AN INVESTIGATION ON LIGHTING LEVELS TO SUIT FABRIC TYPES AND COLOURS DURING SEWING OPERATION IN GARMENT FACTORIES

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Degree of Master of Engineering in Energy Technology

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Sri Lanka

January 2016

M. R. S. Udaya Kumara M.Eng 2016

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Thesis submitted in partial fulfillment of the requirements for the degree

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January 2016

DECLARATION

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ABSTRACT

The illuminance, colour and the fabric type in workplaces of garment industry are directly linked to energy saving and safety hazards of the work place. The garment industry worldwide makes the use of different illuminance and different kinds of lighting systems with which any factory can face issues. Employees face these issues with lighting systems due to the use of different materials in different lighting conditions where materials vary according to the fabric type and their colours. Improvements in lighting do not necessarily mean that workplaces need more lights. Also we can ensure that less electrical energy is consumed in case of ensuring that lights are positioned correctly for each task to make better use of existing lights and guarantee that all lights are clean and in good condition. Moreover, from the workers' point of view, poor lighting at workplace can lead to eye-strain, fatigue, headache, stress and finally accidents.

Findings of this research suggest that long-duration exposure to different illuminance levels together with wavelength give rise to eye fatigue, and illuminance can be changed in industry according to different fabric materials and colours in order to reduce eye fatigue. If the illuminance is reduced from the maximum of the lighting standard for sewing operations to the minimum, for a 1m × 1m floor area, the calculated energy saving is 42Wh per hour. Therefore, under different required conditions the lighting levels can be changed (i.e. according to fabric type and colour) with the aim of reducing lighting energy consumption and eye fatigue. In this research carried out in the sewing sections in the garment industry, the illuminance preferred for different fabric types and colours were determined with a view to reduce eye fatigue. Taking 800 lx as the prevalent illuminance in sewing sections, the energy saving potential when illuminance is changed to reduce eye fatigue for different fabric types and colours were then calculated. Results show that the energy saving potential is 640 Wh, 480Wh,320Wh, and 160Whper hour per 1 m x 1 m floor area for the fabric colours blue,green, yellow, and red respectively, resulting the minimum energy saving potential by the red colour. However, the energy consumption is changed depending on the fabric density as well as the colour. For an example for red colour, energy consumption varies as280 Wh, 224 Wh,144 Wh and 96Whper hour per 1 m x 1 m floor area for fabric densities 1.02 kg/m, 0.85kg/m, 0.51 kg/m and 0.34 kg/m respectively.

Key words: Lighting energy consumption, eye fatigue, fabric type, illuminance, colour.

ACKNOWLEDGEMENT

I am very much grateful to Dr. H.K.G. Punchihewa, Senior Lecturer, Dept. of Mechanical Engineering, University of Moratuwa for giving me his utmost support and guidance on this research. I would be very much grateful to Dr. (Mrs) M.A. Wijewardane, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa, for giving her fullest support in every stage of this research. I wish to thank Dr. R.A.C.P. Ranasinghe, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa,Mr. S.D.L. Sandanayake, Lab Attendant, Department of Mechanical Engineering, University of Moratuwa, Mr. A. Delay, General Quality Manager, MAS Holdings (Pvt) Ltd, Mr. S.Abenayake, Assistant Manager, Brandix Lanka (Pvt) Ltd, Mr. N.D. Premadasa, Engineer, Sri Lanka Sustainable Energy Authority for their support and being the resource people for the research. This research was carried out under the supervision of Dr. H.K.G. Punchihewa, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa and Dr. (Mrs) M.A. Wijewardane, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa. I am indebted to them for the valuable guidance, kind hearted co-operation and encouragement extended to me throughout the study. Finally, I would appreciate everybody, who helped me in numerous ways at different stages of the research, which was of utmost importance in bringing out this effort a success.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
IES	Illuminating Engineering Society
IEED	Leadership in Energy &EnvironmentalDesign
LED	Light Emitting Diodes
CFL	Compact Fluorescent Lamp
IES	Illuminating Engineering Society of North America
LOR	Light Output Ratio
IT	Information Technology
HPS	High-Pressure Sodium lamps
OLED	Organic Light Emitting Diodes
CRI	Colour Rendering Index
SPD	Spectral Power Distribution

CHAPTER 1: INTRODUCTION

1.1.Background

The lighting system is very important for energy saving and hazard prevention at a workplace. Identification of the illuminance with colour and the method of controlling the illuminance according to the fabric type in the garment industry are timely concerns. Even though there are different kinds of lighting systems available, most of them are useless and unsuitable, resulting to be harmful to eyesby causing to eye fatigue and energy loss in many ways.

People receive about 85 percent of their information through their sense of sight [1]. Appropriate lighting without glare or shadows, can reduce eye fatigue and headaches, as a result it can prevent workplace accidents by increasing the visibility of moving machinery and other hazards. Moreover, good quality lighting system reduces the probability of accidents and injuries from "momentary blindness"

The ability to "see" at work place depends not only on lighting but also on:

- The time to focus on an object (e.g.:- fast moving objects are hard to see)
- The size of an object(e.g.:- very small objects are hard to see)
- Brightness (e.g.:- too high or too little reflected light makes objects hard to see)
- The contrast between an object and its immediate background (e.g.:- too little contrast makes it hard to distinguish an object from the background)

As there are many types of lighting systems and devices, various illuminance and usage of different kinds of fabrics absorb different level of light, there is a need of special method to control the light level according to the fabric type (i.e. cotton, nylon) and fabric colour (i.e. white, black). In this context it is essential to identify the illuminance variation with fabric type and method to control the illuminance according to the fabric colour in the garment industry. Further analysis can be done on the cost effectiveness of replacing the lighting system with the available best technologies.

1.2. Present status

In garment industry some lighting standards are used for different workplaces, for an example,600-800 illuminance is required in sewing area. But changes of illuminance according to the fabric type or colour have not been considered in anywhere. Due to this reason, improvements of lighting without considering the actual required illuminance for the fabric type and colour in industry tend to consume more electricity and decrease the productivity of the workers.

1.3. Problem statement

The garment industry uses different illuminance and different kinds of lighting systems for their workplaces. However the lighting systems have not been optimised and they are depending upon the factors i.e. fabric type, fabric colour or texture and hence, facing some issues from the worker's perspective and in the sense of energy usage as mentioned above. Therefore, critical study has to be carried out to analyze the variation of illuminance with some identified key factors in the garment industry, which will eventually results in reducing the energy consumption.

1.4. Aim and objectives

Aim of the research is,

- To identify the optimum lighting levels required to enhance the energy consumption, work place safety and productivity in the garment industry

The objectives are,

- To identify the illuminance used in industry with respect to the fabric type and the colour.
- To identify the required illuminance according to the fabric type and the colour in sewing sections of garment factories in order to reduce eye fatigue.
- To propose recommendations on workplace lighting levels required to be maintained in the sewing sections.

1.5. Methodology

During the study, the views of the employees working in the sewing sections in the garment industry regarding the ‘quality of their workplace lighting systems' have analysed. Then, the deviation of existing lighting systems from the currently accepted international standards is evaluated. Finally, a set of recommendations will be proposed to the garment industry, based on the findings of the research.

Lighting standards and illuminance vary dramatically across different working environments. These standards do offer methods of maximising lighting effectiveness for the functions and demands of the specific workplace settings by optimising initial design principles as well as guidelines for system upgrades. Workplace lighting standards address various concerns associated with the principles of design, placement, installation, energy requirements and upgrades to light fixtures in various workplaces. Proper illumination is essential for the optimisation of both the comfort and productivity in the workplace. Workplace lighting level also decides the quality of perception, mood, and performance of employees. Lighting quality depends on colour rendering index (CRI) and it is related to the light source. However when considering illuminance in sewing areas, correct identification of material colours is not essential as in the material inspection and selection areas. Thus, maintenance of a particular CRI value in sewing sections is not essential.

After finalising the standards about the suitable lighting system, it can be introduced to the industry to determine the illuminance changes with fabric type and colour. Furthermore, guidelines could be set to control the illuminance and thereby energy wastage can be reduced.

1.6. Chapter introduction

The first chapter describes the importance of an optimised lighting system for the garment industry and why the illuminance should be changed in the workplace. The present status of lighting systems used in the garment industry and their trends are also highlighted. Fundamental theories, which describe the association of illuminance with lighting systems affecting to change the illuminance are discussed in chapter two. Available technologies of lighting systems and developments that have been carried out various researchers were also studied and discussed in the same chapter. The research methodology is described in detail in chapter three. The results of the study are discussed in chapter four. Chapter five directs the reader to present the key findings this study and future work.

CHAPTER 2: REVIEW OF LITERATURE

2.1. Importance of light and needs of standardisation

It is essential to implement a better lighting system at a work place to save money and reduce the carbon emission [1]. The quality of artificial lighting is one of the most important influences on performance at the workplace[2]. It is very important to provide good quality lighting that is designed to match the tasks being undertaken and to respect not only the needs of the occupants but also the visual effects of lighting need to be bear in mind. A recent research has revealed that lighting has a clear impact on our health and well-being in the workplace[2]. The light levels and the quality of light have been affected alertness and accuracy at work[2].

The most important objective with the lighting of a workplace is to satisfy the needs of the staff by giving them a comfortable and productive space[2]. By getting the lighting right, staff will be more comfortable in their working environment and they can be more productive. Almost without exception the highest capital expenditure in any business is staff salaries and associated employment costs that can be as much as 70% of a business, lighting causes a large proportion of the electricity bill. However, the electricity cost in relation to staff is often very low. Human health, well-being, mood, alertness and sleep patterns are directly affected by changing lights. The non-visual receptor in eyes responds to light and controls levels of the key hormones just like Cortisol, Melatonin and Serotonin of humans. Cortisol is commonly referred to as the stress hormone and it triggers the levels of alertness and energy. People become energetic and vigilant if high levels of Cortisol are contained with them while their concentration is lost when those levels are dropped. Melatonin is the sleep hormone, where the high levels of Melatonin helps to sleep prolonged, suppressed levels of Melatonin can cause Insomnia [1, 3].Being Serotonin, humans' happiness hormone or mood hormone, human mood is adversely affected by a deficiency of Serotonin, which is produced by the brain when Melatonin levels are low.

2.2. Lighting system design for energy saving at workplaces

2.2.1. History of the lighting design process

Oil embargoes and subsequent energy crisis initiated in 1973 in the US and the pursuit of more energy-efficient lighting dominated the lighting field well into the late 1980s creating serious problem for lighting designers. Fueled by utility refunds and commodity pricing, new technologies such as the T8 fluorescent lamp and the introduction of the electronic ballast were designed to use minimum power. Existing lighting systems were refitted to save energy. Lighting installations of interior design and product quality were the rule rather than the exception [1, 2, 3].

During 1990 the quality of lighting made a significant comeback. After that a new process for lighting design was forwarded by the Illuminating Engineering Society of North America (IES) from their 9th edition handbook. After many years the first comprehensive design quality application guide for designing light, A Guide to designing quality lighting for people and buildings has been published by the IES to further expand upon those elements affected the lighting quality. The 10th edition of the handbook was planned to be published by IES in the late 2010 or early 2011 further integrating lighting quality considerations into the design process[4, 5, 9].

2.2.2. Lighting design

The methods and tools need to produce with integrated lighting applications that use advanced sources, luminaires and controls [4, 5]. Here it reviews the lighting design process, including issues of lighting quality which includes lighting levels (quantity) and presents a series of guidelines for designing advanced lighting systems. The applications directory provides examples of lighting applications in various areas such as offices and industries. These examples demonstrate how advanced technologies can be integrated to produce very efficient and quality designs. Lighting is essential for people so that they can see, and thus navigate and work on visual tasks. If reducing energy consumption was the only lighting design under consideration, it would be a simple matter not to install any electric lighting at all for interior and let night-occupied spaces. However obviously, there must be a value to human vision and a desire to occupy visually comfortable spaces. The lighting designer must juggle with multiple choices and sometimes competitive criteria in order to achieve a successful lighting design [4, 5].

