Volume 8, Issue 7, pp. 89-97, 2024.
International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

Audit and Optimization of Electric Energy at Training Institution Using the Analytical Hierarchy Process (AHP) Method

Achlis[1], Sukarno Budi Utomo[2], Novi Marlyana [3]
[1, 2]Department of Electrical Engineering, Universitas Islam Sultan Agung, Semarang, Indonesia
[3]Department of Industrial Engineering, Universitas Islam Sultan Agung, Semarang, Indonesia

Abstract— *Training institution with an area of 25,000 m^2, consists of several buildings which are supplied with 53 KVA electric power and a 30 KVA generator as backup power. The use of electrical energy in training institutions has not been recorded in detail. There are no kWh meters in each building. If you don't pay attention to the use of electrical energy, it could potentially result in waste in its use. The aim of this research is to determine the value of energy consumption intensity (IKE) and implement the Analytical Hierarchy Process (AHP) method to optimize electrical energy in selected buildings at training institutions. Alternative solutions to this problem require an energy audit and calculation of the electricity load per building. The Analytical Hierarchy Process (AHP) method as a decision maker based on a set of alternatives is selected to select the building to be optimized. Based on the results of the energy audit, it is known that the energy consumption intensity (IKE) value ranges from 1.606 to 27.870 kWh/m²/month. The highest was 27.870 kWh/m²/month in the information and communication technology (TIK) workshop, the lowest was 1.606 kWh/m²/month in the light vehicle engineering (TKR) workshop. Then AHP was carried out to optimize energy, where the criteria used were IKE value, training intensity, training hours and number of facilities, while the alternative was 6 workshops. The priority choice based on AHP was welding workshop (24.6%). Based on the energy optimization implementation steps in the welding workshop, savings of 590 kWh, equivalent to Rp. 1,002,722.70*.

Keywords— *Audit, Optimization, Training Institution, Analytical Hierarchy Process (AHP).*

I. INTRODUCTION

Training institution with an area of 25,000 m^2, consists of several buildings, namely offices, halls, prayer rooms, theory rooms and workshops. There are 8 workshops, namely sewing workshops, cosmetology workshops, agricultural product processing workshops (PHP), information and communication technology workshops (TIK), motorbike engineering workshops (TSM), light vehicle engineering workshops (TKR), refrigeration engineering workshops and technical workshops welding. Training institution provides 53 KVA electric power and a 30 KVA generator as backup power. The problem with the use of electrical energy has not been recorded in detail. Even though there are no kWh meters in every building. Since training institutions has been operational, power requirements and electrical energy consumption per building have never been calculated. Where from 2009-2023 there has been a change in the function of the room, the addition of a new workshop/building, as well as an increase in electricity loads along with the increase in training facilities and infrastructure at Training institution. If the use of electrical energy is not considered optimally, it has the potential to result in waste in its use.

Alternative solutions to this problem require an energy audit and calculation of the electricity load per building, this is to determine the level of electrical energy consumption. The energy audit aims to assess whether the electrical energy used is optimal or not based on the energy consumption intensity (IKE) value. Analytical Hierarchy Process (AHP) method as a decision maker based on a set of selected alternatives. AHP is used to select buildings to be optimized. Apart from that, the basis chosen by AHP can solve the complexity caused by permit the perception of decision makers and analysed the presence of accurate statistical data [1].

Much research has been conducted on optimizing electrical energy before, but so far there has been no research on energy audits at training institutions [2][3][4]. The difference from previous research is the research object, power, load variables and the AHP implementation criteria used.

Based on this description, this research discusses energy audits to optimize electrical energy in some buildings using an Analytical Hierarchy Process (AHP) based method. The research object is the training institution building.

II. PROBLEM AND THEORY

The problem is that the use of electrical energy at training institutions has not been recorded in detail, which has the potential to result in waste in its use. Even though there are no kWh meters in every building. Since training institutions has been operational, power requirements and electrical energy consumption per building have never been calculated. So it is necessary to carry out an energy audit to determine the value of energy consumption intensity (IKE) and optimize based on the results of the energy audit with the aim of calculating the estimated savings that can be made.

A. *Energy Audit*

An energy audit is a technique used to calculate the amount of energy consumption in a building and identify ways to save it. An energy audit is a periodic inspection activity to determine whether there are irregularities in an energy use activity [2].

International Journal of Scientific Engineering and Science
Volume 1, Issue 1, pp. xx-xx, 2024. ISSN (Online): 2456-7361

B. *Electrical Energy Calculations*

Electric power is the total quantity of electrical energy that electrical equipment uses or produces at any one time. The watt, which expresses the amount of electrical energy flowing per unit of time (joule/second), is the SI unit for electrical energy [5].

Electrical power is produced by energy sources like electric voltage, which is then absorbed by the load attached to it. Equation (2) can be used to express the relationship between powers, voltage, currents. Equation (3) can be used to express the electricity price that must be paid by the use of electrical energy.

