Design Of Artificial Lighting In Reading Room 4th Floor Of Sebelas Maret University Library Using Fuzzy AHP Approach

Bambang Suhardi, Frisheila Sely Apriliana, Taufiq Rochman, Iksan Adiasa

Abstract: One of the main activities in the library is reading which requires a good level of lighting. The intensity of lighting in the reading room based on the measurement result is 179.5 lux. Which does not meet the Indonesian National Standard (SNI) 6197-2011 at 300 lux. This condition causes the users of the reading room experience discomfort in the form of dizziness, tired eyes, sore eyes, and difficulty to finding books. This study aims to design artificial lighting in the reading room of the Universitas Sebelas Maret (UNS) central library on the 4th floor of library building. This research is conducted in three steps. In the first step, energy audit is performed based on SNI 6196-2011. In the second step, we identify the existing lighting. There are three substeps in this second step, namely: 1) determining the coordinates of measurement based on SNI 16-7062-2004, 2) measuring lighting intensity, and 3) comparing the actual lighting intensity with the minimum lighting intensity based on SNI 6197-2011. The third step deals with the improvement of lighting using artificial lighting with the following two substeps, mamely: determine the ranking of the lamps brands using Fuzzy AHP, and determine the energy consumption index (IKE) of the proposed lighting brand. The initial IKE calculation is 0.81 watt/month/m2 and it is included in the efficient category. The fuzzy AHP calculation result shows that Philips lighting brand is ranked 1 with a weight of 0.46, OSRAM brand is ranked 2 with a weight of 0.39, and Hannoch brand is ranked 3 with a weight of 0.15. IKE for the proposed artificial lighting is 1.449 kWh/month/m2 and it is included in the efficient category.

Index Terms: Lighting design, Library, Fuzzy AHP, Energy Consumption Index (IKE)

1 INTRODUCTION

Universitas Sebelas Maret (UNS) is one of the universities that has an environmentally friendly program, namely Green Campus. One effort to implement the program is land use planning and land zoning which directed to building of at least 4 floors and maximum of 8 floors with a maximum site area of 1000 m^2 [40]. In 2018, UNS received Green Campus Award from UI Green Metric as the 7th place in Indonesian universities and 101st in the world. One indicator of Green Campus assessment based on the UI Greenmetric Guide (2017) is energy use with a weight of 21% [33]. The UNS central library building is a relatively new building with seven storeys within the UNS environment. This building was built with an environmentally friendly concept to support the Green Campus program. Reading is the main activity carried out in the library, so lighting is an important aspect that must be considered in library design [30]. One of the rooms in the central library building that has a function as a reading room is located on the 4th floor. The results of the measurement of lighting intensity in the reading room have an average of 179.5 lux. The measurement of lighting intensity was carried out during daytime with the condition of sunlight entering the room and the lights on. The intensity of the reading room lighting is still below the SNI 6197-2011 standard which is 300 lux. The intensity of lighting in the reading room that is not in accordance with the standard causes inconvenience for the users of the reading room. The inconvenience felt by the 22 interviewed respondents included: dizziness, tired eyes, sore eyes, and difficulty for finding books. The tendency in limiting artificial lighting to reduce electricity costs will increase the tendency of the vision problems of the room users [27]. Light is essential for everyday human activities. The main functions of a lighting system are to provide a visually safe environment, provide visual convenience in completing work, and provide a comfortable and pleasant visual environment [16]. The lighting system in the reading room of the UNS central library needs attention because it affects the visual comfort of people carrying out activities in the reading room. Selection of the types and specifications of the lamps used are needed to analyze the level of lighting requirements in the reading room of the UNS central library.

Another problem at the UNS central library building is the increase of electricity cost at 24,808 kWh on March 2019, 27,832 kWh on April 2019, and 27,896 kWh on May in the same year. With the increase of electricity usage, there is a problem in managing the use of electricity in the central library building of UNS. For this reason, it is necessary to conduct an energy audit to determine the level of energy consumption and energy saving opportunities based on the Indonesian National Standard (SNI) 6196-2011. The audit result is used as a basis for energy conservation [32]. Energy saving in a buildings must be done efficiently without reducing the comfort of its users [1]. Energy audit becomes more important because it is able to save energy and natural resources, as well as make a building becomes environmentally friendly [28]. The main purpose of the energy audit is to obtain information about the current condition of the building, such as indoor climate quality [39]. Humans often face problems in decision making in both business and personal fields. Humans need a systematic and comprehensive approach that will provide more effective decision support when decision problems arise in them [18]. The decision-making process can be completed using the Multi-attribute Decision Making (MADM) method. MADM aims to decide by choosing the best alternative from several potential candidates, placing subjects on several criteria or attributes that can be advantageous or not [12]. Moreover, MADM also aims to assist the decision-maker in choosing the most suitable alternative from several alternatives that meet

- *Corresponding Author*: Bambang Suhardi, Department of Industrial Engineering, Sebelas Maret University, Indonesia, bambangsuhardi@staff.uns.ac.id*
- *Frisheila Sely Apriliana, Department of Industrial Engineering, Sebelas Maret University, Indonesia, frisheilasely@gmail.com*
- *Taufiq Rochman, Department of Industrial Engineering, Sebelas Maret University, Indonesia, taufiqrochman@staff.uns.ac.id*
- *Iksan Adiasa, Department of Industrial Engineering, Sumbawa University of Technology, Indonesia, iksan.adiasa@uts.ac.id*

