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Energy Curtain

- a self-sustaining curtain using photovoltaic technology to light up optical fibres

by

Carolin Müller

HÖGSKOLAN I BORÅS
Institutionen Textilhögskolan

Magister examen från Institutionen Textilhögskolan, Högskolan i Borås

Abstract

In the course of this master's thesis, three Energy Curtains have been created. These Energy Curtains are part of Static!, a project initiated by the Interactive Institute funded by the Swedish Energy Agency (Energimyndigheten), to make consumers more aware of energy consumption. All three Energy Curtains are based on the same principle. They have solar cells facing out toward the window, which convert the energy of the sun into electrical power during the day. This power is stored in accumulators to light up optical fibres during the night. The lighting patterns occur on the inner sides of the curtains in different designs. The three curtains differ in their shape. The first curtain, called Interaction Curtain, is fashioned as a Roman blind. The second curtain is a Lamellae Curtain consisting of nine lamellae, whereof two carry solar cells and seven are designed with optical fibres. The third curtain is a Panel Curtain consisting of three panels. Each panel is designed with solar cells and optical fibres and thus the panels are independent of each other. The industrial outcome of this thesis is that some of the patterns with fibre optics can be produced industrially, whereas others are more complicated to produce. The curtains are designed with a variety of different materials, from natural yarns to aluminium foil. This thesis is an interdisciplinary work as designers and engineers from different fields, as well from research and from industry, contributed to the project. The Energy Curtains aroused public interest and were exhibited at different places.

Acknowledgement

This masters thesis was done as the final work of the textile technology education at the Swedish School of Textiles, University College of Borås, Sweden.

Special thanks go to my supervisor Weronika Rehnby at the Swedish School of Textiles. Weronika supported my whole studies and this project with valuable advice. I learned a lot from her through many personal talks about working life and opportunities for the future. I also want to thank my second supervisor at the Swedish School of Textiles, Linda Worbin, for introducing me to the Interactive Institute and supporting this project.

Special thanks go also to my supervisor at the Interactive Institute, RE:FORM Studio, Ramia Mazé for giving me the opportunity to do this masters thesis within the Interactive Institute. Ramia supported me strongly in many fields, not only in this project, but also personally and for future works.

A special thanks goes to Anders Ernevi, electrical engineer and researcher at the Interactive Institute, RE:FORM Studio for the supportive teamwork and sharing his wide knowledge in engineering.

I would like to thank Olle Holmudd and Pepe Comi from Ludvig Svensson AB for their collaboration within this project. They supported my work with contribution of material and their experience and advice with industrial production and designing.

And last but not least, I would like to thank all members from the Interactive Institute for supporting my work by various means and the cooperation within the studio.

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a-Si:	amorphous silicon
c-Si:	crystalline silicon
LED:	Light Emitting Diode
mA:	milli Ampere
MOSFET:	Metal Oxide Semiconductor Field-Effect Transistors
MSUS:	magazine return weft insertion
Nm:	Nummer metric, unit for fineness of yarns

1 Introduction

Energy plays an important role in everyday life in terms of communication, transport, household, entertainment and so much more. It is hard to imagine living without energy and almost impossible to do so. Most technical equipment loses its function if there is no electricity available and therefore hardly anyone would choose to voluntarily live completely without electricity. The storm "Gudrun" for example, which blew over Sweden in January 2005 and destroyed a significant number of power lines, was a situation in which people started to think about living without energy and technology. Due to the storm, over 200 thousand households were without electricity for about one week and some even longer. In those extraordinary situations, our awareness of energy is strongly emphasised. But do we need a lack of energy to discover our dependence on energy or is it possible to create awareness by being reminded in daily life? The aim of the Energy Curtain is to sensitise users for the consumption of energy in everyday situations. Nowadays energy often seems to be a never-ending source, and we use energy as a matter of course. The integration and application of renewable energy sources is very important for our future and those of our descendents. And I think the photovoltaic technology should be something more substantial than black panels on the roofs of some lonely houses. If there is a wider acceptance and usage of solar cells, then the development will in turn get cheaper and more accessible in the future. To reach this, I think it is of potential importance to wider the field of available photovoltaic driven products for an average consumer. The Energy Curtain could be part of this development!

2 Purpose

The aim of this Master Thesis is to re-design an existing product, namely a curtain, by adding additional functions in terms of technology and dynamic aesthetics. This curtain should not be interpreted as establishing a new product on the market, as there already are enough products. The design process is a research approach in the Static! project of treating "energy as design material". The technologies added are photovoltaic modules and optical fibres, which transmit light. The intention of the Energy Curtain is to sensitise consumers to their energy consumption and their behaviour towards energy. Another equally important purpose of this curtain is to make a non-energy consuming product, as we already have loads of them. The Energy Curtain is self-sustaining.

Within this Thesis three types of Energy Curtains are created.

- Interaction Curtain
- Lamellae Curtain
- Panel Curtain

They use the same principles of technology. However they are made to focus on different purposes.

The Energy Curtain called Interaction Curtain is supposed to create energy awareness as the customer uses it. The customer has to make an tangible choice whether to enjoy the energy of the sun as sunlight or drop the curtain down and use the energy to charge the batteries through the solar cells. Then the energy can be enjoyed in the evenings through the glowing of the optical fibres. The real sensitisation to energy consumption and thus the creation of energy awareness will be exposed in a consumer study to test the concept.

The Lamellae Curtain and its model are made to experiment with the design of the different lamellae by using the optical fibres in combination with different textile fabrics. The lamellae offer the possibility to try out different patterns, but still it is one and the same curtain.

The Panel Curtain is the third version of the Energy Curtain consisting of three panels. In this version, the aesthetics stands in the foreground. The products aesthetics is chosen on the basis of the different designs of the lamellae in the Lamellae Curtain.

All three Energy Curtain types are made keeping in mind knowledge about the possibilities in industrial production. And so the patterns are made with respect to potential industrial feasibility. An ambition in the project is to bring technology and design together and combine them by reforming a curtain.

3 Background

This Master Thesis has been conducted in cooperation with the RE:FORM studio within The Interactive Institute in Sweden, Ludvig Svensson AB as industrial partner and The Swedish School of Textiles at the University College of Borås.

The Interactive Institute is an experimental IT research institute consisting of multiple research studios spread throughout Sweden. The institute acts as a meeting place - an interdisciplinary arena joining art, science, industry and public life in research projects and strategic initiatives to promote innovation, creativity and sustainable growth. The Interactive Institute's RE:FORM studio has been based in Gothenburg, Sweden, since 1998.

> *"The RE:FORM studio investigates technology as design material. While the typical notion of 'form' is physical shape, we believe that in considering computation as a design material, concepts of form must be fundamentally re-interpreted since time, flow, and energy and other dynamic elements become central in the interaction with computational things. In our research, we develop both methodological foundations and practical examples, exposing the experiential, social, and design implications of new technologies." [1]*

The research projects of the RE:FORM studio generate results to impact a range of arenas. Practical results are produced in the form of prototypes to reveal and test potential futures with users, stakeholders and collaborators. Theoretical frameworks and methodological foundations are continually deepened in academic contexts and highly reputed publications. Both practical and theoretical results into a variety of regional and international outreach initiatives, including exhibitions, seminars and professional networks are extended. Maintaining a continual flow of impact and foresight in relation to society and business, the extensive cooperation with industrial, cultural and academic partners is important. Static! is a research project within the Interactive Institute, which explores design for energy in daily life by making energy visible and tangible to all senses, expressing the relations among different forms of energy used and supporting reflection on the energy behaviours over time. Static! investigates interaction design as a means of increasing awareness of how energy is used and for stimulating changes in energy behaviour. Revisiting the design of everyday things with a focus on issues related to energy use, a palette of critical design examples is developed - prototypes, conceptual design proposals and use scenarios. These will be used as basis for communication and discussion with users and designers, for developing a more profound understanding of energy in design and to support awareness of design issues related to energy use early in the product development process. [2]

The Energy Curtain is one of several projects within Static!. The brainstorming and idea finding for the project was already done, when I joined the research group. The aim of Static!, and thus of the Energy Curtain, is to create energy awareness among consumers. I was introduced to the Energy Curtain concept, which envisaged that the curtain should have solar cells on the outer side and optical fibres glowing in the evenings on the inner side. That was the point were I started to think about possibilities to fasten the solar cells and optical fibres on textile and make a curtain out of it. The electrical issues within this project are solved by Anders Ernevi, Electrical Engineer at the RE:FORM studio. The design and interaction aspects were discussed with the other group members Ramia Mazé, Studio director, Johan Redström, Research director, Margot Jacobs, Interaction & Industrial designer and Linda Worbin, PhD student at the Swedish School of Textiles.

The industrial partner Ludvig Svensson AB sponsored the project with materials like the optical fibres, the energy weave, other fabrics and hardware for the curtains. Olle Holmudd and Pepe Comi supported the design process with advices and their experience. We produced a warp knitted fabric, which has optical fibres inserted using an industrial machine at the company. This fabric will be described later.

4 Work process

4.1 Materials

4.1.1 Photovoltaic modules

The photovoltaic technology used in this project are solar cells, which are made by the thin film technology. This type of solar cells differs from common crystalline silicon (c-Si) solar cells, which are up to 350 microns thick. Unlike elements used in c-Si solar technologies the absorber layer of the thin layer solar modules is made of amorphous silicon (a-Si). The cell structure consists of a single so called p-i-n sequence, which stands for a combination of three layers, i.e. positive, negative and intrinsic layer (see Fig. 1). These layers build up the generating part of the solar cells [3].

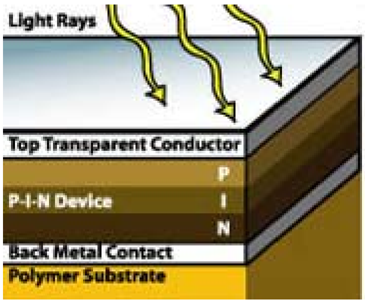

Figure 1: Cross section of a thin film solar modul

Finished modules are encapsulated in materials appropriate for the application environment. Flexible yet durable polyimide substrate results in unsurpassed flexibility, lightweight and paper-thin profile, whereby the substrate is only 0.05 mm thick. The sufficiency degree of thin film solar cells ranges from 5 to 8 % and is thus lower than that of c-Si solar cells, which can have an efficiency of about 30 %. Although they are less efficient, thin film photovoltaic is potentially cheaper than c-Si because of their lower materials costs and larger substrate size.

The type of solar cells we use is called PowerFilm®, is particularly suitable for the application on pliable fabric because of its lightweight and high flexibility. The modules are available in different sizes between 2.5 - 32.5 cm in heights and 6.4 - 27.0 cm in width. The solar cells have a positive and a negative polarity consisting of a copper plate on each side of the element (see Fig. 2).

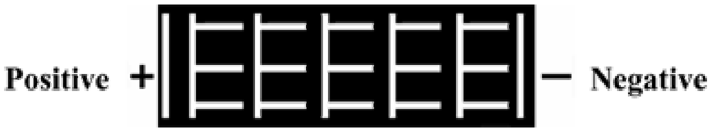

Figure 2: Schematic figure of a PowerFilm® solar cell

With these poles the solar cells can be connected to each other by soldering or crimping to a wire. The modules are available in different voltages from 3.0 and 15.4 Volt and currencies from 22 milli Ampere up to 200 mA. The solar cells can be connected parallel as well as in series depending on the voltage and current required.

A wide range of adhesives can be used on the backside of the solar cells to glue the modules to the intended surface. The wire connecting the solar cells can also be of use for holding the modules together. Extra material, e.g. adhesive tape, around the edges of the solar modules can be used if adhesive on the backside is not efficient.

In the Interaction Curtain, 52 solar cells of the type MP3-37 are used which has a size of 3.7 times 11.4 cm, have 50 mA and 3 Volt. Two lamellae of the Lamellae Curtain in full-scale are designed with 16 solar cells of this type. On one part of the Panel Curtain, there are MP3-37 solar cells used and on the other two panels there are three solar cells each of the type MPT15-75 used, which have a size of 7.5 times 25.3 cm, 100 mA and 7.2 Volt operating voltage [1].

