The Study of Sunscreen Curtain from PET Bottle Yarn and Its Lighting Quantity for Classroom

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Abstract

Currently, the use of environmentally friendly materials is increasing rapidly, all sectors have been focusing on environmental issues with emphasis on recycled materials. The objective of this research was to produce a yarn from PET plastic bottles (used drinking water bottle) for sunscreen curtains in classroom of Rajamangala University of Technology Thanyaburi. The method of research was based on studying the yarn property of PET plastic bottles of sunscreen curtain with a prototype 0.90 x 1.20m through ASTM and lighting quantity measurement in the classroom. The results found that the yarn property: the mean strength, the mean toughness, the tensile stretch before breaking, and the mean percentage of elongation before breaking was 30.25 N, 5.74 gf/den, 37.46 mm., and 149.83% respectively. Also, the average weight and thickness were 311.87g/m^2 and 0.14 mm. The tensile strength of the warp fabric was 438.14 N and the tensile strength of the weft fabric was 674.79 N. The abrasion resistance of the fabric that can cause the fabric to tear by 11,000 cycles. For lighting quantity measurement in the classroom size of 61.41 m2 found that the average lighting quantity was 265.42 Lux that was below the classroom illuminance standard which is 300 - 500 Lux. However, this was natural lighting measurement without studying activities and artificial light combined. Therefore, further investigation on the factors such as visuality of students while studying, light control, high ceiling, heat transmission is needed to be considered.

Keywords: sunscreen curtain, PET plastic bottles, yarn, lighting, classroom

1. Introduction

Currently, the use of eco-friendly materials is increasing rapidly, all sectors have been focusing on environmental issues with emphasis on biodegradable products (bioplastics) and recycled materials (Sarioglu & Kaynak, 2018). In daily life, humans cannot avoid to be involved with plastics in consumption activities especially drinking water because water is the main composition of human body about 80% (Dils, 2021). According to the statistics on the use of plastic bottles in Thailand in 2019, about 975 million of PET bottles were used. Meanwhile, it takes 450 years per 1 plastic bottle to decompose and only 20% of used plastic bottles were recycled properly (Jangprajak, 2020). Another factor is pollution from plastic bottles; for example, the improper producing and decomposing process produce the toxic gases that affect to human and environment which is one of the causes of global warming at/about 4%. However, in the recycling processes, the used PET bottles undergo extrusion process with extreme effects to humans and environment (Nestle, 2020). To reduce the effects of plastics (PET) recycling processes to environment and cut down the complexed process (Rungreangkaisiri et al., 2018), the cutting and stretching prototype machine to make PET bottles into a yarn was made. The main 2
processes are; first, cutting the bottles with blade to make the flat and thin yard and collecting the yarn in a bale. Then, stretching the yarn with heat to smoothen the edges and reduce the yarn to monofilament-fishing-line size by using a motor driving the yard passing the hot plate which the final process results the small, long and round yarn which is suitable for knitting and weaving to produce the home textiles such as cushion covers, placemats, decorative curtains. Generally, a curtain is a material used for blocking indoor light from windows or doors. Most of the material is made of fabric. The installation of the curtain also serves to preserve privacy but still receiving light according to the needs of the building occupants' activities. Nowadays, curtains come in a variety of shapes, materials, sizes, colors and patterns, which plays an important role in promoting efficiency and atmosphere in the room (Kittikong et al., 2017). Using appropriate lighting curtains in the classroom must be contributing an effective learning. According to physical and facilitate survey in classroom of Faculty of Architecture, it was found that the lighting classrooms were controlled for teaching by installing a synthetic olive-green fabric curtain to block the light from outside. However, the lighting quantity in classroom was high average illuminance of 400 – 500 lux between 9:30 a.m. – 12:00 p.m. with a maximum of 3300 lux, which interferes with visual quality and learning activities as excessive brightness (Wongbumru & Saguansub, 2018). Therefore, the researcher purposed to studying the alternative yarn, which is made from the used PET bottles using the prototype cutting and stretching machine, in order to reuse it in the form of sunscreen curtains instead of polyester fiber. The purposes of the study are: 1) to make the yarn sunscreen curtains produced from Polyethylene Terephthalate bottles which its properties are tested and 2) To measure the natural light quantity in a classroom of Faculty of Architecture, Rajamangala University of Technology Thanyaburi.

