PV-ROCK-ROOF

WG2 Summary report

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WG2 Summary report

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Content

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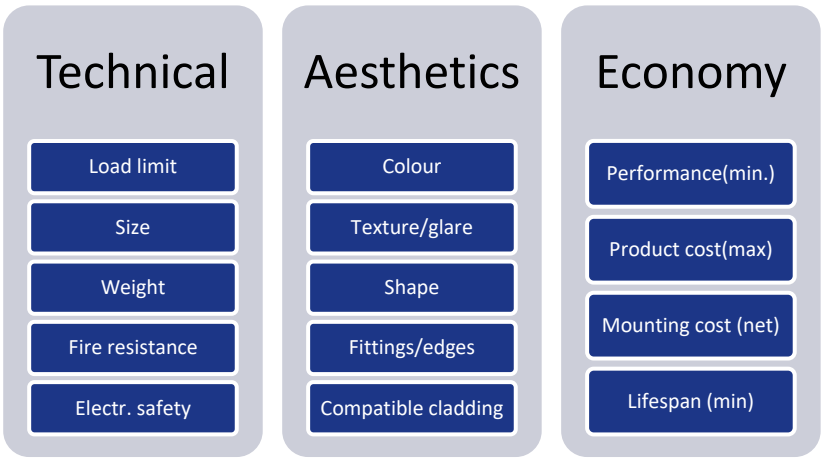
1. Background

The current report is an annex to the final report from the PV-Rock-Roof project and contains non-classified information and results from the design process that was carried out in Work Group 2.
The project aim is to develop a roofing system with integrated PV elements and stone wool insulation for pitched roofs and for flat roofs. The ideas for the solutions have been elaborated at several WG2 workshops focusing on specific requirements for the final product. In this document, the design process is described.

General requirements for the BIPV
PV laminates are developed in their basic form by Danish Solar Energy (DSE) but need redesign. Some of the obvious questions are:

- One size or multiple? Elements for fixation and water proofing need to be integrated.
- Mounting methods: Do the PV laminates need to be glued, or should they be dismountable? What should be the maximum weight or size? Are the elements intended for new buildings or renovation?
- Technical requirements: Fire resistance, durability, water tightness, temperature.
- Economical constraints: Added value vs. added cost. What would the reference cost of a traditional solution be?
- Aesthetic requirements: Should the solution fit to Copenhagen roofs? Reduction of glare (we should compare different glass types).



Pitched roof solution requirements:

- Should it be mounted from the top and down or the opposite?
- Should the design fit existing roofing materials?
- Which type of roof construction should the solution fit to?

Flat roof solution requirements:

- Should the elements be "traditional" warm roofs or inverted roofs?
- Can edges be made of roofing felt, so it fits to the rest of the roof?
- As aesthetics are less critical for the flat roof, what is the added value of integrating PV elements? Multifunctional use of the roof? Easy upgrade of the roof for both insulation and energy generation?

At the time of writing, focus of the development was on the pitched roof solution. The flat roof solution was more complex, as the design would need to deal with standing water.

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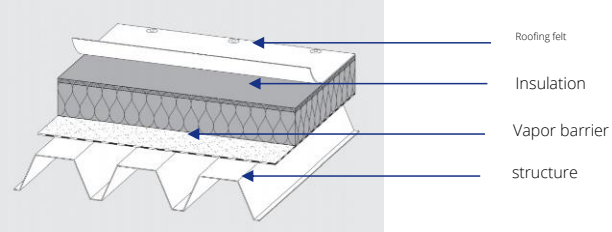
2. Markets and roof types

Initially, it was decided to look at a renovation solution. For both flat and pitched roofs, the believe was that a BIPV system would be most effective in terms of installation costs. In the pitched roof, the aesthetics of the colored elements would have a huge benefit for integration in the existing building environment. The final solution for the flat roof could be used for both new buildings and renovation. The lower weight of the flat roof system would be beneficial for flat roof systems.

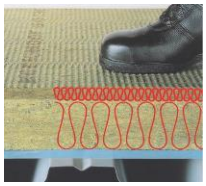
Kommenterede [LAK1]: Mærkelig sætning. Skal der bare stå: the lower weight would be beneficial for....

