AACHENER INSTITUT FÜR BAUSCHADENSFORSCHUNG UND ANGEWANDTE BAUPHYSIK
GEMEINNÜTZIGE GESELLSCHAFT mbH
PROF. DR.-ING. RAINER OSWALD†
DIPL.-ING. MARTIN OSWALD, M.ENG.
PROF. DIPL.-ING. MATTHIAS ZÖLLER

Solar systems on flat roofs in the building stock

Research project: Supported by funds of the Research Initiative Future of Building („Zukunft Bau“) of „Bundesamt für Bauwesen und Raumordnung“ (SWD – 10.08.18.7-13.31 / II 3 – F20-11-1-145)
The responsibility for the content of the research study lies with the authors.

Conducted by: AIBAU – Aachener Institut für Bauschadensforschung und angewandte Bauphysik, gGmbH, Aachen

Project Manager: Prof. Dipl.-Ing. Matthias Zöller

Authors: Dipl.-Ing. Ralf Spilker
Dipl.-Ing. Géraldine Liebert
Dipl.-Ing. Martin Oswald, M.Eng.
Prof. Dipl.-Ing. Matthias Zöller

1. Reasons for the research project

Over the last two decades, solar systems have frequently been installed on flat roofs of existing buildings. In some cases, this has led to considerable damage, because, on the one hand, the roof surface was not designed for such facilities and, on the other hand, the fitters installing the solar systems did not take into account the characteristic function of roof sealings and roof structures when planning and executing their work.

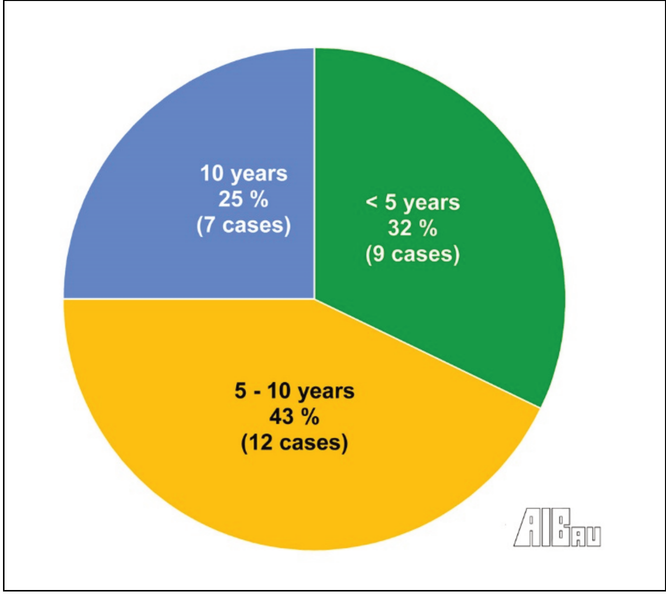
Up to now, current building regulations for flat roof sealing have not adequately dealt with this comparatively new use of flat roofs. So it was necessary to inspect and document typical instances of damage, in order to work out instructions and recommendations to prevent the flat roof layers from damage.