4.1.2 Optical fibres

Optical fibres are known from data transfer whereby data is transferred as light in binary code. In this project however, light emission rather than signal transfer is the function of the optical fibres. Compared to common copper cables, the advantage of optical fibres is the low loss of data across long distances up to two kilometres, their small size and their space. They are originally made of glass, but as they were further developed and used for other purposes as well, the brittle glass turned out impractical in some cases and so plexiglass [2] can be

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[1] Appendix A: 1) Technical data of the solar cells

[2] The chemical name is Polymethylmethacrylate

used as a replacement. Sophisticated layers of strong fibres and coatings surround the optical fibres. In this project not the whole cable, but only the pure plexiglass fibre is used to emit and transmit light from the fibre. The plexiglass is advantageous because it is more flexible and tougher than glass and has a smaller density and is therefore lighter. The type of phenomenon which enables the light rays travelling through the fibre is just reflection, total internal reflection, as the walls of the thin fibre act like mirrors in which the incident light bounces back and forth. An illustration of the reflection of the light rays is shown in Figure 3.

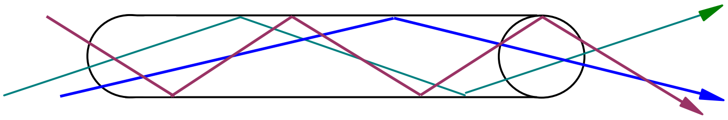

Figure 3: Schematic figure of the reflection of light rays in an optical fibre

The critical angle for total reflection of light within Plexiglas is 42 degrees. That means that the light rays emit from the optical fibre at the cut surface where the reflection angle is smaller than the than 42 degrees. Some of the light signal, however, degrades within the fibre, mostly due to impurities in the glass or polymer. The extent to which the signal degrades depends on the purity of the glass or polymer and the wavelength of the transmitted light. As white light emitting diodes (LED) are used as light sources for the optical fibres there is a wide range of wavelengths and thus no designation can be made for the degradation of light.

The side effect, that light emits if there is not total reflection within the fibre, is the volitional implication in the application of the optical fibres in this project. For achieving a good light effect, certain areas of the optical fibres are sanded. On these areas, the total reflection is only partial and therefore light rays emit from the optical fibre and will be visible for the human eye. There are other light emitting products on the market but especially interesting with the fibre optics is that the area where light emits is variable. Different patterns of striped intervals can be made. It turned out that the intention of the light emitting from the optical fibre is stronger if the area which is sanded is on the back of the fibre - the fibre acts like a lens in that case. The sandpaper used should not be overly coarse, since fine sandpaper diffuses the light and seems matte. It is also possible to use a knife and cut lines into the optical fibre. There are also optical fibres available, which are made especially for light effects and therefore emit light over the whole fibre length, but usually there are stronger light-sources used to light up a bundle of optical fibres. In this project a LED is used, which might be too weak to light up an optical fibre, which emits light over the whole length.

4.1.3 Textiles

4.1.3.1 Weave with special floats

Inspired by a special weaving method from Ekelund, Linneväveriet i Horred, which works with floats for pattering, it turned out that the best option for fastening the solar cells and the optical fibres would be to make floats (parallel warp yarns lifted over several weft yarns). This construction gives the possibility to insert the solar cells optical fibres under those floats. The weaving department in the University College of Borås made two weaves, which are in a plain weave construction of a cotton yarn in natural white. The weave, which is used for the backside of the curtain, has special floats, which are of a size that they can cover the edges of a solar cell. Those floats are span over 37 mm in a vertical direction and are made of 15 parallel warp yarns, which is about five millimetres in width [3] (see also Fig. 4).

Figure 4: Backside weave with floats for fastening the solar cells

Those vertical floats are placed with a horizontal distance of ten centimetres, so that the solar cells can be fastened between them. The warp threads, which are floating on the front-side of the fabric will, due to the weaving construction, cause a hole in the fabric on the backside. As the fabric construction gets slightly weakened by taking out the warp yarns from the normal position, it is an advantage to shift the floats in the row underneath a little to the side. On the other plain weave which has the same basic construction like the front side there are also floats, but in a different sizes and another arrangement. The

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[3] Appendix B: Fabric description 1) Weave with floats to fasten solar cells

floats are also in warp direction but only four respectively two millimetres long and smaller than those on the backside (see Fig. 5). Those floats have a distance of five centimetres lying in horizontal lines and are made to fasten the optical fibres in a vertical distance of about one centimetre [4].

Figure 5: Front side weave with floats for fastening the optical fibres

The position of these floats is in contrast to those on the backside independent the other floats since they are so small that they do not influence the ground construction of the weave. Several samples are made with different floats positions and distances, but finally a horizontal distance of about one centimetre, a vertical distance of five centimetre and an arrangement where the floats are lying under each other in a line were chosen to work with.

4.1.3.2 Energy weave from Ludvig Svensson AB

Ludvig Svensson AB's expertise lies in manufacturing interior and technical textiles, and for the last two decades, the company has been the market leader in greenhouse climate screens. Combining the advanced technology from the greenhouse screening and a vast knowledge of energy saving materials, Svensson recently developed a collection of interior textiles, Svensson's Ups&Downs. These unique fabrics act as energy saving sunscreens, protecting the interior of offices and buildings from sun and heat. Items from the Ups&Downs collection can be used for a number of combinations in the screen world. One of those materials is called MOOD 270 [5] (see also Fig. 6).

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[4] Appendix B: Fabric description 2) Weave with floats to fasten optical fibres

[5] Appendix B: Fabric description 3) MOOD 270

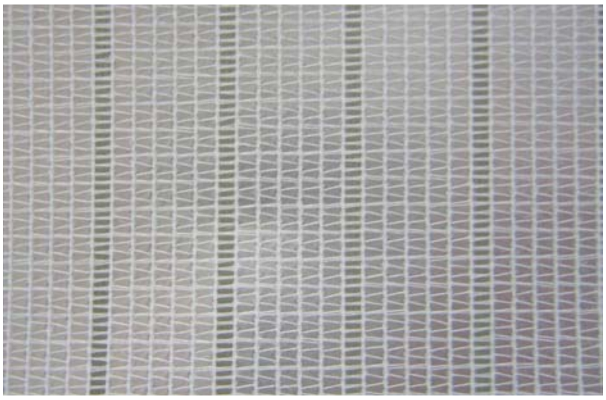


Figure 6: Picture of MOOD 270 white, an energy saving sunscreen

This fabric is used in the lamellae curtain model as a ground material for a lamella on which optical fibres are affixed. It combines sun shading with energy savings and light transmission. This material is a warp knitted fabric, which has fine aluminium strips worked in, which effectively stop incoming light through diffused reflection. According to the software program Parasol, a computer software program developed in 1999 by Lund University's department of Construction and Architecture to predict the impact of shading devices on energy use in buildings, this material can lower air conditioning costs by up to 40-50% if used as blinds. There are several different materials of this type, which differ mainly in the arrangement of the aluminium strips. In this project MOOD 270 and PROG 270 are used and their data is shown in the table below (Table 1).

	Solar optical properties						Shading coefficient			Fastness to light	
Fabric	Ts	Rs	As	Tv	UV	O-F	1/8*CL	1/4*CL	¼*H.A.	B 02	16 E
MOOD 270 white	15	66	19	15	9	8	0.37	0.37	0.34	Class 6	Class 4, 120 hrs
PROG 270 black	16	56	28	11	11	11	0.44	0.43	0.37	Class 6	Class 4-5, 120 hrs

Ts = Solar Transmission
Rs = Solar Reflection
As = Solar Absorption
Tv = Visible light Transmission
UV = Ultraviolet Transmission

O-F = Openess Factor
1/8* CL = 1/8 inch Clear Glass
1/4* CL = 1/4 inch Clear Glass
1/4* H.A. = 1/4 inch Heat Absorbing Glass

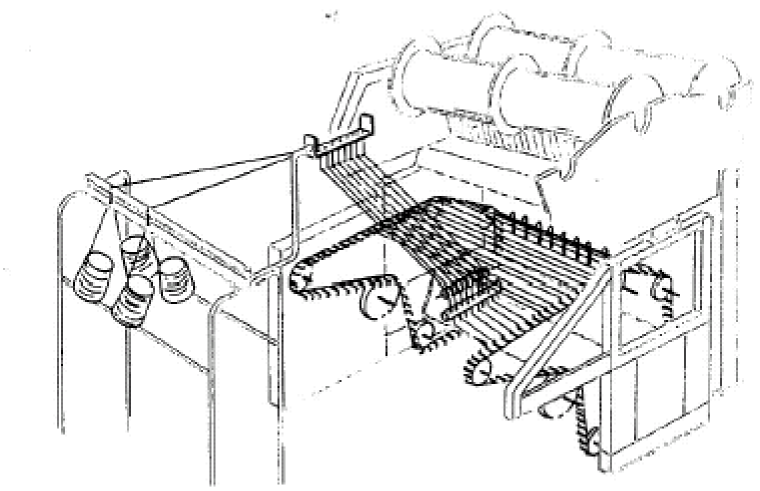
B 02 = ISO 105B02 Bluescale 1-8
16 E = AATCC 16E Greyscale 1-5

Ts, Rs, As, Tv were determined at the Ångström laboratory, Uppsala, Sweden
O-F and Shading Coefficients were determined at Matrix, Inc., Arizona, USA
Fastness to light 16E was determined at IFP Research AB, Mölndal, Sweden
Fastness to light B 02 and UV were determined at AB Ludvig Svensson laboratory

Table 1: Technical data on the energy saving sunscreen material

4.1.3.3 Warp knitted fabric

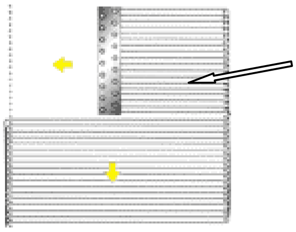
We searched for an alternative for the weave with the floats, described above, where the optical fibres are inserted after production. As mentioned, the optical fibres are quite stiff and cannot form loops tighter than a certain radius without getting damaged. Thus, a method of textile construction where the fibres do not build loops and stay straight for as long distances as possible was aspired to. The warp-knitting method provides an excellent method in this field, namely the MSUS (magazine return weft insertion) principle. This principle is a universal weft insertion system for different yarn materials and yarn counts. Servomotors control a weft-laying carriage operating on the backside of the warp-knitting machine [4]. Figure 7 shows a warp-knitting machine with MSUS principle from the back.



Schematische Darstellung des Magazin-Schußeintrages

Figure 7: Schematic diagram of magazine weft insertion

The normal feed of threads to the weft-laying carriage cannot be used for the optical fibres, since they would be bent too much. A certain number of weft threads are drawn off simultaneously and are laid around the hooks of transport chains circulating on both sides of the machine. Figure 8 shows the path of a weft laying carriage and how the yarns are laid around the hooks. Laying the optical fibres around the hooks of the transport chains was made by hand as they tend to derail from behind the hooks.



Weft threads, here also optical fibres, are laid around the hooks of the transport chain

Figure 8: Schematic diagram of the way of a weft laying carriage in an MSUS-principle.

For our textile production, the optical fibres get bowed in a 90-degree angle around these hooks and therefore they lose their transmitting property at that point. These edges float outside the knitting elements. The advantage of this warp knitting method is that the weft threads and thus the optical fibres are not building loops themselves (illustrated in Fig. 9). The knitting threads are building loops around the weft threads and thus holding the fabric together.

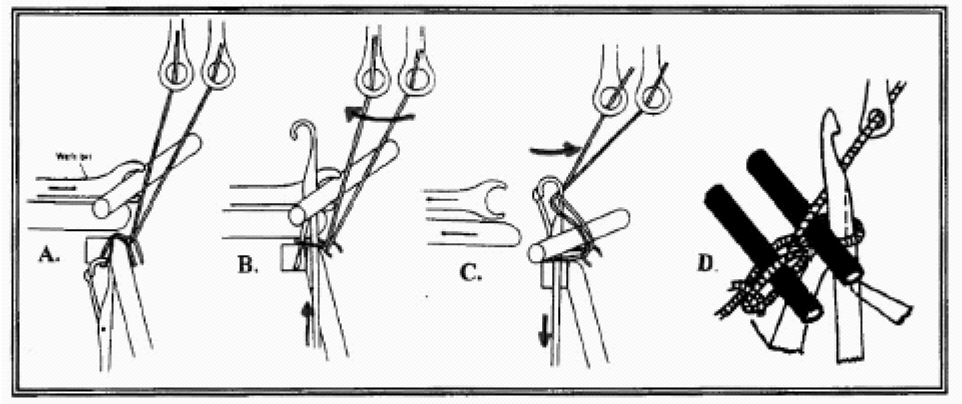


Figure 9: Knitting area of Raschel machine with magazine weft insertion

The ends of the weft threads are cut after having been interlaced into the stitch courses [5]. Hereby, the damaged parts of the fibre optics are cut away and fibre optic sections in the length of the machine width remain. The warp knit can be patterned depending on how many weft threads are inserted and left out. And depending on how many knitting threads are used the fabric can be come more or less transparent.

