ENERGY-ACTIVE ROOF SYSTEM – DESIGN, DEVELOPMENT AND TESTING
Petr Bibora, René Čechmánek, Pavel Leber, Lubomír Vlach
INVOLVED COMPANIES AND FUNDING

DAKO Brno, spol. s r.o., Brno, Czech Republic
• Construction and assembly company specializing in glass fiber reinforced concrete
  http://www.dakobrno.cz

SOLUTRON, s r.o., Brno, Czech Republic
• Sales and service of photovoltaic systems

Research Institute for Building Materials, Brno, Czech Republic
• Private development organisation working more than 70 years in the field of building materials and related problematic
  http://www.vustah.com

• The Ministry of Industry and Trade of the Czech Republic, project TRIO No.FV10297
  Výzkumný ústav stavebních hmot, a.s.
DEVELOPMENT GOALS

New economically effective solar energy roof cladding system
- Thin-walled fibre-concrete elements with integrated photovoltaic and heat transfer layers.
- Reduction of energy consumption of buildings.
- Roof cladding system and solar energy accumulator at the same time.
- The excessive heat generated by PV cells would be transferred by liquid directly into a heat exchanger for further use in the building.
- The roof cladding, the solar panels and the heat collectors are integrated in one complex functional unit.
GLASS FIBER REINFORCED CONCRETE

Fine-grain cement-sand matrix reinforced by alkali-resistant glass fibres

- High strength and durability combined with relatively low weight.
- Good frost and chemical resistance.
- Cement-sand matrix supplied with hydrofobization agents.
- Volume density min. 1950 kg.m\(^{-3}\)
- Flexural strength min. 10 MPa
- Group A – inflammable
- Currently without fly ashes
PHOTOVOLTAIC MODULES

- Flexible crystalline PV cell, output 60 W, solid glass PV cell, output 40 W.
- Connection with FGC panels with silicone adhesive with good thermal conductivity.
TECHNICAL SOLUTION

Development of the heat-transfer layer

• It was necessary to design and verify the main key details of the HT layer in order to ensure the optimal transfer of thermal energy.
• A type of structural element in the form of a scalloped flexible steel tube with a diameter of 11.7 mm and a wall thickness of 0.26 mm was selected.
• In relation to optimal HT layer efficiency, the placement of the HT layer structural elements was designed and verified by measuring of the resulting roof system elements.
• The measurement was also supplemented with results from the software module calculation performed on the VUT FEKT in Brno.
• The results of the measurements showed the optimum distribution of the HT structural element pipes at a distance of 50–75 mm from each other.
TECHNICAL SOLUTION

Development of the heat-transfer layer
TECHNICAL SOLUTION

Solution of electrical interconnection of individual PV roof elements

• It was necessary to assess the individual strings with a heat transfer layer in terms of the limitations associated with the maximum liquid flow rate through the heat transfer layer of the individual PV modules.
• On-grid connection with optimizers and inverter is best suited for our purpose.
• With this type of connection we can combine not only modules with different performance, but also modules with and without heat exchange layer and without loss of performance.
• The entire system can therefore be perfectly supervised and evaluated.
TECHNICAL SOLUTION

Solution of electrical interconnection of individual PV roof elements

• On-grid connection in combination with optimizers and inverter:

![Diagram of electrical interconnection]
EXPERIMENTAL WORKS

Evaluation of the optimal solution from the perspective of electrical parameters

• None of the measured samples degraded the electrical parameters
• From the point of view of the electrical parameters, it is possible to use both types of PV cells
• From the point of view of long-term stability of electrical parameters, design of flexible PV modules seems to be better suited

Advantages of flexible PV cells

• The surface of individual PV cells is perfectly isolated, especially against diffusion moisture
• PV cell has a high self-cleaning ability and better light transmission (> 94%) than conventional photovoltaic glass
• The total weight of flexible PV module is 4 times smaller than the weight of glass PV module
EXPERIMENTAL WORKS

Determination of durability and coherence of PV and GFC layer

- Determination of physico-mechanical characteristics of GFC panels
- Determination of the adhesion of PV elements to GFC panels
- Determination of frost resistance - 100 freezing cycles, visual assessment
- Determination of frost resistance - 100 freezing cycles, determination of adhesion changes
- Determination of resistance to accelerated climatic influences and UV radiation
- Evaluation of tests and recommendation of the optimal variant from the point of view of durability

Výzkumný ústav stavebních hmot, a.s.
EXPERIMENTAL WORKS

Determination of the adhesion of PV elements to GFC panels

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tensile strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible PV panel - REF</td>
<td>251.2</td>
</tr>
<tr>
<td>Flexible PV panel after frost resistance test</td>
<td>329.3</td>
</tr>
<tr>
<td>Solid glass PV panel - REF</td>
<td>314.0</td>
</tr>
<tr>
<td>Solid glass PV panel after frost resistance test</td>
<td>322.1</td>
</tr>
</tbody>
</table>
## EXPERIMENTAL WORKS

