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Experimental Investigation of Visual Comfort Requirement in Garment Factories and Identify the Cost Saving Opportunities

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Abstract**—**Visual comfort is one of the major parameters that can be taken to measure the human comfort in any environment. If the provided illuminance level in a working environment does not meet the workers visual comfort, it will lead to eye-strain, fatigue, headache, stress, accidents and finally, poor productivity. However, improvements in lighting do not necessarily mean that the workplace requires more light. Unnecessarily higher illuminance levels will also cause poor visual comfort and health risks. In addition, more power consumption on lighting will also result in higher energy costs. So, during this study, visual comfort and the illuminance requirement for the workers in textile/apparel industry were studied to perform different tasks (i.e. cutting, sewing and knitting) at their workplace. Experimental studies were designed to identify the optimum illuminance requirement depending upon the varied fabric colour and type and finally, energy saving potentials due to controlled illuminance level depending on the workforce requirement were analysed. Visual performance of workers during the sewing operation was studied using the 'landolt ring experiment'. It was revealed that around 36.3% of the workers would like to work if the illuminance level varies from 601 lux to 850 lux illuminance level and 45.9% of the workers are not happy to work if the illuminance level reduces less than 600 lux and greater than 850 lux. Moreover, more than 65% of the workers who do not satisfy with the existing illuminance levels of the production floors suggested that they have headache, eye diseases, or both diseases due to poor visual comfort. In addition, findings of the energy analysis revealed that the energy-saving potential of 5%, 10%, 24%, 8% and 16% can be anticipated for fabric colours, red, blue, yellow, black and white respectively, when the 800 lux is the prevailing illuminance level for sewing operation.

Keywords**—**Landolt ring experiment, lighting energy consumption, illuminance, textile and apparel industry, visual comfort.

I. Introduction

PEOPLE receive majority of their information through their sense of sight. To spend the life conveniently, they need to see the surrounding, which is supported by lighting. The lighting requirement for a given space can be provided by either natural daylight or by artificial lights. A well designed and visually comfortable environment makes people happy and energize, and it reduces the lighting energy consumption [1], [2]. Moreover, visual comfort is a major fact that decides the performance and productivity of a person who is doing any task in a working environment. Human visual comfort is affected by several parameters such as glare/flicker, illuminance level, illuminance ratios and uniformities, colour rendering index (cri) and correlated colour temperature (cct) [3].

A recent research has revealed that lighting has a clear impact on human health and well-being in a workplace [4]. By providing the correct lighting level, employees will be more comfortable in their working environment, and hence, they are more productive. Human health, well-being, mood, alertness and sleep patterns are directly affected by changing lights. The 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 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 help to sleep prolonged where suppressed levels can cause insomnia. Human happiness or mood is adversely affected by a deficiency of serotonin, which is produced by the brain when melatonin levels are low [4], [5].

Appropriate lighting without glare and shadows can reduce eye-strain, eye fatigue, stress, headache and migraine of the people and, lead to avoid the accidents and other hazards due to 'momentary blindness due to poor concentration' of the people in an industrial environment [3]. According to industrial ergonomics, the visual comfort and the 'ability to see' of a human depends on several factors and are visual acuity, quality of illumination, size and shape of the object, colour and contrast and relative speed of the object [6]. Therefore, it is essential to provide the required visual comfort and understand the different lighting requirement for a given specific environment, e.g. homes, offices, and factories.

The choice of the wall colour in a given environment is also important, because dark surfaces reflect very little light, whereas bright colours reflect more light. As a result, different amounts of artificial or natural lights are required to provide the same visual comfort levels [7]. Unlike in other industries, when considering a garment factory, fabric types and fabric colours are dynamically vary without changing the

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surrounding wall colours of the space and the lighting levels provided by the luminaires. As a result, the visual comfort of the employees in the workplace also dynamically varies and can cause accidents, injuries and also reduces the performance and productivity. In garment industry, some lighting standards are used for different workplaces, for an example 300-750 lux is required in weaving areas [8]. However, changes of illuminance levels according to the fabric colour and fabric type and, resulting effects on employee's visual comfort have not been considered in anywhere. Moreover, increment of lighting levels without considering the visual comfort can lead to consume more electricity, which become wasted energy, while decreasing the productivity of the workers and eventually, reduces the profit of the industry due to unnecessary and excess energy bills.