2. Practical experience with solar systems installed on flat roofs in the building stock

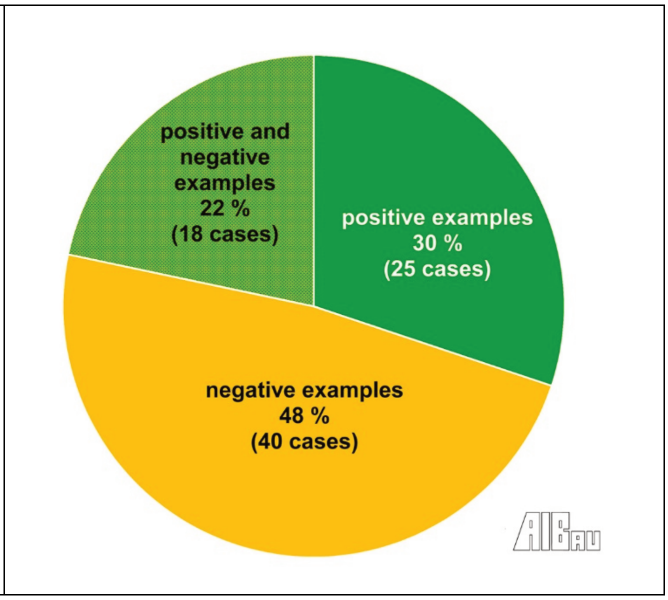
In a survey, 1,448 publicly appointed experts for building failure as well as roofing experts were asked to describe their experience with the installation of solar systems. 138 of them provided detailed answers. They reported on a total of 105 buildings which did not suffer any damage to the flat roof resulting from the subsequent installation of solar systems. On the other hand, there were 149 cases of damage. Moreover, member firms of the Federal Association of Solar Industries ("Bundesverband der Solarwirtschaft") were asked to participate in the survey, eight of which responded to the questions.

The age of the damage-free roofs was reported to be between zero and forty years, with a fairly even distribution among the following periods: 0 - 5 years (9 examples), 5 - 10 years (12 examples), more than 10 years (7 examples).

The main reasons for damage were the penetration of the roof membrane by fastening elements (30 cases) and insufficient examination of the substructure before the installation of the solar system (26 cases). Other reasons were prior damage to the sealing, for example by aging (19 cases), insufficient dimensioning of the load-bearing structure for the additional weight (14 cases), and an inadequate securing of the solar system against wind suction (12 cases).



A 1:
Periods of damage-free solar systems installed on flat roofs in the existing building stock



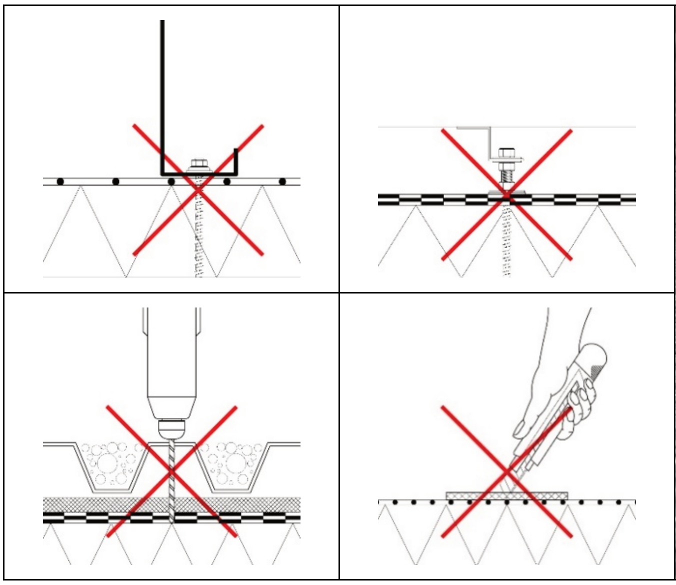
A 2:
Number of positive and negative examples of solar systems installed on existing roofs)

The negative examples can be divided into four categories:

1. Damage due to insufficient consideration of the substructure
2. Damage due to inadequate planning
3. Damage caused by neglect of the technical rules for roof sealings
4. Damage due to insufficient fixation on the roof surface

Reasons for failure in the first group may be insufficient examination of the load-bearing capacity of the substructure and of the structural roof layers, of prior damage to the sealing, (for example by aging) or to the structure (for example because of defects in the structural layers) and of the existing gradient. When solar systems have to be dismantled shortly after being installed, because defective areas in the structural layers must be inspected and differentiated from prior damage, there will be additional costs for dismantling and new installation work. If the condition of the roof surface is not documented before installation, facility fitters will run a high liability risk.

