

Solar thermal facade systems – an interdisciplinary approach

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Abstract

To reach future Net-Zero Energy Buildings as requested by the “Energy Performance of Buildings Directive” (EPBD, [1]) the integration of systems for harvesting of renewable energy is decisive. Building integrated solar thermal (BIST) collectors can play an important role in this paradigm shift. In the R&D projects ArKol and TABSOLAR multidisciplinary teams develop different BIST systems for transparent and opaque facades. These solutions help trigger highly qualitative architectural integration of solar thermal collectors and are planned for future realization. This paper describes the basic layout of these systems and the current state of development.

Keywords

Building-integrated solar thermal (BIST), energy harvesting building envelope, energy-efficient transparent / opaque façade, multifunctional façade, solar thermal venetian blind (STVB), solar thermal ultra-high-performance concrete collector.

1. Building integrated solar thermal (BIST)

Building-integrated solar thermal (BIST) collectors can save 40% in comparison to building-attached collectors installed after the initial construction or retrofitting (Cappel et. al. [2]). But to realize such systems an interdisciplinary planning process is necessary to align architectural design intent and technical requirements and limitations (Hermann et. al. [3]). As Klein [4] describes the architect has influence on most decisions within a planning process. Thus realizing innovative façade solutions such as BIST have to be in tandem with the architect.

Therefore at the R&D projects ArKol [5] and TABSOLAR [6] new BIST systems for higher and more flexible architectural integration of solar thermal systems into the building envelope and building services are being investigated.

2. Solar thermal venetian blinds (STVB) as adaptive energy harvesting facades

Solar thermal venetian blinds (STVB) represent a novel façade technology combining solar thermal, solar control functionalities and control of daylight and glare. Being venetian blinds, this technology can adapt easily by changing the blind curtain position and slat tilt angle, e.g. preventing glare or allowing solar heat gains to the building, while maintaining the functionality as solar thermal collector (except for the case of fully retracted blinds). As such these systems can be integrated into glass facades such as Double-Skin, Closed Cavity or Box-Type Window Facades as shown in Figure 1 (Denz et al. [7]).

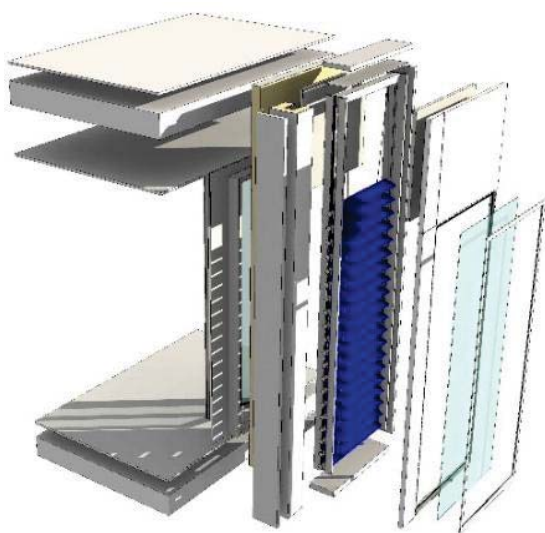


Figure 1: Basic buildup of Solar Thermal Venetian Blind (left). © Priedemann Facade-Lab. Possible facade integration of STVB (right). © IBK2.

2.1 Working principle of STVB

The basic principle of the STVB presented here relies on the use of heat pipes integrated into each slat of the blind curtain (see Figure 2).