The power equation is as follows:

P = V ×I (1)[6]

P = Power (Watts)

V = Potential difference (Volts)

I = Current (Ampere)

The energy equation is as follows:

W = P ×t (2)[5]

P = Power (Watts)

t = Time (Hours)

W = Energy (Watt Hours)

Where:

Cost = energy used x TDL (basic electricity tariff) (3)[7]

C. *Energy Consumption Intensity (IKE) Value*

Energy Consumption Intensity (IKE) based on SNI 03-6196-2000 is a term used to express the amount of energy used per square meter of gross building area within a certain period of time. To calculate the potential energy savings that may be applied in each room/entire building area using IKE as a benchmark. Whether a building is efficient or not is known by comparing the building's IKE with standard IKE criteria [8].

The power equation is as follows:

$$IKE = \frac{\text{Electrical energy consumption (kWh)}}{\text{Building area (m2)}} \quad (3)$$

Where:

Area (L) = length (p) x width (l) (4)[9]

L = Area (m^2)

p = length (m)

l = width (m)

The analysis criteria IKE value is as shown in Table 1 [10].

TABLE 1. IKE Standards for Buildings in Indonesia

Criteria	AC Room (kWh/m^2/month)	Non AC Room (kWh/m^2/ month)
Very Efficient	4.17 – 7.92	0.84 – 1.67
Efficient	7.92 –12.08	1.67 – 2.5
Fairly Efficient	12.08 – 14.58	–
Somewhat Wasteful	14.58 – 19.17	–
Wasteful	19.17 – 23.75	2.5 – 3.34
Very Wasteful	23.75 – 37.75	3.34 – 4.17

D. *Analytical Hierarchy Process (AHP)*

Analytic Hierarchy Process (AHP) is a decision analysis method based on mathematical principles developed by Thomas L. Saaty [11]. In general, the AHP procedure consists of four main stages, namely:

1. Decomposition: compiling a simple hierarchical model consisting of three hierarchical levels, namely objectives, criteria and alternative options. Alternative levels can be further divided into more detailed levels, including several other criteria.
2. Comparison Assessment (comparative assessment): all elements of the strategy/alternative and criteria are compared with each other, to produce a scale of relative importance for each element. Create a pairwise comparison matrix on intensities. Comparisons are made based on the "judgment" of the decision maker by assessing the level of importance of one element compared to other elements. So that a total of n * [(n-1)/2] judgments are obtained, where n is the number of elements being compared. Comparison scores for all elements use a 9 number scale, each indicated with a different level of relative importance as shown in Table 2.

TABLE 2. Saaty's Pairwise Comparison Scale [12]

Verbal Judgment	Numerical value
Extremely important	9
	8
Very Strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

3. Priority Synthesis: priority synthesis is carried out using the eigenvector method, namely to obtain relative weights for decision-making elements.
4. Logical Consistency: The consistency measurement is based on the maximum eigenvalue of the n-order pairwise comparison matrix (λmax). Where the Consistency Index (CI) is obtained from:

   CI = ((λmax-n))/ ((n-1)) (5)

If CI is zero, then the pairwise comparison matrix is declared consistent. The inconsistency limit is determined using the Consistency Ratio (CR), namely the comparison of the Consistency Index with the Random Index (RI) value. Consistency Ratio can be formulated as follows:

CR = (CI)/RI (6)

TABLE 3. Random Index (RI) Value [12]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

E. *Measuring Average Formula (Geometry)[13]*

Calculating the (geometric) mean of a measurement by multiplying all the data in a data group and then taking the exact amount of data to a power. Geometry is used to calculate data from respondents for the AHP stage.

$$G = \sqrt[n]{x1 \, . x2. \dots \dots xn} \quad (7)$$

G = measuring average

xi = i-th x data

n = amount of data

III. RESEARCH MODEL

The research model was prepared to provide systematic guidance in conducting research. This research aims to optimize energy in selected buildings in the Demak Training Institution.

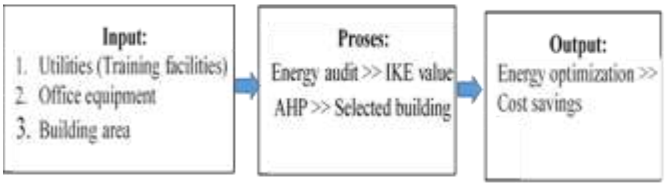

Fig. 1. Research Model

IV. Research Parameters

The research parameters that will be used are data collection which is used as material in Table 4, composition of training institution buildings and Table 5-6, monthly electricity load for rooms in training institution.

TABLE 4. Composition of Training Institution Buildings

No	Room Name	Lenght (m)	Width (m)	Area (m^2)
1	Welding Workshop	9	9	**81**
2	Sewing Workshop	9	9	**81**
3	PHP Workshop	9	7	**63**
4	TKR Workshop	9	9	**81**
5	TIK Workshop	8	6	**48**
6	Refrigeration Workshop	9	7	**63**
7	Make UP Workshop	9	6	**54**
8	Office Room	9	6	**54**

Table 4 is obtained by using equation (4) to calculate the area of the room. While tables 5 and 6 were obtained using equations 1 and 2 to calculate the total electricity load for 1 month.

