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HIGH THROUGHPUT ROOF RENOVATION USING PREFABBED AND PREWIRED WATERTIGHT PV INSULATION ELEMENTS

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ABSTRACT: By a market study and economic modeling we studied the suitability, limitations and opportunities of BIPV products in the Dutch terraced houses renovation sector. A large share of Dutch terraced houses is in the possession of social housing organizations. The combined approach of roof renovation, roof insulation and PV application can lower the energy index of these houses by more than 1.0 and realize a four energy label improvement steps (e.g. from label E to label A). Approaches that combine roofing, insulation and PV functionalities in one product only need to access the roof once and can cut the total system cost by 20%. The annual energy savings on heating and electricity by the combined product add up to 1500 euro for a typical household. An internal rate of return on the initial investment of almost 10% can be achieved. The renovation repays itself in about 12 years. Finally, we describe the development of a prototype BIPV roof that is specifically developed for the Dutch terraced housing renovation market and indeed combines the roofing, insulation and PV functionalities.

Keywords: Building Integrated PV (BIPV); Roofing Systems; Economic Analysis; Solar Architecture

1 INTRODUCTION

In order to meet its energy saving goals, The Netherlands needs a strong national program on renovating poorly insulated residential homes. A recent study estimates that 300 000 dwellings need to be upgraded annually to meet the targets for 2020 and 2050 [1]. This large renovation program holds a big opportunity for residential rooftop BIPV applications. An important prerequisite is that the BIPV system is able to offer clear cost advantages over traditional roof renovation solutions.

The traditional roof renovation process involving PV is sketched in Fig. 1. In this process, specialized roof workers have to access the roof four times: To remove the old roof tiles, to place insulation materials, to install new roof tiles and to install the PV system. A single product that would combine all three functionalities of insulation, roofing and PV would offer a great simplification to this process flow, and be able to realize associated cost advantages.

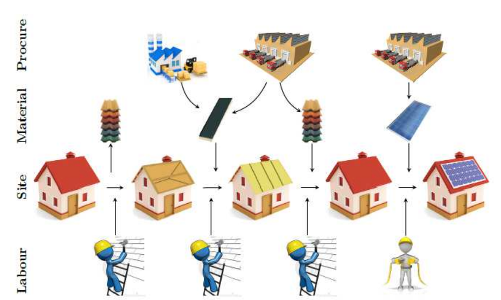

Figure 1 Schematic representation of the traditional roof renovation process involving PV, consisting of the steps roof tile removal, insulation installation, roof tile installation and PV installation.

In recent years, the institutes SEAC and SUPSI conducted various surveys on the BIPV product availability and price levels on the market today [2-5]. Despite having identified more than a hundred BIPV products in these surveys, no dedicated product for the terraced house roof renovation that combined insulation and PV was found.

In this paper the authors report on a study on the social housing roof renovation market and on the business case potential for BIPV products in the market. Finally, we present an 'Insulation Integrated PV' product prototype that has been developed for this market and indeed combines the roofing, insulation and PV functionalities.

2 METHOD

2.1 Market study

We start by estimating the size of the potential market. It is a combination of the sectors for traditional Dutch roof renovation and traditional Dutch rooftop PV installation. The size of these two sectors was estimated using public data from CBS and EPIA [6-7].

2.2 Techno-financial modeling

By techno-financial modeling we investigated the business case potential for roof insulation integrated PV for a typical Dutch terraced house built before 1974.

Cost data for the modeling was mainly gathered via the Dutch Building Costs Institute [8]. The data was cross-checked and complemented by taking interviews with parties active in the roof renovation and PV sectors.

A key performance indicator used in the technical modeling was the Energy Index (EI). The EI of a building represents its standardized and normalized energy needs based on its size, insulation value and technical installations such as PV [9]. Commercial software from W/E Adviseurs was used to calculate the effect of PV and Insulation on the Energy Index and Energy Label of the chosen typical house.

The roof of a typical Dutch terraced house has a typical slope of 35^o and a roof area of 30 m^2 on each side. As PV yield input for the technical modeling we took for one side of the roof the newly defined average Dutch PV yield of 875 kWh/kWp/a [10]. For the other side of the roof we assumed 60% of this value, e.g. 525 kWh/kWp/a.

The obtained cost and technical data was used as input in a techno-financial model developed at the SEAC.

