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Solar energy as a design parameter in urban planning

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Abstract

By the end of 2020, all EU member states need to ensure that all newly constructed buildings consume 'nearly zero' energy and that their energy needs are produced locally as much as possible and with renewable sources; a concept called nearly Zero Energy Buildings (ZEB). At the same time, more and more people live in cities, where the access to local renewable energy sources –wind and solar- is limited. Planning for such ZEBs in cities is therefore a difficult task since urban planners often do not have the technical knowledge to quantify the contribution of solar energy in their urban plans. This study shows an exploration of geometrical forms of urban blocks and the potential of solar energy to the local production of energy. Simulations were performed with the program Ecotect for the city of Lund in southern Sweden. It was found that the impact of the geometry form on the potential of solar energy was significant (up to twice as much) and some forms were found to be less sensitive for different orientations. When the urban blocks were surrounded by other geometry, which resembles the situation of a dense city, the contribution of solar energy decreased by 10-75%.

Keywords: Solar energy; solar zoning; urban plannin; urban morphology; architecture; insolation; parametric study

1. Introduction

More and more people are living in cities and this development seems to continue in the future [1]. In Europe, cities are home to nearly 80% of the population, resulting in the production of 75% of all CO_2 emissions [2] . The urban scale has often been neglected in the debate of energy consumption and climate change [3-4], although data showed that savings in energy cost of 20-50% are possible through integrated planning by carefully considering site orientation and passive strategies [3]. An extensive utilisation of solar radiation in urban areas appears to be essential and a practicable strategy but has a big impact on the

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formation of cities in order to be fully effective [5-6]. Another challenge is that, in Europe by the end of 2020, all newly constructed buildings need to consume ‘nearly zero energy’ and that their needed energy needs to be produced locally as much as possible and with renewable sources [7]. This requirement might be hard to meet in dense cities, where access to local renewable energy sources is limited. In addition, often urban planners do not have the technical knowledge to quantify the potential of solar energy the design process.

Being able to understand the solar potential is also important for architects when designing buildings in urban environments. Integrating solar energy on the building level, with roofs and facades as the most logical places to harvest solar energy, needs to be carefully considered as it significantly affects the architecture. When the integration of active solar technologies is taken into account early in the design process, it is more likely to lead to more attractive solutions [8-10]. The early integration might be made easier when architects are aware of locations where most energy can be produced. The solar potential can also function as an important tool for real estate developers, who can directly see the amount of energy which can be produced on the building envelope.

In order to aid urban planners and architects in their design process, a broad set of guidelines needs to be developed. This parametric study may be the first step in that direction, as it analyses different types of urban blocks and their potential contribution to locally produced energy. By this, the study will attempt to quantify the role of solar energy as a renewable energy source in various urban morphologies.

2. Method

This parametric study consisted of a range of four urban blocks, each with a different design (A, B,C, D). In order to see the impact of density in urban plans, the Floor Space Index (FSI) / Plot Ratio of the urban blocks ranged from 1-5. Both the design options A,B,C,D and the FSI range can be seen in Figure 1.