TABLE 5. Monthly Electricity Load for Rooms without AC

No	Machine Name	Power (W)	Hours	Month	Q	Energy (kWh)
1	2	3	4	5	6	$7=\frac{(3x4x5x6)}{1000}$
	Sewing Workshop					**923.65**
1	Sewing machine	250	5	22	8	220
		550	5	22	8	484
2	Serger machine	550	1	22	4	48.4
3	Elektric iron	350	1	22	4	30.8
4	Fan	100	7	22	4	61.6
5	Light	18	7	22	9	24.95
6	Dispensers	350	7	22	1	53.9
	Welding Workshop					**2031.74**
1	Welding machine	2000	4	22	3	528
		2000	4	22	3	528
		2400	4	22	2	422.4
2	Sitting Grinding	250	2	22	2	22
3	Hand Grinding	600	3	22	2	79.2
		570	3	22	2	75.24
		540	3	22	2	71.28
		540	3	22	2	71.28
4	Cutting Off	2200	0,5	22	2	48.4
5	Elektrode oven	120	2	22	2	10.56
6	Fan	100	7	22	4	61.6
7	Light	18	7	22	12	33.26
		18	5	22	8	15.84
8	Dispensers	420	7	22	1	64.68
	Workshop PHP					**580.64**
1	Mixer	2900	1	22	1	63.80
2	Oven	120	2	22	1	5.28
3	Electric Proofer Machine	1200	2	22	1	52.80
4	Blender	250	0,5	22	8	22
5	Freezer	100	24	30	2	144
		200	24	30	1	144
6	Fan	100	7	22	4	61.60
7	Light	18	7	22	12	33.26
8	Dispensers	350	7	22	1	53.90
	TKR Workshop					**130.06**
1	Compressor	1100	0,5	22	1	12.1
2	Fan	100	7	22	2	30.8
3	Light	18	7	22	12	33.26
4	Dispensers	350	7	22	1	53.9

TABLE 6. Monthly Electricity Load for Rooms With AC

No	Machine Name	Power (W)	Hours	Month	Q	Energy (kWh)
1	2	3	4	5	6	$7=\frac{(3x4x5x6)}{1000}$
	Refrigeration Workshop					**1043.05**
1	PC	180	7	22	1	27.72
2	Monitor	13	7	22	1	2
3	Projecktor	260	7	22	1	40.04
4	AC Split	1920	2	22	2	168.96
		1170	2	22	2	102.96
		840	2	22	2	73.92
		400	2	22	2	35.20
		840	7	22	2	258.72
		400	7	22	2	123.20
5	Recovery Machine Trainer	450	1	22	1	9.90
6	Refrigeration Trainer	175	1	22	1	3.85
7	Vacuum Pump	250	1	22	4	22
8	Refrigerator	115	24	30	1	82.80
9	Exhaust Fan	30	7	22	1	4.62
10	Light	18	7	22	12	33.26
11	Dispensers	350	7	22	1	53.90
	Make Up Workshop					**651.77**
1	Hairdryer	1200	1	22	8	211.20
2	Hair clamp	55	1	22	8	9.68
3	AC Split	1170	7	22	2	360.36
4	Light	18	7	22	6	16.63
5	Dispensers	350	7	22	1	53.90
	TIK Workshop					**1337.77**
1	PC Server	350	24	30	1	252
2	Monitor	13	7	22	17	34.03
3	PC	180	7	22	16	443.52
4	Printer	480	2	22	1	21.12
		15	2	22	1	0.66
5	Projecktor	260	7	22	1	40.04
6	AC Split	1920	7	22	1	295.68
		1170	7	22	1	180.18
7	Light	18	7	22	6	16.63
8	Dispensers	350	7	22	1	53.90
	Office Room					**1316.74**
1	AC Split	1170	8,5	22	1	218.79
2		840	8,5	22	2	314.16
3	PC	200	8	22	8	281.60
4	Monitor	13	8	22	8	18.30
	Printer	10	2	22	2	0.88
5		1300	2	22	1	57.20
6	PC Server	350	24	30	1	252
	TV LED	50	24	30	2	72
7	Light	18	8	22	6	19.01
8	Refrigerator	115	24	30	1	82.80

V. Research Flow

The flow of the research carried out can be seen in Fig. 2 research flowcharts.

