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Utilization and Energy-Saving Analysis of Inkjet and Laser Printed Eco-Hollow Embedded Fonts: A Comparison of English and Thai Alphabets

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Abstract: The utilization of eco-fonts for office printing is a sustainable, "green" printing concept, which has obvious economic benefits. As a result, it has a significant effect on environmental sustainability. This practice's fundamental problem is the decreased quality of text printed using eco-fonts compared to those printed with regular fonts. The aim of this research is eco-font efficiency estimation, i.e. determination of toner usage reduction level of inkjet-printed documents typed with this font type, as well as estimation of the extent humans perceive differences between text printed with eco-font and the one printed by its "non-eco" equivalent. Combining the instrumental measuring method and digital image analysis, it was found that this simple principle (eco-font utilization) enables substantial toner usage reduction for an inkjet printing system. At the same time, a visual test showed that the visual experience of text printed using eco-font was sufficient. In addition, awareness of the benefits that eco-font utilization brings, change users' attitude towards eco-font quality. The concept of removing the black pixel from this commonly used Thai font has a great potential for the sustainability printing process, and this simple solution could be applied to other languages as part of the GIT campaign.

Keywords: Green Information Technology; Energy saving-font; Ink toner consumption; Hollow embedded font; Sustainable printing.

1. Introduction

Nowadays, the world has witnessed many innovations, and artificial intelligence (AI) and the use of modern computer software and hardware have been advanced in many disciplines. On top of these robust and advanced technologies, organizations also have been looking for the balance of nature resources and reduce cost at the same time. The organizations are, presently, focusing on the methods/techniques to reduce materials that have a considerable influence on the natural ecosystem if altered or consumed [1–4]. Besides the resource consumption, both private and government sectors are disposing wastes to the environment that threaten the long-term survival of our species and planet as a whole. This unbalance disturbance to natural forms that foundation of a concept to reduce the use of environmentally harmful materials and/or the use of recyclable products as referred to "Green Information Technology, GIT" [5, 6]. The emission of greenhouse gas during the production process of printing pollutes our environment. Printing is the 3rd largest industry while pulp and paper is the 3rd largest industrial polluter of our environment [7–9]. As

a concept of the GIT, by introducing the concept to the social responsibility and behaviour changes towards sustainability and "GIT" printing technology driven by different social, economic and environmental factors [7, 10–12].

Currently, overall offices in private and government sectors have reduced the office print outputs with great potential to useless even more when electronic devices become readily available with a compromise price in the market [10, 12]. For example, the printing industry in China consumed 1.6 billion tons in 2014, and it is still growing with a rate of 4.68% [13]. Electronic email, projector, e-books, document-scanning, and advanced printer setting (i.e. recycled paper, double-side printing, duplex printing, toner/ink saving modes, etc.) has a great potential to increase the GIT printing output behaviour [14–18]. The concept of GIT has increasingly affected the government's policies; for example, the Chinese government has issued policies to improve the energy that is produced from the pulp and paper industries [19]. However, the before said activities require large investments of such a solution, therefore, many offices are now seeking an alternative solution as a cost-effective choice such as document pixel removal method, and eco-font utilization [20, 21]. One of those mentioned above for the eco-font utilization as green information technology has increasingly attracted many office users. One of numerous open-source such as Ryman Ecofont (Fig 1a) developed by Ryman [22] is free-download eco-font available for Roman alphabets enables to most countries where the English language is an official. Milosevic et al. [23] have reported that when compared the Raman font with the solid filled typeface for the most used font sizes, and reported that approximately 39% inkjet toner reduction was achieved with the text printed with the 11 pt Raman typeface and the visibility of the typeface became noticeable when the font size increases. According to the Handbook of Print Media has recommended that for clear visibility, legible typography, there should be a maximum of around 60 characters per line and around 40 lines per page. It is also recommended that font size be set no smaller than 9 pt and no larger than 11 pt. The leading (line spacing minus size of type height) should be 2 pt [24].

The concept of removing the black pixel from the typeface is of interested to the font designers. One commercially font available is the Eco Vera Sans font [25] which applied the concept by filling the tiny hole of the Vera Sans typeface (Fig.1b). However, it was also reported that observers' visual testing suggested congenitally and legibility, i.e. pleasure to the reading of text wise [26]. In addition, utilization of this font is also available for Roman alphabets where the English language is an official and is not applicable to any other languages where the letter is not based on the Roman letter.

(a) Rayman Ecofon   (b) Ecofont Vera Sans

Figure 1. Free available eco-fonts (a) Rayman and (b) Ecofont Vera Sans (font size 11 pt, zoom 300%).

The previous research on the Eco fonts available in the media only focuses on the Roman alphabets, where the English language is an official. The Eco font does not apply to any other languages. Specific investigations rationally typographic choices can lead to GIT sustainable printing solutions in less ink/toner consumption and utilize any other languages where the letter is not based on the Roman letter. In this study, the commonly used Roman typefaces are utilized by placing the holes within the typeface, and the image analysis on pixel removal is studied. Further studies are implemented for the modern font with the less-ink intensive Century Gothic font, and the most used Roman typeface such as Time New Roman font and compared to the Eco Vera Sans fonts. Using the concept of placing striations by removing the black pixel (hollow-embodied typeface) from the typeface is also applied to other languages such as Thai as a case study where the alphabet is not the Roman letter. Besides, the masses analysis of the ink toner and user visibility and legibility of printed texts written using hollow-embodied typeface compared to solid typeface are also presented. This study's outcome leans towards green information technology printing improvement, which can be termed as sustainable printing that can benefit the environment and minimize the ink/toner consumption as one of the solutions in GIT printing.

2. Methodology

2.1. Sustainable printing solutions

Sustainability can be defined in various definitions in different disciplines as it is declared a balance between the use of natural resources, social engagement, and economic capital for any existence of our present and coming generations [27]. In the graphical communication industry, the Sustainable Green Printing (SGP) organization has defined the" sustainable printing" into three parts; (i) product, (ii) process, and (iii) envelope [28]. The part "product" considers the design aspect and input printing materials during the printing process. The "process" deals with all the production steps to convert the raw material into a finished product, including the waste remaining during the process. Finally, the part "envelope" includes all activities to support the manufacturing process. With this in mind, the American Institute of Graphic Arts (AIGA) has stated the key factors such as designing products they use less material and energy with recyclability and reusability for a longer life span [29]. As a concept of sustainable printing solutions, many researchers have reported various solutions to reduce ink/toner consumption. In early work, researchers have focused on designing/experimenting the font types to reduce the amount of ink and toner usage with a limit to the commonly used Roman alphabets [30].

At the University of Wisconsin-Green Bay, a study has focused on the ink consumption by changing the default font from "Arial" to the less-ink usage "Century Gothic", and they have reported that by using the Century Gothic font in their document, a 30% ink/toner reduction can be achieved [24].

Recently, the team of researchers from Spranq company in the Netherlands has developed a software called "Ecofont" which embodies holes into Vera Sans font, and they reported that the of ink/toner consumption is reduced by up to 28% [25]. A registered commercial version of Ecofont software applies to Sans style, Garamond, some other styles, and even Arial. However, only the Ecofont (Eco Vera Sans) is freely available to download, and the software does not support any other foreign languages where the alphabet is not the Roman letter.

