar trend. Since solar thermal requires a factor of three to four more energy for viability than for daylight, the proximity of the curves suggests these are close to a practical maximum – the remaining surfaces are very heavily obstructed. PV requires a comparably high energy threshold and is therefore sensitive to direct solar irradiation, hence the sensitivity between Bellevaux and Meyrin. However, this may be somewhat dampened by the lack of surfaces oriented close to South. Indeed, the effect of the bias of surface orientation towards SE and SW is clearly apparent in the passive solar results, since these relate only to the heating season – fewer surfaces achieve a balance between thermal gains and losses. In terms of balancing density needs with energy performance it would seem that for these sites, if all technologies are weighted equally, then there is an approximately linear relationship and no clear area of sensitivity to avoid can be observed. However, if we are to optimise for technologies requiring relatively high values of irradiation then penalty in moving from medium (Bellevaux) to high (Matthaeus) would appear to be greater than from low (Meyrin) to medium, so that the former should be targeted, if required.

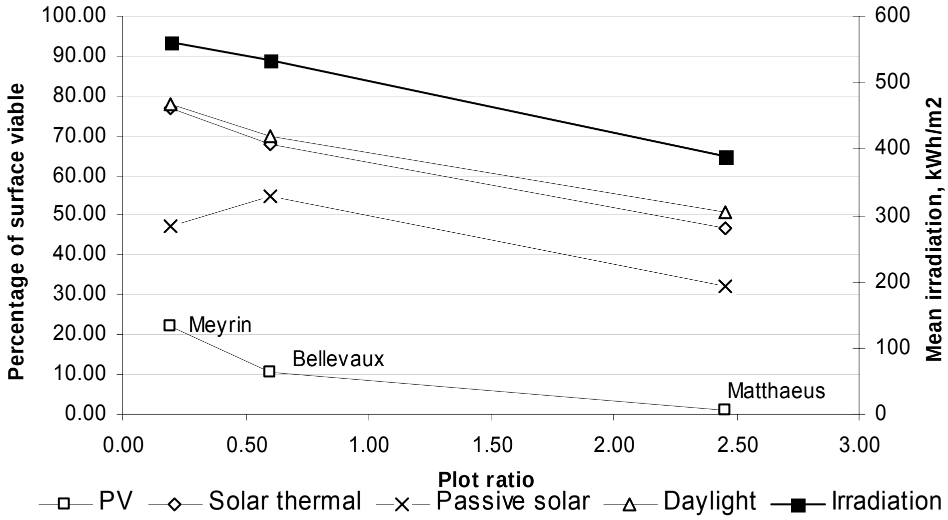


Figure 10: Relationship between radiation technology potential within façades and site density, expressed as plot ratio

<u>Potential solar contribution to building energy consumption</u>

Using average Swiss building energy consumption statistics (Wick, 1984) to predict energy demands for hot water and electricity (not including incidences of electric heating) and assuming an efficiency of utilisation of incident solar radiation of 0.4 and 0.12 for solar water heaters and photovoltaic panels respectively, we find that the energy contribution from installing these solar technologies on roofs alone can offset 310±75% and 52±16% of the respective energy requirement. This is based on analysis of all three districts (hence the range of results) which consume an approximate total of 2430, 360 and 590 TJ heating, hot water and electrical devices respectively.

Now, assuming that solar water heating is installed to fully match the associated energy needs (e.g. it is curbed at 100%), the remaining area for photovoltaics will suffice to meet 36±14% of the electrical energy needs. A further 18±7% can be met using façade-integrated PV. So with no demand-side improvements active solar conversion technologies alone can fully match the requirements for domestic hot water and can provide more than half of the required electrical energy. Even in the absence of other improvements, the demand for electrical energy can be significantly reduced by exploiting daylight responsive lighting controls. Finally, if we install solar thermal collectors into the remaining area of our façades with a similar utilisation coefficient as for use with domestic hot water, we may meet 27±14% of our heating energy requirement. This proportion could be even higher with the targeted utilisation of direct solar gain.

The potential for solar technologies to reduce emissions due to the consumption of non-renewable energy in cities is therefore considerable and is frequently underestimated.

