Feasibility Study to Substitute the EER with the SEER – Case Study Chiang Mai, Thailand

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Abstract—**The objectives of this project are to find out whether the Seasonal Energy Efficiency Ratio (SEER) is more suitable for Thailand than the EER and to compare the energy saving between a fixed speed and an inverter air conditioners. First, both kinds of air conditioners are tested under the Japan Standard (JIS C 9612:2005) and installed in two virtual houses which are identical for data collection (i.e. electric energy consumption and etc). Air conditioners are operated during 8:00 A.M.-12:00 P.M. and 13:00-17:00 P.M. While the ENERGYPLUS program is used for simulation, both results are verified.**

Using Chiang Mai weather data, the EnergyPlus program is used to analyze a virtual house with the design cooling load of 3,500 Watt at 35°C outdoor temperature. The result shows that the air conditioner will start operate at 22°C outdoor temperature and the electric energy consumption is close to the result from the Bin method, used in JIS C 9612:2005. For simplicity, the authors would recommend to use the Bin method for calculating the SEER. For an inverter air conditioner, the SEER value is 13.96 with the EER of 11.38. For a fixed speed air conditioner, the SEER is 11.84 with the EER of 11.59. This study shows that an inverter air conditioner saves 15.38% more energy consumption than a fixed speed air conditioner for Chiang Mai, Thailand.

Index Terms— **SEER, Inverter AC, Inverter Saving**

I. Introduction

Currently, the performance rating of an air conditioner in Thailand is tested according to the TIS 1155-2536 standard [1]. The Energy Efficiency Ratio (EER) at the standard rating conditions is mandatory to be labeled on the name plate of all air conditioners. The EER is point ambient temperature (35°C) performance rating, but in reality, the ambient temperature varies from hour to hour. Therefore, calculating yearly electric energy consumption from EER is not accurate enough. Alternatively, following many countries such as the United State of American, Japan, and Korea, the Seasonal Energy Efficiency Ratio (SEER) can be used to rate the performance of an air conditioner and to obtain yearly electric consumption.

Nowadays, the variable refrigerant flow (VRF) air conditioner such as an inverter compressor and a digital scroll compressor are widely used in an air conditioner as they consume less energy than a fixed speed compressor. Due to higher cost, in 2011 the VRF air conditioner shares only 6 % of the whole market in Thailand. To rate this type of air conditioner, the AHRI standard 210/240 standard [2] is applied in the United State of American and JIS C9612:2005[3] in Japan. Both standards have different testing conditions; i.e. Refer to [2], 5-points testing conditions (2 points at the maximum speed, 1 point at the middle speed, and 2 points at the lowest speed) are applied, while [3] uses 2-points testing conditions (1 point at rated speed and another at the middle rated cooling speed). After the testing results are obtained, the performance curve of an air conditioner can be created and used to calculate the SEER by the Bin method. Korea, Vietnam, and Republic of China have their own testing standards and use the same testing conditions as Japan.

With the aim to improve the standard procedure specifically for Thailand, the Department of Alternative Energy Development and Efficiency (DEDE) has funded this project to study the suitable testing method for rating both VRF and fixed speed air conditioners by using SEER and the potential energy-saving of an inverter air conditioner as compared with a fixed speed one.

II. Study Process

Each type of air conditioner is installed in each identical house. The measurement of energy consumption of an air conditioner is used to verify with the output of EnergyPlus program [4] until they are close together so that it can be concluded that the results from this program are valid. After that, this program is simulated with typical Chiang Mai weather year from TRANSYS program [5]. Yearly cooling load and energy consumption are compared with the output from the Bin method as stated in JIS C9612:2005 [3]. If both results agree with each other within an acceptable range, the Bin method, which is simple and easy to calculate, will be recommended for further calculations.

A. Experiment Setup

Two identical 2.85 x 2.85 x 2.85 m^3 virtual houses, as shown in Fig. 1, were built on the rooftop of an eight-story building. A 3.565 kW fixed speed and a 3.283 kW inverter air conditioners are tested under JIS C9612:2005 [3] and installed in each house.

