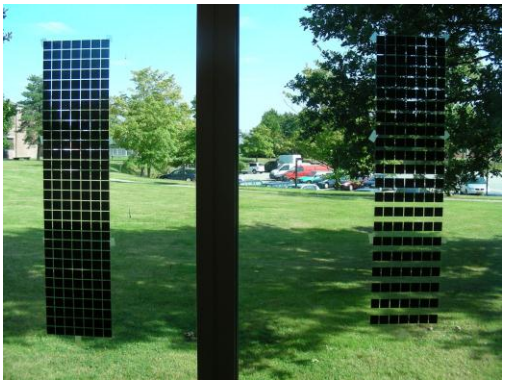
DANISH TECHNOLOGICAL INSTITUTE

Application and design of light filtering solar cells



Danish Technological Institute

Energy and Climate Division

Application and design of light filtering solar cells

Lars Olsen
Energy and Climate Division
Danish Technological Institute

September 2012

Preface

The report is the final report of the study: "Small Scale Demonstration" which is related to utilization of light filtering thin film solar cells as an integrated part of the transparent building envelope. The work is a part of the project "Thi-Fi-Tech - Application of thin-film technology in Denmark" financed by PSO ForskEL project no. 2008-1-0030.

The project is a continuation of the PSO ForskEL project LYS OG ENERGI – solceller i transparente facader project no. 2006-1-6302 reported in (Wedel, 2008 and Hansen, 2008).

The following persons have participated in this part of the project:
Lars Olsen, M.Sc., Ph.D., Danish Technological Institute
Signe Cold, Architect MAA, Entasis
Vagn Borlund, Architect MAA. Entasis.
Peter Krogh, Architect MAA. , Caspersen & Krogh Arkitekter A/S.
Søren Østergaard Jensen, M.Sc., Danish Technological Institute
Kjeld Johnsen, M.Sc., Danish Building Research Institute, Aalborg University
Jens Kristoffersen, Ph.D., Danish Building Research Institute, Aalborg University
Hanne Lauritzen, M.Sc., Ph.D., Danish Technological Institute
Ellen Kathrine Hansen, Architect MAA. Architect School Aarhus.
Per Haugaaard, Esbensen Consulting Engineers

Thi-fi-tech has been carried out by a team consisting of:
Danish Technological Institute (project leader), Danish Building Research Institute, En^{2}tech, EnergiMidt A/S, PhotoSolar A/S, Gaia Solar A/S, Caspersen & Krogh Arkitekter A/S, Entasis, Esbensen Rådgivende Ingeniører A/S, Arkitema A/S, Danfoss Solar Inverters A/S.

The project is documented in the following reports:
Application of thin-film technology in Denmark – Summary Report

With the following annex reports:
1 Application of thin-film technology in Denmark - Feasibility study
2 Application of thin-film technology in Denmark – Measurements and comparison of performance under realistic operational conditions
3 Assessment of indoor light and visual comfort when applying solar cells in transparent facades
4 Impact on indoor climate and energy demand when applying solar cells in transparent facades
5 Application of thin-film technology in Denmark - Product development
6 Application and design of light filtering solar cells (the present report)
7 Application of thin-film technology in Denmark - Medium and large scale demonstration

The reports are available on: www.teknologisk.dk/projekter/projekt-thi-fi-tech/32454.

Impact on indoor climate and energy demand when applying solar cells in transparent facades
1st printing, 1st edition, 2012

Energy and Climate Division

ISBN: 978-87-7756-xxx-x
ISSN: 1600-3780

Summary

In the recent years new types of solar cells have been developed to be integrated as a part of the building envelope. In this part of the project this possibility has been developed seen primarily from an architectural point of view. The aim of the work described is to give ideas for application light filtering thin film solar cells as an integrated part of the building envelope and asses these possibilities in relation to the use of the buildings, the performance and the total expression of the technology.
The use of light filtering thin film solar cells has many implications. The technology will enable the façade to function both as a combined energy producing, solar shading and light transmitting element.

The light filtering solar cells can have different appearances. Some types have the solar cell material on glazing with different geometries as e.g. patterns where only a part of the glazing is translucent while the other parts are opaque solar cell material. Other types are constructed as a metal mesh with penetrations which transmit light and solar radiation while the solar cell material is placed on the metal mesh.
The transmission of solar radiation will influence the thermal comfort of a building due to the added solar gain at times where windows in other parts of the building also transmit solar radiation to the rooms. The function as solar shading will reduce the amount of heat gained from solar radiation.
The other effect is the light filtering where the elements make it possible to vary the daylight entering the room and the outlook from the room to the surroundings.

In several recent types of building constructions large window areas are used which leads to a significant solar gain to the connecting rooms. In order to reduce these gains and to reduce the glare solar shading is needed. For this case light filtering PV-modules can be used to also provide an esthetic design with a solar and light dampening function.

In this part of the project is described and investigated a number of options for utilizing this technology. The report is organized with first a collection of previous experience, next a development of novel ideas, a discussion of the viability of the ideas and finally a selection of the most promising techniques for further investigations.

List of contents

1. Introduction

Integration of PV-modules (with solar cells) in the building envelope is an obvious possibility since the PV-modules have a surface which has to be weather resistant and therefore the surface of the PV-modules can act as an active and protective boundary between the interior of a building and the ambient.
A feature of many PV-modules is a translucency which allows some light and solar radiation to penetrate. This transmittance gives a possibility to apply PV-modules in the transparent part of the facades and roofs as elements with a light filtering effect. This light filtering can provide different effects. Esthetical and architectural it will be possible to give the surfaces an expression which reflects the use of a building and to direct and dose the amount of light which will be useful for the activities in the building.
A number of examples exist in which patterns are used on window glazing for the purpose of an architectural expression or decoration. Se figure 1.1, 1.2 and (Slupinski, A, 2009a and 2009b).
Another feature is the ability to function as shading. Compared to unobstructed full transparent glazing the shading-effect can be placed in such a way that the dampening of the incoming natural light will be varied over the glazed area. This will cause changes of the light intensity (luminance) from the surfaces hit by the incoming light, the visibility through the glazing and the reflections of the light incident on the glazing.
By combining these visual and shading effects by the benefits of a power generating element it will be possible to achieve a pleasant environment by an energy producing element.
The thin film solar cell based PV-modules produced today with light filtering characteristics have different appearances. One of the types has patterns of different shapes with an active (PV) solar cell surface on the glazing material which acts as a window pane. The visual appearance corresponds to a glass pane with a print which can have different shapes as e.g. stripes or spots.
Another type has a mesh with fine small holes shaped as elliptical cylinders penetrating a plate material. The geometry is optimized to give a good performance concerning solar shading and outlook taking the solar altitudes and orientation into consideration. On this mesh can an active thin film solar cell surface be added.
Other possibilities than using the thin film technology exist for obtaining translucency in combination with solar cells other. For crystalline solar cells the translucency is obtained by distance between the single slices. Photo electrochemical (PEC) solar cells can be made evenly translucent in different wavelengths (i.e. colors).

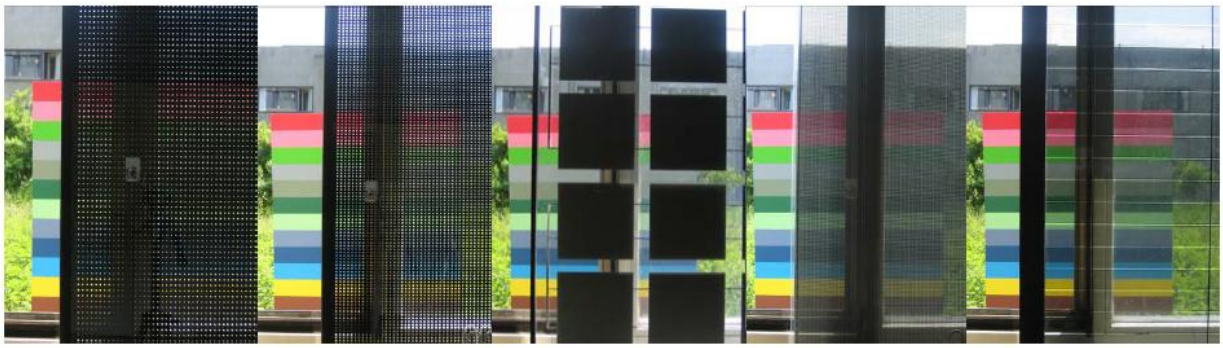


Fig 1.1 Examples of light-filtering PV panels from ‘LIGHT&ENERGY –proof of concept´. The examples show the different transparency.