In 2009, a Dutch company called Printer.com carried out research and reported that the ink/toner consumption reduced by up to 31% where the right choice of font is selected. They have reported the ten most commonly used typefaces printed on inkjet and laser printers with the resolution of 600x600 dpi, and the result agreed with the previous study from the University of Wisconsin-Green Bay, by using the "Century Gothic" that comes with the standard Windows and MS Office shows a minimum ink/toner consumption compared to other typefaces as shown in Table 1. It is also interesting to remake that Century Gothic font shows higher efficiency (Rank #1) in terms of ink/toner consumption, visibility and legibility, and reasonable cost in mind [24].
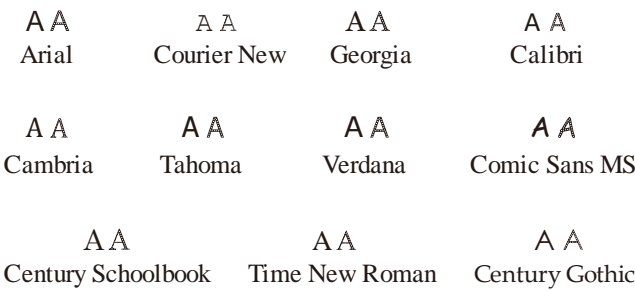
Table 1. Analysis of the most commonly used Roman typefaces and Ecofont by Printer.com [24]

#Rank	Typeface	Font size	Coverage (%)	Private cost ($)	Business cost ($)
1	Century Gothic	10	3.45	46.32	179.29
2	Ecofon Vera Sans	10	3.47	46.59	180.33
3	Time New Roman	11	3.54	47.53	183.97
4	Calibri	11	3.81	51.16	198.00
5	Verdana	10	4.55	61.09	236.45
6	Arial	11	4.97	66.73	258.28
7	Sans Serif	11	5.09	68.34	264.52
8	Trebuchet	11	5.12	68.74	266.08
9	Tahoma	11	5.21	69.95	270.75
10	Franklin Gothic Medimn	11	5.51	73.98	286.34

Note: Typefaces are ranked according top the ink coverage ascending.

2.2. Hollow-embodied in commonly used Roman fonts

As seen in Table 1, a researcher from the Dutch company presented the printing production's ink coverage and cost [24]. The Sans serif font type "Century Gothic" is a modern font that comes as a standard in general typing programme shows a minimum ink coverage compared to the Ecofont and other most commonly used Roman fonts. A traditional looked Times New Roman font type is designed for both legible and print economy. The Calibri font type is particularly legible on the computer screen. The Century Schoolbook font type is also designed to be more legible, especially in books, and is widely used in school books [31, 32]. The majority of the UK universities prefer the Times New Roman font type as it looks a right balance between traditional-looked and ink/toner saving [33]. Then Arial font type was preferred with 9.13%. Other font types are used in very few universities in both the UK and USA [31–33].

A A   A A   A A   A A
Arial   Courier New   Georgia   Calibri

A A   A A   A A   A A
Cambria   Tahoma   Verdana   Comic Sans MS

A A   A A   A A
Century Schoolbook   Time New Roman   Century Gothic

Figure 2. Hollow-embedded on commonly used Roman typefaces.

As seen in Table 1, the Time New Roman (Rank #3), the Serif-type fonts provide a good balance between traditional-looked and ink/toner saving. It is, therefore, in this study, The Rank#1 Century Gothic and Rank#3 Time New Roman fonts will be utilised and investigated further by removing the black pixel from the font typeface in terms of pixel image analysis and compared to the existing Eco Vera Sans fonts (Rank #2) and visibility and legibility tests with the extension to the Thai font as a case study. Two font typeface modifications refereed to the enclosing of open typeface anatomy to generate font version of the hollow-embodied typeface are shown in Fig.3. The implementation is performed using FontLab studio version 7 software. The two modified fonts referred to as Eco-Century Gothic and Eco-Time New Roman are further investigated in terms of pixel and structural visibility compared to the existing Eco Vera Sans font.
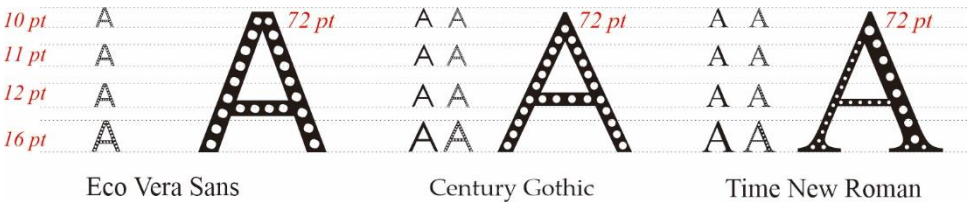

Figure 3. Hollow-embodied typeface visual comparison of Eco Versa Sans, Century Gothic and Tim New Roman fonts.

2.3. Application of hollow-embodied font: an example of Thai alphabet

With the introduction of the Ecofont concept by removing a certain amount of black pixel from the typeface via any shapes such square or circular and it has been reported that the hollow-embodied techniques could reduce the amount of black pixel by up to 28% depending on the font sizes and types [25]. For example, the toner consumption is relatively higher for Sants font types compared to Sant Serif font types [30]. From the previous analysis, the authors have removed the black pixel of both Century Gothic and Time New Roman fonts using the computer software and found that the efficiency of ink toner consumption could be achieved and will be further analysed in phases 1 and 2.   The Thai alphabet is employed as a case study in this paper due to its unique letter and difference from the Roman alphabet to introduce the hollow-embodied typeface concept to the foreigner language in Southeast Asia. In positive typeface design, various Thai fonts have been developed to address the need for increased typographic legibility, visibility, and the well-being of Thai people and culture [34, 35]. At present, government agencies in

Thailand have set the 13 typefaces (Fig. 1) for the Thai alphabet to be used in the formal/government document. Like Sans serif Roman fonts (Headless letters), the 13 typefaces for the Thai alphabet have removed the serif parts from each letter for better readability in both documentation and media. Font typeface modifications referred to the enclosing of the available typeface structures to generate a hollow-embodied version of 13 Thai fonts were also conducted using the FontLab studio software as previously implemented in case of the Roman fonts. An individual letter is divided into a series of the segment and converted into an image for the pixel analysis as shown in Fig. 4.

(a)   (b)   (c)   (d)
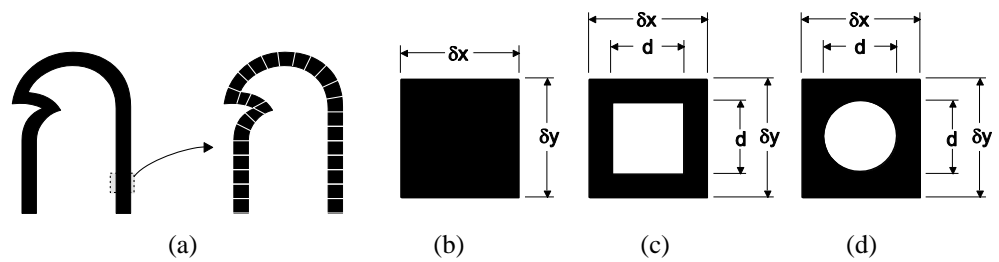
Figure 4. Concept design of hollow-embodied Thai font generated by FontLab Studio.

The image size of the individual segment consists of $\delta x \times \delta y$ pixels have a δx pixels in horizontal and δy pixel in vertical. The number of white pixels is calculated by counting the white pixels by scanning all pixels horizontally and vertically. The number of black pixels is calculated similarly and the sum of the two gives the total number of pixels. The summation of a total black pixel for each letter (n_{black}) is the summation of the black pixel (p_{black}) for individual segments expressed in Eq. (1)