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Fig. 1. Two virtual houses

The indoor temperature, outdoor temperatures, solar intensity, wind speed, and electric consumption are recorded every 5 minutes during 8:00 A.M. – 12.00 P.M. and 13:00 – 17:00 P.M. Four cases of additional internal lighting load are set due to low outdoor temperature (less than 20°C). The response of an air conditioner is studied as follows:

Case 1. – No addition internal lighting load from November 18 – 21, 2010.

Case 2. – Addition internal lighting load of 1,000 W. from November 22 – 25, 2010.

Case 3. – Addition internal lighting load of 2,000 W. from November 26 – 29, 2010.

Case 4. – Addition internal lighting load of 3,000 W. from January 6 – 8, 2011.

The EnergyPlus program [4] is used to simulate the two virtual houses; the energy consumption of the air conditioners obtained from the program is verified by comparing the value with the measured data.

B. Simulation Program Setup

The inputs for the EnergyPlus program [4] are a typical 4 x 4 x 3 m^3 room, 3,500 W. cooling load at Thailand's Design Day, the cooling performance of each air conditioner, and a typical hourly Chiang Mai weather for a year from TRNSYS [5]. Yearly cooling load and electric consumption of each air conditioner are the outputs.

TABLE I
BIN TEMPERATURE FOR CHIANGMAI

Temp. (°C)	No. Of hours	Temp. (°C)	No. Of hours
12	3	26	236
13	3	27	277
14	6	28	304
15	16	29	316
16	18	30	316
17	25	31	238
18	31	32	156
19	34	33	127
20	54	34	105
21	56	35	51
22	59	36	29
23	87	37	14
24	132	38	18
25	202	39	7

C. Bin Method

A typical Chiang Mai weather data from 8:00 A.M. – 12:00 P.M. and 13:00 – 17:00 PM. for one year from TRANSYS program is binned with a bin size of 1°C. The result is shown in Table I.

III. RESULTS AND DISCUSSION

A. Air conditioners Cooling Performance

Both air conditioners are tested with the Calorimeter Air Enthalpy room under the JIS C9612:2005 [3], the results of the cooling load versus the outdoor temperature are shown in Fig. 2. The EER is 11.59 and 11.38 for a fixed speed and an inverter air conditioner respectively.

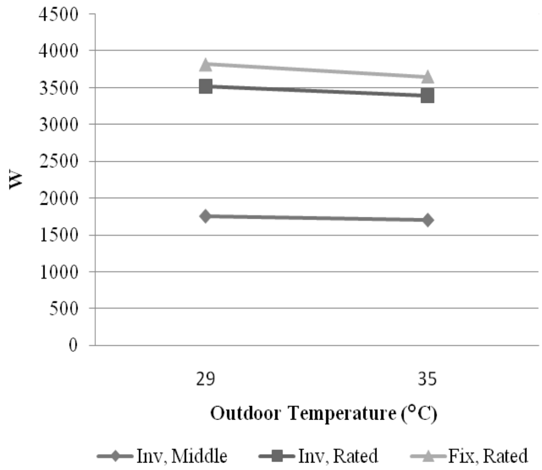

Fig. 2. Cooling capacity curves.

The relationships between the cooling capacity at 29°C ($\Phi_{cr(29)}$) and 35°C (Φ_{cr}) at a rated speed and the middle cooling speed for an inverter air conditioner are shown in (1) and (2) respectively. Equation 3 corresponds to a fixed speed air conditioner.

For an inverter at rated speed,

$$\Phi_{cr(29)} = 1.037\,\Phi_{cr} \tag{1}$$

For an inverter at the middle cooling speed,

$$\Phi_{cr(29)}) = 1.031\,\Phi_{cr} \tag{2}$$

For a fixed speed,

$$\Phi_{cr(29)}) = 1.046\,\Phi_{cr} \tag{3}$$

In Japan, Korea, Vietnam, and Republic of China, Equation (4) is used for all types of air conditioner.

$$\Phi_{cr(29)}) = 1.077\,\Phi_{cr} \tag{4}$$

By comparing the cooling performance curves of Thai's design (1), (2), and (3) with Japan's design (4), the air

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conditioner in Thailand produces less cooling than the Japan air conditioner when the outdoor temperature decreases.

