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Determination of Non-standard Part-Load Value Coefficients for Chiller in Several Cities of Indonesia

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Abstract. There is a common misconception that all central systems are only operating in full-load conditions where in fact, most central systems are have the control system that can adjust the operating condition with the cooling loads. Customers tend to choose the air conditioning systems based only on full-load ratings despite a system may have different ratings on different load profiles. These differences can result in more expensive annual energy cost. The goal of this research is to develop an equation to provide customers with the part-load efficiency ratings of central air conditioning system (chiller) as an addition to full-load efficiency ratings provided by air conditioner companies. Non-standard Part Load Value (NPLV) is an equation to obtain part-load efficiency of a system which coefficients vary with location of interest. In this paper, NPLV for city of Jakarta, Bandung, Pontianak, Kupang, and Palembang were determined by Degree-Hours Method and Radiant Time Series Method. The results are compared and discussed.

INTRODUCTION

Standard rating condition and design efficiency (full-load efficiency) are commonly utilized to compare relative chiller efficiencies so that one may select the most suitable one. In most cases, design efficiency represents the performance of chiller at 100% capacity, occurs very rarely [1]. So, it can be said that design efficiency does not represent the chiller efficiency which operate mostly in part-load operating condition. Integrated Part-Load Value, or IPLV, is used to create a representative and overall chiller efficiency which equation includes 4 operating conditions (100%, 75%, 50%, and 25% load). Each operating condition has its own coefficient related to averaged climate conditions of 29 cities in United States. Hence, the equation is fixed, the coefficients cannot be amended and valid uniquely for United States' cities. On the other hand, the Non-standard Part-Load Value (NPLV) equation has more flexible coefficients which vary accordingly to local climate conditions. This research is focused on determining the coefficients of NPLV for several cities in Indonesia based on their climate conditions.

The IPLV is expressed as [2]:

$$IPLV = 0.01A + 0.42B + 0.45C + 0.12D \quad (1)$$

Where A = COP or EER at 100% load, B = COP or EER at 75% load, C = COP or EER at 50% load, and D = COP or EER at 25% load. Another form of IPLV is:

$$IPLV = \frac{1}{\frac{0.01}{A}+\frac{0.42}{B}+\frac{0.45}{C}+\frac{0.12}{D}} \quad (2)$$

Where A = kW/TR at 100% load, B = kW/TR at 75% load, C = kW/TR at 50% load, D = kW/TR at 25% load. The NPLV in general can be expressed as:

$$NPLV = Y_1A + Y_2B + Y_3C + Y_4D \quad (3)$$

Or

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$$NPLV = \frac{1}{\frac{Y_1}{A}+\frac{Y_2}{B}+\frac{Y_3}{C}+\frac{Y_4}{D}} \quad (4)$$

The objectives of the study is to determine the coefficient Y_1, Y_2,Y_3, and Y_4 for several cities in Indonesia.

There are ways to determine the coefficients for NPLV equation, some are Degree-Hours (DH) Method, Radiant Time Series (RTS) Method, energy simulation, and utilization of building log sheet. However, only DH and RTS methods were used in the analyses because of the availability of data required. Both methods require hourly temperature data for each city which are acquired from local weather station data. DH Method directly converts those data to NPLV coefficients by using probability distributions. On the other hand, RTS method uses those weather data to calculate cooling loads. Then, the cooling load data are converted to NPLV coefficients by using probability distributions. Notice that DH Method uses heat gain to determine NPLV coefficients while RTS Method uses cooling load.

DEGREE HOURS METHOD

DH method needs hourly temperature difference (ΔT) frequency profile. This method assumes that the heat generated by the difference between outdoor temperature and conditioned indoor temperature is equivalent to the cooling load in the room. Hence, whenever the outdoor temperature data are available, it is possible to define the characteristics of temperature distribution to calculate NPLV coefficients. Each ΔT value represents a certain temperature interval. Those intervals are the percentages of temperature distribution divided into *n* sections. Data obtained from weather office are grouped into those intervals to create histograms. The histogram is then converted into normal curve. Then, the NPLV coefficients are determined as the values of area under normal curve.