The textile and garment industry in Sri Lanka has demonstrated a tremendous growth over the past four decades and today, has become the country's primary foreign exchange earning sector, amounting 40% of the total exports and 52% of total industrial exports [9]. Therefore, it is vital to conduct a critical study to understand the required illuminance levels and visual comfort to enhance the performance and productivity of the employees and eventually reduce the building energy consumption.

II. Lighting Systems

Lighting systems can be designed for three main purposes which are *task lighting* to perform different visual functions, *general lighting* for ambient lighting due to unavailability of daylight, and *accent lighting* for decorative and emotional purposes. Main attention is given for *task lighting* when designing a lighting system for a production/working environment.

A. Basic Parameters Used in Lighting

Familiarizing with the parameters used in lighting is very essential. Fig. 1 shows how the lighting parameters are related to each other, and Table I shows the definitions of them.

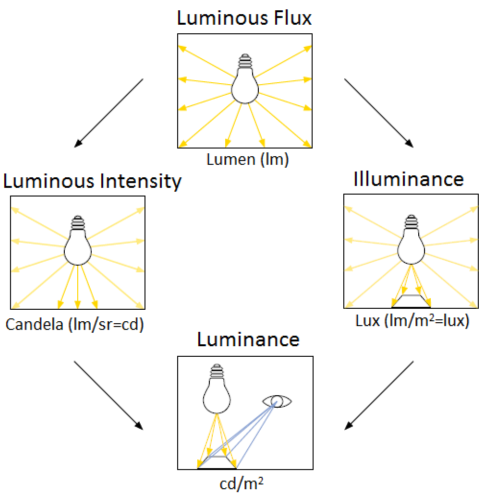

Fig. 1 Relationships of the lighting parameters [10]

TABLE I
Definitions of Basic Lighting Parameters

Luminance flux	The quantity of light emitted by a light source
Luminance efficacy	The ratio of luminance flux to the electrical power
Luminous Intensity	The quantity of light that is radiated in a particular direction
Illuminance	The quantity of luminous flux on a surface
Luminance	Only parameter that is perceived by the eye. It specifies the brightness of a surface and is essentially dependent on its reflectance (depends on the surface finish and the colour)

As shown in Fig. 1 and the definitions in the table, visual comfort of a worker is decided by the *luminance level*, which is highly depended not only on the light source but also the surface finish and the colour. Fig. 2 shows that the reflectance of a surface is highly dependent on the surface colour. However, the reflecting wavelengths are different from each other.

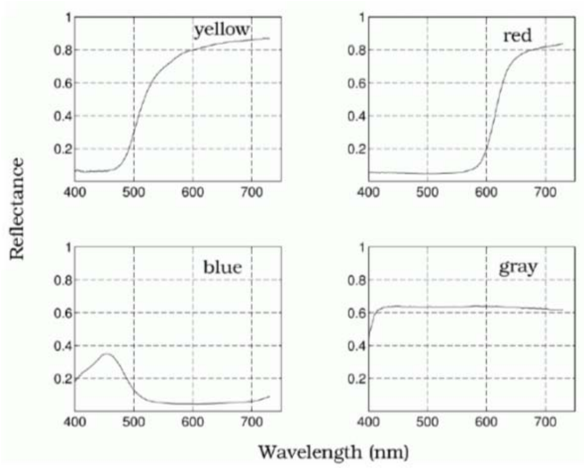

Fig. 2 Surface reflection for different surface colours [11]

When designing the task lighting for a working environment in an apparel company, it should be very thoughtful as the visual comfort of the employee is highly dependent on the fabric colour and the fabric material, which essentially decides the amount of lighting level incident on the eye. The worker might find it difficult to work with different fabric colours with a fixed lighting source which provides a constant illuminance level throughout, which could result highly varied luminance levels incident on the eye. This has been identified as one of the main analyses for this study.

B. Importance of Quantity and Quality of Light Sources

Selection of a light source is dependent on both the quantity and quality. Efficiency of a light source is defined by 'luminous efficacy', which is the ratio between the 'lumen output of the light source to the electrical power consumption'. Luminous efficacy of high pressure sodium, florescent and LED (light emitting diodes) lighting sources are higher than the other available lighting sources, and among them, florescent lamps have been identified as the most economical lighting source for such industrial applications.