The warp knit, which was produced for this project has one knitting thread each centimetre, followed by a sequence of no vertical threads. The inserted weft threads consist of seven natural coloured thin linen threads enclosed by two optical fibres. The special selection of knitting threads and weft-inserted threads makes the fabric appear chequered and opaque [6] (see also Fig. 10).

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[6] Appendix B: Fabric description 4) Warp knit with optical fibres inserted

Figure 10: Warp knitted fabric with optical fibres inserted as weft threads

There are several other textiles used for making the curtains. Those other textiles will be mentioned during the description of the working process and are listed in Appendix B with pictures.

4.2 Experimental design

4.2.1 Interaction Curtain

4.2.1.1 First prototype

Textile development

The very first step of building this initial prototype was to think about how it could be possible to fasten the solar cells and the optical fibres on a fabric. We assumed that the best possibility for fastening the solar cells and optical fibres to a cotton weave construction is as described above. Under those floats, the solar cells and optical fibres can be placed and fastened (see Fig. 11).

Figure 11: Inserted optical fibres under the floats

The warp threads, which are floating on the front-side of the fabric causes a hole on the backside of the fabric due to the weaving construction. To cover those unattractive parts, the curtain is made of two layers, an outer and an inner layer, which are connected to each other. The outer layer is what we refer to as the surface that faces the window and carries the solar cells, whereas the inner layer carries the optical fibres and faces the room. The inner layer is woven out of a natural white yarn and has small floats, which are four millimetres in length and measure five centimetres horizontally. Underneath these floats the optical fibres can be fastened in horizontal lines. Suspecting that the glowing of the optical fibres might not be that bright, tests to enhance glow were made using reflective yarn in silver and blue[7] woven behind the optical fibres, so that the light rays could be reflected. Another idea was to produce an after-glow effect with fluorescent yarn behind the optical fibres to lengthen the duration of the glow. The weave with the three effect yarns is shown in Figure 12.

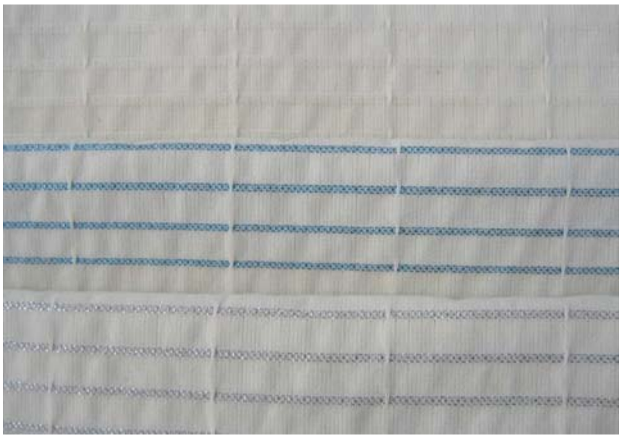

Figure 12: Blue and silver yarns are reflective, the pale yellow is fluorescent yarn

The reflective stripes as well, as the fluorescent stripes did not show the expected effect and turned out to be unnecessary, thus the second prototype was made without the yarns.

The inner side of this first prototype, which faces the room, has a width of about 65 cm and a length of 90 cm. The upper part of this side is white and has light yellow stripes under the optical fibres which is due to the fluorescent yarn. The other sections of the curtain are partly silver striped and blue striped. On the sides, the curtain is held together by a ten centimetre wide overlap on the inner side, which is completely white like the backside and has a hook and loop fastener. This overlap covers the LEDs (light emitting diodes), which will light up the optical fibres and the cables connecting them.

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[7] Lurex® yarn

The backside of the curtain, which faces the window, is 70 cm and thus some centimetres wider than the inner side. This difference in sizes is necessary as the connection between the optical fibres and the LEDs extends the edge of the inner layer. The overlap, which is folded over this protruding electronics, is sewn together with the edges of the outer side. On this backside there are 40 solar cells fastened, which are in a size of 3.7 cm times 11.5 cm each. The horizontal distance between the floats is unfortunately not exactly ten centimetres as expected, so that the floats are not exactly positioned over the copper part of the solar cells but all a bit outside. The vertical distance between the solar cell rows is four centimetres at that first prototype. As the floats are not in a straight line under each other, due to the weaving construction, the solar cells are arranged so that one is placed in the gap between two others in the line above. The solar cells are distributed over the whole outer layer (see Fig. 13). It gives an impression of being spread out and some order might be desirable.

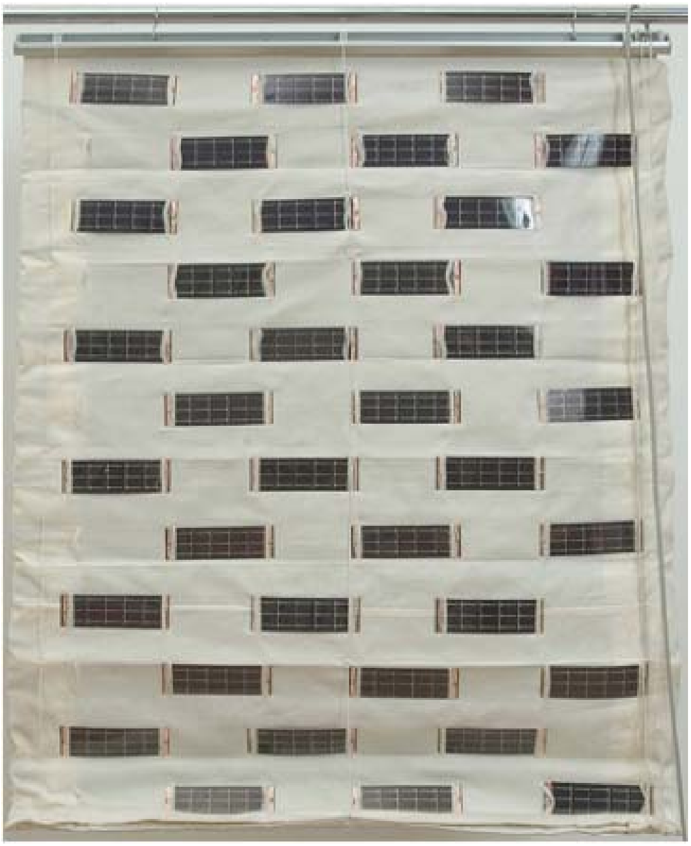

Figure 13: Backside of the first Interaction Curtain prototype

Besides the possibility to place the solar cells in rows directly under each other, which is achieved in the second prototype, it could be possible to reduce the impression of disorder by using a dark ground fabric so that the black solar cells does not stand out so much against the white fabric. The advantage of a white background though is that it reflects the light due to the rules of reflection and absorption (like white snow). Therefore, the probability that light rays hit the solar cells is higher with a reflective background than it is with a black background.

After some preparation the two layers were adjusted to each other, which was quite tricky, as the outer layer cannot be folded at any line due to the solar cells. It was intended to fold the curtain so that each solar cell row would be positioned between two folds, but that was hardly possibly as the solar cell rows are too close together in this first prototype. The inner layer with the optical fibres should also be folded after the same number of optical fibres each time. To get all folds of both sides fitting together, it also has to be considered that the fabric in the loom is under tension, which will be released when the fabric is taken out of the loom and therefore the distances, in this case those of the floats, cannot be adjusted precisely during weaving. The exact distances can only be determined experimentally. So the outer layer is folded after about 12 cm, one part with two rows of solar cells and one empty row in between and the following part with two empty rows and one solar cell row in between (see Fig. 13). And that entails that the inner layer is folded after every tenth optical fibre. The folds can be seen in Figure 14.

Figure 14: Front side folded in zigzag structure

Fibre optics

On the inner layer optical fibres are inserted manually under the floats in horizontal lines. They have a horizontal distance of about one centimetre. The optical fibres are cut to protrude over a few centimetres over the edge. The ends of the optical fibres are connected to LEDs on each side of the curtain. Five optical fibres are taken together and connected to one LED. Therefore black shrinkable tubing is put over a LED and shrunk onto that. This tube covers the LED and builds a funnel in which the optical fibres are taken together. In order to fasten the fibres attaching the LED, hot-melt adhesive is used to glue the optical fibres into the shrinkable tube (see Fig. 15).

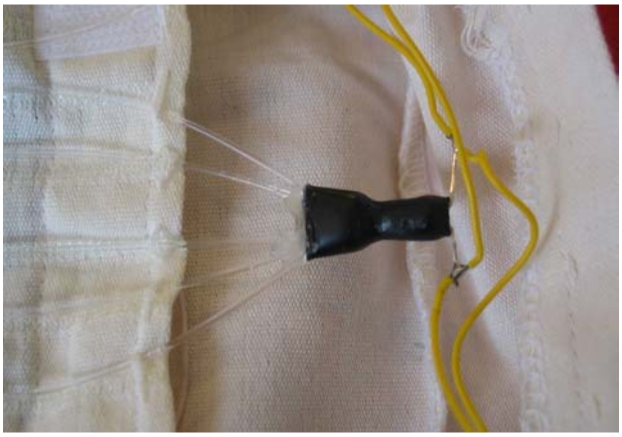

Figure 15: Picture of the connecting part between the light emitting diode and the optical fibres with the shrinking tube and hot melt adhesive

The hot-melt adhesive made it difficult to fasten the optical fibres in the right position and the angle in which the fibres are splayed was quite small, which made the edge of the curtain grow relative wide since the distance required to get the fibres parallel got longer. Furthermore, the light intensity differs sometimes significant between the different fibres connected to one LED and once the hot-melt adhesive is congealed, the position of the optical fibre cannot be corrected. Since the hot-melt adhesive has a different refractive index as the optical fibres and the LEDs it should not cover the end of the optical fibre as that interrupts and inhibits the light transition.

Photovoltaic and Electronics

Subsequently, the solar cells are positioned on the backside and their edges are inserted under the floats to give them hold. White cables are stuck through the fabric so that a cable comes out to the front side below a solar cell pole, goes across it and is then stuck back through the fabric again to the backside. In the middle of the pole, the cable insulation is opened and the cable is welded to the copper pole of the solar cell. Figure 16 shows the cable connecting the solar cells.

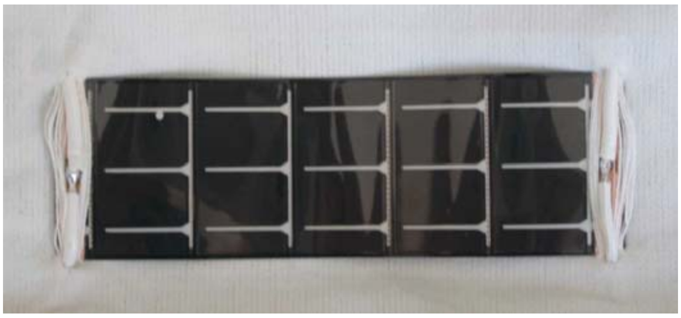

Figure 16: White cables between the floating threads soldered to the poles of the solar cell on each side

The electronic construction of the curtain is quite simple, borrowing many principles from solar garden lights. The solar cells are flexible thin film panels, as described above, that collect a constant charge of 3 V and 0.04 A in normal sunlight conditions. They are arrayed in two rows across and 13 rows down the outer layer of the curtain, thus resulting in a voltage of 6 V and a possible current of 0.52 A, though this may be improved upon in bright sunlight. This power is used to charge four 1.2 V batteries through a diode, which prevents the solar cells themselves from being powered from the batteries in bad weather or darkness. The lighting effect of the inner layer of the curtain consists of a number of LEDs, a light sensor and a MOSFET transistor. When the sun goes down, it is sensed by a LDR (light dependent resistor) that causes a signal to the MOSFET to turn on the LEDs. The batteries supply the power for this - thus the circuit itself is self-sustaining. The LEDs provide light to the optical fibres that distribute light throughout the curtain [3].