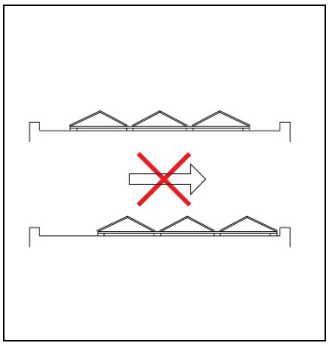
In the second group, damage is likely to occur if the solar system is not adequately secured against wind suction. Other reasons are the neglect of instructions provided by the manufacturer of the installation system, the lack of space between the solar installation and the roof edges or the skylight domes, or the adhesive fixation of facilities on the roof sheet without the required approval of the supervisory building authority. The lift-off of indirectly fixed solar panels is certainly the greatest danger to the public. Often the required ballast is not installed, or the producer's instructions are not complied with, or the material is applied to a type of substructure for which it was not designed; sometimes insulation materials are expected to counteract wind suction, even though they have not been technically or officially approved for this purpose.



A 3:
Leaks caused by inadequate planning (above) and damage caused during installation (below)

A 4:
Inadequate planning of the fixation and attempt at sealing the leaks by liquid plastic

In the third category the methods of fixing solar panels sometimes show that fitters are not familiar with the proper sealing techniques. There are bar-shaped fixing elements which penetrate the sealing layer, followed by incompetent attempts at sealing these leakages. Often, the leaks caused during installation of the solar system cannot be exactly located, so that the whole solar system must be dismantled again.



A 5:
Horizontal movement of ballast-optimized systems must be avoided

A 6:
Horizontal movement of solar facilities over the unsecured roof edge

The most important reason for failure in the fourth category is the insufficient safeguard against horizontal displacement of solar systems. The growing tendency to use lighter elements, whose ballast, as a result of aerodynamic calculations, can be considerably minimized, leads to a greater risk of temperature movements because of the bigger size of the modules. Since the static friction between the roof sheet and the supporting point cannot be safely predicted, there is a danger of horizontal movements caused by wind squalls. If the roof has no stable raised edges, the solar facilities threaten to fall from the roof.

The following criteria have obviously resulted in a positive performance of solar systems on flat roofs in the building stock: Before the decision to install solar facilities, the existing roof was thoroughly inspected. The solar systems were installed on a pressure-resistant roof-structure with sufficient ballast. The facilities were directly fastened to the roof with an adequate sealing of the supports. Regular maintenance (such as the inspection of the protecting mats, or the removal of obstructions from the water discharge) clearly helped to prevent serious damage, too. New types of supporting elements on the roof membrane (made of plastic or of EPDM rubber) have been developed to increase adhesive friction even on smooth plastic sheets and thus minimize the risk of horizontal movement. Fixation supports which are adequately included in the sealing will directly secure a stable position and will thus ensure the reliable performance of the roof structure and the solar systems.

3. Current Regulations

Regulations for the sealing of flat roofs are at present in the process of being revised, first of all the guidelines of the Central Association of the German Roofing Trade (“Zentralverband des deutschen Dachdeckhandwerks”) and DIN 18531 (which has already been valid for non-utilized roofs and will, as the regulation succeeding part of DIN 18195, also become valid for utilized roofs). The old versions do not contain the relevant criteria for the installation of solar systems, especially not for using supports on existing roofs. But some associations of sealing sheet producers and of the metal industry have provided useful information concerning the requirements for installing solar systems, so that one can expect such minimum requirements to be specified in the new editions of the above-mentioned regulations, too. The new Sheet 1.4 (“Blatt 1.4”) of the VDI 6012 published in January 2016 also contains valuable instructions concerning the dimensioning of the facilities.

The requirements of fire and lightning protection are already imposed by current regulations which apply to the housing stock. Requirements for the prevention of accidents during the work on solar facilities, such as safety precautions to prevent workers and maintenance staff from falling off the roof, have recently been stated by insurance companies.

4. Suggestions and recommendations

The conclusions drawn from the survey, from regulations, research projects and the professional experience of the authors are summed up in the form of recommendations for installation systems, roof construction, sealing materials, type of installation, thermal insulation materials and gradients and can be used as a kind of checklist.