Figure 1.2. Examples of buildings with printing on window glazing.

2. Collection of previous experience

The collection of experience is based on different sources:
The previous project ”Lys + Energi + Arkitektur” (Light +Energy + Architecture) (Hansen, E. K., et al. 2008) has provided a survey and collection of light filtering solar cells. The technology has also been evaluated in an architectural context.
Some elements from this report shows that it is expected the market share of thin film technology will expand from 10 % in 2008 to 20 % in 2020 and up to 30 % in the future. (See figure 2.1). The thin film solar cell technology will in most configurations block for solar transmission. But some producers have small translucent stripes or areas between the spots or fields of opaque PV-material. Due to the small size of these transparent stripes or areas the visual appearance will at a distance be translucent. The characteristics of some typical light filtering panels was described and evaluated. The opening area of PV-modules investigated was between 4 % and 49 %. The solar heat transmittance was between 0,09 and 0,3. The relative cost per produced kWh varied about a factor 3 between the most and the least expensive modules.

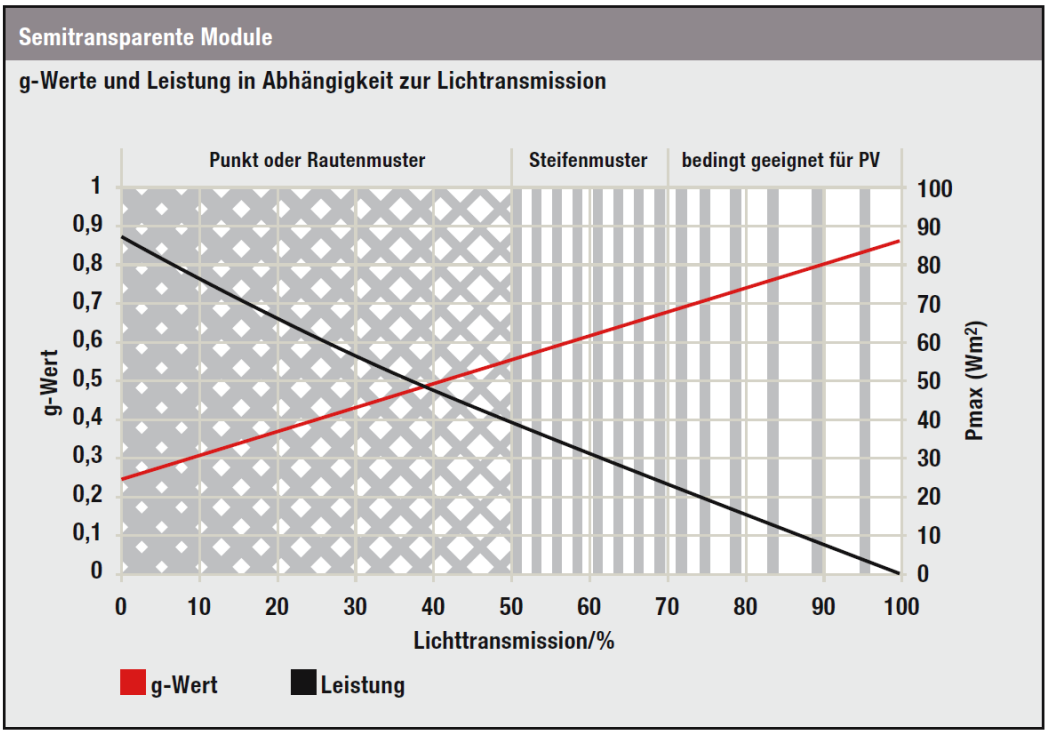


Figure 2.1. Examples of different opening areas. (Würth Solar, 2008)

A workshop has been arranged in the beginning of the project in order to collect and exchange the experience from the persons involved. Presentation was done regarding the different PV-types, the experience on light and PV-modules, indoor climate and examples of different buildings which already have installed this type of PV-modules. (See figure 2.2. and 2.3)
The experience collected gave an inspiration for development of new types and new applications of thin film light filtering PV-modules.

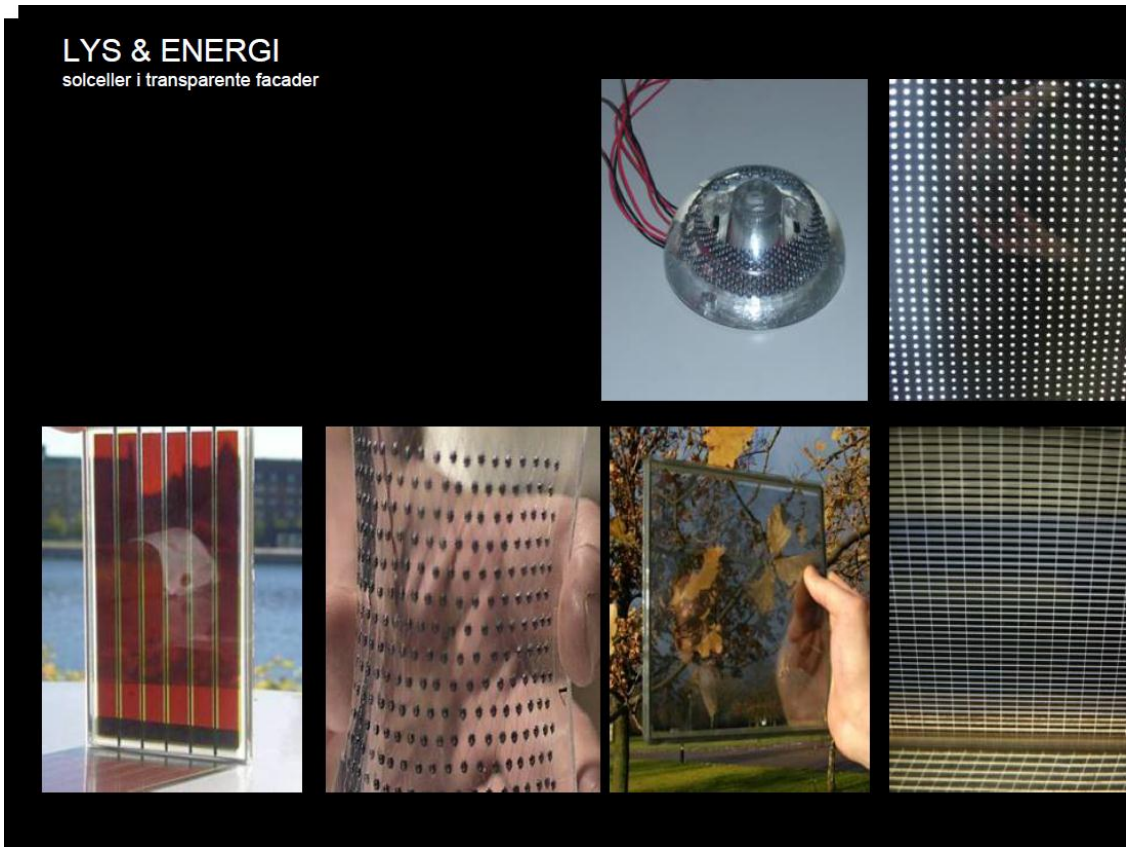


Fig 2.2 Examples of light-filtering PV panels. From presentation by Ellen Kathrine Hansen 27.11.2008.