2. Literature Review

2.1 Sunscreen Curtain and Properties

Curtain means a piece of material, in general made from cloth, that hangs to make a room or across a window (Royal Institute, 2011). The main purposes of curtain usage are to filter the light, protect from heat coming from solar radiation and glare while retain your privacy. Sunscreen curtain can be produced from polyester woven into dark-colour sheet with raisin coated to make a sunscreen curtain which blocks out light (Inoue, 2015). The thermal curtain using the principle of reflecting heat from a patented aluminium-coated surface can reduce the temperature by 1.7 °C (Woodthanan, 2012). The anti-glare curtain is used as a curtain to eliminate light is more translucent than a sunscreen curtain which can be produced from almost all kinds of fabrics, paper and plastics and etc. Furthermore, there are other types of materials chosen to be used for anti-glare and light-blocking curtains. The usage of any curtains contributes to reduce heat and save energy in a room about 5 – 20% in hot season because of the reduction on the incident solar radiation on surfaces in building which can reduce cooling load in a building (Cengel & Ghajar, 2014). Sunscreen curtain is divided in 3 forms, namely 1) curtains made from natural fibers which are from natural resources such as plants, animals, minerals and rubber 2) curtains made of man-made fibers which are from humans' invention and development to replace natural fibers and meet specific requirements such as polymer fiber and 3) curtains made from other materials such as wood and aluminium (Dollar Curtains & Blinds, 2021).

2.2 Recycling of PET Bottles to Make Yarn

Recycling processes are the best way to economically reduce PET waste (Awaja & Pavel, 2005). With both reduced energy costs and raw material costs, recycling fiber production has become a form of production with a significant economic advantage (Telli et al., 2012) . Two forms of PET bottle recycling are a closed loop and open loop recycling. Closed loop recycling or bottle-to-bottle refers to a product system that recycles post-consumer waste within the same system. Open loop recycling denotes the utilization of recycled material in another product system such as bottle-to-fiber recycling (Plastics Europe, 2015). Rungreangkaisiri et al. (2018) created a cutting and stretching prototype machine to make PET bottles into the yarn. The main 2 processes of prototype machine are to cut the bottles with blade to make the flat and thin yard then collect the yarn. Another process is to stretch the yarn with heat to smoothen the edges and make the yarn to monofilament-fishing-line size by using a motor driving the yarn passing the hot plate which the final process result is a small, long and round yarn which is suitable for knitting and weaving to produce the home textiles such as cushion covers, placemats, decorative curtains. Experiments on a sample weaving machine by using yarn made from plastic bottles as weft and acrylic yarn as warp, it was found that the yarns can be woven into textile products. The outstanding of yarns properties are strong and rather highly durable. (Figure 1)

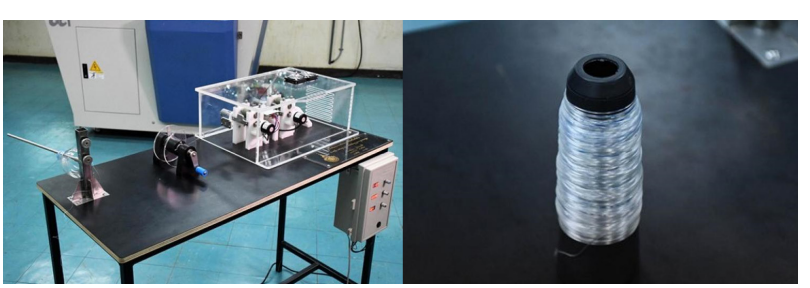


Figure 1. Production process of yarn made from PET bottles (Rungreangkaisiri et al, 2018)

2.3 Standards of Natural Light in a Building

Natural light come from 3 sources as follows: -

1) Natural light from the sun is the natural direct light from the sun.

