

Design and Development of Smart Sportswear Integrated with Energy Harvesting Device



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1 Introduction

Comfort, although a subjective term, is a crucial property in textile for clothing. Comfort is related to how an individual feels. There are three main aspects for analyzing the comfort of any fabric. The first aspect of comfort is thermal comfort. It is a feeling of pleasure or related to how a hot or cold person feels. Thermal comfort is associated with changes in many physiological and environmental variables like the activity level of the individuals and clothing properties, such as the fabric insulation values and water vapor permeability. Thermal comfort is mostly quantified using physiological parameters though it is a psychological concept. Tactile sensation is the second aspect of comfort that is related to the interaction of skin with clothing that results from the fabrics in contact with the skin.

The third component of comfort is related to the fit of the garment. A poorly fitted garment, especially too small or too large can interfere mobility and performance, although the impact on comfort may not be as great, it influences the psychological perceptions of the wearer through personal or cultural preferences regarding fit and fashion size trends. Consideration of thermal comfort, sensory skin-feel comfort, comfort due to fit, or the psychological comfort have a considerable impact on the individual physical and cognitive performance.

Clothing is considered to be second skin playing a vital role in maintaining thermal balance with the environment and keep an individual in a comfortable state. It should be the main property of textiles to conserve the heat that body dissipates away, and dissipate heat from body surrounding when the body generates it. Moisture management is crucial for thermo-physiological comfort as it involves controlled

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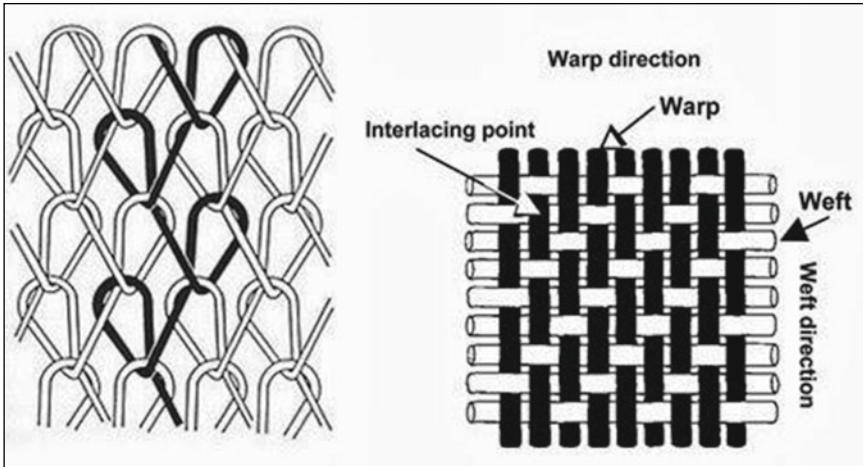


Fig. 1 Knit and woven structure

movement of moisture vapor and liquid perspiration from skin surface to atmosphere through the fabric.

Knitting is a process of fabric manufacturing by interlocking series of loops of one or more yarns. Knitted fabrics are used to produce garments that cover every part of human body, in a wide range of garments types from socks, caps, gloves, and underwear to upper and lower body garments varying from t-shirts to formal jackets. Figure 1 shows a knit and woven structure.

1.1 Requirements of Sportswear

Sportswear are generally involved in sweat generating and rigorous activities like jogging, running, cycling, etc. Therefore sportswear needs to possess the following properties:

- Sportswear garments should be light in weight and dimensionally stable even when wet.
- Outstanding moisture managing properties, which rapidly wicks the moisture away from the body.
- Good perspiration fastness and smart and functional design.
- High electrical conductivity along with superior strength and durability.
- Radiation free

Polyester is the single most common fiber used for sportswear and activewear. Other fibers suitable for activewear are polyamide, polypropylene, acrylics, and elastane. Wool and cotton fibers are still finding applications in leisurewear. Synthetic fibers can either be modified during manufacture, e.g. by producing hollow fibers



Fig. 2 Active and Leisurewear

and fibers with irregular cross section or be optimally blended with natural fibers to improve their thermo-physiological and sensory properties. Synthetic fibers with improved UV resistance and having anti-microbial properties are also commercially available for use in sportswear.

