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Author(s):
Haller, Niklaus; Furrer, P.; Wieser, C.; Leibundgut, Hansjürg

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HYBRID ROOFSCAPES – ARCHITECTURAL IMPACTS OF ROOF-INTEGRATED PV/T-COLLECTORS

N. Haller1; P. Furrer2; C. Wieser2; H. Leibundgut1

1: Swiss Federal Institute of Technology (ETHZ); Institute of Technology in Architecture (ITA); Chair of Building Systems; Schafmattstrasse 32, CH-8093 Zürich

2: Zurich University of Applied Science (ZHAW); School of Architecture, Design and Civil Engineering; Institute for Constructive Design; Tössfeldstrasse 11, CH-8401 Winterthur

*main author email: haller@arch.ethz.ch

ABSTRACT

In the future, buildings must be operated free of CO₂-emissions. To achieve this goal the chair of building systems at ETHZ has developed a system named Sol₂rgie. In a Sol₂rgie building large surfaces of PV/T-collectors (PV/T) are needed to regenerate the deep ground heat exchanger. The system covers up to 90% of all the thermal demand for heating and domestic hot water by locally stored heat and considerably decreases the maximum power requirement.

Architecturally, the PV/T is the most sensible element of the system. For energetic and economic reasons it makes sense to integrate the PV/T into the building skin, but replacing the modular application with functional integration implies a complete new interpretation of historical and contemporary roof constructions. For that reason, this study is part of a research project based on an interdisciplinary cooperation between ETHZ and the institute for constructive design at the ZHAW.

The aim of the presented study is to investigate how this new technology may change the roof on a typological and urban level. Seven scenarios in four different existing urban situations show future transformation strategies. In the conservative scenarios the roofs do not offer enough PV/T-surfaces, whereas in the more progressive and innovative ones the new roof typologies may cover the whole annual energy demand. Therefore we argue that the design of roofs is going to be one of the key aspects on the way towards a more sustainable built environment. In addition this study is also a contribution to the discussion about the vertical densification of central urban districts.

Keywords: PV/T, Sol₂rgie, LowEx, Sustainable Architecture, Building integration

INTRODUCTION

Buildings are artefacts, artificial sub-systems embedded in a larger system, the natural environment. They result from intelligent processes of analysing and adapting natural laws and cultural patterns. While natural laws can’t be manipulated, cultural patterns are in constant change. Today, the building systems we have created cause too much stress to our own natural environment. Buildings’ impact on climate change, mainly due to an extensive and inefficient use of fossil fuels (and other natural resources), presents a major challenge for the construction industry and on a larger scale, society as a whole.

There are many ideas about how this process can be transformed to lead to a more sustainable built environment. New technologies have been developed that significantly decrease a building’s ecological footprint, but many of these solutions lack acceptance, for manifold reasons. So instead of trying to “reinvent the wheel”, we need to develop these existing ideas in such a way that they better fit their respective contexts. In the last decades solar
installations have made a huge progress, both in technology and market penetration. However this clearly illustrates the intricacy between the development of new technologies and their application, especially in domains like the construction sector. Despite some recent advances, a large fraction of products in the field of domestic solar systems has little or nothing to do with their designated ambit, mostly being the roof.

The roof is the uppermost ceiling and thus the vertical completion of a building. It’s part of the building envelope but its exposed situation embodies the constitutional element of a house; to keep the space underneath protected from the natural environment. Due to this dominant primary function almost all historical roof typologies are variations of a pitched roof. Their structure, form and materiality may be diverse, but they all evoke the feeling of security. Since the period of the Renaissance the idea of a horizontal building completion has fascinated architects and their mentors[1], yet the big breakthrough came with the advances in the field of sealing technology and structural engineering in the 19th and 20th century. Despite the fact that until today a flat roof is widely presumed as a modernist statement, its symbolism has never achieved the power of historical roof constructions. Maybe this is because a flat roof has somehow lost the correlation between its primary function and its form[2].

The objective of this study is a similar conflict between a technological development and the architectural inheritance in its wide spectre. Solergie is a building system that is based on the ZeroEmission-LowEx approach and can be applied in new or existing buildings, providing them with emission-free heating and cooling.[1] It only requires electrical energy from the outside. The use of deep ground as a seasonal heat storage for the thermal share of the primary source, the solar irradiation, allows large reductions in electricity required to operate a heat pump in winter. The boundary conditions for the passive components of a building with a Solergie system are set by the low temperature lift between the heat source and the heat sink to reach a high COP of the heat pump to reach a reduced maximum load. With regard to the overall reduction of CO2-emissions, this approach constitutes an interesting strategy, especially in the case of refurbishments.