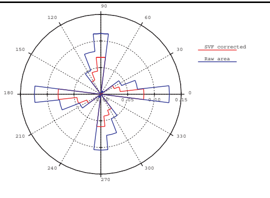
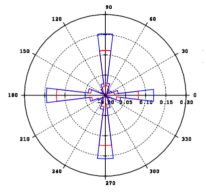
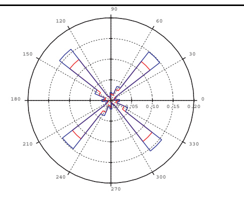
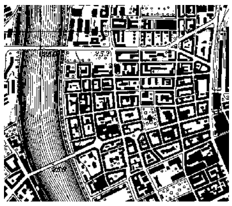
		Matthäus, Basel	Bellevaux, Lausanne	Meyrin, Geneva
				
				
Mean sky view factor (vertical surfaces)		0.29	0.37	0.39
Mean urban horizon angle (vertical surfaces), deg		25	15	13
Mean height to width ratio (vertical surfaces)		0.47	0.27	0.23
Mean annual vertical surface irradiation, $kWh.m^{-2}$		390	540	560
Plot ratio		2.44	0.50	0.19
PV viability, %	Façade	1	11	22
	Roof	49	65	95
Solar thermal viability, %	Façade	47	68	77
	Roof	92	96	99
Passive solar viability, %	Façade	32	55	47
	Roof	91	96	99
Daylighting viability, %	Façade	51	70	78
	Roof	99	99	100

Table 2: Summary of results for Matthäus, Bellevaux and Meyrin.

5 Conclusions

The aim of the Solurban project was to apply radiation modelling techniques to evaluate the potential of Swiss cities to utilise (visible and shortwave) solar radiation, in the form of daylighting and passive and active solar technologies. The purpose here is to support efforts to improve the environmental performance of the existing building stock in these cities and reduce the related greenhouse gas emissions. For this an interface to the ray tracing program RADIANCE has been used to analyse the three urban sites of Matthaeus (Basel), Bellevaux (Lausanne) and Meyrin (Geneva). Called PPF this predicts annual solar irradiation, heating season solar irradiation and mean illuminance for a series of points throughout 3D models of urban neighbourhoods. From this analysis the following conclusions can be drawn:

- The viability of façade integrated photovoltaics is poor throughout the urban sites studied (1-22%). Indeed, due to the extent of overshading even roof integrated PV is only viable for around half of the surfaces within Matthaeus (49%), though viability elsewhere is good (65-95%).
- Façade integrated solar thermal collectors are viable for around half of the vertical surfaces in Meyrin (47%) but for more than two thirds elsewhere (68-77%). Potential for roof integrated solar thermal collectors is universally excellent (92-99%).
- Potential for use of daylight technologies in daylit spaces follows a similar trend to thermal collectors.
- On the basis of contributing a net source of thermal energy, potential for direct solar gain is lower (32-47%), with only Bellevaux exceeding half of viable vertical surfaces (55%).
- A mechanism has been described to translate these theoretical figures into practical solar potential, by accounting for losses in available surface are due to practical constraints relating to glazing and surface protrusions such as chimneys. Means have been described by which one can investigate the implications of alternative viability thresholds.
- Furthermore, a detailed set of images has been produced to support the targeting of specific surfaces for investments in solar and daylight technologies. The question of which technologies to choose for a specific project is a question of matching energy supply with demand and the capital resources available – issues which are beyond the scope of this project on establishing energy saving *potential*. The falsecolor images produced by this project can nevertheless be used to target areas to be subjected to a more detailed feasibility study.
- Based on historical Swiss energy demand statistics, estimates suggest that solar thermal collectors are fully able to match the energy demands for domestic hot water and around a quarter of the heating needs of the average Swiss city. Building integrated PV is able to contribute more than half of the electrical energy demand. There is also ample scope for utilising daylight to displace energy use for electric lighting and direct solar gains to reduce demands for space heating.
- If implemented in conjunction with demand-side reductions, these results indicate that if the fullest use is made of available solar and daylight resources, sustainable urban development is within our grasp!
- The results obtained also suggest that there is potential for further urban site densification, though this should perhaps be concentrated at the medium density site of Bellevaux rather than the low density site of Meyrin, for reasons of solar access.

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Robinson, D. (2005) *Urban morphology and indicators of radiation availability*, Solar Energy (paper submitted).