For most sports, the athletes wear a combination of different items of clothing, e.g. sport shoes, pants, and shirts. In some sports, protective gear may need to be worn, such as helmets or American football body armor. Yoga clothing should use fabrics with the good stretchability for easy movement which will likely require the fabric to be of a knitted construction (Fig. 2).

1.2 Wearable Smart Textiles

Smart textiles, also known as smart garments, smart clothing, electronic textiles, or smart fabrics, are fabrics that enable digital components such as a battery and a light (including small computers), and electronics to be embedded in them. Figure 3 shows some wearable smart textiles.

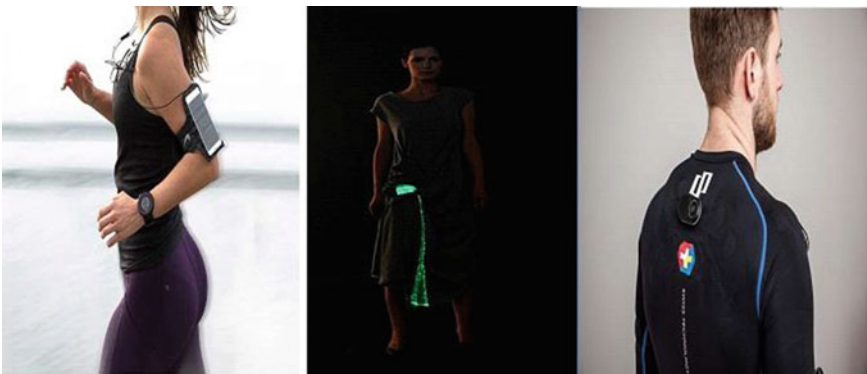
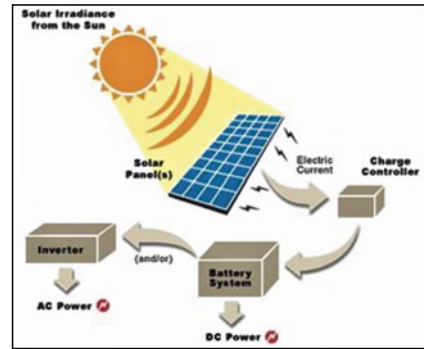


Fig. 3 Wearable smart textiles

Fig. 4 Working of solar panel



1.3 Energy Harvesting Devices and Working of Solar Panel

Energy harvesting, also known as power harvesting or ambient power is the process by which energy is derived from external sources, e.g., solar power, thermal energy, wind energy, salinity gradients, and kinetic energy, also known as ambient energy, captured, and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. Energy harvesters provide a very small amount of power for low-energy electronics. Energy harvesting devices converting ambient energy into electrical energy have attracted much interest in both the military and commercial sectors. The application is in wearable electronics, where energy harvesting devices can power or recharge cellphones, mobile computers, radio communication equipment, etc. Solar panels are those devices which are used to absorb the sun's rays and convert them into electricity or heat. A solar panel is actually a collection of solar (or photovoltaic) cells, which can be used to generate electricity through the photovoltaic effect. These cells are arranged in a grid-like pattern on the surface of solar panels. When the sunlight falls over the solar panel the energy is absorbed in the form of photons and further converted to electric current by the p–n junction diode present in the solar panel. This electric current is then either stored in batteries in the DC power or converted into AC power using the inverters [Fig. 4]. Also, the battery system can be connected to the external USB port in order to transfer the electricity to charge mobiles, torches, power banks etc.