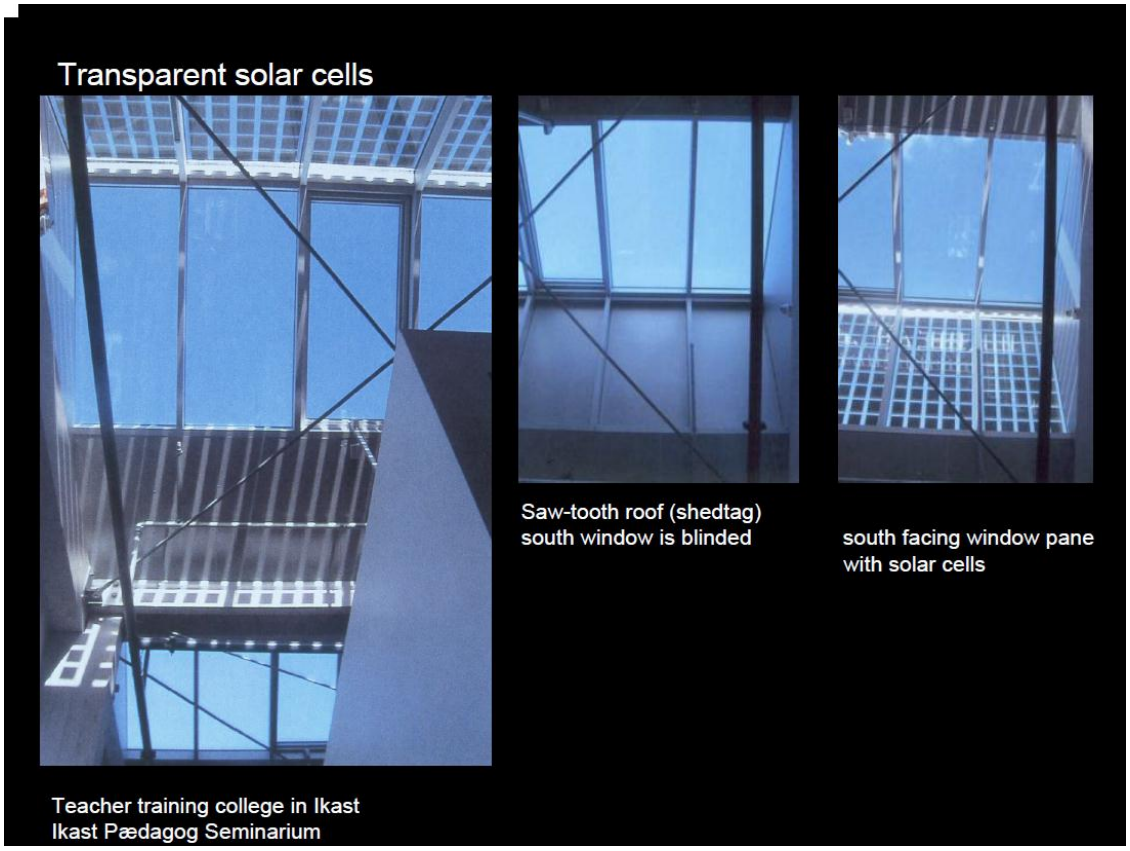


Fig 2.3 Examples of light-filtering PV panels. From presentation by Ellen Kathrine Hansen 27.11.2008.

Some of the detailed experiences from the workshop were:

Installations with low voltage (2 – 24 Volts) will result in a larger cross section of the wires used. There is a lack of standardization on these low voltage applications.
Solar shading in general can lead to conflicts in large office rooms due to the different needs and wishes and varying light and heat effects.

The solar heat transmission (g-value) can normally be calculated in direct dependence of the opening area for light transmission of the PV-modules.
The consequence of an increased glazing temperature due to the PV-modules was discussed.
There is an influence of the durability of the PV-modules due to the increased temperatures and there will be some influence on the performance of the PV-modules due to increased temperatures. The last influence is dependent on the type of PV-modules since some types of solar cells have less temperature sensitivity.

It has been proposed to apply light filtering PV-modules on the facades of the planned towers on a new development where a number of existing industrial buildings are planned to be transformed to a number of different applications as hotel and offices. (See chapter 3.2)
The discussion showed a need for sketches and pilot facades which can be used as test facilities where the performance is calculated, measured and which can be used as show rooms for the PV-modules investigated.

The design of the different PV-modules was discussed. It will in principle be possible to provide the PV-modules with an individual design but it will increase the costs. It will be less expensive to have PV-modules of a certain size and give them a placement corresponding to a patchwork with a number of modules of the same size.

It was suggested to have PV-modules in the glazed wall of an atrium on the south façade of a building.

Another design proposal was to use this type of light filtering PV-modules in a shopping centre where extensive glazing was planned. (See chapter 3.1). One challenge in this proposal was that the glazed part facing south has a circular floor plan which will with integrated PV-modules provide a variation of the momentary output of the different areas of the PV-modules.

The possibilities for using the day light test laboratory at SBi were discussed. The existing facades at that time would lead to a separation of the glazed areas due to the window bars. It will be possible to replace a whole façade or build an atrium building. These options will however involve some expenses.

The output of the work in the group will be a basis for the selection of the PV-modules to be tested. (See chapter 4).

3. Work in project groups

The two architect groups involved in the Small Scale Demonstration part of the project presented two proposals for application of light filtering solar cells. These are described in the following chapters 3.1 and 3.2.

3.1 Utilization in a shopping center

A proposal for a design with light filtering PV-modules to be installed at a shopping center in Randers was presented by Peter Krogh, Caspersen & Krogh. In the proposal the light transmission was at a maximum at the upper part of the façade and gradually reduced at the lower parts of the façade.

The proposal is illustrated in figure 3.1. The possibilities for utilization of semitransparent light filtering PV-modules in this proposal is described, commented and discussed by Peter Krogh below.

Previously it was pointed out that there is an apparent discrepancy, which concerns that first openings in the facades are made in an oversize with relative poorly insulated glazing in a well-insulated building envelope. Secondly the wish to be an ”ecological hero” by installing PV-modules which reduces the light gain through the openings which else would have compensated for the increased the energy loss due to the larger openings.

But…..
The arguments for such a design might be architectural, as in the case of the round shaped building in Haraldsparken, which is a planned business and office building complex located in the southern part of Randers. The building has two wings along two roads and on the corner between these two roads, which will have a pronounced exposure of the road users from both South and Vest, it is suggested to raise a round building, which has the permission to be 1 m taller than the maximum height of 10 m in the area in order to demonstrate the corner

The corner on the ground and first floor of the building is proposed to be rented to a jeweler with exclusive articles. The sales area, which encompasses half of a circle in the ground floor, is a room with double height, which can be entered through a security gate. As a part of the security measures is the area of the windows at the ground floor limited to the minimum. This is the explanation why the window area, separated in bands each 110 cm in height, has an increasingly larger and larger extent, and on the top, the just below the roof, the windows covers a full circle of the building. It is an architectural wish, that the apertures for entering the light shall be distributed in this way so there are natural light sources immediately below the roof in an angle of 180° in the directions from Southeast to Northwest.
This provides, due to the gradual reduction of the window area where the main part is facing in the direction from South to Vest, a risk for over temperatures, which have to be reduced by a cooling system requiring energy consumption. This provides a low score in relation to the energy frame calculations and our ecological moral!

It has to be remarked, that the expression of the building facade is intended to be very tight. Closed plane steel panels and window areas with structural glazing, placed with the front of the glazing in plane with the pate covering, all included in a tight module of 110 cm both horizontal and vertical. External solar shading with venetian blinds, blinds and awnings will in this context be absolutely undesirable.