Montavon, M., Robinson, D., Scartezzini, J-L., Compagnon, R. (2005) *Urban daylight and solar radiation potential: analysis of three Swiss districts*, Solar Energy (paper submitted).

Montavon, M., Gay, J-B. (2005), *Refurbishment or reconstruction?: essential questions to make a sustainable renovation of residential areas*, Environment and Planning B (paper submitted).

Montavon, M., Scartezzini, J-L., Compagnon, R. (2004), *Solar energy utilisation potential of three Swiss urban sites*, Proc. 13th Status seminar Energie und Umweltforschung im Bauwesen, Zürich, Sept. 2004.

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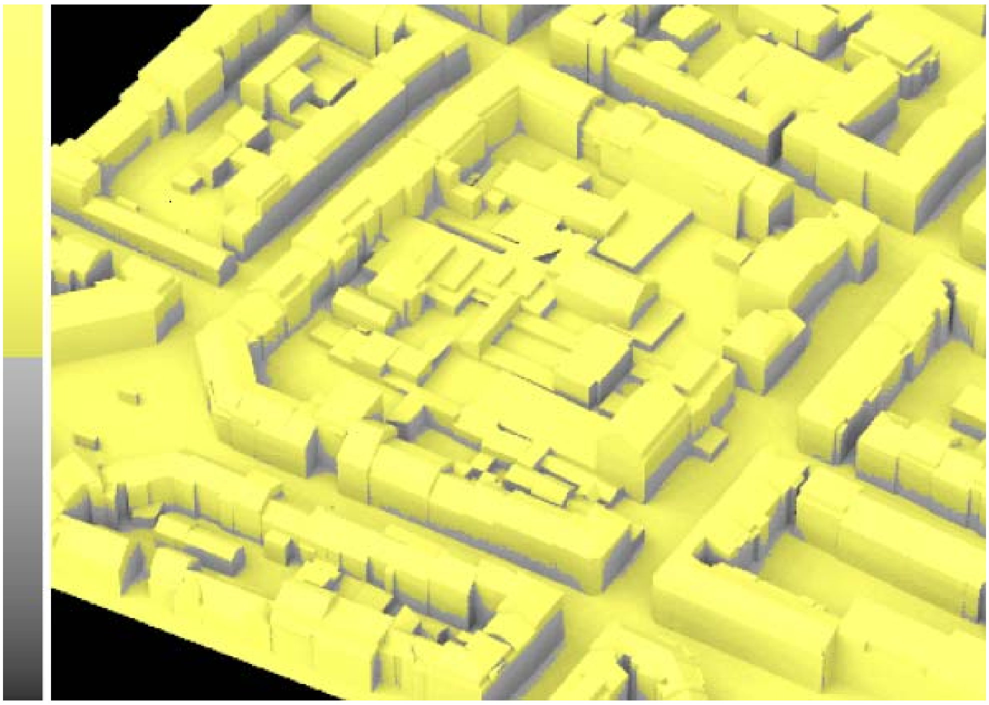
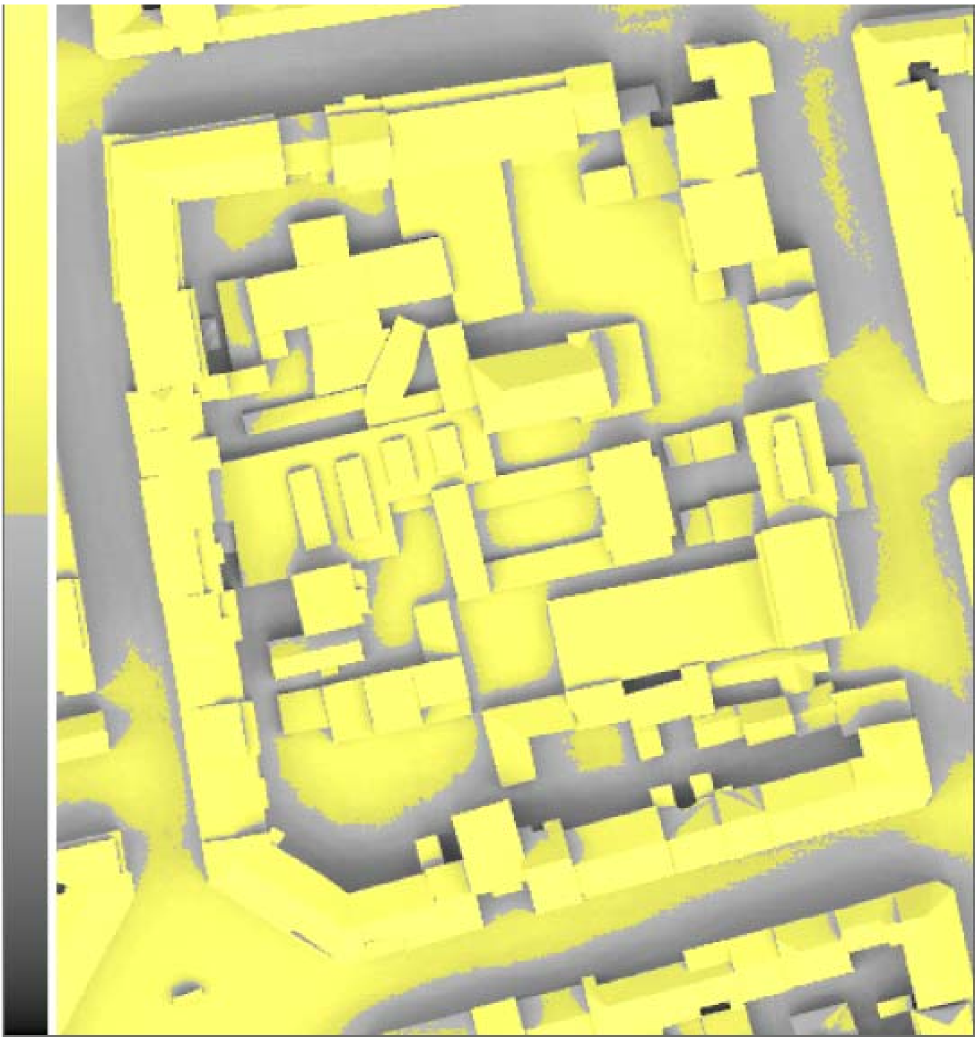
APPENDICES

