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EARLY DESIGN PHASE EVALUATION OF URBAN SOLAR POTENTIAL: INSIGHTS FROM THE ANALYSIS OF SIX PROJECTS

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ABSTRACT

This paper presents the outcome of a study based on the early-stage analysis of six virtual urban-scale designs located in Bern, Switzerland. A preliminary solar potential evaluation methodology is devised, inspired by previous studies, to allow the comparison of the projects' potential for exploiting solar energy through passive (e.g. daylight) and active (e.g. photovoltaic) measures. The workflow employed distinguishes itself by integrating and confronting conflicting performance indicators and geometrical parameters. Findings show diversity in the performance among the different designs, while also highlighting the need to review the definition of urban solar potential and refine its assessment.

INTRODUCTION

The built environment represents a large weight in the energy consumption balance worldwide (IEA, 2012). To remediate this situation, it is essential to move towards a high performance architecture by adopting a bioclimatic design approach, promoting the use of local resources and consequently leading to a more harmonious integration of buildings into their environment. The energy performance of a building is strongly conditioned by its level of solar exposure, which notably influences heating, cooling and artificial lighting needs. Key elements affecting solar exposure can be divided in two main categories: (i) site-specific parameters, such as climate and existing obstructions, and (ii) design-specific parameters, such as conceptual considerations, building height and orientation. While site-specific parameters are imposed by the project's inherent characteristics, design-specific parameters are defined by the designer during the early design phase.

Site-specific parameters are becoming increasingly relevant due to the unprecedented urban sprawl and induced densification. These phenomena cause new projects to be placed in an existing urban context, which leads to new and existing buildings mutually impacting each other. Negative impacts, such as unfavorable shadowing, can be mitigated through the designers decisional freedom over design-specific parameters, e.g. by adjusting the heights of buildings adequately. To ensure that new buildings bear a significant solar potential and that existing ones retain theirs, it is essential that early decisions be taken based on solar considerations at the urban scale.

In this paper, we conduct a comparative analysis of six urban designs to extract knowledge relevant to the development of an integrated solar potential evaluation methodology. Our approach adopts a distinct perspective on urban solar potential, by confronting a set of performance criteria with conflicting requirements. Both site- and design-specific parameters are taken into account and serve to make causal hypotheses on the results obtained.

STATE-OF-THE-ART

Many publications have addressed the issue of assessing and judging the level of solar exposure of buildings. One of the earliest is the Solar Envelopes (SE) concept (Knowles, 2009), which considers that no building should be shadowed for a minimum of six hours on December 21st (winter solstice). However, the value of this concept has recently been questioned through a study suggesting that direct solar exposure may affect energy performance in a significantly different way according to the climate and construction (Niemasz et al., 2011). The latter argues that "there is obviously a need for more climate-specific guidelines and standards that holistically integrate the concerns of solar access and developable density". In line with this statement, certain researchers have developed variants of the SE incorporating thermal considerations. For instance, Pereira et al. (2001) derived SEs based on pondered radiation factors characterizing the desirability of solar radiation, a method which was then implemented in the CityZoom tool (Grazziotin et al., 2002, 2004). The SE concept and its derivatives remain limited by the variety of 'proper' solar access definitions they use - ranging from 2 hrs to 6 hrs of solar exposure - as well as by the static nature of the evaluation - typically based on the winter solstice.

Other urban-scale methodologies employ indicators specific to a passive or active solar measure. For example, the potential for daylighting has been quantified using the *preferable sky window* indicator, representing the sky zone with the greatest daylight potential (Pereira et al., 2009), and the *sky view factor*, indicating the level of 'openness' of a surface and varying from 0 (completely obstructed) to 1 (unobstructed) (Cheng et al., 2006). Robinson (2006) tested the validity of the sky view factor as well as two other related urban geometrical parameters: street canyon height-to-width ratio and urban horizon angle[1]. He found that the validity of such indicators is actually limited and that raw irradiation data are preferred, considering that both methods require computer simulation in any case.

