Innovation in PV-Operated Shading and Heat Recovery

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Abstract

The paper investigates a novel technical approach equipping the slats of insulating roller blinds with photovoltaic elements. The PV-yield and the quality of the shading solution is enhanced by utilizing 100 year old housing technology for inclining the roller blinds in a separate frame. Measurements of the energy yield on cloudy winter days (~ 5Wh per row/panel) allow to postulate that with this solution powering de-central heat recovery devices via PV is possible for households (restricted to a few hours per day). In summer the heat recovery devices shall be circumvented for nightly venting/pre-cooling. For offices - requiring more air exchange and thus energy for the blowers - feasible approaches might utilize the PV system for roller blind operation only; but include safe nightly pre-cooling options with open windows in summer via controlling the gaps between the slats. The SoWa project behind the paper[1] investigates control of the shading and the respective power generation via photovoltaic and delivers a feasibility analysis taking into consideration also progress in thin film photovoltaic, including organic photovoltaic OPV technology. The outcome of the project funded within the Austrian Energie2020 scheme will outline the combined light and heat control technology, the control scheme and its implementation best suited to reduce the overall energy consumption triggered by cooling loads and electric light usage in offices of the system working solely on PV.

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1 Introduction

1.1 Problem setting

There are two facts which raise concerns about the sustainability of energy demand in Austria. In 2008 the power consumption increased in Austria by 23%[2]. Due to the possibility to increase working productivity, the energy consumption now also increases during the summer - caused by more frequent use of air conditioning. In Vienna on hot days the power consumption increases by 10% due to those air-conditioning devices[3]. Exemplary energy balances for offices are showing that illumination is more a problem (23% of primary energy compared to 14% for cooling[4]) when it comes to primary energy demand. This is also caused by increased coefficient of performance COP. But cooling tops the hot water demand in offices.

The indicated added power consumption in cities does not stem only from air conditioning but also from additional illumination of bureaus necessary because of too early closure of the blinds. However the development of energy saving LED technology will reduce this additional demand, so air conditioning will gain importance with regards to energy consumption and thus shading will too. Inner shades might also include insulation (cellular or honeycomb blinds) or allow a certain diffuse ingress of light by using certain fabric or even two type of separately moving horizontal segments with so called illusion shades. Even outer roller blinds of day-light type may have controllable light ingress either by using transparent slats or Venetian Blinds added. Transparent outer roller blinds made of poly-carbonates have only one pre-defined light absorption ratio. Newest developments of special slat profiles and coatings promise to lead the light horizontally into the room but excluding direct sunlight.

Insulating Roller blinds equipped with PV and automated shading control will save cooling energy. It is also investigated that solar power is used for covering part of the (indirect) illumination of the room and also for the recovery of the energy of exhaust air colder than ambient air in the summer scenario.

1.2 Project Approach SoWa

The project described in this paper investigates the feasibility of a photovoltaic supply for the shading control (which might also contribute to temporary insulation), reducing the air conditioning requirements by a shading respectively light distribution in the room adapting to the dazzling effect and operating completely from PV energy sources. The control aims at optimising the total energy balance comprising PV yield, air conditioning (cooling) and illumination demand. In the project the technical feasibility is be tested using a test implementation of the control, the control logic developed and the savings potential determined for typical scenarios via a simulation.

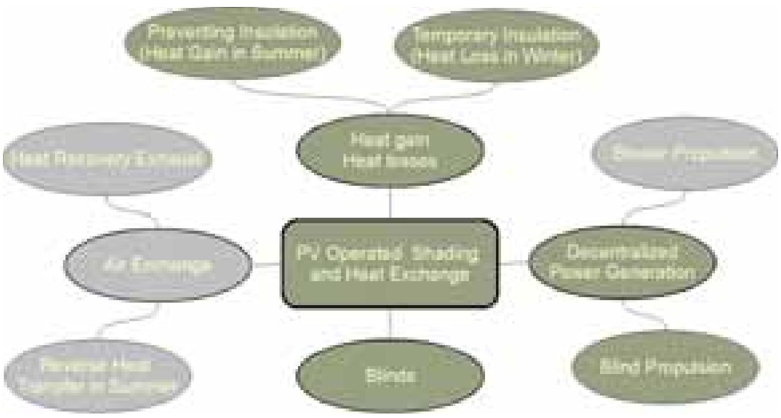

Fig. 1: ControlScheme

Sun blinds of the type used very often in the historical part of city centres, can be positioned in a way allowing maximum performance for photovoltaic elements. This allows for a much higher yield capable of operating heat recovery also in winter and contributing more to the electric lighting demand.