2.2.3. **Lighting design process**

Designing is the science and art of making things useful to humankind and lighting designs the application of lighting. Along with architecture, engineering and other design professions also lighting designs rely on a combination of specific scientific principles, such as established standards, conventions and a number of aesthetic, cultural and human factors applied in an artful manner [4,5,6]. The field of lighting has been struggling with two prominent forces. They are the energy efficiency and lighting quality. As the profession of lighting design began to emerge in which the quality and artistry of lighting is held in high esteem. Energy efficiency has become a major concern in the design of buildings. Lighting designers initially faced the choice between attractive, well-lighted spaces and spaces that used minimum of energy.

In its simplest form, lighting design is the selection and placement of the lighting within a space. Facilitation with the right light, in the right place, at the right time is always stressed by any lighting designer to assure a good lighting design. Perhaps the most crucial of these, from an energy management viewpoint, is the timing. Accordingly, efficiency of a lighting system is neglected if it is on at a time when lighting is not needed. 'At the right time' means it is switched off when there is no need of it. Whilst lighting design is often optimised for new buildings, it is equally relevant for existing buildings. Lighting design draws together the four key components [6,7].

- Lamps
- Control Gear
- Luminaire
- Controls

Each of these components are brought together in a designed solution, they will be combined to provide even greater efficiencies. By combining the control gear and luminaire, good lighting and right lighting can be achieved same time providing the answer for the first question. This takes the form of an appropriate luminaire operating with its control gear and lamp combination to deliver the right amount of light for the purpose of the space. The essential premise is that less light is required in a corridor than in an office, so getting the right amount of light is important. The design of the layout of the luminaires will ensure that the light is delivered in the right place. It is important only to deliver light to where it is required if a cellular office has one desk. Then the light needs to be delivered to the desk and not onto the surrounding carpet. The essence of good lighting design is about delivering the right light, in the right place, at the right time. The demands of light vary according to the people who are in the space and what tasks they are engaging. With the view of finding how much light needs and where it is needed, following questions were asked[7].

- Who is using the space?
- What are they doing?
- When will they be there?
- How long will they be there?

First, address the question of who is using the space. It is important to know this because our eyesight weakens with age. Irrespective of other eye conditions, the visual ability of a 10-year old child is hugely advanced when compared to that of a 50-year old. Due to this, younger people need less light to perform the same task. More often than not, there will be a mix of age ranges in any given space. This is true, albeit to different degrees, whether it is an office or a school and this variance may change during the course of the day. For example, a school may be used predominantly by children for most of the day, but by adults attending night classes in the evening. Knowing who is using the space will help us decide on the lighting requirements; in the example of the school lighting may need to be changed.

Whilst establishing the right light level for the application is an important part of the lighting design process and there are other key objectives and constraints to be considered as one may wish to add some lighting purely for visual interest. This might take the form of wall lights, spotlighting or even the inclusion of colour. Whilst it may be considered superfluous, particularly in an energy context, visual interest can prove a valuable additional benefit for the people who use the space. People generally prefer to sit in front of a window even though the view itself may not be spectacular, the interest created allows human eyes to relax and refocus. Additional lighting to create visual interest can achieve the same objective and this change can reduce eyestrain and headache.

However, one of the biggest hurdles often come across in the design process is that of the architecture of the space. It can be addressed ideally with a combination of light sources and luminaries which might be wanted to include as a part of the solution, but invariably the solution have to be fit around the ceiling type, layout and other features such as pillars [6,7]. They criticise lighting design because it can harm to the users. At all times designers must be mindful to the demands of the people in the building that it is being lighted. In some older buildings, concrete slab ceilings are more prevalent and this can lead to restrictions with wiring. It may appear awkward to replace existing wiring arrangements, but it should still be considered as the benefits of making a deeper refurbishment that outweigh the cost and inconvenience.

2.2.4. Lighting quantity

An important trend in lighting philosophy and research is redefining lighting quantity as just one component among many of lighting quality. In the past, lighting quantity has held a dominant role in lighting design and most likely because it is a readily measurable aspect of lighting. However, defining overall lighting quality is highly elusive. Even though numerous attempts to create metrics of lighting quality, the lighting quality remains a seemingly intangible combination of identifiable physical quantities, placed together in a particular system which is highly dependent on numerous factors involving space, setting and task. The current challenge for researchers is to provide more objective metrics of lighting quality to make it possible for more predictably successful projects of all types [4,6,10].

2.2.5. Lighting quality

Lighting deeply affects many human reactions to the environment. These human reactions range from the obvious, such as the dramatic beauty of an illuminated landmark to the emotional response of a candlelight dinner, to subtle impacts on worker productivity in offices to sales in retail stores. The profession of lighting design, which grew from a mixture of theatrical and architectural methods, is largely valued for its ability to creatively and artfully provide high quality lighting consciously meeting visual, environmental and efficiency requirements [8, 11].

2.2.6. **Colour rendering index (CRI)**

Colour rendering index is a quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. CRI has worked well as a benchmark for lighting, particularly in situations where it is important that artificial light renders colors accurately, such as factories and offices [8, 11]. Use of the correct lighting technology is useful in fabric selection because rendering effects due to the light source and the environment could potentially affect the identification of true colours. However, once the fabric with the correct colour is purchased, identifying true colours in the sewing sections is not as important as in fabric selection in the garment industry.

2.2.7. **Implementation of new lighting systems**

A high quality and sustainable design must be implemented in order to provide a good work place for achieving tasks successfully[4].Changes in design phase of the lighting system could benefit a manufacturer, sales representative, distributor or contractor without concerning owners prospective. In this phase, it is critical the fact that the design integrity is held without substitutions, changing of criteria or cost. Subsequently, a cost benefit analysis may be required during the implementation phase which establishes the designer's reputation.

Commissioning of the lighting and control system is critical to achieve the proper operation and the economic benefits of the lighting design [12]. Some programs such as Leadership in Energy & Environmental Design (LEED) require commissioning as a requirement to achieve the LEED status. Energy codes may soon begin to require proof of commissioning before a certificate of occupancy is given. Some advanced lighting systems increase construction costs. Designers need to know when these additional costs can be justified through future energy savings or other benefits. Energy efficiency advocates have long thought that if and only they could prove the economic rationality of efficiency improvements and then surely reasonable decision makers would choose the more efficient strategies. This has repeatedly proved a much more difficult sell than originally thought. Lighting systems in commercial buildings have been greatly undervalued and often are of much poorer quality than could be easily justified economically [7] (lighting systems available in different workplaces are shown in Figure 2.1 to Figure 2.6). Most companies spend very little time assessing the economic value of lighting alternatives. Some companies may do a quick payback check, which might be preliminary stage estimation. However, without more careful financial assessment, many of the advantages of advanced lighting systems will be ignored or undervalued [12].

Figure 2.1: Balance of light on walls and tasks [7]

Figure 2.2: Good examples of day lighting in the work place [7]

Figure 2.3: A well-controlled office building with lights turned off at night [7]

Figure 2.4: Inappropriate luminaries for application modular lay-in in industry[7]

Figure 2.5: Poor maintenance illustrated by mixture of lamps in luminaire [7]

Figure 2.6: Poor LG3 application [7]

2.3. Lamps

Light sources are called lamps, rather than light bulbs and each lamp type have different characteristics which affect where and when they should be used. The most important three characteristics are the efficacy, its expected lifetime and its colour rendering ability. Artificial light can be created in different ways where in incandescent lamps, light is created by passing an electrical current through a wire so that it glows white hot(e.g. Tungsten).In fluorescent lamps, the generation of light occurs within a gas filled envelope that is driven by an electric circuit. In solid state lamps, light being generated at the junction of a semi-conductor (e.g. Light Emitting Diodes) although there are some other methods [9, 11].

Incandescent lamps

Incandescent lamps were invented well over 100 years ago. Currently, their use is restricted due to their poor performance. Even though they have a short lifetime, they do offer good colour rendering though their parts are being deteriorated. Many incandescent lamps are currently being phased out of the market because they are so inefficient. However, there are some incandescent lamps which are more efficient thanks to the addition of halogen within the glass surrounding the tungsten element. In recent years, the low voltage versions of tungsten halogen lamps have had their efficacy improved by around 30%. In Figure 2.7, we can see some different kinds of Incandescent lights [13].

Figure 2.7: Incandescent lighting [14]

Discharge lighting

Most commercial lighting relies on a range of lamps that use glowing gas discharges and Phosphors to create light. Examples for lamps which use this principle are,

- Fluorescent
- Low pressure Sodium
- High pressure Sodium
- High pressure Mercury
- Metal Halide
- Ceramic metal Halide.

Different types of discharge lights are shown in Figure 2.8. Mostly, discharge lighting is characterised by its need to warm up as they do not come on instantly at full brightness. This is called the strike time, which can vary from a few seconds to many minutes with some types. Additionally, some types will not re-strike when they are hot, so if a lamp is switched off, it then cannot be turned back on immediately and this affects their controllability [8].

Fluorescent

Fluorescent lamps are supplied in tubes or compact forms by far the most common form of discharge lighting. The warm up to full brightness is quick and usually less than one minute. It is an efficient source, with typical efficacy around 80 Lumens per Watt and fluorescents have better colour rendering ability than LED lamps. The lifetime varies over quite a broad range, with compact fluorescents typically from around 6,000 hours while the tubular versions start at around 12,000 hours, although there are long life tubular versions rated at 70,000 hours. Among this type, fluorescent lighting is the most easily controllable category. They can be switched on and off quite readily, and with the right control gear they can be successfully dimmed [7, 8].

Low pressure sodium

This is a highly efficient lamp and these are almost exclusively used in street lighting. These are the familiar orange lights that seem to turn all colours to dirty brown. Although they are still the most efficient light source they are progressively being replaced by other lamp sources because they take up around ten minutes to reach full output and cannot be dimmed [8].

High pressure sodium

These lamps are easily identified as the bright golden street lights on many of our motorways and they are also often used in warehouses and floodlighting. They have a high efficacy (125 lumens per Watt) and a long lifetime around 20,000 hours. However, they have poor colour rendering and take a long time to reach full brightness. As a result, they are not easily switched ON and OFF although with the right gear they can be dimmed to a limited degree [8].

High pressure mercury

They produce white light with a bluish tinge. They are not very efficient and have poor colour rendering. Any installations using these lamps should be considered for refurbishment [8].

Metal halide and ceramic metal halide

This group of lamps offers a highly efficient source, typically 80 Lumens per watt, in a very large range of power ratings. They have colour rendering from Ra60 right up to Ra90 or more and, a lifetime typically around 12,000 hours.