Regarding active solar applications (photovoltaic and collectors), thresholds are often used to judge of the acceptability of a situation. Yet, these diverge between countries and sources; e.g. the acceptable ratio of available to maximum irradiation (for an optimally inclined and oriented surface) ranges from 55% to 80% (Cronemberger et al., 2012). Based on such recommendations and to avoid the need for a full radiation simulation, geometrical indicators are often used, namely, the optimal tilt and orientation of the surface on which the active system is to be installed. Multiple values are employed in the literature, such as setting the tilt equal to the latitude versus 10° below the latitude (Cronemberger et al., 2012). Cronemberger et al. (2012) have, however, shown that such variants for the recommended tilt are not valid for low latitude cities in countries like Brazil. From the 78 cities studied, optimal tilt and orientation were found, distinct from the widespread recommendations. These results emphasize the importance, highlighted earlier, of using climate-based values as indicators in the evaluation method.

To bypass the eventual risk of using simplified methods or indicators as the ones introduced above, full energy simulations are also commonly conducted (Tereci et al., 2010) to obtain numerical energy consumption or production estimates. However, the complexity involved in setting up all the required details (e.g. heat transfer coefficient (U-value) of each surface), particularly important at the urban scale, makes such an approach inappropriate and undesirable for early stage evaluation. A simpler method consists in applying ‘common-sense’ recommendations for the climatic location considered, e.g. by respectively maximizing and minimizing winter and summer gains (Aguilar et al., 2011) or winter and summer building absorptance (Oliveira Panão et al., 2008). However, such methods restrict the comparison of early design alternatives, as their purpose is to render a design optimal. Moreover, they hold the risk of providing unsound guidance due to the fact that certain criteria, such as lack of daylight in summer, are not examined.

From the literature emerges a general tendency to focus on a small set of indicators, e.g. heating demand in the case of northern climates, which leads to the risk of overlooking potential counteracting impacts on disregarded performance indicators. A small number of more comprehensive studies can be found, such as the one by Compagnon (2004) which considers both passive and actives solar measures. A set of lower solar exposure thresholds were applied to evaluate, in a comparative way, different urban layouts in a case study located in Fribourg (Switzerland). The main limitation of this method is that it ignores the summer period and the associated overheating risk.

In this paper, we build upon Compagnon (2004)’s approach by adding the passive cooling threshold, which causes a confrontation within the criteria evaluated. Performance results are further challenged by additional considerations including geometrical parameters (e.g. compactness). As such, our method takes on a new perspective around the solar potential issue, by attempting to integrate conflicting goals and identify performance compromises.

METHODOLOGY

Specific issues are revealed by the previous developments and review of the literature, namely: (i) can urban solar potential be assessed in a more holistic way, such as to integrate the potential for daylighting, active harvest of solar energy (e.g. collectors), and passive heating and cooling; (ii) is it possible to do so reliably using only the scarce information known at the early design phase, (iii) and through a climate-based approach, involving adaptive performance goals, ensuring a case-specific and flexible evaluation.

The work presented in this paper represents a preliminary effort towards tackling these challenges. A performance evaluation methodology, fulfilling the above objectives, is devised inspired from previous work. Through a comparative study of six distinct neighborhood projects, knowledge is extracted about the implications of conducting such a performance analysis across various designs.

This study builds upon the outcomes of an architecture studio and summer workshop at the EPFL led by one of the authors (Rey, 2011, 2012) and consisting in the design and comparative assessment of six urban visions (Rey et al., 2013).

In the following, we describe the case studies and the simulation tools and methodology employed, before discussing the obtained results.

Modeling and Simulation of Studied Designs

The six early stage designs emanating from the abovementioned architecture studio were elaborated for the Waldstadt area in the city of Bern, Switzerland. A simple version of each design was modeled in Rhinoceros (Rhino, 2012), consisting in 3D versions of the schematic master plans of Fig. 1. To evaluate solar exposure levels, hourly irradiation (Wh/m^2) and illuminance (lx) data were obtained for each exposed surface using the DIVA-for-Rhino plug-in (Jakubiec and Reinhart, 2011), which is based on the Radiance (Larson and Shakespeare, 2011) engine. All exterior surfaces were assigned the default outside fa-

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[1] The urban horizon angle is measure from the building’s facade and represents the average elevation, in degrees, of the skyline (Ratti et al., 2005).

cade material (opaque diffuse with 35% reflectivity). Sensor nodes, which are the points at which irradiation/illuminance levels are calculated by the program, were positioned on the exposed surfaces at intervals of approximately four meters, as for the example building of Fig. 2. Following the modeling and simulation of the designs, a solar potential evaluation was conducted based on the annual and seasonal level of solar exposure of each design in kWh/m^2 and klx. The radiation map of Fig. 2 illustrates the annual level of exposure for a sample bloc of project 2.