2) Natural light from the sky is the natural light from sunlight which is passed through the atmosphere and scattered light throughout the sky.

3) Natural light from ground is the light reflected off the ground before it diffuses into the openings inside the building. It averages about 10-15% of the total quantity of light that passes through the openings of the building.

However, the ability to see clearly and correctly must come with comfort while doing everyday activities without over or less little light. In the activity area that has over little light has a negative effect on eyesight (Chirarattananona et al., 2013). Eye muscles are overworked by focusing causing eye fatigue, eye pain, dizziness and decreased work efficiency. On the other hand, if there is too much light, it will cause eye discomfort, eye pain, eye burning, dizziness and possibly accidents, including resulting in reduced work efficiency or may be the cause of disease (Metropolitan Electricity Authority, 2018). The brightness standard was shown in Table 1.

2.4 Reusing Materials for Sunscreen curtains

Khunthong (2019) has designed a curtain made from toddy palm leaves to block the light by experimenting with forming fibers from palm leaves. It was then analyzed to be as a guidance and to select the most suitable method of molding the curtain material. The results found that when fiber from palm leaves is merged with the binding material, it can be utilized. Also, the researcher has defined the concept in terms of curtain properties as follows:
1) The material must allow air to enter and circulate freely in order to have air circulation inside the building 2) Sunlight can pass through the room that is blocked. Sunlight can also allow light to pass through, keeping the room from being too opaque.

Area	Illuminance (LUX)	Area	Illuminance (LUX)
Toilet, Washroom	100	In front of Meeting Stage, In front of Board	700 - 1000
Corridor inside the Building	200	General Area of the Building	200
Meeting Room	200 - 300	Light of the Shops	500 - 1000
Library, Classroom, Laboratory	300 - 500		

Table 1. Information on brightness standards in different areas of schools and convenience stores

3) The material must be able to be seen through to some extent for safety and not to make the room look too uncomfortable. In case using recycled materials by a shield of cut aluminum-cans and a shield of misprinted plastic cards in different colors method for lighting distribution. A daylight meter (Gossen, model Mavolux 5032C), which measures both the room light power (lux) and contrast level (luminance / Candela) were applied. The result found that the aluminum cans spread the light with a great reflection capability than plastic cards (Kastberg & Vestergaard, 2011). According to the study of lighting for the classroom in the Faculty of Architecture Rajamangala University of Technology Srivijaya which focused on the quality and quantity of light in classrooms, the various factors were the opening material, suitable aperture size, types of shading devices, and the appropriate reflectivity of materials such as inside curtain. These would be increasing the amount of internal light to draw more natural light into the building (Sangkakool, 2019). Tusoy et al. (2005) mentioned that to success of recycling plastic wrappers and turned into useful materials, such as curtains and picture frames the students should be involved for creativity and willingness to be practical for saving environments. In case of using bamboo as alternative materials for blind, it found that the illuminance ratio affects the visibility value. Also, high visibility value can be achieved when the illuminance ratio is more than 4.30 (Hariyadi & Fukuda, 2017).

From the above literature review, the researcher purposed to create a screen curtain based on reuse material principle as new alternative sustainability in textile development to reduce environmental impact. A prototype of the bottle cutting and stretching machine patented by Rajamangala University of Technology Thanyaburi (RMUTT) has been applied and the resulting yarn was used in the weaving process using sample loom CCI TECH INC. SL1900 EG and put it to measure the quantity of light in the classroom.