Before installing solar systems there must be, first of all, a thorough inspection by planners and roofers of the load-bearing structure and the roof layers. For this purpose, a sufficient number of openings will be necessary.

4.1 Load-bearing structure

The examination of the load-bearing structure does not only serve to assess the dimensions and materials, but also possible damage by corrosion or existing overloads. This is especially important for components hidden from sight. For example, until a few years ago, it was common practice to use galvanized corrosion- resistant trapezoid steel sheets. After, in a few cases, the upper belts of the metal sheet began to corrode because they lacked contact with CO_2, a process unnoticed from within the room, corrosion-resistance was improved by an additional plastic coat. It is important to ascertain this on the spot. Another possibility is that girders within the wall cross section are considerably damaged by corrosion, although this is not visible from within the room.

In the past, load-bearing structures were not only inadequately designed, but also erected with insufficient dimensions. In some cases, the girders were not reinforced against wind or torsion. Even if some of such buildings have been damage-free over decades and their use has remained the same, they will not be granted the right of continuance if their structural stability is endangered, especially by additional loads, e.g. by solar facilities.

4.2 Roof sealing

To assess the quality of a bituminous roof coating, a roofer should not only inspect the condition of the surface, but also the functioning of the joint and seams of the edge connections and other joints. The surface of bituminous roof sheets should be free from crackles, a sign of advanced aging (embrittlement), and from cracks above the joints in the substructure. The reasons for wrinkling should be assessed, to find out if the movements within the roof surface have stopped. The formation of bubbles may be caused by incomplete or unsuitable bonding. Even if bubbles can be partly removed it is likely that the bonding of the roof sheets is defective in other places and that the sealing will need intensive maintenance. In that case, the renewal of the sealing would be advisable.

Frequently the problem with plastic sheets is that the material cannot clearly be identified. Then a sample should be taken and analyzed in a laboratory.

If the plastic roof sheet shows signs of chemical changes, the roof sealing should be replaced before installing solar facilities. Changes in the material are often indicated by wrinkles at the edges of joints in an otherwise smooth sheet surface, due to a shrinking process. Undulations in the sheet surface probably show that the sheet has swollen up. A change in the material can also be assumed when the surface of the sheet looks different in comparison with covered or bonded patches, especially if it looks like a kind of “orange skin”. After long periods of very cold weather, plastic sheets without inlays or reinforcement are liable to crack into very small pieces or to develop unstable fractures (the so-called shattering-effect). Since the reasons for this phenomenon are not yet clearly understood, it is not possible, even by analyzing the material, to assess the likelihood of “shattering”. In this case the sealing sheet should be replaced before installing solar facilities.

Plastic sheets are required to have a minimum thickness of 1.5 mm and a homogeneous bonding of the seams. If the sealing of the seams consists of self-adhesive layers, it will be necessary to protect the seams from the impact of mechanical stress (caused, for example, by horizontal movement of the facilities).

The sealing sheet should be repairable; it should not consist of materials that cannot be homogeneously bonded on the roof, and it should not be so old and dirty that bonding becomes impossible. It has to be resistant to microbes, that means it should also be approved by the manufacturer for the installation beneath a gravel layer. Furthermore, it must be ascertained whether the material of the sheet and the support of the solar system are compatible.

Professionally installed sealing sheets with lightweight surface protection are expected to have a lifespan of ca. 20 years, those with heavy surface protection a lifespan of 30 years. In many cases the roof sealing will be already past the first half of its technical lifespan; so, before installing solar facilities, planners have to decide whether to completely replace the sealing, or to apply an additional upper layer, so that its lifespan will be comparable to that of the solar system.

If the age of the roof sealing exceeds 5 years (or 10 years in the case of heavy surface protection) an expert should decide what repair and modernization measures will be necessary to achieve an estimated lifetime matching that of the solar system (i. e. 20 years). Otherwise there should be an agreement with the owner of the roof that repair measures will become necessary during the service life of the solar system and that this requires the temporary dismantling of those facilities.