2.1. Flat roof

Insulated flat roofs can be divided into cold, warm, and inverted roofs. Cold roofs are usually not recommended and will not be discussed further. Practically all the flat roof insulation (FRI) that Rockwool supplies is for warm roofs, named so as the structure is kept warm by the insulation.

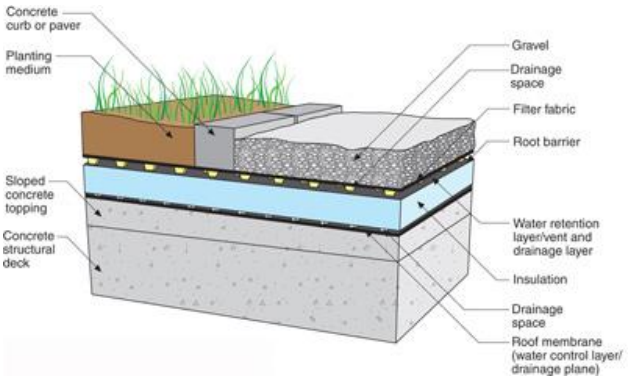


Roofing felt for flat roofs consists mostly of Bitumen and PVC and is intended to keep rain and snow out of the construction. For the insulation, Rockwool sells three types of insulation: mono-density slabs (usually only for underlay products), dual-density slabs (products with a hard-top layer for improved walkability) and lamellas (products with vertical fibers direction for improved mechanical strength.



The vapor barrier is usually a PE fleece added to prevent condensation in the insulation. In Denmark, it is mandatory to put an incombustible layer of insulation underneath a vapor barrier. In those cases, another layer of stone wool will be placed there. The structure can be steel, concrete or wood.

In an inverted roof, the insulation is placed on top of the roofing felt. This has some hygro-thermal disadvantages, as the insulation will get wet. In recent years, this way of building has grown in popularity due to the increase in green and other functional roofing where this construction method has some advantages.



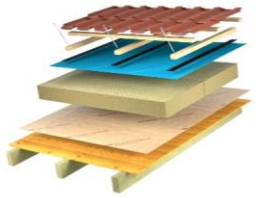
Usually, the insulation is water and vapor tight like XPS insulation in combination with a ballast layer that keeps the insulation in place. Rockwool has sold inverted roofs in the past, notable without ballast, as the open structure of stone wool prevents wind uplift. Special measurements need to be taken to prevent the wool from absorbing to much water.

2.2. Pitched roofs

In Pitched roofs, there is a wide variety of structures and systems on the market. Waterproofing is mostly provided by tiles or plates.

From Rockwool's perspective, there are three different types of insulation principles for the pitched roof: insulation on the rafters, between the rafters, and prefabricated systems.

For the project, the 'on the rafter' solution would make the most sense.



Besides the various structures, there are also various details like skylights, ridges and wall connects that can vary from building to building.

For the project, it was decided to focus mostly on renovation systems, as colored PV panels would fit better in an existing building environment.

There is a numerous building stock from the 60s and 70s that need a change of roof cover or a completely new roof construction with utilization of the 1st floor. Especially in the latter case, it adds value if insulation and roof cover are a part of the same product and process.

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3. Technical and legal requirements to the product

3.1. BIPV standards

Building integrated PV systems have been in the market for some time, yet there have been no specific international standards specifically for this segment until recently. In this section, some of the technical requirements in these standards are described.

BIPV standard IEC 63092-1 defines 0-75 degrees slope as one category and 75-90 as another. There is a subdivision in categories of 'accessible' or 'not accessible'. Both the pitched roof and the flat roof solution would be in category 0-75 and A.

Category A:	**Sloping, roof-integrated, not accessible from within the building** The BIPV modules are installed at a tilt angle between 0° and 75° including horizontal (see Fig.1), with another building product installed underneath.	
Category B:	**Sloping, roof-integrated, accessible from within the building** The BIPV modules are installed at a tilt angle between 0°and 75° including horizontal (see Fig.1).	

