Integration of Renewable Energies into Cityscape

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Abstract

A visually appealing integration of renewable energies into cityscape is important to retain acceptance. Therefore, recommendations considering aesthetic requirements have been developed for photovoltaic (PV), solar thermal (ST) and air-based heat pumps. PV and solar thermal on pitched roofs should match the roof's shape and color and do without any elevation. On flat roofs, the installations should be as invisible as possible, which can be achieved by low elevation angles and large distances to the building's edges. As visibility can often not be avoided completely, it is important to at least install the modules or collectors parallel to the roof edge. Showcase simulations have shown that an aesthetically optimized solar thermal system has a decreased energy output compared to a conventional installation, but it has almost no effect on the overall costs for heat generation in a time span of 20 years. Especially outdoor units of air-based heat pumps should be installed with some kind of noise and sight protection (e. g. enclosure).

Keywords: photovoltaic, solar thermal, heat pump, outdoor unit, cityscape, urban planning, aesthetic aspects, renewable energies, cost efficiency

1 Introduction

The acceptance of solar energy and heat pumps is high among the public in Germany (Lichtblick SE, 2020). To ensure that this remains the case, aesthetic aspects must be considered during planning. Therefore, recommendations for the integration of photovoltaic, solar thermal and heat pumps into cityscape have been developed at Technische Universität Dresden on behalf of and in interaction with Dresden's Urban Planning Office.

2 Recommendations for solar energy systems on pitched roofs

2.1 Shape and arrangement

Fig. 1: Examples for photovoltaic area matching the roof shape (left, © Felsmann) and zigzag arrangement (center, © Felsmann), further a combination of horizontal and vertical PV modules and solar thermal collectors (right, © Felsmann)

The shape of the PV or solar thermal system should be oriented towards the roof and compact areas or stripes are to be favored (see lift picture in Fig. 1). At valleys and ridges, zigzag arrangements should be avoided (see center picture in Fig. 1), meaning no fragmentation of the total area due to roof-lights or roof penetrations (see right picture in Fig. 1). Broad installations on large, continuous dormers are particularly good solutions regarding cityscape. In general, the arrangement of modules or collectors should be consistently horizontal or vertical in every area or – even better – at the whole building.

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2.2 Elevation

On pitched roofs, an elevation of solar thermal collectors or photovoltaic modules is quite common, but not acceptable from an aesthetic point of view (see left picture in Fig. 2). Considering urban planning aspects, only roof-parallel and roof-integrated systems are acceptable, as a more consistent overall appearance is achieved (see center and right picture in Fig. 2). In-roof systems are a particularly aesthetic solution but may cause a higher heat input into rooms behind. This might make stronger heat protection measures necessary or decrease thermal comfort. In case of photovoltaic, a higher module temperature decreases efficiency, whereas a solar thermal system becomes more efficient.

Fig. 2: Elevated photovoltaic modules (left, © Felsmann), roof-parallel evacuated tube collector (center, © Vaillant GmbH) and in-roof flat-plate collector (right, © Vaillant GmbH)

2.3 Color

The modules' or collectors' color plays an important role on pitched roofs. From an aesthetic point of view, their color should match the roof's color. Contrasts – as in the left picture in Fig. 3 – should be avoided. Photovoltaic in various colors is already available on the market[1]. The center picture in Fig. 3 shows red modules on a common brick-red roof. However, colored solar thermal collectors are still a subject of research. First results of a project conducted by Fraunhofer ISE are very promising (see Fig. 3 right). The developed MorphoColor™ technology for coating flat-plate collector's and PV module's glass covers allows to achieve different colors (Wessels et. al., 2021).

Fig. 3: High color contrast between roof and PV modules (left, © Felsmann), red photovoltaic on red roof (center, © BISOL Production Ltd.) and green solar thermal collector developed by Fraunhofer ISE (right, © Fraunhofer ISE (Andreas Wessels))

3 Recommendations for solar energy systems on flat roofs

3.1 Elevation

In terms of cityscape, a visibility of PV and solar thermal on flat roofs should be avoided completely, as roof edges appear erratic due to elevated modules or collectors. Besides, people tend to feel more comfortable in urban areas that are clearly delimited towards the sky. It follows that, considering urban planning requirements, the optimum elevation angle of PV and solar thermal on flat roofs is 0° and that the installation should not include any substructure. These demands are often opposed to a desired maximization of energy output. For solar thermal, elevation angles between 25° and 70° are common, for PV 30° to 45° (depending on orientation and load profile in both cases).