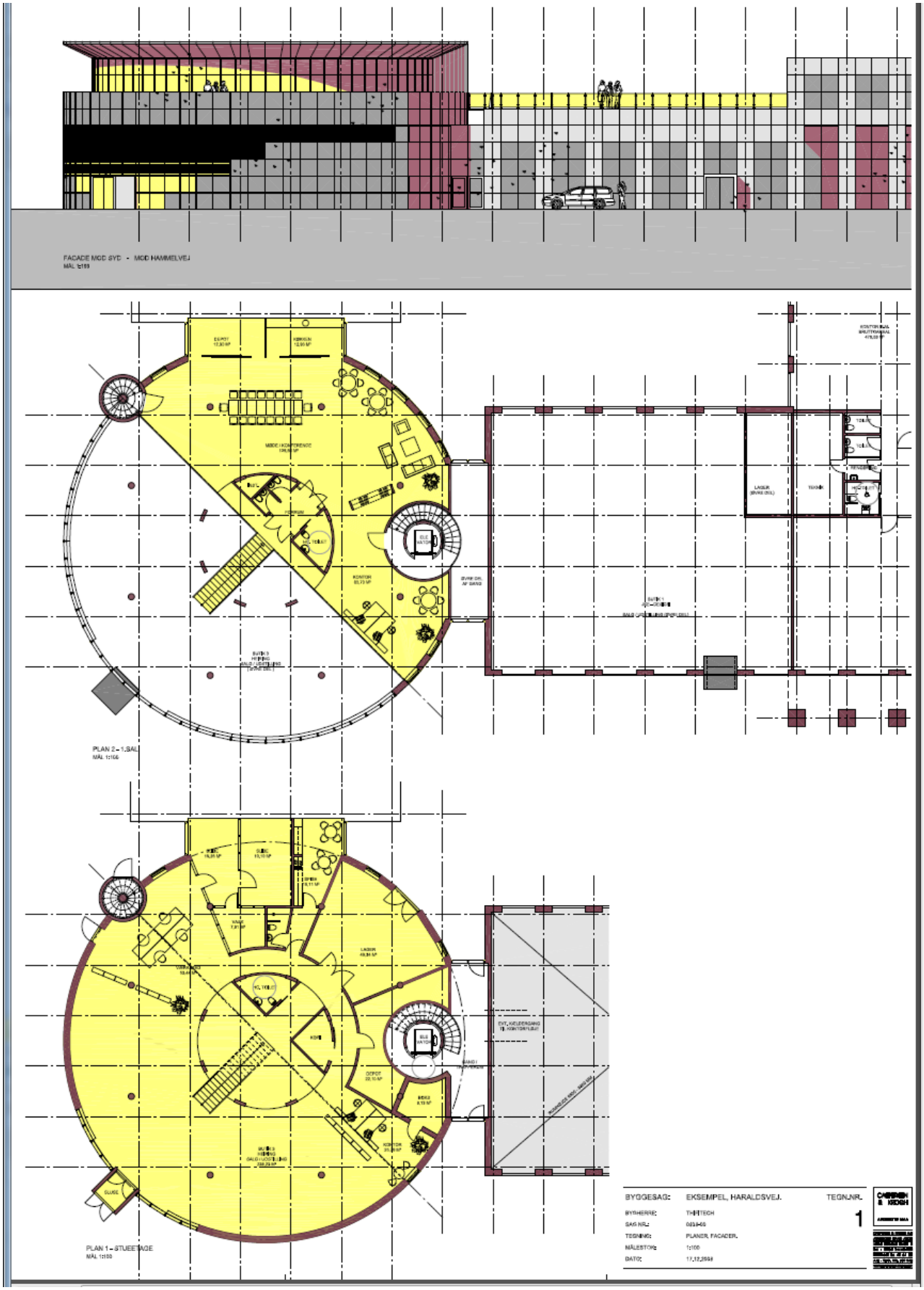


Figure 3.1. Proposal for a shopping centre. Caspersen & Krogh.

Due to this will a dampening of the light and the solar gain with transparent PV-modules in the double glazed window units be an obvious possibility. As well in this measurement project as well as in the proposed large scale project it could be a desire that the percentage of transparency can be graduated from a large to a small opening area.
In the circular shaped building on option could be to have two window bands with panes without PV-modules where there is a need for undisturbed view into the building and where there are the largest problems with overshadowing of the building. In the 3th, 4th and 5th window band it is assumed the window panes has PV-Modules with a reduced transparency for each window band. This seems to be feasible technical but maybe not economical according to information from PhotoSolar.
In the proposals for a façade element to be used in the daylight laboratory is this graduation of the transparency from high to low made in the single pane. Generally it is an exciting perspective by thin film based PV-modules that the intensity of the day light can be graduated.

It is already known from Fortbildungsakademie Mont Cenis I Herne, where the poly crystalline PV- solar cells are integrated in the panes of the shed roof with varying distance, which contributes to provide a unique lightening environment in this "building".

From previous time we have in Denmark a tradition for painting our window frames and sashes white at the inner side, which regarding the visual comfort is correct, because it reduces the contrast glare at the transition between frame/sash and the window pane. If it could be possible to extend this transition to the area of the pane it could be an interesting possibility.

The proposal involves a challenge to introduce solar cells in curved glazing and to control the output of the solar cells with different orientations. There will be an advantage in using solar cells placed at curved glazing since the output will be distributed more evenly during the day than if the solar cells are placed on a single plane surface which will have a larger peak once a day.

3.2 Application in a high rise building

A proposal for a design with light filtering PV-modules to be installed was presented by Vagn Borlund, Entasis.

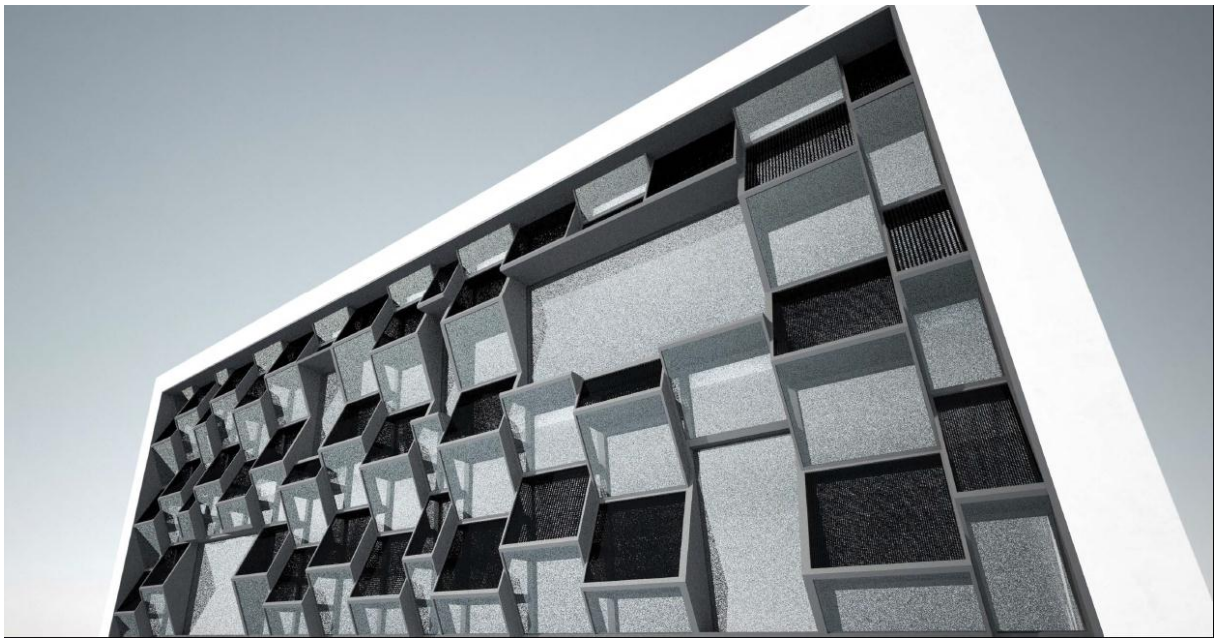


Figure 3.2. Proposal for a structure with PV-modules, exterior view. Illustration from a presentation14.04.2009 by Vagn Borlund - Entasis Architects.