Requirements for products with at least one glass panel according to IEC 63092-1

Mechanical resistance and stability

Since there is no international consensus upon further requirements for mechanical resistance of BIPV modules, other than IEC 61215-1, IEC 61215-2 and the IEC 61730 Series, and the high-temperature standard IEC TS 63126 (in progress), the requirements specified under national or local standards or codes are to be met. BIPV modules must withstand the loads that are expected at the location (incl. position with regard to the building) of their application. Compliance can be verified either by calculation or by testing.

In the project, the solutions will be tested according to IEC 61215 to be on the safe side.

Safety in case of fire

The BIPV module shall meet the fire safety requirements of the local national building code (or similar) for the building function it provides.

Hygiene, health, and the environment

Until an international standard is published, national or local codes or standards may apply.

Safety and accessibility in use
In addition to IEC 61730-1 and IEC 61730-2, the following standards or technical specifications shall apply.

The BIPV module may be required to comply with national, regional, or local standards or codes addressing safety and accessibility in use.

Pendulum test
The BIPV module shall meet the impact requirements of IEC 61730-2 MST 32 and ISO 29584 together with the local national building code (or similar) for the building function it provides. It should be noted that additional testing for impact from both sides of the module may be required.

Table 2. Summary of the building-related requirements for BIPV modules with at least one glass pane

Basic requirements	Application category based on Table 1				
	A	B	C	D	E
Mechanical resistance and stability	National, regional or local codes, or standards IEC 61215-1 and IEC 61215-2 (if relevant) IEC 61730-1, IEC 61730-2 IEC TS 63126 (if operating under high temperatures) Annex A				
Safety in case in fire	National, regional or local codes				
Hygiene, health and the environment	National, regional or local codes, or standards				
Safety and accessibility in use	National or regional building codes IEC 61730-1 and IEC 61730-2 ISO TS 18178 (if laminated glass) ISO 28278-1 (if structural sealant glazing) ISO 29584				
Protection against noise	ISO 16940, ISO 22897				
Energy economy and heat retention	National, regional or local codes, or standards ISO 9050 and/or ISO 15099				
	ISO 10291 and/or ISO 10292 and/or ISO 10293				
				ISO 19467 (if relevant)	ISO 52022-1 ISO 52022-3
Sustainable use of natural resources	National, regional or local codes				

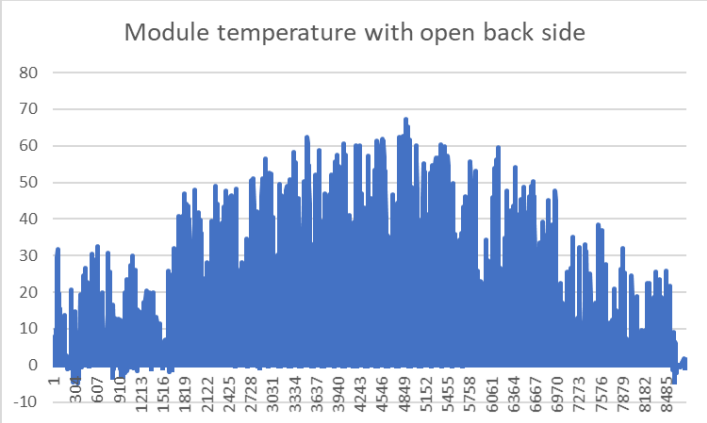
Requirements and standard references for the PV modules.

Driven rain test
Is not a part of the BIPV standard but thought to be necessary for this project. The BIPV roof must be comparable or better than competing roof materials, and this is one of the major challenges in the project.