1.4 Applications of Solar Power in Apparels

The solar power is now being considered as the future for the generation of electricity due to rapid exhaustion of fossil fuels. Also, solar power has emerged as an economic, sustainable and eco-friendly option to the textile, fashion and apparel industry. From the rooftop solar power plants in the textile industries providing a large amount of electricity to the garments and accessories using the solar power for various decorative, smart and protective features. Figure 5 shows the application area of solar panel in apparels and accessories.



Fig. 5 Application areas of solar panel in apparels and accessories

2 Materials and Methods

2.1 Materials

Different knit structures of cotton single jersey and polyester interlock mesh knit structure were used for the study. The fabrics were procured from Vardhman Polytex Ltd., Ludhiana for the study. The details of the fabrics procured have been provided in Table 1.

The solar panel integrated into the designed apparels was procured from Manohar Electronics, Bhiwani. A range of trims and notions like velcro, snap fasteners, and elastic were used.

Table 1 Details of fabric samples and plan for the development of sportswear

Samplecode	Fiber composition	Design aspects	Level of physical activity	End products
SJ_B	PET/C	Wristband	Static/low	Wristband
I_w	100% PET	Zonal garment integrated with solar panel	Dynamic/high	T-shirt, shorts & cap
I_N	100% PET	Zonal garment integrated with solar panel	Dynamic/high	T-shirt, shorts & cap
I_B	PET/C	Zonal garment integrated with solar panel	Dynamic/high	T-shirt, shorts & cap

Note I_w interlock white fabric, I_B interlock black fabric, I_N interlock neon fabric, SJ_B single jersey fabric

The trims and notions were procured from Vinod General Store, Bhiwani for apparel and accessory designing. The trims and notions used in the project were elastics, used in shorts and wristbands for good fit and firmer grip; buttons, for holding the wires of solar panel arrangement; velcros, to firmly hold down the solar panels at their proper position and angle of inclination and also to make the arrangement detachable; piping, used for covering the wires in order to resemble them with the design aspects of the whole garment; interlining, used in the cap for the firmer shape retention.

2.2 Methods

The procured materials were evaluated for their physical and moisture management properties to assess their suitability as sportswear textiles. The prepared fabric samples were evaluated for their fiber content to determine the content or ingredient of provided fabric. The aerial density of samples was determined according to ASTM D-1059. The thickness of fabrics was determined using a fabric thickness gauge. CPI and WPI were measured using the magnifying glass. Moisture management properties of developed knit samples were determined on moisture management tester (MMT) (SDL Atlas, Hong Kong) (AATCC Test method 195-2009) Fig. 6 shows moisture management tester and top and bottom sensors of moisture management tester.

3 Results and Discussion

Different moisture management indices were obtained for the top (next to skin) and bottom (outer layer) for the four test samples under consideration. Analysis of water content versus time curve, fingerprint of moisture management properties are shown in Figs. 7, 8 and 9. It was observed that interlock mesh structures (I_W and I_N) composed of 100% polyester were moisture management fabric as indicated by their fingerprints. Overall moisture management was observed to be highest for I_W and lowest for single jersey structure. I_W fabric was observed to be quick-drying and wicking fabric with lower absorption rate in top (next to skin) layer and higher absorption rate in bottom (outer layer) which is prerequisite for wickable sportswear design. I_N although moisture management fabric has a lower value of AOTI and OMMC as compared to I_W . Moreover, the I_N fabric exhibited lower spreading speed and absorption rate in the bottom layer compared to I_W indicating that fabric would be slow drying and wickless liquid moisture compared to I_W .

I_B although interlock mesh structure exhibited inferior moisture management properties compared to its interlock counterpart with a lower value of OMMC as compared to I_W and I_N .



Fig. 6 Top and bottom sensors of moisture management tester

Wetting of the surface is essential to propagate wicking to the outer layer. Hence, such a structure won't be very effective in transferring the liquid to outer layer as wetting of inner layer takes place gradually.