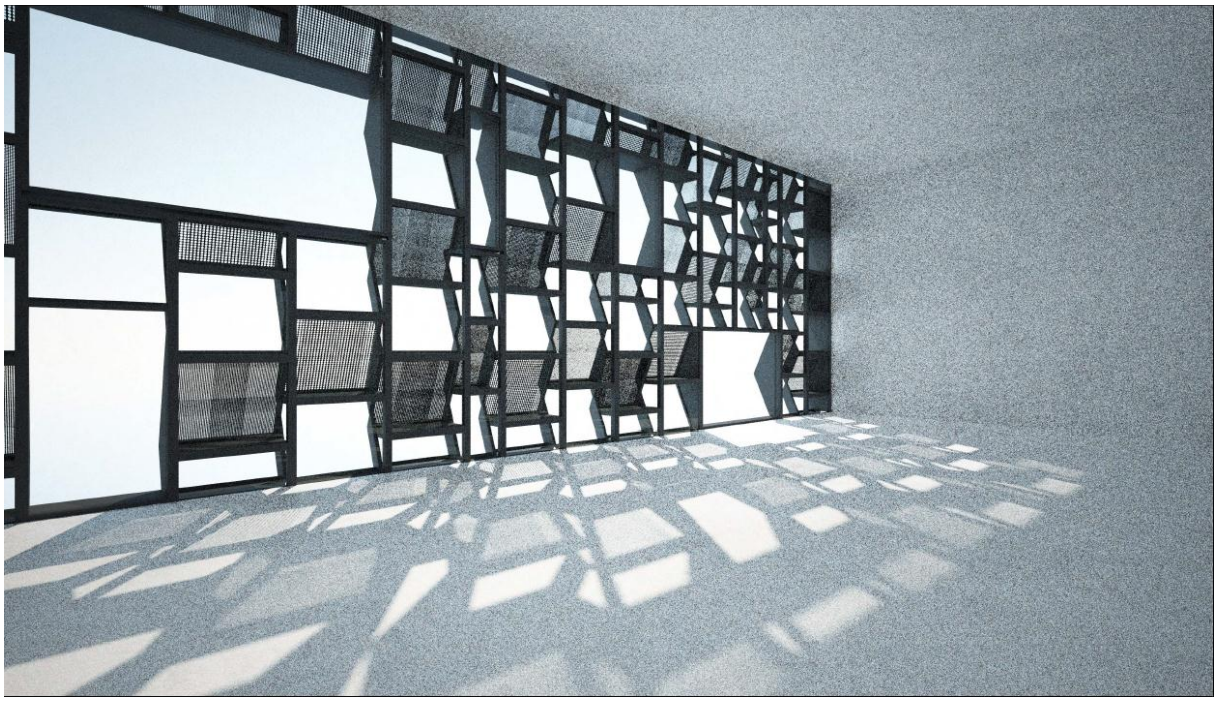


Figure 3.3. Proposal for a structure with PV-modules, interior view. Illustration from a presentation 14.04.2009 by Vagn Borlund - Entasis Architects.

It is proposed to apply PV-modules on a new development where a number of existing industrial buildings are planned to be transformed to a number of different purposes which could be as hotel or offices.
The design principle is an update of a proposal for a high rise building placed in the Carlsberg development scheme, where there in the local plan for building regulation are specified precise requirements for the geometry and materials, together with a goal of CO_2-neutrality.

The design proposal use large adjoining glazed facades which will be suitable for integration of PV-modules. A possibility is to use PV-modules on roof coverings and light filtering PV-modules on the facades of the planned towers.
In the areas where the high rise buildings have an expression of being heavy (and dark); it is proposed to install the glazing elements at a certain limited area of the exposed façade facing south.

The glazing elements are formed as a three-dimensional structure, partly as a contrast to the heavy solid but simple facade expression which dominates the tower house, partly for optimization of the energy producing surface and create a living and dynamic expression.
The glazing will form a shape corresponding to a crystal composed of aluminum frames with single layer panes at the outer side and an insulating glazing unit at the inner side. In the intermediate space is placed shading in the form of a blind. The thin film solar cells are placed in the upper angled part of the glazing element, thus having an angle to the sun with a slope of 66° to horizontal which optimizes the utilization of solar radiation and provides a solar shading for the activities in the adjoining rooms.

Two different window sizes are employed, a narrow and a wide element. For each of these are adjustment elements needed. By displace and vary the elements and also include large calm plane parts it is possible in total to achieve a vivid façade expression.

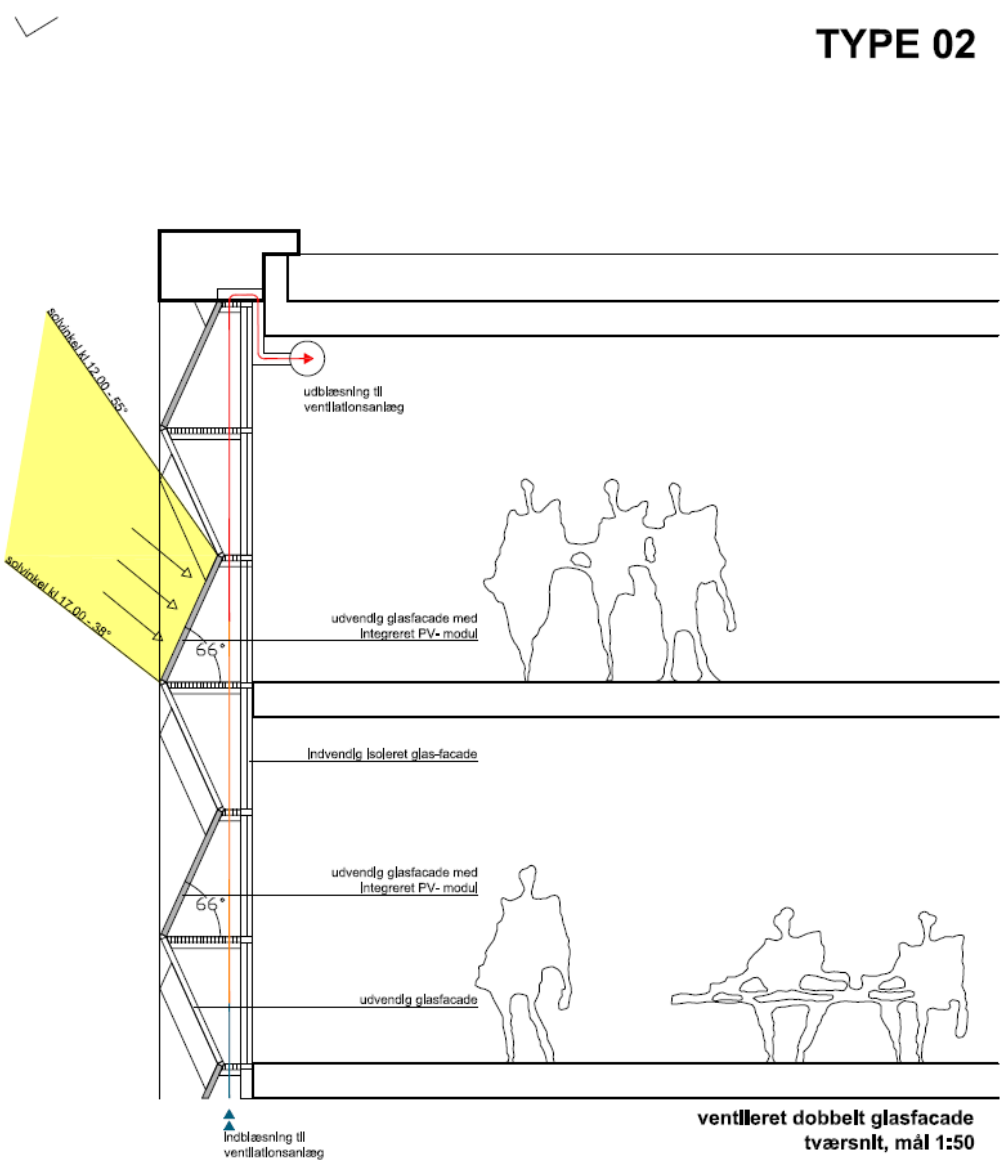


Figure 3.4. Proposal for a structure with PV-modules, section. The structure is combined with a ventilated double glazed façade. Illustration from a presentation 14.04.2009 by Vagn Borlund - Entasis Architects.