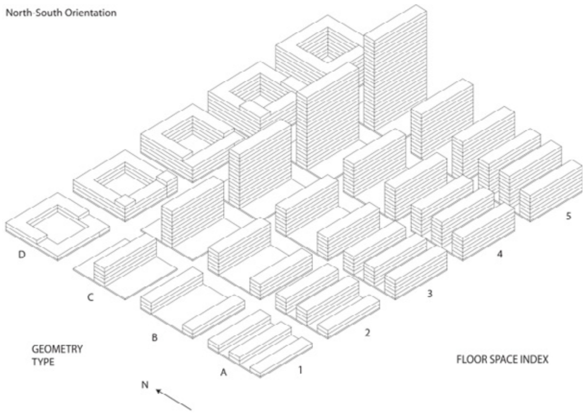


Fig. 1. Overview of geometry types in North-South orientation

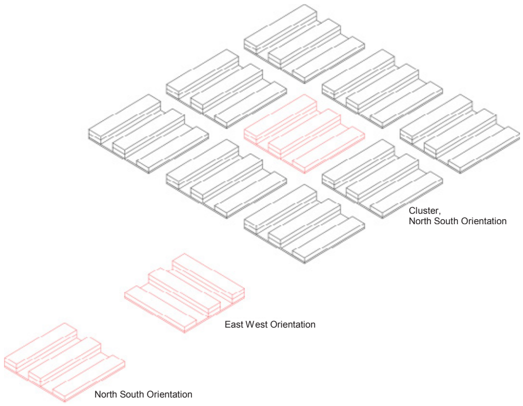


Fig. 2. Overview of changes of direction and environment

Besides changing the form and the density of the blocks, orientation and environment was also changed: first, blocks were simulated in North-South (NS) direction, then in East-West (EW) direction. In the third case, blocks were placed North-South direction within surrounding buildings with the same density (Cluster / CL) (Figure 2).

All geometry was drawn in 3D in AutoCAD and imported into the Building Performance Simulation tool Ecotect [11] with all floors 10 metres wide and 3 metres high. Ecotect 2011 was chosen as the main simulation tool, since it enables the user to export a large amount of data to Excel, and the visual user interface was experienced to be easy to use. Another reason to use Ecotect was the fact that it is used extensively by the industry [12-13]. However, the authors were aware of the lack of transparency of Ecotect's calculation methods and reported possibility of errors as mentioned by Ibara and Reinhart [13], where the Building Performance Simulation tools Ecotect and DIVA with measured data were compared. DIVA is a Radiance-based simulation program which works which the CAAD program Rhinoceros. In this parametric study, a comparison between DIVA and Ecotect was performed to see how much the values differed by using the two different calculation methods.

In Ecotect, a solar access analysis was run using 'medium' settings, looking at the incident solar radiation over a whole year on the building envelope of the urban block, for the location of Lund, Sweden (N55.705, E13.191). Then, within Ecotect, surfaces with an annual solar radiation above 650 kWh/m2/year were identified and selected. This value was chosen because they can produce around 100 kWh/m2/year with a 15% efficient PV cell; for Solar Thermal it would roughly mean a production of 250 kWh/m2/year. Furthermore, the solar panel area was considered to be 75% of the facade area, leaving 25% for fenestration. The value of 25% for fenestration is realistic since too much fenestration can lead to visual problems and overheating [14]. The same ratio was chosen for the roof, since a certain portion of the roof surface is needed for maintenance of the building and building service installations. In this study, the solar panels were considered to be PV cells, but a similar method can be used for Solar Thermal. The electricity use of the buildings was considered to be 50 kWh/m2/year. Out of that, 30 kWh/m2/year is taken as an indication for the average household electricity used annually in Sweden. The remaining 20 kWh/m2/year was assumed to cover the shared energy use, like for the whole-building ventilation system, etc. The electricity coverage was calculated by dividing the annual solar produced electricity in a building by the annual electricity demand in the building. The incident solar radiation was simulated annually, meaning that the problem of seasonal imbalance between energy production and need was not taking into account here. The production and need for domestic hot water (DHW) was also not considered in this research.

3. Results

3.1.Comparison Ecotect and DIVA.

First, a comparison was made between the simulation programs Ecotect 2011 and DIVA-for-Rhino 2.0 [15], similar to a study performed by Ibara and Reinhart [13]. This comparison was done to test how both simulation programs perform and how the output of the program is facilitated. Two models were tested for the annual solar insolation; one block North-South orientated, FSI=5, and design C (Figure 1), the other block was North-South orientated, FSI=5, and design A. The results are shown in Table 1.