Determination of physico - mechanical characteristics of carrier GFC panels

<table>
<thead>
<tr>
<th>Test sample</th>
<th>Flexural strength (MPa)</th>
<th>Bulk density (kg/m³)</th>
<th>Water absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.03</td>
<td>1997.3</td>
<td>5.60</td>
</tr>
<tr>
<td>2</td>
<td>18.43</td>
<td>1993.9</td>
<td>5.91</td>
</tr>
<tr>
<td>3</td>
<td>20.11</td>
<td>2007.5</td>
<td>5.76</td>
</tr>
<tr>
<td>4</td>
<td>18.99</td>
<td>1998.9</td>
<td>5.72</td>
</tr>
<tr>
<td>5</td>
<td>18.33</td>
<td>2002.8</td>
<td>5.74</td>
</tr>
<tr>
<td>6</td>
<td>17.69</td>
<td>2008.1</td>
<td>5.45</td>
</tr>
<tr>
<td>7</td>
<td>17.53</td>
<td>2006.5</td>
<td>5.50</td>
</tr>
<tr>
<td>8</td>
<td>19.93</td>
<td>2002.1</td>
<td>5.73</td>
</tr>
<tr>
<td>9</td>
<td>17.19</td>
<td>2004.8</td>
<td>5.62</td>
</tr>
<tr>
<td>10</td>
<td>15.97</td>
<td>2003.4</td>
<td>5.83</td>
</tr>
<tr>
<td>Ø</td>
<td>18.22</td>
<td>2002.5</td>
<td>5.68</td>
</tr>
</tbody>
</table>

Výzkumný ústav stavebních hmot, a.s.
EXPERIMENTAL WORKS

Long-term durability tests
• Determination of resistance to accelerated climatic influences and UV radiation.
EXPERIMENTAL WORKS

Evaluation in terms of durability

• Compared to solid-glass PV modules, flexible PV modules bring an advantage in terms of lower weight and slightly higher energy efficiency.
• Solid-glass PV modules showed better resistance and stability to long-term effects of UV radiation and climatic influences.
• The tensile force required to detach the PV panel from the bonded silicone sealant does not change even after the carried out durability tests.
• The physico-mechanical resistance of GFC elements has proved to be satisfactory, due to achieved high flexural strength values and low water absorption.
• Based on these evaluations, a combination of used materials and production methods can be recommended for further research works.

Výzkumný ústav stavebních hmot, a.s.
EXPERIMENTAL WORKS

Measurement of GFC panels with integrated PV and HT layers
• The aim of the measurement was to verify the heat transfer efficiency from the integrated PV layer to the HT layer in the GFC panel.
• The measurement was carried out at 3 measuring stations with regard to the environment, exposure and diversity of used roof elements.
• The measurements showed slightly different values, which were caused by different meteorological conditions.
• It can be stated that the roof elements continue to generate a temperature difference of 1.5 to 2.5°C during sunny days.
• The measurements showed that the roof elements with active heat transfer layer had about 8% higher performance due to heat removal.
• The thermal energy generated was directly proportional to the electrical energy obtained. The daily yield was in the range 1,100 to 2,000 J.
EXPERIMENTAL WORKS

Measurement of GFC panels with integrated PV and HT layers

• The energy efficiency of the developed roof elements was measured in terms of proportion.
• Two nearly identical PV modules, in terms of dimensions and performance, were compared.
• This was achieved by laboratory measuring of the I/V characteristics of PV modules on the PASAN Sun Sim3C tester.

I/V characteristic of PV module without active HT layer.  
I/V characteristic of PV module with active HT layer.
EXPERIMENTAL WORKS

UV diagnostics of developed roof elements

Temperatures of GFC elements without active TS layer (left) and with active TS layer (right).

Temperatures of GFC elements without active TS layer (left) and with active TS layer (right).
EXPERIMENTAL WORKS

Static assessment of the system
• The assessment was performed according to ČSN EN 1991-1-3, for the roofs of buildings for the Czech Republic snow areas, class I to VII.
• The results showed that the construction of the developed roof element is suitable for I. and II. limit state in terms of static assessment.

Wind resistance assessment
• The assessment of PV roof elements in terms of resistance to wind was carried out in cooperation with VUT FAST university.
• The aim of the load tests was to verify the load-bearing capacity of the panels in order to determine the recommendations for the ultimate load from the effects of suction or wind pressure based on the test results.
EXPERIMENTAL WORKS

Wind resistance assessment

• In case of loading of the roof element by wind suction, the safe recommended design value of the surface uniform load was equal to $pd = 3.75 \text{ kN/m}^2$, based on the performed tests.

• In the case of a roof element loaded with effects simulating wind pressure, the safe recommended design value of the surface uniform load was equal to $pd = 3.80 \text{ kN/m}^2$. 
CONCLUSIONS

• The authors’ efforts aim was to develop a completely new system of economically effective use of solar energy.
• Electric energy acquired will be used immediately, while acquired thermal energy can be stored for future use.
• Numerous laboratory testing tasks were accomplished to design and verify suitability of chosen materials for future active roof cladding system production.
• Realized development works included testing of the individual parts of the roof system, their connection and composition, mostly from a long-term point of view.
• Technical realization of the whole system focused on achieving the highest functionality – durability, effectivity and energetic efficiency.
CONCLUSIONS

• The technological solution of individual tile structure was developed, including profiled GFC element with integrated HT layer bearing a system of PV cells.
• Static and fire-resistance evaluation of the system was conducted.
• Interconnection of individual tiles was designed and electric and heat-transfer efficiency was studied.
• The results achieved during this project are protected by copyright and will be commercialized until 2022.
THANK YOU FOR YOUR ATTENTION

The authors wish to express their gratitude and sincere appreciation to the authority of The Ministry of Industry and Trade of the Czech Republic, project No.FV10297 for financial support.