[1] E. g. Spectrum Series by BISOL Production Ltd., see brochure here: https://dl.bisol.com/files/Spectrum%20Brochure/BISOL_Spectrum_Brochure_DE.pdf

Besides, minimum elevation angles usually must be abided by for static reasons. Even if an installation with almost 0° is possible, usually a substructure of 10 to 30 cm height is necessary. Hence, visibility from the surrounding urban space cannot be avoided completely.

Evacuated tube collectors that can be installed with an angle of 1° to 3° have been commercially available for more than 10 years already. The showcase collector in Fig. 4 (left picture) furthermore offers the possibility to rotate single tubes. Elevated installations are still standard though, which makes recommendations for these systems necessary (see the following paragraph 3.2).

Fig. 4: Evacuated tube collector lying flat on the roof (left, © Viessmann GmbH) and solar thermal system with orientation parallel to building's edges (right, © Ritter Energie- und Umwelttechnik GmbH & Co. KG)

3.2 Shape and arrangement

To decrease visibility from the surrounding area, the horizontal distance between module/collector and the building's edge should be as large as possible (guiding value: 1,50 m). However, this leads to decreased energy outputs as the area available for PV or solar thermal diminishes. In terms of maximum energy output, it is also possible to always choose a south exposure for the system. This cannot be favored in terms of cityscape though, as orientation should always be parallel to the roof edge (see Fig. 4 right).

4 General recommendations for solar energy systems

4.1 Roof greening

The positive effects of roof and façade greening in urban areas are well known (e.g., improvement of microclimate, sound absorption, time-delayed wastewater effect in the case of heavy precipitation, habitat for beneficial organisms in the city) and go far beyond the simple, appealing appearance that can be perceived by everyone. Despite formal competition for space, the approach of combining photovoltaic and solar thermal systems with roof greening is increasingly being adopted and available on the market (e.g., "SolarGrünDach" by Optigrün) - see Fig. 5.

Fig. 5: Showcase combination of photovoltaic and green roof (© Optigrün)

The following aspects should be taken into account in a pro and con consideration:

- Plants can bind CO_2. However, this does not lead to an actual avoidance since the CO_2 is released back into the environment at the end of the plant's lifetime. The proportion that is sequestered as carbon in the soil in the long term is relatively small: 23.6 kg_{CO2}/m^2 in 50 years (Thiele, 2015). PV or solar thermal can achieve double the amount *per year*, i.e., 100-fold values during their lifetime. In terms of maximum CO_2 avoidance, PV or solar thermal systems are therefore to be preferred over roof greening.

- Plants lead to a reduction in local and surface temperature, especially in summer. The combination with PV results in slightly increased yields, while the solar thermal energy output rather decreases.
- Greening leads to savings in heating and especially cooling demand. A general quantification and thus recommendations are difficult; individual case studies are necessary.
- In the case of construction asymmetries (chimneys, roof exits, etc.) or technically required gaps in the arrangement of PV and solar thermal fields, an architectural solution using roof greening can be extremely positive for the cityscape.

4.2 Glare effects

The cover glasses of photovoltaic modules - so-called solar glasses - reflect sunlight, so that a reflection cannot be completely prevented. Manufacturers of these solar glasses estimate the reflection percentage at approx. 8 %. The left picture in Fig. 6 shows the exemplary reflection of sunlight on PV modules.

The reflection properties of solar thermal collectors differ depending on the manufacturer/model and depend on various properties. Nowadays, the reflected portion of the incident radiation is usually well below 5 % (see right picture in Fig. 6 for an example of the reflection on vacuum tube collectors). The only exception are vacuum tube collectors with CPC reflectors - their overall reflection properties are dominated by the CPC reflector.