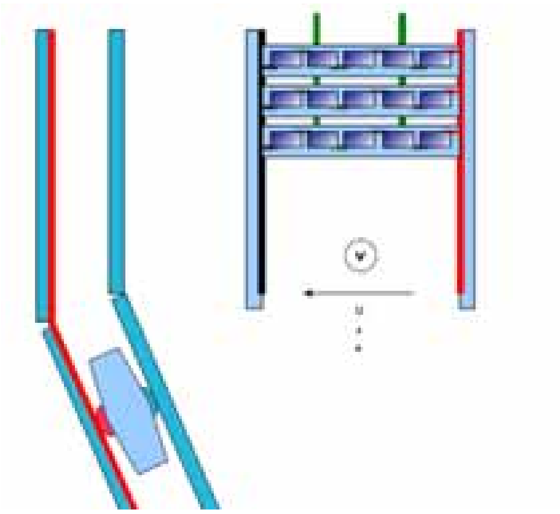

Fig. 2: Schematic of a possible electric connection of PV panels in blinds and polarity of the connectors

The reason why this construction is so attractive, is the possibility to alter the distance between the fins/panels as well as the inclination of the (lower part of the)PV equipped roller blind itself towards the sun, enabling an optimization possibility of the total energy balance offering awning functionality and thus visual contact to the environment. But the biggest advantage is to increase the area/aperture collecting solar energy. This is possible when using the blinds for expelling summer sun or expelling low sun throughout all the year. The SoWa project presented here is exploring the possibility to realize a construction, which reduces the demand for air-conditioning working in stand-alone operation. The question whether the low usage hours will compensate the additional PV-integration cost may be answered positively in cases air conditioning is expensive or impossible to retrofit.

2 Boundary Conditions

2.1 Scenarios For Shading and Heat Recovery

A first analysis by the evaluators gave a recommendation to focus solely on PV and shading. The reason might be that in winter continuous operation of the fans would be required and at the same time the yield from PV would be lower, not allowing a continuous operation of air based the heat recovery unit. The following table summarizes the most feasible operating scenarios being shading and temporary insulation which is using the same mechanics as well as cooling/heating systems powered by photovoltaic energy.

Table 1: Seasonal application scenarios of the PV-use in offices – grey cells are excluded in SoWa

	Shading	**Insulation**	**Air/Ventilation**
Winter	Seldom, when heavy PC screen glaring occurs	2 operations a day	Blowers operation for heat recovery
Spring	Partly, adapting continuously	2 operations a day	Blowers for air exchange, and (negative) heat recovery
Summer	Adapting continuously	Safe closure in rainy nights, when pre-cooling the room	Blowers for pre-cooling/negative heat recovery
Fall	Partly, adapting continuously	2 operations a day	Blowers for air exchange and (negative) heat recovery

A continuous direct use of the PV-power is only feasible in summer, whereas running fans for air-air heat exchange in winter will not be possible on cloudy days. For winter application grid connected operation will be mandatory to guarantee functionality of the heat recovery device (blowers) throughout the year avoiding costs of investments in big chargeable batteries. Stand alone PV-operation however constitutes also a feasible solution in cases of absent grid access near big windows. Higher integration cost for this type of façade-PV [5] and lower solar yield is compensated by saving on installation cost for grid connection in case of de-central usage.

2.2 Measurements Of The PV-Yield

A measurement of one solar string on a winter day gave a first insight into the yield to be expected. Using 9 PV-cells, embedding an thin film (a-Si) PV between two sheets of glass, (those elements having 10 cells 6x6cm each, being used normally with LED Lamps for gardens delivering approx. 4V at maximum) enough voltage was generated to be able to connect to a solar controller feeding a 12V battery. It turned out that one PV-string having 9 pieces will deliver approx. 0.33 Wh on a partly cloudy January day. Operating a solar tube motor for one sequence (45 sec.) requires 0.2 Wh. Minimizing consumption of the charging controller will be important because 10A PV-chargers consume as much as 3.5 Wh per day, which would require the 11 strings alone without any other load. Of course light blinds including PV are a must keeping the consumption value moving the blinds low – unfortunately high geared motors do not allow regeneration of potential energy. Measurements in spring and in summer have shown that only on sunny days the energy balance is positive including the consumption of the big controller – so not enough energy might be provided for ventilation and moving the shading devices continuously if PV is only placed on the slat frame and not included into the slats. Dye technology or *Grätzel* cells[6] for less costly application of PV on the slats (or the glass) might be only assessed theoretically if samples prove not to be usable. Flexible PV using UV-stabilised polymers meet the weight requirements but currently not the price expectations. Assuming economy of scale effects and process improvements integration of flexible PV into the slats promise a very good economy. Envisaged increase in efficiency of flexible organic cells to 8% or 10% [7] are harmonising with shading slats having a lifetime of ten years. For climates with seldom shading requirements, integration of longer lasting and higher efficiency PV cells in the frame is more promising offering also yield with open blinds.