However, not only quantity, but also quality of the light source should also be carefully examined before the installation. There are two main parameters that can be used to describe the quality of a light source, and they are colour rendering index (CRI – evaluate the ability of a light source to accurately reproduce the colours in comparison to an ideal or natural light source) and the correlated colour temperature (CCT – provides the colour of a given light source and determines whether the light source is warm or cool). It is recommended to use a light source with high CRI and high CCT, when designing a lighting system for '*task lighting*' in a production/working environment. So that, it will make sure that the worker sees the particular object by its natural colour and might find it easier to work under the lighting source for a longer period when providing a cool colour light [11].

III. Investigating the Visual Comfort

It is significantly important that the required lighting system for a production environment should be perfectly designed in order to facilitate the visual comfort of the workers to enhance the productivity as well as identify the cost saving opportunities. So, the following methodology was followed during this study to determine the visual comfort of the workers.

A. Feedbacks from the Employees

As this study is mainly focusing on the apparel industry, it was required to get the genuine feedback from the employees in the apparel industry. Employees of two apparel companies in Sri Lanka were interviewed as the first step of the study. During the experimental study, it was found that the two factories maintain different average illuminance levels in the working premises which are 600 lux and 800 lux. This fact proves that some industries do not maintain the basic lighting standards in their work floors.

A questionnaire was prepared in order to identify whether the workers are satisfied with the provided lighting levels and whether they experience any disease related to work place lighting levels. The given questionnaire explores their (i) personnel data, i.e. gender, age, and illnesses, i.e. eye diseases and headaches, (ii) nature of the working environment, i.e. nature of the work, working hours and finally, (iii) the lighting condition of the work floor, i.e. whether they are satisfied with the existing lighting levels.

Moreover, the workers' satisfaction for different lighting levels was also evaluated by using additional light sources in the work floor. Lighting satisfaction of the workers in Company A (average illuminance 600 lux) was evaluated by varying the illuminance from 451 lux to 700 lux, and for workers in Company B (average illuminance 800 lux) it was tested by varying the illuminance from 700 lux to 1000 lux, in 50-lux increments. The responses from the workers were recorded, analysed, demonstrated in the results and discussion section below.

B. Visual Performance Test

Evaluating the visual comfort is a challenging task as it is a relative and a qualitative parameter, which varies from a person to person. Identifying the visual performance in a working environment is even harder as it is required to identify a common platform. So, one of the standard optotype test methods, e.g. Landolt ring (shown in Fig. 3), Snellen E, Kolt tests (geometric shapes), can be used to conduct the test to identify the visual performance of the workers at different lighting levels [12].

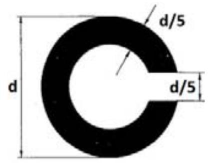

Fig. 3 Standard Landolt Ring used for the testings

Fig. 4 shows an example of a visual test designed based on Landolt-rings to identify the visual performance of the workers. The worker has to identify the similar pattern shown in the top most row, among the patterns given in the column 1 and column 2 starting with row 2 to row 5. Four similar tests were designed and printed on five different colours (red, blue, yellow, black and white) of fabrics. Then, four different types of fabrics used to identify the performance depend on the different densities (type - 1.02 kg/m, type 2 – 0.51 kg/m, type 3 – 0.34 kg/m and type 4 – 0.85 kg/m) to mimic the actual sewing operation in the garment factory. The workers were shown the best ergonomics posture for the sewing operation before starting the test and then, the time consumed to do the Landolt-ring experiment was measured for different lighting conditions. The lux level of the lighting system was varied by 50-lux interval during the test.

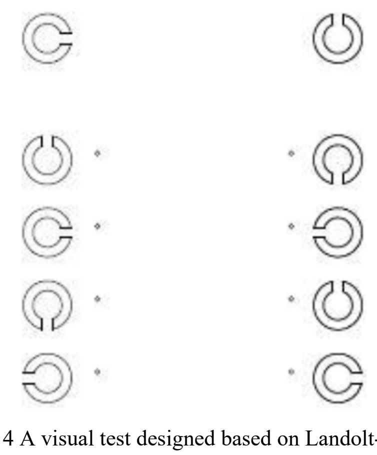

Fig. 4 A visual test designed based on Landolt-Ring

Then, the visual performance of the workers was numerically evaluated using the parameters; visual acuity (shown in (1)), time consumed (measured) and the performance index (shown in (2)) as given below.

$$Visual\ Acuity = \frac{E}{N} = \frac{R - N.p}{N(1-p)} \tag{1}$$

where E – number of correct responses after correction for guessing probability, N - number of presentations, R – measured number of correct responses and p – guessing probability (1/8 for Landolt-ring tests)

$$Performance\ Index = \frac{Visual\ Auity}{Consumed\ Time} \tag{2}$$

The above tests were conducted in an actual working premise of a factory, and the illuminance levels were varied by introducing additional artificial lamps. The results obtained from the study are shown in the results and discussion section given below.