Fig. 6: Reflection of sunlight on photovoltaic modules (left, © SOLARWATT GmbH) and solar thermal collectors (right, © Ritter Energie- und Umwelttechnik GmbH & Co. KG)

For both photovoltaic modules and solar thermal collectors, the type of solar glass is determining for the resulting glare effect. Structured glass (microstructures on both sides, with high proportions of diffuse reflection) should be preferred over float glass (similar behavior to window glass). Moreover, flat inclination angles have a positive effect in most urban locations (e.g., no glare for traffic). Nevertheless, a glare effect cannot completely be ruled out, so that in the case of exposed locations (e.g., airport approach lane, direct view from certain city views), it may be necessary to check on a case-by-case basis.

4.3 PVT

For more than 20 years, the development of hybrid modules that provide both electrical energy and heat at low to medium temperature levels is advanced. They are referred to as PVT collectors. The basic idea addresses the drawback that the performance of current standard photovoltaic modules decreases significantly at module temperatures above 25 °C. By using a liquid or air flow, cooling of the modules is achieved, and the annual PV yield can be increased. If a designated use is found for the heat at low to medium temperature levels, the overall efficiency can be increased even further. Moreover, less area is required for installation.

4.4 Combining solar thermal or PVT collectors with heat pumps

Heat pumps are an important element when it comes to increasing the amount of renewable energy sources in the heating sector. The German federal government is aiming at installing half a million new heat pumps in Germany per year during the next few years. But tapping environmental energy as a heat source often proves problematic in urban areas, since neither the ground nor the ambient air can make significant contributions regarding the trend toward increasing building density.

A combination with solar thermal can be a very good alternative. Commercially available collectors can realize direct supply at the level needed for domestic hot water and space heating in summer and spring/fall. During the rest of the year, the solar system then serves as a heat source for the heat pump, thus contributing indirectly to the heat supply.

If PVT collectors are used, increasing the temperature level using the heat pump is required almost all year round. The situation is similar for low-cost solar thermal collectors (e.g., uncovered finned absorbers), although there is the option of using it for cooling as well if the heat pump can also realize cooling functions via additional components. In this operating mode, the collectors take over the heat dissipation to the environment.

Current research on pilot installations combining PVT collectors and heat pumps is for instance conducted by Fraunhofer ISE. Two showcase installations using PVT as the only heat source for the heat pump reached seasonal performance factors of 3.3 and 3.8 in the year 2021 (Helmling et. al., 2022), which is almost as efficient as common brine-water heat pumps with flat ground collectors as heat source.

5 Showcase simulations for solar thermal systems

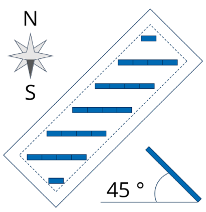
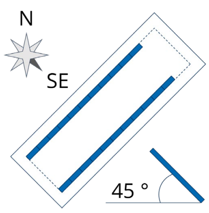
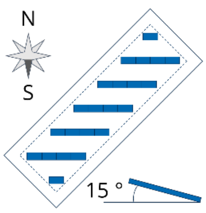
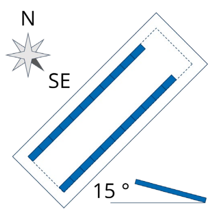
5.1 Simulations of solar thermal systems with 22 collectors

The effects of aesthetical optimization measures were examined through annual yield simulations (using *Polysun*) and simple estimations of overall costs in a period of 20 years. The following boundary conditions were selected for all simulated scenarios:

- Apartment house: new building with flat roof
- Building orientation: southeast
- Floor/roof area: 28 m x 10 m
- 8 residential units with 4 persons each
- Heat demand for space heating: 30 kWh/(m²a)
- Domestic hot water demand: 50 l/d per person at 60 °C
- Solar thermal system with 22 flat plate collectors
- Collector dimension: 1.00 m x 2.00 m
- Distance to the roof edge: 1.50 m
- Buffer storage with a volume of 2,000 l
- Additional gas boiler with a capacity of 100 kW

The scenarios differ in orientation and elevation angle of the collectors (see Table 1). The reference simulation sticks to common design conventions, assuming that an elevation angle of 45° and south exposure will lead to a rather high (area-specific) heat output. In contrast, there is a scenario optimized aesthetically with a southeast orientation and an installation angle of 15° (last column in Table 1). Additionally, there are two "compromise installations" in which either only the orientation was adapted to aesthetic requirements ("parallel to roof edge") or only the installation angle ("small elevation angle").