3. Materials, Equipment and Research Methods

3.1 According to threading machine as limited width fabric size of 0.90 meter,

thus researchers determined the style of sunscreen curtains prototype with the size is 0.90 * 1.20 meter. The yarn size is 0.40 millimeters thick, and there is a longitudinal pattern, changing the warp yarn color, the weaving method by using warp yarn from acrylic yarn and weft yarns from recycled plastic drinking bottles (PET). Choosing the curtain color is able to solve the problem of room brightness as well as the environmental adjustments. The curtain color in office or study room should be only plain fabrics color to match the interior and be simple as a room needs atmospheres for thought or concentration of reading a book or working (Ritruechai et al., 2017). The natural monochromatic color tone; white. gray or orange brown is the most appropriate and easiest way to be used in working room or study room with a mid-range color reflection value for visual disturbance (Neuner, 1970). Therefore, the gray acrylic warp yarn was selected with a reflectance of 54percent (white is the highest reflectivity of 86 percent).

Table 2. Materials and equipment

Materials 1) Drinking water bottles, 2) Cutter blade, 3) Acrylic yarn, 4) Adhesive tape
Equipment 1) Scissors, 2) Hot Air Blower PUMPKIN Model J-H2000, 3) Needles for Counting Yarn, 4) 1 inch Diameter Magnifying Glass, 5) Ruler length 30 cm.
Tools 1) Threading machine CCI TECH INC. SW550, 2) Sample Loom CCI TECH INC. SL1900 EG, 3) Bottle Cutting and Stretching Prototype Machine, 4) Thickness tester, 5) 4 Decimal Weighing Scale, 6) Tensile Strength Tester Instron 5566

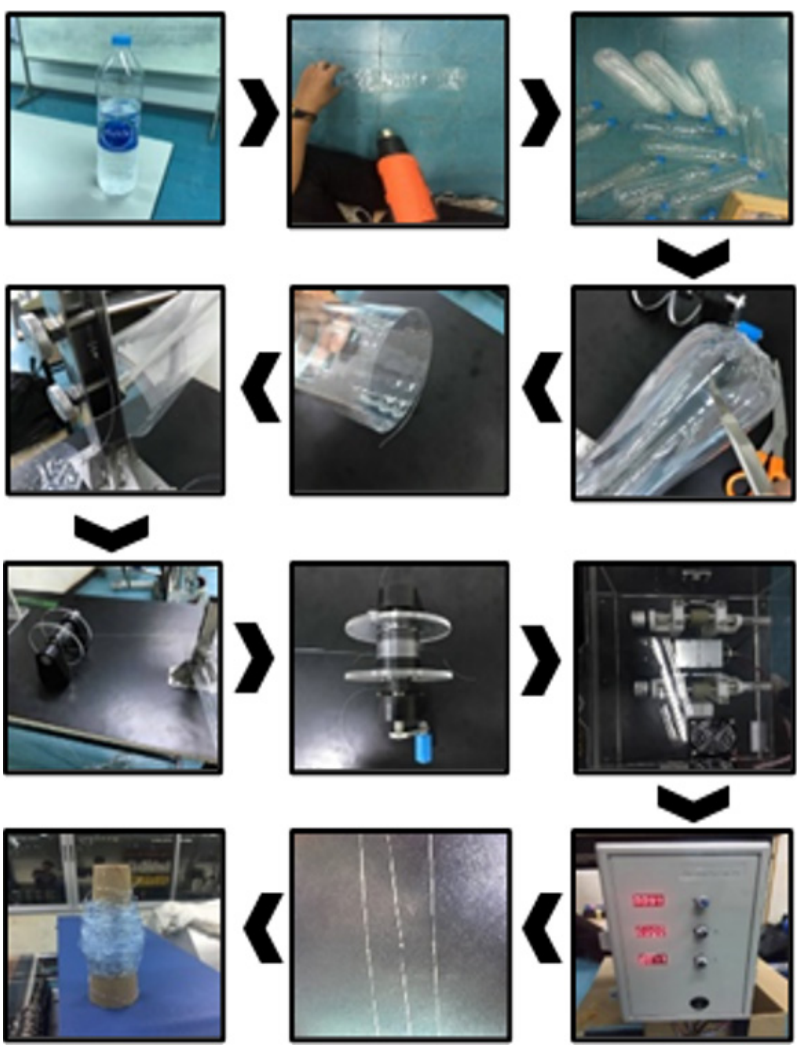


Figure 2. The process of preparing warp and weft yarn made from a PET plastic bottle.