C. Analysing the Energy Saving Opportunities

After obtaining the feedbacks from the workers and the experimental study of the work place illuminance level vs performance, it was required to investigate the energy saving opportunities in the work floor due to lighting, by varying the illuminance levels against the different fabric colours used in the sewing areas. The analysis was performed using the 'REVIT 2016' software.

Simulation was performed for the Apparel Company B, which maintains 800 lux illuminance level in the production floor. Firstly, the work floor of the sewing area was modeled in the software by providing the actual dimension of the building, and then, the light sources were located similar to the actual locations in the factory. Actual power and the lumen output of the light sources were also defined. The power consumption by the lighting system was measured and validated with the results obtained by the software. Finally, the required lighting energy consumption was obtained to maintain a constant light level in the work floor for different fabric colours. The obtained results are shown in the results and discussion section in the below.

IV. Results and Discussion

A. Feedback from the Employees

The feedbacks received from the questionnaires were analysed and tabulated as follows. Table II shows the workers satisfaction for different illuminance levels in the Apparel Company A, which maintains 600 lux uniform illuminance around the working areas, whereas Table III shows the workers' satisfaction for different illuminance levels in the Apparel Company B, which maintains 800 lux.

TABLE II
Workers Satisfaction for Different Lighting Levels – Company A

	451 lux > Ill > 500 lux	501 lux > Ill > 550 lux	551 lux > Ill > 600 lux	Ill > 601 lux	Total
Satisfied	3	1	16	28	48
Unsatisfied	42	35	2	0	79
	Total				127

According to the feedbacks obtained from the workers, it was found that approximately 36.3% of the workers are happy to work if the illuminance level of the working environment is varied from 601 lux to 850 lux. Among the others, 45.9% of the workers do not satisfy and surprisingly, only 17.8% of the workers satisfy to work if the illuminance level is lower than 600 lux and higher than 851 lux. So, excessive illuminance levels do not increase the workers satisfaction or the visual comfort, but it will increase the lighting energy requirement unnecessarily. Moreover, the different diseases that the workers experience were also recorded to identify whether they are work place related diseases as the workers experience different luminance levels. Tables IV and V show the feedbacks from the workers obtained from Apparel Company A and apparel Company B respectively.

TABLE III
Workers Satisfaction for Different Lighting Levels – Company B

	751 lux > Ill > 800 lux	801 lux > Ill > 850 lux	851 lux > Ill > 900 lux	901 lux > Ill > 950 lux	Ill > 951 lux	Total
Satisfied	47	23	18	6	4	98
Unsatisfied	0	0	8	18	19	45
		Total				143

TABLE IV
Workers Satisfaction for Different Lighting Levels – Company A

	Disease Type				Total
	Eye	Headache	Both	No	
Satisfied	11	7	5	25	48
Unsatisfied	24	14	16	25	79
	Total				127

TABLE V
Workers Satisfaction for Different Lighting Levels – Company B

	Disease Type				Total
	Eye	Headache	Both	No	
Satisfied	23	19	5	41	88
Unsatisfied	14	6	15	20	55
	Total				143

Results of the above analysis show that in Company A (where the illuminance is 600 lux), only 47.9% of the workers suffer from any eye disease, headaches, or both among those who are satisfied with the illuminance level. However, 68.4% of the workers suffer from those diseases among those who are unsatisfied with the current illuminance level. On contrary, in Company B (where the illuminance is 800 lux), 53.4% of the workers suffer from above diseases, whereas only 63.6% of the workers suffer from above diseases among those who are unsatisfied with the current illuminance level. Hence, it is proven that those who are unsatisfied with the existing illuminance levels in the both companies experience more diseases (either eye or headache or both) due to poor visual comfort than the others. As suggested in the early explanations of the paper, poor visual comfort may result in poor productivity in the production environment due to poor health conditions of the worker.