In this research, the outdoor data are obtained from) Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) and the indoor temperature is set 25 °C. Figure 1 and 2 shows the temperature histograms and normal curves of Kupang and Jakarta City as typical profile for Indonesia cities. From the figure it can be seen that the most occurrence temperature in Kupang is around 31 to 32 °C, while in Jakarta is around 26 to 28 °C.

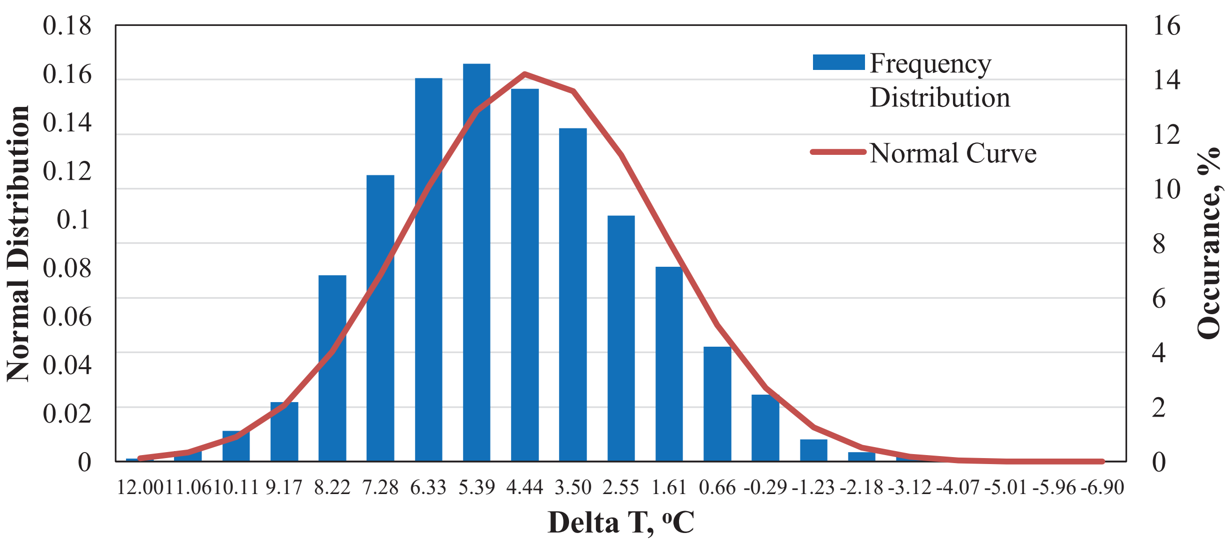

FIGURE 1. Histogram and normal curve of temperature differences in Kupang

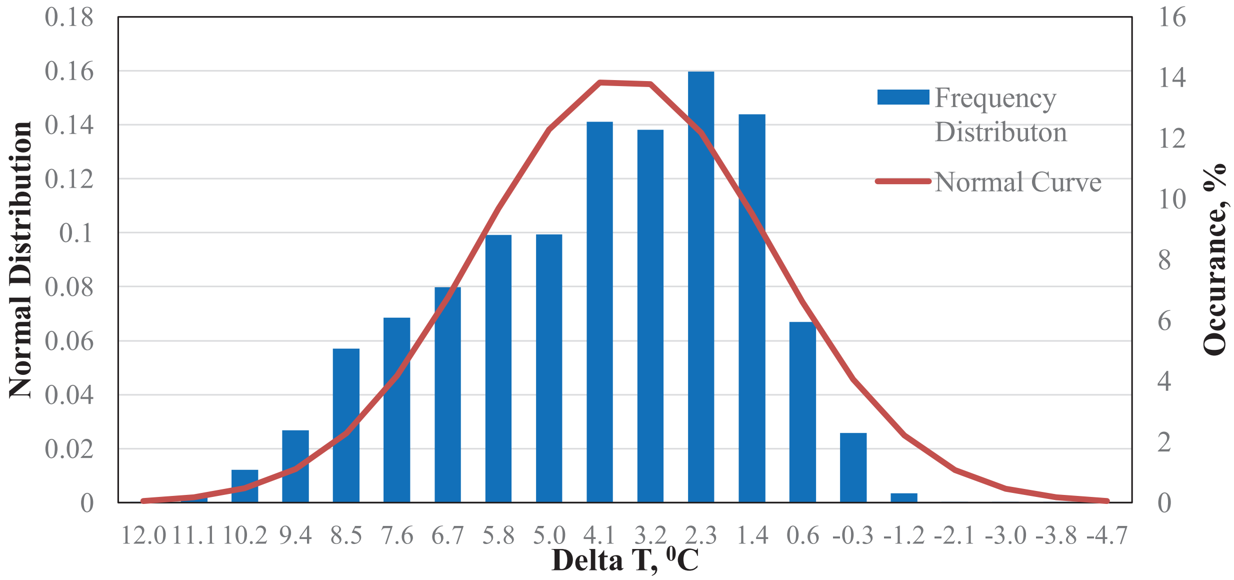

FIGURE 2. Histogram and normal curve of temperature differences in Jakarta – Tanjung Priok

The normal distribution curve is then divided into four portions with 25% interval. The area under the normal curve within each portion show the probability of the occurrence of a temperature within the portion. By assuming that this temperature probability occurrence is representing the probability of partial load with 100% load occurs at the highest temperature portion and subsequently to the 25% load occur at the lowest temperature portion. In another word the probabilities representing the NPLV coefficients Y1 to Y4 in Equation 3 and 4 that has to be found in this study. The area under the curves can be found by integral table of normal distribution curve obtained from [2].

RADIANT TIME SERIES METHOD

Radiant Time Series (RTS) method uses cooling load to determine NPLV coefficients. In this study CADL Building in ITB was used as model for the coefficients determination in several cities.

Climatic Design Conditions