The model combined input on performance, costs and policy schemes to calculate financial indicators such as the net present value and financial payback time.

2.3 Product development

Finally, we present a product developed specifically for the described niche market. In the product development, we followed a structured approach of various iteration loops of brainstorming, prototyping, and evaluation against the derive market criteria. After several iteration loops we constructed a prototype roof for a dedicated field test.

The prototype roof was built up on the SolarBEAT test site of SEAC [11]. It consisted of an artificial roof of 6.00 meter wide and 5.30 meter long mounted under 35° angle. The output of the BIPV system installed on the roof was monitored using UPP Energy AC power meters. We compared the output of the system to a predictive simulation using the commercial software PVSYST. The input parameters used for the PVSYST simulation were as follows: Location: Eindhoven, NL; Inclination angle: 35 degrees; Orientation: 180 degrees true south; Mounting: U-value 15 W/m^{2}K; Ohmic losses (cables): 1.5% at STC.

3 RESULTS AND DISCUSSION

3.1 Market study

The results of the market survey on the Dutch housing stock is shown in Fig 2. Houses built before the oil crisis in the 70s are poorly insulated an consequently show an Energy Index of more than 2.0, giving the house an E, F or G energy label. There are 2.7 million of these houses with pitched roofs. The majority of these houses are terraced houses. A large share of these terraced houses is owned by social housing organizations.

Type	Period	Usage [%] private	Usage [%] rental	Usage [%] social	Stock [1000]	EI	EL
	until 1945	71	6	23	523	3,18	G
	1946 to 1964	40	3	57	478	2,49	F
	1965 to 1974	47	6	47	606	2,08	E
Terraced houses	total	52,7	5,1	42,2	**1637**	2,56	F
	until 1964	84	6	10	285	2,79	F
	1965 to 1974	84	2	14	142	2,38	E
Semi-detached	total	84	4,7	11,3	**427**	2,65	F
	until 1964	91	8	1	441	2,96	G
	1965 to 1974	95	4	1	119	2,42	F
Detached	total	91,9	7,1	1	**660**	2,84	F
Total		67,1	5,5	27,4	**2724**	2,64	F

Figure 2 Types of dwellings, building period, usage, stock, average Energy Index (EI) and Energy Label (EL) for Dutch houses with a pitched roof built before 1974.

The size of the Dutch pitched roof renovation market is approximately 1.000.000 m^2/a. The Dutch rooftop PV market is already bigger, and growing fast. In 2014 the installed PV capacity rose from 350 to 700 MWp. About 85% of the capacity consisted of small scale rooftop PV systems. Fig. 3 sketches the position of the target market of BIPV for roof renovation. It is an emerging niche market originating from the overlap between the two existing markets of rooftop PV installations and traditional roof renovation.

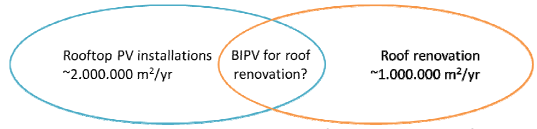

Figure 3 Schematic representation of the existing rooftop PV and roof renovation markets with in between the emerging niche market of BIPV for roof renovation.

3.2 Techno-financial modeling

Fig. 4 demonstrates how the insulation of a roof and the application of a PV system on a roof will affect the house's Energy Index. For this calculation we took a typical terraced house built before 1974. The figure shows that a PV system of 4 kW$_p$ will have the same effect on the Energy Index as a roof insulation of 4 m^{2}K/W. The combined effect of PV and insulation will be able to bring down the energy index by more than 1. In terms of the Energy Label, the house will go from label E to label A or B just by renovating the roof alone, without any changes to installations or other parts of the building skin.

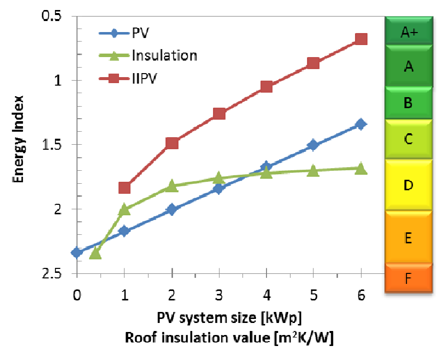

Figure 4 Effect on the Energy Index (left y-axis) and Energy Label (right y-axis) of a typical Dutch terraced house built before 1974. Shown is the effect of the application of a PV system (blue line), the insulation of the roof (green line), and the combined Insulation Integrated PV on the roof (IIPV – red line).