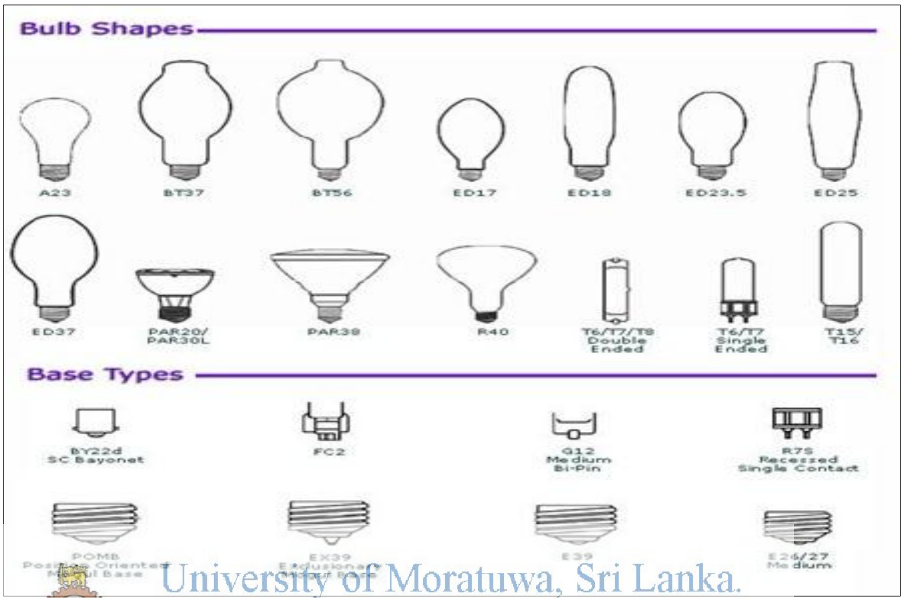

Figure 2.8: Discharge lighting [15]

Solid state lighting

There are two types of solid state lighting:

- LED (Light Emitting Diodes)
- OLED (Organic Light Emitting Diodes),

The two types are quite different in form and in their potential applications.

Light emitting diodes (LEDs)

LEDs have been in common use for over 40 years and most traditionally as the indicator on televisions when they are in standby mode. They are a very small, point source that can appear to be very bright. The light output of these devices has developed rapidly over the past few decades, making their use in commercial lighting viable. They have a very long life, typically 50,000 hours and their efficacy is increasing all the time. Unlike other lamps, LEDs are often integrated into the light fixture so there is no lamp replacement [7, 9, 12, 16].

Organic light emitting diodes (OLEDs)

OLED is a flat panel giving even diffuse light and still very much in development as a light source so not yet viable for commercial use [12].

Efficient and feasible lighting systems for workplaces

There are different kinds of lighting sources available in market. Some ideas about efficacies of sources can be listed according to comparison with the available sources as shown in the Table 2.1. In addition to that we can see different feasible lighting systems in Figure 2.9 to Figure 2.14 [7, 12, 16].

Table 2.1: A comparison of light source efficacies [12]

Light type	Typical efficacy (lm/W)	Usable optical light (lm/W)	Lifetime (hours)
Incandescent	17	10-17	3,000
Halogen / HPL	20/25	12-20	10,000
T12 fluorescent	60	45-50	20,000
Compact fluorescent	62	31	10,000
Metal halide	70	<40	<15,000
T8 fluorescent	74	55-60	20,000
High-pressure sodium	91	<50	<24,000
T5 fluorescent	100	80	20,000
Best high power white LED in 2007	105	85	>50,000
Low-pressure sodium	120	65-75	18,000
Record LED – research	`150	120	TBD

Modular luminaries with reflector

Figure 2.9 shows Modular luminaries with reflectors having specifications of,

Mounting: surface, recessed;

Lamp types: fluorescent;

LOR(Light Output Ratio) 0.6 – 0.9 and

Having applications of offices and IT(information technology) areas.

Figure 2.9: Modular luminaries with reflectors [7]

Modular luminaries with diffuser

Figure 2.10 shows Modular luminaries with diffuser with specifications of
Mounting: surface, recessed;
Lamp types: fluorescent;
LOR: 0.5 – 0.9 having applications of offices and retails.

Figure 2.10: Modular luminaries with diffuser [7]

Down lights

Figure 2.11 shows down lights with specifications of

Mounting: recessed;

Lamp types: CFL, Tungsten halogen; metal halide, LED;

LOR: 0.6 – 0.9 having applications in circulation applications and retails.

Figure 2.11: Down lights [7]

Pendants

Figure 2.12 shows Pendants with specifications of mounting: suspended; lamp types: fluorescent, metal halide, HPS (High-pressure sodium lamps); LOR: 0.5 – 0.9 having applications in offices, industrial and retails.

Figure 2.12: Pendants [7]

Spotlights

Figure 2.13 shows spot lights with specifications of mounting: surface, track; lamp types: metal halide, LED, Tungsten, halogen; LOR: 0.8 – 1.0 having applications in retails.

Figure 2.13: Spot lights [7]

Wall Lights

Figure 2.14 shows Spot lights with specifications of Mounting: Recessed, Surface; Lamp types: CFL, Metal halide, LED, LOR: 0.4 – 0.6; Applications: Office, Circulation

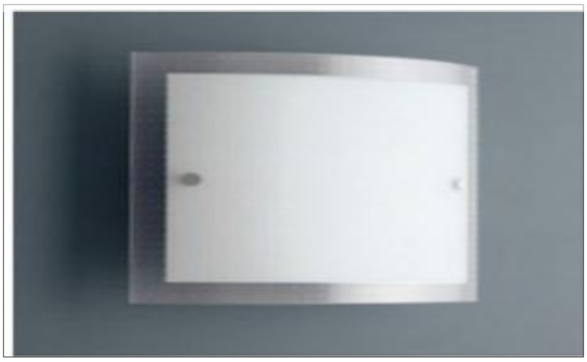

Figure 2.14: Wall lights [7]

2.4. Industrial lighting calculations

Lx to watt calculation

lx to watts calculation with area in square feet is given by Equation. 2.1 as given below [16],

$$P(W) = 0.1 \times E_v \times \frac{A(ft^2)}{\eta(\frac{lm}{W})} \text{...}(2.1)$$

lx to luminous flux calculation with area in square feet is given by Eq. 2.2 as given below [16],

$$\Phi V\ (lm) = 0.1 \times Ev\ (lx) \times A\ (ft2) \text{..}(2.2)$$

The power P in watts (W) is equal to the luminous flux ΦV in Lumens (lm), divided by the luminous efficacy η in Lumens per watt (lm/W) [17].

$$P(W) = \frac{\Phi V(lm)}{\eta(\frac{lm}{W})} \text{...}(2.3)$$

So, the power P in watts (W) is equal to the 0.1 times the luminance E_v in illuminance(lx) times the surface area A in square feet (ft^2), divided by the luminous efficacy η in Lumens per watt (lm/W). From Equation 2.1,

$$P(W) = 0.1 \times E_v \times \frac{A(ft^2)}{\eta(\frac{lm}{W})}$$

Then,

Watts = 0.1 × lx × (square feet) / (Lumens per watt)

Or

$W = 0.1 \times lx \times ft^2 / (lm/W)$

Colour to energy calculation

The luminous flux, Φlum, is obtained from the radiometric light power using the equation [18]

$$\emptyset_{lum} = 683 \frac{lm}{W} \int_{\lambda} V(\lambda)\, P(\lambda)\, d\lambda \text{...}(2.4)$$

Where $P(\lambda)$ is the power spectral density, The eye sensitivity function has been determined by the V(λ),(Sensitivity function change against wavelength can see in

Appendix A). The light power emitted per unit wavelength, and the pre factor 683 lm/W is a normlisation factor. The optical power emitted by a light source is then given by,

$$P = \int_{\lambda} P(\lambda)\, d\lambda \text{..........} (2.5)$$

The luminous efficacy of optical radiation (also called the luminosity function), measured in units of luminous per watt of optical power, is the conversion efficiency from optical power to luminous flux. The luminous efficacy is defined as

$$\text{Luminuous efficacy} = \frac{\emptyset_{lum}}{P} = [\, 683 \frac{lm}{W} \int_{\lambda} V(\lambda)\, P(\lambda)\, d\lambda]/[\int_{\lambda} P(\lambda)\, d\lambda] \text{..........} (2.6)$$

The luminous efficiency of a light source, also measured in units of lm/W, is the luminous the flux of the light source divided by the electrical input power

$$\text{Luminous efficiency} = \Phi\, lum\, /\, (IV) \text{..........} (2.7)$$

Where the product (IV) is the electrical input power of the device. Note that in the lighting community, luminous efficiency is often referred as the luminous efficacy of the source [18].

Density to energy calculation

Fabric thickness is defined as the perpendicular distance through the fabric, which determines the dimension between the upper and lower sides of the fabric. It is possible to use the geometric model described on the basis of fabric structure and warp and weft waviness. In the under mentioned model the main influence is exerted by the yarn diameter and weft and warp waviness [20, 21].

$$\text{Thickness} = \left[(d_o + d_u) + \left[+\frac{(d_o+d_u)}{2}.\, el + \frac{(d_o+d_u)}{2}.\, (1-el)\right]\right] f \times \beta \text{..........} (2.8)$$

Where: $d_{o,u}$ - warp and weft diameter, e1 - warp waviness, $f \times \beta$ -interlacing coefficient, C - yarn compression in fabric (the yarn deformation in interlacing).

Density (ρ) and refractive index (n) are critical. These two parameters are related approximately as,

$$n = (\rho + 10.4)/8.6 \quad (2.9)$$

Then Transmission intensity is given by,

$$I_T = I_O(1-R)^2 e^{-\beta l} \quad (2.10)$$

For an incident beam of intensity I_0 that impinges on the front surface of a specimen of thickness l and absorption coefficient ß the transmitted intensity at the back face I_T is where R is the reflectance.

2.5. Garment factories' workplace lighting systems

According to the compliance rules and regulation for garment factories Illuminance standards for workplaces are mentioned in Table 2.2.

Table 2.2: Garment Factory Illuminance(lx) for workplace [22]

Illuminance(lx)	Examples of Area of Activity	Workplace
200-300	Minimum service illuminance on the task	Office area
300-400	Medium bench & machine work, general process in chemical and food industries, casual reading and filing activities	Cutting area, Packing area
600-800	Hangers, inspection, drawing offices, fine bench and machine assembly, colour work, critical drawing tasks.	Sewing area, quality inspection
1000-1500	Very fine bench and machine work, instrument &small precision mechanism assembly; electronic components, gauging & inspection of small intricate parts	Final Quality inspection area

Garment factory lighting controls

Lighting controls generally react to three main stimuli,

- Movement sensor – occupancy control
- Time clock – timed schedule
- Light sensor – daylight linking.

Always the garment industry looks for reducing the energy consumption because they spend heavy costs on electricity. So they are trying to control energy consumption by using different types of lighting systems to improve the efficiency. Although standard illuminance(lx) and lighting systems have been defined for the garment industry by guidelines, it was identified that there is an issue with these illuminance. As an example, although it requires 1500 illuminance for the quality checking table, they have to use different levels due to the fact of using different fabrics. So it will adversely affect to the eye, if this fact are neglected. Hence most suitable illuminance should be defined and recommended. In addition to that illuminance corresponding to each colour and types of the fabrics should be controlled with a view of saving energy without using unwanted light.

CHAPTER 3: RESEARCH METHODOLOGY

To assess the past and current developments in lighting systems a comprehensive literature review is performed and then interviews are conducted with stakeholders and collected data of lighting systemsusing a questionnaire. In addition, the calculation of this research supports the measures mentioned below in Tables 3.1 and 3.2 respectively.

Table 3.1: Photometric quantities [18]

Radiometric	Photometric	Symbol	Units	
Power	Luminous Flux	Φ_v	Lumen	Lm
Intensity	Luminous Intensity	I_v	lm/sr=candela	Cd
Irradiance	Illuminance	E_v	lumen/m^2	Lx
Existence	Illuminance	M_v	lumen/m^2	Lx
Radiance	Luminance	L_v	lm/(m^2sr)=	Nit

Table 3.2: Significant performance measures [18]

Figure of merit	Explanation	Unit
Luminous efficacy	Luminous flux per optical unit power	lm/W
Luminous efficiency	Luminous flux per input electrical unit power	lm/W
Luminous intensity efficiency	Luminous flux per input electrical unit power	cd/W
Luminance	Luminous flux per chip unit area	cd/m^2
Power efficiency	Optical output power per input electrical unit power	%
Internal quantum efficiency	Photons emitted in active region per electron injected	%
External quantum efficiency	Photons emitted from LED per electron injected	%
Extraction efficiency	Escape probability of photons emitted in active region	%

3.1. Obtainingemployees' recommendations about illuminance

Interviews were conducted with stakeholders and collected data of lighting systems according to the questionnaire.This study has been explicitly designed to build upon the findings on Employees recommendations about the illuminance in the garment industry. It is assumed within this research that the only variable is illuminance while the other conditions remain unchanged. Also it was explored how differently factory workers responded to the questionnaire.