The two layers of the curtain are already matched to each other in size and folds and they are now put together and are sewn together at the top and along the sides where the overlaps hold the two layers together. On the bottom of the curtain there is also a hook and loop fastener to hold the both layers together. A weight in form of a heavy bar is fastened between the two layers at the bottom of the curtain, such that drawing down the curtain is easier. The curtain is constructed and hung up like a roman blind, while it is folded in an about ten centimetres wide zigzag structure. The bands that make the pulling up and drawing down possible are fastened with loops on the backside (see Fig. 17).

Figure 17: Picture of the backside and the bands making it possible to pull up the curtain

Finally the light pattern based on the optical fibres is made at the end to determine the lighting within the whole appearances of the curtain. Different patterns where tried out, small fine patterns with sharp cuts and bigger patterns with relative large sanded areas. Thereby it turned out that a relative symmetric and easy pattern would be the best as the viewer's eye can recognize a big pattern easier than a fine pattern because the optical fibres have a horizontal distance of about one centimetre and that makes the whole pattern intermittent to a certain degree. Besides that, the pattern made by sanding the optical fibres is uneven itself. Both equality and size of the sanded areas differs, as the sanding is made manually and pressure, angle, range and other factors changes from one area to the other. If that process is made mechanically a higher equality can be reached, which might enable other pattern possibilities (see Fig. 18).

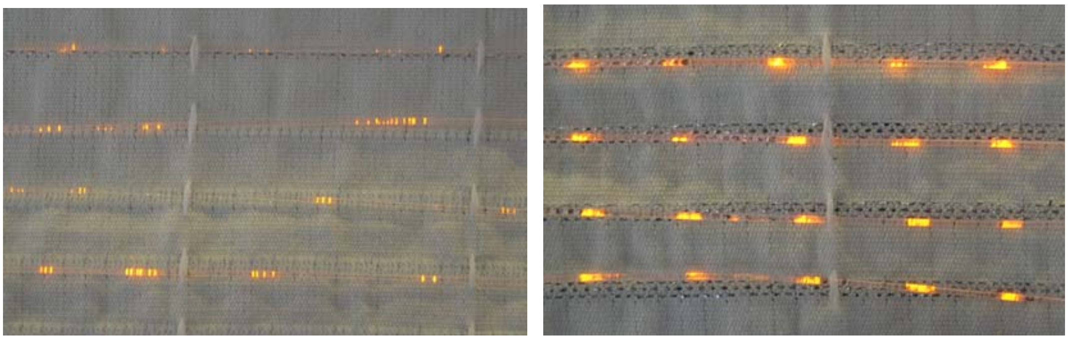

Figure 18: Picture of the different possibilities to make the optical fibres lighting. Sanded areas and areas with fine cuts

When the curtain hangs in a window while the sun is shining, the solar cells shine through and can be seen on the inner side. In order to create a real black out effect, a black thin non-woven with a temperature sensitive adhesive on one side is ironed on one of the two layers. This minimizes the shadows of the solar cells that can be seen on the inner side.

4.2.1.2 Second prototype

By improving and learning from the first curtain, a second prototype was made, which is by large very similar to the first one. The curtain also has an outer and an inner layer, which are both made of a fabric of natural white coloured yarn with floats for fastening the solar cells on one and the optical fibres on the other layer. The inner layer is only made of natural white yarn without reflective or fluorescent stripes as in the first prototype, because the effect of reflection was negligible. However, the white yarn under the optical fibres is patterned slightly differently through a different weaving bonding compared to the rest of the fabric to accentuate the position of the optical fibres slightly. It turned out that the floats holding the optical fibres do not need to be larger than two millimetres in length, moreover it is an advantage to make the floats tighter as the optical fibres will be hold even straighter in line. As the optical fibres need to be bowed a bit to come together to the LED and tend to be bowed on the first centimetres of the inner side, it is necessary to have an additional float under the overlap shortly next to the last float which is positioned next to the overlap. That makes the optical fibres parallel within a shorter distance. To shorten the width of the overlap or at least have more space under it the connecting parts between the LEDs and the optical fibres are improved by means of a greater similarity and therefore better reproduction.

The connecting parts now consist of a black insulation tape, which is first wrapped around the LED and then the LED is put onto a strong black tape and then the optical fibres are placed funnel-like towards the LED. It is important for an optimal light transition that the ends of the optical fibres are cut flat and connected to the top of the LED. Then, the tape on which the optical fibres and the LED are sticking is covered with another strong black tape and pressed close together. This connection was an improvement compared to the connection with shrinking tube and hot-melt adhesive in the first version, as it is more controllable and precise, however, the differences in light intension could not be eliminated. Each light emitting diode is connected to four optical fibres (see Fig. 19).

Figure 19: Connecting part, made of black adhesive tape, between the light emitting diode and four optical fibres. The diode is covered separately in black adhesive tape. Also on the picture are two floats in a short distance for getting the optical fibres parallel.

In this second prototype, the distance between two floats is adjusted so that it fits exactly over the copper parts of the solar cells edges. The cable, which is used to connect the solar cells, is selected because it is thicker than in the first prototype to reduce the electrical resistance to a minimum, but therefore it gets more difficult to draw the wire through the fabric without destroying any threads. The floats on the outer layer under which the solar cells are fastened are now placed directly under one another, since the distance between two rows of solar cells is made longer there is no risk for a stability problem. The vertical distance between two solar cells is now seven centimetres and the floats are arranged so that four vertical rows of solar cells, one under the other, are formed. Figure 20 shows the arrangement of the solar cells on the backside of the curtain.

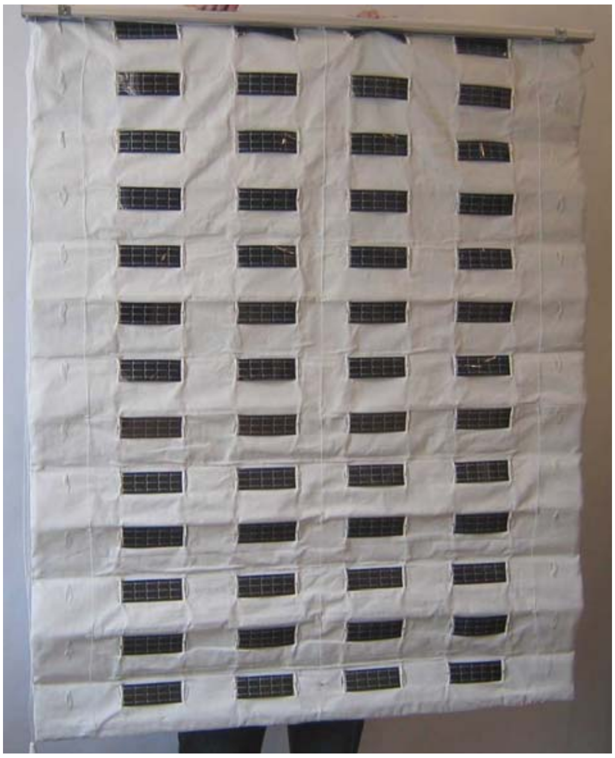

Figure 20: Back side of the Interaction curtain where the solar cells are arranged in four rows of 16 solar cells

The zigzag folds have a width of about 11 cm, which means that normally eight optical fibres seperate two folds. Figure 21 shows the overlap on the side of the curtain under which the LEDs are hidden.

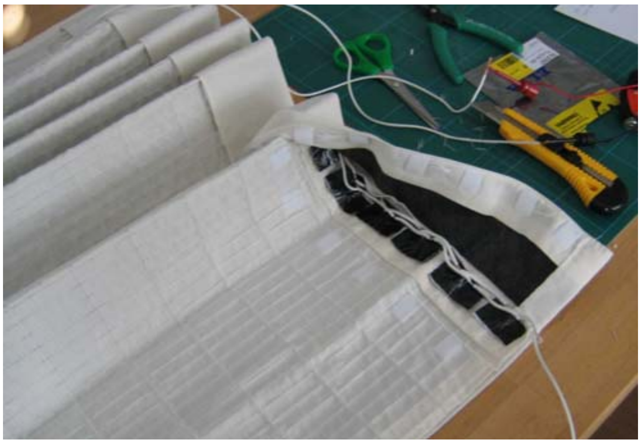

Figure 21: Connecting elements between optical fibres and light emitting diode under the overlap on the side. The white cables connect the light emitting diodes.

4.2.2 Lamellae Curtain and its model

The outcome from making the first prototype was mainly to have learned what can be improved for making the second prototype and that, was the motive to do a model of the lamellae curtain before making a final large scale one. The lamellae curtain provides the possibility to experiment with different materials and the light effects of the optical fibres as the surface area of each lamella is limited but it is possible to design several different lamellae. The idea is that there are one or two lamellae of one curtain carrying solar cells and the other lamellae are designed with optical fibres. The energy from the lamellae with the solar cells supplies the light to the optical fibres on the other lamellae. While working with the optical fibres on the Interaction Curtain, several ideas came up how the optical fibres could be used to pattern the fabric and create a nice lighting effect. Inspired by the textiles from Ludvig Svensson AB and examples of curtain systems, ideas came up for designing different lamellae. Sketches and small samples were the beginning of the lamellae curtain. Some of those samples are shown in Figure 22.

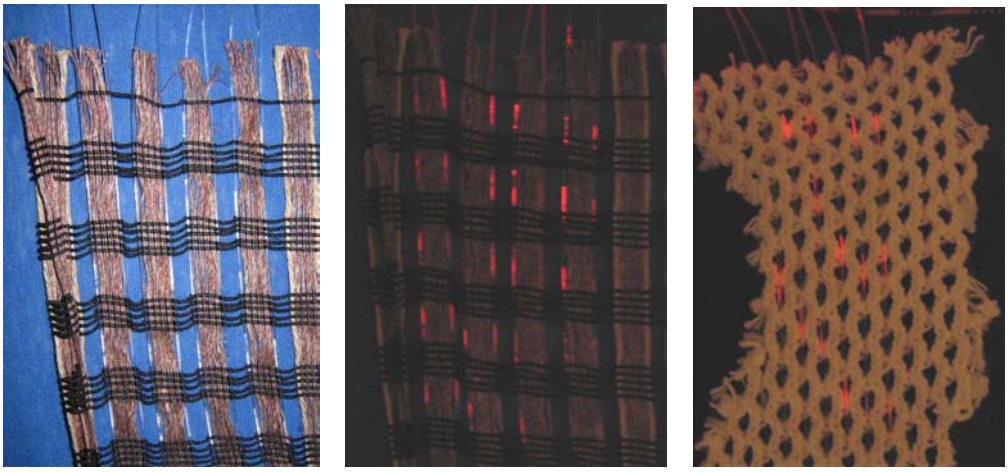

Figure 22: Samples of fabrics with optical fibres

4.2.2.1 Lamellae Curtain Model

In the very first step some small samples were made of how the lamellae could look. Then a unique lamellae size of 8 times 45 cm was set and the first sample was sewn. Each lamella has a casing on the top, which is 5.5 cm long and has a hook and loop fastener at the top (see Fig. 23.1) The casing is used to hide the elements, which connect the optical fibres with the LED and the cables to the power source. The batteries, which are charged by the solar cells and supply the LEDs are hidden in the guide rail of the curtain. It is set high up to have a united look for the main part of the lamellae and the top and bottom part so that they do not seem attached. The casing on the bottom has a heights of three centimetres in which a weight -here in the form of a heavy bar- is laid (see the sketches in Fig. 23.2).

Fig. 23.1

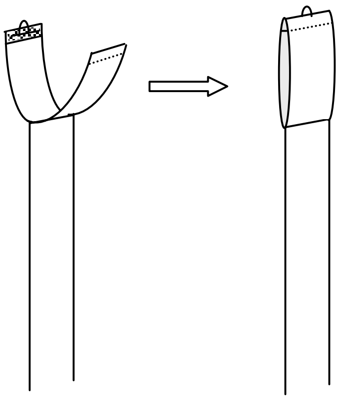

Fig. 23.2

Figure 23.1: Shows a top casing of a lamella in which the light emitting diodes are hidden. Opening and closing by a hook and loop fastener.
Figure 23.2: Shows a bottom casing of a lamella in which a weight is put to gain a straight hanging.