the requirements using several different choice parameters [23]. Decision-making is research that has developed over the last twenty years, while research on the theory and methods of decision-making has always received the attention of researchers in the world [13][19]. Analytic Hierarchy Process (AHP) is the most common multi-criteria decision-making method and was first introduced by Saaty in 1977 [36]. The Analytical Hierarchy Process (AHP) approach is proposed in the design of decision making in uncertainty assessment [19]. The case study is focused on discrete decisions. The interests and preferences in this case use a key performance indicator. This process can solve the problem of consensus-based group decision-making to choose one of two options. The AHP method was used to select the main fan used in a coal mine in Turkey [23]. The hierarchical structure of this problem consists of three levels with three alternatives to choose. Conventional AHP is very strong in extracting expert knowledge, but still cannot reflect human thinking style, because precise data regarding human attributes is quite difficult to extract [35]. AHP uses judgment based on expert opinion to determine the relative value or contribution of these attributes and synthesize solutions. For example, the AHP method does not consider the uncertainties associated with natural language in mapping human judgment to crisp numbers [43]. Therefore, Fuzzy AHP, a fuzzy extension of AHP, was developed to solve hierarchical fuzzy problems. In the Fuzzy AHP procedure, the pairwise comparison in the judgment matrix is a fuzzy number. Therefore, decision-makers can specify preferences in the form of natural language expressions about the importance of each criterion [44]. Thus, Fuzzy logic offers a systematic basis in dealing with ambiguous or poorly defined situations [20]. Fuzzy AHP (FAHP) is a synthetic extension of the classic AHP method, which considers the ambiguity (uncertainty or insufficient information) of decision-makers. Because it has a wide area of application, the FAHP approach has been the subject of sensational research for many different field researchers. Fuzzy-AHP approach has been effectively applied in various applications, for example supplier selection [3][10][17][22], personnel selection [21], measurement instrument selection [25], job selection [34], project selection [14][41], the selection of construction project management [9] and many others. The method of decision making for some fuzzy attributes has been developed due to the inaccuracy in assessing the relative importance of the attributes and the alternative performance ratings related to the attributes [11]. There are varieties of reasons for the inaccuracy: information that cannot be quantified, information that is incomplete, information that cannot be obtained, and partial ignorance. The conventional multiple attribute decision-making method cannot solve this problem effectively [29]. The Fuzzy-AHP method is a translation of the standard AHP method into a fuzzy domain by using fuzzy numbers to calculate, not real numbers [31]. AHP is a robust and flexible decision-making process [35] to help decision-makers make the best decisions when qualitative and quantitative aspects of a decision problem need to be considered. Since the uncertainty and obscurity of expert opinion are the main characteristics of a problem, the inaccuracy of human judgment can be handled through the fuzzy set theory developed [45]. To deal with types of information that are qualitative, imprecise, or unstructured decision problems, fuzzy set theory can be used as a modeling tool for complex systems that can be controlled by humans but are difficult to define precisely [7]. A side from the convenience of AHP in handling qualitative and quantitative criteria of multi-criteria decision-making problems based on the judgment of the decision-maker, the obscurity that exists in many decision-making problems can contribute to the improper judgment of decision-makers in conventional AHP processes [8]. MADM can help to determine the brands of lamps used in the reading room of the UNS central library. Fuzzy AHP is one of the MADM methods used to analyze the parameters and criteria for decision-making. MADM can be used as input for the electrical planning team, especially the room lighting system in making decisions about which lamp brands to use. The aim of this research is to design artificial lighting on the 4th of UNS central library. The artificial lighting is used, because the UNS central library operates 08.00 PM. The design of artificial lighting is based on SNI 6197-2011 as the standard of energy conservation in lighting systems. Fuzzy AHP in this study is used to select the lamp brand that will be used for artificial lighting. The introduction section has described various studies relevant to this research. Many researchers have conducted their research using the Fuzzy AHP method to select the best alternative among several options. However, from several studies using Fuzzy AHP, none of them used this method to select a lamp brand. In this paper, a multi-criteria decision-making procedure based on Fuzzy AHP is recommended to select a lamp brand that matches the criteria set by UNS. Fuzzy AHP will provide convenience to the parties involved in the selection of lamp brands that will be used in the reading room of the UNS central library.

2 METHODOLOGY

This study uses primary and secondary data. The primary data needed in this study include the number and types of the lighting and the respective intensity of lighting in the reading room in the morning, daytime, and afternoon. The secondary data used in this study is the floor plan on the 4th floor. This study conducted in three stages, follows:

2.1 Energy Audit

Energy audit was carried out based on SNI 6196-2011 [6]. The steps in conducting an energy audit are as follows:

1. Calculate the total electric power for lighting (DTLP)
   The formula used is as follows:
   $$\text{DTLP} = \text{The number of lamps x lamp wattage} \quad (1)$$
2. Calculate the installed lighting power (Watt/m2)
   The formula used is as follows:
   $$\text{Installed Power}\left(\frac{\text{watt}}{\text{m}^2}\right) = \frac{\text{DTLP}}{\text{room area}} \quad (2)$$
3. Calculate the monthly total lighting power (DTPB)
   The formula used is as follows:
   $$\text{DTPB} = \text{installed power x} \sum \text{working hours x} \sum \text{working days x room area} \quad (3)$$
4. Calculate the monthly electricity cost
   The formula to calculate the monthly electricity cost is as follows:
   $$\text{Electricity cost} = \text{DTPB x electricity unit cost per kWh} \quad (4)$$
5. Calculate the energy consumption index (IKE)
   The formula used is as follows:
   $$\text{IKE} = \frac{\text{DTPB}}{\text{room area}} \quad (5)$$

2.2 Identification of Existing Lighting

The identification of existing lighting in the 4th reading room is

done through 3 stages.

