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Solar Thermal Venetian Blinds – Transparency, User Comfort and Solar Energy in one!

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Abstract: Solar thermal venetian blinds (STVB) combine the switchable transparency and glare protection of venetian blinds with decreased temperatures of the interior glass pane and a supply of solar thermal heat. Venetian blinds placed between two glazing units as e.g. in closed-cavity façades can reach high temperatures. Removing the solar thermal heat from the slats reduces the temperature of the glass unit facing the interior which increases the thermal comfort for people inside the building. This also reduces the cooling load because less heat flows from the façade to the building interior. The solar thermal heat can be used e.g. for domestic hot water and dehumidification to reduce the carbon footprint of the building. Different varieties of STVB can be designed and two examples are presented to show the potential of STVB.
Heat pipes are used to transfer the absorbed solar energy from the slats to the vertical header tube. Heat pipes and header tube are connected by a dry switchable thermal coupling allowing full movement of the slats. As the STVB uses only few additional parts compared to conventional venetian blinds and focuses on mass-produced parts, it has the potential to offer a very competitive price for solar thermal heat.

Keywords: building-integrated solar thermal (BIST), solar thermal building envelope, thermal comfort, venetian blind, double-skin façade

Introduction

The development of solar thermal venetian blinds (STVB) pursues the idea to use the energetic potential of solar irradiation on transparent façades. STVB can enhance the functionality of venetian blinds by adding solar thermal collector functionality into it. Large transparent façade areas can thus actively contribute to a reduction of primary energy demand while having the same structure and benefits of the façade system. Furthermore STVB have the potential to improve the thermal comfort by lowering temperatures for venetian blinds mounted in between glass units as e.g. in double-skin façades.

Building-integrated solar thermal collectors (BIST) have saved 40% in the past compared to building-attached collectors installed after the initial construction (Cappel et al., 2015; Maurer et al., submitted). But space for opaque BIST is limited with modern architecture thriving for highly transparent façades. Especially in high-rise buildings, venetian blinds are often used in between an outer and inner glazing and can reach high temperatures due to solar irradiance (Gratia and Herde, 2007a). STVB could resolve this problem and reduce the heat flux to the building interior which decreases the cooling load.

State of the art

BIST & Transparency

The idea of removing solar thermal heat from the building envelope dates back to (Morse, 1881). Semi-transparent solar collector window systems were proposed by (Fuschillo, 1975). An overview of related research on Trombe walls, BIST air collectors, is presented by (Saadatian et al., 2012). BIST collectors for opaque building envelope areas are market-available in various forms (IEA SHC Task 51, 2016; Maurer et al., submitted). For transparent BIST, fewer technologies are available. A semi-transparent BIST with seasonal sun shading was invented by (Robin, 2002; Robin Sun) and installed in many buildings. Permasteelisa developed a semi-transparent BIST with small slats and seasonal shading (Maurer et al., 2013; Maurer et al., 2014). A semi-transparent BIST with vacuum tubes and perforated concentrator sheets is available from (Ritter XL Solar GmbH, 2017; Wolf and Molter, 2012). All previously listed collectors work with liquid as heat-transfer medium, whereas Kollektorfabrik developed a semi-transparent BIST which is used to heat air directly (Maurer et al., 2012). Two transparent BIST technologies using water in between glass units are under development (InDeWag, 2017; Stopper et al., 2013). This approach offers full visual contact to the exterior but lacks glare control and the solar thermal efficiency is small.

Several patents have been filed which claim or could be interpreted as solar thermal blinds, some of which appear to be tiltable like (Bittmann, 2006; Pierce, 1977). However none of the technologies known to the authors offer STVB that are both tiltable and retractable as proposed in this contribution. To the best of our knowledge only theoretical studies of fully tiltable and retractable STVB with liquid heat transfer medium have been published. Different theoretical approaches for solar thermal venetian blinds were discussed by (Cruz Lopez, 2011). Another theoretical study claims possible reduction of solar heat gain by 33% in Mediterranean climates for STVB in double-skin façades (Guardo et al., 2015). The STVB presented in this contribution aims to close this gap between theory and practice by employing a switchable thermal coupling.

Overheating of conventional venetian blinds in cavities

Venetian blinds placed in the cavity between an outer and inner glazing can experience a serious overheating problem. (Gratia and Herde, 2007a, 2007b) studied the effect of venetian blinds, their color and position and other parameters on cavity and blind temperatures and energy consumption in double-skin façades (DSF). Thermal comfort can be affected negatively if the temperatures of the glazing facing the room differ significantly from the air temperature and surface temperature of the room's walls as defined in the ISO standard 7730 (International Organization for Standardization, 2005).