Research design

The study sets out as an exploratory inquiry into different people's experiences in garment factories. Five garment factories were selected as a sample which would enable to analyse with a broad range of employees' recommendations. The names of five factories were MAS Slim Line, MAS Casualine, Trinity Apparel, Istra International and SevaVanitha Garment factory. Around 80% of the employees were represented the production are became the maximum of energy consumption is used in sewing area in the garment factories. In addition, it is considered that employees' previous experience about lighting levels in other factories. There were differences in the sampling methods used to compose the focus groups at each factory. Over 500 employees were interviewed as for the research sample quantity. The sample included a wide range of employees from different factories. At the beginning of the interview they were explained the aims of the study and the guidance were set out to give them anopportunity to ask questions about the research. During the interview it was considered about the sensitive issues and environmental safety. They were explained that their responses would remain confidential and participants agreed with respecting the importance of fellow participants' confidentiality regarding any issue which would be raised in the research. Desires of participants on their exposure to the existing policy discourse on 'lighting standard' would inadequate as they feel. Consequently they were expected to give a particular account of their experiences which will review in this research. Interview schedules were designed as guidance to provide initial prompts for a structured, conversational interview guided by open-ended questions. Using a structured approach allowed to follow up on issues that participants considered as important in relation to key topics and clarify the meaning with participants during the interviews as factories had different lighting techniques, line layouts and workplaces.

Research questions

1) What is your daily responsible duty in the factory?

This question has used to identify the employee's workplace and analysis the important area of the place. Then, the research details can be applied according to the needs of employees' perspectives area.

2) Are you satisfied with the intensity of light to perform your duty well in your section?

The purpose of this question is to identify the employees' satisfaction about available lighting system in industry and get an idea on problems with the lighting system.

3) Have you ever worked in any other garment factory?

This question aims to know about the working experiences of employees.

4) If you have worked somewhere else, what can you say about the intensity of light in the present and previous factories?

This question desires to grasp some comparison among factories, by collecting the answers from experienced employees.

5) Explain your answer for question no. 4 above.

This question intends to take further details for comparison between factories, through the answers form experienced employees.

6) Do you agree with the fact that the intensity of light should be changed according to the types and colours of the fabric?

This question aims to analysis the employee's perspective on light intensity and the fabric type.

7) Do you agree with the fact that the intensity of light should be increased for dark colours?

This question aims toanalysis the employees' perspectives on light intensity and the fabric colour.

8) Do you agree with the fact that the intensity of light should be increased for light colours?

This question aims toanalysis the employees' perspectives on light intensity and the fabric colour.

9) Is it good to have a spot light?

This question aims toanalysis the employees' perspectives on having a spotlight.

10) Is the bulb too closer to you?

This question aims toanalysis the employees' perspectives on proximity of light system.

11) Is it good to have an upper light?

This question aims to analyze the employees' perspective on lighting placement.

3.2. Measuring illuminance available in factories

Illuminance is the most common parameter to be measured in a lighting assessment. It refers to the amount of light falling on a unit area of the work surface and its measurement unit is lx. Illuminance was measured by a Lux meter which is a handy instrument with a sensor for light detection. The measured Illuminance was directly displayed in Lx. The work area was first divided into a number of equal small areas. For example, for an ordinary medium sized work area of $50m^2$ where the light incidents at a height of around 2.5m, the work area was normally divided into a minimum of 16 small squares for work area size up to around $100m^2$as the recommended minimum number of small squares was 25. If the work area was larger, a minimum number of 36 small squares was recommended. After setting the small squares, illuminance measurements were taken at the centre of each square with a Lux meter. The path between the lighting source and the point of measurement was kept cleared as far as practicable when measuring the illuminance level.

3.3. Identification of fabric types and fabric colour

The density of a material is considered to be the most important factor which governs the sound absorption of the material. Following differences can be seen in range of fabric types [22].

Cotton Density: 1.54 g/cm^3

Linen Density: 1.5g/cm^3

Silk Density: 1.25 - 1.34 g/cm^3.

Wool: Density: 1.30 – 1.32 g/ cm^3

Rayon Density: 1.5 g/ cm^3

Nylon Density: 1.1 g/ cm^3

Polyester Density: 1.38 g/ cm^3

According to the spectrum of electromagnetic radiation, it includes wavelength ranges for the various colours in the visible spectrum as mentioned in following Figure 3.1.

The spectral components of the light determine how well various fabric colours can be reproduced. The higher the colour rendering index or the lower the colour rendering group number improves the colour rendering in comparison with the optimal reference light.

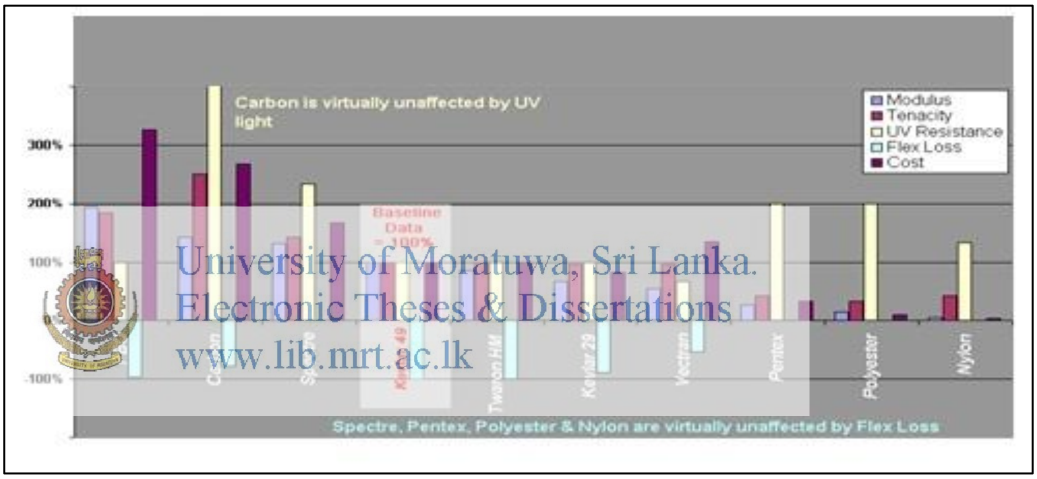

Figure 3.1: Wavelength ranges [22]

3.4. Case study

A garment factory was selected and illuminance was changed by redistributing the light sources. The following steps were carried out.

- Measuring the average illuminance throughout the workplace and comparing it with the recommended levels.
- Identifying shadows, especially over work areas.
- Studying eye fatigue among sewing workers.
- Calculating eye fatigue, using the following equation.

3438/PRI(pixels per inch)= number of inches from eyes to display

To adjust the lighting, the following steps were followed:

- Replacing bulbs on a regular schedule and follow manufacturers' instructions.
- Cleaning light fixtures regularly.
- Adding light fixtures at appropriate places.
- Using more reflected light and local lighting to eliminate shadows. For example, a covered light mounted under a transparent guard on a grinding wheel provided additional light needed to clearly see the task.
- Positioning workstations with light fixtures to be directly behind the workers.

After following the above steps, illuminance was again analysed. Energy saving was calculated and simultaneously eye fatigue was also analysed.

3.5. Data analysis

Calculation of the energy loss with standard illuminance range

Collected data and luminance levels in garment factories are analysed according to the following methods by using Equations 2.1 to 2.10.
What is the power consumption with an illuminance of 50 lx, luminous efficacy of 15 Lumens per watt and surface area of 200 square feet?

$P = 0.1 \times 50\ lx \times 200\ ft^2 / 15\ lm/W = 61.94\ W$

By using above methods, watts can be calculated according to the change of illuminance and without changing the other details. In addition, the energy can also be calculated according to the time period that we are using. Then, final argument can be made to determine how much of the energy losses within the range of illuminance.

Method of questionnaire analysis

Questions were analysed according to the facts of illuminance calculation and effect to the people by information through their sense of sight and appropriate lighting, fabric type and colour within the standard lighting level. Questions were analysed according to methods as mentioned below.

- Question numbers 1, 3, 4 and 5 are concerned for assessing standards of lighting levels. It is referred from employee information and their experiences.
- Question number 2 referred for collecting the employer's consideration about the available lighting system and illuminance.
- Question numbers 6, 7 and 8 were concerned for collecting the information, the lighting system changes and illuminance. In addition it was used to collect the details of the effect of fabric type and colour for lighting system and illuminance.
- Question numbers 9, 10 and 11 were concerned for collecting information about employees' perspectives about lighting standard.
- According to the above analysis final argument is made.

3.6. Assumptions

When calculating the energy loss and consumption, following assumptions have been made.

- The colour of the background is same
- Height of the lighting system is same
- Environmental conditions are same (E.g.:- Humidity, sunlight, etc.)
- This research assumes that the light source is identical (standard systems and light sources used).

CHAPTER 4: RESULTS AND DISCUSSION

The questionnaire was distributed among 515 participants who responded from the five different factories. Question numbers 1, 3,4 and 5used for analysing of the peoples' perspectives and their attitudes for the comparison between companies, using fabric type, available lighting technology (available illuminance are in Appendix D) and identify their daily duties. According to these questioned answer could be connected with the real life experiences, here this research will be quite successful.

Question number one considers about employees daily duties. When considered about a garment industrial sewing area, there are different kinds of duties available. Those duties need different levels of intensity to do the work without any hazard, hence when considering about illuminance in the garment factory one needs to consider about duties as well. Question number three has given the details of employees with working experience in different factories. According to the question number three, they have given answers to question number four to compare those other factors, under which employees had worked. Further details used question number five. Accordingly those answer analysis effects for coming to the final result of this research.

4.1. Employee satisfaction

Question number two formed in order to analysis of the employees' perspectives on available intensity of light level to perform the work. This question mainly aims to identify the available scenario in garment factories. The labour law and regulation standards are being used for the lighting systems and illuminance at present. Illuminance standards are established within the range in that regulation. As an example, the sewing area needs 600-800 illuminance. Due to this reason the illuminance may be vary from factory to factory. In addition the employees can argue about that standard as well. When considering the question number two, both answers were received from the employees. Accordingly 57% answered "Yes" and 38% answered "No" (refer Appendix C), hence some problem can be considered that exists with the lighting level or systems. Thus it is needed to pay attention to reasons for this observation. Finally, with this question it is highlighted that there are some issues exists with the lighting system or illuminance.

4.2. Employee perspective on light intensity and the fabric type

Question number six relates to the analysis of the light intensity and the fabric type. Many types of fabrics are used in the garment industry. They are vary according to the construction of the structure, hence their characteristic are also vary. There are many fabric types such as cotton, nylon and polyester. According to the different characteristics, lighting absorption also differs, thus the need of light intensity must also change with the fabric type. Otherwise, it will create a problem with the sight due to low or high level of illuminance. With this issue, no one is able to work for long periods of time in the workplace. Employees have answered regarding this issue by only “Yes”(refer Appendix C). A conclusion can be made in considering this answer. According to that employee’s perspective, the illuminance should be changed for fabric type. Lighting level cannot be changed in available scenario in garment factories. They only use one level within the range for every type of fabrics. But fabric characteristics are varied from fabric to fabric, hence the absorption and reflection do also change with these characteristics. According to this reason it would be better to change the lighting level according to the fabric type for maintaining the same reflecting level in the workplace. Otherwise it may create a situation for energy losses. In addition, there will be a possible eye hazard as well due to the unwanted lighting levels using at the workplace. Kevlar fabric by Laboratory screening method practically proves that, energy absorption varies with density as mention in Figure 4.1 [39].