Table 1: Overview of scenarios – 22 solar thermal collectors

Scenario	Conventional (reference)	Parallel to roof edge	Small elevation angle	Aesthetically optimized
Elevation angle	45 °	45 °	15 °	15 °
Orientation	S	SE	S	SE
				

The results of the yield simulations are shown in Table 2. First, it is noticeable that the solar yields decrease at least slightly through all urban planning optimization measures (see lines 3 to 5): When placed parallel to the roof edge and continuing with a 45° installation angle, the yield decreases by 0.2 %. With an additional reduction of the installation angle to 15°, the yield even decreases by 7.0 % compared to the reference case.

When considering the natural gas consumption, however, it is noticeable: The relative increase (line 8) for the aesthetically optimized scenario is only 1.3 %. This is due to the fact that the gas boiler takes over most of the heat supply in all scenarios, which means that the reference value for this percentage is rather high in all cases.

Table 2: Results of yield simulations - 22 solar thermal collectors

0	Scenario	unit	conventional (reference)	parallel to roof edge	small elevation angle	aesthetically optimized
1	Elevation angle		45°	45°	15°	15°
2	Orientation		S	SE	S	SE
3	Solar yield	MWh/a	21.862	21.813	20.505	20.324
4	Difference compared to reference	MWh/a		-0.049	-1.357	-1.538
5	**Relative difference compared to reference**			**-0.2 %**	**-6.2 %**	**-7.0 %**
6	Natural gas consumption	MWh/a	133.502	133.576	134.998	135.186
7	Difference compared to reference	MWh/a		0.074	1.496	1.684
8	**Relative difference compared to reference**			**+0.1 %**	**+1.1 %**	**+1.3 %**
9	Consumption of electricity	kWh/a	300	300	309	305

To be able to better classify the results, a simplified profitability analysis was carried out. The assumptions made and the results are shown in Table 3. For the reference case, area-specific investment costs of 350 EUR/m² gross collector area were assumed. For the two scenarios with southeast orientation, this value was decreased by 15 % (see line 3), since two instead of seven collector rows must be installed here and thus a significantly decreased expenditure for the piping must be expected. For the two systems with a flat installation angle (15°), the area-specific costs were reduced by 10 % (see line 4), since a less complex substructure is required here.

Table 3: Estimation of overall cost – 22 solar thermal collectors

0	Scenario	unit	conventional (reference)	parallel to roof edge	small elevation angle	aesthetically optimized
1	Elevation angle		45°	45°	15°	15°
2	Orientation		S	SE	S	SE
Investment cost						
3	Factor for reduction of piping cost		1	0.85	1	0.85
4	Factor for reduction of cost for substructure		1	1	0.9	0.9
5	Area-specific cost of collector	EUR/m²	350	298	315	268
6	Overall cost of collectors	EUR	15,400	13,090	13,860	11,781
7	Cost of buffer storage	EUR	2,500	2,500	2,500	2,500
8	Cost of gas boiler	EUR	7,000	7,000	7,000	7,000
9	Assembly charges	EUR	3,000	3,000	3,000	3,000
10	Overall investment cost	EUR	27,900	25,590	26,360	24,281
Running cost						
11	Natural gas price	EUR/kWh	0.10	0.10	0.10	0.10
12	Electricity price	EUR/kWh	0.30	0.30	0.30	0.30
13	Maintenance cost in relation to investment cost		0.5 %	0.5 %	0.5 %	0.5 %
14	Yearly natural gas cost	EUR/a	13,350	13,358	13,500	13,519
15	Yearly electricity cost	EUR/a	90	90	93	92
16	Yearly maintenance cost	EUR/a	140	128	132	121
17	Overall yearly cost	EUR/a	13,580	13,576	13,724	13,732
Total cost						
18	Period under review	a	20	20	20	20
19	Total cost in 20 years	EUR	299,494	297,101	300,846	298,911
20	Additional total cost compared to reference	EUR		-2,393	+1,352	-583
21	**Relative additional cost compared to reference**			**-0.8 %**	**+0.5 %**	**-0.2 %**
22	Yearly additional cost per housing unit compared to reference	EUR/a		-15.0	+8.5	-3.64

Investment costs for buffer storage (line 7 in Table 3), gas boilers (8) and assembly (9) were assumed to be identical for all scenarios, as were natural gas and electricity prices (lines 11 and 12). A price increase in the period under consideration was neglected here for reasons of simplification. Natural gas and electric energy consumption are the result of Polysun annual simulations (see Table 2, lines 6 and 9).