1. Determining the coordinates of the measurement of lighting intensity based on SNI 16-7062-2004.
2. Measuring the intensity of lighting at the determined coordinates using luxmeter with a height of 0.75 m [4].
3. Comparing the result measurement of lighting intensity with minimum lighting intensity standard based on SNI 6197-2011 Nasional [5].

2.3 Design of Artificial Lighting

The steps in designing artificial lighting in the 4th reading room are as follows:

1. Determining the Brand Rank of the Lamp

The reason for determining the rank of lighting brand in this study is to find the best brand suited to be used in the reading room since each brand has its own advantages and disadvantages. There are three stages in choosing a lamp brand. First, determine the criteria and sub criteria for selecting a lamp brand. This stage is carried out by compiling a stage 1 questionnaire and then distributing it to respondents. The first stage questionnaire aims to bring up the criteria and sub-criteria used in making decisions for lamp selection. The question model in the phase 1 questionnaire is semi-open, in order to consider suggestions or input from related parties regarding the criteria and sub-criteria that might be added or removed. The selected respondents were 4 people, consisting of staff from the household division, staff from the procurement service unit, and 2 electricians. The household staff was chosen as the respondent, because the staff of the household section are administratively responsible for the procurement of goods at the UNS Library. Procurement service unit staff as the party responsible for the procurement of goods. The electrician is technically responsible for the electrical equipment in the UNS central library. The output of the first stage questionnaire is in the form of criteria and sub criteria for selecting lamp brands.

Second, create a hierarchical structure of the problem. Hierarchy creation is used to break down the problem into smaller and simpler parts. The hierarchy consists of several levels, the top level (level 0) is the main objective, the second level (level 1) is the criteria, the third level (level 2) is the sub-criteria and the last level is the alternative. Next, determine the weight of the criteria and sub criteria. The determination of the weight of the criteria and sub-criteria was carried out by compiling and distributing the stage 2 questionnaire. The second stage questionnaire was compiled based on the results of the analysis of the questionnaire 1. Respondents who filled out the second stage questionnaire were the same as the respondents who filled out the stage 1 questionnaire.

Third, the stages in Fuzzy AHP are as follows:

a. Pairwise comparative assessment

The pairwise comparisons will produce different opinions. At the aggregation stage, Saaty (1994) used geometric mean due the use of ratio number and be able to reduce the disturbance arising from one of the numbers that too large or too small [26][36].

Geometric mean is mathematically written as follows:

$$\alpha_{ij} = (Z_1, Z_2, Z_3, .. Z_n)^{1/n} \quad (6)$$

With:

αij = The average value of pairwise comparison of Ai and Aj criteria for n participants.

Zi = Comparison value between Ai with Aj criteria for i participants with i = 1, 2, 3,.., n

b. Consistency test

Inconsistencies might occur in the AHP method because they use the perception of the decision makers as input and humans have limitation in expressing their perceptions [38]. Therefore consistency test needs to be carried out to prove the consistency of the pairwise comparison matrix. CR (Consistency Ratio) value from the consistency test stage in Fuzzy AHP is as follows:

Step 1: determine the value of eigen vector and λ maximum

Step 2: determine the value of CI (Consistency Index) with the following equation:

$$CI = \frac{\lambda max - n}{n-1} \quad (7)$$

With:

CI = Consistency Index

λmax = average eigen value

n = matrix order

Step 3: Determine the value of Consistency Ratio (CR) with the following equation:

$$CR = \frac{CI}{RI} \quad (8)$$

With:

CR = Consistency Ratio

CI = Consistency Index

RI = Random Index (see Table 1)

TABLE 1
THE VALUE OF RANDOM INDEX

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	1	1	1	1	1	2	2	2	2	2	2	2

c. Conversion of AHP to Triangular Fuzzy Number (TFN)

Triangular Fuzzy Number (TFN) is a type of Fuzzy set that helps in measurements related to human subjective judgements based on linguistic scales [15]. TFN is denoted by M = (l, m, u), where l is the lowest value, m is the middle value, and u is the highest value.

TABLE 2
TRIANGULAR FUZZY NUMBER

Fuzzy Scale	TFN Value	Fuzzy Scale Inversion	Information
1	(1,1,1)	(1,1,1)	Equally important
2	(1/2,1,3/2)	(2/3,1,2)	Mid
3	(1,3/3,2)	(1/2,2/3,1)	A little more important
4	(3/2,2,5/2)	(2/5,1/2,2/3)	Mid
5	(2,5/2,3)	(1/3,2/5,1/2)	More important
6	(5/2,3,7/2)	(2/7,1/3,2/5)	Mid
7	(3,7/2,4)	(1/4,2/7,1/3)	Very important
8	((7/2,4,9/2)	(1/9,1/4,2/7)	Mid
9	(4,9/2,9/2)	(2/9,2/9,1/4)	Absolute more important

d. Fuzzy Synthetic Extend (FSE) Analysis

Fuzzy Synthetic Extend (FSE) analysis aims to

overcome the problems that may arise in decision making related to tangible and intangible criteria with uncertainty of assessment. The following is the formula used to determine the value of SI (Fuzzy Synthetic Extend):

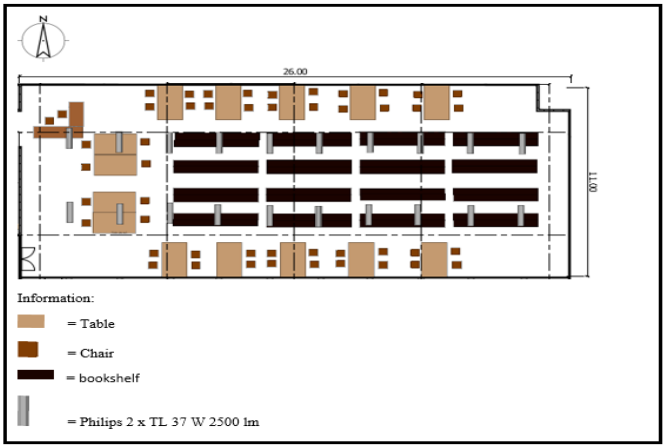
$$SI = \sum_{j=1} M_{gi}^{i} \, x \, \left[\sum_{i=1}\sum_{j=1} \sum_{gi}^{i}\right]^{-1} \quad (9)$$