The formula to capture the change in energy absorption (y)according to density (x) changes is shown in Figure 4.1.

$$y = 2000.X^5 - 5722.X^4 + 6077.X^3 - 2965.X^2 + 693.8\,x - 52.07 \quad \ldots\ldots(4.1)$$

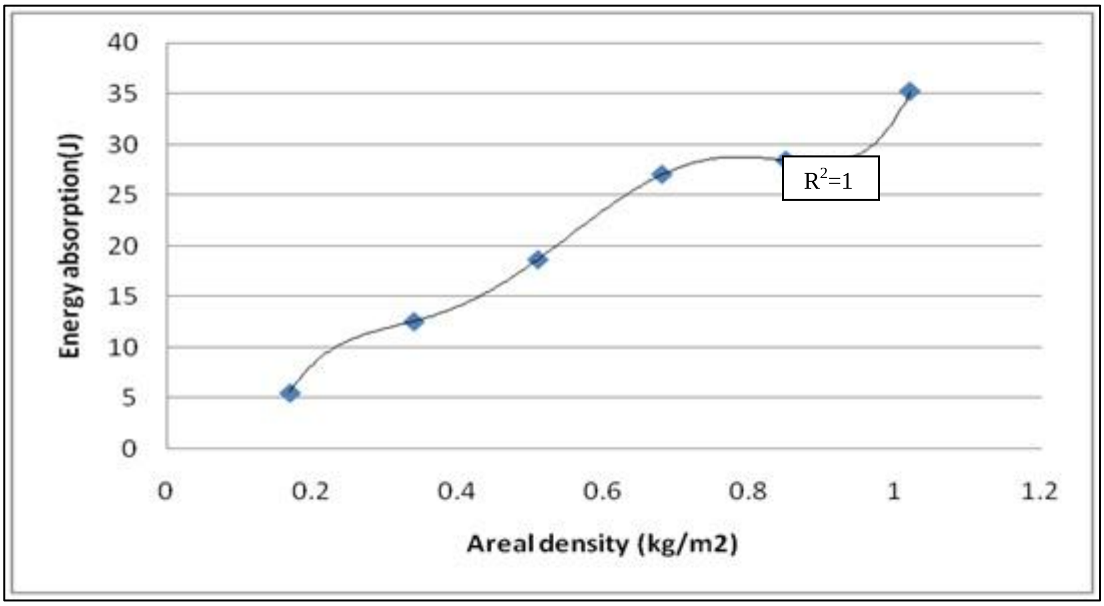

Figure 4.1: Energy absorption and density by Kevlar fabric laboratory screening method [39]

According to the Table 4.1 and Appendix E, The approximate yarn measurement comparison can be seen and the variations of the fabric can be identified as well.

Table 4.1: Approximate yarn measurement comparison [26]

Denier	Tex (m/g)	Worsted (m/g)	Cotton (m/g)	Woolen (run) (m/g)	Linen (lea) (m/g)
50	5.6	160	106	56	298
75	8.3	106	72	37	198
100	11.1	80	53	28	149
150	16.6	53	35	19	99
200	22.2	40	27	14	74
300	33.4	27	18	9.3	50
400	44.4	20	13	7	37
500	55.5	16	11	5.6	30
700	77.7	11.4	7.6	4	2
1000	111	8	5.3	2.8	15
1500	166	5.3	3.5	1.9	10
2000	222	4	2.7	1.4	7

4.3. Employee perspective on light intensity and the fabric colour

Question number seven and eight have used to get information to analyse the light intensity and the fabric colour. Fabric colour directly affects the lighting level, so according to that this research has analyzed about variations of wavelength and energy absorption by colour. Thus, intensity should also be changed from colour to colour. Otherwise, it will create a problem with eye hazard due to the presence of low or high level of illuminance. With this issue, no one can work longer periods of time in the workplace. Only the answer "Yes" was given by employees (refer Appendix C) for this question. In considering this answer, a conclusion can be made. According to that, employees' perspectives on the lighting level suggest that it should be changed according to the fabric colour. Along with the available scenario in garment factories the lighting levels cannot be changed. They use only one level within the range for every fabric colour. However the fabric colour characteristics are varied by colour wised; hence the absorption and reflection also change with these characteristics. According to this reason the lighting level need to be changed consisting with the fabric colour to maintain the same reflecting level in the workplace, otherwise an adverse issue may be created for energy saving. In addition, there will be an eye hazard too as a result of using unwanted lighting levels in the workplace. Past experiments and researches have proposed these factors and were changed lighting absorption. It can be proved with following details as well.

For wavelengths ranging from 390 to 720 nm, the eye sensitivity function V(λ) is greater than 10^{-3}. Although the human eye is sensitive to light for wavelengths less than390 nm and greater than720 nm, the sensitivity at these wavelengths is extremely low. Therefore, the wavelength range 390 nm ≤ λ ≤ 720 nm can be considered the visible wavelength range. The relationship between the colour and the wavelength within the visible wavelength range is given in Table 4.2.

Table 4.2: The colours of the visible light spectrum [27]

Colour	Wavelength interval (nm)	Frequency interval (THz)
Red	625-740	480-405
Orange	590-625	510-480
Yellow	565-590	530-510
Green	500-565	600-530
Cyan	485-500	620-600
Blue	440-485	680-620
Violet	380-440	790-680

In addition, the effect of wavelengths for the reflection and absorption of light is illustrated in Figure 4.2.

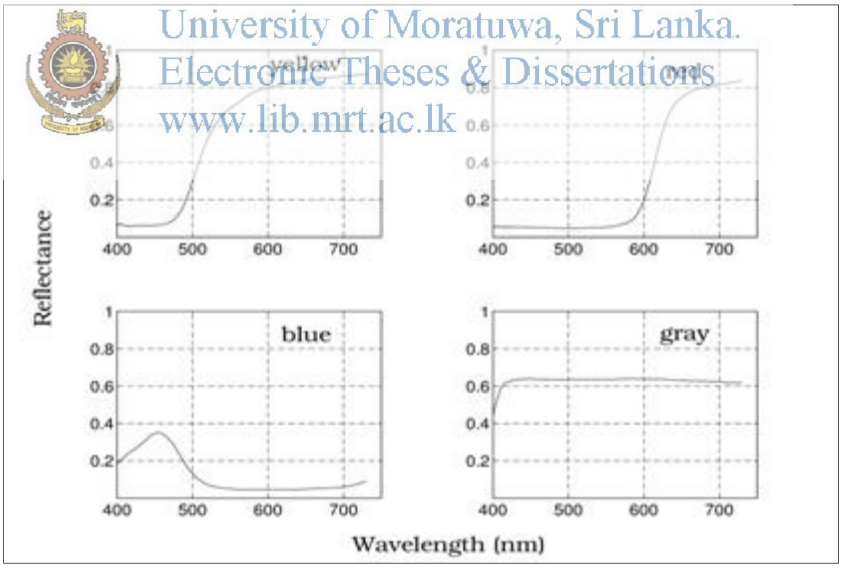

Figure 4.2: Reflectance change with wavelength [28]

The luminous flux, Φlum, is obtained from the radiometric light power using the Equations, 2.4, 2.5 and 2.6.

The luminous efficiency of a light source, also measured in units of lm/W, is the luminous the flux of the light source divided by the electrical input power, from Equation 2.7.

$$\text{Luminous efficiency} = \Phi_{lum} / (IV)$$

Where the product (IV) is the electrical input power of the device. Note that in the lighting community, luminous efficiency is often referred to as the luminous efficacy of the source.

According to this formula, highlighted colour variation effect for the eye sensitivity and it directly emphasises that the lighting level can be changed with colour for keeping equal intensity at the same workplace. Thus, it is affected with the energy consumption as well. This problem is emphasised around 90% according to the answers obtained from the questionnaire.

As per the discussion related to question number seven, fabric colour directly affects the sensitivity of the lighting level. Accordingly, the research has analysed on how to vary the wavelength and absorption depending on the colour. Thus, intensity should also be changed with the colour. Otherwise, it will create a problem with eye hazard because of low or high level of lighting level. With this issue, no one is able to work for long periods of time in the workplace. All the employees responded as 'NO' for this question. According to that employee's perspectives about the lighting level, for maintaining the same reflecting lighting level in the workplace should be changed by depending upon the fabric colours. Otherwise it may be caused an issue for energy losses. In addition, there will be eye hazard as well because of unwanted lighting level.

Both seven and eight questions are focusing on the colour of the fabric. The analysis emphasises the fact that intensity should be changed with the colour. The previous analysis has impressed the same results as illustrate in Figure 4.3 and Figure 4.4 respectively.

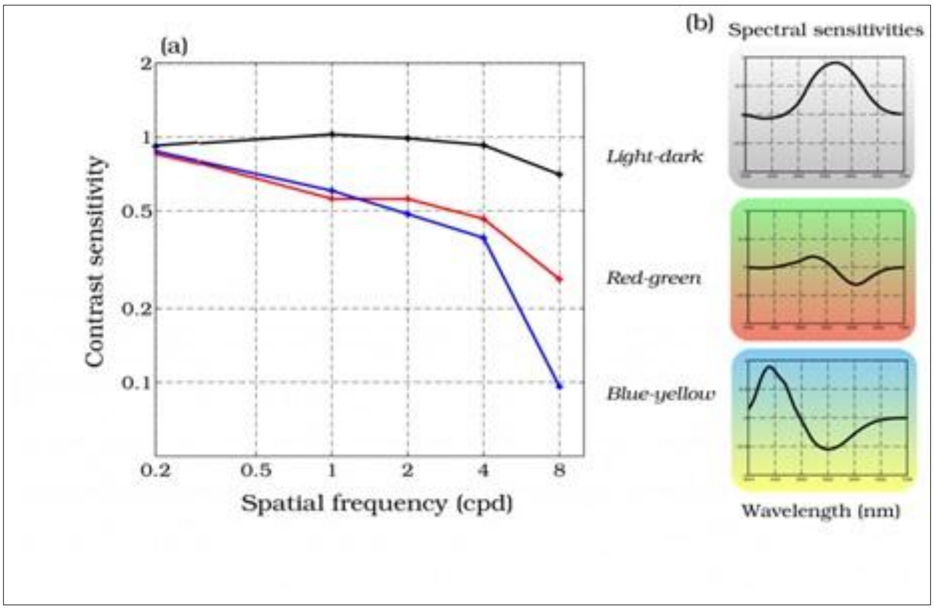

Figure 4.3: Spectral sensitivity and wavelength [28]