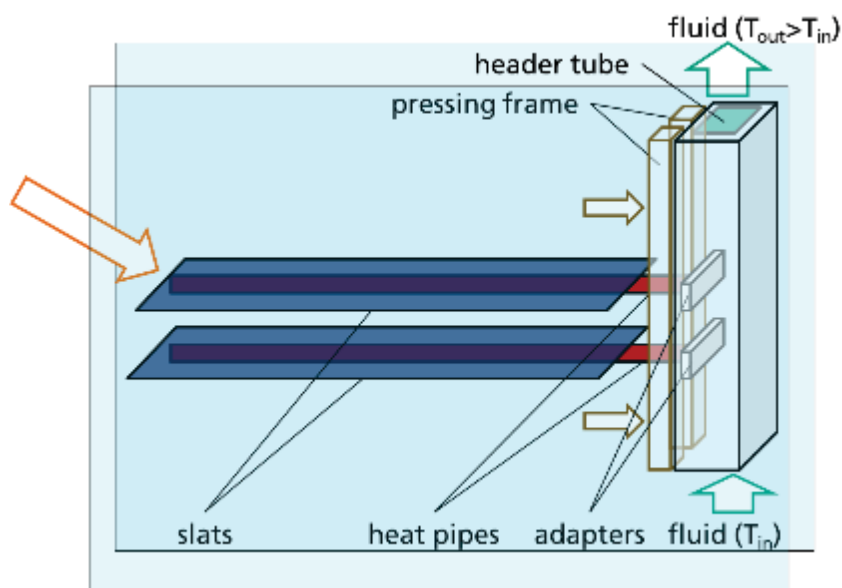


Figure 2: Basic working principle of solar thermal venetian blinds with switchable thermal coupling consisting of pressing frame and adapters. © Fraunhofer ISE.

The top surface of the slat acts as absorber of the incident solar radiation. The heat is then transferred by the heat pipes to the header tube in a comparable manner as in evacuated tube collectors. A switchable thermal coupling is used to allow the heat-transfer from the heat pipe condensers to the vertically aligned header tube while enabling the slats to be lifted and tilted as in a conventional venetian blind. An adapter is placed around the heat pipe condensers to increase the heat transfer to the header tube. These adapters are being pressed against the header tube by a pressing frame which is moved by actuators such as springs and solenoids or camshafts. If the switchable thermal coupling is closed, i.e. the adapter is pressed against the header tube; heat transfer from the slat to the header tube and the fluid within is efficient. On the other hand the switchable thermal coupling can be opened to allow movement of the slats. Each STVB has two hydraulic connections, inlet and outlet pipe of the header tube.

The STVB can be placed within the cavity of a double skin façade between an outer single glazing layer and a double or triple glazing layer. This position is likely to achieve good solar thermal performance as the slats (i.e. absorber) are insulated via the outer single glazing layer from the ambient temperature (Haeringer et al. [8]).

Various blind control strategies can be employed. Ideally an algorithm is used to optimize thermal and visual comfort as well as energy demand, including solar thermal energy gain, heating and cooling loads of the building and artificial lighting demand. Thus the system can be realized either for high solar thermal performance generating maximum outcome with a selective coating on the slats and highly insulated glazing to the interior. Or the STVB can enable a controllable g-value lowering the heat income into the building being constructed with aluminum slats and for example only double glazing to the inside (see Figure 3).

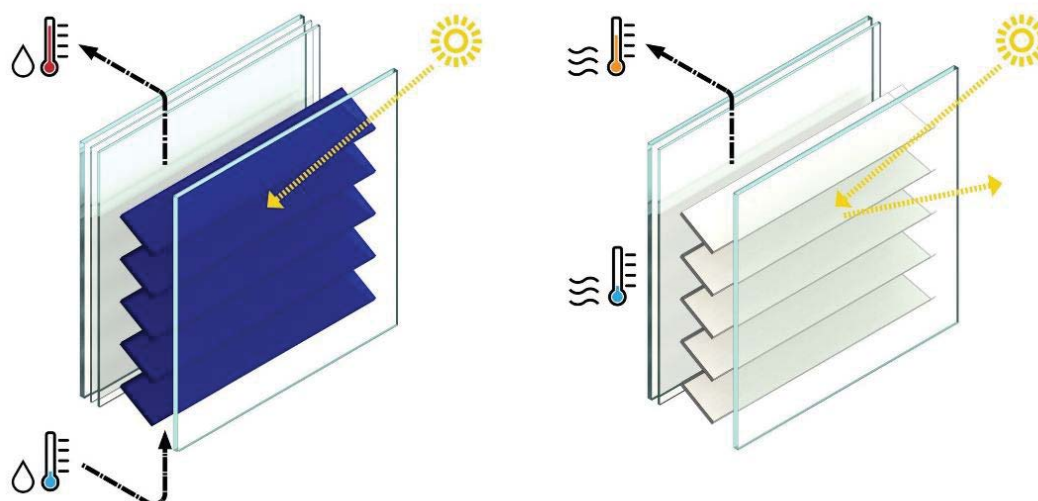


Figure 3: Usage of STVB for high solar thermal performance (left) or low g-value (right). © Priedemann Facade-Lab.