A period of 20 years is considered, for which total costs of approximately 300,000 EUR result for all variants (see line 19 in Table 3). The comparison shows: The scenario "small installation angle" (15° and south orientation) has the highest total costs. Compared to the conventional reference case, this results in additional costs of about 1,350 EUR (+0.5 %).

The aesthetically optimized system is about 600 EUR (0.2 %) *less* expensive than the reference case. The most cost-effective variant is the installation parallel to the roof edge with an installation angle of 45°. Compared to the reference case, the total costs are reduced by about 2,400 EUR (0.8 %) over the observation period of 20 years. This is due to the lower investment costs resulting from the reduced effort for pipe installation, which compensate for the additional costs of the slightly higher natural gas consumption.

For a better classification, the cost differences were finally related to the number of residential units (eight) and a period of one year (see line 22 in Table 3). This results in a cost reduction of 3.64 EUR/a per housing unit for the aesthetically optimized installation compared to the conventional system.

Overall, the differences in total costs between the various scenarios are very small. The deviations of the assumptions made for e.g., costs are certainly in a similar order of magnitude. It follows that a general rejection of the urban planning optimization measures on *purely economic grounds* would not be justified.

5.2 Simulations with reduced row distance

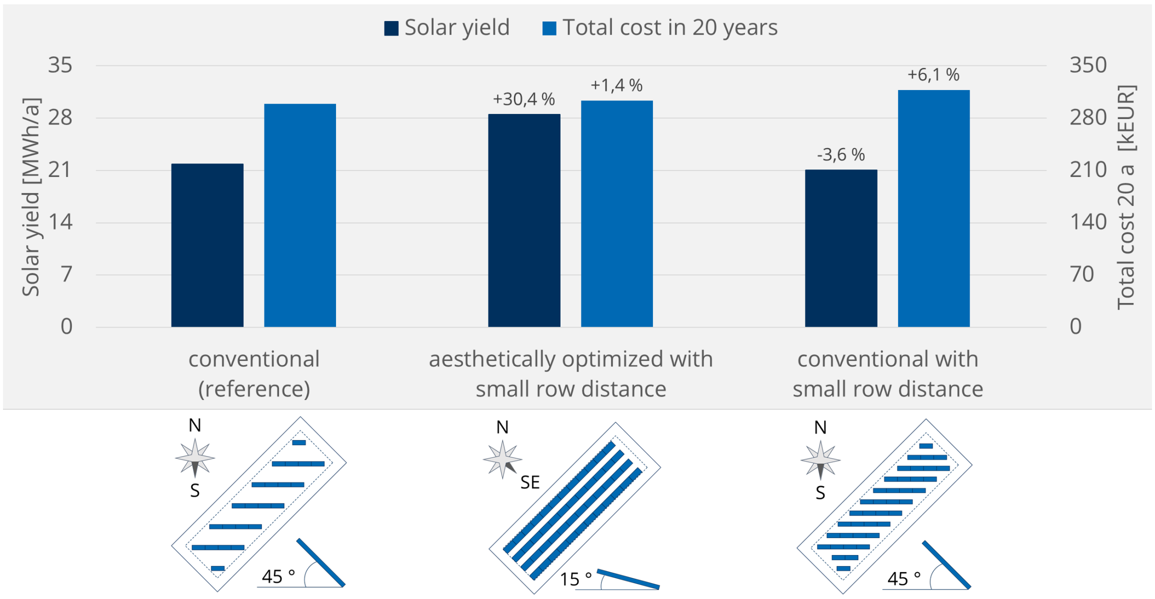


Fig. 7: Results of energetic and economic comparison of solar thermal systems with reduced row distance

It could be argued though that in terms of a *high amount of renewable energy sources* in the heating system, the reference case ("conventional") is still to be favored, as the solar thermal output is the largest. To examine this statement, another effect must be taken into account: The design of the simulated reference case was done using a common rule for determining row distances in solar energy systems. It aims at minimizing row distance, but the collectors should *not* shade each other at noon on winter solstice. The solar radiation angle is about 15.6° in Dresden at that time. This leads to a required row distance of 2.53 m and further to a total of 22 collectors fitting on the roof in the conventional scenario (45° installation angle). To simplify the comparison of the different variations, the number of 22 collectors has been assumed for *all* the simulations. However, it would also be possible to recalculate the minimal row distance for the variations with an elevation angle of 15° using the described rule. In this case, only 0.93 m would be required, leading to a total of 48 collectors fitting on the roof in case of southeast orientation ("aesthetically optimized" version).