PV/T are an essential part of the system. In principle they consist of water-cooled PV-modules, which can be thermally insulated on the backside. Their characteristics correspond to those of unglazed thermal collectors. The cooling effect of the heat absorber increases the electrical output whilst the insulation enhances the thermal gains[3]. In total, PV/T embedded in a low-temperature heat pump system with seasonal heat storage have exergetically wise the highest surface efficiency in transforming the solar irradiation[4]. The surface efficiency of PV/T is a significant advantage compared to other systems, however the current high cost of installation and system integration as well as the bulky modularity of contemporary products represents a major hurdle. The integration analogous to the developments in the BIPV would lead to economic synergies and alleviate the need for maximum surface efficiency in favour of higher design liberty[5, 6]. For this reason the chair of building systems at ETHZ is developing a new hybrid roof construction with integrated PV/T. A first prototype is completed and currently being tested. A large-scale application is scheduled for autumn 2013.

Eventually Solergie isn’t just a technical system that replaces the old ones. Moreover it is an approach that tries to find a balance between the culturally inherited patterns and the exigencies of our contemporary society as well as of the natural environment.

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For this study three main research questions were formulated:

- How could the roofs of the considered buildings be transformed so that they contribute a significant part of the thermal need following the Sol²ergie concept?
- How can the numerous synergetic effects of constructively integrated PV/T affect and maybe revive the almost abandoned typology of the pitched roof?
- How could this approach influence the contemporary discussion about the vertical densification of central urban districts?

**METHOD**

In most studies technical aspects and numerical analysis dominate the evaluation of solar installations as a contribution to a more sustainable future energy system. Furthermore they consider existing structures as to be conserved. The result is a countrywide rag rug of little solar fields that is driven by the idea of efficiency of the single surface and has little to do with the phenomenology of existing roofscapes.

For this reason we have developed a method, which combines numerical modelling with spatial analysis using detailed 3d visualisations. This combination allows an assessment on different scales, as well as the appraisal of objective and more subjective parameters.

In this study, a total of 122 buildings in four existing areas are investigated and 7 different scenarios are developed. All of them are situated in urban centres (Zurich and St. Gallen) where the pressure for transformation is high but which are also admitted to be maintained or strengthen in their physical substance and overall architectural character. Most of the buildings date from the late 19th and early 20th century implicating all the well-known difficulties when it comes to questions of energy saving refurbishments. The typological inventory ranges from perimeter block development to single, multi-storey houses and covers a wide range of roof typologies.

In a first phase the 3d model is set up and every building is characterised by quantitative indicators with an emphasis on the roofs. Illustrations of these indicators allow an additional and more objective comparison between the areas and serve as a basis to develop the different transformation scenarios.

**Energy model**

The geometric data is used to establish the buildings energy balance and the dimensioning of the Sol²ergie building system. Passive measures are defined so that the temperature in the heat distribution system can be set to a maximum of 35-40°C. The second target for the passive transformation is the symmetry of radiation to guarantee the users’ thermal comfort. Subsequently the resulting u-value of the vertical façade must be lower than 0.65 W/m²K in the weighted average. This is achievable with economical and aesthetically acceptable. Invisible parts like basement ceilings are highly insulated (u < 0.20 W/m²K). Together with an adapted domestic hot water system, these transformations lead to an average energy demand of 60 kWh/m²a and a max. load of 36 W/m² according to SIA 380/1 (2009). The other important system temperature depends on the source for the heat pump. To achieve a constantly high source temperature, Sol²ergie uses the deep ground under or nearby the building as a seasonal heat storage, which must be regenerated in summer. In this study the only sources for this process are local PV/T. Consequently their summer yield must match the whole annual thermal energy demand minus the electrical input to the heat pump. Assuming a performance factor of the heat pump g=0.5, the thermal yield that must be generated by the PV/T can be defined. The thermal output of the PV/T for the specific locations and
orientations is simulated with TRNSYS (Table 1). The absolute value for the best orientation (Incl. 20°;180°S) are 451 kWh/m² in summer for Zurich and 436 kWh/m² for St. Gallen. This reduction ratio is applied to determine the thermal yield of every specific roof surface.