Moreover, the energy consumption (P_c) at two different outdoor temperature is shown in Fig. 3. The relationships between energy consumptions can be represented by the (5), (6), and (7).

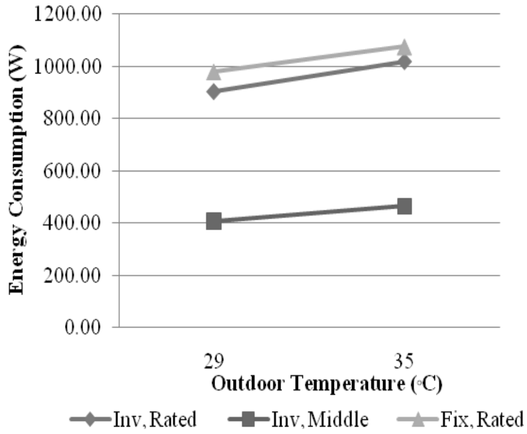

Fig. 3. Energy consumption curves.

For an inverter at rated speed,

$$P_{c(29)} = 0.888P_c \tag{5}$$

For an inverter at the middle cooling speed,

$$P_{c(29)} = 0.877P_c \tag{6}$$

For a fixed speed,

$$P_{c(29)} = 0.909P_c \tag{7}$$

For Japan, Korea, Vietnam and Republic of China, Equation (8) is applied for all types of the air conditioners.

$$P_{c(29)} = 0.914P_c \tag{8}$$

By comparing the energy consumption curves of Thai's design (5), (6), and (7) with Japan's design (8); the air conditioner in Thailand consumes less energy than the Japan air conditioner when the outdoor temperature decreases.

Similarly, Figure 4 compares the EER of the air conditioners at two different outdoor temperatures.

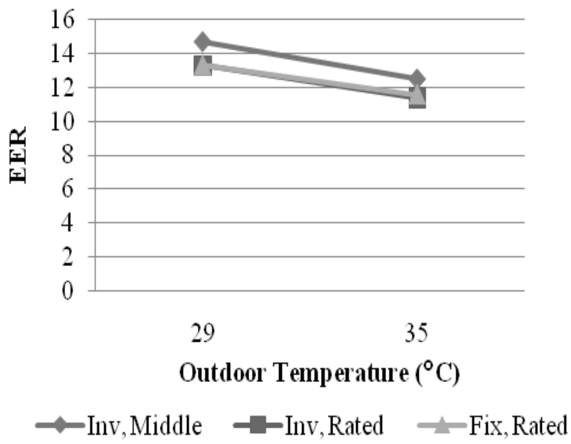

Fig. 4. Energy consumption curves.

B. Energy consumption of the air conditioners.

The energy consumption of each air conditioner and different internal light loads, as stated in Section II.B, are averaged with the same time interval. The results are plotted in Fig. 5, 6, 7, and 8.

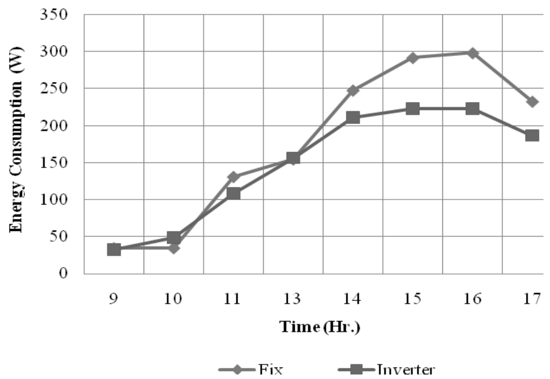

Fig. 5. Energy consumption over time when there is no internal light load.