B. Visual Performance Test

As explained above, the performance index of the workers was obtained from the Landolt-ring experiment. The results of the analysis obtained for different fabric colours are shown in

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Figs. 5-8. The results show that the performance index of the workers depends on both the fabric colour and the fabric type (density in this study).

It can be seen that the illuminance level provided by the light sources should be reduced to 550 lux, irrespective of the fabric type when working with yellow colour fabrics to improve the worker performance. Higher illuminance levels may increase the luminance level incident on the eye and will reduce the performance of the worker. Similarly, when working with blue, white, black and red, the illuminance levels should be maintained around 650 lux – 700 lux, 635 lux – 725 lux, 700 lux – 725 lux and 750 lux respectively to increase the performance of the workers, so that it ensures that the productivity will increase. Further, the results suggest that the red colour fabric demands more illuminance levels irrespecting of the material type.

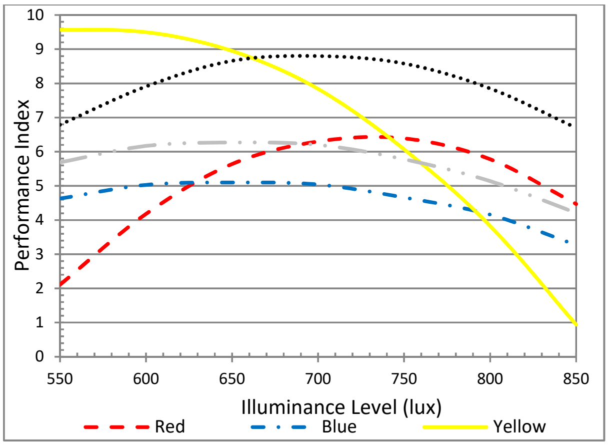

Fig. 5 Landolt Ring results – Fabric type 1

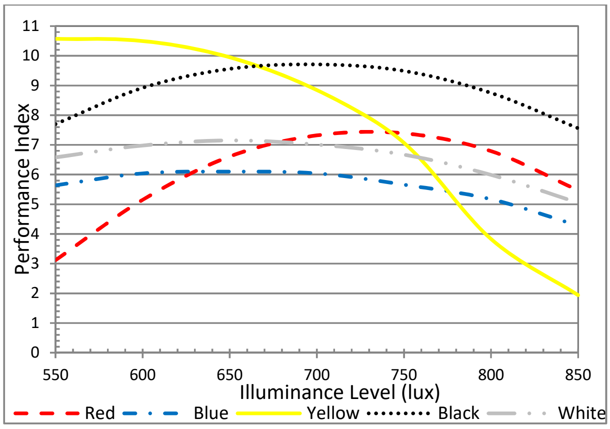

Fig. 6 Landolt Ring results – Fabric type 2

Fig. 9 shows the variation of the performance index for different fabric densities which are type - 1.02 kg/m, type 2 – 0.51 kg/m, type 3 – 0.34 kg/m and type 4 – 0.85 kg/m. Fabric absorbs more light when the density increases and the fabric colour is kept constant. Therefore, high density fabric materials need more illuminance level compared to low density fabrics.

C. Energy Saving Potential

Energy saving potentials when using different colours of fabric by varying the illuminance levels of the working environment is shown in Fig. 10.