3.2. Heat load

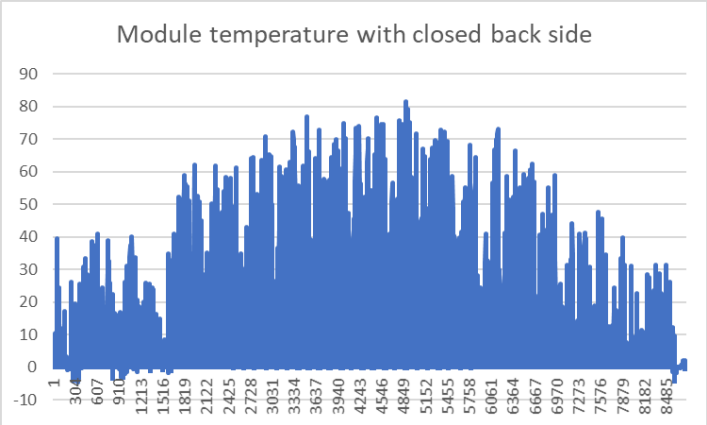
As the project deals with combining insulation with PV elements, it is important to check if the PV elements don't overheat. According to the scope of IEC TS 63126, it is only relevant as supplement to the usual IEC tests if the module temperature is expected to equal or exceed 70 °C for 175,2 hours per year. Therefore, an analysis was made in Pvsyst for a typical south facing PV system with 40 degrees slope. The analysis is made with an overall heat transfer coefficient of 20 and 15 W/m2K respectively as per the PVsyst manual.

For a module with open back side, there are not any operating hours exceeding 70 °C under Danish climate conditions, but from the graph it is obvious that in a climate with higher summer temperatures this will be the case.



Hours exceeding 70 °C: 0.

For a system with full rear insulation operating in Denmark, the result from Pvsyst calculation shows the following hourly distribution:



Hours exceeding 70deg C: 48.

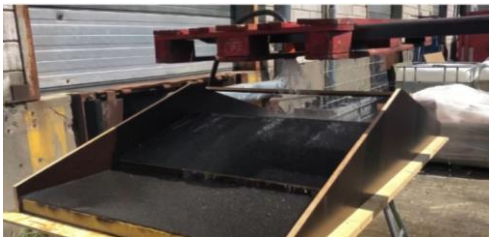
This value is comfortably lower than the threshold value, so from an approval point of view, the standard IEC61215 test procedure is sufficient.

3.3. Rainwater protection

As mentioned in 3.1., BIPV systems need to be protected against rainwater penetration. Several tests and norms have been investigated to see if the solution would be sufficient.

3.3.1. Flat roof

Due to budget constraints, the flat roof was tested with a self-made setup. Joints were closed with a known solution used in the building industry today. In the case of the test setup, standard bitumen was used to close most of the roof. This applied upward underneath the overhang of the PV-panels. The top of the setup, where two PV-panels meet, is closed with a metal profile.



Test setup for flat roof.

Bottom of setup, no water is coming through.

3.3.2. Pitched roof

The pitched roof was tested according to EN 12865:2001 'Hygrothermal performance of building components and building elements - Determination of the resistance of external wall systems to driving rain under pulsating air pressure'. The construction was tested without an underroof layer. In the demonstration roof, it was decided to use an underroof layer anyway. This will make it easier to convince specifiers to choose this solution.

Kommenterede [LAK2]: ? hvem/hvad er specifiers?

859287-VPS%20-%20
Rockwool%20Internati

3.4. Thermal performance.

3.4.1. Flat roof

The final concept selected for this project would likely work best for new roofs. In newly constructed buildings the thermal insulation will need to comply to local regulation. The insulation thickness must be adjusted to U- or R-value demand needed for the building. In Denmark a concrete flat roof would typically be covered with a layer of 180mm of Underlag Energy and 100mm of Hardrock energy insulation giving a U-value of 0.12 m2K/W. In the PV-rockroof concept stone wool lamellas are used to get the right inclination of the PV-elements. These will be thicker than the overall insulation and thus have a lower U-value.

3.4.2. Pitched roof

The pitched roof is designed as a renovation solution. When roofs are being renovated, a combination of thermal improvement with energy generation is advantageous, as the upgrade can be made in one instalment. In the chosen solution, the renovation of the roof can be combined with the renovation of the facade by using the Rockwool REDAir system.

Typically, in renovation, the required U or R value is more flexible (although, depending on the country, there is a minimum). Esthetical or structural demands might limit the maximum thickness of the renovation. If the roofing system is combined with insulation between the rafters, relatively low U values can be achieved.

The advantage of placing insulation on the rafters is that cold bridges are closed. In traditional renovation, rafters are heightened by placing extra wood on top of the rafter. This creates a thermal bridge within the structure meaning that the total construction needs to be bigger to reach the same U value. Roughly 3 cm can be saved by using the PV-ROCK-ROOF solution.