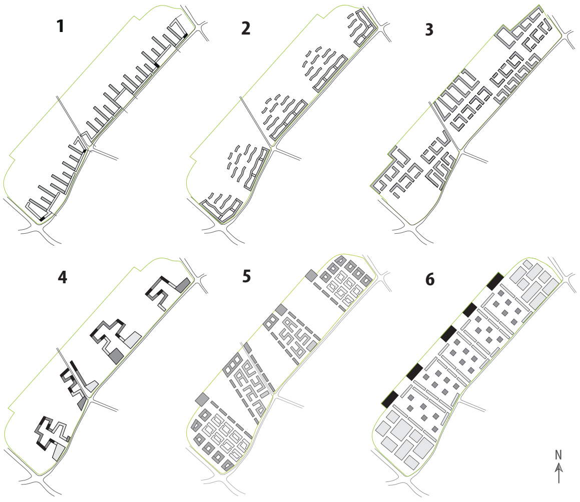

Figure 1: Virtual projects evaluated in the study. The shade of gray gives an indication of the height of the buildings; darker = higher. Location: Waldstadt district in Bern, Switzerland

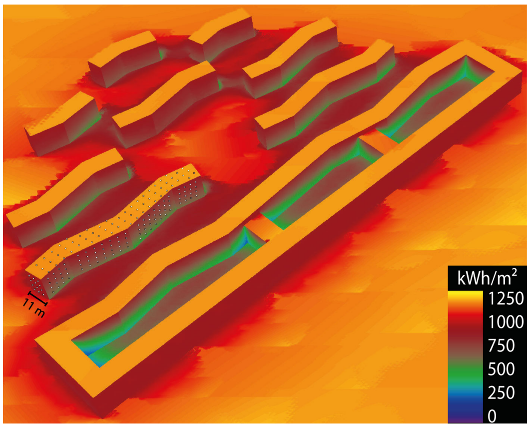

Figure 2: Example radiation map (irradiation over year) and simulation setup (sample node grid for irradiation/illuminance calculation)

Performance Indicators and Associated Threshold

The solar potential evaluation was based on four indicators: (i) the potential for winter passive solar heating, (ii) the risk of summer overheating, (iii) the potential for active harvest of solar energy through photovoltaic (PV) panels and solar collectors, and (iv) the daylighting potential. Solar exposure thresholds are associated to each indicator, in the form of an illuminance level (for the daylighting indicator) or irradiation level (for all other indicators). Criteria (iii) was further decomposed into facade- and roof-mounted systems, leading to a total of seven different threshold values: one each for indicators (i), (ii) and (iv), and a set of four values for indicator (iii). The thresholds corresponding to a lower limit (indicators (i), (iii) and (iv)) were based on the work by Compagnon (2004), while the passive cooling threshold, which represents an upper and therefore conflicting limit, was set by the authors. The origin and calculation of each threshold are described in the following.

Passive Heating

The passive heating threshold represents the amount of solar energy (kWh/m^2) collected over the heating period, from September 15 to May 15 [2], required to compensate the heat losses through glazing (Compagnon, 2004):

$$T_{\mathrm{PH}} = \frac{24 \cdot DD \cdot U}{1000 \cdot g \cdot \eta} = 172.7 \mathrm{kWh/m^2} \qquad (1)$$

where

***DD*:** heating degree days for Bern = 2906°C · day (Meteonorm, 2012)

***U*:** thermal transmission coefficient for a typical double glazing = 1.3 W/m^2°C

***g*:** solar energy transmission coefficient for a typical double glazing = 0.75

η: utilization factor taking into account occupants and building's dynamic behavior = 0.7