Fig. 5 shows the result of the cost data analysis for roof renovation and PV installation. The figure shows the cost composition for the traditional PV installation and for the traditional 'insulation & tiles' renovation. Together they sum up to more than 250 eur/m^2 for a typical renovation project. The 'Insulation Integrated PV' approach should be able to prevent the costs for roof tiles and strongly reduce costs for on-roof installation, and consequently realize all-in costs below 200 eur/m^2.

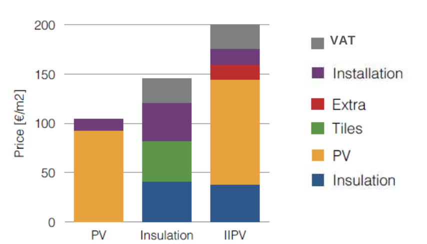

Figure 5 Typical prices per square meter for PV installation, roof insulation and the combined installation of Insulation Integrated PV (IIPV).

Combining Figs. 4 and 5 shows the strength of the roof insulation integrated PV approach: The effect on the Energy Index of the combination is extremely high allowing 4 full energy label steps *and* the cost of the combined approach is lower than the individual sums.

The calculated energy savings were used as input in the techno-financial model. The techno-financial model calculates when the investment in the roof renovation would be paid back by cost savings for heating and electricity. We found that for the typical Dutch house built before 1974, the cost savings would reach 1500 euro per year. These savings are about 50/50 distributed over insulation-related cost savings and PV-related cost savings. A typical payback time for the roof renovation was 12 years. A typical internal rate of return was 8-9%. Fig. 6 shows the annual earnings of the house after renovation.

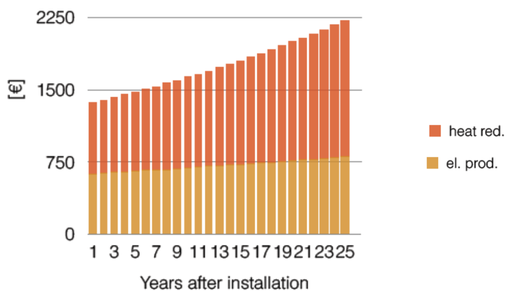

Figure 6 Annual cost savings in euro for a typical Dutch house built before 1974, after renovation of the roof with roof insulation integrated PV. The cost savings are split up in insulation related heating savings and PV-related electricity savings.

3.3 Product prototyping

From the market study and interviews with various parties active in the social housing roof renovation sector a few key prerequisites for successful roof insulation integrated PV product development were derived:

- The insulation elements & PV panels should be pre-assembled and pre-wired in an automated mass manufacturing process to allow lowest in class system costs and fast on-site mounting.
- The electricity production of the roof should match the demand of about 4000 kWh/a for a typical Dutch household. For a typical roof size of 30 m^2 on each side this corresponds to an ideal energy density of the panels of either 152 W_p/m^2 for a south roof only, or about 95 Wp/m^2 in case both sides of the roof are covered (irrespective of the roof orientation).
- The roof renovation/installation should be fully executable from the outside of the house, leaving the residents unaffected. The same holds for possible future maintenance, repair & replace.
- The PV roof should be designed for good insulation value, long damp diffusion lengths and sufficient ventilation to prevent mould and wood rot in the roof.
- The aesthetic value of the PV roof as perceived by architects and end-users should be high. In practice this means that small, full black panels are to be preferred over large blue/white panels.
- The PV panels are preferably 1.20m wide to comply with Dutch building standards (typically built in multiples of 1.20 m).
- The PV panels preferably show a low temperature coefficient, because of higher temperatures typically observed in BIPV installations compared to conventional rooftop installations.
- The PV panels preferably show a high resilience to partial shading. This will allow a standard product for all roofs that does not need project-specific engineering.

The list mentioned above guided us in the iterative product development. An important decision to make was the choice of the PV panel. In the case of a crystalline silicon PV panel, only one side of the roof needs to be covered to make the house net electricity neutral. In the case of a thin film PV panel, both sides of the roof would need to be covered. Table I lists the response of the crystalline silicon and thin film technologies to the mentioned criteria.

Table I Capability of the crystalline silicon technology and thin film technology for the demands of roof insulation integrated PV.