Accordingly, another simulation with 48 collectors, 15° elevation and southeast exposure was conducted, called "aesthetically optimized with small row distance". Buffer storage size was changed to 4,000 l and its investment costs were assumed to be 4,500 EUR. The results are displayed in Fig. 7: The thermal output of the system is about 28.5 MWh/a and thus more than 30 % higher compared to the reference case, while the overall costs are increased by only 1.4 %. So, in case the aim is to achieve a high ratio of renewable energy sources in the system, the aesthetically optimized version is to be favored over the reference case.

However, the sheer number of collectors on the roof might be the driving factor for the high heat output in this scenario. This leads to another question: Might the conventional installation – with 45° elevation and south exposure – achieve an *even higher* yield if the row distance is reduced and thus the number of collectors is increased? (This obviously means that the collectors would indeed shade each other at noon on winter solstice!) This was examined in the last solar thermal simulation: The row distance of the conventional scenario was lowered to 0.93 m (same as in 48 collector version "aesthetically optimized with small row distance"). In this case, 39 collectors fit on the roof (assumptions for buffer storage: 3,000 l and 3,500 EUR). Fig. 7 includes the results: The yield is about 3.6 % *lower* compared to the reference case (and even 26.0 % lower compared to "aesthetically optimized with small row distance"). This is due to the large amount of shading caused by the small row distance. While the system generates about 25 % more heat than the reference case during summer, the heat output in winter is drastically reduced as many of the collectors are shaded most of the time. Furthermore, it is the most expensive installation examined – the total costs are about 6.1 % higher than those of the reference case.

It can thus be concluded that in terms of total energy output *and* economic efficiency, the showcase system benefits from aesthetical optimization measures.

6 Showcase simulations for photovoltaic systems

6.1 Simulations of photovoltaic systems with 27 modules

For photovoltaic yield simulations and estimations of overalls costs, the same assumptions as for the solar thermal systems (see chapter 5) were made whenever possible. *Additional* conditions and properties include:

- Power consumption: 3,500 kWh/a per housing unit (28,000 kWh/a for the whole building)
- Module dimensions: 1.00 m x 1.72 m
- Module efficiency at STC: 17.5 %
- Number of modules: 27
- Power output: 8.09 kWp
- Investment cost: 1,500 EUR/kWp
- Feed-in tariff: 6 ct/kWh
- Maintenance charges: 1.5 % of investment cost per year

The scenarios examined are the same as in the solar thermal simulations as well: There is a conventional reference case with south exposure and 45° elevation angle, two "compromise scenarios" and the aesthetically optimized version with southeast exposure and 15° installation angle (see pictographs at the bottom of Fig. 8).

The results of the yield simulations and the overall cost estimations are shown in Fig. 8. In all scenarios, the electricity output is between 7,200 and 7,600 kWh/a and the overall cost in 20 years is between 141,000 and 145,000 EUR.

The system parallel to the roof edge with 45° installation angle generates about 2.1 % less electricity compared to the conventional (reference) case. However, the absolute self-consumption almost does not change. As feed-in remuneration is one of the driving factors regarding running cost, and investment cost are the same as in the reference scenario, both 45° scenarios result in almost the same overall cost.

In the "small elevation angle" scenario, the electrical output is almost the same as in the reference case. However, the self-consumption increases by 3.7 %. Apparently, the characteristics of the building's load and the photovoltaic output match better at 15° elevation angle in case of south exposure. Hence, less electricity from the grid is needed. This is the main reason why the "small elevation angle" scenario is the least expensive.

The aesthetically optimized installation has the lowest electricity yield (-3.4 % compared to conventional system). But as the self-consumption is still 1.1 % higher compared to the reference case, the overall costs decrease.