While the equation used in determining the degree of possibility is as follows:

$$V\,(M_2 > M_1) = \begin{cases} 1 & ,m2 \geq m1 \\ 0 & l1 \geq u2 \\ \frac{l2-u2}{(m2-u2)-(m1-l1)} & \text{the opposite} \end{cases} \quad (10)$$

e. Normalization

From the calculation of degree possibility, the



normalization of weight can be done. This stage is a defuzzification process to convert vector numbers into non fuzzy (crisp) so that they become analog weight criteria and sub criteria [42]. Following is the formula used to determine the value of crisp:

$$CRISP\,(di) = \frac{d'j}{\sum_{i=1}^{n} d'i} \quad (11)$$

With:

Di = crisp value for criteria 1

d'i = the mínimum degree of possibility value for criteria i

2. Calculating the number of lights needed

To calculate the required number of lights (N), the average lighting level data (E), lumens (ϕ), usage coefficient (CU), depreciation factor (LLF) and surface area (A) are required. The calculation of N using the following equation:

$$N = \frac{E \, x \, A}{n \, x \, \phi \, x \, CU \, x \, LLF} \quad (12)$$

3. Calculating the proposed lamp power

The calculation of the proposed lamp power uses the following equation:

$$Power = \frac{N \, x \, n \, x \, (lamp \; wattage)}{Room \; Area} \quad (13)$$

4. Calculating the monthly electricity cost

Equation 3 and 4 are used to determine the monthly electricity cost.

5. Calculating the proposed IKE

Equation 5 is used to determine the IKE.

3 RESULT

3.1 Energy Audit

The existing lamp used in the reading room is Philips TL 36 Watts with a total of 27 units. Within a day, the light is on for 12 hours. There are 20 working days in a month. The reading room on the 4th floor has an area of 286 m^2

The total electrical energy for lighting in the reading room on the 4th floor of UNS central library was obtained using Equation 1. The calculation result is shown as follows:

$$DTLP = 27 \, x \, 36 \; watt$$

$$DTLP = 972 \; watt$$

The installed power used for lighting is obtained using Equation 2. The calculation result of installed power for lighting is as follows:

$$Installed\ Power = \frac{972 \; watt}{286 \; m^2}$$

$$Installed\ Power = 3.4 \; watt/m^2$$

The total power used for lighting in 1 month is obtained using Equation 3. The calculation result is as follows:

$$DTPB = 3.4 \; {}^{watt}/_{m^2} \; x \; 12 \; hours \; x \; 20 \; days \; x \; 286 \; m^2$$

$$DTPB = 233376 \; watt$$

$$DTPB = 233.38 \; kWh$$

Electricity cost in 1 month is obtained using formula 4. The cost of electricity per kWh for government offices is set at Rp 1114.74. So the cost of electrical energy for lighting can be calculated as follows:

$$Electricity\ cost = 233.38 \; kWh \; x \; Rp \; 1114.74/kWh$$

$$Electricity\ cost = Rp \; 260{,}158.02$$

The next step is to calculate IKE using Equation 5. IKE calculation result is as follows:

$$IKE = \frac{233.38}{286}$$

$$IKE = 0.81 \; kWh \; / \; m^2 \; /month$$

The calculation result shows that reading room on the 4th floor of UNS central library has IKE of 0.81 kWh/m^2/month and it is included in the efficient category according to SNI 6196-2011 [6].

3.2 Identification of Existing Lighting

The first step in identifying existing lighting is to determine the layout of reading room on the 4th floor of UNS central library. The layout is shown in Figure 1.

Fig. 1. 4th Floor reading room layout.

Reading room in 4th floor of UNS central library uses TL lamp 36 watt which has 2500 lumens. Next is to determine the lighting measurement points. According to SNI 16-7062-2004, the determination of lighting measurement points with a room area of more than 100 m^2 is as shown in Figure 2. The next step is to determine the coordinates of the measurement points based on intersections of vertical and horizontal lines with a distance of 6 m. The last step is to measure lighting intensity using an envirometer.

***Fig. 2**. Determination of measurement points.*

Measurements were taken 3 times, namely in the morning, daytime, and afternoon. The morning measurement was carried out 07.00 – 10.00 AM. The daytime measurement was carried out 12.00 – 15.00 PM. While the afternoon measurement was carried out 16.00 – 18.00 PM. The measurement of lighting intensity was carried out in the condition of the lights were on and the sun's light could enter the room. The coordinate points of measurement and the result of lighting intensity measurement are shown in Table 3.

TABLE 3
THE COORDINATE POINTS OF MEASUREMENT AND THE RESULT OF LIGHTING INTENSITY MEASUREMENT.

Room	Coordinate Point		07.00-10.00 AM	12.00-15.00 PM	16.00-18.00 PM
	x	y	lux	lux	lux
Reading Room	1	2.5	275.7	207.5	241.9
	1	8.5	106.1	88.4	226
	7	2.5	757.2	575.8	194.8
	7	8.5	514.6	129.5	179.8
	13	2.5	186.2	86.1	147.7
	13	8.5	425.2	134.8	220.4
	19	2.5	98.6	73.7	244.3
	19	8.5	176.9	309.4	246.8
	25	2.5	100.5	193.6	115.6
	25	8.5	100.8	192.5	115.2
Average			274.18	199.13	193.25

The intensity of lighting with a high value is located at the edge of the room because it is exposed to sunlight which coming directly through the window. The highest average lighting intensity occurs 07.00 – 10.00 AM.WIB. That is because the reading room is located at the east of the building, so that the sunlight can enter the room in the morning. The average lighting intensity at three time measurements does not meet the standard based on SNI 6197-2011 at 300 lux. Lighting level which is not in accordance with the standard can cause visual disturbances for library users. Therefore, it is necessary to improve lighting in the reading room.