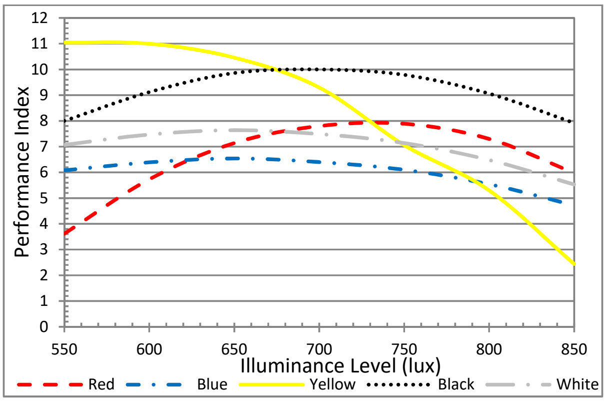

Fig. 7 Landolt Ring results – Fabric type 3

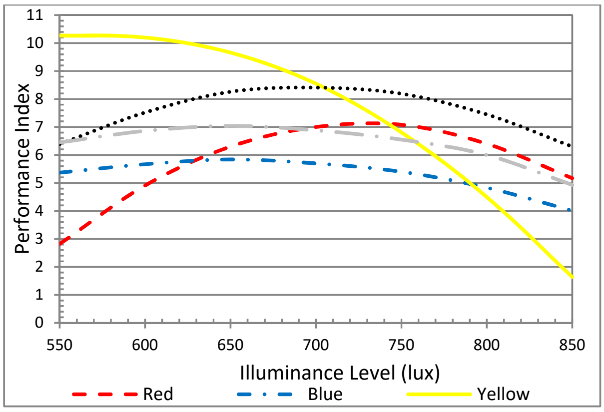

Fig. 8 Landolt Ring results – Fabric type 4

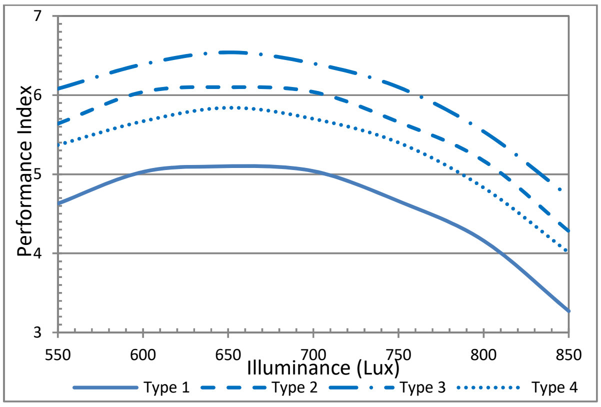

Fig. 9 Landolt Ring results – Blue colour – Different fabrics types

Highest energy saving potential is anticipated for yellow colour as the required illuminance level is lowest while working with yellow colour fabrics, as shown in Fig. 11. On contrary, energy saving potentials is lowest when working with red colour fabrics as the red colour fabrics demands the highest illuminance level. However, the results show that the energy saving potential can be significantly improved if the illuminance level in the work floor varies depending upon the fabric colour used in the production area.

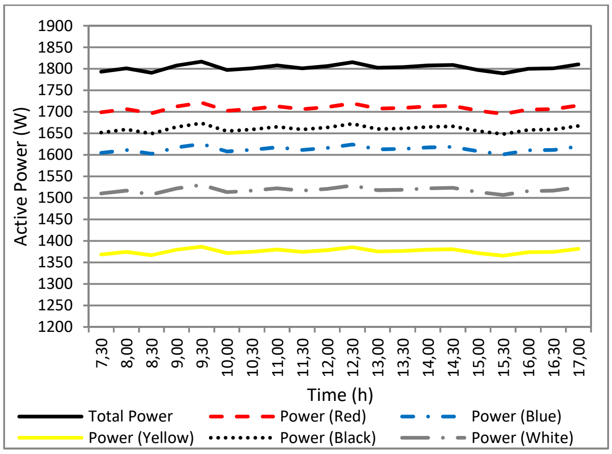

Fig. 10 Expected power consumption for the corresponding fabric colours obtained from the 'REVIT' software simulations

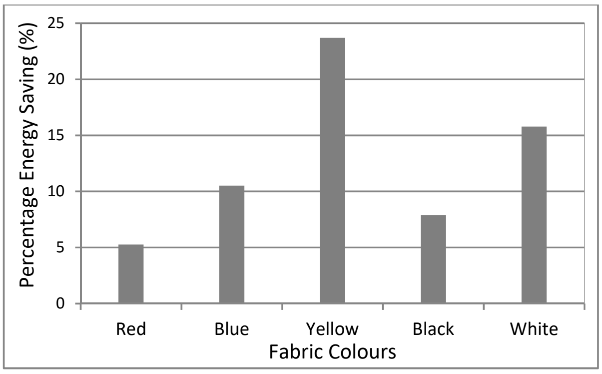

Fig. 11 Energy saving potentials when varying the illuminance level against the different fabric colours

V. FUTURE WORK

This study will extend to identify the optimum illuminance levels for other fabric colours and different fabric types, i.e. different densities, different surface textures. Further, the results obtained from all the analysis can be used to establish an illuminance guideline for textile and apparel industry.

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