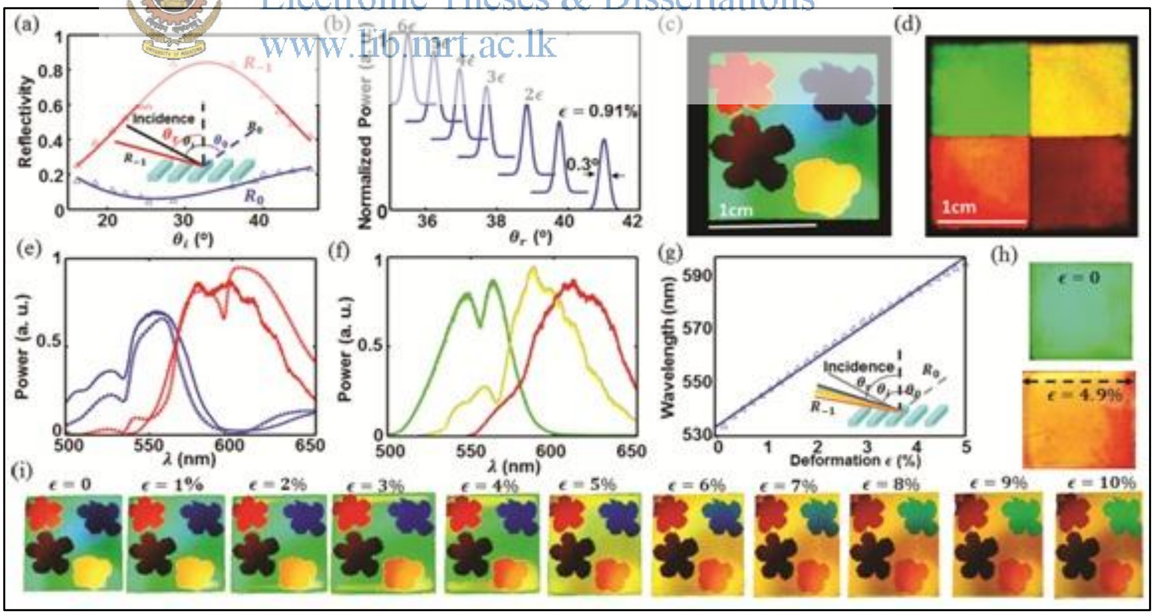

Figure 4.4: Power and reflectivity with wavelength [29]

4.4. Employee perspective on having a spotlight

Although lighting levels may be adequate in the factory as a whole, a glare from a direct light source or reflection of equipment or shiny surfaces can cause discomfort, eye strain and fatigue which contribute to an increase in errors and a reduction in quality and productivity. Question number 09 refers to this and both "Yes and "No" answers were given by the employees. Among them, 12% answered "Yes" and 78% answered "No" (refer Appendix C). Hence, some kinds of problems in relation to the lighting level or systems can be considered. Thus, reasons for these outcomes can be concluded. Ultimately, with this question it has shown that there is some issue with the lighting system or illuminance. Most of the employees are not satisfied with the spot light. Reason for this answer is glare which has been described as "light in the wrong place" and comes with three different kinds as,

- Glare can dazzle and impede vision, and therefore may be a cause of accidents. It is the result of too much light entering the eye directly.
- Discomfort glare is more common in work situations. It can cause discomfort, strain and fatigue, especially over long periods. It is caused by direct vision of a bright light source and background.
- Reflected glare is bright light reflected by shiny surfaces in the field of vision

According to these reasons lighting system need to be considered essentially also. Overcoming glare from lamps can be changed as mention below.

- Ensure that no naked lights are in direct view of workers;
- Raise the light fittings (if suspended) providing this does not reduce the overall level of lighting; and
- Use shades or shields, but ensure that the work area is well lit.

To reduce reflected glare

- Change position of the light source and reduce its brightness;
- Cover reflecting surfaces with opaque, non- glossy materials; and
- Change the layout of the workstations.

4.5. Employee perspective on proximity of light system

Improvements in lighting do not necessarily mean that it needs more lights and therefore uses more electricity. It is often a case of making better use of the existing lights, making sure that all lights are clean and in good condition and ensuring that lights are positioned correctly for each task. To go with these lines, the question was made hearing these in mind and answers were given by employees as only “No” , and they mentioned that lighting system height is not an issue in their workplace(refer Appendix C).

4.6. Employee perspective on lighting placement

Good lighting helps to see the work without straining in the eyes. Insufficient light makes squint or worker gets too close to the work which weakens the eye muscles and can lead to the blurred vision. To overcome these obstacles, the prevention methods like install better lighting system and exercises should be done to strengthen and stretch the muscles around the eyes. With this scenario in mind this question was made and answer has been given on this question by employees as only “Yes”. They mentioned that the available lighting system height as not an issue in their workplace.

4.7. Energy saving potential

4.7.1. Illuminance and energy consumption

When considering the questionnaire analysis, energy losses are mostly made in garment industry due to negligence about lighting systems. This happens according to the fabric type, colour and available lighting standard. As pointed out in the above analysis, some changes were suggested by the employees. Because they asked some different light level in different scenarios in which some kinds of energy losses would be anticipated. For an example, according to the labour rules and compliance standard the illuminance range should be 600-800at the sewing area. If that range is observed, in one sewing area it may varies the material and colour as well. By considering two different scenarios within the range as one needs 650 lx and then another one needs 750lx, energy difference in these two scenarios can be calculated without changing other parameters within one square meter, in one hour as mention below from using Equations 2.1 to 2.3.

$$P(W) = 0.1 \times E_v(lx) \times A(ft^2) / \eta(lm/W)$$

Using this equation,

At the illuminance level 650 lx, energy consumption is calculated to be

= 136W (by using lx to watt converter)

Where, E_v is illuminance, A is the surface area and η is the luminous efficacy

At the illuminance level 750lx, energy consumption is,

=157W

Power requirement is different in these two scenarios,

=157. 08W-136.14W

=20W

It is shown that, if illuminance is changed energy can also be saved as above calculation.

4.7.2. Energy consumption and fabric density

According to the fabric type, energy consumption of the lighting system is changed. There are different types of densities according to the fabric type. In addition to this, the same fabric has different densities because of manufacturing composition. This density change causes for the different light absorption and reflectance and needs different illuminance for various fabric. As a result, the energy consumption is also changed. As an example, there were experimental details as mentioned below in Table 4.3 and Figure 4.5.

Table 4.3: Density vs. energy

Areal Density(kg/m)	**Energy(J)**
0.17	5.56
0.34	12.57
0.51	18.67
0.68	27.04
0.85	28.42
1.02	35.2

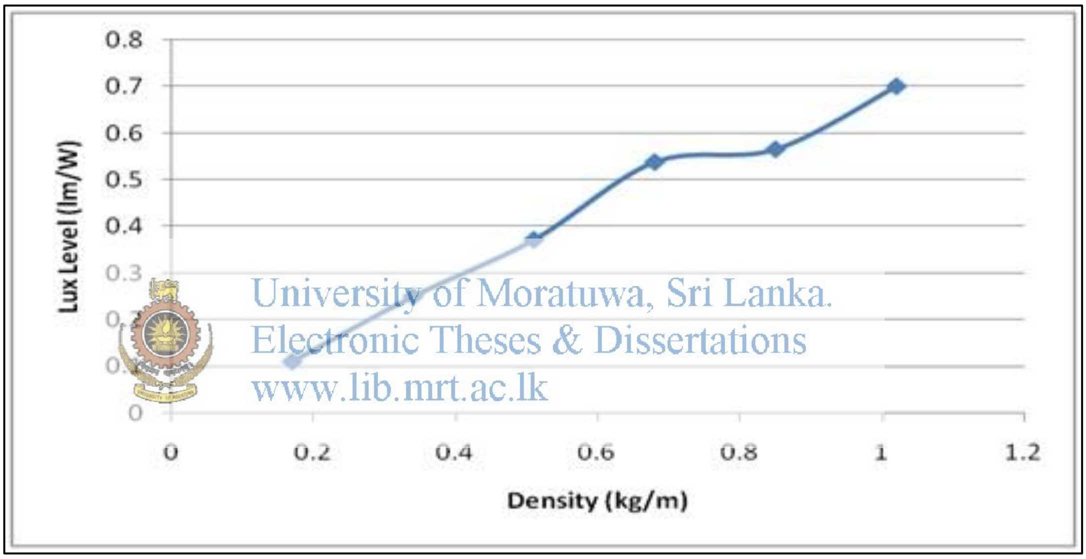

Figure 4.5: Density vsilluminance

In conclusion, densities have been changed in the same manner and, therefore energy consumption can be calculated by using Equations 2.8, 2.9, 2.10and 4.1. Then it is clear that the illuminance is changed with the density of the fabric according to the Figure 4.5. As shown by line graph, illuminance is varied linearly with the densities. In contrast with the Table 4.3 as shown above, data can be calculated and transferred as illuminance to energy level, density to energy as shown in Figures 4.6 and 4.7.Those figures are also changed in a similar pattern as in Figure 4.5. By taking into consideration of Figure 4.5, 4.6 and 4.7, the final judgment can be foreseen. Accordingly linear changes can be resulted as lighting properties are related each other. Hence, densities are affected to the energy consumption of the fabric. It is proven, if the fabric density is different, in return energy consumption is also changed as well.

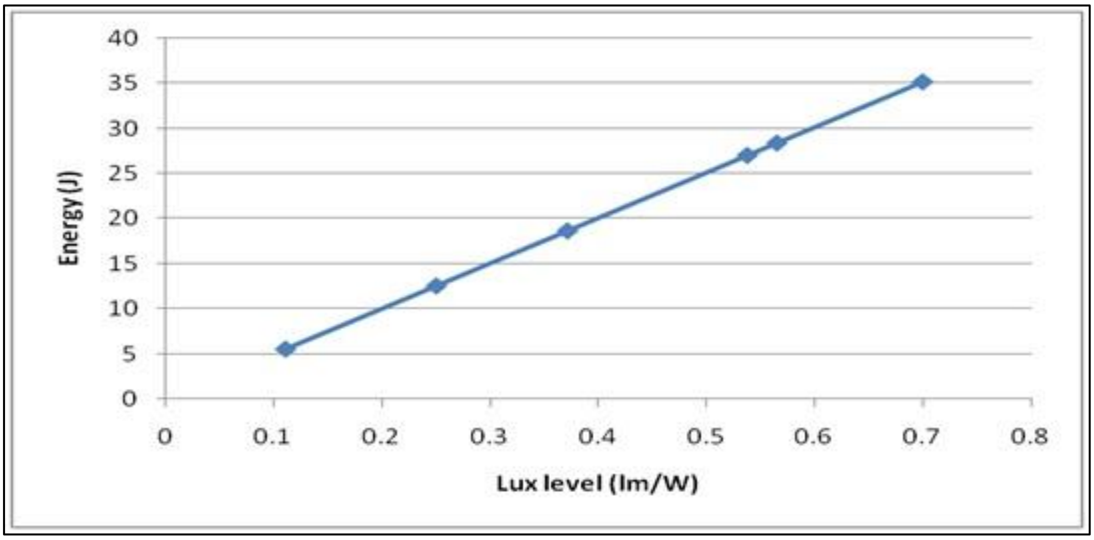

Figure 4.6: illuminancevs. energy

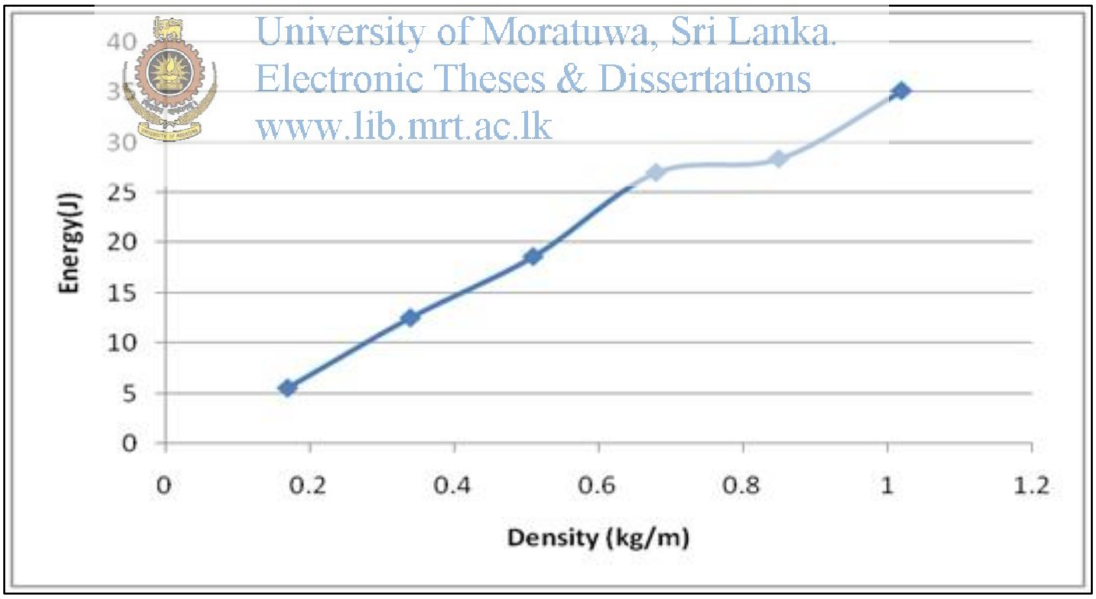

Figure 4.7: Density vs. energy

4.7.3. **Energy consumption and colour variation**

There are different colours available in textile fabrics where. These colours have different wavelength as given below. In addition to the wavelength, there are other parameters for different energy consumption depending on colour relations, as shown in Figures 4.8 and 4.9.