Another drawback of high cavity temperatures is the additional stress it puts on components. In closed-cavity façades (CCF) this is particularly important as they by design lack the option for ventilation as possible for DSF and can reach temperatures up to 85°C (Lutz, 2012). New technical solutions were developed e.g. for the venetian blind mechanism to withstand the high temperatures (Schrag, 2015). Last but not least high cavity temperatures can also increase solar heat gains to the building interior (Gratia and Herde, 2007a). Depending on the U-value of the interior glazing a significant portion of the heat absorbed in the cavity can enter the building rather than being released to the environment.

Working principle of solar thermal venetian blinds

A typical façade element with a solar thermal venetian blind consists of an outer glazing and an inner double or triple glazing. The STVB is mounted in between the glass units as shown in Figure 1. The slats of the STVB absorb the incident sunlight. Different types of slat coatings can be used such as conventional or spectrally selective coatings with strong absorption. Solar heat pipes are used to extract the absorbed solar energy from the slats. Different heat pipe geometries can be used and either be attached to the bottom of the slat (e.g. cylindrical heat pipes) or used as slat itself (e.g. flat heat pipes). The heat pipes are connected to a vertical header tube placed in the façade element frame. The heat is transferred from the heat pipes to the fluid in the header tube via a dry connection. For this purpose a switchable thermal coupling is being developed and has been filed for a patent. This switchable thermal coupling transfers the heat when it is closed. If it is open the slats are free to move and can thus be tilted, raised and lowered as known from regular venetian blinds. To improve the thermal contact between each heat pipe and the header tube adapters can be used. The combination of using heat pipes and the switchable thermal coupling leads to having only two simple hydraulic connections per façade element and no flexible tubes. The STVB is designed to need as little maintenance as conventional solar thermal systems. A control strategy can be implemented to optimize thermal comfort, energy harvesting and user comfort considering daylight demand and glare protection. Ideally an automatic but user-adaptive control is used with purpose of maximizing user comfort and energy performance.

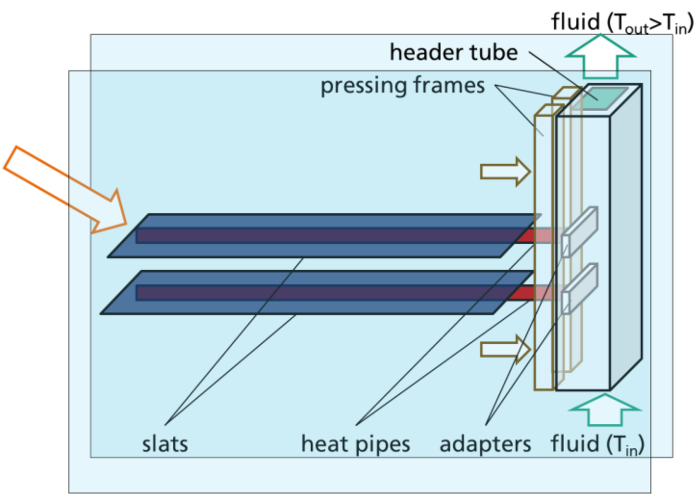

Figure 1: Working principle of solar thermal venetian blind

Solar heat pipes are well-known from their application for example in vacuum tube collectors. However operating these heat pipes in horizontal orientation is yet challenging and is currently being optimized for application in STVB. Another technical challenge is designing the switchable thermal coupling in a way that it provides good heat transfer, allows all slat movements and has the same service life as the façade at competitive costs. A test sample with two different mechanisms is being manufactured to gain more knowledge about feasibility and durability of the mechanisms (cf. section “First test sample”).

Potential benefits of solar thermal venetian blinds

STVB have the potential to integrate solar thermal functionality into transparent façade areas and to improve thermal comfort in the building interior. STVB are particularly interesting to be used in double-skin façades (DSF) and façades with box-type windows. Closed-cavity façades (CCF) as a subcategory of DSF are promising, as they provide a clean environment to the STVB and no soiling of the slats will occur. The overheating problem present in CCF could be reduced by using STVB. An ideal application of STVB would be a building with large transparent building envelope areas, significant demand for domestic hot water in which external blinds are not desired or feasible. The design of STVB has large freedom since it combines the design possibilities of venetian blinds (e.g. shape, geometry, top and bottom surface coating, cf. (Kuhn, 2017)) and adds a dimension for the solar thermal functionality which includes the choice of heat pipe, mechanism etc. To illustrate the large design variety of STVB a variant focusing on a *low g value* and a variant focusing on a *high solar thermal performance* are being discussed in the next two subsections.