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Renovering - ROCK ROOF LØSNING/new renovation method			**Renovering – TØMRERLØSNING/traditional renovation**	
UK terms	mm		Danish terms	mm
RockRoof	100		RockRoof	0
Insulation thickness	340		Samlet isoleringstykkelse	355
Total thickness	440		Konstruktionstykkelse	473
U-værdi	**0,12**		**U-værdi**	**0,12**
Wood percentage in insulation layer	5.25%		TRÆANDEL i isoleringslaget	6.21%

thermal%20calculation.xlsx

Kommenterede [LAK3]: Denne figur skal vist finpudses lidt mht. sprog?

4. Work process, description of ideas

In general, most of the design work was done in workshops with several smaller groups working on details. Ideas were mostly presented in the form of drawings and then worked out in mockups to discuss the principle. Most drawings were made by Effekt, PV-elements were supplied by DSE, and most of the mockups were made by Rockwool carpenters.

4.1. Flat roof

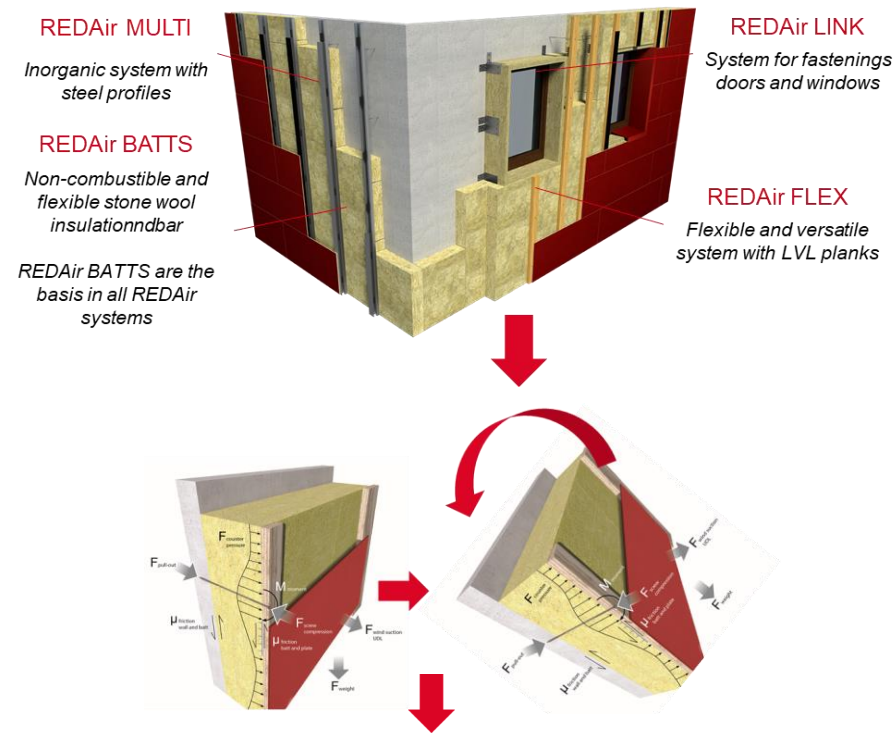
Several ideas were developed within the course of the project. Some of them will be investigated by Rockwool after the project is finished. Finding a feasible solution for the flat roof solution proved to be quite difficult, especially for ideas where the PV was a part of the water-resistant membrane. In the pitched roof, gravity helps with the removal of water which makes the design a little easier. The original idea was to have a PV element that would provide both the water proofing and the solar energy. In theory, it could even be a single element with integrated stone wool insulation. This proved to be too difficult to make.

The follow up of this idea was to accept water penetration of the system by going for an inverted roof concept by fixing PV panels on top of stone wool inverted roof boards. As the PV would close of the stone wool, it could be that some form of fixation of the insulation to the roof is required. Studies on uplift of this concept were inconclusive.

The final idea that was selected for this project was combining traditional insulation with stone wool lamellas that are cut to fall. Traditional insulation will ensure the right walkability, while lighter wool that is cut to fall allows for the correct orientation towards the sun. From a water proofing point of view, the traditional insulation can be clad with a regular roofing felt. The cut to fall part will be closed with a solution like the pitched roof solution.