3.2 Materials, equipment, and tools

To make a screen curtain from recycle bottle yarn. All the materials, equipment, and tools were shown in Table 2 and Figure 2.

3.3 Curtain Weaving Test

Design the weave pattern with ArahWeave DEMO program and input the weave pattern on the sample loom CCI TECH INC. SL1900 EG, adjust the weft density 25 threads per inch, weft transmission speed and speed of reed. Start weaving with a sample loom CCI TECH INC. SL1900 EG.

3.4 Measuring Light Quantity in Classroom

The lighting quantity test in the case of no sunscreen curtains and window curtains was closed was performed with the experimental parameters as shown in Table 3.

4. Results and Discussion

4.1 Properties of Plastic Yarn

The prototype sunscreen curtain was made (Figure 3) and tested its properties. The result of the yarns made from the plastic bottles of the curtains according to the standards were the following:

1) Yarn Test Result

After finding the number of yarns made from PET plastic bottles according to ASTM D1059 - 01 (Standard Test Method for Yarn Number Based on Short-Length Specimens) and testing yarn strength with a tensile strength tester in accordance with ASTM 5034. (Standard Test Method for Breaking Strength and Elongation of Textile Fabrics) as shown in Table 4. It was found that the average yarn number made from plastic bottles was 1,986.3 Denier which was larger than acrylic yarn which its average yarn number was 1,157.4 Denier and its average strength was 30.25N. The tenacity was 5.74 gf/den, the mean elongation before break was 37.46 mm. and the mean percentage of elongation before break was 149.83%, less than that of acrylic yarns.

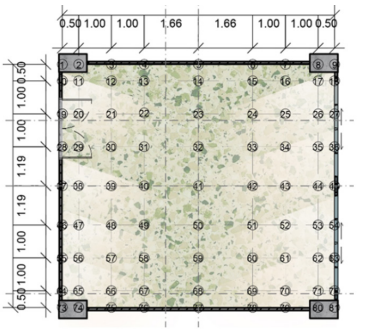
Parameters in Light Quantity Measuring	Unit	Locations of Measuring Lighting Points
Room Size	61.41 square meter	
Window Size	1.2 x 0.80 Meter	
Classroom Illuminance (Measuring Natural Light Only)	Lux	
Height of Lux Meter from Floor of Room	0.75 Meter	
Measurement Spots in Classroom	81 points	
Idle Time Between Measurements to Read the Lux Meter in Each Location	5 – 10 Seconds	
Trial time: 1 Week	08.00 a.m. – 05.00 p.m.	

Table 3. Parameters in light quantity and measuring points

2) Weight and Thickness of Fabric

The woven fabric from plastic bottle yarn was tested according to ASTM D 3776-96 (Standard Test Method for Mass Per Unit Area for Fabric) and ASTM D 1777-96 (Standard Test Method for Thickness of Textile Materials), the average weight was 311.87 g/m2 which was in the heavy range (fabric weight: 213.33 - 308.15 g/m2), while the average thickness of the woven fabric was 0.14 mm. The thickness of the fabric was at a thin level because the thickness was less than 0.23 mm.

3) Thread counts of fabric, Fabric Tensile Strength and Abrasion Resistance

Thread counts of fabric test according to ASTM D3775-98; fabric tensile strength test according to ASTM D5035; Strip test, Tinius Olsen CRE and fabric abrasion resistance test according to ASTM D4966-2012(2016); Option 1, Martindale Abrasion and Pilling Tester, 9Pa Total Pressure was carried out and it was found that the tensile strength of fabric in the warp yarn was 438.14N and the tensile strength of fabric in weft yarn was 674.79N. The abrasion resistance test of fabric was 11,000 RUBS, the results are shown as Table 5.