Passive Cooling

To mitigate the risk of overheating, the solar exposure in summer should be minimized. To allow a comparison among the six designs, an upper limit of 346.8 kWh/m^2 was set based on the energy received on average on the exposed surfaces of all designs over the cooling period (non-heating period: May 16 to September 14). This value does not necessarily represent the amount of energy that will lead to an overheating of the buildings, as obtaining such a precise value for each design would have required full energy analyses involving many assumptions on the construction. However, this upper limit enables us to fulfill our goal of establishing a relative ranking of the projects. Indeed, it allows demarcating which projects are above and below the average and thus provides us with a reliable indication of how they would ultimately compare should a full simulation be conducted.

Active Systems

The photovoltaic and solar collectors thresholds for both roof- and facade-mounted systems represent the values currently considered, to quote Compagnon (2004), as 'reasonable', based on the technological status of the systems and in the Swiss context. The values, given in Table 1, represent the amount of energy collected throughout the year.

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[2] http://www.hausinfo.ch/home/fr/droit/droit-bail/utilisation/chauffage.html

Table 1: Active systems thresholds

System	Threshold (kWh/m^2)
Facade-mounted PV	800
Roof-mounted PV	1000
Facade-mounted col.	400
Roof-mounted col.	600

Daylighting

The daylighting threshold is computed from the following equation (Compagnon, 2004):

$$T_{\text{daylighthing}} = \frac{E_i}{CU} = 10 \text{ klx} \tag{2}$$

Where

$\boldsymbol{E_i}$: mean indoor illuminance on workplane, typically fixed at 500 lx for the working hours (8am-6pm)

$\boldsymbol{CU}$: coefficient of utilization taking into account construction details (e.g. daylighting system, glazing ratio), typically of about 0.05 for vertical openings

Performance Evaluation

After simulating each project as described earlier, the node-specific hourly irradiation and illuminance data were stored as matrices. Basic mathematical operations (e.g. sum) were applied in the Matlab environment (Matlab, 2012) to obtain the performance results, according to the following main steps.

Daylight indicator

1. For each node, compute the average illuminance over the working hours (8am-6pm) of the year
2. Count the number of nodes for which the average illuminance exceeds the 10 klx threshold
3. Divide this number by the total number of nodes to obtain a percentage equivalent to a percentage of exposed surface

All other indicators

1. For each node, sum the irradiation over the relevant hours (e.g. falling with the heating period for the passive heating indicator)
2. Count the number of nodes for which the summed irradiation falls under (for the passive cooling indicator) or exceeds (for all other indicators) the corresponding threshold (e.g. 172.7 kWh/m^2 for the passive heating indicator)
3. Divide this number by the total number of nodes to obtain a percentage equivalent to a percentage of exposed surface

RESULTS AND DISCUSSION

Performance Indicators

Results of the performance evaluation are presented in Fig. 3 for projects 1 to 6 and for each indicator, under which the corresponding threshold is given. Boxes displayed at the bottom of the bars indicate the maximum difference observed between the best and worst performance amongst the six projects for each indicator (Δ_{max}). A first observation shows that projects perform differently, and that this difference is not the same across all performance indicators. It is more pronounced for the passive measures indicators, followed by the facade-mounted systems. Performance results for the roof-mounted systems are closer to each other, and show some similarities (projects 2, 3 and 5 at 100% for roof-mounted collectors). Such results demonstrate the value of performing early-stage solar analyzes to quantitatively compare design options that might be difficult to classify, intuitively or by experience, in terms of their potential for the measures of interest.