The principle of the facade is suggested to be developed together with a facade manufacturer. Together with the planned construction of the mock-up it is intended to also have assistance from engineers and manufacturers.

The other parts of the project will provide information about the performance with respect to both visual and thermal comfort as well as the pleasure with working or living behind such a vivid façade expression. The areas to be investigated in the comfort study should have key words as outlook, experience, inspiration, distraction, overheating, concern and fascination.
The comfort study should also be accompanied by measurements of the energy related performance, since this part is un-separable part of the proposed principle and should therefore be compared with the resulting economy involved in such a project.

Considerations should also be done concerning reducing the overshadowing of the PV-modules due to the complex shape of the structure.

3.3 Work in project groups

Some general remarks from the working group were made concerning the use of light filtering PV-modules.
In order to reduce glare it is recommended to apply venetian blinds behind the light filtering PV-modules in order to reduce glare.
Cases have been seen where transparency obtained by the use of small transparent spots have caused problems with glare. The possibility for the use of varying aperture area of the transparent spots and shading should be investigated.

Two working groups were formed: One group with Danish Technological institute, SBi and Caspersen & Krogh), The second group with Danish Technological institute, Entasis and Esbensen).
The aim of group 1 was to develop designs of light filtering PV modules suitable for building integration. The selected design was produced as ”dummy” modules where a pattern is printed on acrylic panes simulating/representing a realistic pattern of the PV-modules. (see chapter 4). The modules was used for the tests in the day light laboratory at SBi as a part of the project: ’Measurements, Light & Comfort’. See the description and results in (Markvart et al, 2012) and (Jensen S. Ø., 2012).
In group 2 work was continued with elaborating the 3 dimensional structure with PV-modules. (see chapter 5). This resulted in a plan for building a mobile pavilion (showroom), which originally was intended to be used during the COP15-meeting. Entasis has elaborated a total visual description of a pavilion based on building a number of containers together. A budget was made for production and operation for 2 years at a total of 2.7 mio. DKR. Applications for support were sent to different potential financial sources. However this was coincident with the financial crisis and it was necessary to give up the construction of the pavilion. Later it was investigated if it was possible to find another suitable place for an exhibition if we could finance production of a mock-up which could show the characteristic qualities of the design of Entasis. Such a mock-up might be less expensive for both investment and working costs. An exhibition facility at the Brundtland center in Toftlund has been considered in cooperation with the innovation network VE-NET. Also the exhibition facilities at Byggecentrum in Middelfart have been considered due to the many visitors annually.

4. Selection of elements for test in the day light laboratory

Below is shown a number of test patterns which have been discussed at a workshop. The single patterns was printed on transparent film and mounted at window panes. (See figures 4.1, 4.2 and 4.3). The single patterns suitability was discussed and 3 sets of patterns were proposed for further tests.

A sketch of an element to be installed in the day light laboratory was presented. The transmittance can be varying at the different parts of the façade. A problem might be the use of black colored frames (due to the visual glare effect). It should be possible to have undisturbed view to the exterior in an appropriate height over the floor.

Figure 4.1 Discussion concerning the different sets of patterns.

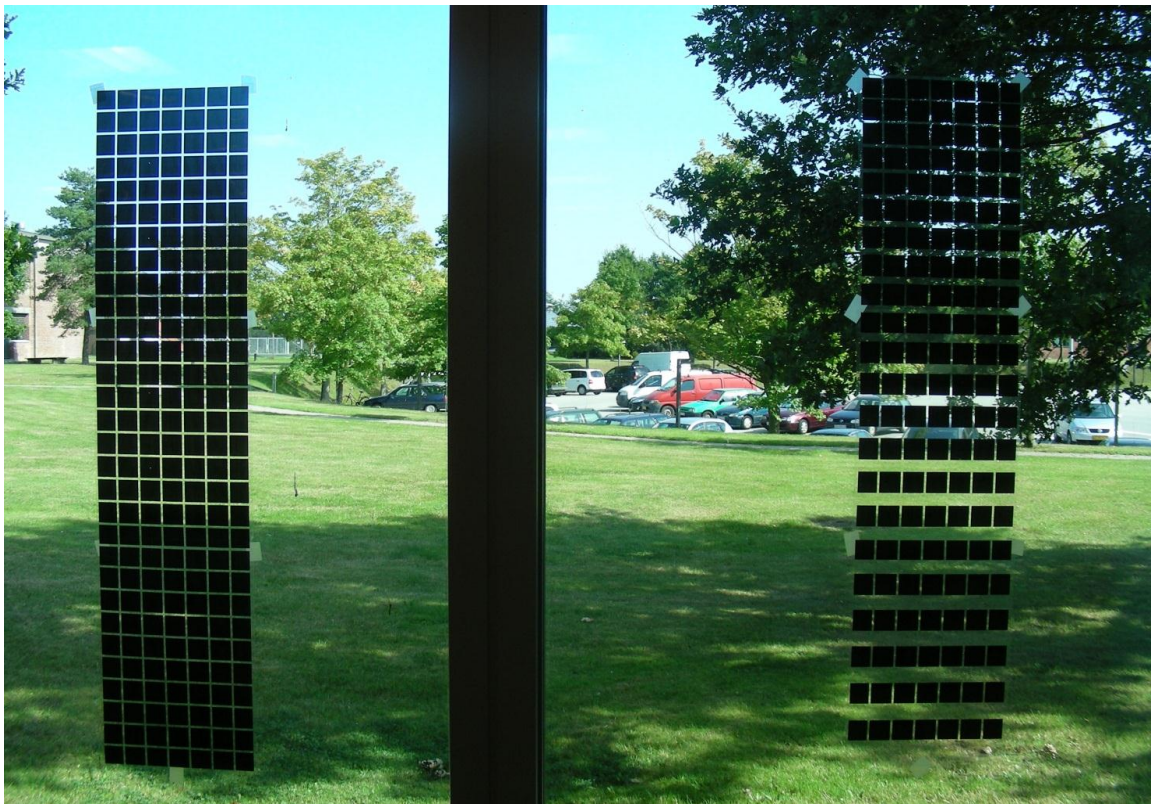


Figure 4.2. Two sets of patterns with spuares of different density.

Figure 4.3. Two sets of patterns with stripes of different density.

5. Dissemination

Description of proposal for a mobile pavilion
In the project there has been developed a plan for a demonstration of thin film technologies covered in the project. This plan had not been completed by implementation of the actual demonstration as it described below:

Title: PRISMEPAVILLONEN (demonstration of sustainable energy for buildings)

Aim: The aim was to show that sustainable energy technology, comfort and architecture are linked together. This is done by building a transportable pavilion where contemporary energy technologies are demonstrated in practice.

It is suggested to build a dissemination platform in order to show results from a number of interesting projects with both electricity producing and electricity saving technologies.
The energy counsellors will here have a unique place to communicate results to the users and the facilities will be suitable as education facilities where the single technologies can be shown in practice.

The technologies will be promoted as an integrated part of the building, partly as prototypes or models and partly by assistance of poster or video presentations. Also systems which are on the market will be demonstrated in order to increase the demand for the different systems. A pavilion will create a unique opportunity to present results from new investigations and initiatives in an exciting frame, as well as giving a possibility to transport the material easily around the country for relevant venues and exhibitions etc.

In the south facing facade of the pavilion thin film PV-modules will be integrated in a facetted three-dimensional structure which provides both an optimal angling of the PV-modules as well as an interesting play of light and shadows in the pavilion.
I the pavilion it is intended to include and show other energy technologies: Heat pumps, energy and visual optimal LED-lighting, double facade with possibilities for preheating of ventilation air, solar cells (PV-modules) or possibly solar heating on the roof, PCM (Phase Change Materials) in the floor (heat tube are casted in concrete so the slab acts as a thermo active construction).