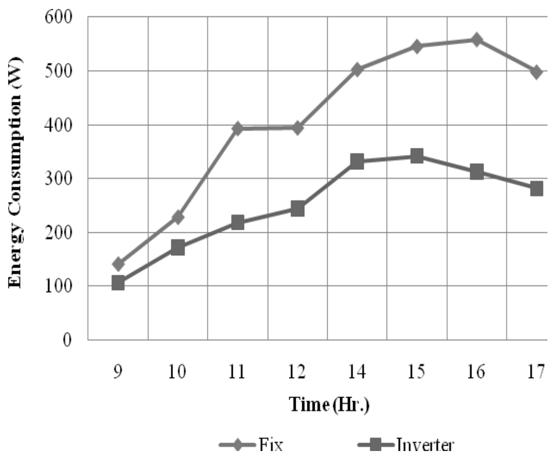

Fig. 6. Energy consumption over time when 1 kW internal light load is applied.

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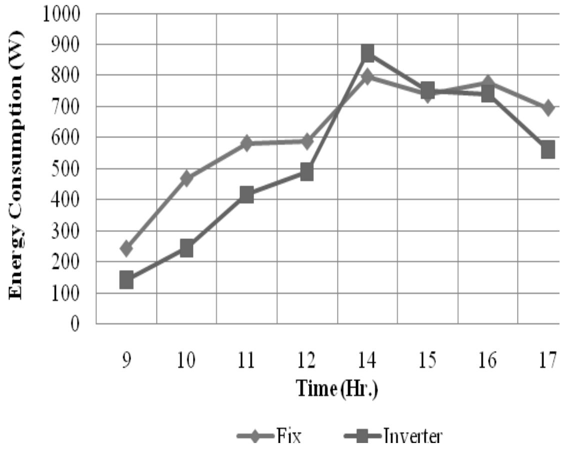

Fig. 7. Energy consumption over time when 2 kW internal light load is applied.

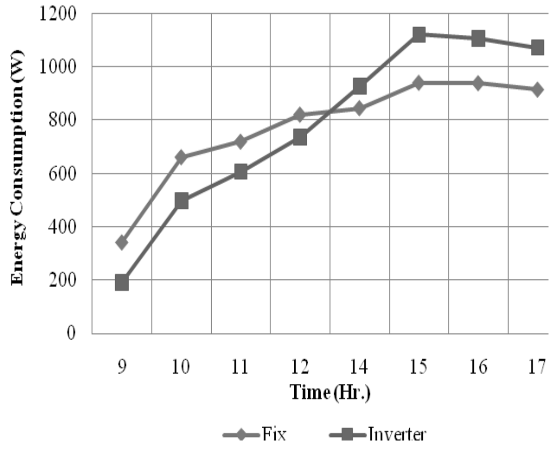

Fig. 8. Energy consumption over time when 3 kW internal light load is applied.

From Fig. 5-8, it can be concluded that if the cooling load is less than the minimum speed of the inverter type, both types are in the ON-OFF mode; therefore, both consume almost the same amount of energy. When the cooling load is between minimum speed and rated speed, the inverter type shows some energy saving as shown in Fig. 5-7. When the cooling load is greater than the rated cooling, the inverter type consumes more energy than the fixed speed air conditioner because this inverter type can increase the speed more than the rated speed as shown in Figure 8, from 13:00 to 17:00 P.M. Table II shows the saving percentage for each internal lighting loading conditions.

TABLE II
SAVING PERCENTAGE FOR EACH INTERNAL LIGHTING LOADING CONDITION

Internal lighting load (W)	Energy consumption (W-hr) Inverter	Energy consumption (W-hr) Fix speed	Saving (%)
0	1204	1435	16.12%
1000	2086	3363	37.98%
2000	4274	4967	13.95%
3000	6316	6243	-1.17%

C. *Results from EnergyPlus Program*

When all details in Section II.B are input into the EnergyPlus program [4], the energy consumption output is compared with the measurements from the air conditioners as shown in Table III. It is found that large discrepancy between the program output and the measurements from the air conditioner occurs when the cooling load is less than the middle cooling rated (1750 W) for the inverter type. This is because, for the inverter one, the actual minimum speed is far less than the middle cooling speed; keeping the inverter type in the operating state. Contradictory, in the program, the inverter acts as a fixed speed air conditioner (ON-OFF mode), therefore, the energy consumption from the program will be higher than the real measurement. If the cooling load is above the middle cooling, both results are similar at 2000 and 3000 W internal lighting load.