Figure 4.8: Same fabric colour for differentsight in human eyes

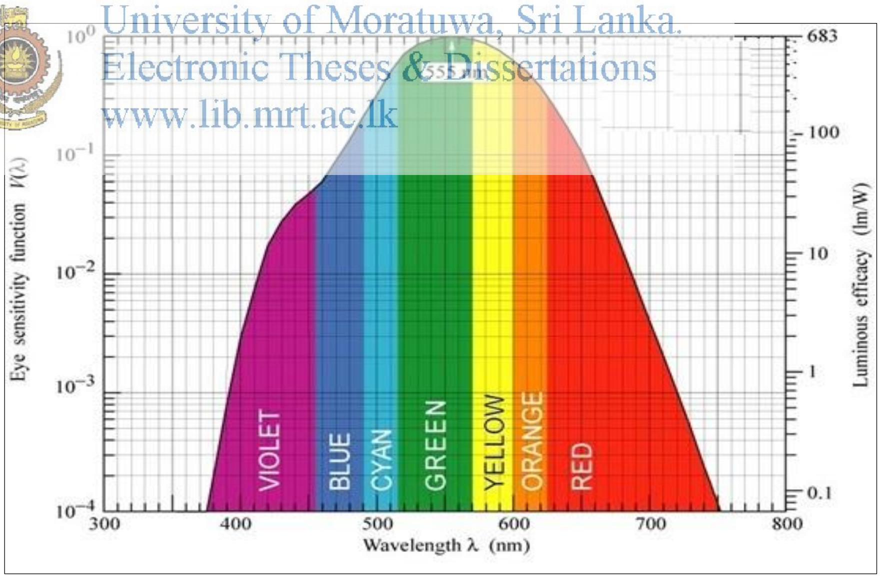

Figure 4.9: Wavelength vs. eye sensitivity vs. luminous efficacy [18]

The photopic efficacy curve was extrapolated from the test done on 'Standard Observers' as shown in Table 4.4. The relative sensitivity curve is illustrated in Figure 4.10.

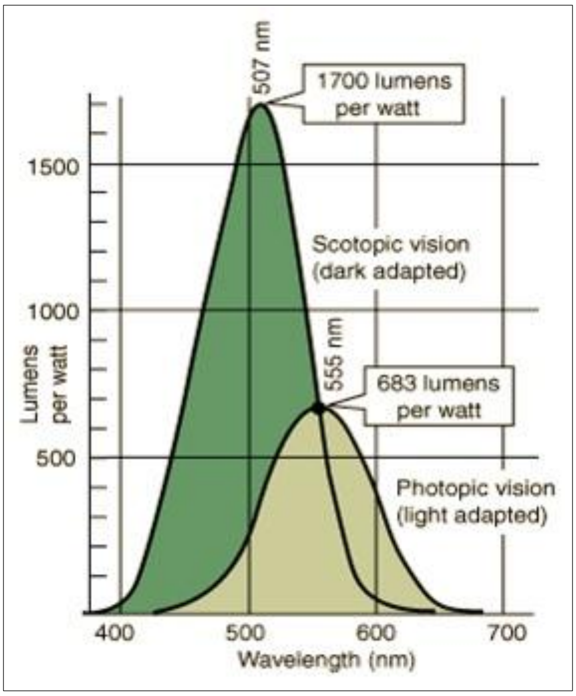

Figure 4.10: Eye sensitivity, luminous efficacy vs. wavelength [30]

As an example, at the 400 wavelength it needs 550 lx and at the 650 wavelength it needs 750 lx.

Using Equations 2.4, 2.5 and2.6 and following experimental data in Table 4.4, energy losses can be calculated as mentioned in following method.

Table 4.4: Wavelength, eye sensitivity function and power spectral density

Wavelength(λ)	**Eye sensitivity function V(λ)**	**Power spectral density P(λ)**
625-740	0.003	2.8×10^{12}
590-625	0.06	2.8×10^{13}
440-485	0.46	2.8×10^{14}
380-440	0.94	2.8×10^{15}
565-590	0.57	2.8×10^{16}

From Equation 2.3,

$$\emptyset_{lum} = 683 \frac{lm}{W} \int_{\lambda} V(\lambda)\, P(\lambda)\, d\lambda$$

From using above Table 4.4 data,

$$V(\lambda) = -0.79\ln(\lambda) - 0.2 \quad (4.2)$$

$$P(\lambda) = 10^{10}\lambda^3 - 2\times10^{13}\lambda^2 + 10^{16}\lambda - 2\times10^{18} \quad (4.3)$$

$$\emptyset_{lum} = 683\frac{lm}{W}\int_\lambda (-0.79\ln(\lambda) - 0.199)(10^{10}\lambda^3 - 2\times10^{13}\lambda^2 + 10^{16}\lambda - 2\times10^{18})d\lambda \quad (4.4)$$

$$\emptyset = 683\{\frac{\lambda^4}{16}(-7.9\times10^9)(4\ln(\lambda)-1) + \frac{\lambda^3}{9}(1.58\times10^{13})(3\ln(\lambda)-1) + \frac{\lambda^2}{4}(7.9\times10^{15})(2\ln(\lambda)-1) + \lambda\ln(\lambda)-1) + \frac{\lambda^4}{4}(-1.9\times10^9) + \frac{\lambda^3}{3}(3.98\times10^{13}) + \frac{\lambda^2}{2}(-1.99\times10^{15}) + 3.98\times10^{18}\lambda\}\lambda^2\lambda \quad (4.4)$$

Then, $\emptyset$lum was calculated by substituting λ values to Equation 4.4 and the way of changing the illuminance was identified according to the wavelength. According to the value of wavelength, illuminance is changed, hence it must be the cause for variation of the energy consumption.

4.7.4. Case study analysis

Analysis of data from the case study revealed the following results.

- After modification of the lighting system, illuminance was 750 illuminance level equally distributed in the sewing flow.
- Energy losses were reduced in sewing area by 3700 kWh per month
- Eye fatigue was reduced Likert scale based from 13-point to 11-point. Crew Alert fatigue risk management tool is used for quantifying current fatigue levels.
- Due to the changes in the lighting system and workplace arrangement, the electricity bill was reduced by Rs 85,000 per month.

4.8. Limitation of the study

When calculating the energy loss and energy consumption, there are limitations to be considered. Otherwise, following changes might occur.

- Height of the lighting system was kept unchanged.
- The color rendering index (CRI) is a quantitative measure of the ability of a light source to reveal the colors of various objects reliably in comparison with an ideal or natural light source. However in this research, the light source was kept constant because the CRI does not have an effect on sewing operations as it requires colour contrast rather than colour recognition.

CHAPTER 5: CONCLUSION AND FUTURE WORK

This study was carried out to analyse the required lighting levels suit to fabric type and colours in the garment industry. The lighting standards which are available in garment industry are made according to the compliance rules and regulations. Standards are confirmed within the same range. However, available lighting systems in garment factories cannot be changed the lighting levels after once they are installed. According to the garment industry they sew different types of garments and use different types of fabrics and colours according to the customer demand. Consistent with the research analysis of this study, there are some kinds of lighting levels that need to be changed along with the fabric types and colours. This situation is observed in garment industry as they are using useless and inappropriate lighting levels. But it will be an energy loss in many ways and harmful to eyesby leading to eye fatigue as well.

The lighting absorption and reflection vary according to the fabric type and colours. Because of this reason there should be different lighting levels as well. If lighting level is higher than the requirement of the appropriate level. There will be energy losses and safety issue with eyes as well, because of lighting level changes effect to the energy losses and eye fatigue.

If the illuminance is changed from the maximum standard level to the minimum standard level in a 1m × 1m floor area, the energy saving that can be achieved is42 Wh per hour. In addition to that, if the illuminance is changed for the colour, the energy saving potential is shown in Table 5.1.

Table 5.1: Energy saving per lighting unit (with wavelength)

Colour	Wavelength(nm)	Energy consumption (W)	Average energy saving during an 8 hour shift (sewing area) (E_{max}- E) (Wh)
Black	740-800	80-100	000
Red	625-740	60-80	160
Yellow	565-900	40-60	320
Green	500-565	20-40	480
Blue	440-485	10-20	640

As shown in the Table No:,5.1 energy saving potential is minimum for red colour. However, for the same fabric colour the energy consumption is changed according to the fabric density as shown in the Table No:5.2

Table 5.2: Energy saving per lighting unit (with density) for a Red colour fabric

Density(kg/m)	Energy consumption (Wh)floor area 1 m x 1 m
1.02	280
0.85	224
0.51	144
0.34	96

Lighting system and illuminance directly effects to the energy consumption. Higher the illuminance is, it is higher the energy consumption and when lower the illuminance, lower the illuminance is the energy consumption is lower as well. Therefore, if somewhere in appropriate use of illuminance in workplaces, lighting level should be changed to an appropriate level. Then, the energy can be saved and the safety standards in relation to eye hazards can be maintained.

Different types of fabrics have different levels of densities. According to this mechanism the fabric property affects to the change the level of energy absorption and lighting reflection. Therefore different fabric needs different levels of energy and different illuminance to maintain the unity intensity with every fabric. Therefore, illuminance should be changed according to the available scenario of fabric types and the standard of intensity can be maintained for all types of fabrics. According to the standard of intensity, energy losses can be saved and hazards can be avoided as well.

Different colours of fabrics have different levels of wavelengths according to the change of wavelength the level of energy absorption and lighting reflection are changed as well. Therefore different fabric colours need different energy levels and different illuminance to maintain the equal intensity with every colour of fabrics. Hence according to the available scenario of fabric colour, illuminance should be changed then, the standard of intensity can be maintained for all colour of fabrics. In consistent with standard of intensity, energy losses can be saved and hazards can be kept away.

By considering the above recommendations, available standard for the garment industry would be changed. Because these recommendations are included with situation of the employees' perspectives, available lighting systems, illuminance, fabric type and fabric colour as well. But some more future works should be followed. According to this research and analysis, it needs to consider collecting more information and data for developing the lighting level for maintaining the energy losses and safety hazards. As mentioned in following details before changing the standards and collecting more information and data for developing the lighting level for maintaining the energy losses and safety hazards.