Calculation of cooling load requires information on climatic design conditions. There are four important parameters of climatic design conditions needed to be determined: monthly design dry-bulb, monthly design wet-bulb temperatures, mean daily dry-bulb and mean wet-bulb temperatures. The parameter values are calculated from chosen design condition failure rate. ASHRAE [2] specified the failure rate limit to be 0.4%; 2%; 5%; or 10%, depending on the building usage. In this study, the building model is assumed as an office with failure rate design condition value of 5%. Design dry-bulb temperature is calculated by summing the frequency of sorted monthly temperature data to create cumulative frequency of occurrence. Design condition value of 5% means that design dry-bulb temperature value is equal to 95% cumulative frequency of occurrence. Design wet-bulb temperature is the averaged wet-bulb temperature data coincident with the value of monthly design dry-bulb temperature. Mean daily temperature range is defined as the average of temperature differences per day when the maximum temperature exceeds the design temperature. This definition applies to both dry-bulb and wet-bulb temperatures.

The cooling load was then calculated by using ASHRAE RTS program [3,4]. The results for Kupang and Jakarta City can be seen in Figure 3, and 4 respectively. From the figures it can be seen that the cooling load profile are not similar to the temperature profile, these indicating that the cooling load is not depend on the temperature difference between outdoor and indoor only, but also depend on other factor such as radiation through transparent wall.