3.3 Proposed Lighting Improvement

The lighting improvement stage in the reading room performed in two steps, namely: the determination of the lighting brand, and IKE assessment of the proposed lighting.

3.3.1 Determine the Brand Rank of the Lamp

This stage is to determine the rank of the lamp brand based on the criteria and sub criteria shown in Figure 3. There are 3 proposed lighting brands: Philips, OSRAM, and Hannoch. These three lighting brands are the most widely used in Indonesia. The hierarchy of the problem of choosing alternative lighting brands can be seen in Figure 3.

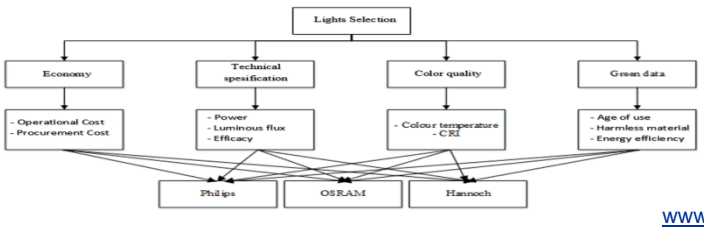


***Fig 3.** Hierarchy structure of weight determination for lamp selection criteria.*

The next step is to distribute questionnaires to determine the hierarchical structure. Questionnaires were distributed to experts and those who have the right to make decisions. The next step is to aggregate respondents' assessments using the geometric mean method. The geometric mean result is shown in Table 4.

TABLE 4
GEOMETRIC MEAN OF THE ASSESSMENT AGGREGATION OF MAIN CRITERIA RESPONDENTS

Criteria	C_1	C_2	C_3	C_4
C_1	1	0.58	0.49	0.52
C_2	1.71	1	2.47	0.58
C_3	2.03	0.41	1	0.41
C_4	1.91	1.71	2.47	1
Total	6.65	3.70	6.43	2.51

The next step is to perform a consistency test. If the value of CR < 0.1, then the values in the previous matrix must be improved until it reaches the value of CR < 0.1 [2].

TABLE 5
CONSISTENCY TEST OF THE MAIN CRITERIA WITH THE SUB CRITERIA

Criteria	Sub Criteria	λmaks	CI	RI	CR	Information
C_1	C_{11}	1	-1	0	0	Consistent
	C_{12}					
C_2	C_{21}	1.00	-1.00	0.90	-1.11	Consistent
	C_{22}					
	C_{23}					
C_3	C_{31}	1.00	-1.00	0.90	-1.11	Consistent
	C_{32}					
C_4	C_{41}	1.00	-1.00	0.90	-1.11	Consistent
	C_{42}					
	C_{43}					

The next step is to convert the AHP linguistic scale to TFN. The result of the conversion of AHP to TFN for the main criteria is shown in Table 6.

TABLE 6
TFN CONVERSION

Criteria	Pairwise Comparison Matrix for The Main Criteria											
	C_1			C_2			C_3			C_4		
	l	m	u	l	m	u	l	M	u	l	m	u
C_1	1	1	1	2/3	1	2	2/3	1	2	2/3	1	2
C_2	1/2	1	3/2	1	1	3	1/2	1	3/2	2/3	1	2
C_3	1/2	1	3/2	2/3	1	2	1	1	1	2/3	1	2
C_4	1/2	1	3/2	1/2	1	3/2	1/2	1	3/2	1	1	1

The next step is to carry out Fuzzy Synthetic Extend (FSE) analysis which aims to overcome problems that sometimes arise in decision making related to tangible and intangible criteria with uncertainty of assessment. This stage can include uncertainty in determining criteria and comparing each pair of membership functions that are built for each criteria. The FSE value for the main criteria can be seen in Table 7.

TABLE 7
FSE OF MAIN CRITERIA

Si = Fuzzy Synthetic Extend			
	l	m	U
C1	0.11	0.25	0.64
C2	0.1	0.25	0.73
C3	0.1	0.25	0.59
C4	0.09	0.25	0.5
Total	0.41	1	2.45

From the result of the Fuzzy approach which is weighted, then the value of membership called the degree of possibility is obtained.

TABLE 8
DEGREE OF POSSIBILITY OF THE MAIN CRITERIA

Criteria	C1	C2	C3	C4	Min
C1	1	1	1	1	1
C2	1	1	1	1	1
C3	1	1	1	1	1
C4	1	1	1	1	1
Total					4

The final stage in the Fuzzy AHP which distinguishes it with the AHP method is the weight normalization stage. The calculation result of weight normalization for the main criteria can be seen in Table 9.

TABLE 9
NORMALIZATION OF THE MAIN CRITERIA

Vector Weight		Normalization	Crysp Weight
d'C_1	min	C_1	0.25
d'C_2	min	C_2	0.25
d'C_3	min	C_3	0.25
d'C_4	min	C_4	0.25
Total			

After the weighting stage is carried out for all the criteria and sub criteria, then an alternative selection is made based on the weighting result that has been obtained. The recap of the weighting results for all criteria and sub criteria can be seen in Table 10.