ISSN (Online): 2456-7361

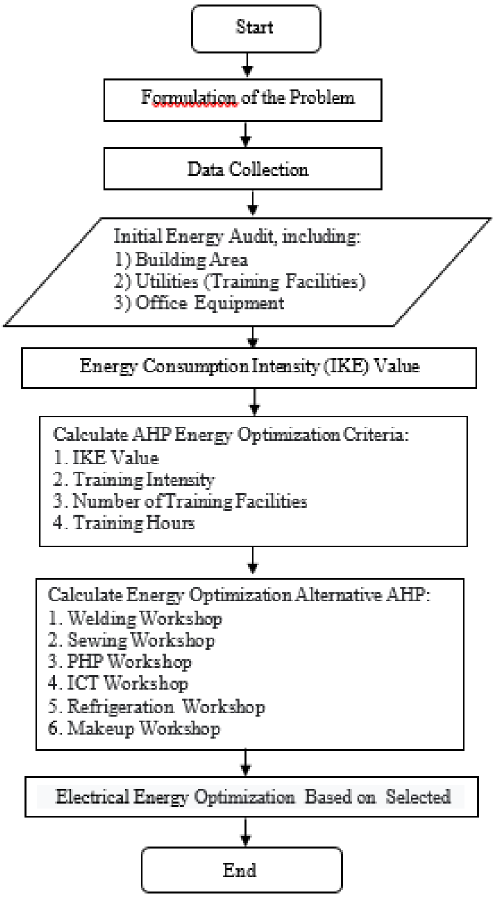

Fig. 2. Research Flowchart

VI. Results and Discussion

Based on Table 4, composition of the training institution buildings and Table 5-6, monthly electricity load for rooms in training institution and referring to eq (3) to determine the IKE value for each room. The results look like in table 7. Where the criteria categories are based on table 1 so that it is known whether the room is wasteful or efficient.

TABLE 7. IKE Value of Training Institution Building

No	Room Name	Energy (kWh/month)	Area (m^2)	IKE Value (kWh/m^2/month)	Info
1	2	3	4	5=3/4	6
1	Welding Workshop	2.031,74	81	25,283	**VW**
2	TKR Workshop	130,06	81	1,606	**EF**
3	PHP Workshop	580,64	63	9,217	**VW**
4	Sewing Workshop	923,65	81	11,403	**VW**
5	Refrigeration Workshop	1.043,06	63	16,556	**SW**
6	Make Up Workshop	651,77	48	12,070	**FE**
7	TIK Workshop	1.337,77	54	27,870	**VW**
8	Office Room	1.316,74	54	24,384	**VW**

Category description:
EF : Efficient
FE : Fairly Efficient
SW : Somewhat Wasteful
VW : Very Wasteful

Analytical Hierarchy Process (AHP)

In this method the problem is described into several criteria and strategies/alternatives which are arranged in a hierarchy. The criteria are obtained from the energy audit carried out. Fig.3 is the energy optimization AHP tree used in this research.

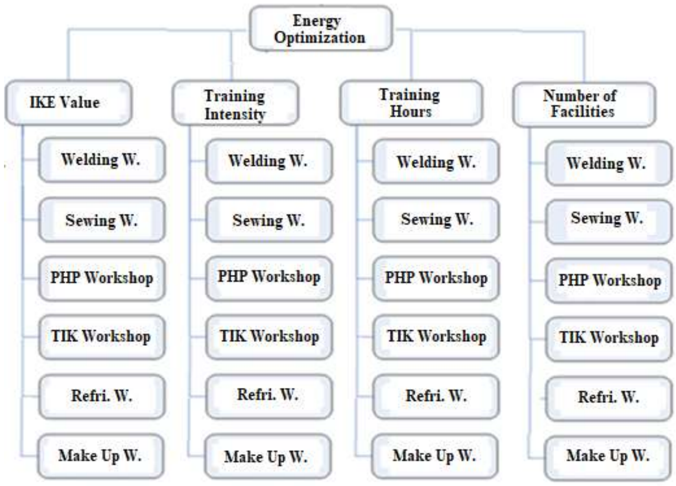

Fig. 3. Energy Optimization AHP Tree

TABLE 8. Respondent Criteria Weighting Recap Matrix

Criteria	Respondent			Geometri Mean
	A	B	C	
1	2	3	4	5=(2x3x4)$^{1/3}$
IKE Value- Training Intensity	3	4	3	3.302
IKE Value- Training Hours	6	3	5	4.481
IKE Value- Numbers of Facilities	3	1/4	3	1.310
Training Intensity- Training Hours	6	8	7	6.952
Training Intensity- Numbers of Facilities	2	1/4	2	1.000
Training Hours- Numbers of Facilities	1/8	1/4	1/7	0.165

Table 8 is obtained from summarizing questionnaires from 3 respondents. Then look for the geometric mean using equation 7 for pairwise comparison data which is used to find the priority criteria and Consistency Ratio.

The weighting result matrix for the criteria is processed through several stages. The initial step is to add up the columns in the pairwise comparison table, then normalize them. So, we get the average λ Max to calculate the CR value (consistency ratio). More specifically, the sequence of stages is as follows:

Stage 1: Column Addition Criteria

Criteria	IKE	IT	HT	FN
IKE Value (IKE)	1.000	3.302	4.481	1.310
Training Intensity (IT)	0.303	1.000	6.952	1.000
Training Hours (HT)	0.223	0.144	1.000	0.165
Numbers of Facilities (FN)	0.763	1.000	6.073	1.000
Sum	2.289	5.446	18.507	3.475

Stage 2: Normalization and Priorities (Row Averages) Criteria

Criteria	IKE	IP	JP	JS	Priority
1	2	3	4	5	6=(2+3+4+5)/4
IKE	0.437	0.606	0.242	0.377	0.416
IT	0.132	0.184	0.376	0.288	0.245
HT	0.097	0.026	0.054	0.047	0.056
FN	0.333	0.184	0.328	0.288	0.283

International Journal of Scientific Engineering and Science
Volume 1, Issue 1, pp. xx-xx, 2024. ISSN (Online): 2456-7361

The normalization stages are as follows:

The value of each row in stage 1 divided by the sum of the column values. The following is an example for normalization calculations.