The graph also shows that the relative ranking of the designs generally differs between indicators. For example, for the passive heating indicator, projects are ranked from best to worst as 4-2-3-5-6-1, which is distinct from all other results. This result does however fit almost perfectly with the passive cooling ranking, which is logically reversed except for projects 1 and 6. Considering the fact that the evaluation method is the same for all indicators except for the value of the threshold, some differences in rankings can appear non-intuitive at first glance. For example, one might expect the same order for both facade-mounted systems, which is not the case; while it can be expected that a greater proportion of the facades will be adequate for collectors than for photovoltaic panels, due to their respective thresholds, the different rankings of the projects between these two indicators reveals information less likely to be foretold without such a performance assessment. For instance, project 1 has a smaller proportion of its surface receiving an irradiation above 400 kWh/m^2 (collectors threshold) than project 2, while a bigger proportion of its surface is receiving higher levels of irradiation (>800 kWh/m^2, PV threshold) than project 2. This observation indicates that the exposed surfaces in project 1 present more contrast (highs and lows) in their solar exposure levels than the ones in project 2, which receive a more spatially uniform irradiation. These distinct spatial irradiation profiles may well be caused by a predominant design difference; it can be seen from Fig. 1 that the general orientation of the two first projects is opposite; the majority of the buildings in project 1 follow a NW-SE axis, while most buildings in project 2 are aligned on the NE-SW axis. This distinction is clearly more explicit between those two projects than within any others, as is the contrast in the performance outcome for the facade-mounted systems.

Geometrical Parameters

To push the analysis further, we introduce two parameters descriptive of the geometry of the designs: the Site Ratio (SR: total conditioned floor area/site area), an indicator of the level of exploitation of the land or density of the urban construction, and the Compactness (C: total conditioned floor area/thermal envelope area), given in Table 2. Referring back to Fig. 1 and bearing in mind the SR, we can speculate on the rea-

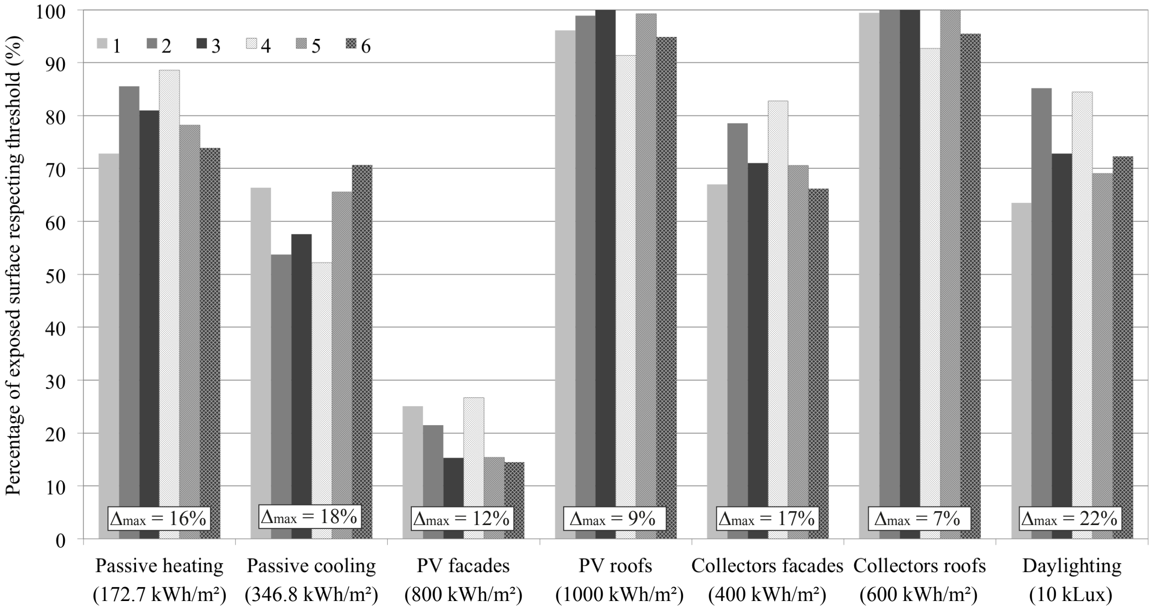

Figure 3: Results from the performance evaluation. Bars represent the percentage of the exposed surface, for each of the six projects, which receives a level of irradiation below (for passive cooling) or above (for all other indicators) the respective threshold displayed under each indicator on the x-axis. The higher the percentage, the better the performance.

sons behind the overall results. It can be seen that projects 2 and 4 have a lower SR and that most of their buildings are aligned on the NE-SW axis. The combination of these two characteristics appear favorable for the passive heating, daylighting and facade-mounted systems indicators. Roof-mounted systems are more adequate for projects 2, 3 and 5, where buildings are more uniform in their height, leading to less shadowing of neighbor roofs. Projects 5 and 6 benefit from a mitigated overheating risk (passive cooling indicator) seemingly due to their high density (SR) and height variability, which cause facade and roof shadowing. Project 1 falls in second place for this indicator, with most of its facades being protected from the afternoon sun due to the prevailing NW-SE orientation.