4.3 Thermal insulation

Thermal insulation materials have to transmit the pressure from the imposed load of the solar system. As a rule, this is no problem with rigid foams made of expanded polystyrene (EPS), extruded poystyrole (XPS), polyurethane (PUR) or Polyisocyanurate (PIR). In general, thermal insulation materials made of pressure-resistant mineral wool in non-ventilated flat roofs can also transmit the load of photovoltaic systems. However, they may become less resistant when frequently exposed to pressure. This risk is especially given during installation or maintenance work. For this reason, paths for fitters and maintenance staff should be paved with load-distributing plates. The resistance to pressure (and if necessary the moisture content) of the thermal insulation should be at least randomly tested and documented in order to avoid later disputes about damage caused during assembly.

The resistance to pressure of installed insulation slabs is an essential aspect to be considered by planners. But reduced pressure resistance does not necessarily require the exchange of slabs, provided that sufficient dimensional stability can be permanently assured through load-distributing measures. Another solution would be to fasten the solar modules directly through the roof structure to the layer beneath, which would not have any impact on the thermal insulation and the sealing.

If the thermal insulation material contains moisture, one has to examine the reasons for this condition and find out whether it can damage the function of the roof structure. In many cases, a slightly increased moisture content has little effect on thermal protection; it does not reduce the resistance to pressure of foam plastic materials and therefore the replacement of the insulation layers will not always be necessary. This problem has been dealt with in several research studies by the authors in the past.

The decision whether a moisturized roof structure should be exchanged or left in its place, involves great responsibility and careful consideration of the individual case. It should be based on the available financial means and the predicted service life of the roof. If measures have to be carried out beneath a newly-installed solar system, it will mean higher expenditure.

When the roof structure is to remain in place in spite of its moisture content, the distribution and extent of humidity should be assessed if that can be done at reasonable costs. Mostly, the humid parts are clearly confined to some areas. It is best to document these findings in order to ascertain the development of the roof condition at later inspections. If liquid water has collected in the roof structure, the water should be removed at regular intervals. Apart from that, the necessity for, or the possibility of improving thermal insulation should be examined.

5. General recommendations

In order to install solar facilities without the risk of damage on flat roofs in the building stock, the following preconditions should be fulfilled:

1. A thorough **inspection and documentation** of the load-bearing structure, the roof layers and the intended use of the building, and, on that basis, the decision on preparatory repair and modernization measures. It is advisable to use the expertise of architects, structural engineers and roofers.
2. A comprehensive **design** of the solar system, clearly defining the responsibilities of the various planners involved; a detailed static calculation taking into account the load transmission of the roof structure; protection against fire and lightning as well as safeguards against the risk of falling off the roof.
3. A careful **installation** of the facilities in accordance with the producer's instructions; measures to protect the roof structure during the assembly of the solar system.
4. Regular **maintenance** of the facilities including inspections after extraordinary weather incidents.

6. Conclusions

In the future flat roofs bearing solar systems will – in terms of building regulations – rightly be considered as utilized roofs with a special use for building services. So the assembly of solar systems on existing roofs will have to fulfil the same requirements as on newly-erected buildings. Since existing roofs were usually not designed for the later installation of solar modules, a strict assessment according to current standards would not permit the installation of solar modules. For example, when the resistance to pressure of the insulation material does not comply with the latest regulations, the question is whether the roof surface can nevertheless be suitable for solar facilities. Should the top sealing layer show symptoms of beginning corrosion, planners have to decide whether it can still be used after an additional layer has been applied, or whether the whole structure has to be modernized. To judge economic profitability, this will require an assessment of the service life of the roof during the average lifespan of the solar system. On the other hand, exaggerated demands on existing buildings should not prevent the use of solar energy because then the additional measures required would reduce economic profit.

Provided that the recommendations suggested in the research study are complied with, solar systems can safely be installed on roofs in the building stock and can thus meet the need for renewable energy.