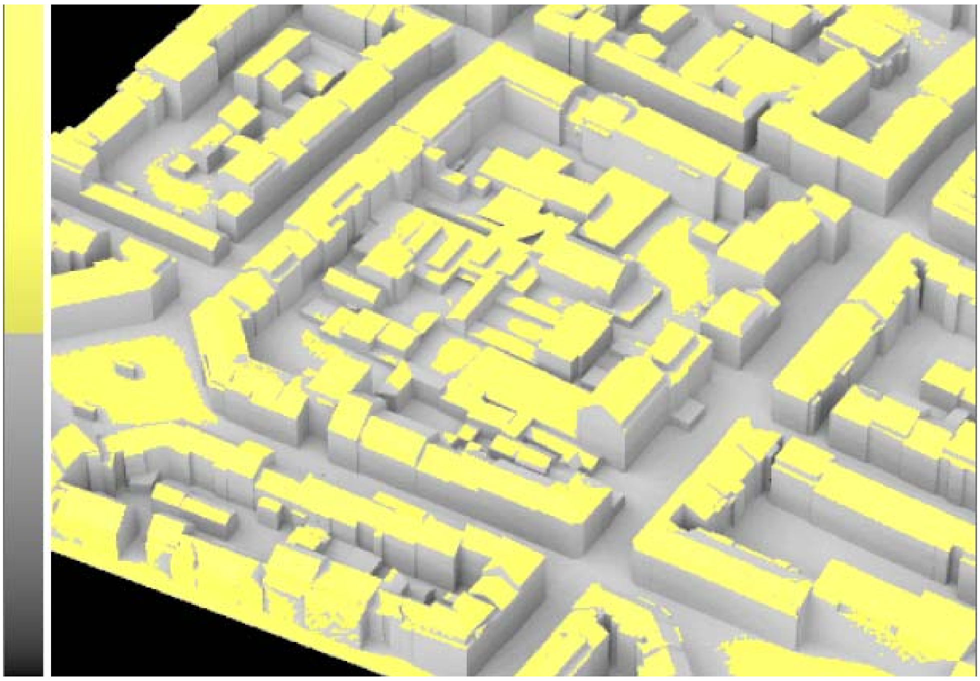
A1 FURTHER THRESHOLDED IMAGES OF RESULTS FOR MATTHAEUS



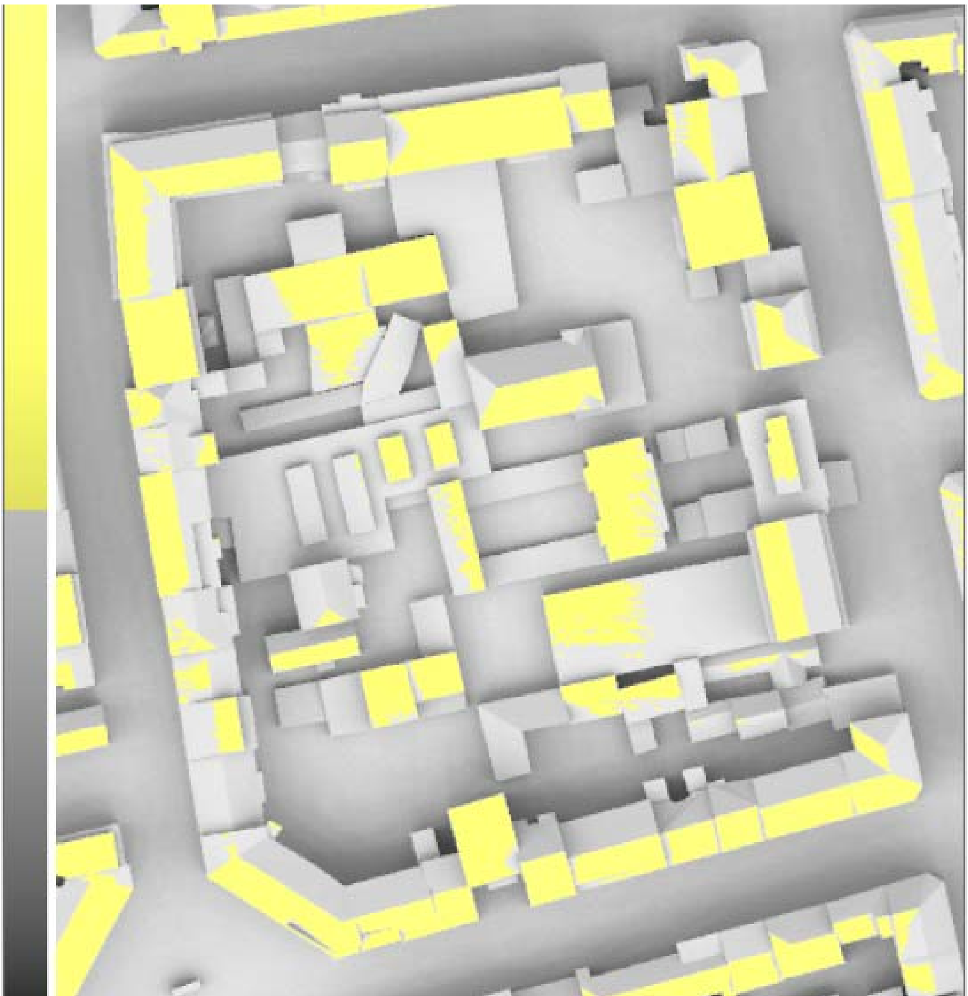
Thresholded image relating to facade-integrated solar thermal collectors (400kWh.m^{-2}+)