Table 2: Site Ratio (SR: total conditioned floor area/site area) and Compactness (C: total conditioned floor area/thermal envelope area) for each project

Project	SR	C
1	0.62	0.92
2	0.6	1.04
3	1.25	0.79
4	0.64	1.39
5	1.27	1.41
6	1.68	1.52

Additional Considerations

It is important to emphasize that the passive cooling performance criterion is only based on the amount of solar radiation received. No consideration is given to the potential for natural ventilation, an additional passive cooling method complimentary to solar shading. However, a qualitative assessment of this potential is possible by examining the wind rose of Fig. 4. The prevailing wind blows from the W (slightly N) direction, while a smaller contribution comes from the SE.

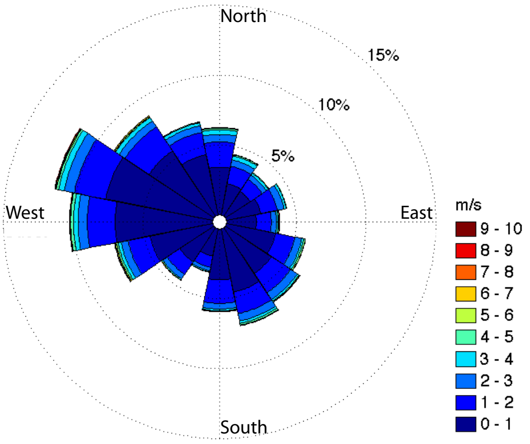

Figure 4: Wind direction (coming from) and speed in Bern. Climate data obtained from Meteonorm (2012).

Going back to Fig. 1 and considering that buildings aligned against the wind are in better position to exploit it (assuming openings are placed adequately), the following remarks can be made: project 2 is likely to have the highest potential for natural ventilation, followed by projects 4 and 1, the latter being able to exploit to some extent the smaller contribution coming from the SE. The higher density of projects 3, 5 and 6 is prone to reducing their natural ventilation potential. Project 6 is further disadvantaged by its enclosed design, acting as a wind shield.

A deeper analysis can also be done for the passive heating indicator, by converting the average energy received over the heating period per exposed surface area to its equivalent per floor area. This value is clearly dependent on the compactness of the design, as shown in Fig. 5, since a more compact building will have less surface area to collect energy for the same enclosed floor area. While the results of Fig. 5 are in disagreement with the ones obtained for the passive heating indicator (Fig. 3), neither provide information regarding the actual heating demand to be met.

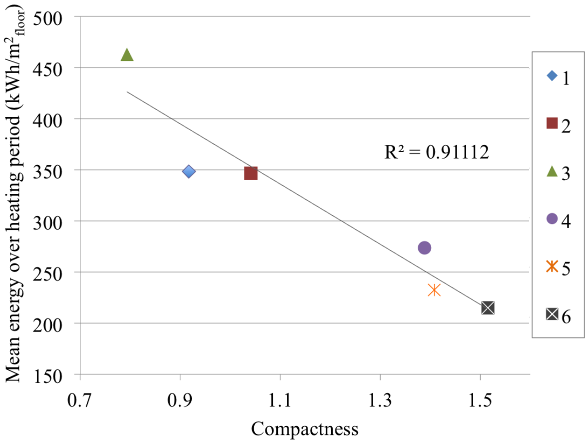

Figure 5: Mean energy received over the heating period per floor area versus compactness for each project

This demand can be qualitatively assessed by further examining the compactness, often used as an indicator of the energy consumption for heating (Pessenlehner and Mahdavi, 2003). For the same contained volume, the most compact building suffers less heat losses than its peers, due to its smaller exposed surface area. Based on their compactness (Table 2), the projects are ranked from most to least compact as follows: 6-5-4-2-1-3. The lower passive heating performance of project 6 is thus moderated by the fact that it is a very compact design, which indicates smaller heating requirements than the other projects. This is also true to a lesser extent for projects 5 and 4.