IKE-IKE = 1/ (1+0.303+0.223+0.763)
= ½.289
= 0.437

In the same way, the normalization figure obtained in stage 2 above is obtained.

Priority is the average across rows. The following is an example for calculating the IKE priority value.

Priority IKE = (0.437+0.606+0.242+0.377)/4
=0.416

Stage 3: Priorities as Factors Criteria

Criteria	IKE	IT	HT	FN
Priorites	0.416	0.245	0.056	0.283
IKE	1.000	3.302	4.481	1.310
IT	0.303	1.000	6.952	1.000
HT	0.223	0.144	1.000	0.165
FN	0.763	1.000	6.073	1.000

Stage 4: Calculation of Weighted Columns Criteria

Criteria	IKE	IT	HT	FN	Weighted Sum
1	2	3	4	5	6=(2+3+4+5)/4
IKE	0.416	0.808	0.252	0.371	1.848
IT	0.126	0.245	0.392	0.283	1.046
HT	0.093	0.035	0.056	0.047	0.231
FN	0.317	0.245	0.342	0.283	1.187

The calculation of the total weight is obtained using the following steps:

1) Calculate the value of each column, here is an example for the calculation.
IKE-IKE = (0.416x1) = 0.416
In the same way, the magnitude of the number in step 5 above is obtained.
2) The total weight is the average of the rows. The following is an example for calculating the number of weights.
Number of Weights IKE = (0.416+0.808+0.252+0.371)
= 1.848

Stage 5: Criterion Consistency Value

Criteria	Weighted Sum	Priority	λ Max
1	2	3	4= 2/3
IKE	1.848	0.416	4.446
IT	1.046	0.245	4.270
HT	0.231	0.056	4.100
FN	1.187	0.283	4.192

To find λ Max by dividing the number of weights by priority, to obtain λ Max for the IKE value, namely:

λ Max = 1.848/(0.416)
= 4.446

In the same way, the magnitude of λ Max is obtained in stage 5 above.

So we get λ Max average = (4.446+4.270+4.100+4.192)/4
= 4.252

For n=4 from the table 3, the RI value = 0.9. Now we need to calculate the consistency index (CI) as follows:

C.I. = (λ Max - n)/ (n -)
= (4.252 - 4)/ (4 - 1)
= 0.084

CR = CI/RI
= 0.084/0.9
= 0.093

Because the value of 0.093 for the proportion of inconsistent CRs is less than 0.10, the assessment matrix is consistent enough so that the next process can be continued. Decision making using AHP can be done.

TABLE 9. IKE Value Alternative Weighting Recap Matrix

Alternative IKE Value	Respondent			Geometric Mean
	A	B	C	
1	2	3	4	$5=(2x3x4)^{1/3}$
Welding Workshop- Sewing Workshop	2	3	3	2.621
Welding Workshop- PHP Workshop	5	4	3	3.915
Welding Workshop- TIK Workshop	2	3	3	2.621
Welding Workshop- Refri.Workshop	6	1	1	1.260
Welding Workshop- Make Up Workshop	4	2	2	2.520
Sewing Workshop- PHP Workshop	3	3	3	3.000
Sewing Workshop- TIK Workshop	3	2	1/2	1.442
Sewing Workshop - Refri.Workshop	2	1/3	1/3	0.606
Sewing Workshop -WR Make Up Workshop	3	3	1/3	1.442
PHP Workshop- TIK Workshop	3	1/3	1/3	0.693
PHP Workshop - Refri.Workshop	3	1/3	1/3	0.693
PHP Workshop -WR Make Up Workshop	3	1/3	1/3	0.693
TIK Workshop- Refri.Workshop	3	1/3	1/2	0.794
TIK Workshop - Make Up Workshop	3	1/3	1/2	0.794
Refri.Workshop- Make Up Workshop	3	2	2	2.289

The weighting result matrix for alternative IKE values is processed through stages as in the criteria. More specifically, the sequence of stages is as follows:

Stage 1: Column Addition Alternative IKE Value

Alternative IKE Value	WW	SW	PW	TW	RW	MW
Welding Workshop (WW)	1.000	2.621	3.915	2.621	1.260	2.520
Sewing Workshop (SW)	0.382	1.000	3.000	1.442	0.606	1.442
PHP Workshop (PW)	0.255	0.333	1.000	0.693	0.693	0.693
TIK Workshop (TW)	0.382	0.693	1.442	1.000	0.794	0.794
Refri.Workshop (RW)	0.794	1.651	1.442	1.260	1.000	2.289
Make Up Workshop (MW)	0.397	0.693	1.442	0.794	2.289	1.000
Sum	3.209	6.992	12.242	7.810	6.642	8.739

Stage 2: Normalization and Priorities (Row Averages) Alternative IKE

IKE Value	WW	SW	PW	TW	RW	MW	Priority
1	2	3	4	5	6	7	$8=\frac{(2+3+4+5+6+7)}{6}$
WW	0.312	0.375	0.320	0.336	0.190	0.288	0.303
SW	0.119	0.143	0.245	0.185	0.091	0.165	0.158
PW	0.080	0.048	0.082	0.089	0.104	0.079	0.080
TW	0.119	0.099	0.118	0.128	0.119	0.091	0.112
RW	0.247	0.236	0.118	0.161	0.151	0.262	0.196
MW	0.124	0.099	0.118	0.102	0.345	0.114	0.150

The normalization stages are as follows:

International Journal of Scientific Engineering and Science
Volume 1, Issue 1, pp. xx-xx, 2024. ISSN (Online): 2456-7361

The value of each row in stage 1 divided by the sum of the column values. The following is an example for normalization calculations.