2.2 First functional test sample



Figure 4: Facade models for STVB integration. © Priedemann Facade-Lab.

Based on first geometrical façade models for the integration of STVBs into glass facades (see Figure 4) a fully functional test sample is being built at Fraunhofer ISE as shown in Figure 5. It consists of a STVB with 37 slats integrated into the cavity of a fully glazed double skin façade element with single outer glazing of 3.6 m height and 1.4 m width and double inner glazing.



Figure 5: Functional test sample of façade element with integrated solar thermal venetian blinds. Visualization: Exterior view (left and center), interior view (right). © Priedemann Facade-Lab.

Each slat is 90 mm in width and incorporates a mesh heat pipe of 8 mm diameter along its diagonal axis (see Figure 6). This diagonal orientation of the heat pipe allows the heat pipe to be at a working angle larger than 0° when the slats are in a non-horizontal position. With a working angle larger than 0° the heat pipe runs more efficient as the fluid can return with the help of gravity and not solely relying on the mesh to redistribute the fluid from the condenser. As slat top surface conventional absorber sheets are used which are laser-welded to the heat pipes.

The adapters of the switchable thermal coupling have been optimized to save weight while keeping a good thermal performance having a contact area to the header tube of 100x15 mm. As header tube a multi-chamber profile with 160 mm width was chosen. To minimize deformation due to water pressure within the header tube a multi-chamber profile had to be chosen over a simple rectangular pipe. Both contact surfaces of adapter and header tube were milled to allow a highly planar and smooth surface to allow good heat transfer.



Figure 6: Top view of slat of functional test sample. © Fraunhofer ISE.

The mechanism of the switchable thermal coupling was investigated in detail in (Haeringer et al. [9]). A combination of compression springs to create the contact pressure with self-latching solenoids for opening the switchable thermal coupling was used. The blind mechanism uses conventional blind motors but improved attachment like steel ropes and scissor chains to deal with the increased slat weight.

To meet the state of the art demand on venetian blinds (Kuhn [10]) future slat design possibilities are investigated. Giving the architect, client and planning team a variety of geometrical options in relation to price and appearance as described by Denz et al. [11] (see Figure 7).