Focus low g-value

The aim of the STVB variety *low g-value* is to minimize the solar gain to the building interior and maximize thermal comfort in the building. The primary purpose of the solar thermal functionality is thus to lower the slat and cavity temperatures. By lowering the cavity temperature less heat flows to the inside and the temperature of the interior glass unit is closer to room temperature. If the STVBs are lowered and closed very small g-values could be reached. This is possible because the STVB in this case acts as solar control device and as solar thermal collector, i.e. direct radiation is absorbed or reflected by the blinds and excess heat is removed. However the excess heat is not simply removed but turned into useful energy which could be used to heat domestic hot water or for solar dehumidification thus providing a renewable energy source.

Figure 2: Visualization of three different façades with STVB, variety *low g-value*

STVB aiming at minimal g-values should employ slats with a reflective coating to minimize the absorption of solar radiation in the cavity in the first hand (cf. Figure 2). To remove the absorbed energy efficiently the heat transfer from the slat through heat pipe and switchable thermal coupling into the fluid in the header tube needs to be good. The temperature of the fluid when entering the header tube at the bottom of the façade element should be low to extract as much heat as possible, i.e. to cool the slat effectively. Also the thermal insulation between cavity and interior needs to be large to ensure heat is removed via the header tube and not into the building. This means double or even triple glazing should be used for the interior glazing and also the frame should be well insulated. With outdoor temperatures comparable or higher than the cavity temperatures a good insulation to the exterior is preferable. For outdoor temperatures lower than cavity temperature a small insulation could be helpful in additionally removing heat from the cavity. This heat however is lost as it is not turned into useful energy. A control should aim at maximizing daylight while minimizing glare and overheating of the room.

A promising application case of this STVB is an office high-rise building with solar dehumidification. To prove the potential of the STVB future studies will compare a building with STVB with reference cases. Examples for reference cases include the same building with conventional blinds in the glazing cavity with or without improved solar control glazing or with less transparent areas in building envelope.

Focus solar thermal performance

The STVB variety *high solar thermal performance* aims at maximizing the collected solar energy in form of heat. The solar thermal functionality aims at significantly heating up the collector fluid, e.g. to use it to heat domestic hot water. The STVB thus has to be designed such that it absorbs a maximum amount of incident solar radiation and to minimize losses of this absorbed energy to the environment.

Figure 3: Architectural model of façade with *high solar thermal performance* STVB as presented at the trade fair BAU 2017 in Munich

High solar thermal performance STVB could use spectrally selective coating as known from conventional solar thermal collectors and photovoltaic cells. The appearance of this coating is dark blue as illustrated in Figure 3. The heat transfer between absorbing slat and fluid in the header tube should be maximized as in the *low g-value* variety. The fluid temperature at the inlet could be set to reach desirable outlet temperatures useful for its designated purpose such as heating domestic hot water. Here an optimization could take place with regard to maximizing the solar thermal performance and still maintaining a low g-value by operating the STVB at low fluid inlet temperatures. Insulation should be good to interior and exterior to minimize all losses. For the exterior glazing a trade-off has to be found between maximizing solar transmission and maximizing insulation properties with the overall goal of maximizing the solar thermal yield. If maximizing the solar thermal yield is the only criteria blinds should always be lowered and slats tilted to face the sun as proposed by (Cruz Lopez, 2011). However this is an impractical assumption. Daylight demand and user comfort should be taken into account and included in an automatic control that can be overruled by the user.

The application of the *high solar thermal performance* STVB would be promising for example in a high-rise building which is partly used as hotel. Reference cases for further studies aiming to prove the potential of this STVB could include the same building with conventional blind in the glazing cavity, or with conventional solar thermal collectors on opaque building envelope areas, or with stationary semi-transparent solar thermal collectors on opaque building envelope areas.