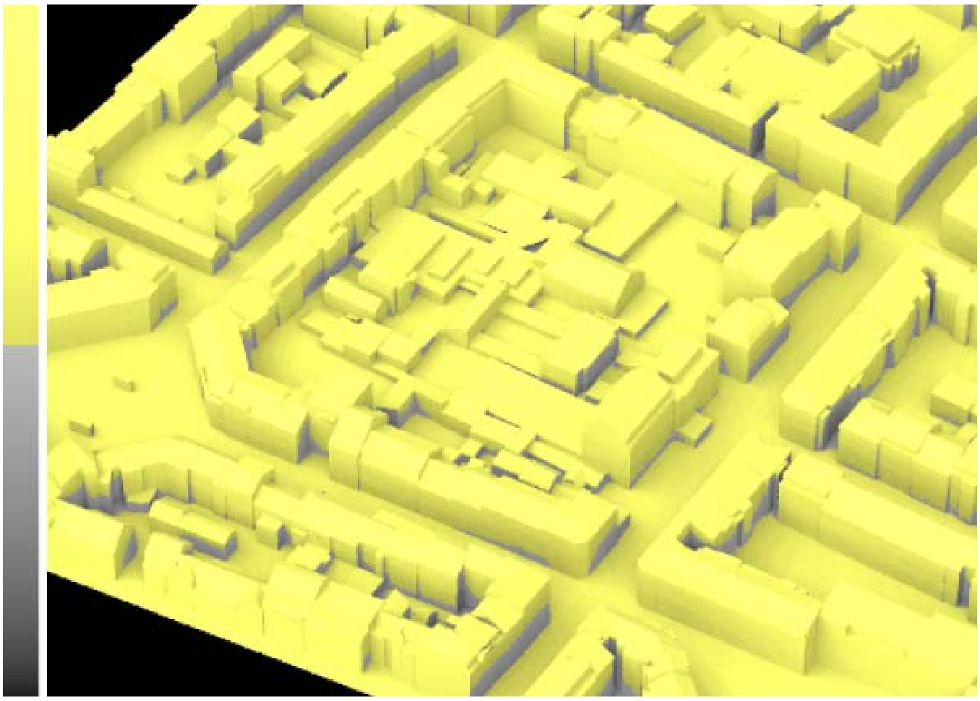
Thresholded image relating to roof-integrated solar thermal collector (600kWh.m^{-2}+)



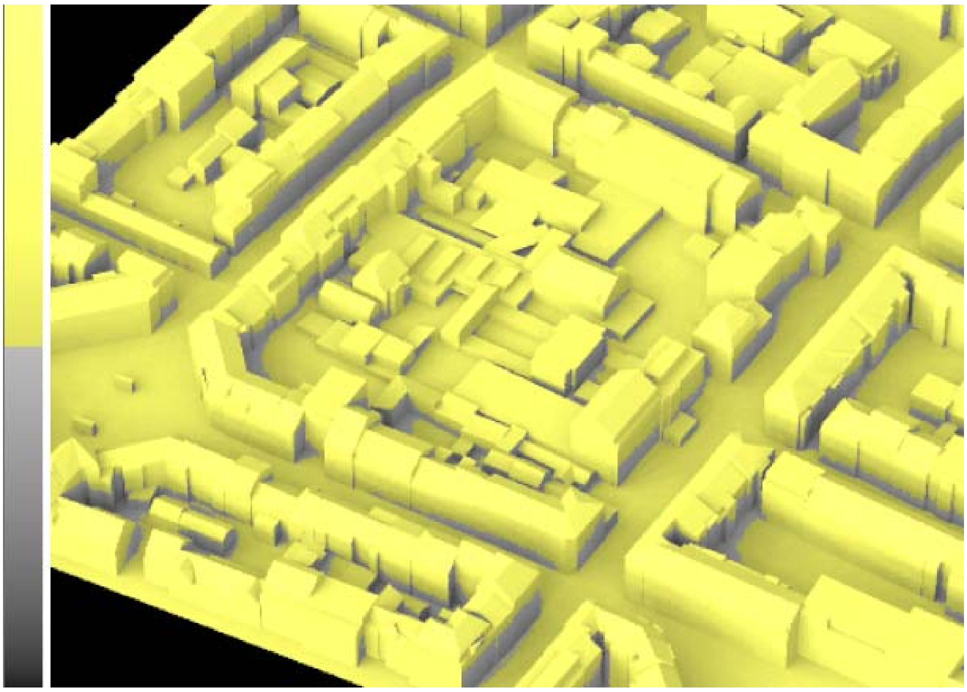
Thresholded image relating to facade-integrated PV (800kWh.m^{-2}+)



Thresholded image relating to roof-integrated PV (1000kWh.m^{-2}+)



Thresholded image relating to daylighting (10 000 Lux +)



Thresholded image relating to passive solar gain (117 $kWh.m^{-2}$+)