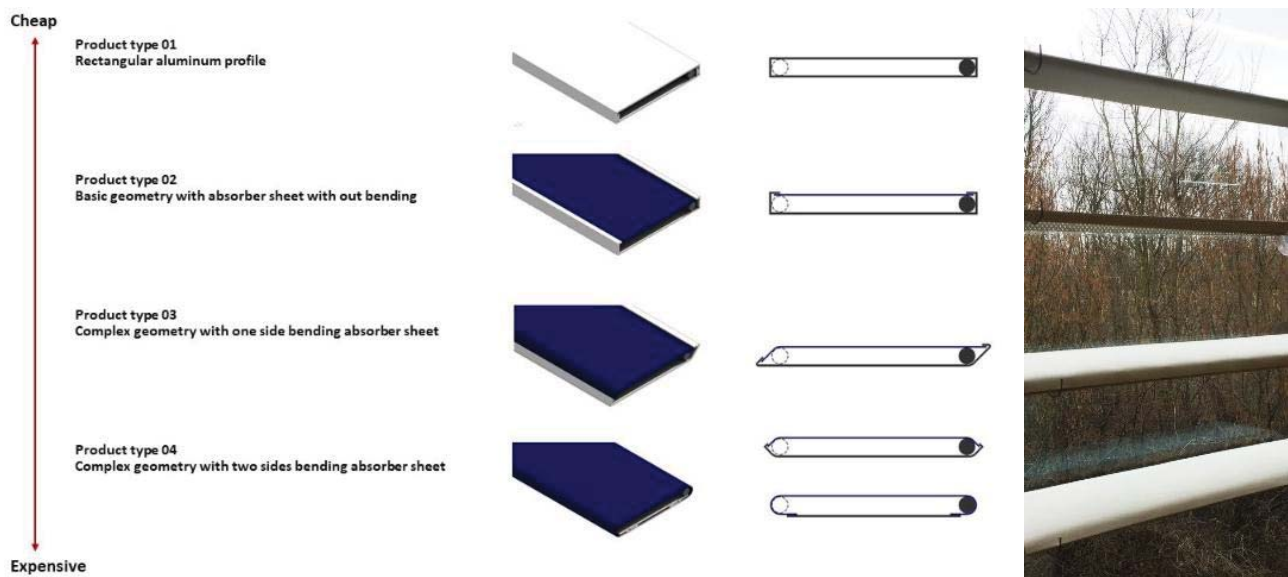


Figure 7: Various slat geometries (left) and geometrical models for sampling (right). © Priedemann Facade-Lab

3. Solar thermal strip collector (STSC)

The aim of the solar thermal strip collector (STSC) is to reach a high flexibility in architectural design of opaque solar thermal façades (see Figure 8).

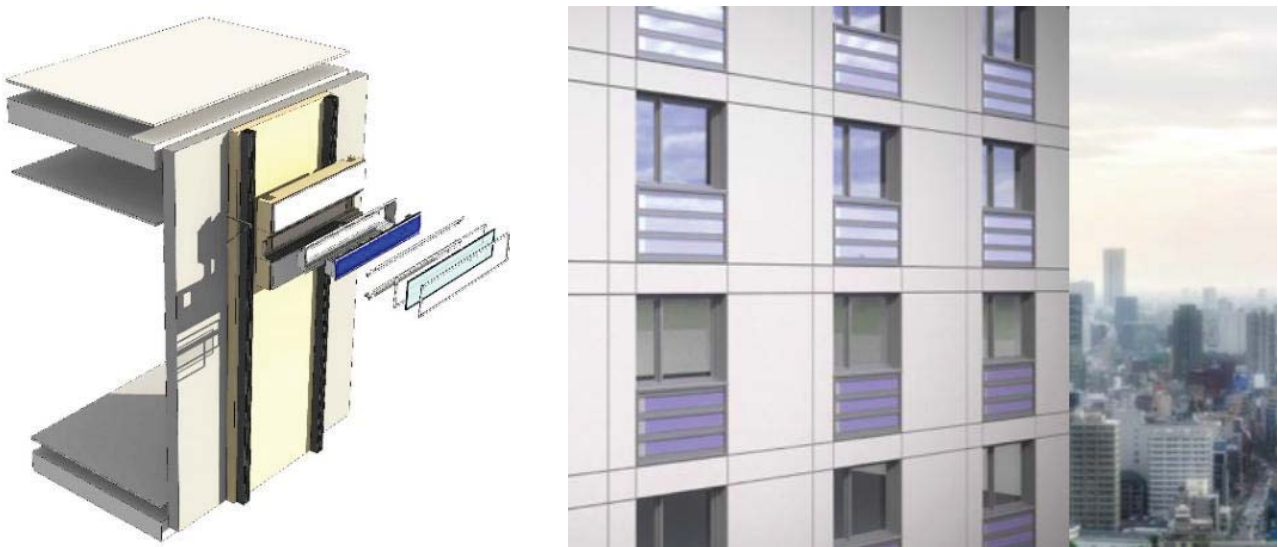


Figure 8: Basic buildup of Solar Thermal Strip Collector (left). © Priedemann Facade-Lab. Possible facade integration of STSC (right). © IBK2.

In contrast to conventional solar thermal collectors with module dimensions of e. g. 1 x 2 m (Aelenei [12]) the STSC has a height of only 250 mm and flexible lengths. In combination with a newly developed stepless connector system between strip collector / heat-pipe and header tube the STSC can be placed individually, stacked and changing in length as shown in Figure 9. These solar thermal strip collectors can moreover be combined with façade systems and cladding materials such as rear ventilated façades, plaster walls etc.



Figure 9: Possible Façade designs based on solar thermal strip collectors. © Priedemann Facade-Lab.