4.2. Pitched roof

As with the flat roof solution, initially the idea was to have a single element with insulation and PVs. The downside of that idea was that the final product would be very complex and very heavy. Waterproofing, electrical cabling and insulation all had to be combined. There were some proposals which could be investigated further, but in the end it was decided to install the PVs separately from the insulation. The PV elements would be installed with metal hooks on lattes. The insulation system is based on the Rockwool REDAir system, a facade system that will now be given a pitch.



Development of the pitched roof solution. On the left: LVL planks with metal hooks. On the right: The multi system.

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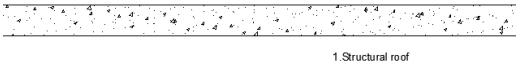
5. Mounting issues (top-down or the opposite, disassembling etc.)

5.1. Flat roof

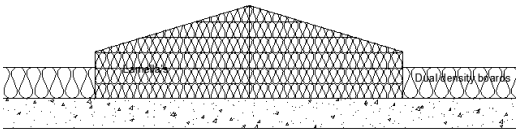
In normal warm roof constructions, the insulation is placed first and then covered with rolls of roofing material. Solar elements are installed later. In the solution that was selected, installation will go similar, although the PV elements are a part of the rainwater protection.

Below, a step-by-step overview of the installation. Total weight is similar to a regular stone wool roof.

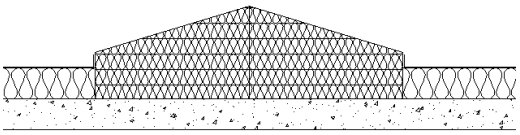
Insulation	90	kg/m3	PV	12 kg/m2
	1.6	long		0.44 m2
	0.2	wide		5.28 kg
	0.4	thick		
	0.064	m3		
	5.76	kg	Total	11.04 kg per unit
	0.32	m2 footprint		34.5 kg/m2 roof



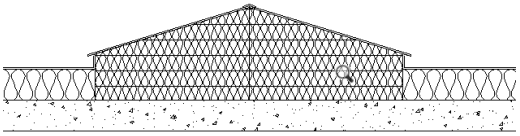
1.Structural roof



2.Place insulation



3.Fix roofing felt



4.Place PV panels

An inverted roof would be executed in a similar fashion. In the case of a warm roof solution, mechanical fixation or glue can be used to fix the insulation.

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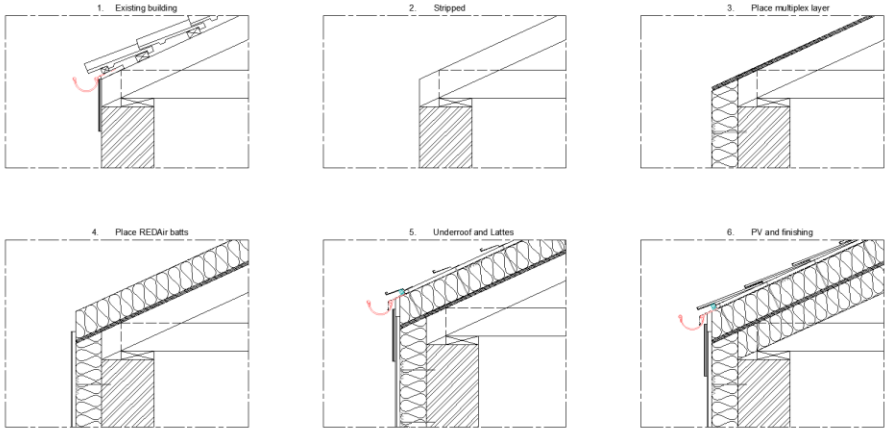
5.2. Pitched roof

In the case of renovation, the existing building will be stripped from the outer material. A multiplex layer will be placed on top of the rafters, which will be the basis of the REDAir batt insulation. The lattes will be fixed through the insulation. Tooth plates on the back of the lattes increase the friction between insulation and the lattes, reducing the load on the fixations. The PV panels will be installed like regular roofing tiles.