Taking into account these additional factors bring out the limitations associated to the applied threshold-based method, which does not consider counteracting phenomenons, such as natural ventilation, and by how much the thresholds are exceeded or not reached.

The compactness has even more implications when confronted to the results obtained for the active systems indicators. To demonstrate this, a simple calculation can be done to estimate the amount of energy produced by the facade-mounted collectors for instance. If collectors were installed on the whole facade area holding a potential, the project with the best performance (project 4, 83%) could produce annually about 202 kWh per m^2 of floor, which is *less* than the 307 kWh per m^2 of floor produced by the project in third place (project 3, 71%).

Although project 4 performs better than project 3 according to Fig. 3, its potential production per floor area is brought down by its higher compactness. In other words, project 4 has less exposed facade area through which solar energy can be collected for the same contained floor area. In fact, a strong correlation (R = 0.964) is found between the potential energy production and the compactness, based on the six data points, as seen in Fig. 6. Considering that the energy demand, to be met by the solar collectors, for space and water heating is of equal amount per floor area for all projects, project 3 would ultimately have a higher autonomy than project 4. This reverses the results of Fig. 3 and consequently challenges the validity of the threshold-based method as a way of ranking the potential for active systems in the context of distinct urban designs. It simultaneously highlights the need to include extra criteria (e.g. compactness), not directly related to solar considerations, into the evaluation methodology.

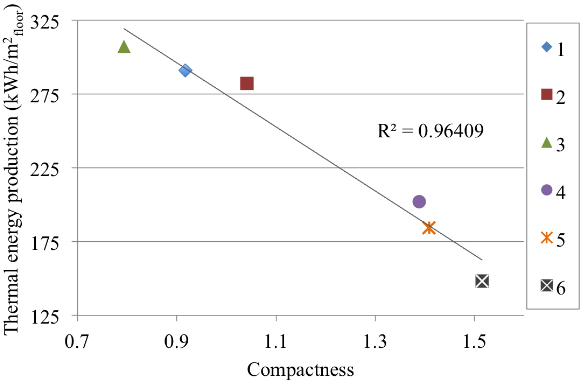

Figure 6: Thermal energy production per floor area, through facade-mounted collectors, versus compactness for each project

Aggregate Result

In the previous developments, we have assessed the potential and limitations of a solar performance evaluation method identified as promising from the literature. It was demonstrated that the seven integrated thresholds (including the six proposed by Compagnon (2004)), are not sufficient to draw trustworthy conclusions on the relative solar performance of urban projects with respect to the indicators addressed.

However, to push the analysis further and illustrate the concept of an aggregate score, we will assume that we hold accurate performance results. To draw conclusions on the overall performance of the designs, relative weights can been assigned to each indicator as in Table 3, reflecting the priorities of the practitioner. Three criteria, introduced earlier, were added to the performance indicators: the potential for natural ventilation, the compactness, and the density, expressed by the SR (Table 2). Giving weight to the compactness can lower the importance granted to the passive heating indicator, as the former can be seen as a compensation of the latter. Similarly for the passive cooling and natural ventilation. For these reasons, the two pairs of criteria have been placed as such in Table 3. Weights were allocated based on the following intuitive reasoning. Priority was given to passive measures, aiming at decreasing energy consumption before implementing renewable energy systems. Weights of 20 and 10 (out of 100) were assigned to the passive heating and cooling indicators respectively, since the climate of Bern is characterized by a dominant heating period. Facade-mounted systems were given a smaller weight (5) than the more commonly installed roof systems (10), while the daylighting criterion was given a weight of 15 due to its passive nature. Since the potential for natural ventilation was estimated only visually, it was given a small weight of 5. As many cities are adopting a strategy of densification as part of a sustainable approach (Riera Perez and Rey, 2012), built density was also considered and given a weight of 10. Finally, compactness as an indicator of heat losses was given a weight of 10.