The weight causes a straight hanging of the lamella. This bar has an ear on each side to pull a band through it in order to connect the lamellae and hold a certain distance between them. The different lamellae have different designs, which will be described in the following (see also Fig. 24).

Figure 24: Picture of the Lamellae Curtain Model

1 The warp knitted fabric with optical fibres integrated is used at the front side. It is used so that the optical fibres are upright. Another slightly shiny, beige fabric [8] is used as the back side. This fabric accentuates the warp knitted fabric and screens from views through. The top and the bottom casings are also made of this beige fabric.

2 The second lamella also has the warp knitted fabric in the main part but there are only two narrow bands of the beige fabric on the long sides. This lamella is supposed to be transparent. The two above described lamellae can be perfectly combined as they have the same design except for the transparency of the one.

3 The third lamella is made like the above described but with a black cloth behind the warp knitted fabric. The dark colour is chosen because it gives a stronger contrast to the white light and therefore the light can be seen well. All three lamellae are sanded on the same areas in a quite simple pattern. When it gets dark, the same lighting pattern appears on all three lamellae.

4 The fourth lamella is made by a sample of the natural white cotton weave and sewn with five-millimetre stitches horizontally at a vertical distance of 2.5 centimetres. These stitches can easily be made industrially as woven floats. The optical fibres are inserted under the floats in a special pattern as illustrated in the sketch below (see Fig. 25). As the fibres have a certain stiffness, circles can be formed. The optical fibres are sanded on two areas of each circle, so that even in the darkness the circle structure can be assumed.

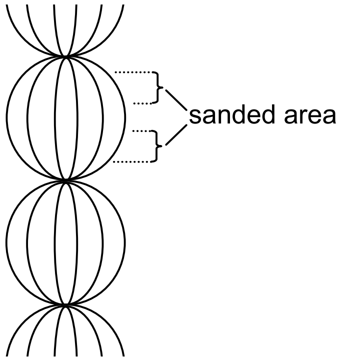

Figure 25: Sketch of circle pattern on lamella 4

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[8] Appendix B: Fabric description 5) beige bought

5 The fifth lamella is made of a black fabric (see [7]). This lamella has seams with five millimetres long stitches, in a vertical distance of five centimetres, and through every second of the stitches in one row an optical fibre is drawn. Thus the optical fibres are arranged upright and parallel on the lamellae. The optical fibres are patterned with big and small areas of light emitting parts and as expected the light can be seen well on a dark background. In case that every lamellae was black the curtain would be too dark as a whole. Therefore this effect of contrast is only used on some lamellae.

6 The sixth lamella is made of MOOD 270, which is a reflective energy saving warp-knitted fabric, as described above, whereby the silver part is facing the room and the white part is facing the window. On the silver part there are optical fibres attached with an adhesive. The possibility that the optical fibres can be included already in the knitting process of the fabric is unfortunately not practical not because of the machinery but because of the finishing process which follows the production. There is a drying and fixating process of the fabric necessary which needs to be carried out at 150-180°C and the optical fibres do not resist more than 110°C [9]. The possibility of changing the finishing recipe was observed but it turned out to be too time intensive for inclusion in this project. Therefore another solution, namely gluing, is chosen to fasten the optical fibres onto the energy weave. Common super glue turned out to be the best adhesive for this purpose.

7 The seventh lamella is made of ZOUK [10], which is a quite opaque warp knitted fabric. The top and the bottom casing are made of an aluminium foil, which is coated with a thin polymeric film. The polymeric coating makes it possible to sew the aluminium foil like textile. The combination of aluminium and textile visualises the transfer from old to new materials. Optical fibres are inserted straight in lengthwise direction and sanded in about one centimetre long lines.

Solar cell lamellae: There are two lamellae in the curtain that carry solar cells. These solar cells supply the energy for the optical fibres on all lamellae. Both lamellae are made of PROG 270 black [11], an energy saving sunscreen material, which has a black back side. For one solar cell lamella, a solar cell of the type MP7.2-75, which is 8 times 27 centimetres large, is adhered onto the silver side

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[9] Appendix A: 2) Temperature resistance of the optical fibres
[10] Appendix B: Fabric description 6) ZOUK
[11] Appendix B: Fabric description 7) PROG 270

of the fabric. A frame of the same fabric surrounds the active part of the solar cells and covers the wire connected to the solar cell.

On the other lamella there are 6 solar cells of the type MP3-37 placed lengthwise underneath each other in two rows. The solar cells are connected with a thin black cable, which is soldered to the poles. The solar cells are adhered to the black side of the fabric. Since solar cells and fabric are black there is a much less contrast between them as compared to the Interaction Curtain, for example, where the black photovoltaic modules are placed on a white fabric.

The connecting parts between the optical fibres and the LED are further developed for this prototype and the following. With polymer clay, a form is made with the cast of a LED and optical fibres pointing towards it. The negative of the original form is filled with liquid rubber and, after drying, the approximately three millimetres thick rubber form has a gummy consistency. The rubber forms are coloured with black spray colour and dried.

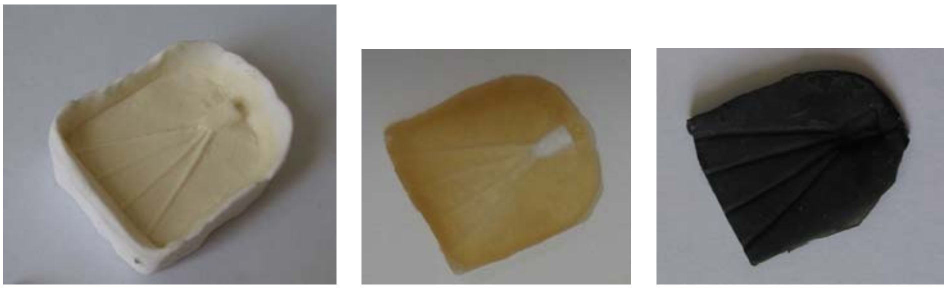

Figure 26: Polymer clay form, rubber part and black painted rubber part

Then the LED and the optical fibres are placed in between two of those forms and they are stuck together. The equality between the light intensity is significantly improved. Another advantage is that those devices can be opened again if the contact between the optical fibres and the LED is not as good as desired.

The electronic parts are equivalent to those in the Interaction Curtain. The solar cells are connected to the batteries and they in turn are connected to the LEDs. A small "electronic card" steers the electricity flow. The guide rail for this model is about 60 cm long and has nine carriers on which the lamellae are fastened. In this guide rail, the cable is hidden that leads to the diodes and to supply them with electricity.

4.2.2.2 Full-scale Lamellae Curtain

Based on the experiments and experience with the Lamellae Curtain Model, a full-scale Lamellae Curtain was made. Most of the lamellae are quite similar to those in the model, though there are some fabric substitutions or improvements.

Figure 27: Picture of the Lamellae Curtain in full-scale

1 The warp knitted fabric is used in three lamellae. One is transparent and the top casing for the electronics and the bottom casing for the weight are made of a white linen/cotton weave called Olivin[12]. The same fabric is used for white edges on the sides of the lamella. The side edges function as connection between the top and the bottom casing.

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[12] Appendix B: Fabric description 8) Olivin

2 and 3 The two other lamellae are made of this warp knitted fabric, with a backcloth of Olivin. One lamella has a white backcloth and casings and the other has a black background. The lighting of the optical fibres can be seen well against the black background.

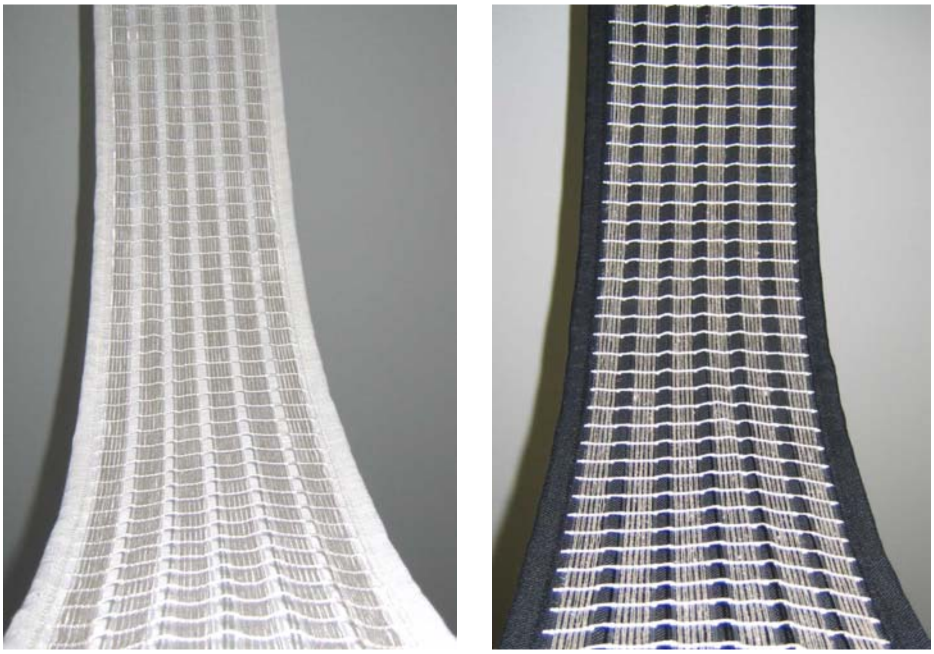

Figure 28: Picture of the second and third lamella

4 The fourth lamella is made of black Olivin fabric into which optical fibres are inserted. The pattern is relatively simple as it consists of parallel optical fibres. They appear on the back side for certain sequences, which also helps them to keep their position. The overall curtain appears quite dark though, if all the lamellae have a black background.

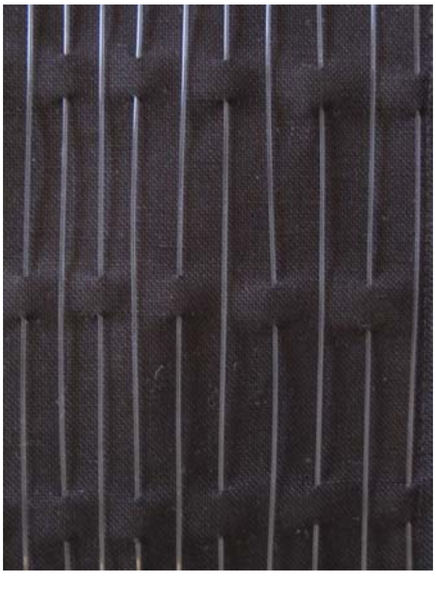

Figure 29: Picture of the black lamella with straight, inserted optical fibres

5 The fifth lamella is made of the fabric NOT [13]. This fabric has certain floats in its pattern, which are very useful to draw optical fibres through. The floats are arranged on the fabric in a special pattern, which offers several possibilities for patterns. I experimented drawing the optical fibres through the floats in different patterns similar to wiggly lines building half circles and ellipses. The remaining pattern is called circles and consists of six optical fibres. Two of them cross each other after a certain distance and thereby build an outer circle. The other two cross each other on the same point like the first ones but describe more of an ellipse. And the inner optical fibres are shaped in an even tighter ellipse, but though having the same crossing point as the other four optical fibres. Several of those circles are placed underneath one another.