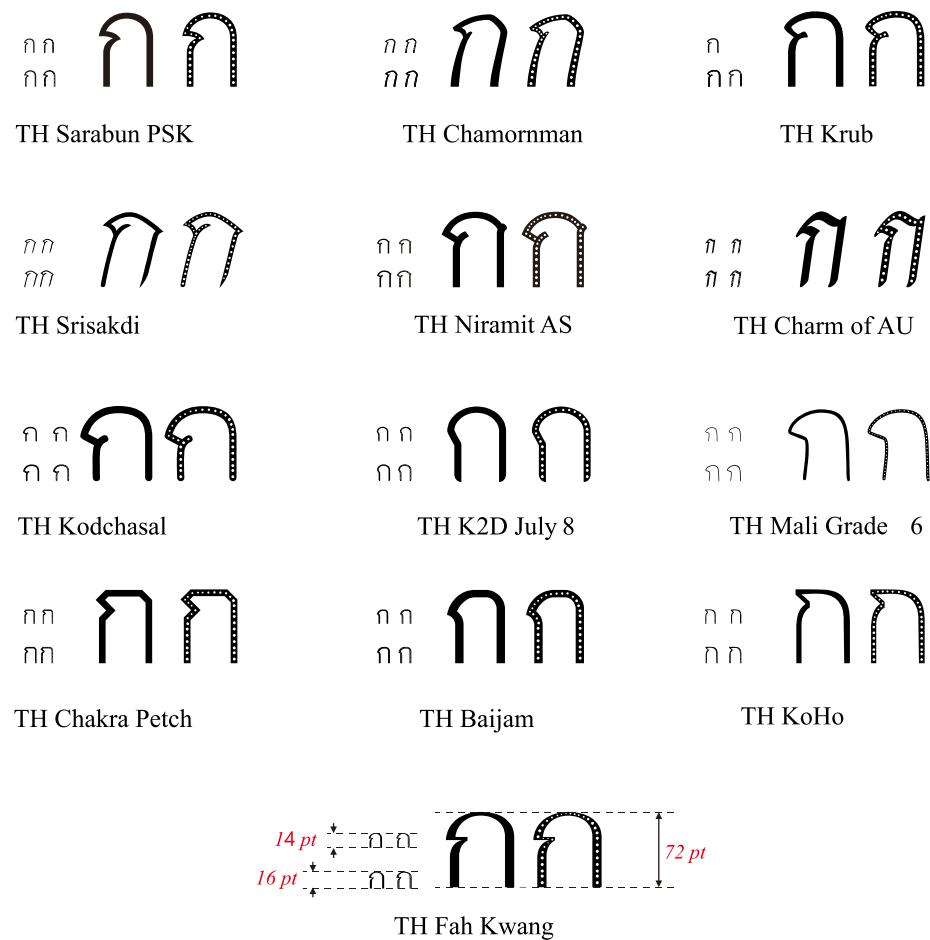$$n_{black} = \sum_{i=0}^{\delta x} \sum_{j=0}^{\delta y} p_{black} \tag{1}$$

The modification by removing the black pixel in the solid face of the Thai font along with the original version by either square or circular white pixel into an individual segment and by setting the width (δx) of the font size to the most commonly used i.e. 16 pt in case of Thai font, the optimum size of the total white pixel inserted in each letter (n_{white}), is the summation of the white pixel (p_{white}) for individual segments can be calculated in Eq. (2)

$$n_{white} = \sum_{i=0}^{\delta x} \sum_{j=0}^{\delta y} p_{white} \tag{2}$$

Fig.5 displayed the most commonly used Thailand fonts with the font size of 16 pt and the modification of the typeface by removing the certain amount of black pixel from the solid face with MATLAB computer's help programming for image analysis. Finally, a

series of the modified Thai fonts were generated using the FontLab software, as and this Thai Ecofont family is referred to as "*TH Imjai-Ecofont*" licensed to Walailak University [36].

TH Sarabun PSK

TH Chamornman

TH Krub

TH Srisakdi

TH Niramit AS

TH Charm of AU

TH Kodchasal

TH K2D July 8

TH Mali Grade   6

TH Chakra Petch

TH Baijam

TH KoHo

14 pt

16 pt

72 pt

TH Fah Kwang

Figure 5. Original most commonly used Thai font and the *TH Imjai-Ecofont* family [36]

Among the most commonly used in Thai fonts (e.g. Fig. 5), TH Sarabun PSK font was one of the award-winning fonts from Thai font competition organized by Department of Intellectual Property (DIP) and Software Industry Promotion Agency (SIPA) in 2007. TH Sarabun PSK was declared in Thai government gazette as a font for Thai government documents, instead of other Thai fonts [37]. The font size of 16 pt is recommended for the official document used in the government agencies. In the implementation, approximately 20% of black pixel removal, the algorithm of black pixel removal for TH Sarabun PSK font with the font size = 16 pt and the full set of TH Sarabun PSK from TH Imjai-Ecofont family is displayed in Fig. 6. Thai characters consist of eighty-seven letters: forty-six consonants, eighteen vowels, four tone marks, ten digits, seven signs, one repetition mark, and one currency symbol for the Unicode Standard [38].

Further details regarding the Thai writing system for a better understanding, further resources can be found in 'The Thai System of Writing' [39] and 'Thai and Lao Writing' [40]. In TH Imjai-Ecofont family, not only the ink/toner saving is considered following the GIT concept, the psychological studies on legibility, visibility of typefaces, short-exposure and distance methods were also studied to the overall efficiency Thai Ecofont. The amount

of the black pixel removal of the 13 Thai fonts is relatively less than Roman fonts due to the anatomy of the character of the Thai font relatively thinner than the English characters. For example, the typeface TH Mali Grade 6 is relatively thin and constant, resulting in the minimum black pixel. However, only a limit amount of the white pixel could be filled in the solid face due to the typeface's visibility, which will be confirmed by the image analysis result presented in Section 3.

Consonants

ก ข ฃ ค ฅ ฆ ง จ ฉ ช ซ ฌ ญ ฎ ฏ ฐ ฑ ฒ
ณ ด ต ถ ท ธ น บ ป ผ ฝ พ ฟ ภ ม ย ร ล
ว ศ ษ ส ห ฬ อ ฮ

Vowels   Tone marks
ั า ำ ิ ี ื ุ ู โ ใ เ   ่ ้ ๊ ๋

Thai digits   Roman digits
๑ ๒ ๓ ๔ ๕ ๖ ๗ ๘ ๙ ๐   1 2 3 4 5 6 7 8 9 0

Figure 6. Hollow-embedded generated on TH Sarabun PSK typeface from TH Imjai-Ecofont family.

2.4. Phase 1: Analysis of pixel reduction

As mentioned earlier, ten commonly used Roman fonts (Sans and Sans Serif typefaces) and thirteen Thai fonts were used as font samples to examine the ink/toner consumption. First, the pixel analysis in the printed sheets written with texts using solid and hollow-embodied typefaces is investigated using the computational image analysis. For this reason, an 11 pt commonly used Roman fonts (one set includes capital, small letter and Arabic numbers) with a total of 50 sets were written in MS Word 365 to fit on one A4 page (setting four side margins = 25.4 mm). For Thai alphabets, a total of 13 typefaces with a 16 pt commonly used as official government document were examined. Thirty sets of each Thai typefaces (one set includes 44 Thai letters, Thai numbers and Arabic numbers) were written in one A4 page with a similar page setting with the Roman fonts. Each font type had been designed with different characteristics, for example weight, width, contrast, X-height and geometry. The level of ink or toner consumption depended on font type and its size [30]. In the computational image analysis, the English and Thai letters were written on one page of MS word documentation was subsequently converted to pdf format by Adobe Acrobat Pro DC version 20.006. Next, this document was finally exported into image size 2339x1654 pixels with tiff extension, which contained only black and white colours. Each character had a black colour in this image. Therefore, the ratio between black pixels and white pixels had been used to analyze the necessary printed area for each font type. This study implemented a MATLAB to calculate the black and white pixels in RGB colour mode. Black and white pixel read red, green, blue values equal to 0, 0, 0 and 255, 255. 255 respectively.