TABLE 10
RECAP OF THE WEIGHTED RESULTS FOR ALL CRITERIA

Goal	Criteria		Sub Criteria		Weight Sub Criteria	Alternative		Weight
Selection of Lights Brands	C_1	0.25	C_{11}	1.00	0.25	Philips	0.45	0.11
						OSRAM	0.45	0.11
						Hannoch	0.11	0.03
			C_{12}	0.00	0.00	Philips	0.73	0.00
						OSRAM	0.27	0.00
						Hannoch	0.00	0.00
	C_2	0,25	C_{21}	0.14	0.03	Philips	0.39	0.01
						OSRAM	0.39	0.01
						Hannoch	0.23	0.01
			C_{22}	0.30	0.07	Philips	0.39	0.03
						OSRAM	0.39	0.03
						Hannoch	0.22	0.02
			C_{23}	0.57	0.14	Philips	0.45	0.06
						OSRAM	0.41	0.06
						Hannoch	0.14	0.02
	C_3	0,25	C_{31}	0.43	0.11	Philips	0.56	0.06
						OSRAM	0.34	0.04
						Hannoch	0.10	0.01
			C_{32}	0.57	0.14	Philips	0.39	0.06
						OSRAM	0.39	0.06
						Hannoch	0.23	0.03
	C_4	0,25	C_{41}	0.33	0.08	Philips	0.45	0.04
						OSRAM	0.41	0.03
						Hannoch	0.14	0.01
			C_{42}	0.33	0.08	Philips	0.65	0.05
						OSRAM	0.19	0.02

			Hannoch	0.16	0.01
			Philips	0.46	0.04
C_{43}	0.33	0.08	OSRAM	0.46	0.04
			Hannoch	0.07	0.01

The next step is to calculate the selected alternative. The calculation result of the selected alternative brand of lights is shown in Table 11.

TABLE 11
CALCULATION RESULT OF THE SELECTED ALTERNATIVE

Alternative	Weight		Ranking
Philips	0.46	46%	1
OSRAM	0.39	39%	2
Hannoch	0.15	15%	3
Total	1	100%	

Based on the calculation result that shown in Table 11, the priority order of the lighting brands that can be selected as a recommendation for lighting in the reading room of the 4th floor UNS central library is:

1. Philips lighting brand with the weight of 0.46
2. OSRAM lighting brand with the weight of 0.39
3. Hannoch lighting brand with the weight of 0.15

3.3.2 Determine the IKE of the Proposed Lighting

The next step is to determine the number of lights that will be used in the reading room on the 4th floor. The first is determining the type of armature that will be used. In this study, the armature used is type which attached to the ceiling. Each armature contains of two lights that use a general lighting system. This lighting system was chosen so that the light intensity can spread evenly throughout the room. The second is determining the number of lights that will be used for the reading room. The minimum lighting level (E) required for the reading room on the 4th floor of UNS central library refers to SNI 6197-2011 is at 300 lux. The light that will be used is Philips TL 80 Super 36 W 3350 lm. The coefficient utilization (CU) and light loss factor (LLF) for the calculation of the number of lights have been set. The CU value is 0.69, while the LLF value is 0.77. The number of lights needed is obtained using the Equation 12. The calculation result is as follows:

$$N = \frac{300 \text{ x } 286}{2 \text{ x } 3350 \text{ x } 0{,}69 \text{ x } 0{,}77}$$

$$N = 24 \text{ lights}$$

The proposed lights power can be obtained using Equation 13. The calculation result is as follows:

$$\text{Power} = \frac{24 \text{ x } 2 \text{ x } 36}{286}$$

$$\text{Power} = 6.04 \text{ watt} / \text{m}^2$$

Electricity cost that must be paid in 1 month is obtained using formula 3 and formula 4. The calculation result of electricity cost in 1 month is as follows:

$$\text{DTPB} = 6.04 \text{ x } 20 \text{ x } 12 \text{ x } 286$$

$$\text{DTPB} = 414585.6 \text{ watt hour/ month}$$

$$\text{DTPB} = 414.59 \ {}^{\text{kWh}}/_{\text{month}}$$

$$\text{Electricity cost} = 414.59 \ {}^{\text{kWh}}/_{\text{month}} \text{ x Rp } 1114{,}74$$

$$\text{Electricity cost} = \text{Rp } 462{,}148.90$$

The last step is to calculate IKE of the proposed lighting. IKE is calculated using Equation 5. The IKE calculation result is as follows:

$$\text{IKE} = \frac{414.58 \text{ kWh/month}}{286}$$

$$\text{IKE} = 1.449 \text{ kWh /month/ m}^2$$

4 DISCUSSION

The average of lighting intensity measurement in the reading room on the 4th floor of UNS central library is still below the standard set by SNI 6197-2011. The lighting level below the standard will cause visual disturbances for library users. Based on interviews with 22 respondents, complaints were found due to lighting level that did not meet the standard. Complaints experienced by respondents include headaches, tired eyes, sore eyes, and difficulty for finding books. These findings agree with the result of the research [27], that limiting artificial lighting to reduce electricity cost will increase the tendency of eye injuries to users of the room. The calculation of installed power for reading room lighting in existing condition is 3.4 watt/m^2. The result of this calculation is still below the maximum electrical power standard for lighting in a library room that should be 11 watt/m^2 based on SNI 6197-2011 [5]. The total electrical energy for lighting used is 233.38 kWh. The electricity cost that must be paid is Rp 260,158.02. IKE for reading room is 0.81 kWh/m^2/month and it is included in the efficient category according to SNI 6196-2011 [6]. The IKE result shows the efficient category but the level of lighting used in the reading room is still below standard. But it must be remembered that energy saving in building must be done efficiently without reducing the comfort of building users [1]. Lamp brand ranking weights based on Fuzzy AHP are as follows: Philips lighting brand with the weight of 0.46, OSRAM with the weight of 0.39, and Hannoch with the weight of 0.15. In this study the proposed lighting brand is the Philips. So that the light that will be used is the Philips TL 80 Super 36 W 3350 lm. The number of lights needed is 24 units. The installed power for the proposed lighting improvement in the reading room is 6.04 watt/m^2. The result of this calculation is still below the maximum electrical power standard for lighting in a library room which should be 11 watt/m^2 based on SNI 6197-2011 [5]. Installed power has increased compared to the installed power of existing condition. This increase is caused by the intensity of the lighting for the reading room which has adjusted to the standard. The increase in installed power causes an increase in the total power used for lighting to 414.59 kWh. The electricity cost has increased to Rp 462,148.90. IKE for the proposed lighting improvement becomes 1.449 kWh/month/m^2. Although IKE has increased, it is still included in the efficient category.