Table 1. Difference in reference point on surfaces (values in kWh/m^2/year)

North – South orientation, FSI = 5, design option = C (E=Ecotect, D=DIVA, Diff.= Absolute value difference Ecotect-DIVA / relative difference)

South			North			East			West			Roof		
E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff	E	D	Diff.
670	780	**-110** / **16,4%**	293	221	**+72** / **24,5%**	487	482	**+5** / **1%**	453	500	**-47** / **10,4%**	985	976	**+9** / **0,9%**

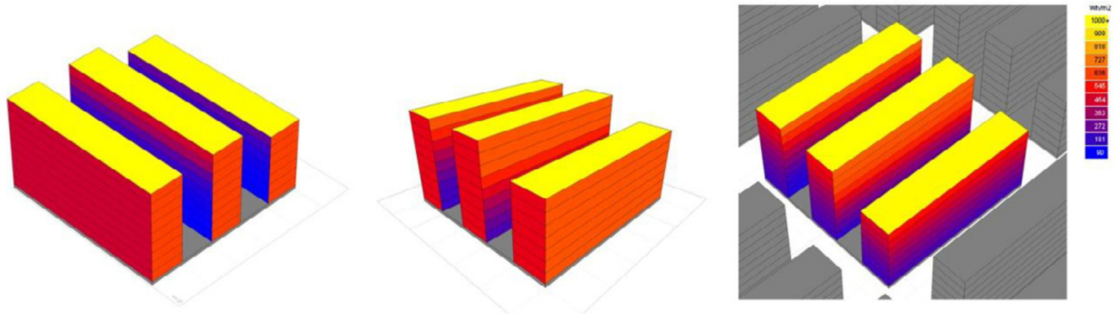
North-South orientation, FSI = 5, design option = A

South			North			East			West			Roof		
E	D	Diff.	E	D	Diff.	E	D	Diff.	E	D	Diff	E	D	Diff.
669	741	**-72** / **10,8%**	292	220	**+72** / **24,7%**	487	482	**+5** / **1,0%**	453	500	**-47** / **10,4%**	967	970	**-3** / **0,3%**
604	571	**+33** / **5,5%**	220	244	**-24** / **10,9%**									
512	354	**+158** / **30,9%**	192	189	**+3** / **1,6%**									
247	183	**+64** / **25,9%**	138	105	**+33** / **23,9%**									

Results show that the simulations done in both Ecotect and DIVA differ significantly for mostly the South and North, with relative differences of ~10-30%. Surfaces directed towards East and horizontal surfaces had the lowest differences. These differences are due to the difference in calculation methods in the two programs.

3.2. Results of the simulations

In this section the simulation results of the building blocks are presented. Figure 3 presents the visual results of some of the simulations in Ecotect for some of the building blocks.



NS5A EW5A NSCL5A

Fig. 3. Graphical output of annual solar insolation in Ecotect

The solar performance of the blocks are divided into two parts: a) The PV potential –the percentage of building envelope which receives an amount of solar radiation greater than or equal to a preset threshold [16]- and b) the electricity coverage –the annual solar produced electricity in a building divided by the annual electricity need, a unit which has been used in similar studies by Izquierdo et al., Wiginton et al., Jeppesen and Ordóñez et al. [17-20]. Figure 4 shows the PV potential of the different building blocks in different settings.