All in all, from a financial point of view, a 15° elevation angle is to be preferred over 45° in the given scenarios. The two main reasons for that are:

- Corresponding to the assumptions for solar thermal simulations, investment costs are reduced by 10 %, since a less complex substructure is required.
- The load curves seem to match better, resulting in a higher self-consumption and thus decreased yearly electricity costs.

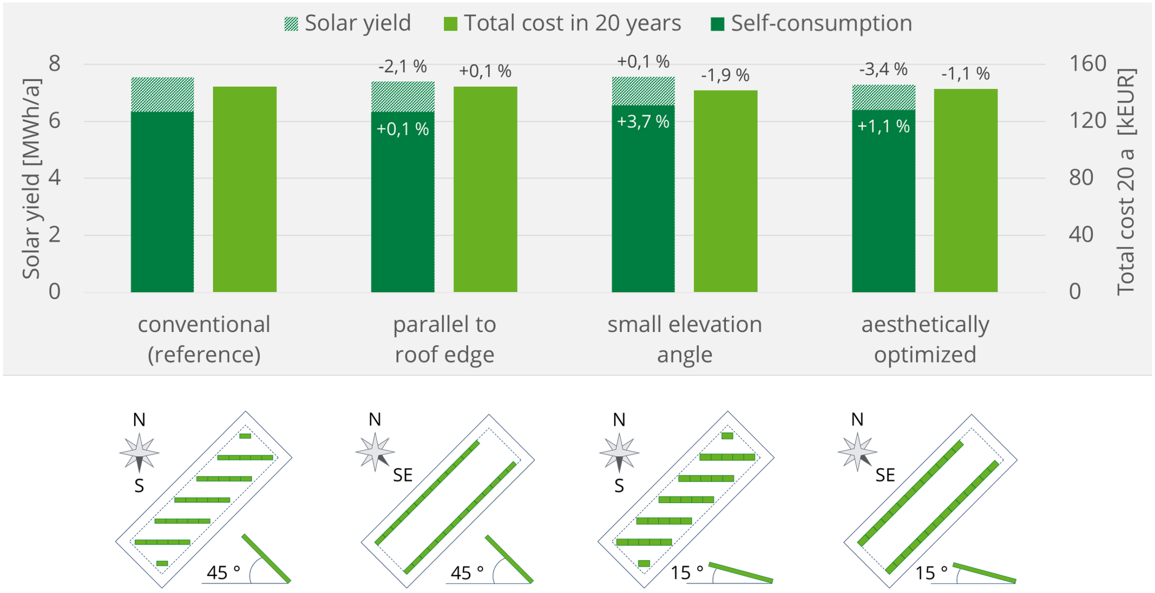


Fig. 8: Yield simulations and cost estimations including percentage of change compared to reference case for photovoltaic systems with 27 modules

6.2 Simulations with reduced row distance

According to the adaptions made for the solar thermal simulations in chapter 5.2, the row distance was decreased to 0.93 m for the aesthetically optimized as well as the conventional scenario (see pictographs on the bottom of Fig. 9). This results in 56 modules fitting onto the roof in the "aesthetically optimized with small row distance" variant and 50 for the "conventional with small row distance" case. The specific costs of the system have been lowered to 1,400 EUR/kWp in both cases (it was 1,500 EUR/kWp for the systems with 27 modules). The results of the calculations are displayed in Fig. 9.