5 CONCLUSION

The average lighting intensity for reading room on the 4th floor of UNS central library is still below the standard of SNI 6197-2011. IKE for existing lighting condition is 0.81 watt/m^2 and it is included in the efficient category. Lamp brand ranking weights based on Fuzzy AHP as follows: Philips with the weight of 0.46, OSRAM with the weight of 0.39 and Hannoch with the weight of 0.15. The improvement of artificial lighting was carried out using Philip TL 80 Super 36 W 3350 lm lighting

brand. The installed power for lighting becomes 6.04 watt/m^2. IKE for the proposed lighting improvement becomes 1.449 kWh/month/m^2 and it is included in the efficient category. The increase in IKE is due to the use of lights that have been adjusted to the standard. Opportunities for saving electricity for lighting can be done by turning off the lights if there is no activity in the room. Recommendation that can be given for further study is to carry out further analysis of the relationship between lighting levels with eye fatigue.

REFERENCES

[1] T.R. Adiprama, and U. Ciptomulyono, "Audit Energi dengan Pendekatan Metode MCDM-PROMETHEE untuk Konservasi serta Efisiensi Listrik di Rumah Sakit Haji Surabaya", Jurnal Teknik ITS, 11;1(1):A465-70, Sep. 2012.

[2] Y. Anshori, "Pendekatan Triangular Fuzzy Number dalam Metode Analytic Hierarchy Process", Jurnal Ilmiah Foristek, 2012;2(1).

[3] F. Arikan, "An interactive solution approach for multiple objective supplier selection problem with fuzzy parameters", Journal of intelligent manufacturing, 26(5):989-98, Oct. 2015.

[4] S.N. Indonesia, Pengukuran intensitas penerangan di tempat kerja, SNI 16-7062-2004, Jakarta: Badan Standar Nasional Indonesia; 2003.

[5] B.S. Nasional, Konservasi energi pada sistem pencahayaan, SNI 6197: 2011, Jakarta: Badan Standar Nasional Indonesia; 2011.

[6] B.S. Indonesia, Prosedur Audit Energi pada Bangunan Gedung, SNI-03-6196-2011, Jakarta: Badan Standar Nasional Indonesia; 2011.

[7] R.E. Bellman and L.A. Zadeh, "Decision-making in a fuzzy environment", Management science, 17(4):B-141, Dec. 1970.

[8] D. Bouyssou, T. Marchant, M. Pirlot, P. Perny, A. Tsoukias, and P. Vincke, "Evaluation and decision models: a critical perspective", Springer Science & Business Media, Nov 30. 2000.

[9] F.T. Bozbura, and A. Beskese, "Prioritization of organizational capital measurement indicators using fuzzy AHP". International journal of approximate reasoning, 44(2):124-47, Feb 1. 2007.

[10] I. Chamodrakas, D. Batis, and D. Martakos, "Supplier selection in electronic marketplaces using satisficing and fuzzy AHP", Expert Systems with Applications, 37(1):490-8, Jan 1. 2010.

[11] C.W. Chang, D.J. Horng, and H.L. Lin, "A measurement model for experts knowledge-based systems algorithm using fuzzy analytic network process", Expert systems with applications, 38(10):12009-17, Sep 15. 2011.

[12] K.T. Cho, "Multicriteria decision methods: an attempt to evaluate and unify", Mathematical and computer modelling, 37(9-10):1099-119, May 1. 2003.

[13] P. Dongjin, "A new method for Fuzzy Multiple Attribute Decision Making based on interval numbers", International Forum on Information Technology and Applications, May. 2009.

[14] M. Enea, and T. Piazza, "Project selection by constrained fuzzy AHP", Fuzzy optimization and decision making. 3(1):39-62, Mar 1. 2004.

[15] M. Elveny, and R. Syah, "Analisis Metode Fuzzy Analytic Hierarchy Process (FAHP) Dalam Menentukan Posisi Jabatan", TECHSI-Jurnal Teknik Informatika, 6(1), Apr 14. 2014.

[16] J. P. Guyer, "Introduction to Interior Lighting Design", Continuing Education and Development, Inc, 2010.

[17] Z. Güngör, G. Serhadlıoğlu, and S.E. Kesen, "A fuzzy AHP approach to personnel selection problem", Applied Soft Computing, 9(2):641-6, Mar 1. 2009.

[18] Y. Hadad, and M.Z. Hanani, "Combining the AHP and DEA methodologies for selecting the best alternative", International journal of logistics systems and management, 9(3):251-67, Jan 1. 2011.

[19] C.J. Hopfe, G.L. Augenbroe, and J.L. Hensen, "Multi-criteria decision making under uncertainty in building performance assessment", Building and environment, 69:81-90, Nov 1. 2013.

[20] C. Kahraman, U. Cebeci, and D. Ruan, "Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey", International journal of production economics, 87(2):171-84, Jan 28. 2004.