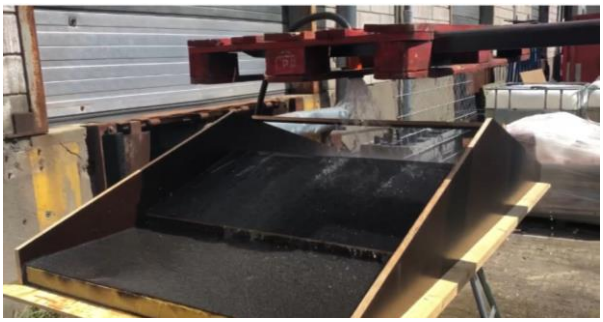


Insulation	60	kg/m3	PV	12	kg/m2
	1,6	long		0,6	m2
	0,3	wide		7,2	kg
	0,15	thick			
	0,072	m3			
	4,32	kg	Total	11,52	kg per unit
	0,48	m2 footprint		24	kg/m2 roof

6. Construction of mockups

6.1. Flat roof

As mentioned under Chapter 3, Mockups have been made for the final solution and were tested for water resistance. The parts that are higher are made with lamella insulation, while the places that are covered with bitumen are standard flat roof insulation products. Bitumen is also fixed on top of the vertical parts of the insulation. The PV elements cover the "horizontal" parts. By making the lamellas cut to fall, a lot of water can be removed naturally. The joint between the panels will be closed by placing a stainless plate that laminated in one panel underneath is placed underneath the next panel. By making the PV panels slightly larger than the lamellas, an overlap can be created, ensuring the closure of the system.

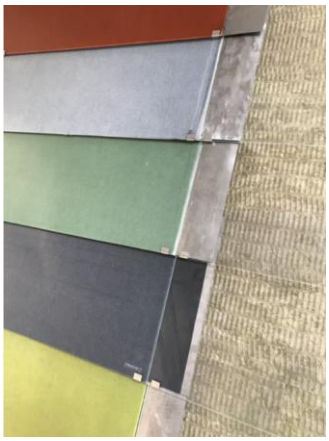


Test setup for flat roof.

6.2. Pitched roof

In the pitched roof solution, lattes carry the PV elements. The lattes are screwed through the stone wool to the understructure. The lattes compress the wool which in return gives support to the screws in the lateral direction of the roof. This removes the need of expensive steel ankers to support the lattes.

Kommenterede [LAK4]: Anchors?



The PV elements are hung inside hooks that are in turn screwed to lattes. Installations of the PV panel are easier in this manner.

Water repellence is achieved by creating an overlap in horizontal and vertical direction. In vertical direction, the PV elements are stacked similar to slates. In horizontal direction, a stainless-steel plate is laminated inside the PV element, which will be placed under the PV element next to it.

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7. Selection of candidates for final product

7.1. Flat roof

The final solution for the flat roof was a combination of lamellas with PV panels glued on them and traditional stone wool insulation in between. The reasoning was that the maintenance around the PV panel is usually more impact full on the insulation (walking) than the load of the panels itself. So, in the final idea, standard flat roof insulation that has been proven for this application is used in between the PV elements. It had the following advantages:

- Water proofing can be made with traditional materials.
- Optimal orientation towards the sun can be arranged.
- No separate materials, like aluminum, required to make a slope.
- Weight of the insulation can be optimized with heavy density insulation for the walkable areas and lamellas for the PV elements.

7.2. Pitched roof

The argumentation for the pitched roof solution is as follows:

- The insulation can be put directly on an OSB board on the rafters and prevent the downwards sliding.
- Standard insulation (produced online) can be used and is as such not tied to a special format.
- By using the LVL lath from the REDAir System, we will create a ventilation gap behind the PVs and by this increase their effectiveness.
- The installation is business as usual for the carpenter.
- A watertight underroof can be placed under the PVs and REDAir System lath.
- As there is no mechanical demand for the insulation in this solution, a product with better insulation values can be used.
- The hooks for the PVs are so much smaller and can be fixed directly to the laths. Or PVs overlay can be fixed directly or put on a rail.
- No need for gluing PVs to the wool.

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