Table 2: Reasoning about best suited PV technology (northern hemisphere)

Orientation	Application Scenario	Operating Hours PV	Solar Irradiation	PV requirements
East or west looking window	Early opening of east looking or late closure of west looking blinds	few	low	High efficiency with (diffuse) global radiation, frame integration, durable
East or west looking window	Late opening of east looking or early closure of west looking blinds but no illumination demand	medium	low	Standard PV, frame integration, durable
South looking window	Demand for additional controlled PV based illumination when blinds are closed	few-medium	high	Flexible/curved cells to be integrated into the slats having the same lifetime
South looking window	Living Room	medium	high	Frame integration of flat durable cells

2.3 Preferences of Users

An internet based survey has been analysing the status-quo and the acceptance of shading control systems. Underlining the non standardised sample (n=55, 2/3 of them men), the results are as follows:

- 55% of the respondents do have outer shading systems, only do have 10% shading structures above the window height (roofs)
- only 6% have experience with automated shading control (and some do have a very bad one)
- 71% have positioned their screens well (90° to the window)
- 61% may control their own working place light and are less depending on the quality of the shading control
- The most embarrassing fact to be avoided by the shading control is sun on the screen, but other illumination criteria are important (including the category very important) for approximately 2/3 of the respondents.
- Manual shading control is appreciated most (67% see it as their best solution), followed by remote control (which is claimed to get lost often)
- Visibility of the exterior scenery is important for the majority (38% important+38% very important) as well as natural light (63% very important) although 41% want to be able to close the shading system completely in summer.
- Sensors in the room are a delicate issue creating mixed responses (a total of 1/3 tends to see it as not acceptable), especially if the sensor is detecting presence of employees (35% accept and 35% don't).

Concluding, user autonomy is high on the agenda also because 74% of the users claim that they check low energy consumption themselves and do not want to be overridden by systems. The challenge is to show the benefits of an automated systems and develop solutions where automated control is seen as help - but not an embarrassment. For this purpose coupling the individual illumination preferences to the employee is an argument with roaming working places. In standard cases communication of actual energy savings and the actual status for the light quality will help to raise acceptance of the working staff. Manual override should be able without a hassle. In order not to sabotage the energy savings, individual working space lamps should be of LED type.

2.4 Control System Scenarios

By introducing control systems for shading alone, there might be energy savings: The (roller) blinds are regulated as such that the maximum of light may enter the room without infringing illumination quality and requiring electric lighting. The efficiency of the light control system is heavily depending on the quality of the shading system. Some allow for lower calorific transmission but higher light ingress towards the ceiling via two different surfaces on the slats of the blinds. Transparently coated micro-structure mirrors on slats are preferred over a micro-structured surface because of the easier cleaning[[8]]. Further projects could test super hydrophobic Lotus-plant-inspired structures. Light guiding systems allowing for an indirect illumination via the ceiling are preferable, but of course more prone to defects depicted in a directive[9] and seen in practice amounting to 38% of the window area[[10]]. Additional IR-reflective coating might be beneficial on the outer side in the summer case and especially on the inner side for the winter case reducing the losses by 40% [[11]]. Thus 180° reversal of the coated blind slats are wish-able, but necessary high reflection rate for the solar spectrum on the outer side might be face acceptance problems when faced inwards in winter. For manual controlled light and absent air conditioning, the automated control system shall be closing the blinds to a degree that the added heat production of the light is compensated to a minimum level. Electric lighting may allow for a staged manual operation of different light sources. The challenge is to detect manually switched light sources attributing the thermal load to them. This might be done via lensed light sensors and knowledge of the amount of light transmission through the blinds relying on measured values (sun sensor and ingress factors if sensing of ingressing light is not possible) preferably. Following the room temperature as optimisation target is only possible for rooms not equipped with air conditioning. Integrating the shading control system into the IT-system wirelessly may allow to learn the actual cooling load and lighting status for the optimisation and to give recommendations for manually switching the electric lighting.