WW-WW = 1/(1+0.382+0.255+0.382+0.794+0.397)
= 1/3.209
= 0.312

In the same way, the normalization figure obtained in stage 2 above is obtained.

Priority is the average across rows. The following is an example for calculating the welding workshop (WW) priority value.

Priority WW = (0.312+0.375+0.320+0.336+0.190+0.288)/6
=0.303

Stage 3: Priorities as Factors Alternative IKE Value

IKE Value	WW	SW	PW	TW	RW	MW
Priorites	0.303	0.158	0.080	0.112	0.196	0.150
WW	1.000	2.621	3.915	2.621	1.260	2.520
SW	0.382	1.000	3.000	1.442	0.606	1.442
PW	0.255	0.333	1.000	0.693	0.693	0.693
TW	0.382	0.693	1.442	1.000	0.794	0.794
RW	0.794	1.651	1.442	1.260	1.000	2.289
MW	0.397	0.693	1.442	0.794	2.289	1.000

Stage 4: Calculation of Weighted Columns Alternative IKE Value

IKE Value	WW	SW	PW	TW	R RW	MW	Weighted Sum
1	2	3	4	5	6	7	$8=\frac{(2+\cdots+7)}{6}$
WW	0.303	0.414	0.314	0.295	0.247	0.379	1.951
SW	0.116	0.158	0.241	0.162	0.119	0.217	1.012
PW	0.077	0.053	0.080	0.078	0.136	0.104	0.528
TW	0.116	0.110	0.116	0.112	0.155	0.119	0.728
RW	0.241	0.261	0.116	0.142	0.196	0.344	1.299
MW	0.120	0.110	0.116	0.089	0.448	0.150	1.033

The calculation of the total weight is obtained using the following steps:

1) Calculate the value of each column, here is an example for the calculation.
   WW-WW = (0.303x1) = 0.303
   In the same way, the magnitude of the number in step 5 above is obtained.
2) The total weight is the average of the rows. The following is an example for calculating the number of weights.
   Number of Weights welding workshop (WW) = (0.303+0.414+0.314+0.295+0.247+0.379) = 1.951

Stage 5: Criterion Consistency IKE Value

IKE Value	Weighted Sum	Priority	λ Max
1	2	3	4= 2/3
WW	1.951	0.303	6.433
SW	1.012	0.158	6.405
PW	0.528	0.080	6.583
TW	0.728	0.112	6.479
RW	1.299	0.196	6.631
MW	1.033	0.150	6.879

To find λ Max by dividing the number of weights by priority, to obtain λ Max for the welding workshop (WW), namely:

λ Max = 1.951/(0.303)
= 6.433

In the same way, the magnitude of λ Max is obtained in stage 5 above.

So we get λ Max average = (6.433+6.405+6.583+6.479+6.631+ 6.879)/6 = 6.568

For n=6 from the table 3, the RI value = 1.24. Now we need to calculate the consistency index (CI) as follows:

C.I. = (λ Max - n)/ (n -)
= (6.568 - 6)/ (6 - 1)
= 0.114

CR = CI/RI
= 0.114/1.24
= 0.092

Because the value of 0.092 for the proportion of inconsistent CRs is less than 0.10, the assessment matrix is consistent enough so that the next process can be continued. Decision making using AHP can be done.

TABLE 10. Training Intensity (IT) Alternative Weighting Recap Matrix

Alternative Training Intensity (IT)	**Respondent**			**Geometric Mean**
	A	**B**	**C**	
1	2	3	4	$5=(2x3x4)^{1/3}$
Welding Workshop- Sewing Workshop	1/7	1/7	1/3	0.189
Welding Workshop- PHP Workshop	1/7	5	1/3	0.620
Welding Workshop- TIK Workshop	1/7	1/8	5	0.447
Welding Workshop- Refri.Workshop	5	1/8	3	1.233
Welding Workshop- Make Up Workshop	1/7	4	1/3	0.575
Sewing Workshop- PHP Workshop	5	3	1/2	1.957
Sewing Workshop- TIK Workshop	3	4	1/2	1.817
Sewing Workshop - Refri.Workshop	3	2	8	3.634
Sewing Workshop -WR Make Up Workshop	3	5	1/2	1.957
PHP Workshop- TIK Workshop	1/7	1/7	1/2	0.217
PHP Workshop - Refri.Workshop	4	1/7	3	1.197
PHP Workshop -WR Make Up Workshop	2	3	1/2	1.442
TIK Workshop- Refri.Workshop	3	4	3	3.302
TIK Workshop - Make Up Workshop	5	3	1/2	1.957
Refri.Workshop- Make Up Workshop	1/7	4	1/3	0.575