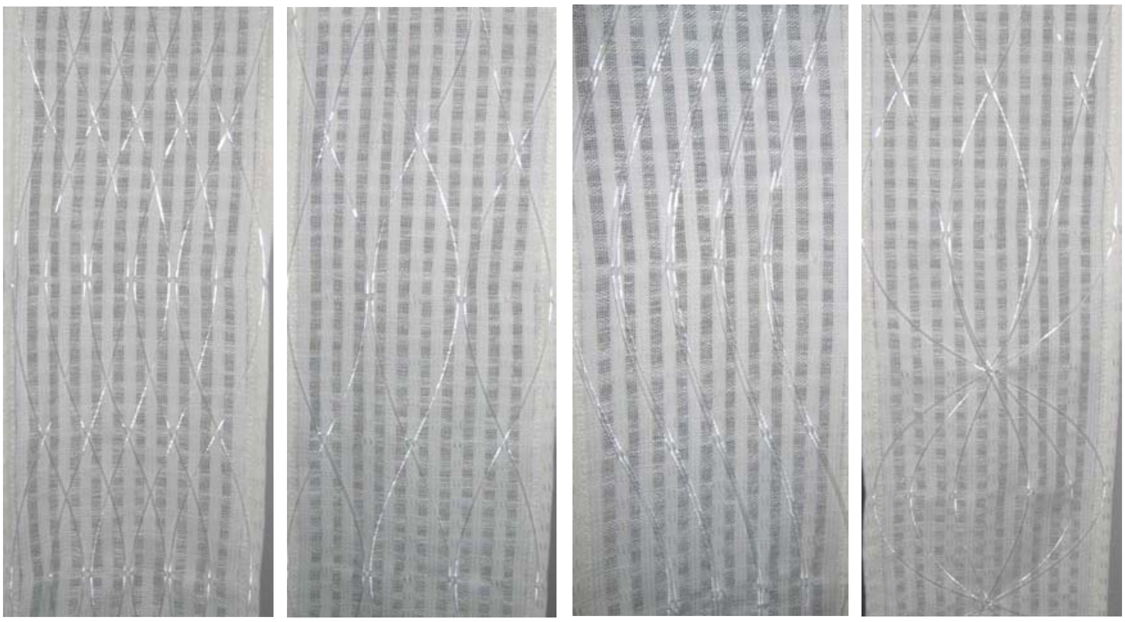

Figure 30: Different patterns using the floats for fastening the optical fibres

As the optical fibres are dawn through all of those circles, light transmission over the whole length of the lamella is guaranteed. Weaving, knitting or warp knitting cannot be used to produce this pattern as the optical fibres are inserted in a wiggly line. But special "sticking methods" could be used to realise this pattern industrially. If the industrial production is not realisable, it could be possible to sell the lamella "unfinished", so that the customer can make his own pattern by putting in the optical fibres himself.

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[13] Appendix B: Fabric description 9) NOT

6 The sixth lamella is made of ZET[14] -a warp knitted opaque fabric. The top and the bottom casing are made of NOT whereby the inner side is turned out so that the striped pattern is accentuated. Optical fibres are inserted lengthwise. Sanding randomly distributed areas generates the pattern on the lamella.

Figure 31: The sixth lamella made of ZET

7 A characteristic of the energy weave PROG 270 is that it has a passage of tight fabric with no gaps in between the aluminium strips and a passage where every second aluminium stripe is left out. This interesting technique is used as the ground material for this lamella. The transfer between tight and open fabric is set so that two thirds of the lamella in the lengthwise direction consists of the tight fabric and one third of the open fabric. Several optical fibres are adhered on the silver side of the fabric in the lengthwise direction with super glue. Those fibres are patterned with sandpaper to glow along those areas.

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[14] Appendix B: Fabric description 10) ZET

Figure 32: Lamella of PROG 270

8 There is another lamella also made of PROG 270 whereby only the tight fabric without gaps is used as ground material. This lamella carries no optical fibres but solar cells. 16 solar cells of the type MP3-37 are fastened along a line under one another with a distance of five centimetres in between. The solar cells are glued to the lamella and are connected by two 100 % stainless steel yarn [15] on each side. The stainless steel is hard to solder and even a special tin used for stainless steel could not make the soldering possible. However, a conductive adhesive that contains silver makes it possible to fasten the yarn on the solar cells. This lamella is extremely thin, as PROG 270 and the solar cells are thin itself and the yarn has a diameter of about 0.7 millimetres. Judging by appearance, it is almost surprising that it works as an energy converter.

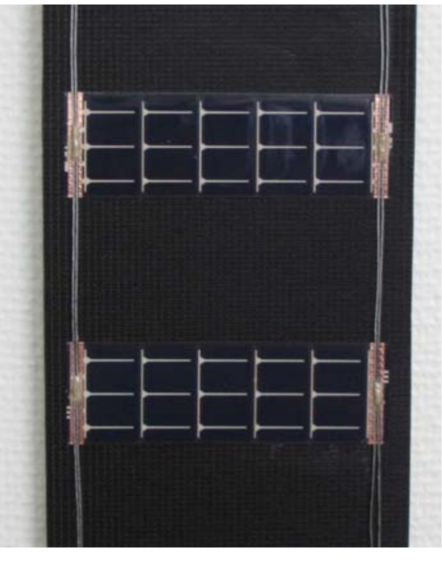

Figure 33: Solar cell lamella of PROG 270

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[15] Appendix B: Yarn Description

9 The other solar cell lamella consists of a black tight fabric, called Silhouette [16]. An extra band of the same fabric covers the edges of the lamella. On this lamella 16 solar cells of the type MP3-37 are placed under one another in a row similar to the lamella described above. The solar cells are glued to the fabric using common epoxy glue. A copper cable with a transparent insulation in the style of an old stereo cable is used to connect the solar cells. This lamella has a more substantial look than the other one. It looks more traditional and not as high tech as the other solar cell lamella since the fabric and the cable give a more voluminous look. It shows the transfer from the traditional textile to the high-tech photovoltaic elements.

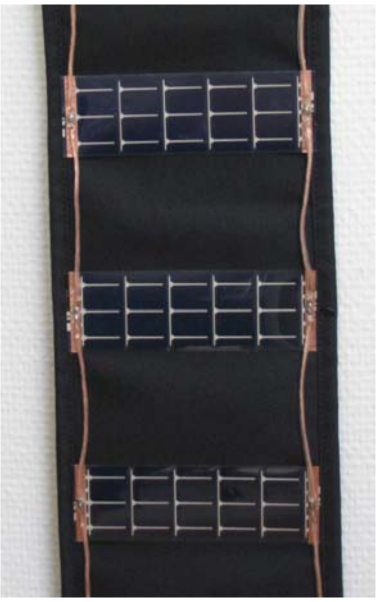

Figure 34: Solar cell lamellae of Silhouette fabric

On each of the two solar cell lamellae, there are 16 MP3-37 solar cells. The solar cells on each lamella are connected parallel. To get the necessary voltage, the two electric circles are connected in series at the top of the lamellae. The cables from the solar cells to the light emitting diodes are hided in the guide rail. The electronic card is three square centimetres. However, the electronic card and the batteries are too big to be hidden in the guide rail. They are covered with a white shrinking tube and placed on the back side of the rail, so that they are invisible from the front. The light detector sticks out from the electronic card so that it can be positioned at a suitable place. As the solar cells on each lamella are connected in parallel and then in a series at the top, it is necessary such that an even number of solar cell lamellae in a curtain. However, a different connection of the solar cells is possible and then a combination of an odd number of solar cell lamellae is possible. That means

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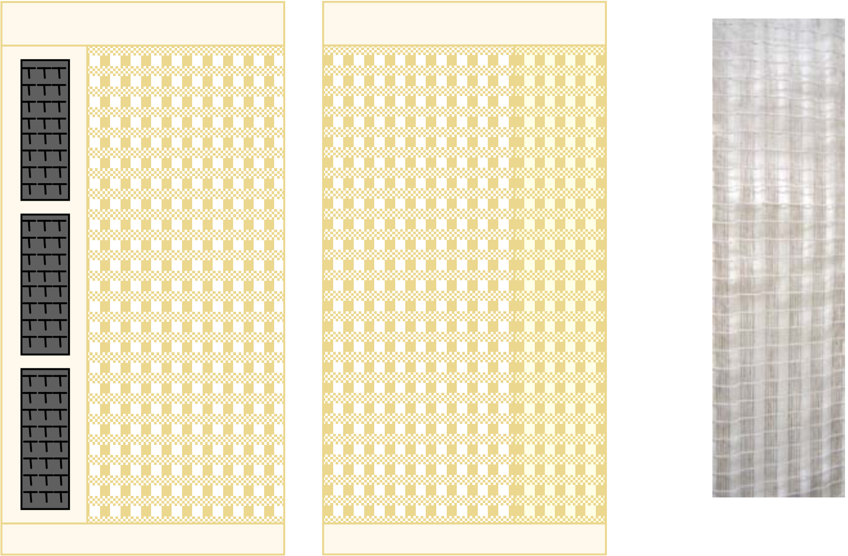
[16] Appendix B: Fabric description 11) Silhouette

that the consumer could buy the number of solar cell lamellae he needs depending on the light intensity and the area of his window.

4.2.3 Panel Curtain

The Panel Curtain consists of three panels, which are 45 cm wide and 100 cm long. The main materials for this curtain are the warp knitted fabric, which has optical fibres inserted and is described above, and a unicoloured beige fabric from Ludvig Svensson AB. The panels have in common that the warp knitted opaque fabric faces into the room. The part of each panel where the solar cells are fastened is made of the non-transparent beige unicoloured fabric named Silhouette. These solar cell parts are designed differently so that it is possible to screen views in the width of one panel if all three panels are shifted over each other.

One panel has three MP7.2-75 solar cells, which have an approximate size of 9 by 27 cm, and they are placed in a row under each other on the left longside. That means that the left third of the panel will not be transparent any more as a textile carrying the solar cells covers it.



outer side **inner side** **real fabric**

Figure 35: Sketch of a panel

The active solar parts of the solar modules itself have a nice design. But the poles on the sides and the cables connecting the solar cells look quite technical. In order to cover those parts, another layer of the beige fabric is prepared as a frame with three rectangular gaps in the size of the solar active area. This layer covers the cables.

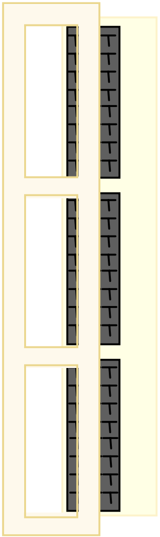


Figure 36: Sketch: Three layers of the Panel Curtain backside: Ground fabric, solar cells and frame fabric

The gaps in the frame fabric are cut out and the edges are seamless adhered to the inside. The two other thirds of the panel are opaque as they are made of the warp knitted fabric without a background material. The other panel looks similar but vice versa, which means that the solar cell part is positioned on the right side. The third panel is designed for the middle. For this panel, another kind of solar cells are used, namely the MP3-37 type. Twelve of those solar cells are positioned under one another in the middle of the panel hence the transparent parts are on the sides.

The panel's top-casings are about ten centimetres in height and they have a hook and loop fastener to maintain the possibility to reach the electronics. Each panel has about 50 optical fibres whereby eight optical fibres are connected to each light emitting diode. This connection part consists of a metal sleeve of about two centimetres, whereby the optical fibres point to the light emitting diode in a bundle. For a permanent fixation, hot-melt adhesive is applied to the optical fibres and the sleeve.

Figure 37: Connection between the optical fibres and the light emitting diodes in the Panel Curtain

The optical fibres are bowed to minimize the angle of insertion and thus the tension on the entrance to the sleeve.

There are six LEDs providing light for each panel. The LEDs and the electronic card are positioned in the top casing. The three solar cells are adhered behind the gaps and connected to each other. The batteries are positioned in the bottom casing and thus additionally function as weight to provide a straight hanging of the panel. Each panel has individual solar cells, electronic card and batteries so that the panels are self-sustaining and completely independent of each other.

Figure 38: Top casing of a panel in which electronic card and light emitting diodes are stored.

There is also a hook and loop fastener used to fasten the panel on the top triple track rail. The batteries, which are necessary for the electric circuit anyway, replace the bottom bar to provide a straight hanging. As the panels are self-sustaining, it is possible to shift them along the top rail completely independent from each other. The optical fibres have a length of about 90 centimetres and there is a light source only on one end. That means that the areas sanded cannot be arbitrarily large, as the light intensity decreases with the area.

5 Results / Prototypes

5.1 Interaction Curtain

The Interaction Curtain is the result from the first and second prototype. The most important thing within this curtain is that the user has to make a tangible choice about using or saving energy. This curtain blocks the sun completely out when it is pulled down but exposes on the other hand the solar cells to the sun so that the energy can be stored and used later.

The first prototype was a test and builds a basis for the second one. The second prototype is a combination of textile curtain, photovoltaic modules, and optical fibres as a light source. It has the shape of a roman blind and can be pulled up and drawn down with a standard pull string. The curtain has ten centimetre wide horizontal folds in zigzag style. On the white front side there are optical fibres horizontally fastened under floats. The optical fibres are separated by about one centimetre. On the back side there is an array of 52 solar cells. These solar cells deliver the power for the 52 LEDs, which light up the optical fibres from the sides. The lighting pattern is quite simple. There are sixteen, about one centimetre wide, sanded areas on each optical fibre.