Single jersey fabric (SJ_B) exhibited the lowest OMMC. The results obtained shows that the structure shows higher absorption and spreading speed in next to skin layer (as indicated by AR_t and SS_t), thus making structure suitable for low physical activity or for static conditions in summers.

The results for moisture management properties indicated that Interlock mesh structure (I_W) exhibited excellent moisture management properties. Moreover, the above-stated fabric exhibited the highest one-way transport capability suggesting that structure is capable to keep wearer skin dry with sweat readily transferring from next to the skin to the outer layer.

Results of the study prompted the usage of this knit structure (I_W) for designing sportswear intended for a high level of physical activity.

I_B fabric ranked second compared to I_W as far as moisture management properties are concerned. Therefore, the two mesh structures were predominantly used for designing sportswear.

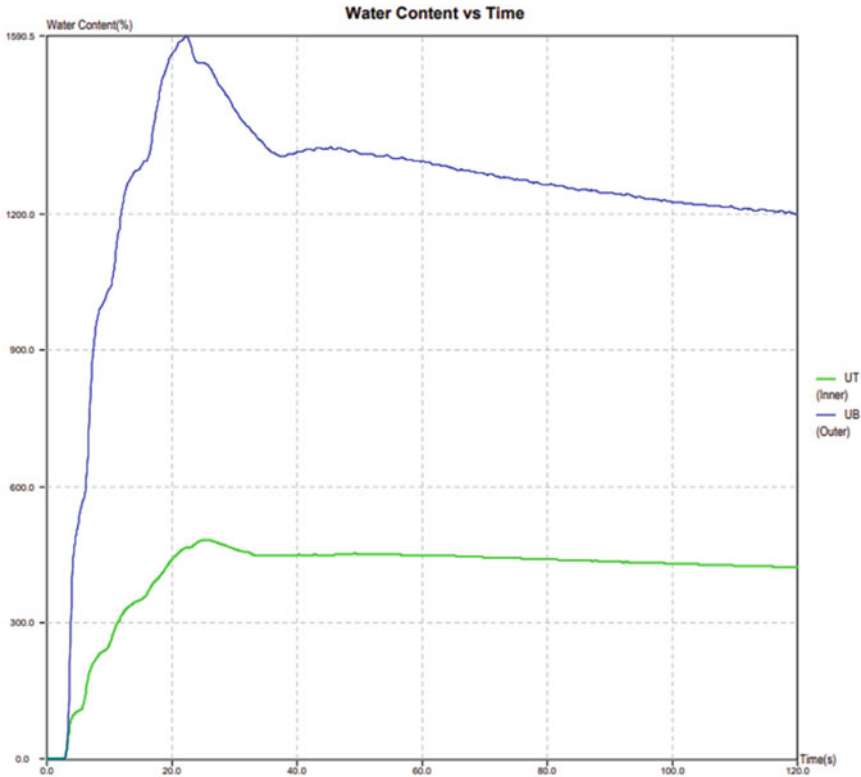


Fig. 7 Water content versus time curves for I_W fabric (I_W —100% P, Interlock mesh)

3.1 Designing

Solirt, the solar sports T-shirt complemented with a pair of shorts, baseball cap, and wrist bands were developed using the above-mentioned fabrics that exhibited the moisture management properties suitable for sportswear design.

The design inspiration was taken from sportsperson who give precedence to comfort over the aesthetic appeal. Accordingly, the design was proposed which reflected functionality rather than aesthetic appeal thereby minimal use of surface embellishment of designed and developed apparels and accessories. Furthermore, the design proposed zonal garment with zones to distinguish profusely sweating and low sweating areas of the garment. Mood board and storyboard were designed for the sportswear to be developed. Mood board and storyboard are shown in Fig. 10a, b.