TABLE III
COMPARISONS OF ENERGY CONSUMPTION OBTAINED FROM ENERGYPLUS PROGRAM AND REAL MEASUREMENTS

Date	Energy consumption (W-hr) Fixed Speed Program	Fixed Speed Measurement	Inverter Program	Inverter Measurement
1000 W on 11/25/2011	3162.291	3264.217	2751.316	2010.278
Error (%)	-3.123		36.862	
2000 W on 11/26/2011	5086.608	4959.835	4404.89	4240.155
Error (%)	2.556		3.885	
3000 W on 11/26/2011	6550.359	6227.829	6478.514	6300.143
Error (%)	5.179		2.831	

To reduce the error, the inverter air conditioner should be tested at minimum and maximum speeds at the AHRI standard 210/240 [2]. These results can then be used as the inputs into the TRNSYS program [5].

D. *Results from the EnergyPlus Program and Bin Method*

The details of house, performance of both air conditioners under JIS C9612:2005 and typical Chiang Mai weather data are put into the EnergyPlus program [4] and simulated during 8:00 A.M. – 12:00 P.M. and 13:00 – 17:00 P.M., excluding weekends. The results are discussed separately as follow,

Building cooling load

According to the program, it is found that this house has no cooling load at 21^{o}C outdoor temperature which is different from [3] which uses 23^{o}C. Fig. 9 shows the building load curve.

Bin method calculation

Using the binned weather data and the building load as shown in Fig. 9, the performance of a fixed speed and an inverter air conditioner are calculated. The results are compared in Table IV.

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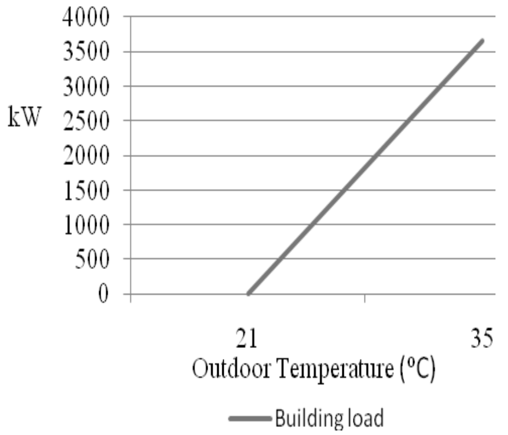

Fig. 9. Building load curve.

TABLE IV
OUTPUT FROM PROGRAM AND BIN METHOD

		Cooling load (kW-hr/yr.)	Energy consumption (kW-hr/yr.)	SEER	Rated EER
fixed speed	Program	5,832.00	1,738.00	11.44	
	Bin Method	5,635.60	1,622.45	11.84	11.59
	Error (%)	-3.37	-6.65	3.51	
Inverter	Program	6,025.00	1,531.80	13.41	
	Bin Method	5,619.18	1,372.92	13.96	11.38
	Error (%)	-6.74	-10.37	4.06	

The errors of the cooling load, energy consumption, and SEER for the fixed speed are -3.37, -6.65, and 3.51 % and -6.74, -10.37, and 4.06 % for the inverter respectively. The cooling load and energy consumption from the Bin method are less than those obtained from the program. However, the SEER from the Bin method is higher than from the program. Furthermore, the results show that the SEER for a fixed speed is less than an inverter type, consistent regardless of the calculation methods used in this study.

For the range of errors as showed in Table IV, the authors still recommend to use the Bin method to calculate the SEER for Chiang Mai because of the simplicity and fast.

SEER from this study and JIS C9612:2005

The SEER in this study are calculated using the cooling performance from (1), (2), and (3) and the energy consumption from (5), (6), and (7). The resulting values are shown in Table V. When the Equations (4) and (8) (the Japanese standard) are used instead, the different SEER are obtained, as shown in Table VI.