TABLE 11. Training Hours (HT) Alternative Weighting Recap Matrix

Alternative Training Hours (HT)	**Respondent**			**Geometric Mean**
	A	**B**	**C**	
1	2	3	4	$5=(2x3x4)^{1/3}$
Welding Workshop- Sewing Workshop	1/7	1/7	3	0.394
Welding Workshop- PHP Workshop	3	5	2	3.107
Welding Workshop- TIK Workshop	5	1/7	2	1.126
Welding Workshop- Refri.Workshop	3	1/7	7	1.442
Welding Workshop- Make Up Workshop	3	5	2	3.107
Sewing Workshop- PHP Workshop	3	5	3	3.557
Sewing Workshop- TIK Workshop	5	1/7	7	1.710
Sewing Workshop - Refri.Workshop	3	5	3	3.557
Sewing Workshop -WR Make Up Workshop	3	5	2	3.107
PHP Workshop- TIK Workshop	2	1/7	1/3	0.457
PHP Workshop - Refri.Workshop	3	1/7	1/3	0.523
PHP Workshop -WR Make Up Workshop	1/7	3	1/3	0.523
TIK Workshop- Refri.Workshop	3	1/7	2	0.950
TIK Workshop - Make Up Workshop	3	4	2	2.884
Refri.Workshop- Make Up Workshop	1/7	1/7	1/3	0.189

TABLE 12. Numbers of Facilities (FN) Alternative Weighting Recap Matrix

Alternative Numbers of Facilities (FN)	Respondent A	Respondent B	Respondent C	Geometric Mean
1	2	3	4	5=(2x3x4)$^{1/3}$
Welding Workshop- Sewing Workshop	1/3	5	1/3	0.822
Welding Workshop- PHP Workshop	7	7	4	5.809
Welding Workshop- TIK Workshop	1/3	5	1/2	0.941
Welding Workshop- Refri.Workshop	5	8	2	4.309
Welding Workshop- Make Up Workshop	7	3	7	5.278
Sewing Workshop- PHP Workshop	7	1/7	5	1.710
Sewing Workshop- TIK Workshop	3	5	1/2	1.957
Sewing Workshop - Refri.Workshop	7	1/7	3	1.442
Sewing Workshop -WR Make Up Workshop	7	1/7	4	1.587
PHP Workshop- TIK Workshop	1/7	1/7	1/3	0.189
PHP Workshop - Refri.Workshop	3	1/7	1/3	0.523
PHP Workshop -WR Make Up Workshop	3	1/6	1/3	0.550
TIK Workshop- Refri.Workshop	7	1/8	3	1.379
TIK Workshop - Make Up Workshop	7	1/8	5	1.636
Refri.Workshop- Make Up Workshop	1/7	1/8	5	0.447

The matrix of weighting results for the alternative values of Training Intensity, Training Hours, Number of Facilities in table 10-12 is processed through stages as in the alternative IKE Values. So that alternative priority values and Consistency Ratio (CR) are obtained as follows:

Criterion Consistency Training Intensity

Training Intensity	Weighted Sum	Priority	λ Max
1	2	3	4= 2/3
WW	0.512	0.079	6.503
SW	2.015	0.309	6.512
PW	0.774	0.123	6.295
TW	1.723	0.261	6.591
RW	0.494	0.077	6.430
MW	1.087	0.151	7.218

λ Max = 6.503+6.512+6.295+6.591+6.430+7.218)/6 = 6.591
C.I. = (λ Max - n)/ (n -)
= (6.591 - 6)/ (6 - 1)
= 0.118
CR = CI/RI
= 0.118/ 1.24
= 0.095

Because the value of 0.095 for the proportion of inconsistent CRs is less than 0.10, the assessment matrix is consistent enough so that the next process can be continued. Decision making using AHP can be done.

Criterion Consistency Training Hours

Training Hours	Weighted Sum	Priorities	λ Max
1	2	3	4= 2/3
WW	1.278	0.192	6.664
SW	2.130	0.335	6.360
PW	0.424	0.067	6.368
TW	1.157	0.172	6.735
RW	0.665	0.106	6.295
MW	0.942	0.129	7.282

λ Max = (6.664+6.360+6.368+6.735+6.295+7.282)/6
= 6.617.
C.I. = (λ Max - n)/(n -)
= (6,617 - 6)/(6 - 1)
= 0,124
CR = CI/RI
= 0,124/ 1,24
= 0,099

Because the value of 0.099 for the proportion of inconsistent CRs is less than 0.10, the assessment matrix is consistent enough so that the next process can be continued. Decision making using AHP can be done.

Criterion Consistency Number of Facilities

Number of Facilities	Weighted Sum	Priorities	λ Max
1	2	3	4= 2/3
WW	2.083	0.318	6.557
SW	1.411	0.210	6.715
PW	0.393	0.063	6.234
TW	1.299	0.193	6.728
RW	0.632	0.100	6.344
MW	0.784	0.117	6.728

λ Max = (6.557+6.715+6.234+6.728+6.344+6.728)/6
= 6.551.
C.I. = (λ Max - n)/(n -)
= (6,551 - 6)/(6 - 1)
= 0,110
CR = CI/RI
= 0.11022/1,24
= 0.089

Because the value of 0.089 for the proportion of inconsistent CRs is less than 0.10, the assessment matrix is consistent enough so that the next process can be continued. Decision making using AHP can be done.