Figure 3. Weaving curtains from PET plastic bottles

Table 4. Yarn test results

Test Items	Test Results	
	PET Plastic Bottle Yarn (Weft Yarn)	Acrylic Yarn (Warp Yarn)
1. Yarn Number (Denier)	1,986.3	1,157.4
2. Strength (N)	30.25	22.69
3. Tenacity (gf/den)	5.74	4.36
4. Elongation Before Break (mm.)	37.46	102.36
5. Percentage of Elongation Before Break (%)	149.83	406.83

Table 5. Test results of thread count of fabric, fabric tensile strength and abrasion resistance of fabric

Test	Thread per inch	Tensile Strength (N)	Test	Quantity (Cycles)
Warp Yarn	25	438.14	Abrasion Resistance	11,000
Weft Yarn	18	674.79		

4) Environmental impacts in production of screen curtain

In process of recycled bottles (used drinking water) into yarn, the plastic bottles (PET) were washing to be cleaned. After washing, the bottles were dried and cutting. Yarn stretching was completed by heating plate, a temperature of 100 °C allowed the yarn to stretch, that remove all dirt from yarn surface. Thus, the yarn of sunscreen curtain was not harm to users. For using a long-term of sunscreen curtain in a class room to filtering sunlight that can break plastic down, however PET has a melting point at 260 °C that could not be braking plastic into fragment plastics or chemical compounds regarding health effects (Speight, 2005). Further benefit of using recycled bottles yarn cutting was saving energy as unrequired hot melting process compared to open-loop recycling (downcycle) and closed-loop recycling (up-or downcycling) for garment (Sandin & Peters, 2018) as shown in Figure 4.

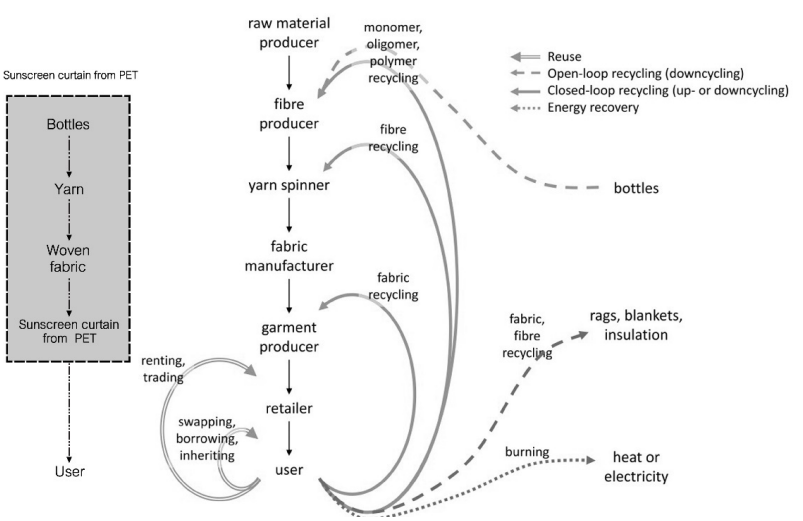


Figure 4. A classification of textile reuse and recycling routes compare to sunscreen curtain from PET (Adaptation from Sandin & Peters, 2018)

Although the plastic bottled drinking water has been gradually decreased, however the PET bottles are developed that can be turned into recycled PET as cycle process. This study of PET bottle yarn can be useful to provide a simple alternative solution for creating value of PET waste as upcycling principal approach.