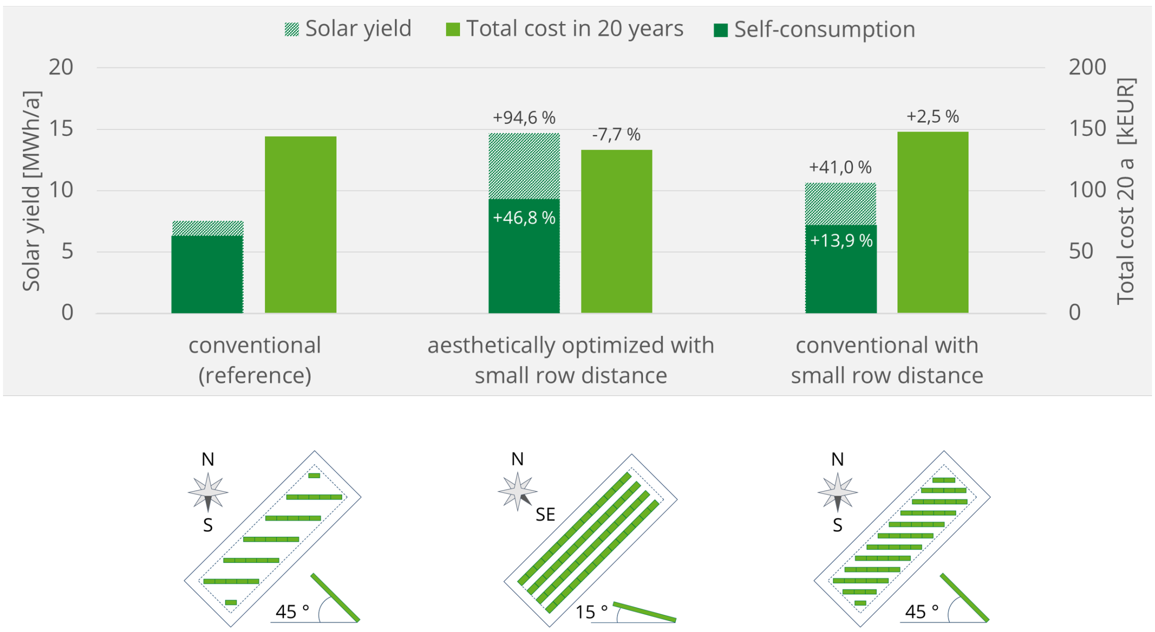


Fig. 9: Yield simulations and cost estimations for photovoltaic with reduced row distance

It is obvious that the aesthetically optimized version with small row distances generates by far the most electricity and the least cost. The conventional scenario with small row distances has a 41.0 % increased electrical output compared to the reference case, even if the number of modules is almost doubled. The self-consumption is increased by 13.9 %, but as investment cost almost doubled, the overall cost in 20 years slightly increases. This example proofs how relevant shading is for the efficiency of photovoltaic systems. It must be considered though that it is not trivial to represent shading effects in simulation software such as *Polysun*. Therefore, discrepancies between simulation and actual application cannot be excluded.

All in all, both maximizing the yield/self-consumption of the system and minimizing cost do not conflict at all with aesthetical optimization measures in the examined cases.

7 Recommendations for outdoor units of heat pumps

Besides aesthetic aspects, noise pollution is to be considered as well when planning an air-based heat pump – especially in areas with a high building density. Indoor installations generally have a smaller noise impact on the environment than split or outdoor systems. Depending on the type of installation, heat load etc., distance areas or additional noise protection measures are required.

Enclosures for heat pump’s outdoor units are commercially available and provide optical improvement as well as noise prevention and access security (see left and center picture in Fig. 10). If the heat pump is not split but installed outside as a single device, sight and noise protection constructions should be considered as well. Installing the heat pump on the rooftop behind an attic or any other roof structure is a particularly good solution which also provides protection from water damage in flood-prone areas (see right picture in Fig. 10). Enclosures should not restrict the airflow to prevent performance losses in the heat pump.

Fig. 10: Enclosures for heat pump’s outdoor units (left and center, © REMKO GmbH & Co. KG), rooftop installation of a heat pump with sight and noise protection (right, © iDM Wärmepumpen)

8 Summary

The most important, general design guidelines for solar thermal and photovoltaic systems are:

- For pitched roofs, the collector/module color should match the roof color, if possible. Compact surfaces or strips are preferred, and elevation should be avoided.
- On flat roofs, visibility of the collectors/modules should be avoided if possible. This means that large edge distances and flat installation angles are to be preferred. Alignment should be parallel to the roof edge.

Showcase simulations indicate that conventional design approaches for flat roofs should be reconsidered and adapted to meet requirements regarding cityscape, as this might even lead to higher yields and decreased cost. The number of collectors/modules that fit on the roof as well as the shading are essential influencing factors regarding energy output, making smaller elevation angles favorably in the examined simulations.

For heat pumps, enclosures or similar constructions ensure both an aesthetical integration into cityscape as well as noise protection without having relevant effects on the efficiency of the system as long as the airflow is not restrained.

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