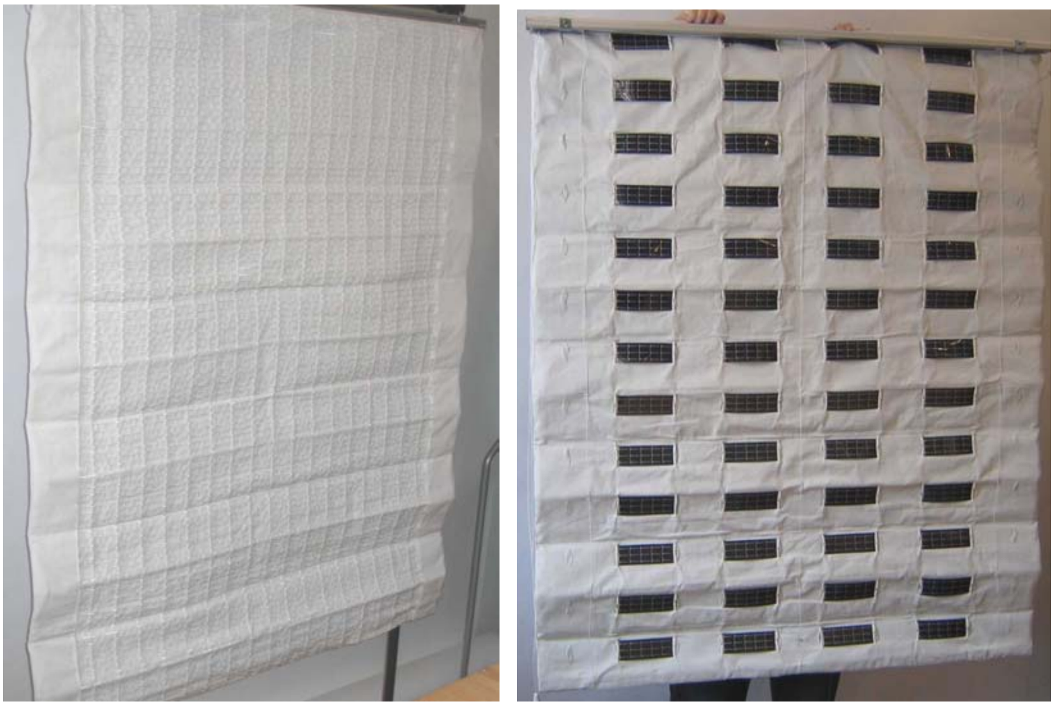


Figure 39: Picture of the Interaction Curtain. Front and back sides.

Figure 40: Picture of the lit Interaction Curtain

5.2 Lamellae Curtain and its model

The Lamellae Curtain and its model are made as an experimental design. The Lamellae Curtain and its model consist of nine lamellae each. Two lamellae carry solar cells and supply the other seven lamellae with electricity and light. Experimenting with the different materials and the properties of the optical fibres, such as stiffness and glint, lead to different designs of the lamellae. They all look different as different materials are used to create different styles. A variety of traditional and new materials is used. New materials like the energy saving sunscreen, has aluminium and optical fibres inserted, which are used to form different patterns. But also traditional materials like linen and cotton yarns are used. Three of the lamellae are quite similar to each other as they are made of the same warp knitted fabric. Those three look quite traditional as the optical fibres are not overly accentuated and the chequered pattern of the fabric might also give the impression of tradition. The lamella made of ZOUK and the solar cell lamella with the copper cables are in combination state between old and new materials. Traditional fabric and new materials like optical fibres, solar cells and copper cable are added to a traditional fabric. On the white lamella with the circles and the black lamella with the straight inserted optical fibres, the enhancement lies in the optical fibres, which are clearly visible. The optical fibres have a decorative effect and this is accentuated here, even without lighting them up. The lamellae made of the energy saving sunscreen material look quite futuristic as the aluminium is reflective and the material has a paper-like touch.

The Lamellae Curtain and its model show the transfer from common textiles to new materials. And it shows how photovoltaic techniques can be combined with textiles and it shows how renewable energy could move into our living rooms.

Figure 41: Picture of the Lamellae Curtain Model

Figure 42: Picture of the full-scale Lamellae Curtain.

5.3 Panel Curtain

The Panel Curtain is a large scale, beautiful, finished piece for exhibition. The materials used for this curtain, were chosen based on experiments in the Lamellae Curtain. Inspired from a curtain system from Ludvig Svensson AB where two panels, one with horizontal stripes and one with vertical stripes, can be pulled over each other to gain a nontransparent surface, this three-panel principle was created. It consists of three panels of 45 centimetres width. Each panel has an opaque part of two-thirds and a nontransparent part of one-third. The nontransparent parts are arranged in different positions; one panel has the nontransparent part on the left side, the other in the middle and the third on the right side. These panels hang in a triple track rail and by shifting them over each other the curtain becomes nontransparent across one panel's width.

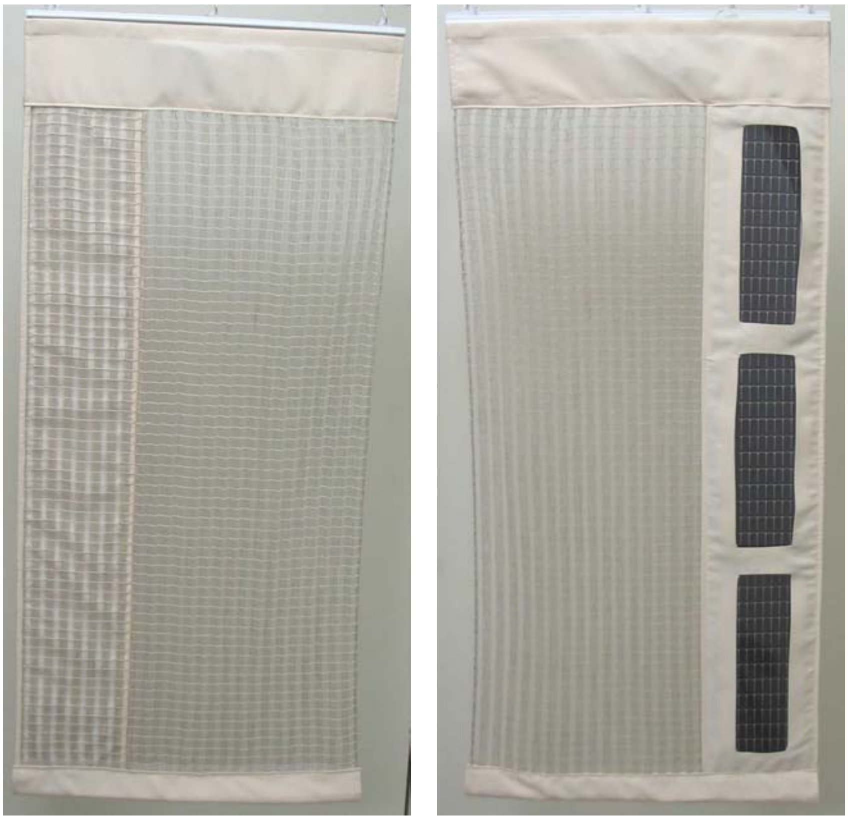


Figure 43: Picture of a panel front and back side at daytime

Figure 44: Pictures of the front side of a panel at night

5.4 Optical fibres in industrial production

Involving optical fibres into industrial production presents some difficulties based on the properties of the optical fibres. They are not flexible like other yarns are and therefore they cannot be treated and guided like common yarns. That means that an optical fibre cannot just replace a common yarn without making any changes. Though it was difficult, a warp knitted fabric was produced on an industrial warp-knitting machine from Ludvig Svensson AB. In the warp knitting process with magazine weft insertion, as described above, it was necessary to guide the optical fibres by hand into the weft insertion magazine. The reason for this is that the angles of the normal yarn insertion way are too tight and the friction within the eyelets would become too high and would damage the optical fibres. And as the optical fibres have certain stiffness, it was necessary to press them into their position behind the hooks of the transport chains. However no problems appeared in the knitting region, where the loops are made around the optical fibre. And even the cutting of the edges did not cause a problem. That means that the industrial insertion of optical fibres within a warp knitting process is possible. To guarantee a trouble-free production, however, some changes in the yarn guidance of the optical fibres need to be done. The optical fibres need to be guided around a radius of about two centimetres and an additional advice should be installed which bends the optical fibres around the hooks on the transport chain.

The integration of optical fibres into the weaving process should be possible, though not all looms are appropriate to integrate optical fibres. An air-jet weaving machine, for example, could not handle those especially smooth fibres. A rapier-weaving machine could be suitable for weaving in optical fibres. The most suitable way of weaving them would be a bonding whereby some warp yarns float over the optical fibre to fasten it without covering the whole fibre.

Trying to integrate the optical fibres into the energy saving sunscreen from Ludvig Svensson AB failed when it came to the finishing process after production. The sunscreen material is treated with a resin and a flame retardant, which need to be fixated at 160 - 180 °C. The optical fibres though, are made of Plexiglass. It is not recommended to heat them over 85 °C. That means that it would be necessary to replace the resin treatment with a recipe based on polyacrylate, for example, which requires lower fixation temperatures.

6 Discussion

6.1 Difficulties and Improvement

A problem that appeared while working with optical fibres is their effectiveness. It requires precision to bring the ends of the optical fibres in relation to the light source such that the light transmission is most effective. The optical fibres were sanded to get an uneven surface from which light rays could emit. But this area needs to be at the back of the optical fibre to see the lighting properly. If this surface is on the side it cannot be seen from the top at all and if it is on the top the light can be seen, but much weaker than on the back. The possibility to cut slices into the fibre instead of sanding is not so effective either. The light is emitted in fine lines and appears more fragmented compared to the sanded areas.

A big problem was that the light sources could not be used to full capacity. The light emitting diodes spread out the light rays in a certain angle. And it was very difficult to use the light most efficiently and keep the length between the LED and the designed distance between the optical fibres as short as possible. Ideally the optical fibres should hit the light source perpendicularly. But that means that the optical fibres can only be spread after that. And that in turn lengthens distance between the LED and the optimal distance between the optical fibres. Another problem was to fasten the optical fibres in the right position at the light source. The disadvantage of using hot-melt adhesive is that the optical fibres are fastened permanently and a maybe necessary position correction is impossible. Another disadvantage is that the hot-melt adhesive is transparent and the light rays emit through the adhesive. The advantage of using adhesive tape is that the optical fibres can be carefully put in the right direction in relation to the LED and they can already be spread in direct contact with the diode. But the problem of using adhesive tape is that this fixation is not really permanent. The adhesive tape loosened its contact after some weeks and the optical fibres slipped away from its original position. The advantage of the rubber parts is that they are not permanently closed. The two parts stick together but can be opened again and so the position of the optical fibres can be corrected if necessary. Through the black colour no light rays can be emitted to the outside. The disadvantage is that the rubber material absorbs a lot of light and so the efficiency of light transmission is not perfect either with this solution. The last solution of using a metal sleeve to bundle the fibres together and connect a LED to the ends is the best possible solution so far. Within this thesis this connection between optical fibres and light emitting diodes was improved continuously, though a perfect solution has not be found so far.

The light sources, however, can be improved significantly. There is a company called JLT in Gothenburg, which develops light emitting diodes that are surface grounded. Thereby a chip is placed in a small light-reflecting cavity. It could be possible to place a socket on this chip in which several optical fibres could be stuck. That would guarantee an optimal light transmission for all the optical fibres. The light could be coloured as well as white.

A problem might be that a curtain, which has optical fibres on it, cannot be washed. However, the fabrics could be treated to be soil-repellent before the insertion of the optical fibres. Or fabrics should be chosen, that do not need to be washed such as materials for roller blinds. The solar modules and the light emitting diodes cannot be washed either, however they could be removable.

Considering the marketing of the Energy Curtain, there is already a consumer market existing for curtains. The scope of this market ranges from simple curtains with a practical purpose up to high priced designer curtains with added value functions like anti static properties. So any marketing concept for the Energy Curtain should target the later added value function segment of this market. For solar powered products like solar driven garden lamps there is already a market. Combining those two markets in a modern marketing concept should make the Energy Curtain commercially successful.

The material costs for the Interaction Curtain were considered as follows.