[21] H.S. Kılıç, and E. Çevikcan, "Job selection based on fuzzy AHP: an investigation including the students of Istanbul Technical University Management Faculty". International journal of business and management studies. 3(1):173-82, 2011.

[22] O. Kilincci, and S.A. Onal, "Fuzzy AHP approach for supplier selection in a washing machine company", Expert systems with Applications, 38(8):9656-64, Aug 1. 2011.

[23] N. Kursunoglu, and M. Onder, "Selection of an appropriate fan for an underground coal mine using the Analytic Hierarchy Process", Tunnelling and Underground Space Technology, 48:101-9, Apr 1. 2015.

[24] C.A. Kusumawardani, "Penentuan kriteria dan sub kriteria serta pembobotan penilaian research project selection PNBP LPPM UNS dengan metode Fuzzy AHP", Bachelor of Engineering Thesis, Dept. Of Industrial Eng., Sebelas Maret Univ., Indonesia, 2016.

[25] P. Mahendran, M.B. Moorthy, and S. Saravanan, "A fuzzy AHP approach for selection of measuring instrument for engineering college selection", Applied mathematical sciences, 8(44):2149-61, 2014.

[26] D.A. Mardhikawarih, "Pemilihan pemasok drum pelumas industri menggunakan fuzzy analytical hierarchy process (studi kasus: PT. Pertamina pusat (oil centre) dan production unit Gresik)", Performa, 19 (1);67-74, 2012.

[27] M.C. Ho, C.M. Chiang, P.C. Chou, K.F. Chang, and C.Y. Lee, "Optimal sun-shading design for enhanced daylight illumination of subtropical classrooms", Energy and buildings, 40(10):1844-55, Jan 1. 2008.

[28] M. Nurmammad, and A. Samira, "New Methodology of Multi-Disciplinary Energy Auditing of Buildings in Azerbaijan.", In 5th International Symposium on Innovative Technologies in Engineering and Science 29-30 September 2017 (ISITES2017 Baku-Azerbaijan), Sept 29. 2017.

[29] S. Oguztimur, "Why Fuzzy Analytic Hierarchy Process approach for transport problems?", In Proceedings of 51st Congress of European Regional Science Association - ERSA, 1-10. Barcelona, SPAIN, 2011.

[30] O. Omar, B. García-Fernández, A.Á. Fernández-Balbuena, and D. Vázquez-Moliní. "Optimization of daylight utilization in energy saving application on the library in faculty of architecture, design and built

environment, Beirut Arab University", Alexandria engineering journal, 57(4):3921-30, Dec 1. 2018.
[31] J. Petkovic, Z. Sevarac, M.L. Jaksic, and S. Marinkovic, "Application of fuzzy AHP method for choosing a technology within service company", Technics technologies education management-ttem, 7(1):332-41, Jan 1. 2012.
[32] A.D. Putri, S. Sugiono, and R.A. Sari, "Pemilihan Alternatif Peluang Hemat Energi Listrik dengan Pendekatan Metode ANP dan PROMETHEE", Jurnal Rekayasa dan Manajemen Sistem Industri, 3(1):p142-153, Mar 2. 2015.
[33] A. Rohman, "Guide to the Greenmetric World University Rankings 2017". Concepts and Applications of Inferential Statistics, 2017.
[34] S.M. Saad, N. Kunhu, and A.M. Mohamed, "A fuzzy-AHP multi-criteria decision-making model for procurement process". International journal of logistics systems and management, 23(1):1-24, 2016.
[35] T.L. Saaty, Analytic hierarchy process. Wiley Online Library, 1980.
[36] T.L. Saaty, "Highlights and critical points in the theory and application of the analytic hierarchy process", European journal of operational research, 74(3):426-47, May 5. 1994.
[37] T.L. Saaty, "Fundamentals of decision making and priority". Pittsburgh, PA: Rws, Publications, 1994,
[38] T.L. Saaty, and L.G. Vargas, "Models, methods, concepts & applications of the analytic hierarchy process", Springer Science & Business Media, Apr 12. 2012.
[39] A. Samira, and M. Nurmammad, "Multi-disciplinary Energy Auditing of Educational Buildings in Azerbaijan: Case Study at a University Campus", IFAC-PapersOnLine, 51(30):311-5, Jan 1. 2018.
[40] Sebelas Maret University, Rector regulation of Sebelas Maret University Number: 827A/UN27/KP/2013 About the Sebelas Maret University green campus management guidelines, 2013.
[41] A. Shaygan, Ö.M. Testik, "A fuzzy AHP-based methodology for project prioritization and selection", Soft computing, 23(4):1309-19, Feb 27. 2019.
[42] H.N. Shega, R. Rahmawati, and H. Yasin, "Penentuan faktor prioritas mahasiswa dalam memilih telepon seluler merk blackberry dengan fuzzy AHP", Jurnal Gaussian, 1(1):73-82, 2012.
[43] C.C. Sun, "A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods", Expert systems with applications, 37(12):7745-54, Dec 1. 2010.
[44] T. Yaghoobi, "Prioritizing key success factors of software projects using fuzzy AHP", Journal of software: Evolution and process, 30(1):e1891, Jan. 2018.
[45] L.A. Zadeh, G.J. Klir, and B. Yuan, "Fuzzy sets, fuzzy logic, and fuzzy systems"; selected papers, World Scientific, 1996.
[46] E. Zarghami, H. Azemati, D. Fatourehchi, and M. Karamloo, "Customizing well-known sustainability assessment tools for Iranian residential buildings using Fuzzy Analytic Hierarchy Process", Building and Environment, 128:107-28, Jan 15. 2018.