In this case, similar analysis is implemented as for individual typefaces for both Roman and Thai fonts, and the total pixel count (n_{tot}) of the sample printed sheets is the

summation of total black pixel (n_{black}) and total white pixel (n_{white}), can be expressed as Eq. (3)

$$n_{tot} = n_{black} + n_{white} \tag{3}$$

As a result of these values' ratio with the following Eq. (4), the printing area utilization ratio for solid face (μ_{SF}) is calculated.

$$\mu_{SF} = \frac{n_{black}}{n_{black} + n_{white}} \tag{4}$$

For the modification of the solid face by removing the black pixel from the original typeface structures using FontLab software, the printing area utilization ratio for such modification typeface can be referred as μ_{HF} and can be calculated by multiplied the reduction coefficient α_b to the amount of black pixel as shown in Eq. (5)

$$\mu_{HF} = \frac{\alpha_b n_{black}}{\alpha_b n_{black} + n_{white}} \tag{5}$$

2.4. Phase 2: Analysis of toner consumption

In this study, both samples of solid and hollow-embodied fonts were printed on a total of 500 papers using selected 1200x1200 dpi workgroup printers: HP Smart Tank 500 All-in-One inkjet and Ricoh SP C440DN laser office printers on standard office copy paper (80 g/m2 uncoated wood-free paper). In addition, a Multifunction Printer Ricoh MP 6055SP also used as a copier machine for the papers printed from a laser printer (Ricoh SP C440DN) to evaluate the toner usage in a copier. The black cartridge ink toners used to print the samples were also supplied from the printer manufacturer. The technical specification of the printers used in this study is shown in Table 2.

Table 2. Technical specification of the printers used in this study.

General printing specification	HP Smart Tank 500 ink jet printer	Ricoh SP C440DN laser printer	Ricoh MP 6055SP Multifunction Printer
Printer Type	Inkjet / color	Laser / color	Black & White
Print Speed	Up to 34 ppm - B/W Up to 34 ppm - colour	Up to 42 ppm - B/W Up to 42 ppm - colour	Up to 42 ppm - B/W Up to 42 ppm - colour
Max Resolution B/W	1200 x 1200 dpi	1200 x 1200 dpi	1200 x 1200 dpi (printer) 600 x 600 dpi (copier)
Max Resolution Color	4800 x 1200 dpi	1200 x 1200 dpi	n/a
Max Printing Speed B/W (ppm)	11 ppm (black, ISO)	42 ppm (black, ISO)	60 ppm (black, ISO)
Max Printing Speed Color (ppm)	5 ppm (color, ISO)	42 ppm (color, ISO)	n/a
Media Weight	60 g/m² - 90 g/m²	52 g/m² - 256 g/m²	52 g/m² - 300 g/m²

| Black Cartridges | 1VV22AA black ink | 821094 Black Toner | 842126 Black Toner |

The basic physical and optical properties of the sample paper were measured and presented in Table 2. According to the ISO 536 standard, the paperweight was measured using ABJ-120 KERN analytical balance [41], while the paper thickness was measured according to the ISO 534 standard [42]. The paper surface roughness also was measured using the Surface Roughness Tester TR 200 (from a paper sample of 5 cut-off wavelengths of 0.8 mm; RC filter; range: ±40 μm), and mechanical properties of the sample paper (break force, break stress, stroke, and strain) were determined using the Shimadzu EZ-LX/SX series compact table-top universal tester, as specified by TAPPI T-404 [43] and TAPPI T-494 [44]. The test result shows the mechanical properties of two strips cut from the same sample of paper in different directions: machine direction (MD- the direction in which the paper moves during manufacture) and cross-machine direction (CD- the direction at right angles to the machine direction). The sample paper's optical characteristics were measured using a portable Techkon SpectroDens kit to detect the whiteness and yellowness (measurement geometry 0/45°, illuminant D65, standard observer 2°) in accordance with ISO 13655 [43]. The mechanical properties and physical characteristic of the sample papers are shown in Table 3.

Table 3. Mechanical properties and physical characteristic of the sample papers.

Properties	values
Nominal weight (g/m^2)	80
Paper thichkness (mm)	0.1065
Specific volume (cm^3/g)	1.329
Surface roughness (μm)	2.751 (MD) , 2.928 (CD)
Breaking load (N)	119.99 (MD), 60.38 (CD)
Breaking stress (N/mm)	4.800 (MD), 2.410 (CD)
Stoke (mm)	2.80 (MD), 6.67 (CD)
Strain (%)	1.89 (MD), 4.42 (CD)
Yellowness (Y1925)	-18.60
Whiteness (WCIE)	124.00

To evaluate the ink/oner consumption of the solid and hollow-embodied font types, the texts on sample papers used in the testing phase 1 were also employed in Phase 2. A total of 500 sample paper sheets were used to find an average ink/toner consumption per pages by measuring the weight of the ink used for inkjet and laser printers. In addition, the weight of the black toner consumed in the copier using the sample papers printed from the laser printer is also evaluated. Exiting Ecofont Vera Sants font and proposed hollow-embodied Time New Roman and TH Sarabun PSK fonts were evaluated for the ink/toner consumption using masses analysis. First, the weight of 500 sheets of blank papers was measured using a Mettler Toledo Analytical Balances (AB204-Series) with the precision of 0.0001 g. The sample papers were then sent to print for solid and hollow-embodied faces for different fonts employed in this study. For the case of the copier

machine, the Ricoh MP 6055 multifunction printer was used as a copier to make a copy of 500 sheets that were previously printed from the laser printers (Ricoh SP C440DN). During the weight measurement, the temperature and relative humidity (RH) in the laboratory were recorded and found to be 27.5 ᵒC and RH=80%. The average value of the paperweight was calculated from six measurements which were generally found the small difference at the fourth decimal places. The toner's weight can be calculated by subtracting the weight of the blank and printed papers, as it allows the direct comparison of the toner consumption after printing process between solid and hollow-embodied typeface of the 41fonts employed in this study. At the end of the study in phase 2, all sample papers were used as re-used papers in the School of Engineering and Technology, Walailak University.

2.4. Phase 3: Visibility of typefaces and legibility study

Psycho-visual studies are traditionally carried out in standardized laboratory environments to ensure repeatability and comparability between each graphical display such as image visibility and legibility. An important method in evaluating image quality in graphical reproductions is the human observer's evaluation through psychophysical assessment [34, 35, 45], with the visibility control environment [46–49]. The context of this project in Phase 3 is the need to find more time-effective, cost-saving methods for determining subjective hollow-embodied font faces quality, i.e. human's capability to distinguish the visibility differences between texts printed with the hollow-embodied and solid face of Roman and Thai fonts. In this project, we implement the same psychometric test for a calibrated laboratory environment setting to visibility and legibility of web-based hollow-embodied fonts. To investigate the visibility and legibility of the hollow-embodied typeface to Time New Roman (English) and TH Sarabun PSK (Thai) fonts, the pair comparison design which includes the fonts with solid and hollow-embodied faces were employed as it has been studied that human observer perceives relative changes in different viewing conditions equally, even though the viewing conditions might change [37, 45–47].

2.4.1 Paired comparison index

One of the classical models for the human comparative judgment was Thurstone's model for reliability, scaling and comparative judgment [50] as the model assumed the human option's quality is a Gaussian random variable and can be quantified using an arbitrary constant γ as shown in Eq. (6), so-called *Thurstone's law for case V*.

$$\gamma = \frac{\sum_{i=1}^{n} r_i}{2n(m-1)} \qquad (6)$$

where n is the number of observers, m is the number of samples and r_i is the value given by observer (i.e. value 0 for visually less pleasing font type, value 1 if observer do not notice any visual difference between fonts, and value 2 for visually more pleasing font type).

The visibility result is implemented by calculating the pair comparison index (Ipc) multiplied by the interval quality scale (0 to 100), as shown in Eq. (1); where high values mean the observers perceived as having a good text quality, whereas low values correspond to observers perceived as having more inferior text quality.

$$I_{PC} = \gamma * 100 \qquad\qquad (7)$$

Previous research by Milosevic et al. [23] to determine the visibility of the open-source Rayman Eco font [22]. In their study, the *Thurnstone's law for case V* was adopted to the respondents' grading data from the text paragraphs printed using eco and non-eco fonts from 40 observers. From their study, it showed that using the I_{pc} is less-time consuming and required less laboratory setting. The results also reflect the observer's reliability and congeniality [51].