From Table V, the error is less than 2%; therefore the Japan standard equations (4), and (8) are recommended because the testing conditions require only two points as JIS C9612:2005 [3], consequently, reduces the cost for testing.

Table VI shows the study which has been done using 23 °C outdoor temperature with the building load equal to zero as stated in JIS C9612:2005 [3]; the maximum error is 2.64%, as shown in Table VI. The authors strongly recommend using the same testing standard JIS C9612:2005 [3] for SEER calculation by using Thailand weather.

TABLE V
COMPARISONS OF SEER BETWEEN THIS STUDY AND JAPAN STANDARD

SEER	Fixed Speed	Inverter
This study	11.84	13.96
Japan standard	12.04	13.96
Error (%)	1.69	0

TABLE VI
SEER BASED ON JIS C9612:2005

SEER	Fixed Speed	Inverter
Building load starts at 21 °C	12.04	13.96
Building load starts at 23 °C	11.73	13.71
Error, %	2.64	1.79

E. Comparison between EER and SEER

Table VII shows both EER and SEER for both fixed speed and inverter air conditioners. Because most outdoor temperature of Chiang Mai, as shown in Table I, is below the rated outdoor temperature, both SEER are higher than the EER. For the fixed speed air conditioner, both EER and SEER are not much different due to ON-OFF cycle at every outdoor temperature. However, for the inverter air conditioner, the EER increases when the outdoor temperature reduces and no effect of ON-OFF cycle so that SEER will be certainly increased.

For the reasons mentioned above, the SEER represents a real energy consumption of all air conditioners better than the EER. It is recommended to label the SEER on the name plate of an air conditioner instead of the EER.

TABLE VII
OUTPUT FROM PROGRAM AND BIN METHOD

	Fixed Speed	Inverter
Rated EER at 35°C	11.59	11.38
Rated EER at 29°C	13.33	13.29
SEER	11.84	13.96
Average outdoor temperature (°C)	29	

F. Effect of Bin Hour on SEER

3 Cases of Bin hours of Chiang Mai weather data have been used to calculate the SEER, the results are compared in Table VIII.

TABLE VIII
SEER'S COMPARISON

	Time Interval	SEER Fixed Speed	SEER Inverter
Case A	8 – 12, 13-17 Hr.	11.84	13.96
Case B	6 – 24 Hr.	12.07	14.05
Case C	0 - 24 Hr.	12.08	14.11

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It is found that for Case A, average outdoor temperature is the highest, so the SEER is the lowest. For a Case B, average temperature is between Case A and C so the SEER is in between. For all cases, the SEERs are not much different. So, the Bin hours from Case B method which is reasonable represented average day temperature should be used to calculate yearly Bin hours for Thailand.

If looking at the energy consumption from Table IX, the energy consumption will be increased as the Bin hour is increased. To account for both outdoor temperature and Bin hour, the author is recommended to use Case B to represent the method to calculate the SEER for Chiang Mai. So for Chiang Mai, the inverter air conditioner can save at least 15.38 % of energy consumption as compared with a fixed speed air conditioner.

TABLE IX
ENERGY CONSUMPTION FOR 3 CASES

	Time Interval	Energy Consumption (kW-hr)		Saving (%)
		Fixed Speed	Inverter	
Case A	8 – 12, 13-17 Hr.	1,622.45	1,372.92	15.38
Case B	6 – 24 Hr.	2,623.40	2,096.65	20.07
Case C	0 - 24 Hr.	2,718.31	2,162.70	20.44

IV. CONCLUSION

From this study, both EER and SEER increase when the outdoor temperature decreases. The inverter air conditioner achieves more than 15.38% energy saving than the fixed speed one. The authors strongly recommend that the SEER, which depends on seasonal weather data, should be used to label on all types of air conditioners in Thailand instead of the EER which is limited only to one fixed point weather data. Moreover, all types of air conditioners in Thailand should follow the testing standard JIS C9612:2005 and use a typical weather from 6 to 24 Hr. throughout a year in Thailand to calculate the SEER by the Bin method.

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