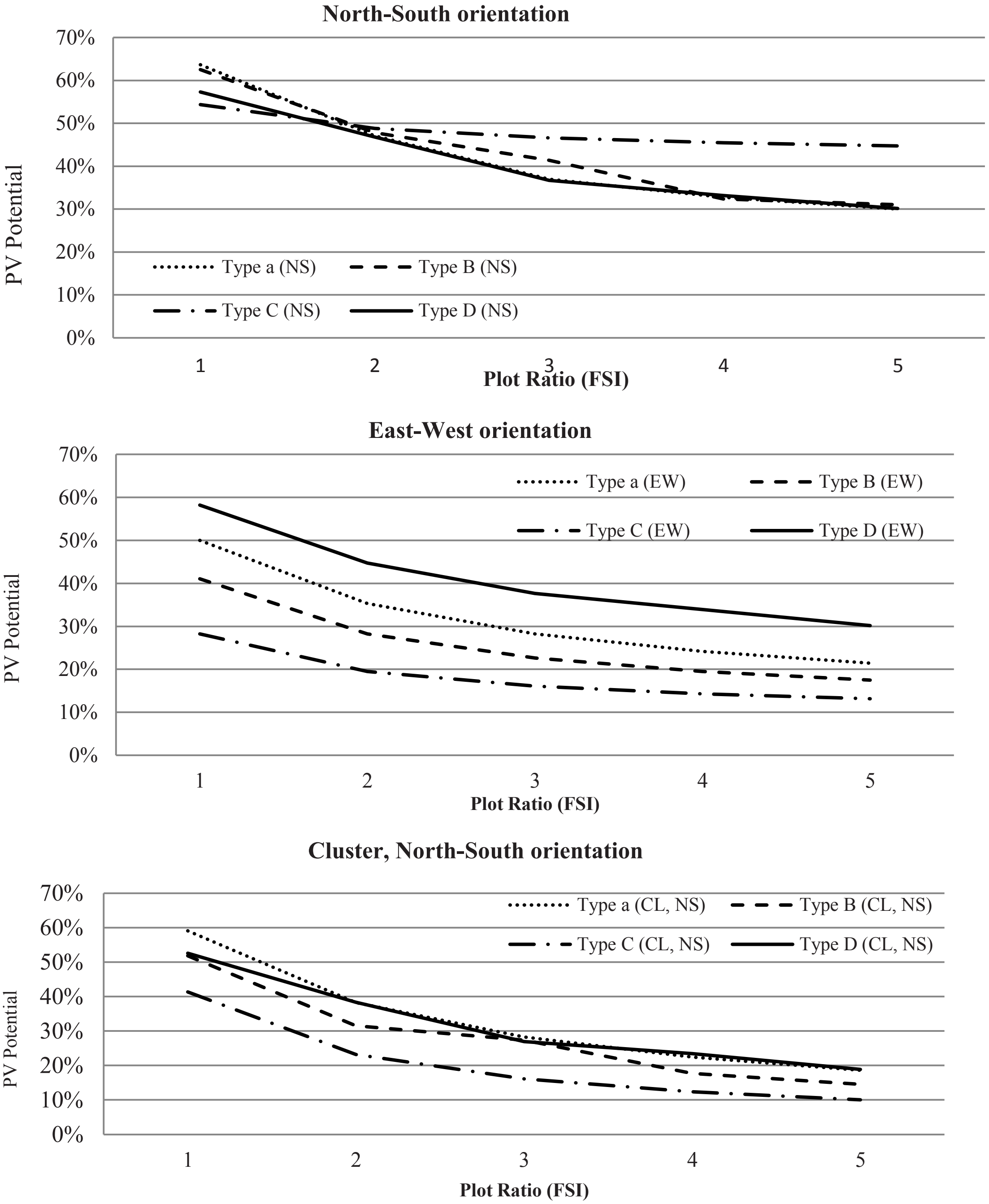


Fig. 4. PV potential of the blocks

Although the start values are not the same due to the design, it can be seen that, in general, the decline of the PV potential per case is the same, except for the Type C, in the NS orientation.

Type B in the cluster setup also shows different behaviour. Even in cases of a high FSI (5), still 30-45% of the facade receives more than the threshold annually in case of the NS orientation. In the case of the EW orientation and FSI=5, the PV potential is still 15-30%. This implies that a relative big part of the facade can be used to generate energy on the building, which will have its impact on the architecture. Furthermore, increasing the FSI from 1 to 5 in the EW orientation will decrease the PV potential by 50%. Increasing the FSI from 1 to 5 in the NS orientation will also decrease the potential by 50%, except for Type C. In the situation with surrounding geometry, the PV potential dropped by 70-75% when FSI increased from 1 to 5, a much higher decline compared to the two other cases without surrounding geometry.