3.1 Working principle of STSC

Apart from the different dimensions, the high flexibility is based on the fact that the heat is transferred from the absorbers to the header tube via heat pipes mounted with a so-called “dry” connection, which means that solar fluid only flows through the header tube, but not through the individual absorbers. This allows variable positioning and at the same time makes hydraulic balancing of the whole collector field easier. The setup of an individual strip collector can be seen in Figure 10. The solar absorber sheet is connected to one or more heat-pipes (depending on the concept and performance of the heat-pipe). The absorber is mounted in a collector casing which is surrounded by an insulation casing and covered by a solar glass. Mounting is enabled by conventional agraffe profiles known from cladding elements of rear-ventilated façades. The condensers of the heat-pipes are joined to an adapter allowing an appropriate thermal contact to the header tube when fixed.

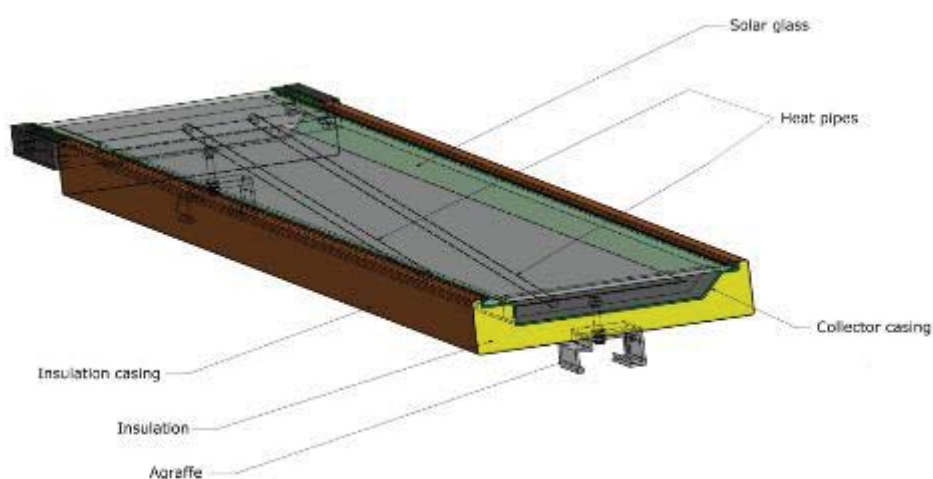


Figure 10: Setup of a strip collector. © Fraunhofer ISE.

3.2 Test sample



Figure 11: Facade models for STSC integration. © Priedemann Facade-Lab.

As illustrated in first façade models (see Figure 11) one important usage case for the STSC is a horizontal installation. Since conventional heat-pipes for solar thermal collectors do not operate efficiently in fully horizontal position (0°) it has to be ensured that the heat-pipes work properly in this orientation as investigated by Morawietz et al. [13]. One approach within the research project is to develop appropriate heat-pipes capable of transporting the condensed working fluid back to the evaporator zone without gravity, e. g. using capillary forces in wick structures and / or by overfilling. An alternative solution uses conventional tilted thermosyphons (heat-pipes without wick structures) allowing the condensed working fluid to flow back to the evaporator zone by gravity. Using these absorbers 1.5 m long test collectors have been built to investigate its performance and façade integration (see Figure 12).