3.2 Lighting Quantity

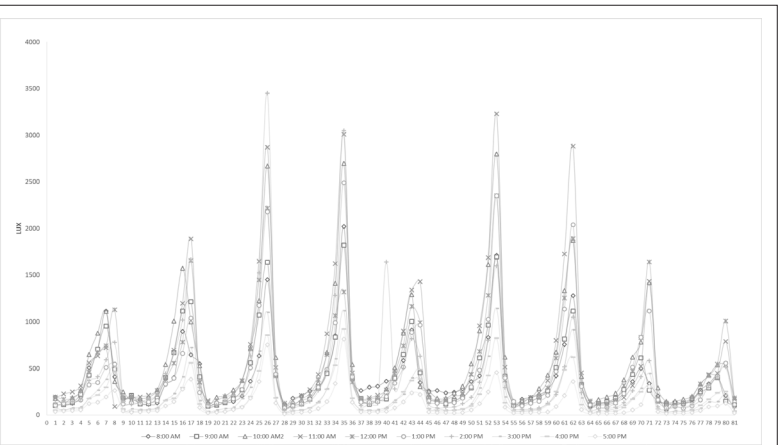
The results of the experiment with the no sunscreen curtains in the room and measuring the lighting quantity in 81 locations at different times starting from 08.00 a.m. to 17.00 p.m. for 1 week showed that the lighting quantity had a higher value depending on time changed that the maximum change was at approximately 3300 Lux, about 33%, which the measurement location was near the window at a distance of 1.50 meters that has a higher luminance than other locations. This was consistent with the study by (Khunthong, 2019). In the case of classrooms without curtains, the lighting quantity of ambient light would range between 3000 - 5000 Lux, representing 30% - 50%. However, most of the measurement points located at a distance of 4.00 m or more from the window had lighting quantity below 500 Lux or 0.50% (Figure 5).

When considering average lighting quantity of natural light throughout the day, it was found that most of the luminance was within the standard of the classroom setup at 300 – 500 Lux, representing 0.30 - 0.50% (Metropolitan Electricity Authority, 2018). However, there were quite high lighting quantity spot from 09.30 a.m. – 05.00 p.m. (see Table 6), which may interfere with vision and teaching activities from excessive brightness. This was consistent with Kittikong et al. (2017) in their study of lighting quantity and physical characteristics in the classroom that affects student's fatigue of eyes feeling case study: a primary school at Khon Kaen province, it has been found that installing sunscreen curtains during the said time can reduce the problem of excessive brightness in

classroom, but at the same time, the sunscreen curtains must have suitable and adequate dimming properties for visibility in classroom and rely on artificial light as necessary.

In the case of closing the prototype curtains made of PET bottle yarn in the classroom and measuring the lighting quantity at 81 locations at different times starting from 08.00 a.m. to 05.00 p.m., it was found that the highest quantity of luminosity of the curtains was closely 1000 Lux, representing 10% (Figure 6) and the measurement area away from the window at 1.50 m has a higher lighting quantity than the other locations. However, at the measurement point located at a distance of 4.00 meters from the window, it was found that the lighting quantity was less than 300 Lux, representing 0.30%, and when considering the average natural lighting quantity throughout the day, it was found that the luminance value was lower than the standard of the classroom set at 300 – 500 Lux which is 265.42 Lux or 0.26% (Metropolitan Electricity Authority, 2018). Moreover, comparing the lighting quantity of high spot in case of no curtain installed and installed was found that the luminance value was extremely lower (Table 7). As the result of this experimental of lighting quantity was unincluded artificial lighting, to meet the luminance of classroom standard, thus the properly designing of artificial lighting in classroom of Faculty of Architecture, RMUTT must be further added for comfortable parameters of students' learning.

A study of Jantarkot and Chaiyakul (2017) in lighting for classroom at Khon Kaen Uni versity found that the lighting quantity lower than 300 – 500 Lux was inconsistent with the actual usage because in the actual classroom, there are many forms of teaching materials. This makes it necessary to control the quantity of light in the classroom so that the students can see the board comfortably and can read and write when the screen is projected. Therefore,