2.4.2 Test procedure

Pair-comparison test using a visual method was carried out to investigate observers' capability to distinguish the visual difference between texts written with solid and hollow-embodied typefaces. In the testing phase 3, a single man visibility test was implemented using sample cardboards with ten A4 sheets written with the same fonts with the different text sizes (i.e. Fig. 7a) and a group test (Fig. 7b) on the readability of the two dummy text paragraphs with the commonly used text size with the black text on a white A4 paper (8,9,10,11pt for Vera Sans (Original version of Eco Vera Sans), Century Gothic (minimum ink coverage reported by Printer.com [24]), Time New Roman (Most commonly used for graduated thesis text guidance in UK and US [31–33]) and 11,12,14,16,18 pt for original TH Sarabun PSK font and the modified version from) TH Imjai-Ecofont family. The typographic (such as line spacing, text-indent, page layout) was controlled on the sample cardboard. The environment such as lighting, temperature and humidity were also kept as in the normal classroom. For a single man test, a total of 32 from third and fourth years undergraduate students and 15 academic staff from the Computer Engineering Software department, Walailak University were acted as an observer in this study. The individual observer was also taken an eye-examination test as the normal eye-sight was set by proving glasses before the test. Every observer was instructed to detect each of these ten cardboards individually and to mark if they detect any visual difference between two cardboards as they were asked to focus only the visual difference. For the readability and performance test implemented in the groups, they were focused on the text paragraphs written from two dummy sample pages (solid and hollow-embodied typeface), and they were asked to give a preference which one they would select as more visually pleasing. At the end of the test, all observers were informed about the hollow-embodied typeface used in this study, and they were asked whether they would select to use the hollow-embodied fonts to print their documents by knowing the ink/toner consumption evidence from test phases 1 and 2.

<div align="center">
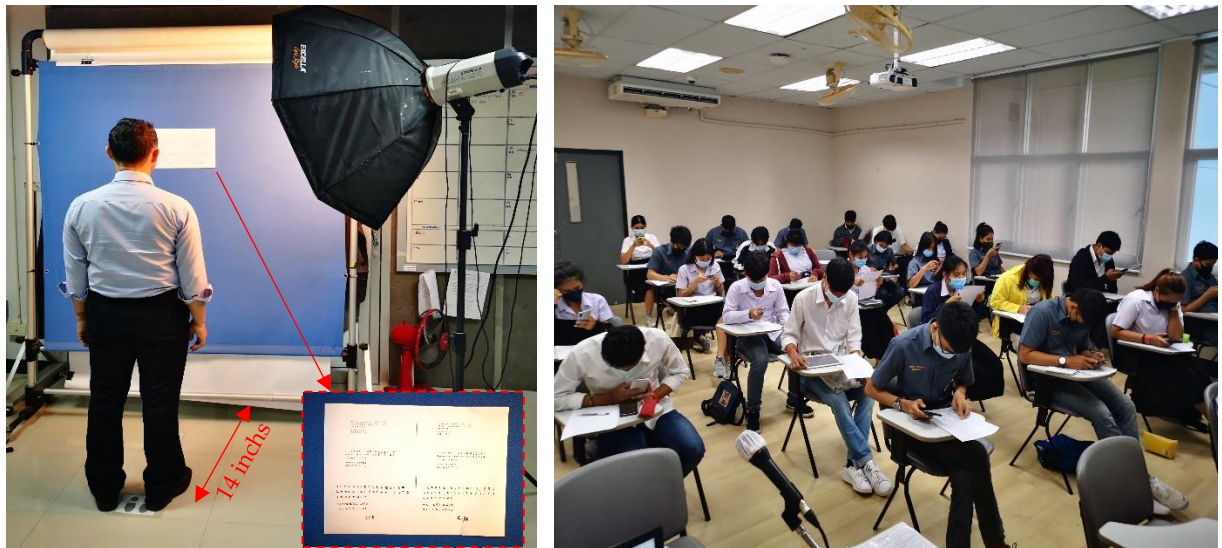
(a) Single man visibility test   (b) Readability and performance test

Figure 7. Visual and legibility test in phase 3; (a) single man visibility test and (b) readability and performance test.

</div>

3. Results and Discussion

3.1. Phase 1: printed area usages and hollow-embodied fonts performance

The calculated number of black pixels and white pixel numbers according to Eq. (1) and (2) for investigated Roman and Thai typefaces are presented in Tables 2 and 4. Since the font type of the current graduated Engineering thesis guideline at Walailak University is Time New Roman with a font size of 11 point, the comparison in spending if it was switched to Century Gothic and Verdana was calculated to come up with the result as shown in Table 3. As both Century Gothic and Verdana have a relatively wider font than Time New Roman, therefore a font size of 10 point was chosen for both Century Gothic and Verdana for a fair comparison. From the result showed in Table 3, the font with the least use of the black pixel (consider both n_{black} and μ_{HF} values) on a print area was Courier New with μ_{HF} = 0.11. The Century Gothic font is 0.163 followed by the Times New Roman (0.197). Comic Sans MS, Tahoma, Vera Sans, and Arial typefaces have been found to have the higher printing area fonts (n_{black}> 1,200,000). It would be correct to say that these fonts use approximately twice as much printing space as the Courier New type-face. There is a 9.5% difference between Times New Roman and Century Schoolbook font type. Black pixel numbers according to font types are shown in Table 3 and there is very little difference between Times New Roman, Cambria and Calibri but this difference is very high for Times New Roman compared to Comic Sans MS, Tahoma, Vera Sans, and Arial.

As seen in Table 3, Courier New typeface has minimum black pixel coverage (453,900 pixels) whereas the Comic Sans MS yields the maximum black pixel coverage (1,380,582 pixels) due to relatively thicker font characters. However, when we are trying to remove the amount of black pixel from the original version of the typeface, Courier New shows the total black pixel (μ_{SF}) from 0.117 to 0.110 which comes up with the smallest black pixel removed = 27,143. In contract, Comic Sans MS has the maximum black pixel coverage and yet yields the maximum of black pixel removal (434054). For the most used Time New Roman, it is found that the black pixel removal = 172192 and yields the μ_{HF} = 0.197. As reported by previous studies [24], Century Gothic shows a superior ink/toner consumption saving and the result from this study has confirms that Century Gothic has ranked 2nd after Courier New and yields μ_{HF} = 0.163. From the analysis, it shows that the classical, thin,

typed-writer looked Courier New is less-black pixel intensive font. However, this font is not among famous to use in graduated thesis and/or media e-book in the present day. Fig. 8a concluded the amount of black pixel removal and the printing area utilization ratio for the modified original typeface implemented in this study.

Table 3. Print area of the commonly used Roman font types after the embodied of hollow-embodied faces.

#Rank	English typeface	n_{white}	n_{black}	n_{tot}	μ_{SF}	# of black pixel removed	μ_{HF}
1	Courier New	3414806	453,900	3868706	0.117	27143	0.110
2	Century Gothic	3087206	781,500	3868706	0.202	149346	0.163
3	Times New Roman	2935406	933,300	3868706	0.2412	172193	0.197
4	Century Schoolbook	2846306	1,022,400	3868706	0.2643	186179	0.216
5	Cambria	2903240	965,466	3868706	0.2496	88340	0.226
6	Verdana	2767856	1,100,850	3868706	0.2846	221821	0.227
7	Calibri	2911559	957,147	3868706	0.2474	78103	0.230
8	Comic Sans MS	2488124	1,380,582	3868706	0.3569	434054	0.245
9	Tahoma	2564165	1,304,541	3868706	0.3372	324178	0.253
10	Georgia	2750816	1,117,890	3868706	0.289	135376	0.254
11	Vera Sans	2501156	1,367,550	3868706	0.3536	381546	0.255
12	Arial	2583956	1,284,750	3868706	0.3321	292152	0.257

Note: Typefaces are ranked according top the rinting area utilization ratio (μ_{HF}) ascending.