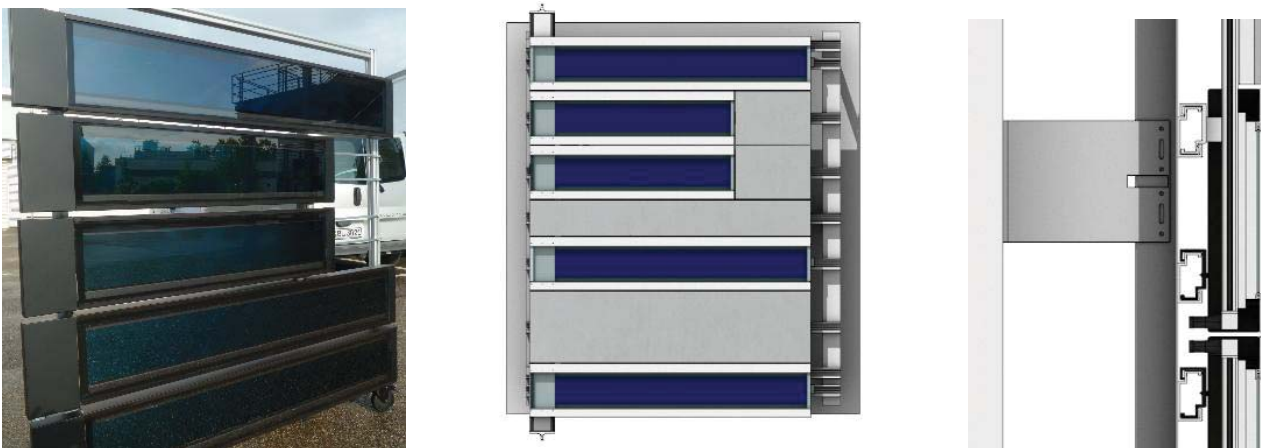


Figure 12: Test samples of STSC (left). © Fraunhofer ISE. Façade integration of STSC (right).
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4. Solar thermal UHPC façade panels (TABSOLAR)

Ultra-high performance concrete (UHPC) is an ideal material for façade panels such as TAKTL [14] for rear-ventilated façade systems. The concrete panels are flexible in sizing, colouring and surface geometry enabling an individual adjustment to the architectural design intent.

TABSOLAR elements push this façade material further by integrating fluid channels (Hermann et. al. [15]). Thus the TABSOLAR panels out of UHPC can be activated and used either as solar thermal façade collectors or – within the building – as thermo-active building systems (TABS) for heating and cooling (Hermann et. al. [16]).

It is intended to develop three TABSOLAR product families for façades with different appearances, yields, temperature levels, and thus applications. E. g. for direct domestic hot water preparation or as low-temperature source for heat pumps. TABSOLAR “Premium” and “Economy” are glazed enabling higher fluid temperatures whereas TABSOLAR “Design” is unglazed and therefore can achieve the same appearance as current state of the art façade cladding (see Figure 13).

TABSOLAR Elements can be used within different façade systems such as External Thermal Insulation Composite Systems (ETICS), rear-ventilated façade systems or pre-fabricated concrete walls such as double or sandwich-wall (see Figure 14).



Figure 13: Small samples of planned TABSOLAR product families: TABSOLAR “Premium”, TABSOLAR “Economy”, TABSOLAR “Design” (from left to right). © Priedemann Facade-Lab.