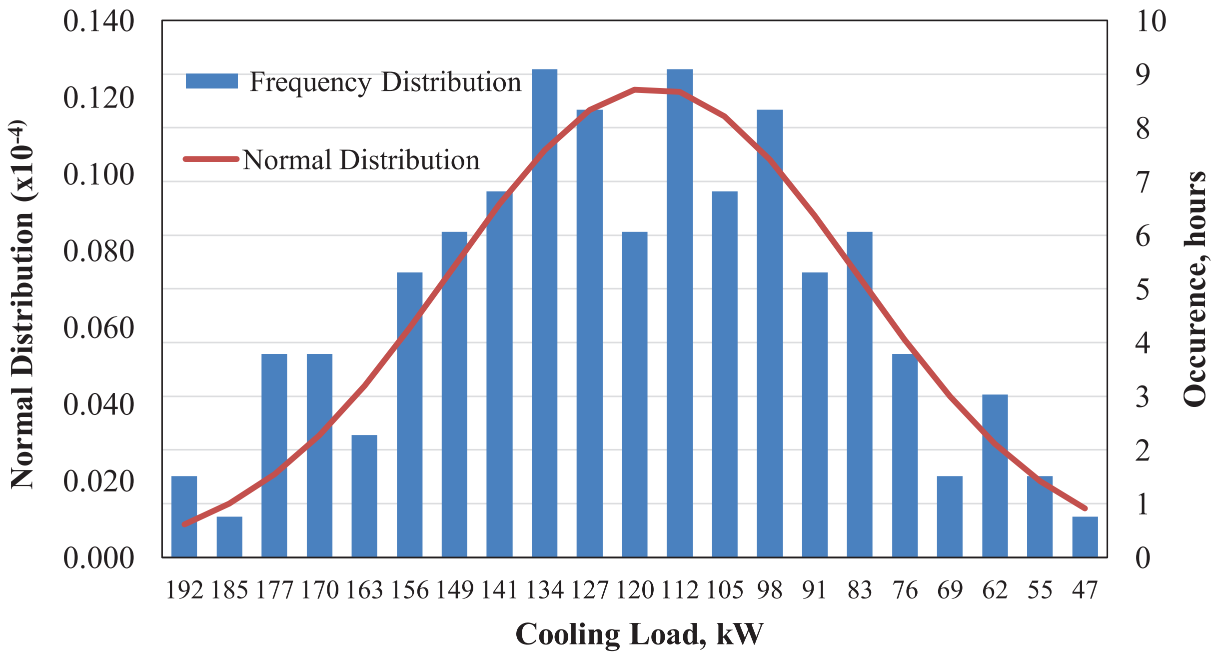

FIGURE 3. Histogram and normal curve of the cooling load in Kupang

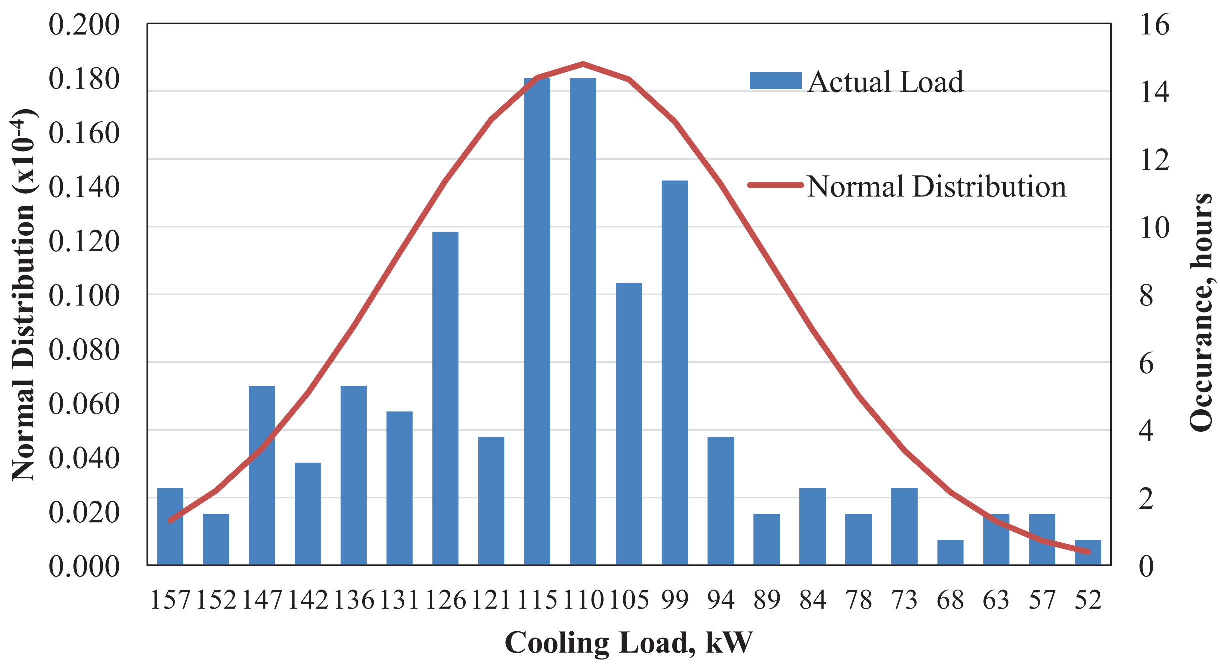

FIGURE 4. Histogram and normal curve of the cooling load in Jakarta – Tanjung Priok

The NPLV coefficient from the cooling load histogram can be determined in similar way to those of temperature histogram. The normal distribution curve was divided into four portion of partial load, and the area under the curve for each portion represent the NPLV coefficient. The results and the comparison with the NPLV coefficient obtained from the Degree hours methods is shown Table 1. Based on discussion above NPLV coefficient obtained from RTS method is recommended to be used in NPLV calculation.

TABLE 2. NPLV Coefficients for Several Cities in Indonesia

	NPLV Coefficient			
Variable	Y_1	Y_2	Y_3	Y_4
Part Load	100%	75%	50%	25%
City	Bandung			
Degree Hours	0.16	0.54	0.28	0.02
RTS	0.19	0.43	0.31	0.07
City	Kupang			
Degree Hours	0.11	0.64	0.24	0.01
RTS	0.13	0.35	0.38	0.14
City	Pontianak			