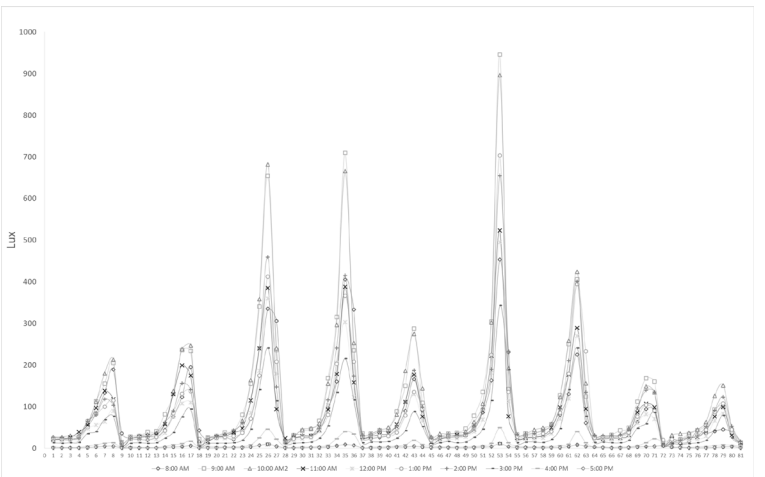
a) lighting quantity between 8.00 a.m. – 5.00 p.m.

b) 3D of classroom feature without curtains installed

Figure 5. Lighting quantity in case of no curtains installed

Table 6. High spot of lighting quantity in case of no curtains installed

Measured point	Lux	Measured point	Lux	Measured point	Lux
7	661.4	34	953.2	52	951.0
8	503.8	35	1926.4	53	1815.8
16	822.2	42	538.0	61	876.3
17	1078.4	43	841.9	62	1402.5
25	1024.4	44	620.8	70	512.8
26	1918.6	51	504.4	71	785.2
There were 18 points of 81 points or 22% that was high light quantity as over the luminance standard of the classroom					



a) lighting quantity between 8.00 a.m. – 5.00 p.m.

b) 3D of classroom feature with sunscreen curtains installed

Figure 6. Lighting quantity in case of installing sunscreen curtain from PET bottle yarn

Table 7. High spot of lighting quantity in case of sunscreen curtains installed

Measured point	Lux	Measured point	Lux	Measured point	Lux
7	98.1	34	179.5	52	176.9
8	113.6	35	355.3	53	512.7
16	78.8	42	90.5	61	154.0
17	137.3	43	151.3	62	276
25	191.2	44	78.7	70	98.9
26	361.0	51	78.2	71	96.3
The same point of high light quantity was remeasured and lower illuminance value standard of the classroom					

the results of this study revealed that the properties of yarn curtains made from used plastic drinking water bottles contribute to good light filtering to some extent. Therefore, in the design of classroom lighting, the use of artificial light is also necessary to develop to suit the teaching and learning activities.

4. Summary

The development of textile fibers from PET bottles has been applied to a wide range of products, including synthetic fibers in pillows, cushions, sofas, dolls, clothing, and indoor products such as curtains. Sunscreen curtains are considered as important materials for lighting control functions to be suitable for the needs of the activities of the users in the building. The results showed that most of the properties tested in various fields of PET plastic bottle yarn were within the standard of testing. Sunscreen curtain from PET production process is also recycle bottles, but reduces the process of forming into yarn. Yarns are normally made by spinning fibers into yarns. This reduces the process and reduces the energy required to fuse bottles to be injected into fibers. From the analysis of the lighting quantity test in a classroom, it was found that the luminance of the yarn curtains made from used plastic drinking water bottles had the average quantity of natural light below the classroom illuminance standard. The study results revealed that the properties of the yarn curtain made from used plastic drinking water bottles will help filtering the light well to some extent. Therefore, to design a sunscreen curtain from PET bottle for the classroom, it is still necessary to adjust the sunscreen curtain prototype pattern as fabric property that could be resulting lighting quantity properly. Installing blackout curtains can help reduce the problem of excessive glare in the classroom, but at the same time, blackout curtains must be properly dimming properties and rely on artificial lighting as needed. In addition, the sunscreen curtain

yarn from plastic bottles (PET) as upcycling material can increase the waste cycle economy and reduce the number of bottles in industrial recycling processes as well as energy recovery, which further contributes to reducing environmental impacts.

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