More savings are expected by including dim-able light control and automating nightly cooling. For living rooms the amount of days above 27°C might be reduced to 54% according to literature using nightly cooling[[12]]. The challenge for light control is a coupling of the autarcic (e.g. energy independent) shading control system with the manual light control. Some detection of working spaces in operation together with measurements of the illumination values may help to save energy. But in offices with only one concentrated worker it is usual that the screen is the only light source till dawn. This is an analogy to the usage factor which increases when switching from individual ovens to automated central heating. But in the long run the health/productivity of the employees is more important than higher savings. Shading and cooling control also contributes to increased productivity reducing the maximum room temperature without restricting the amount of natural light unnecessarily. With non dim-able systems at least a staged automated on/off operation is possible. The additional PV-gains in summer might also contribute to an illumination of the ceiling from the window position where batteries and sensors will be positioned; which adds a controllable light system without touching the existing light installation. The automated shading system allows to start with a lower room temperature in the morning preventing from precipitation ingress even with open windows. During the day it takes the energy consumption and cooling load of the light into consideration when adjusting the slats of the shading system knowing if switching on the lights in a room adds to the cooling load and energy consumption. First descriptions of control systems for blinds recommended several adjustments per day[[13]], newer work was done on model based predictive control using Fuzzy algorithms and Fuzzy rules [12]. Without being predictive in the first run, the control system to be developed shall be stable, precise, withstanding dynamic requirements and be robust [12].

3 Evaluation

3.1 Usability of shading systems

The first project period had an orienteering phase to see what shading system should be used from a practical standpoint, even if in a lot of the cases the building design decides. Internal blinds do not deliver sufficiently low solar heat gain coefficient SHGC because of the convective and radiative transfer of the absorbed heat to the room[14]. The combination of an external translucent shading with an awning might be very functional but resistance against wind has to be proven. Systems using two outer roller blinds which might be operated separately are coming next in the ranking. They save on average 17% lighting energy and 6% cooling energy[15]. Best ranked are roller insulating shades having incline-able slats or transparent intermediate slats. Especially winter scenarios are profiting from the insulation characteristics. Those systems also benefit the integration of photovoltaic compared to the first system mentioned using translucent fabrics. Shading systems shall also have low propulsion demand for the PV-operation.

3.2 Achievable Savings

Modelling different slat positions using a Mathcad® based model combining, air exchange, convective fluxes through window and blinds and directly (partly) transmitted solar flux was done for two scenarios – with and without air conditioning on a hot and sunny summer midday. In a simplified statical calculation in the not cooled case the temperature had to rise above the ambient temperature to compensate for the cooling load. Switching on the light with closed blinds adds cooling load so a higher temperature is resulting and slightly open slats are the optimal solution. Summarising, the solar gain increased by the cooling load of the light is cooled by air exchange mostly. For the conditioned case the energy consumption also has an optimum with slightly closed slates. Without dimm-able lights or the possibility to switch only part of the lights, more open slats are the better solution.

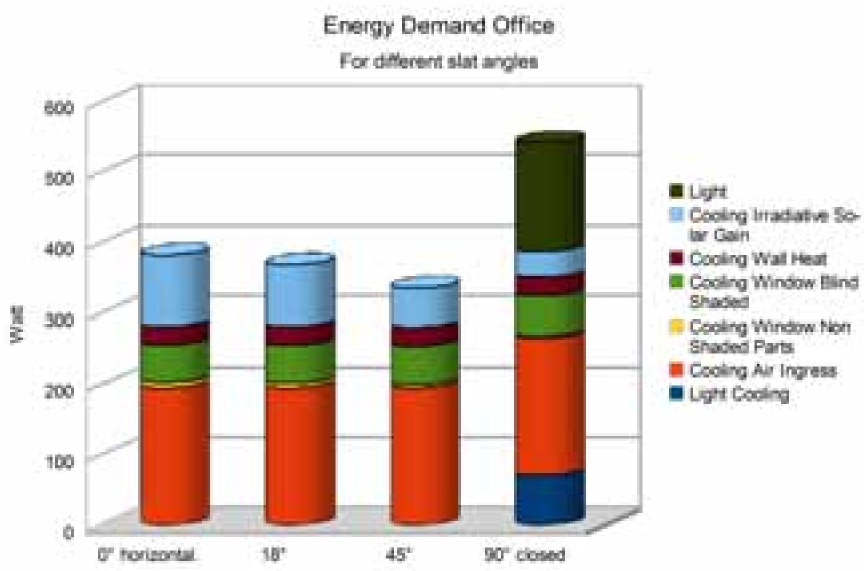

Fig. 3: Energy Consumption for different slat positions - own calculations

Preliminary results of the ParaSol simulation of active shading with a similar scenario than set up in Mathcad showed an (optimistic) reduction in cooling load of 36% over the year when automated adjustment of the blinds is enabled – compared to fixed angles. We are comparing this to savings from a system which controls the light via three switch-able glass window bands. Up to 20% reduction in cooling load and –10% to +60% reduction in lighting energy use may be achieved using an adaptive control[16].