Degree Hours	0.08	0.35	0.44	0.13
RTS	0.12	0.36	0.39	0.13
City	Jakarta (Kemayoran)			
Degree Hours	0.03	0.53	0.42	0.02
RTS	0.21	0.44	0.29	0.06
City	Jakarta (Soekarno-Hatta International Airport)			
Degree Hours	0.1	0.62	0.27	0.01
RTS	0.26	0.43	0.26	0.05
City	Jakarta (Tanjung Priok)			
Degree Hours	0.02	0.52	0.44	0.02
RTS	0.21	0.44	0.29	0.06
City	Palembang			
Degree Hours	0.04	0.33	0.49	0.14
RTS	0.17	0.43	0.33	0.07

APPLICATION OF NPLV COEFFICIENT

When NPLV coefficient are known the NPLV can be calculated if the Chiller COP or EER are known. The resulted NPLV can be used to select which type of chiller is suitable to be applied in a city, i.e. chiller type which give highest value of NPLV. Figure 5 shows the variation of EER of three type of chiller with partial load. By using Equation (2), the NPLV for each chiller and city can be calculated. The results are shown in Figure 6. It can be seen that reciprocating chillers is the best chiller for all selected cities. The selection using NPLV is clearer compared to the EER comparison shown in Figure 5.