Designing phase was followed by pattern making. Flat pattern making i.e. drafting was employed for the same. A standard size chart was referred for the sizes and

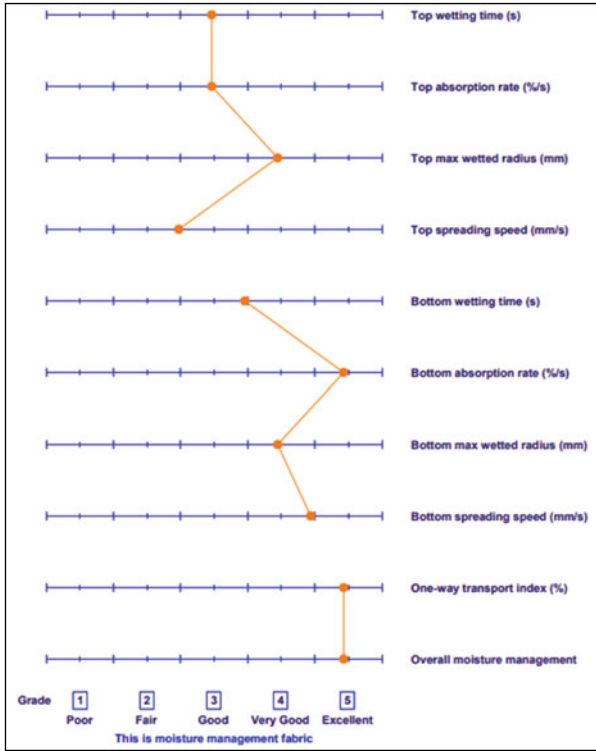


Fig. 8 Fingerprint of moisture management properties of I_W fabric (I_W —100% P, Interlock mesh)

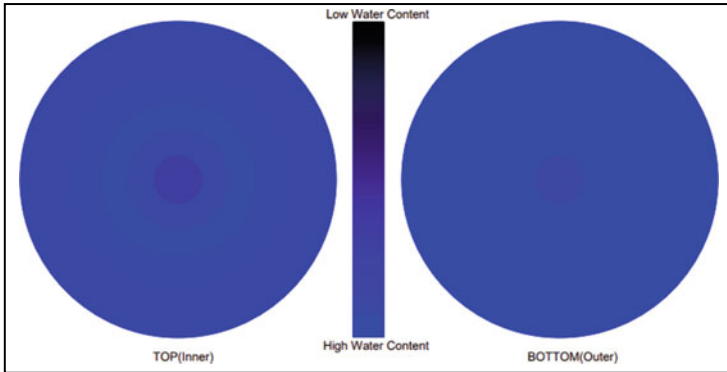


Fig. 9 Water location vs time plot for I_W fabric



Fig. 10 a Moodboard, b Storyboard

patterns of L size were made. Garment assembly designed for sportswear includes t-shirts, shorts, baseball cap and wristbands as shown in Fig. 11.

3.2 Solar Panel Integration

It was intended to further enhance the functionality of designed sportswear. Henceforth, solar panels were integrated into **Solirt** t-shirt which served as energy harvesting device and could assist the sportsperson to charge their gadgets, specifically a mobile while on the move or involved in any activity. The Solirt is shown in Fig. 12.

4 Conclusions

- Interlock mesh (100% polyester) structures were the most suitable knit structures for sportswear design and development owing to their excellent liquid moisture transmission properties.



Fig. 11 a T-shirt, b Shorts, c Wrist band, d Baseball cap



Fig. 12 Solar panel integrated t-shirt

- Interlock mesh structures exhibited highest one-way transport capability and wicking property compared to their counterparts indicating that such structure would be suitable in transmitting liquid sweat to outer layer effectively, thereby keeping next to skin layer dry.

- The subjective evaluation of designed and developed sportswear by sportsperson involved in dynamic physical activity revealed that sportsperson found the combination of sportswear and accessories functionally as well as aesthetically appealing. However, the subjects suggested to reduce the cumbersome solar panel attachments.