Below is shown examples (figures 5.1 to 5.4) of a presentation by Signe Cold from Entasis of the proposal for a pavilion (Cold, S., 2009).

Figure 5.1. Proposal for a mobile pavilion with PV-modules, inside view. The structure is combined with a ventilated double glazed façade. Illustration from a presentation 27.08.2009 by Signe Cold - Entasis Architects.

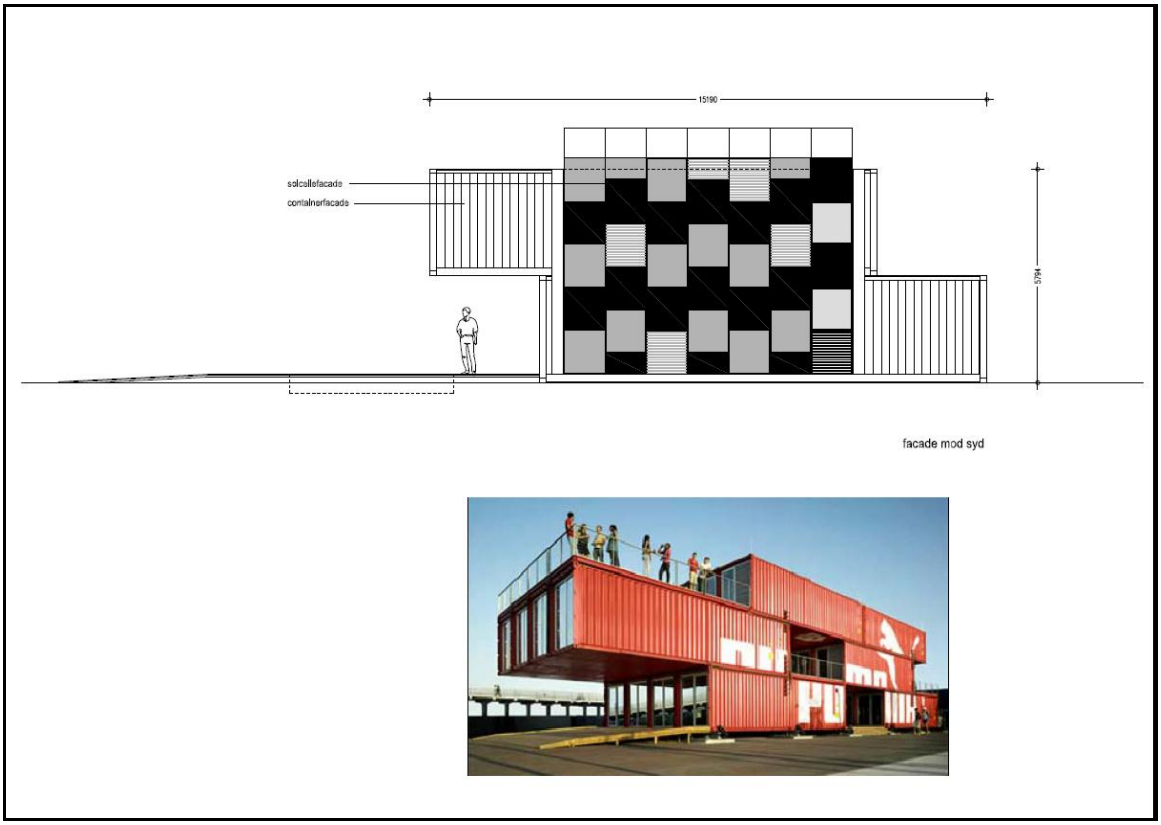


Figure 5.2. Proposal for a mobile pavilion with PV-modules. Below an example on application of containers for an exhibition. Illustration from a presentation 27.08.2009 by Signe Cold - Entasis Architects.

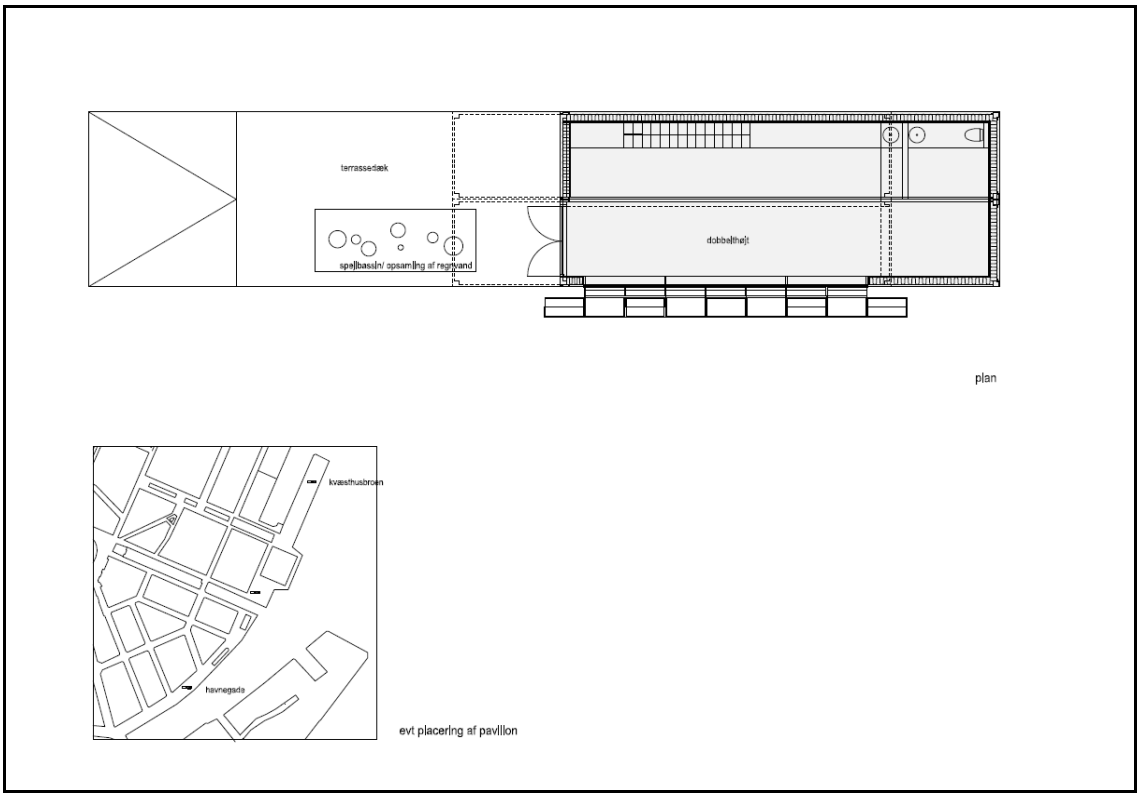


Figure 5.3. Proposal for a mobile pavilion with PV-modules, plane. Below an example on where the show might be placed. Illustration from a presentation 27.08.2009 by Signe Cold - Entasis Architects.