For the case of Thai font types, the font with the least use of the black pixel on a print area was TH Mali Grade 6 with μ_{HF} = 0.086 as presented in Table 4. The TH Sarabun PSK font is 0.095 followed by the TH KoHo (0.096). TH Baijam and TH Niramit AS typefaces have been found to have the higher printing area fonts (n_{black}> 620,000). It can be seen that these fonts use approximately twice as much printing space as the TH Mali Grade 6 typeface. There is a 0.79% difference between TH Sarabun PSK and TH KoHo font type. In addition, but this difference is very high for TH Sarabun PSK compared to TH Baijam, TH Niramit AS, TH Krub, and TH Kodchasal. In the attempt to remove the black pixel from the solid typeface of the Thai fonts, the efficiency of the typefaces is expressed in term of the printing area utilization ratio (μ_{HF}) and it found that the TH Mali Grade 6 shows the less black pixel removal as it is relatively thin font character (approximately 2.3% of black pixel removal). When it comes to the most commonly used TH Sarabun PSK font, the amount of black pixel removal is 73,210 with the μ_{HF}=0.095, thus yields approximately 18.2% of black pixel removal. The maximum amount of black pixel removal was found for the TH Chakra Petch (23.4%) with the μ_{HF}=0.113. Fig. 8b illustrated the amount of black pixel removal and the printing area utilization ratio for the typefaces taken from TH Imjai Eco font family.

Table 4. Print area of the Thai font types after the embodied of hollow-embodied faces with 16 pt font size.

#Rank	Thai typeface	n_{white}	n_{black}	n_{tot}	μ_{SF}	# of black pixel removed	μ_{HF}
1	TH Mali Grade 6	3529226	339,480	3868706	0.0878	7,638	0.086
2	TH Sarabun PSK	3425546	443,160	3868706	0.1145	73,210	0.095

3	TH KoHo	3422036	446,670	3868706	0.1154	76,425	0.096
4	TH Fah Kwang	3331946	536,760	3868706	0.1387	125,870	0.106
5	TH Chakra Petch	3332306	536,400	3868706	0.1387	97,678	0.113
6	TH K2D July8	3297566	571,140	3868706	0.1476	130,733	0.114
7	TH Srisakdi	3345266	523,440	3868706	0.1353	22,769	0.129
8	TH Baijam	3231506	637,200	3868706	0.1647	136,105	0.130
9	TH Niramit AS	3241316	627,390	3868706	0.1622	103,644	0.135
10	TH Krub	3212516	656,190	3868706	0.1696	125,660	0.137
11	TH Kodchasal	3183806	684,900	3868706	0.177	135,952	0.142
12	TH Charm of AU	3225836	642,870	3868706	0.1662	72,194	0.148
13	TH Chamornman	3208196	660,510	3868706	0.1707	38,639	0.161

Note: Typefaces are ranked according top the rinting area utilization ratio (μ_{HF}) ascending.

(a)

(b)
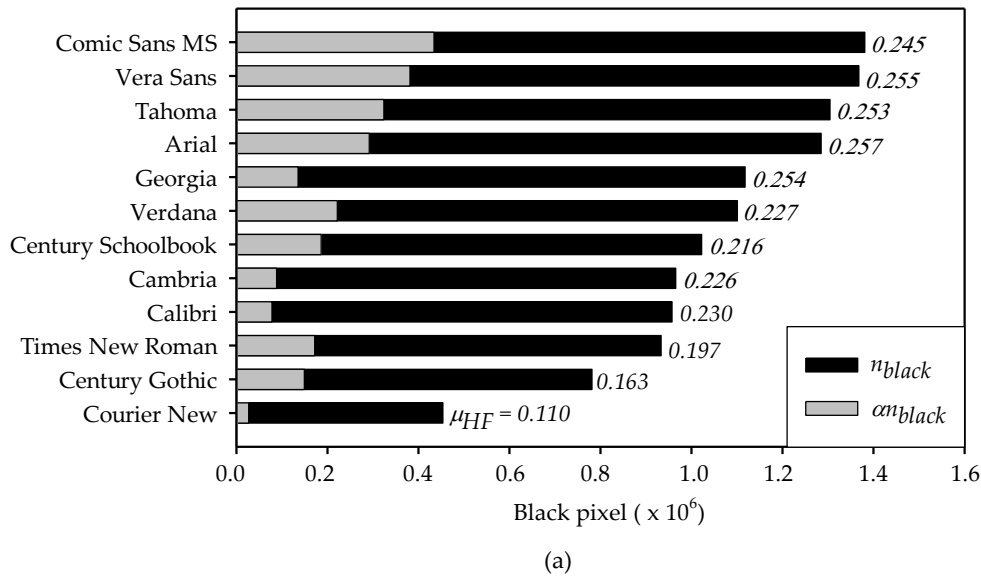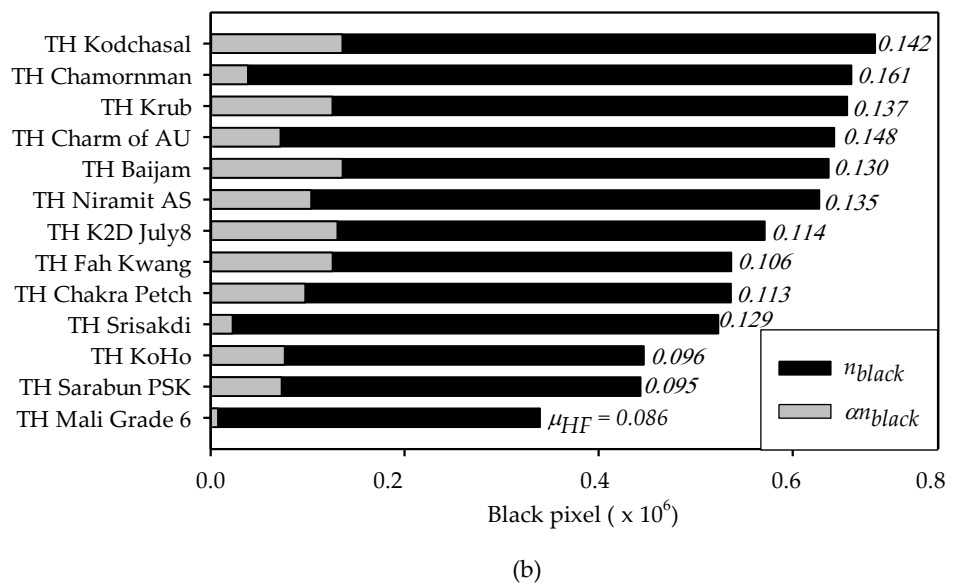
Figure 8. Analysis of black pixel and %removal of blax pixel using hollow-embodied typefaces; (a) commonly used Roman fonts and (b) commonly used Thai fonts.

As part of a study in phase 1, ink consumption analysis was also performed using the commercial software; APFill Ink Coverage Meter version 6.1 and Adobe Photoshop Pro version 2020 for analyzing the amount of ink used to print on the A4 sample paper sheets from the test phase 2. Regarding on the printed samples, type I is the printed samples from an inkjet printer (scan), type II is the printed samples from laser printer (scan), and type III is the built-in MS Word printer to pdf file. As seen in Table 5, the result from Apfill shows that Century Gothic yields less ink coverage (16.87%) when printed using original typeface (S-Face) and reduced to 13.75% when printed using hollow-embed typeface (H-Face) for the sample paper of type I (sample paper printed using inkjet). When using the paper printed from the laser (type II), the ink coverage of Century Gothic is 16.01% and 11.02% for S-Face and H-Face, respectively. Surprisingly, the Century Gothic font even beat the Eco Vera Sans font from Apfill and Photoshop's analysis results. For the results obtained from the sample papers type II (digital original pdf file generated by MS Office), it shows that both solid face (S-Face) and hollow-face (H-Face) consumed less ink coverage when compared to sample types I and II. It is also found that the sample printed using inkjet has the highest ink coverage compared to sample types II and III, because the inkjet rheological characteristics are spreading on the sample papers surface and absorbed by the fibrous nature of the raw material made-up of the papers. For the case of TH Sarabun PSK, the type I samples printed using S-Face font show higher toner coverage for 13.70% and reduced to 11.16% when H-Face is used. This proposition is observed when using samples type II and III (see Table 5).