For each project, the normalized performance results were multiplied by the corresponding weight and then summed, resulting in the aggregate scores presented in Fig. 7. The difference between the projects ranked first (project 4) and last (project 1) is of 9.4%. As the weighted sum was done in an empirical way, this difference should not be overlooked, as it may lead to significant deviations in terms of the ensuing energy consumption. In contrast with the individual results of Fig. 3, projects 2, 4 and 6 now perform similarly, by means of the weights given to their respective strengths (passive heating and daylighting for projects 2 and 4; density, compactness and passive cooling for project 6). This result highlights the implications of confronting conflicting performance criteria, and the consequent necessity of doing compromises in early-stage decision-making.

Insights gained and limitations

As mentioned earlier, the assessment of the threshold-based method has revealed shortcomings, brought out in particular by the estimation of the potential energy production and by investigating the implications of the compactness. In light of the contradicting results obtained, it can be concluded that the definition of urban solar potential must be reviewed and refined, so that it incorporates relevant geometrical considerations and provides reliable design guidance. Results have shown that a performance evaluation method based on a binary response - exceeding or not a certain threshold - is not sufficiently exhaustive and detailed to draw irrefutable conclusions over the relative performance of distinct urban projects. The percentages obtained as solar potential ratings do not appear to offer a proper assessment of the indicators. Moreover, it can be questioned if evaluating the potential is sufficient to guide decision-making, or if it would not be necessary to estimate the level of autonomy of urban projects, by looking at the balance between the potential for solar resource exploitation and the expected needs.

Table 3: Weight assigned to each performance indicator and additional criterion

Indicator	Weight	Add. criterion	Weight
Pass. heating	20	Compactness	10
Pass. cooling	10	Nat. ventilation	5
PV facades	5		
PV roofs	10		
Col. facades	5		
Col. roofs	10		
Daylighting	15		
		Density	10

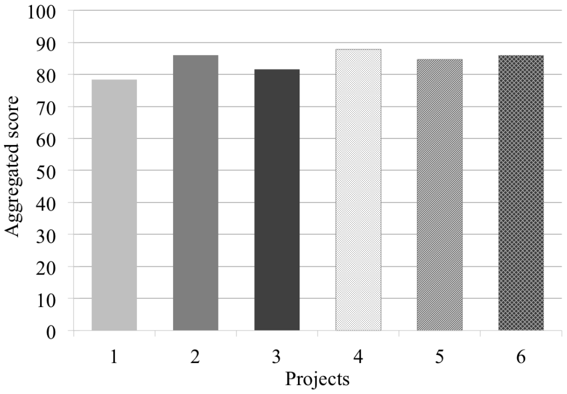

Figure 7: Aggregated results based on weighted performance indicators and additional criteria

The main limitations of the method are associated not only to its nature, but also to the thresholds employed, which are either technology-dependent (active systems) or yet to be validated through extensive simulation and testing (passive measures, particularly risk of overheating). Other limitations come from the uncertainties inherently associated to the modeling and simulation of the designs, as well as from the compilation of the irradiation values over the entire year and over all exposed surfaces.

CONCLUSION AND FUTURE WORK

Through the analysis of six urban projects, this paper has provided insights into the implications of assessing, based on early design parameters, the solar potential at the urban scale. By confronting various indicators and geometrical parameters, it has highlighted the divergence in terms of performance, caused by specific design features, and the need to make compromises between performance criteria.

An attempt was made to evaluate, in a more holistic and integrated way, the main solar performance indicators through a threshold-based method. When confronted to additional considerations, such as the compactness of the designs, the performance results appeared less adequate to serve as indicators for the comparative assessment of urban solar potential.

An example weighted sum was employed for illustrative purposes to allow drawing conclusions on the relative global performance of the projects. This flexible approach can be adapted to the designers objectives and priorities, while allowing a concise presentation of the overall performance results.

Future work will focus on refining and validating the urban solar potential evaluation method, according to the limitations highlighted by the study. To this end, we will use more detailed models regarding geometry parameters (e.g. window-to-wall ratio) and simulation modes (e.g. cooling). The concept of a user-defined aggregated score will also be further investigated, to ensure that such a condensed value remains reliable.

ACKNOWLEDGEMENT

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