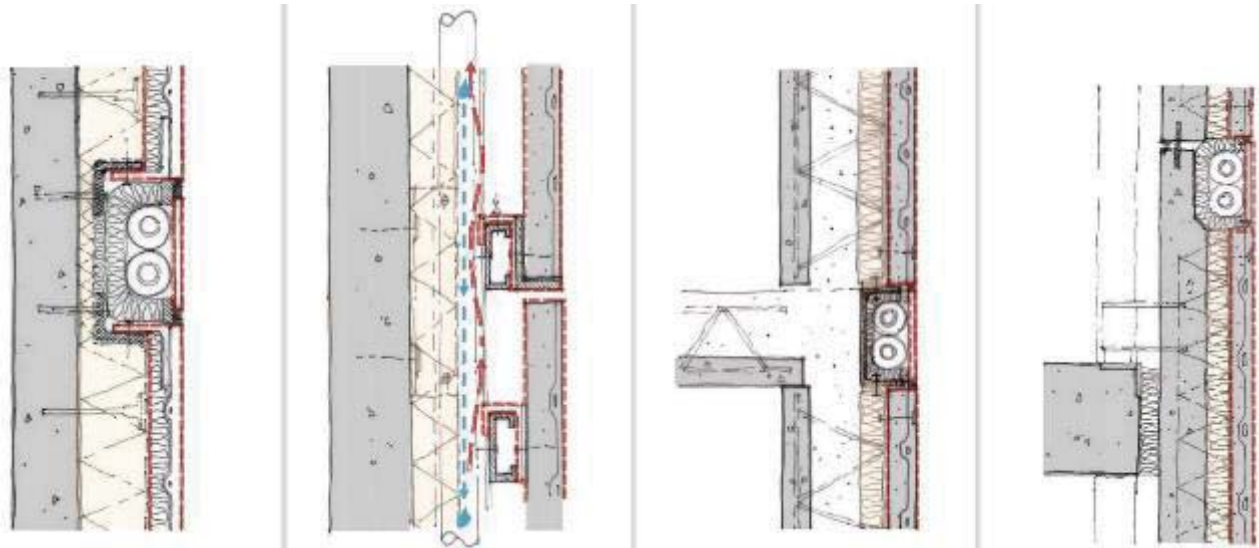


Figure 14: Possible façade systems for the integration of TABSOLAR elements: external thermal insulation composite system, rear-ventilated façade, double and sandwich wall (from left to right). © Priedemann Facade-Lab.

4.1 Manufacturing of TABSOLAR elements

The fluid channels inside TABSOLAR elements are produced directly from UHPC by the so-called membrane vacuum deep-drawing process shown in Figure 15 (Hermann et. al. [17]). The fractal-like, bionic channel structures are generated by the FracTherm® algorithm developed by Hermann [18]. Thus leading to a uniform flow distribution and low pressure drop on an individually given area which can also be non-rectangular and / or three-dimensional.



Figure 15: Production of TABSOLAR elements by means of membrane vacuum deep-drawing process: a) covering mold with concrete, b) deep-drawing, c) joining channel part and flat part, d) demolding after hardening © Fraunhofer ISE.

4.2 Test samples

Within the research project TABSOLAR II various small and large sample elements have been produced. Figures 16 and 17 give an impression of possible front and back side structure, appearance and coloring.



Figure 16: Cuts of TABSOLAR element showing fluid channels on the back side. © Fraunhofer ISE.



Figure 17: Different surfaces: smooth, flat and uncoated (left), structured with spectrally selective coating for higher thermal yields (right). © Fraunhofer ISE.

5. Outlook

The research strategy by the German Solar-Thermal Technology Platform highlights a demand for optimized and cost-effective integration of large collector areas in roofs and façades taking architectural and technological aspects into account (DSTTP [19]) underlining the goals of ArKol and TABSOLAR.

Of course already several other solutions for BIST exist (Cappel et. al. [20]). But these still lack a high flexibility and joint approach by all necessary stakeholders within a planning and construction process of a building.

The described developments aim at tackling these issues by offering various systems. These different façade solutions could meet different architectural design intents and individual building demands. Moreover the R&D projects consisting of researchers, planners, lecturers, innovation managers, material scientists and manufacturers bring together as many planning participants as possible and already develop future business models to guarantee fabrication, installation and operation of these systems.

Therefore the project teams will further develop the mentioned BIST solutions not only based on its energetic performance but also façade installation methods and architectural design possibilities. Furthermore first

reference façades and demonstration buildings are under planning to test the functionality and appearance of these solution in in-situ condition.

6. Acknowledgements

The authors gratefully acknowledge the financial support of the research projects ArKol (STVB/STSC, support code: 0325857A/B/C) and TABSOLAR II (support code: 03ET1310A/B/C/D) by the German Federal Ministry of Economic Affairs and Energy (BMWi) as well as all project partners.