Table 5. Analysis results for an average ink coverage per page.

Type of samples	Analysis tools	Vera Sans (10 pt)		Century Gothic (10 pt)		Time New Roman (11 pt)		TH Sarabun PSK (16 pt)	
		S-Face	*H-Face*	*S-Face*	*H-Face*	*S-Face*	*H-Face*	*S-Face*	*H-Face*
I	Apfill	24.21 %	17.70 %	16.87 %	13.74 %	18.04 %	15.06 %	13.70 %	11.16 %

	Photoshop	26.31 %	19.54 %	18.65 %	16.45 %	20.41 %	18.01 %	15.78 %	13.40 %
II	Apfill	20.74 %	14.98 %	16.01 %	11.02%	16.05 %	12.87 %	11.52 %	9.45 %
	Photoshop	23.41 %	16.2 %	17.95 %	13.77 %	18.45 %	14.89 %	15.23 %	12.78 %
III	Apfill	11.78 %	8.54 %	6.11 %	5.01 %	8.05 %	6.60 %	5.46 %	4.33 %
	Photoshop	13.12 %	9.45 %	8.18 %	6.98%	10.78 %	8.84 %	7.45 %	5.98 %

Note: type I is the printed samples from inkjet printer (scan), type II is the printed samples from laser printer (scan), and type III is the built-in MS Word printer to pdf file.

3.1. Phase 2: toner saving result

Table 6 shows the obtained average and overall mass values of 500 sample papers before and after the printing process using three English fonts and one TH Sarabun PSK fonts. The toner mass values are calculated by subtracting the weight of the blank papers and after printing, papers using different processes (inkjet, laser, and copier). The results indicate that the papers printed using H-Face (Eco fonts) has fewer mass values compared to the solid face (original typeface) in all cases. As seen in the table, when using Eco Vera Sans font reduced the ink consumption by up to 28% per page and similar ink reductions were also obtained for Century Gothic, Time New Roman and TH Sarabun PSK in which the ink-saving was found to be 25%, 12%, and 18%, respectively. As reported by the previous studied [24], the original version of Century Gothic has less ink consumption even compared to the Eco Vera Sans, and it is evident when compared the mass of the ink used in the tested papers. For example, 1 page printed using Eco Vera Sans from inkjet consumed toner about 0.0846 grams, and when using original Century Gothic (S-Face), the ink usage is about 0.0758 grams and even further reduced to 0.0603 grams when the H-Face was used. For the case of the most commonly used Time New Roman, it also shows great potential in term of ink reduction in case the H-Face was used (0.0691 grams/page), compared to the S-Face (0.0765 grams/page). A similar tendency was also observed for the papers printed using laser and copier machines. Therefore, both Century Gothic and Time New Roman (both original and modified version) could be a good solution for the users to reduce the ink/toner consumption as one of the GIT solutions without investing any special printing machines or commercial software packages.

In the case of former language where the letters are not English, the TH Sarabun PSK was used as a case study by implementing the concept of black pixel removal. It is found that an average mass for the toner usage per pair was 0.0774 grams when using the H-Face printed from the inkjet printer (if printed using S-Face, the toner was 1.8045 grams). The ink usage even reduced when using laser and copier in the printing process and seen in Table 6. Therefore, the concept of removing the black pixel from this commonly used Thai font has a great potential for the sustainability printing process, and this simple solution could be adopted into other languages as part of GIT campaign.

**Table 6.** Masses analysis and toner saving results of the before and after printing products.

	Vera Sans (10 pt)		Century Gothic (10 pt)		Time New Roman (11 pt)		TH Sarabun PSK (16 pt)	
	S-Face	H-Face	S-Face	H-Face	S-Face	H-Face	S-Face	H-Face

500 blank papers (g)	2506.1137	2504.1137	2507.4115	2502.7841	2505.8015	2505.8120	2501.0812	2501.0981
Paper+Inkjet (g)	3361.2415	2546.3951	2545.3124	2532.9738	2544.0312	2540.3443	3403.3522	2539.8151
Paper+Laser (g)	3374.2264	2537.0124	2536.1245	2518.0023	2543.4551	2520.6781	3376.4678	2519.7521
Paper+Copier (g)	3270.6465	2522.8050	2522.1184	2517.9578	2541.5515	2520.0548	3353.9125	2513.3496
Toner usages								
Inkjet (g)	855.1278	42.2814	37.9009	30.1897	38.2297	34.5323	902.2710	38.7170
	(1.7103)	(0.0846)	(0.0758)	(0.0603)	(0.0765)	(0.0691)	(1.8045)	(0.0774)
Laser (g)	868.1127	32.8987	28.7130	15.221	37.6536	14.8661	875.3866	18.6540
	(1.7362)	(0.0658)	(0.0574)	(0.0304)	(0.0753)	(0.0297)	(1.7508)	(0.0373)
Copier (g)	764.5328	18.6913	14.7069	15.1737	35.7500	14.2428	852.8313	12.2515
	(1.5291)	(0.0374)	(0. 0303)	(0. 0294)	(0.0715)	(0.0285)	(1.7057)	(0.0245)

Note: The values shown in the parentheses is an average mass of the ink toner usage for 1 sheet paper.