First test sample

Currently a laboratory test sample is being manufactured with the aim of testing the mechanisms of the switchable thermal coupling and the tilting and retracting of the slats. One particular configuration of the STVB was chosen for this test sample. A cylindrical heat pipe dummy of 10 mm diameter is attached diagonally to the bottom of the slat (cf. Figure 4). The diagonal configuration leads to a small operating angle of the heat pipe which improves its performance compared to horizontal orientation. Currently, flat heat pipes which work efficiently in horizontal orientation within the façade systems are under development. For the switchable thermal coupling an adapter between heat pipe and header tube was designed as visible in Figure 4. Two different mechanisms will be investigated for the switchable thermal coupling. Both aim at using a minimum amount of energy. For this purpose self-locking mechanisms were chosen that only require energy for the movement but none for the end positions *open* or *closed*. The first mechanism employs springs and self-locking solenoids, while the second mechanism uses a cam-shaft driven by a stepper motor.

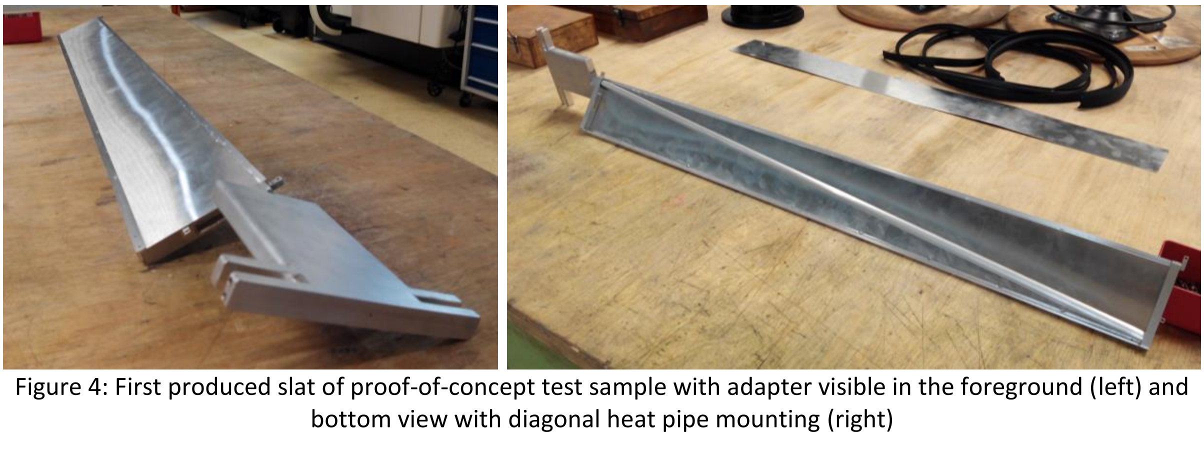

Figure 4: First produced slat of proof-of-concept test sample with adapter visible in the foreground (left) and bottom view with diagonal heat pipe mounting (right)

During the design of the test sample it was found that the slat design with the non-centered adapter poses a challenge to the tilting mechanism. This was resolved by moving the rotation axis of the slat into the actual center-of-mass of the slat assembly and adding mounting pieces to attach the tilting mechanism to the slat. Main focus during the testing period will be the reliability of the pressing mechanisms over many cycles of opening and closing the switchable thermal coupling combined with a large variety of blind movements.

Conclusion and outlook

The solar thermal venetian blinds offer the same flexibility as conventional venetian blinds and can improve the user comfort and the carbon footprint of the building additionally. With a few more components compared to conventional venetian blinds between glass units, STVBs can reduce the temperatures of the interior glass unit, the cooling demand and supply solar thermal heat to the building services. Many variants can be realized. Two promising cases are variants focusing on a *low g-value* and *high solar thermal performance*. Using heat pipes for the heat transfer and a switchable thermal coupling offers a safe and effective way to implement this functionality into a venetian blind. Two mechanisms for the switchable thermal coupling were developed and a test sample is currently being manufactured. It will be tested for reliability of the mechanism, especially with regard to the combination of blind mechanism and switchable thermal coupling mechanism.

Optimization of the slat in combination with improved horizontal heat pipe performance is an important next step in improving STVB. Thermal, energetic and optical measurements on a first STVB façade element are planned. The measurement results will then be used to calibrate a simulation model of STVB facades which can easily be used by planners to quantify the benefits of solar thermal venetian blinds for a specific building project. To enable the implementation of the system the constructional and architectural integration of STVB into the façade is developed in parallel to the technical aspects of the STVB itself. Finally, an integrated façade and building service solution for the STVB system should be designed to realize a holistic STVB façade solution in first reference projects.

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