7. References

- [1] Richtlinie 2010/31/EU des Europäischen Parlaments und des Rates vom 19. Mai 2010 über die Gesamtenergieeffizienz von Gebäuden (Neufassung), <http://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32010L0031&from=DE>, 04.06.2018.
- [2] C. Cappel, W. Streicher, M. Hauer, F. Lichtblau, T. Szuder, T.E. Kuhn, C. Maurer, "AktiFas Fassadenintegrierte Solarthermie: Bestandsaufnahme und Entwicklung zukunftsfähiger Konzepte.", *Schlussbericht*, Fraunhofer Institut für solare Energiesysteme ISE, Freiburg. 2015. Online accessible: <http://publica.fraunhofer.de/dokumente/N-349495.html>.
- [3] M. Hermann, P.-R. Denz, C. Cappel, C. Maurer, „Fassadenkollektoren – alles Ansichtssache?“, *OTTI e.V. (Hg.): 25. Symposium Thermische Solarenergie*, Bad Staffelstein, 06. - 08. May 2015.
- [4] T. Klein, "Integral Façade Construction – Towards a new product architecture for curtain walls", *dissertation*, Delft University of Technology, 2013.
- [5] <https://arkol.de/de/>, 15. June 2018.
- [6] <https://tabsolar.de/>, 15. June 2018.
- [7] P.-R. Denz, P. Vongsingha, S.F. Haeringer, C. Maurer, "Solar Thermal Venetian Blinds – transparency, user comfort and solar energy in one!", *ne-xt facades, COST Action TU 1403 Adaptive Facade Network Mid-Term Conference*, Munich, 7. November 2017.
- [8] S.F. Haeringer, I. Abderrahman, P. Vongsingha, T.E. Kuhn, P.-R. Denz, C. Maurer, "Solar Thermal Venetian Blinds – Transparency, User Comfort and Solar Energy in one!" *Proceedings of the PLEA 2017 conference*, Edinburgh, 2017.
- [9] S.F. Haeringer, I. Abderrahman, P. Vongsingha, S. Camarena Covarrubias, U. Amann, T.E. Kuhn, et al., "Solar Thermal Venetian Blind - Development and Evaluation of a Switchable Thermal Coupling." *OTTI e.V. (Hg.): 27. Symposium Thermische Solarenergie*. Bad Staffelstein, 10. - 12. May 2017.
- [10] T.E. Kuhn, "State of the art of advanced solar control devices for buildings." *Solar Energy*, DOI: 10.1016/j.solener.2016.12.044. 2017.
- [11] P.-R. Denz, P. Vongsingha, J. de la Fuente, "I&D por la cubierta de edificios." *Workshop de Fachadas COAM*, Madrid, 23. May 2018.
- [12] L. Aelenei, "Overview of Building Integrated Solar Thermal Systems State of the Art, Models and Applications.", *COST Action TU1205 - Building Integrated Solar Thermal Systems*, 2015.
- [13] K. Morawietz, T. Röschl, I.A.B.A. Halim, T. Paul, M. Hermann, "Effects of Measurement Conditions on Operating Limits of Solar Horizontal Heat Pipes.", *Energy Procedia* 91, S. 366–375. 2016.
- [14] <http://www.taktil-llc.com/>, 15. June 2018.
- [15] M. Hermann, L. Koch, P. Di Lauro, C. Hildebrandt, C. Jerg, „TABSOLAR – Solarabsorber und andere thermisch aktive Bauteile aus Ultrahochleistungsbeton (UHPC)“, *Tagungsband*, 23. OTTI-Symposium „Thermische Solarenergie“, Bad Staffelstein, 24. - 26. April 2013
- [16] M. Hermann, P. Di Lauro, F. Kennemann, L. Koch, T. Teichmann, T. Sablotny, "TABSOLAR – Materialentwicklung und Fertigung durchströmter Bauteile aus Ultrahochleistungsbeton (UHPC)“, *Tagungsband*, 24. OTTI-Symposium „Thermische Solarenergie“, Bad Staffelstein, 7. - 9. May 2014.

- [17] M. Hermann, J. Koschikowski, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., "Verfahren zum Herstellen von Hohlkörpern aus pastösem Material und Vorrichtung zum Durchführen des Verfahrens", patent, D000019935603C2, 1999.
- [18] M. Hermann, „Bionische Ansätze zur Entwicklung energieeffizienter Fluidsysteme für den Wärmetransport“, *dissertation*, Universität Karlsruhe (TH), 2005.
- [19] „Forschungsstrategie Niedertemperatur-Solarthermie 2030 für eine nachhaltige Wärme- und Kälteversorgung Deutschlands“, *Deutsche Solarthermie-Technologie Plattform (DSTTP)*, <http://www.solarthermietechnologie.de>, 04.06.2018.
- [20] C. Cappel, T.E. Kuhn, C. Maurer, „Verfügbare Komponenten und Systeme fassadenintegrierter Solarthermie“, 2014, available from: <http://publica.fraunhofer.de/documents/N-307397.html>