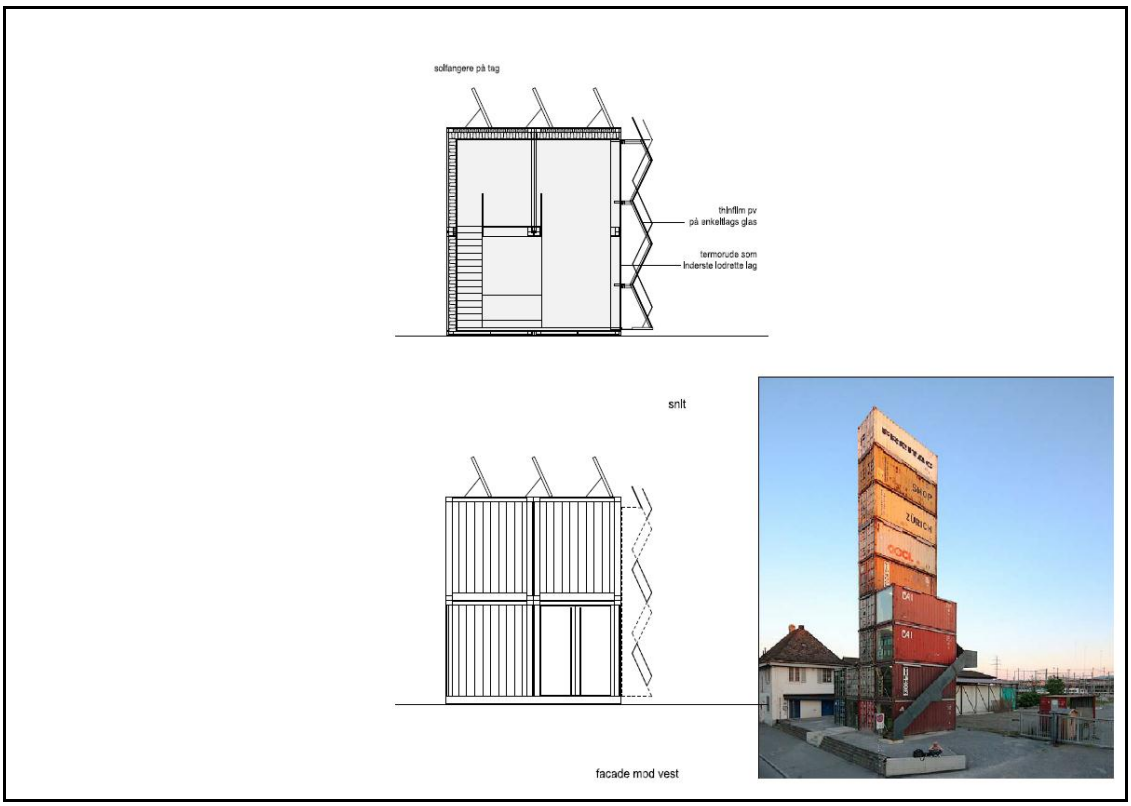


Figure 5.4. Proposal for a mobile pavilion with PV-modules, section. Below an example on application of containers for an exhibition. Illustration from a presentation 27.08.2009 by Signe Cold - Entasis Architects.

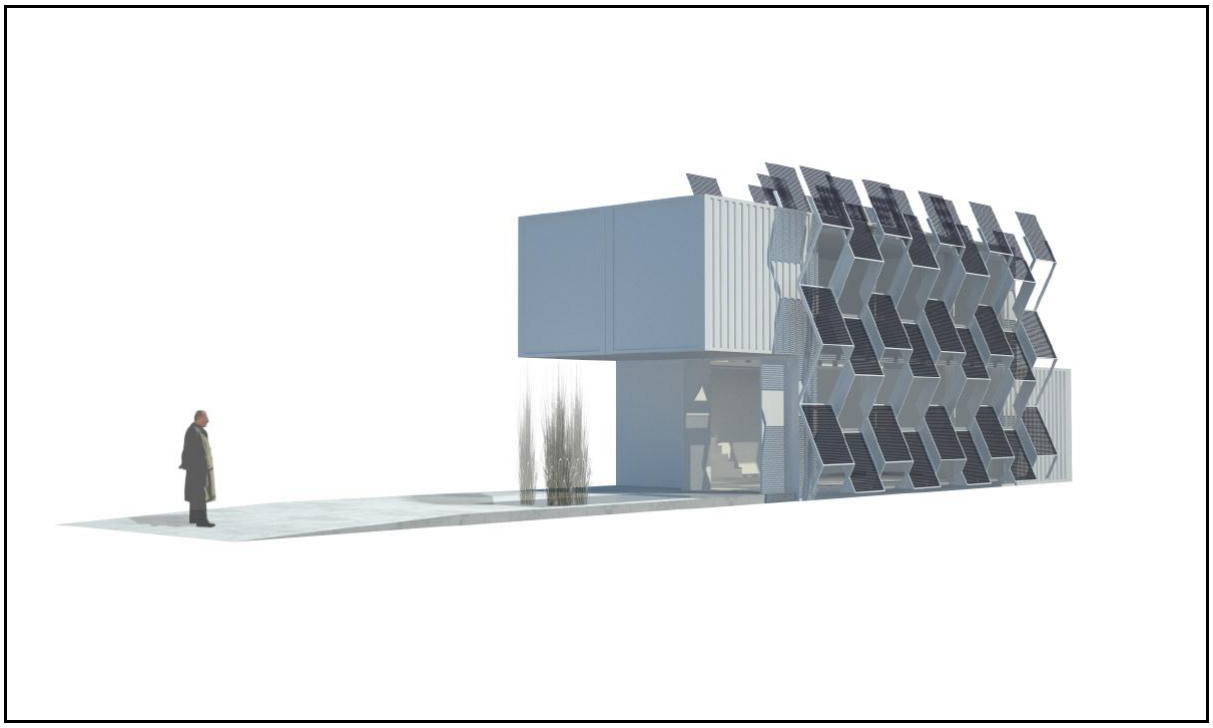


Figure 5.5. Proposal for a mobile pavilion with PV-modules, exterior view. Illustration from a presentation 27.08.2009 by Signe Cold - Entasis Architects.

6. Conclusion

The project demonstrates there exists a number of possibilities for application of light filtering solar cells.
Some buildings have already designs and features today which can be exploited by integration of solar cells on the surfaces. This is for example patterns printed on windows or transparent solar shading. The performance of solar cells can be increased if the light filtering surfaces have a slope. The slope can be varied at certain sections of the facades.

If the light filtering is obtained by patterns of solar cells on windows the size of the patterns should not be too large in size due to potential glare problems from bright and dark areas placed close to each other. It is expected that a gradual change of translucency due to varying density (per area) of patterns will be more acceptable than abrupt changes in density. It will also be convenient to have an undisturbed visual outlook in the parts of the windows which gives a view to the surroundings of the building. The patterns can be used as a tool for controlling the light and solar transmission for glazed areas where there might be overheating or other discomfort due to glare.

7. References

Jensen, S. Ø. 2012. Impact on indoor climate and energy demand when applying solar cells in transparent facades. Danish Technological Institute. 2012.

Hansen, E. K., et al. 2008. LyS + EnErGi + ArKiTeKtUr. Potentialer i Transparente Solceller. Institut for Arkitektonisk Design. Arkitektskolen Aarhus. .
http://www.re-ad.dk/aarch/files/74767/Endelig_20LYS_2BENERGI_2BARKITEKTUR.pdf

Markvart. J., Iversen, A., Logadóttir, A. and Johnsens, K., 2012. Assessment of indoor light and visual comfort when applying solar cells in transparent facades. Danish Building Research Institute (SBi).

Olsen, L., 2012. Application and design of light filtering solar cells.

PhotoSolar, 2012. http://www.photosolar.dk/pages/id1.asp

Schultz. J. M., 2007. Transmittance. reflectance and g-values for glas and windows with integrated PV-modules (in Danish). BYG·DTU SR-07-11. ISSN 1601 – 8605.
http://www.byg.dtu.dk/upload/institutter/byg/publications/rapporter/byg-sr0711.pdf

Slupinski, A, 2009a. SOL-SLØR. Del 1. Udvikling af undersøgelsesteknikker til design af lysfiltrerende solcellerude. Arkitektskolen Aarhus.
http://www.re-ad.dk/aarch/files/112915/Slupinski_afhandling_1_del.pdf

Slupinski, A, 2009b. SOL-SLØR. Del 1. Undersøgelsesteknikker og laboratorieundersøgelser. Arkitektskolen Aarhus.
http://www.re-ad.dk/aarch/files/112916/Slupinski_afhandling_2_del.pdf

Wedel. S. D. (ed.), 2008. Light and Energy – solar cells in transparent facades. Danish Technological Institute. May 2008.
http://vbn.aau.dk/files/16203556/Solceller_i_transparente_facader.pdf

Würth Solar, 2008. CIS Module von Würth solar. Arkitektur unter Strom.

Cold, S., 2009. Thifitech. Forskningsprojekt om anvendelse af solceller i bygningsfacader. Præsentation 27.08.2009. Entasis.