A2 SCIENTIFIC COLLABORATIONS

National

A synergy with national projects centered on the urban environments problems [Novatlantis2001] [Montavon2004a] was targeted in order to reach a sufficient scientific and operational critical mass. They are mainly the following projects in favour of sustainable development:

- CEPF Project « NOVATLANTIS – 2000 Watt Society / Pilotregion Basel » (Amstein & Walthert, R. Stulz; Fachhochschule Beider Basel, Prof. A. Binz)
- OFEN Project « Quartier durables BaLaLuZh» (EPFL/LESO-PB, Dr J.-B. Gay, M. Montavon et al)

An active collaboration with the "University of Applied Sciences of Western Switzerland" of the EIAF/HES-SO (Prof. Raphaël Compagnon), which has been involved within the framework of the PRECis European project (Compagnon and Raydan, 2000, Compagnon2004), was practiced during the project It allowed to benefit from competences acquired about data-processing software dedicated to urban sites and to pursue their development.

International

Several scientific communications (Scartezzini 2002, (Montavon et al, 2004a, b) were presented within the framework of international conferences, such as the Eurosun 2002 « European Solar Energy Conference in Bologna » (Italy), the PLEA2004 « Conference on Passive and Low Energy Architecture » in Eindhoven (The Netherlands) and the 13. Status-Seminar « Energie und Umweltforschung im Bauwesen » in Zürich (Switzerland). Several research projects, centred on renewable energy use in urban environment were initiated, these last years, at the European level. During the formal and informal year events, discussions and contacts with other researchers were made, particularly, for the following European projects:

- EU Project « PRECis – Assessing the Potential of Renewable Energy in Cities » (HES-SO/EIF, Dr R Compagnon et al)
- EU Project « RUROS – Rediscovering the Urban Realm and Open Spaces » (HES-SO/EIF, Dr R Compagnon et al)
- EU Project « SunTool – Sustainable Urban Neighbourhood Modelling Tool » (EPFL/LESO-PB, Dr N Morel, Dr D Robinson et al)
- EU Project « URBVENT – Natural ventilation in Urban Areas: Potential Assessment and Optimal Facade Design » (EPFL/LESO-PB, Dr C-A Roulet et al)

The computer methodology (PPF/Radiance Tool), which was used to assess the solar energy utilisation potential of urban sites, is based on the novel method de-veloped by R. Compagnon within the framework of the PRECis European project.

A3 DISSEMINATION AND KNOWLEDGE TRANSFER: CONNECTION WITH PUBLIC ORGANISATIONS

Swiss Federal Office for Energy

Andreas Eckmanns, Rational Use of Energy - R&D Programme, Bern
Martin Stettler, Rational Use of Energy R&D - Programme, Bern
Mark Zimmermann, Eidg. Materialprüfungs- und Forschungsanstalt, Dübendorf

Council of Swiss Federal institutes

Roland Stulz, Novatlantis Programme – Sustainability in the ETH Domain, Zürich
Christoph Hartmann, Novatlantis Programme – Sustainability in the ETH Domain, Zürich

Matthaeus District – Basel

Heinz Theus, Hochbau- und Planungsamt, Kanton Base-Stadt
Dr Dominik Keller, Amt für Umwelt und Energie, Kanton Basel-Stadt
Rudolf Jegge, Amt für Umwelt und Energie, Kanton Basel-Stadt
Walter Meier, Grundbuch- und Vermessungsamt, Basel-Stadt
André Moosmann, Fachhochschule Beide Basel, Basel
Silvia Tzenkova, Institut für Energie und Umwelttechnik, FHBB, Basel

Bellevaux District – Lausanne

Daniel Brélaz, Syndic de Lausanne, Ville de Lausanne
Jean-Pierre Allamand, Service des Etudes générales et des Relations extérieures, Ville de Lausanne
Bernard Bolli, Service d'Architecture, Ville de Lausanne
Pascal Chatelain, Service d'Urbanisme, Ville de Lausanne
Armand Amez, Service du Cadastre, Ville de Lausanne
Elinora Krebs, Service de l'Environnement, de l'Hygiène et du Logement, Ville de Lausanne

Meyrin District – Genève

Dr Jacobus Van der Mass, Service de l'Energie, Canton de Genève
François Mumenthaler, Service des Systèmes Information et Géomatique, Canton de Genève