To do a research for different fabric wise employees' perspectives and classify the fabric reactions and characteristics with lighting level. There are so many differences with the material wise density of fabrics. In addition, the fabric appearances also change according to the type of fabric. These types of characteristics effect on lighting absorption and reflection, hence data should be collected from employees to clarify their perspectives and practical data should also be gathered for analyzing of the real situation and to confirm the standard for changing with the type of fabrics. Then, changes can be finalized along with the fabric wise lighting effect and standards can be referred for relevant materials according to the requirements.

There is a need to conduct research for different colours to obtain employees' perspectives and classify the reactions with lighting level. There are so many colour differences with the material. These colours have different wavelengths, hence there are different types of characteristic effects of lighting absorption and reflection. Hence, it needs a different illuminance of quality and safety visibility. Due to these reasons, data should be collected from employees to clarify their perspectives. Practical data should be accumulated to analyse real situations and confirm the standard inconformity with the fabric colour with light. Then, changes can be finalized in relation to the fabric colour wise lighting effect and standard can be used for relevant colour according to the requirements.

As the research is carried out to estimate out the amount of energy consumption according to the different fabric types and colour. The final objective of this research is justifying the energy consumption and saving energy. According to the above two research data it needs to estimate the fabric in type wise and colour wise with in the energy consumption by changing the requirements. Then finally it needs to compare those results and employees' perspectives by finalizing the needs of lighting level consistent with the fabric type and colour.

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APPENDIX A: Sensitivity function change

λ(μm)	Vλ
0.39	0.0022
0.4	0.0093
0.41	0.0348
0.42	0.0966
0.43	0.1998
0.44	0.3281
0.45	0.455
0.46	0.5672
0.47	0.6756
0.48	0.793
0.49	0.9043
0.5	0.9817
0.51	0.9966
0.52	0.9352
0.53	0.811
0.54	0.6497
0.55	0.4808
0.56	0.3288
0.57	0.2076
0.58	0.1212
0.59	0.0655
0.6	0.0332
0.61	0.0159
0.62	0.0074
0.63	0.0033
0.64	0.0015
0.65	0.0007
0.66	0.0003
0.67	0.0001
0.68	0.0001
0.69	0
0.7	0
0.71	0
0.72	0
0.73	0
0.74	0
0.75	0
0.76	0
0.77	0

APPENDIX B:Questionnaire

Relationship among
fabric types, fabric colours and illuminance level in garment industry
for energy saving and eye fatigue

Name of the Factory -..

1) What is your daily responsible duty in the factory?

   ....

2) Are you satisfied with the intensity of light to perform your duty well in your section?

   ....

3) Have you ever worked in any other garment factory?

   ....

4) If you have worked somewhere else, what can you say about the intensity of light in the present and previous factories?

   ....

   ....

5) Explain your answer for question no4) above.

   ....

   ....

   ....

6) Do you agree with the fact that the intensity of light should be changed according to the type and colour of the fabric?

   ....

7) Do you agree with the fact that the intensity of light should be increased for dark colours?

   ....

8) Do you agree with the fact that the intensity of light should be increased for light colours?

....

9) Is it good to have a spot light?

....

10) Is the bulb too closer to you?.

....

11) Is it good to have an upper light?

....

APPENDIX C: Questionnaire responses

	Q2	Yes	No	No answer	**Q6**	Yes	No	No answer	**Q7**	Yes	No	No answer	**Q8**	Yes	No	No answer	**Q9**	Yes	No	No answer	**Q10**	Yes	No	No answer	**Q11**	Yes	No	No answer
	Yes	1	0	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	Yes	1	0	0	No	0	1	0	Yes	1	0	0
	Yes	1	0	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0		0	0	1	No	0	1	0	Yes	1	0	0
	Yes	1	0	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0		0	0	1	No	0	1	0	Yes	1	0	0
	Yes	1	0	0		0	0	1	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	Yes	1	0	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	Yes	1	0	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	Yes	1	0	0	Yes	1	0	0		0	0	1		0	0	1	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0		0	0	1	Yes	1	0	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	Yes	1	0	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	Yes	1	0	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0		0	0	1	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0

	Yes	1	0	0	Yes	1	0	0		0	0	1		0	0	1	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0		0	0	1		0	0	1	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0		0	0	1		0	0	1		0	0	1	No	0	1	0	Yes	1	0	0
	Yes	1	0	0	Yes	1	0	0		0	0	1	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	Yes	1	0	0		0	0	1	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	Yes	1	0	0		0	0	1	Yes	1	0	0	No	0	1	0		0	0	1	No	0	1	0		0	0	1
	Yes	1	0	0		0	0	1	Yes	1	0	0	No	0	1	0		0	0	1	No	0	1	0	Yes	1	0	0
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	Yes	1	0	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
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	No	1	0	0		0	0	1	Yes	1	0	0	No	0	1	0	Yes	1	0	0	No	0	1	0	Yes	1	0	0
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	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
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	Yes	1	0	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
	No	0	1	0	Yes	1	0	0	Yes	1	0	0	No	0	1	0	No	0	1	0	No	0	1	0	Yes	1	0	0
QTY		**293**	**197**	**25**		**494**	**0**	**21**		**470**	**0**	**45**		**0**	**482**	**33**		**60**	**403**	**52**		**0**	**515**	**0**		**463**	**0**	**52**
%		**57**	**38**	**5**		**96**	**0**	**4**		**91**	**0**	**9**		**0**	**94**	**6**		**12**	**78**	**10**		**0**	**100**	**0**		**90**	**0**	**10**

APPENDIX D: Available illuminance levels in factories

Name of factory	illuminance level (lx)
I	1000
II	1000
III	750
IV	650
V	800

APPENDIX E: Fabric density testing report

Material Content (Face)	Primary Weight (g/M^3)	Fabric Width (M)	Yarn Count (Nec)	Density (Warp/Weft)	Yarn Type
100% Polyester	72.00	53.00	50dx50d	158x120	DTYxDTY
100% Polyester	72.00	53.00	50dx50d	158x120	DTYxDTY
100% Nylon	98.00	57.00	70D/48FX50D/96F*2PLY	121X110	FD Nylon Woolly X FD Nylon Textured
100% Polyester	140.00	56.00	75D X 75D	224 X 110	WP: P.MEMORY 75D FILAMENT WT: P.75D FILAMENT YARN
100% Nylon	51.00	57.00	30D/24FX30D/24F	193X157	SD Nylon Filament X SD Nylon Filament
100% Nylon	46.00	58.00	40D/10FX40D/10F	125X113	SD Nylon Filament X SDnylon Filament
100% Nylon	45.00	58.00	40D/10F X 40D/10F	125 X 113	SD FILAMENT

100% Nylon	45.00	60.00	40D/10F	120 X120	SD Nylon Filament x SD Nylon Filament
100% Polyester	85.00	60.00	55D/192FX55D/192F	186X125	
100% Polyester	85.00	60.00	55D/192FX55D/192F	186X125	SD Polyester Woolly X SD Polyester Woolly
100% Cotton	230.00	56.00	20 X 20	96 X 92	Combed X Combed
98% Polyester, 2% Elastane	176.00	55.00	SP30/1 x 150D/144 + 40DOP + 150D/144	115 x 85	Polyester Spun x Polyester + Elastane + Polyester
100% Polyester	137.00	55.00	75D/72F X 160D/72F	142 X 72	FD POLYESTER DTY X FD POLYESTER ATY
100% Nylon	35.00	57.00	15d/5f x 15d/5f + 40d/34f	233 X 164	Nylon Textured Yarn
100% Cotton	175.00	55.00	2/30 X 2/30	54 X 52	Combed X Combed

70% Polynosic Modal, 30% Polyester	157.00	56.00	(MODAL30'S+P150/48)X(MODAL30`S+MODAL30` S/2)	115 X 58	MODALXPOLYESTER FILAMENT
100% Cotton	160.00	55.00	20 X 20	66 X 62	Combed x Combed
70% Cotton, 30% Viscose	112.00	56.00	40 X 40	100 X 80	Compact X Compact
100% Nylon	260.00	58.00	(210D/48Fx2+N70D/68F) x (N/F210D/48Fx2+N/F70-D/68f)	54 X 35	Nylon Filament
100% Polyester	292.00	53.00	75D X 75D	129X104	SD DTY x SD DTY
100% Polyester	137.00	55.00	75D/72F x 160D/72F	142 X 72	FD Polyester DTY x FD Polyester ATY
93.0% Polyester, 7.0% Elastane	280.00	53.00	(75D/72f+40D)x(300D/144 f+75D/72f+40D)	156 X168	(semidull DTY+OP) X (cantonicDTY+semidull DTY+OP)
100% Nylon	136.00	57.00	320T	70X90	

100% Polyester	43.00	55.00	NE20/24FD*NE20/24FD	239X188	
89% Polyester, 9% Rayon, 2.0% Elastane	357.00	56.00	300DX28/2+40D	104 X 80	
100% Polyester	60.00	58.00	68X68	117X85	
100% Polyester	70.00	59.00	68x68	117X85	
100% Nylon	35.00	57.00	15d/5f x 15d/5f + 40d/34f	233 X 164	Nylon Textured Yarn
95% Polyester, 5% Elastane	182.00	57.00	30/1 X 30/1 +70d	112 X 76	spun poly X spun poly + Lycra
100% Nylon	114.00	57.00	70D/48FX160D/96F	115X65	FD Nylon Filament X FD Nylon Textured
100% Polyester	70.00	56.00	50D/72FX50D/72F	167X129	

100% Polyester	228.00	58.00	POLY 600d/144 F x POLY 600d/144 F	44 X 28	SD Polyester X SD Polyester DTY
100% Polyurethane	0.00	0.00			
100% Nylon	250.00	58.00	420D	66/41	
100% Nylon	175.00	58.00	FILAMENT	58 X 38	400D/72F SD X 400D/72F SD
100% Nylon	240.00	58.00	N/420D(SD) X N/420D(SD)	64 X 40	SD NYLON FILAMENT X SD NYLON FILAMENT
100% Nylon	111.00	55.00	70D(48F) x 120D(96F)	166 X 98	FD FLAMENT x FD ATY
100% Nylon	112.00	57.00	70D (48F) X 120D (96F)	163 X 95	FD FLAMENT X FD ATY
100% Nylon	113.00	58.00	70D/34F x 110D/96F	168 X 101	FD Filament Nylon x FD ATY Nylon

100% Nylon	113.00	56.00	70D(48F)x120D(96F)	161 X 98	FD FLAMENT x FD ATY
100% Polyester	228.00	58.00	POLY 600d/144 F x POLY 600d/144 F	44 X 28	SD Polyester X SD Polyester DTY
80% Polyester, 20% Polyurethane	320.00	52.00			
100% Cotton	90.00	55.00	40 Slub X 40 Slub	72 X 72	Combed X Combed
100% Nylon	230.00	58.00	200D/34f X 200D/34f	65TX55T	210DX210D
100% Nylon	79.00	53.00	15d/5f+40d/34f x 15d/5f+40d/34f	208 X 156	SD Nylon wooly + Bright Nylon filament x SD Nylon wooly + Bright Nylon filament
100% Nylon	86.00	55.00	N15/5 SD DT N50/48 SD FIL X N15/5 SD DTY50/48 SD FIL	250 X 174	Nylon Filmaent SD DTY X Nylon Filmaent SD DTY
100% Nylon	96.00	56.00	N15DxN15D		Filament

100% Polyester	180.00	57.00	150d/144f x 175d/144f	142 X 84	Poly DTY x Poly DTY
74% Cotton, 26% Polyester	255.00	57.00	10XT300	84X46	Open End
100% Polyester	228.00	58.00	POLY 600d/144 F x POLY 600d/144 F	44 X 28	SD Polyester X SD Polyester DTY
85% Modacrylic, 15% Polyester	790.00	58.00	acrylic 3dx76mm, acrylic 3dx51mm, acrylic 3dx38mm, polyester dty 150dx36f		