3.1. Phase 3: visibility analysis and legibility test

Fig. 9 shows the PC-index scales (I_{PC}) for the fonts investigated in this study. Existing Eco Vera Sans font is also used as a comparison purpose. As seen in the figure, the observers' capability of distinguishing the visual differences between texts printed either with the original version of Roman fonts (i.e. solid typeface) and the modified version with the hollow-embodied typeface. Thurnstone's V law of comparative judgement with the statistical assumptions was applied to the obtained data in which reflects the observers' grading of the text paragraphs printed using solid typeface and hollow-typeface. The scale is ranked from 0 to 100, where the higher value refers to the samples perceived good visibility of the text quality. In all cases, when the text size increases, the PC-index value decreases as a result of a clear contrast of the hollow in the text structure. However, at the most commonly used font sizes, i.e. 10 pt or 11 pt for Roman fonts and 16 pt for TH Sarabun PSK, the observers' perceived a good visibility of the texts and the hollow-embodied typeface becomes unnoticed with the text quality still maintained (i.e.   < 10). It is not surprising that when the font size increase will result in a greater perceptibility of differences between the texts printed from solid and hollow typefaces and therefore, the perceived text quality and visibility of the hollow-embodied typeface (e.g. Ecofonts) reduces as a physical font structure become obvious. Regarding the readability and visibility tests, almost all observers (78% from the 47 observers) noticed visual differences between the solid and hollow-typefaces when the font size = 12 pt and 18 pt for Roman and TH Sarabun fonts, respectively. For the total of 47 observers from the Department of Computer Engineering Software, Walailak University, about 90% (42 observers) have detected the visual difference between the two fonts printed using solid and hollow-embodied typefaces. As they have been well-trained and familiar with the various topographical aspects, the correspondences' grading was prone to spotting the visual notices between these two fonts. However, after they were told about the hollow-embodied typeface as an eco font with efficiency to reduce ink/toner consumption by up to 28%, all of them prefer to use the eco fonts in their document. This implies that observers are aware of visual differences between two fonts when the size becomes larger, however, when they know about the GIT concept, and the use of font ink-saving solution could be a good solution without a big investment, most of them indicate that the reliability and text quality becomes less important.
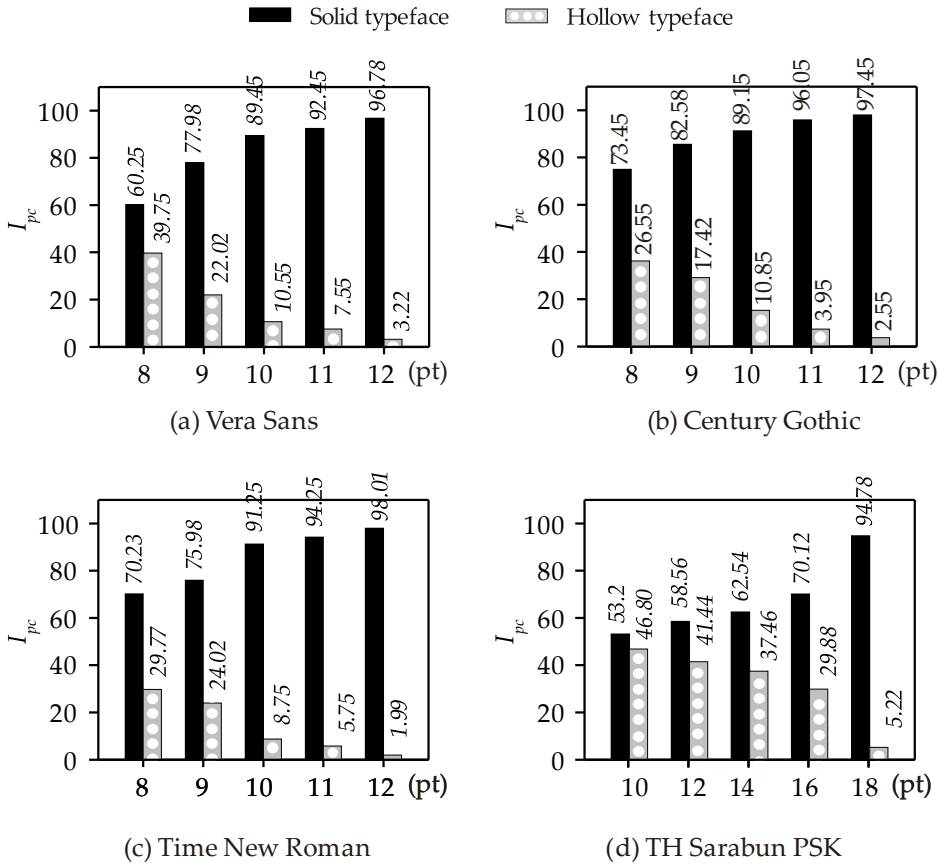
Figure 9. I_{PC} values for (a) Vera Sants, (b) Century Gothic, (c) Time New Roman and (d) TH Sarabun PSK according to the pair-comparison pyschology test.

Fig. 10 shows the quality of the original version of Time New Roman and TH Sarabun PSK and modified Eco fonts with the different text sizes printed from inkjet, laser and copier machine. As seen in the figure, when the hollow-embodied typeface becomes more noticeable when the text size increases, the text structures' imperfection becomes more noticeable (i.e. Fig. 9). Interestingly, when the most commonly used text size is tested, the visibility and legibility are acceptable with a good text quality compared to the solid typefaces.

(a)　Printed by Inkjet printer

(b)　Printed by Laser printer
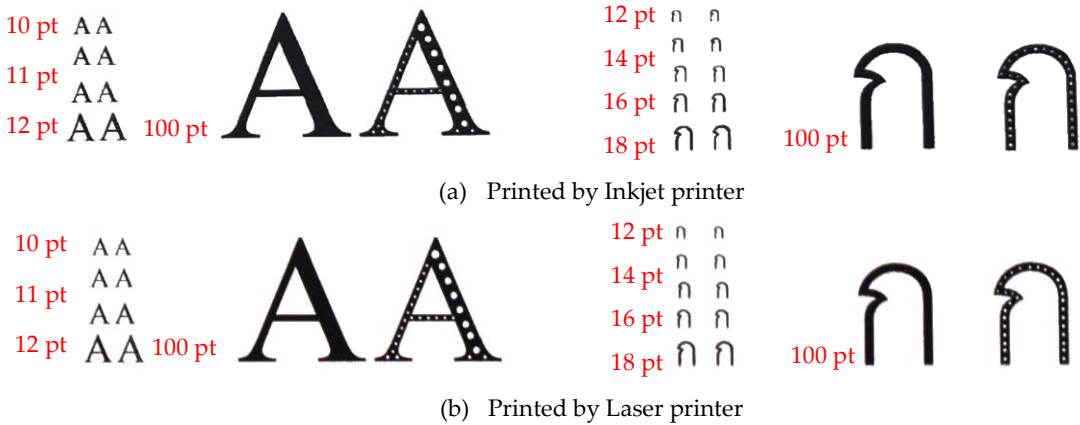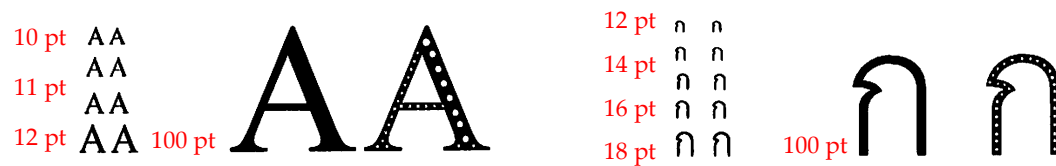
(c) Photograph scanner from a photo printed by Laser

Figure 10. Visual comparison of the solid face and hollow-embodied font printed using Ink Jet Laser and photograph scanner from photo printed by Laser (100% original size and 30% white noise reduction).

5. Concluding remarks

As a result of introducing the Green Information Technology to the green printing campaign, together with our societies, together with economical and sustainable environmental factors, various alternative solutions have been introduced to cope with such campaign. One solution is the use of ink-saving fonts that require less investment than more advanced IT units such as Eco-printers and virtual Eco-printers. Existing open-source Eco-font that filled with the hole in the typeface is examined together with the most commonly used Roman typefaces. The concept of removing the black pixel from the original typefaces of the Roman fonts is also studied and compared in term of ink/toner coverage. Further study has then employed the concept of hollow-embodied into the solid typeface for the Thai fonts where the font characters are not based on Roman alphabets. Based on the results investigated in this study, the following conclusions have been drawn:

- From the analysis from the pixel and printing area in this study, the Courier New followed by Century Gothic, and Time New Roman are the first top three as the less-ink intensive font compared to other most commonly used Roman fonts.

- In case of Thai typefaces, the TH Mali Grade 6 followed by TH Sarabun PSK, and TH KoHo are the first top three as the less-ink intensive font compared to other most commonly used Thai fonts.

- When compared the font image analysis, the Comic Sans MS, Vera Sans, Tahoma, Arial and Georgia are the top five in higher black pixel coverage. TH Kodchasal, TH Chamornman, TH Krub, TH Charm of AU, and TH Baijam are the top five in higher black pixel coverage in case of Thai font.

- For the ink/toner analysis, it is found that existing Eco Vera Sans fonts have shown the ink/toner reduction by up to 28%.

- The modified original version of Roman fonts using the hollow-embodied into the typeface and the results from the ink consumption analysis for Century Gothic, Time New Roman and TH Sarabun PSK in which 525 the ink-saving was found to be 25%, 12%, and 18%, respectively.

- Result from visibility and legibility tests reveals that the reading behaviour obtained from 47 observers when reading on a sample paper is very similar when using solid and hollow-embodied typeface printed sample papers.

- Using the font size bigger than the most commonly used, the observes can notice the physical difference between the font types. However, they were happy to use the hollow-embodied fonts as the Ecofont as the less-ink intensive font in their document rather investing the high-cost eco printers.

- The concept of removing the black pixel from this commonly used Thai font has a great potential for the sustainability printing process, and this simple solution could be adopted into other languages as part of GIT campaign.

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