The electricity coverage of the buildings blocks are displayed in Table 2.

Table 2. Annual Electricity Coverage of photovoltaic cells in the buildings (in %)

	Type A					Type B					Type C					Type D				
FSI	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
NS	169	93	65	54	46	134	81	63	47	43	90	68	60	57	54	149	85	59	48	43
EW	141	75	53	42	35	97	53	39	31	27	53	31	24	20	18	154	80	61	47	43
Cluster	159	79	53	40	32	115	57	44	29	23	71	36	24	18	14	139	73	47	36	30

When calculated annually, in 8 out of 60 cases (13%), the electricity need can be met with locally produced electricity with the preset assumptions. In order to become Net Zero Energy Buildings, heat and DHW will also need to be provided by local sources. In all other cases, the electricity demand cannot be met with the solar cells. The range of coverage is rather wide: the highest coverage is 169%, while the lowest coverage is 14%.

Results show that the impact of geometry on the solar potential was significant: Type C gave in most cases the worst coverage while Type A gave the best performance. Type D was relatively less sensitive for rotating from North-South to East-West direction. This was obviously due to the design of Type D, which has almost equally much surface area to East, West, North, and South. Interestingly, Type D outperformed Type B when it comes to electricity coverage.

When the urban blocks were surrounded by other geometry, the coverage decreased by 6% to 74% due to shading of the adjacent geometry. Figure 5 shows the influence of surroundings on the electricity coverage; in the graph, the difference between the NS model and the cluster model represents this influence. The graph shows that Type C is very sensitive when it is placed in a dense built environment, especially with a high density. Type B is the second most sensitive design, while Type A and D show almost the same increase when placed in a dense built environment.