Criterion	*Crystalline silicon (south roof only)*	*Thin film (both roof sides)*
High 'avoided costs' for roof tiles?	Partly (only half of the total roof covered with PV)	Yes (both roof sides covered).
Size 1.20m available?	Only on specific request, leading to higher price and lower power density.	Yes.
Tolerant to partial shading?	No. A shaded cell blocks all current.	Yes. A shaded cell does not block the current.
High in-roof temperature allowed?	No. High temperature coefficient of typically 0.4-0.5 %/K	Yes. Low temperature coefficient of typically <0.25 %/K
Low price per m^2?	No. Typically 100 euro/m^2.	Yes. Typically 40 euro/m^2.
Aesthetic black appearance?	Not really. Tabs and cell-to-back foil contrast are distorting the view.	Yes.

The thin film technology was a clear winner in the analysis. We chose to construct prototype roof insulation integrated PV products using an insulation element of 1.20m × 5.30m topped by 8 all-black thin film PV panels of 1.20m × 0.60m and one dummy panel of 1.20m × 0.30m. The 8 panels in an element were parallel connected to ensure even higher system resilience to shading. Micro inverters were mounted on one of the elements for the DC to AC conversion.

Finally, the pre-assembled and pre-wired elements were crane-mounted on an artificial test roof as shown in Fig. 7.

Figure 7 Crane mounting the prototype roof insulation integrated PV elements on the constructed artificial test roof in May 2014.

Since the installation in May 2014, the roof is carefully being monitored on various key performance parameters, including water tightness, ventilation levels, thermal homogeneity and energy production. So far, the performance of the roof is fully according to expectations.

An example of the analysis on PV performance is shown in Fig. 8. The output of the PV system of the first three months of operation is compared to a typical meteorological year prediction using the commercial software PVSYST. The output of the roof perfectly agreed with the simulation, and corresponded to an expected specific yield for the prototype system of 900 kWh/kWp.

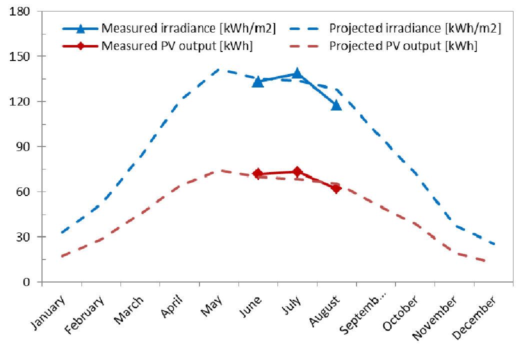

Figure 8 Projected versus measured irradiance [kWh/m^2] and energy output [kWh] for the prototype insulation integrated PV element equipped with micro-inverters.

4 CONCLUSIONS

A Dutch niche market for the simultaneous application of roof renovation, roof insulation and PV installation is emerging. A total stock of almost 3 million houses with pitched roofs is in need of such an advanced roof renovation. The market is mainly driven by European and National sustainability targets for 2020 and 2050.

A large share of Dutch terraced houses is in the possession of social housing organizations. The so-called Energy Index and associated Energy Label are important figures-of-merit for these organizations. The combined approach of roof insulation and PV application can lower the energy index by more than 1.0 and realize 4 label improvement steps (e.g. from label E to label A).

In the conventional approach of separate roof insulation, roof tile installation and PV panel installation, roof workers have to address the roof three consecutive times. Approaches that combine roofing, insulation and PV functionalities in one product only need to access the roof only once. These products can cut the total system costs by about 20%.

Financially, the combined approach of roofing, insulation and PV is highly attractive. The annual energy savings on heating and electricity are of similar value and add up to 1500 euro for a typical household. An internal rate of return on the initial investment of almost 10% can be achieved. The renovation repays itself in about 12 years.

In a Dutch nationally funded R&D project, the partners SEAC, Unilin Insulation and Zonnepanelen Parkstad developed a product that indeed combined the roofing, insulation and PV functionalities. The prototype roof was based on thin film PV because this technology allows high ‘avoided costs’ for roof tiles, is available on a size of 1.20m, is tolerant to partial shading, shows low temperature coefficients, is sold at a low price per m^2 and has a homogeneous black appearance.

A prototype roof was constructed and was still extensively being monitored at the time of writing the paper. The product will be brought to the market starting Q4 2014.

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