**Table 1: Relative PV/T surface efficiency (thermal yield in summer). The system configuration allows more flexible placement compared to installations, which focus on the yearly gains.**

**Transformation scenarios**

The seven scenarios are described in table 2. They vary in terms of their conceptual approach and their depth of penetration into the existing structures. For each scenario the contribution of the PV/T is calculated as a ratio between the thermal yield and the demand of the specific building. To discuss the spatial and typological transformation, every scenario is illustrated in two street views, one view from the roof level and one bird’s eye view (Figure 1-3).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1_SG_P</td>
<td>All existing surfaces larger than 5m² and a surface efficiency above 60% are replaced by integrated PV/T-collectors. It shows the theoretical potential of the present roof surfaces.</td>
</tr>
<tr>
<td>S2_SG_P</td>
<td>PV/T-collectors are applied as standard modules (PV/T-collector 3S-PV, size: 1.65*1m) according to the current building legislation and recommendations for the integration of PV and solar thermal installations in Zurich.</td>
</tr>
<tr>
<td>S3_SG_P</td>
<td>A secondary building element is applied in the form of a shed dormer that offers a good surface orientation for PV/T and additional useable volume underneath. The shape of the primary roof construction is not manipulated whereas the secondary structure is a modification of an existing typology.</td>
</tr>
<tr>
<td>S4_SG_S</td>
<td>The kerb roof serves as a typological reference to establish a horizontal zoning. The 1st level mediates between the corpus and the roof. The 2nd level accommodates well-oriented, integrated PV/T-surfaces and the 3rd level is used as a terrace as soon as the energy benchmark is accomplished. Additional living space.</td>
</tr>
<tr>
<td>S5_SG_S</td>
<td>An integrated PV/T surface is applied on every building. The size, orientation and inclination are chosen to achieve the benchmark with a minimal PV/T area. The emphasis is placed on efficiency and autonomy with no regard on existing typologies. Additional living space.</td>
</tr>
<tr>
<td>S6_SG_S</td>
<td>A layer of integrated PV/T replaces the existing roof scape. This scenario is deduced from the idea of a superior, communal infrastructure. The maximal total yield is attained with an E-W orientation and a 15° inclination (minimal shadows). The building corpus is heightened to maintain the initial volume.</td>
</tr>
<tr>
<td>S7_SG_S</td>
<td>Similar to S6 a “solar layer” replaces the existing structures. But the homogeneous pattern is altered by the size and orientation of the buildings to merge the existing urban layout.</td>
</tr>
</tbody>
</table>

**Table 2: Schematic illustration and description of transformation scenarios.**
RESULTS AND DISCUSSION

To compare the scenarios the thermal contribution potential of the PV/T-collectors are shown in table 3. Since the energy and the power demand per m² heated are normalised, the remaining variables are the ratio between the heated floor area and the PV/T area as well as the quality of the latter (surface efficiency). This becomes obvious in scenario S3. The buildings in Paradiesstrasse, St.Gallen (S3_SG_P) are mainly 3-4 stories high and have well oriented and simple primary roof structures while they are 5-6 stories high and have a lot of very steep roof surfaces in the case of Kanzleistrasse, Zurich (S3_ZH_K). The district ratio raises the possibility of trade-off systems between several buildings (e.g. perhaps some buildings should be preserved whereas others offer good installation opportunities).

![Graph showing district ratio and building ratio (median).]

Table 3: Thermal contribution potential of PV/T-collectors for the different scenarios.

![3D visualisations from different viewpoints (ex. S2_SG_S).]

Figure 1-3: 3D-visualisations from different viewpoints (ex. S2_SG_S)

![3D visualisations of three different scenarios (ex. S3_SG_S; S4_SG_S; S7_SG_S).]

Figure 4-6: 3D-visualisations of three different scenarios (ex. S3_SG_S; S4_SG_S; S7_SG_S)

In general one can see that a consequent accomplishment of contemporary installation paradigms does not lead to satisfying results in terms of energy as well as roof design (S1.3).
On the other hand, all the scenarios that are emphasising the maximum energy yield while neglecting the physical heritage lead to abrupt ruptures. S3 and S4 may be successful strategies, because they are developed from existing typologies in an “amalgamating” process.

CONCLUSION

As a conclusion of this study we argue that:

1. Even though technology will become more surface-efficient, the problem lies in the lack of well-suited surfaces. If the entire thermal energy demand is locally generated by PV/T, the roof needs to be reinterpreted. The additional function must be carefully brought in line with traditions, but by doing so the functional densification increases the (positive) ambiguity and (lost) integrity of the building element. Instead of creating a rig rug, the roof as whole must be seen as an energy-generator. Pursuing the synergetic effects of the building integration will lower costs and facilitate architecturally coherent and energetically sufficient constructions.

2. The indirect correlation between energy consuming area and energy generating area may launch a new planning instrument. Given a certain energy standard, a building should be able to generate the heat on-site and therefore offer enough well suited surfaces as long as there is no other heat source available.

3. Even though the aesthetic legacies of the modernist movement and the subsequent developments in the construction industry have almost replaced traditional roof typologies, the archetype is still a pitched roof. The technical benefits of slanted solar installations may introduce a renaissance of pitched roof constructions.

4. These new hybrid roofscape have manifold economical leverage effects to be studied. They increase the buildings’ value by creating additional and attractive living space and supply their host buildings with CO₂-emission free energy without burdening the existing communal infrastructure.

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