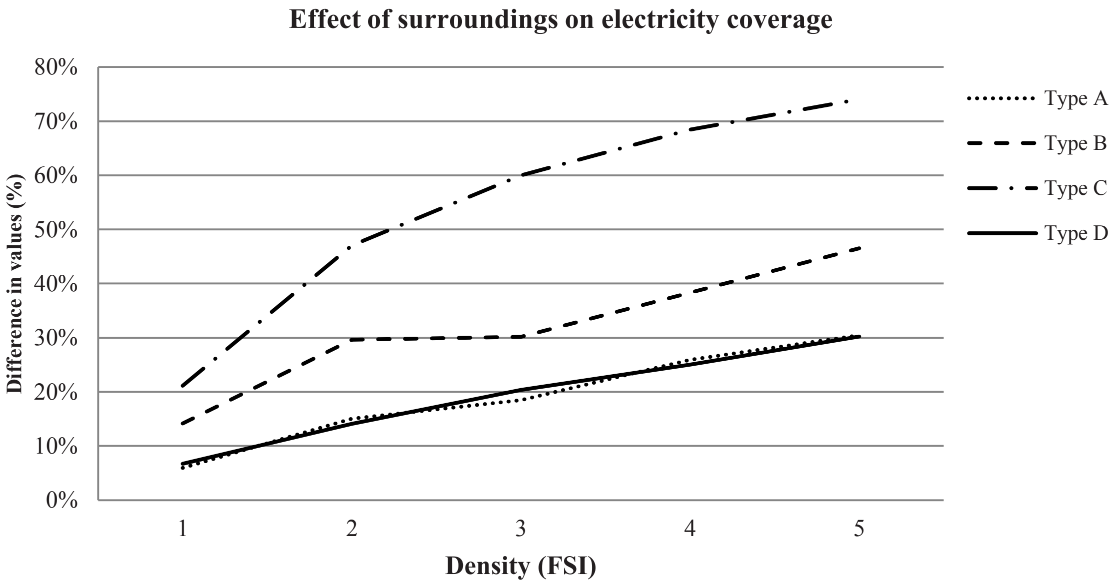


Fig 5. Effects of surroundings on electricity coverage of the simulated models

3.3. Implementation and future work

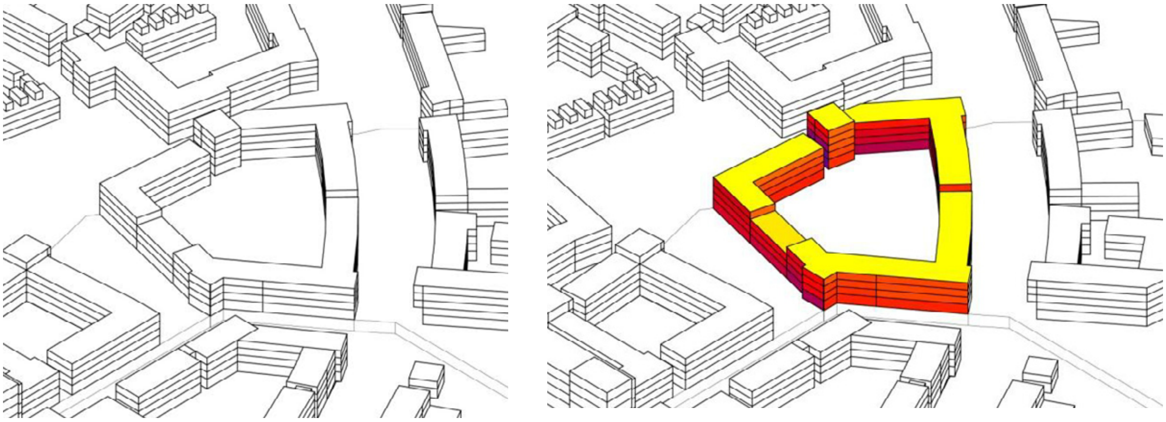
This parametric study represents a start of the development of a working method which ultimate goal is to implement solar energy into the daily practice of urban planners and architects. The next step was to understand how this could fit into the current design practice of urban planners. In order to do so meetings were set up between the authors and the planning departments of the cities Malmoe and Lund, located in the south of Sweden. Both cities expressed a will to implement more solar energy into future buildings planned to be built in the near future. The cities provided all proposals' documentation and 3D digital models for the newly planned urban districts.

The used method in the cases of both cities Malmoe and Lund can be seen in Figure 6. The building blocks were simulated in Ecotect directly to get numerical results. In order to get a better integration in the daily workflow of designers, the graphical output of the annual solar radiation analysis was performed by connecting the CAAD program Rhinoceros through the GECO plug-in to Ecotect[21]. The method consists of five steps: 1) a design alternative is developed and drawn in 3D, 2) the annual solar insolation is simulated, 3a and 3b) by setting a certain threshold (in this case 650 kWh/m2/year), a certain part of the building envelope is selected as the most appropriate for harvesting solar. This is both visualised graphically and numerically. Step 4 is the evaluating phase: does the design alternative live up to the expectations? If not, than another design alternative is performed and will go through step 1-3, otherwise the process goes on to step 5. In step 5, both the graphical and numerical output of the solar potential is given to the architects who will design the building in detail. It is important that this is the knowledge transfer is done properly so that this information is not lost in later design phases. In such a way, design alternatives can be compared with each other for their solar potential and performance.

However, certain issues need to be addressed first so the method can become more versatile:

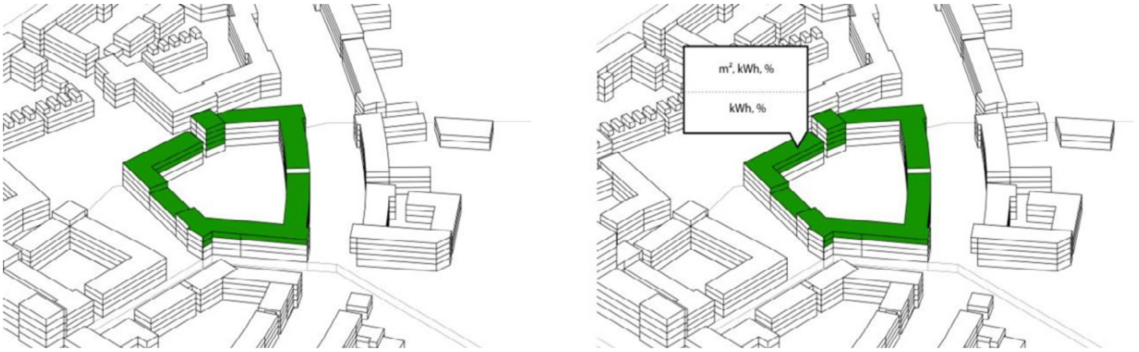
Solar Thermal needs to be implemented in the method. This is a rather simple adaptation of the calculation method. By doing so, the tool can take into account both DHW / heat, and electricity.

- Giving an overview of the costs and benefits of implementing active solar harvesting would provide an extra factor to take decisions upon.
- The threshold value should be discussed. With the threshold of 650 kWh/m^2/year as it is taken now, parts of the facades and roofs were selected. If the threshold was instead set much higher, only roof areas would be valid for placing PV cells.

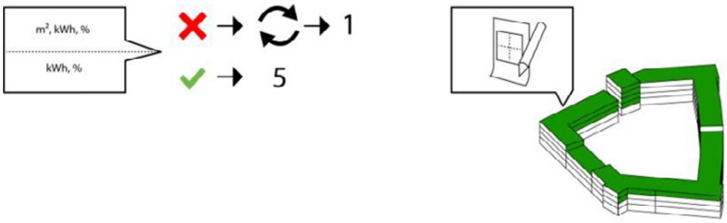


Step 1. Design alternative is developed, building is available in 3D.

Step 2. A simulation is run for the annual solar insolation



Step 3. All surfaces above a certain threshold are shown visually and numerically



Step 4 and 5. If the design alternative performed as planned, information is given to the architects. Otherwise, back to step 1.

Fig. 6. Visualisation of a possible working method for urban planning

4. Conclusions

The results of the simulations done in this study show that taking solar energy into account when designing new urban district can provide a significant contribution to the local production of renewable energy. Also, solar zoning [22] can contribute to solar access for solar energy in denser cities.

Certain designs of building blocks performed better than others in the simulations, especially when the blocks were surrounded by a dense built environment. When the plot ratio / FSI was 1, almost all design options were able to meet the energy need with energy produced by solar energy. When the FSI was increased, building blocks were not able to meet all the energy need with locally produced energy. In one case, the solar potential decreased by 75% when it was placed in dense built environment, which meant that the electricity coverage of this design was very low.

Urban planning is a process in which many factors play a role. Solar energy is just one of these components which urban planners have to take into account. Urban planners should be informed about the consequences of building blocks' layout on the solar potential. In an ideal situation, one actor in the design process should perform the simulations and calculations regarding the solar potential as described in this article. This actor could be an external consultant, an urban planner or an architect. The further in the design process, the more detailed the solar potential analysis can be done. Important issues in these analysis are: the production of the active solar systems (kWh), the production over the year, the ratio between PV and ST, architectural integration issues (colour, texture, dimensions) etc.

It is also important that real estate developers are well-informed about the latest technology and prices, since they are a very important factor in the decision process. In the two cities of Lund and Malmoe, the urban planning department has set up meetings with real estate developers to talk about sustainability issues, of which solar energy is an important contributor.

In general, the production of electricity did not meet the electricity need. In this study, only the electricity need was taken into account, not the heat / DHW need. If those two components will be taken into account, the question whether to produce heat or electricity on which places in the building will become very actual. Furthermore, the fact that the annual solar energy production is not able to meet the energy need of buildings in cities leads to the issue if it is right to force future all buildings to generate all their energy locally within cities. Another conflict of using the whole roof is the competition with the green roofs.

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