Material **for the Interaction Curtain**	**Costs**
Textile material and Roman blind construction like fabric, hook and loop fastener, vlisselin	~ 45 Euro
Optical fibres 150 metre	~ 25 Euro
Accumulators 4 accumulators with 4100 mAh	~ 36 Euro
Diodes 52 diodes times 2,40 Euro	~125 Euro
Solar Cells 52 solar cells times 4,85 Euro	~ 252 Euro
	~ 483 Euro

Table 2: Cost evaluation for the Interaction Curtain

It has to be considered that this curtain is a prototype and that the production costs are therefore respectively high. The working hours can be calculated with 5 weeks at 40 hours. What means that working costs add up to about 6500 Euros.

6.2 Conclusion

The proposal of the Energy Curtain project has been successfully fulfilled. The construction of the three prototypes was done in only six month. The Interaction Curtain was exhibited in Eskilstuna at the Energitinget in March 2005. A positive feedback was received, where two aspects were pointed out by key innovation and academic people invited to evaluate the prototypes: the product is self-sustaining and stimulates people to think about their energy consumption. The finding from this exhibition was to work more with the design and the appearance of the optical fibres and to include the solar cells more into the fabric. This was taken into account and realised by designing the Lamellae and the Panel Curtains.

This Masters Thesis is neither an extensive scientifical project nor an extensive design project. The challenge in this work was to combine technology, textiles and design and bring those fields together - not only by working with the different materials but also by communicating between the different approaches.

It is an achievement that at least two fabrics with optical fibres could be produced industrially. The special properties of the optical fibres might require some small changes on the particular machine to adapt the input of the yarn.

7 Future versions

As mentioned above, the light intensity of the optical fibres could be improved, so that the lighting pattern can be seen well. The improvement suggested is based on a replacement of the light emitting diodes, as they diffuse the light rays and therefore the efficiency of the light source cannot be used in full capacity. By working together with JLT from Gothenburg another more efficient and thus brighter light source was developed as a proposal. It is based on surface grounded light emitting chips. These devices consist of a small reflective cavity located in a plate, which dissipates the heat. On the ground of this reflective cavity a chip of a light emitting diode is placed. A sleeve into which the ends of the optical fibres will be put surrounds this cavity. These devices make it possible to minimize the loss of light, which was a critical point in this work. The possibility to dissipate the arising warmth sets the limits for the light intensity. If a high effect diode chip is used then the light will be ten times more intense than common light emitting diodes. The light emitted from a chip is coloured, what means that if there is one chip placed in the cavity then the light will be coloured. There are up to eight different wavelength on the market, for example blue, green or yellow. By mixing the coloured light a large variety of nuances can be created. For achieving white light, the four ground colours have to be mixed, but then a larger amount of heat has to be dissipated. That means that low effect diode chips have to be used to create white light in these small dimensions. Low effect diode chips are as intense as common diodes, but the big advantage of using these surface grounded diodes is that the light emission can be controlled much better. And thus a higher effectiveness of guiding light rays into the optical fibres is guaranteed. I hope that there will be a possibility that these light sources can be developed further and that they open a new possibility to light up optical fibres in combination with textiles most efficiently.

There are now optical fibres on the market called sidelight optical fibres. They light to the side without requiring sanding. That is a big advantage for industrial application of optical fibres with light effect, because a much more even light can be gained. Development in this area could lead to a stronger light effect of the optical fibres.

The Energy Curtains, within the Static! project, aroused public interest and so there were several opportunities to exhibit the curtains. Right now the Interaction Curtain and the Lamellae Curtain are exhibited in Gothenburg at the Elyseum at the second seminar for Energy+Design. In June 7-9, I have the possibility to present my Thesis work at the Avantex, a fair for technical textiles in Frankfurt, Germany in conjunction with the presentation of The Swedish School of Textiles at this fair. And in June 24-26, the Panel Curtain will be exhibited at Wired NextFest in Chicago, Illinois, together with other prototypes from the Static! project and a related project called IT+Textiles from the Interactive Institute RE:FORM Studio. And in September 19-20, I will present the Energy Curtain at Ambience, International Scientific Conference for Intelligent Textiles, Smart Clothing, Well-being and Design in Tampere, Finland.

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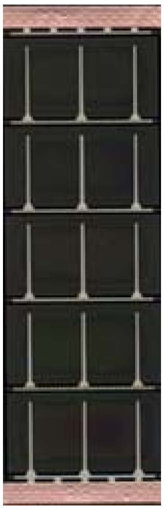
9 Appendix

9.1 Appendix A: Technical Data

1) Description of solar cells



MP3-37

Operating Voltage	3 V
Operating Current	50 mA
Typical Voc	4.1 V
Typical Isc	60 mA
Total Size	114mm x 37mm (4.5 x 1.5inches)
Aperture Size	100mm x 37mm (3.9 x 1.5 inches)
Total Thickness	0.2mm (8mil)
Weight	1.2g (0.04oz)

MP7.2-75

Operating Voltage	7.2 V
Operating Current	100 mA
Typical Voc	10.5 V
Typical Isc	120 mA
Total Size	253mm x 75mm (10.0 x 3.0 inches)
Aperture Size	240mm x 75 mm (9.5 x 3.0 inches)
Total Thickness	0.6mm (24mil)
Weight	12.9g (0.5oz)

© 2004 Iowa Thin Film Technologies, Inc. All rights reserved. Source [2]

2) Temperature resistance of the optical fibres

Temp. in °C	**Time** in sec	**Optical fibres with diameter**			**Fabric:** **PROG 270 grey**	**Appraisement**
		0,50 mm	**0,75 mm**	**1,00 mm**		
70	60	-	x	x	-	bending slightly reduced
80	60	-	x	x	x	fibre are ok fabric slightly stiffer
90	60	x	x	x	x	optical fibres soften fabric slightly stiffer than with 80°C
	180	-	x	x	-	no significant changes
100	60	x	x	x	x	optical fibres still clear, diameter unchanged fabric slightly stiffer than with 90°C
	180	-	x	x	-	no changes in diameter, 0,75-fibre got slightly bended
110	60	x	Ø → 0,76	Ø → 0,99	x	optical fibres are a bit stiffer, clear, fabric is stiffer
	60	Ø → 0,505	Ø → 0,77	Ø → 1,01	fibres fastened **on** the fabric	optical fibres slightly softened and diameter increased, fabric shrinks
	180	-	Ø → 0,78	Ø → 1,02	-	slightly bent
120	60	-	Ø → 1,00	Ø → 1,27	-	fibre diameter significantly increased and fibres are melted and shrank in length

Mathis stentering frame at the Swedish School of Textiles, Borås

Conditions:	Heating 3
	Ventilation 2
	Steam 0
	Moisture >10%
	Fastening the optical fibres with a separate fabric to avoid direct contact to the metallic frame

9.2 Appendix B: Fabric description

1) Weave with solar cell floats

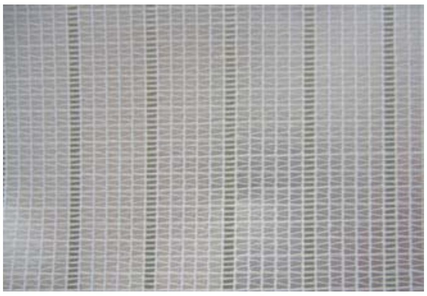
A plain weave fabric of Nm 50/2 cotton yarn with a density of 33 warp yarns per cm and 12 weft yarns per cm with special floats of 5 mm in width and 37 mm in length.

2) Weave with optical fibres floats

A plain weave fabric of Nm 50/2 cotton yarn with a density of 33 warp yarns per cm and 12 weft yarns per cm with special floats of 2 mm length in warp direction. Fluorescent yarn and reflective yarn beyond.

3) MOOD 270

Material:	76% Trevira CS 24% Polyester
Weight:	102 g/m²



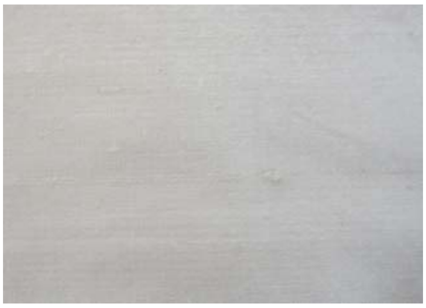
4) Warp-knitted fabric

Material:	ca 60% linen ca 20% optical fibres ca 10% cotton/polyester yarn
Weight:	160 g/m²

5) Artificial silk

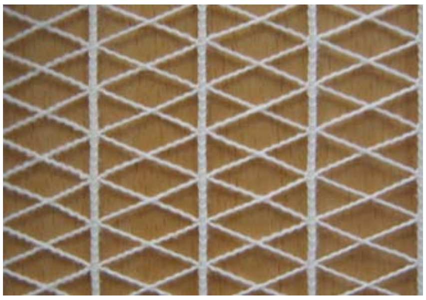
Slightly shiny beige polyester fabric

Slightly shiny black polyester fabric (no picture)



6) ZOUK

Material:	85% Trevira CS 15% polyester
Weight:	120 g/m²
Shrinking:	2%



7) PROG 270

Material:	76% Trevira CS 24% Polyester
Weight:	102 g/m²

Front side

Back side

8) Olivin

Material:	58% linen 42% cotton
Weight:	160 g/m²
Shrinking:	4%

white 8000

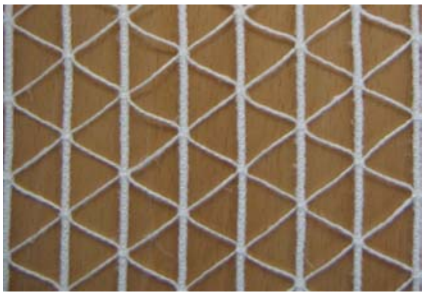
black 8900

9) NOT

Material:	56% cotton 44% linen
Weight:	180 g/m²
Shrinking:	2%

10) ZET

Material:	82% linen 18% polyester
Weight:	100 g/m²
Shrinking:	4%



13) Silhouette black

Material:	100% Trevira CS
Weight:	257 g/m²
Light transmission:	less than 0.01%

(no picture)

Silhouette is a denim weave

14) Silhouette beige

Material:	100% Trevira CS
Weight:	257 g/m²

Yarn description

BEKINOX® VN is a continuous multifilament yarn in 100% stainless steel and is the most flexible and durable electrically conductive filament yarn. This stainless steel multifilament is used in a wide range of applications related to:

- Anti-static textiles
- Intelligent textiles
- Signal transfer
- Power transfer
- Heat resistant sewing
- Thermal conductivity

A special range of *BEKINOX® VN/HT* continuous stainless steel filament yarns is available for heating applications, having a very precise electrical resistance.

2005.7.3

INSTITUTIONEN TEXTILHÖGSKOLAN

Textilhögskolan i Borås är Sveriges enda textilhögskola och tillhör det fåtal högskolor och universitetsutbildningar i världen som har en egen textilindustriell fullskalemiljö.

Textilhögskolan har laboratorier för undervisning, forskning och utvecklingsarbete inom design och tillverkning. På designutbildningarna har studenterna en egen arbetsplats och har stor tillgång till ateljéer och datorsalar. Den kreativa miljön medför att studenterna ofta utmärker sig både nationellt och internationellt i olika visningar och tävlingar.

Borås har en lång textil tradition och är ett naturligt centrum för produktutveckling, design och handel, vilket gör att studenterna får en bra kontakt med branschfolk.

HÖGSKOLAN I BORÅS

Högskolan i Borås är nationellt rekryterande och spelar samtidigt en viktig roll i regionens utveckling. Högskolan i Borås växer och ett spännande campus tar form mitt i stadskärnan. År 2003 studerar 11 000 studenter här.

Högskolan i Borås bedriver utbildning och forskning inom sex huvudområden: Biblioteks- och informationsvetenskap, ekonomi och data, lärarutbildningar och pedagogik, teknik, textil samt vård och omsorg.

Flera av utbildningsprogrammen är unika och studenterna är eftertraktade på arbetsmarknaden. En ny undersökning visar att 95 procent får arbete inom sex månader efter examen inom de områden de utbildats till.

Läs mer på högskolan hemsida: www.hb.se

HÖGSKOLAN I BORÅS
Institutionen Textilhögskolan
501 90 Borås

Besöksadress Bryggaregatan 17
Tel 033-16 40 00 vxl
Fax 033-16 40 09
E-post Info@hb.se
Internet: www.hb.se/ths