3.4 Outlook

The upcoming work in the project is structured in the following way:

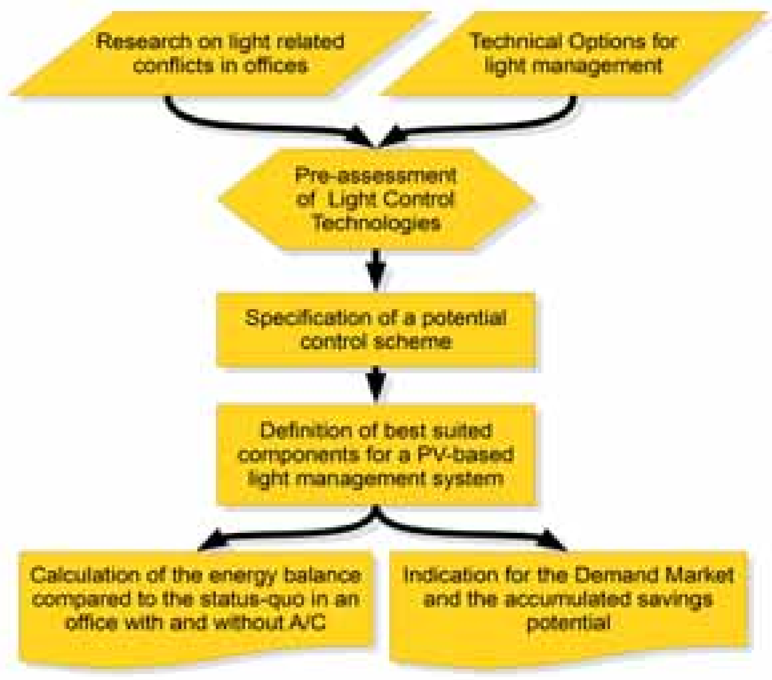

Fig. 4: Flow-Chart of the upcoming project work

4. Conclusions (preliminary)

Measurements using a ready made PV-system for a roller outer blind have brought very little yield of only 0.25 Wh in operation, but this relates to the fact that the secondary battery had a high state of charge. The maximum charging current was 150mA for the 12V system. One very stunning fact is whilst we may see a 10% difference between PV moved out with the frame and the inner position that there are cases where more yield is to be expected from the inner position. This was measured in case the sun hits an opposite reflecting building surface, in our case an innovative external controllable shading system made of aluminium.

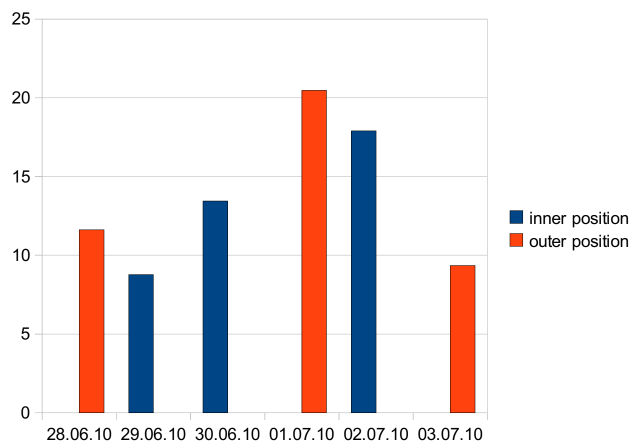

Fig. 5: Comparison of the yield in mAh - 12V

The project is in its first part so the final conclusions are not here by end of July. By statical modelling of the energy consumption depending on the slat angle the working hypothesis could be validated that there is a potential to reduce the total energy demand running an air conditioning device or both the room temperature and the energy consumption for light in the other case. The potential savings amount to 13% for cooling and 38% including light also for a hot summer day. Simulation of an similar case using ParaSol gave savings of 36% using automated tilt control of the Venetian Blinds..

We may already indicate what the final poster for the conference will contain also and may be found at the website www.effiziente.st after the end of the project:

- outline of the combined light and heat control technology best suited to reduce the overall energy consumption in offices
- presentation of the control scheme balancing minimal energy consumption and visual comfort of clerks
- description of the PV panels, charging controller, sensors and and controller necessary to implement the said scheme

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