WW	0.303	0.079	0.192	0.318
SW	0.158	0.309	0.335	0.210
PW	0.080	0.123	0.067	0.063
TW	0.112	0.261	0.172	0.193
RW	0.196	0.077	0.106	0.100
MW	0.150	0.151	0.129	0.117

x

0.416	IKE	
0.245	IT	
0.056	HT	
0.283	FN	

The overall calculation of the value of each alternative option for energy optimization is as follows:

Welding Workshop (WW) priority
=(0.303x0.416)+(0.079x0.245)+(0.192x0.056)+ (0.318x0.283)
= 0.246

Sewing Workshop (SW) priority
=(0.158x0.416)+(0.309x0.245)+(0.335x0.056)+ (0.210.283)
= 0.220

PHP Workshop (PW) priority
=(0.080x0.416)+(0.123x0.245)+(0.067x0.056)+ (0.063x0.283)
= 0.085

TIK Workshop (TW) priority
=(0.112x0.416)+(0.261x0.245)+(0.172x0.056)+ (0.193x0.283)
= 0.175

Refrigeration Workshop (RW) priority
=(0.196x0.416)+(0.077x0.245)+(0.106x0.056)+ (0.100x0.283)
= 0.134

Make Up Workshop (MW) priority
=(0.015x0.416)+(0.151x0.245)+(0.129x0.056)+ (0.117x0.283) = 0.140

The highest priority option for energy optimization in this decision making case is the welding workshop (24.6%).

Implementation of welding workshop energy optimization through:

Welding machine

- In general, welding amperes range from 70-140 A depending on the diameter of the electrode and the thickness of the iron being welded. Where for ⌀ = 2.6 mm the amperage is ideally 80 A, according to the thickness of the iron used.
- The use of the welding machine can be maximized for 3 hours per day. This saves time on setting up work pieces and repairs.

Welding workshop equipment

- Use of the bench grinder can be maximized to 1.5 hours per day. Where with savings in usage queue time.
- Use of the hand grinder can be maximized to 2 hours per day. Where with savings in repair time.
- The use of welding cabin lights can be maximized to 3 hours per day according to welding usage.
- The use of the dispenser can be maximized to 2 hours per day, turning it on when really needed, especially during break times.

TABLE 13. Monthly Electricity Load for Welding Workshop

No	Machine Name	Power (W)	Hours	Month	Q	Energy (kWh)
1	2	3	4	5	6	7= $\frac{(3x4x5x6)}{1000}$
	Before Optimization					**2031.74**
1	Welding machine	2000	4	22	3	528
		2000	4	22	3	528
		2400	4	22	2	422.4
2	Sitting Grinding	250	2	22	2	22
3	Hand Grinding	600	3	22	2	79.2
		570	3	22	2	75.24
		540	3	22	2	71.28
		540	3	22	2	71.28
4	Cutting Off	2200	0,5	22	2	48.4
5	Elektrode oven	120	2	22	2	10.56
6	Fan	100	7	22	4	61.6
7	Light	18	7	22	12	33.26
		18	5	22	8	15.84
8	Dispensers	420	7	22	1	64.68
	After Optimization					**1441.75**
1	Welding machine	1980	3	22	3	392.04
		1980	3	22	3	392.04
		1980	3	22	2	216.36
2	Sitting Grinding	250	1.5	22	2	16.5
3	Hand Grinding	600	2	22	2	52.8
		570	2	22	2	50.16
		540	2	22	2	47.52
		540	2	22	2	47.52
4	Cutting Off	2200	0,5	22	2	48.4
5	Elektrode oven	120	2	22	2	10.56
6	Fan	100	7	22	4	61.6
7	Light	18	7	22	12	33.26
		18	3	22	8	9.5
8	Dispensers	420	2	22	1	18.48

Based on Table 4.13. Obtained the monthly electricity load for the use of the welding workshop before and after energy optimization, so that the amount of savings that can be made is:

W Savings = W before Optimization – W after Optimization
= 2,031.74 kWh - 1,441.75 kWh
= 589.996 kWh
= 590 kWh

Optimized welding workshop savings: (eq:3)
= Optimized welding workshop savings x electricity rates
= 590 kWh x Rp. 1,699.53/kWh
= Rp. 1,002,722.70

VII. CONCLUSION

The conclusion of the research is that energy audit to find the IKE value for basic optimization. Based on data processing using the AHP method approach, the results obtained from the priority proposed energy optimization alternatives for the welding workshop were selected (24.6%) with implementing energy optimization in the welding workshop resulted in savings of 590 kWh equivalent to Rp. 1,002,722.70.

ACKNOWLEDGMENT

The authors are grateful to my family, all the teacher, staff and students of Magister Program of Electrical Engineering Department, Universitas Islam Sultan Agung, Semarang, Indonesia.

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