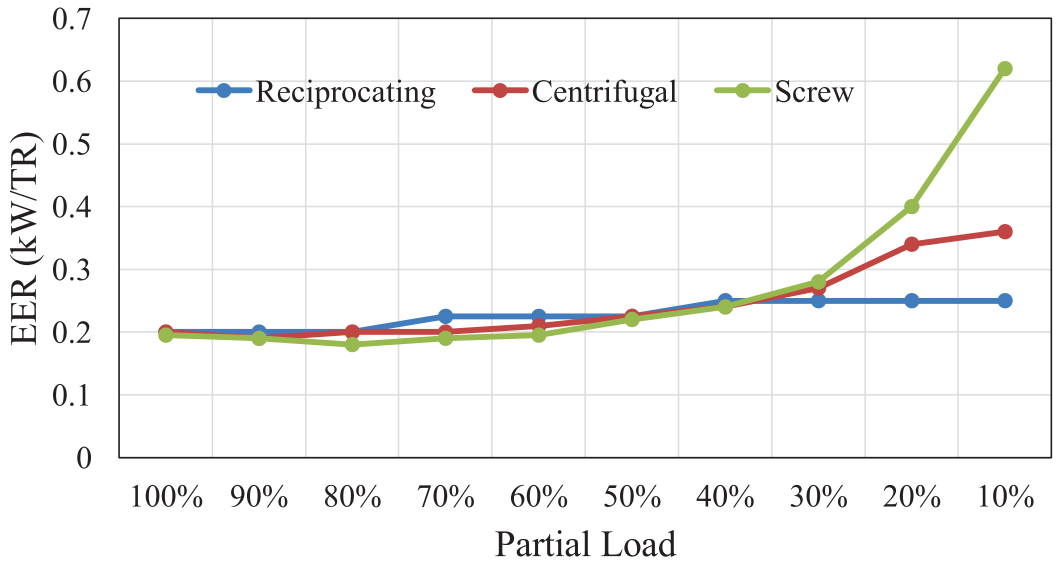

FIGURE 5. Variation of three type of chillers with partial load [5]

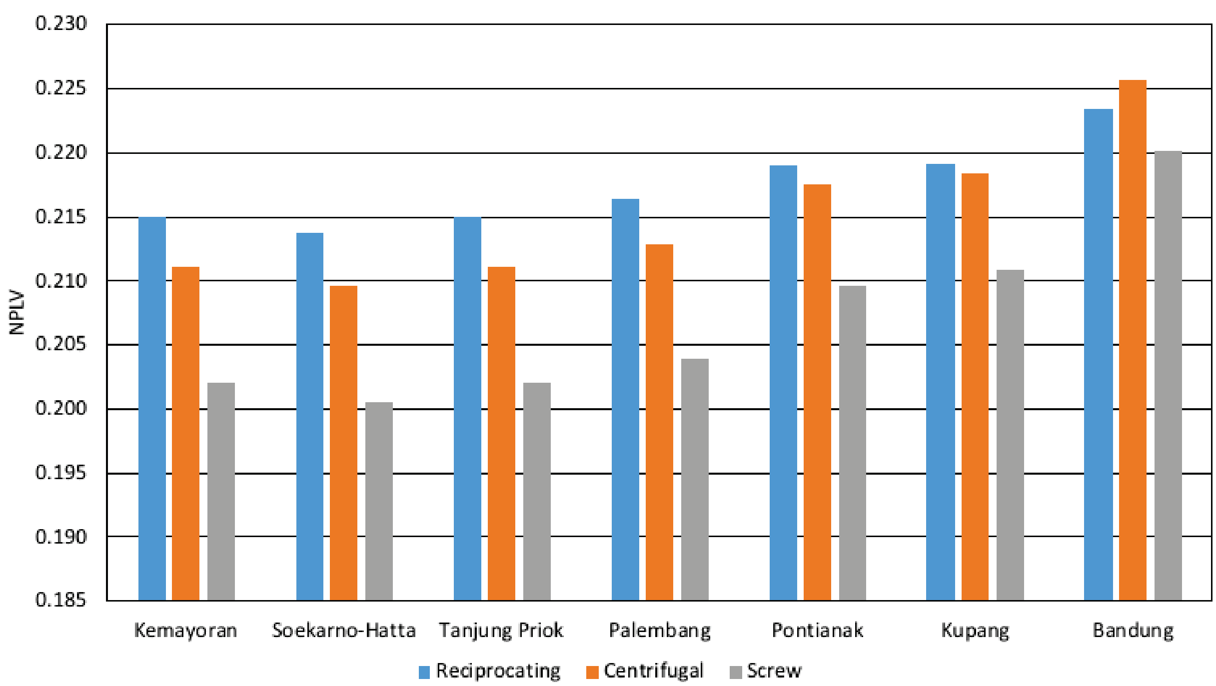

FIGURE 6. NPLV of three type of chillers for selected cities

CONCLUSION

Based on the discussion above it can be concluded that the NPLV calculated based on the RTS method give more reasonable results compared to the Degree hours method. The NPLV value varies for different city because of different weather conditions. The NPLV value is useful for selection of chiller type for a particular city. Further studies for various cities and comparison with actual data from chillers log book are needed.

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