World Sustainable Built Environment Conference 2017 Hong Kong
Transforming Our Built Environment through Innovation and Integration:
Putting Ideas into Action
5-7 June 2017

Registration ID: 2438.

BSEEP: Development of MERIT and Normalization Factor for Different Operating Hours for Building Energy Intensity (BEI)

ABSTRACT

The JKR-UNDP's Building Sector Energy Efficiency Project (BSEEP) in Malaysia is aimed at reducing the growth rate of GHG emission of the building industry in Malaysia. Component 4 task in BSEEP in 2015 was to develop a document allowing the Malaysian building industry to compare energy efficiency of different buildings in a fair manner. The MERIT is one of the output by this project.

MERIT is a proposed methodology for gathering, interpreting and the use of data for the purpose of obtaining an accredited Malaysian Energy Efficiency Rating of Building for Offices (MERIT for Offices) for existing buildings using 12 months of actual data. MERIT is based on the computed Building Energy Intensity (BEI) in kWh/(m^2.year); an index that is commonly used in South East Asia.

During the development of MERIT, a study was made on the linear normalization of operational hours of office building that is commonly practised by the building industry in South East Asian region. It was found in this study that a linear normalization significantly misrepresents the BEI of an office building operating 24 hours daily versus a building that is operating only 8 hours a day from Monday to Friday.

A linear normalization was unable to capture the effects of building thermal mass and base-load effects of buildings with different operating hours. Further studies establish that a logarithmic fit is more appropriate method for normalizing operational hours of building's BEI.

This will be the 1st tool in South East Asia that will use a logarithmic normalization methodology to allow better representation of the BEI due to different operating hours in buildings.

Keywords: Energy use; Building energy rating tool; Normalization Factor

1. INTRODUCTION

A recent study made by Exergy Sdn Bhd verified the proposed MERIT logarithmic normalization of different operational hours for buildings in Malaysia. Since there is a second verification party that conducted the study using different methodology, building conditions and software; and arriving at the same result; it is hereby proposed to use the proposed MERIT logarithmic normalization method to compute MERIT's BEI. The proposed changes to the BEI computation is shown as Eq. (1-1) below, incorporating the logarithmic "normalization factor (NF)".

$$BEI = \frac{Total\ Building\ Energy\ Consumption}{Rated\ Areas\ x\ Rated\ Hours}\ x\ 52\,\frac{hours}{week}\ x\ NF \qquad \text{Eq. (1-1)}$$

Where NF is defined as:

Rated Hours per Week (x)	NF
40	0.89
45	0.94
50	0.99
52	1.00
60	1.02
85	1.15
105	1.21
168	1.35

$Where, NF = 0.3113\ln(x) - 0.2381$, R^2 = 99.45

The linear BEI formula that is commonly in use in South East Asia today is as shown as Eq. (1-2):

$$BEI = \frac{Total\ Building\ Energy\ Consumption}{Rated\ Areas\ x\ Rated\ Hours}\ x\ 52\,\frac{hours}{week} \qquad \text{Eq. (1-2)}$$

The MERIT logarithmic normalization is a proposed method that accounts for the effect of base building load during unoccupied hours and the thermal mass effect of the building in the computation of BEI.

The development of this "normalization factor" is similar to the development of the constants in OTTV (Overall Thermal Transmission Value) equation used in Malaysian Standard 1525 since early 1990s; that is based on approximately 60 building energy simulation results [7].

A total of 72 simulation studies was conducted with different base loads and operating hours to derive the normalization fit for MERIT's BEI.

Finally, it should also be highlighted that the American's EUI (energy usage intensity) also employed a logarithmic fit to normalise buildings with different operational hours of use. The derivation of the logarithmic fit for building operational hours in US was based on thousands of actual performance data collected from existing buildings [4].

2. BASE LOAD EFFECT

Consider two identical building with the same occupancy density, same air-conditioning system, same lighting system and same plug load. One is being operated 10 hours per day from Monday to Friday and the other one being operated 24 hours a day, 7 days a week. The BEI computed for the 10 hours building and 24 hours building should be the same because the default BEI is normalised to 52 hours per week (via a linear normalization). However, the linear normalization method does provide the same BEI number and one of the reason for this error is due to the base load effect as presented in Figures 2-1, 2-2 and 2-3.

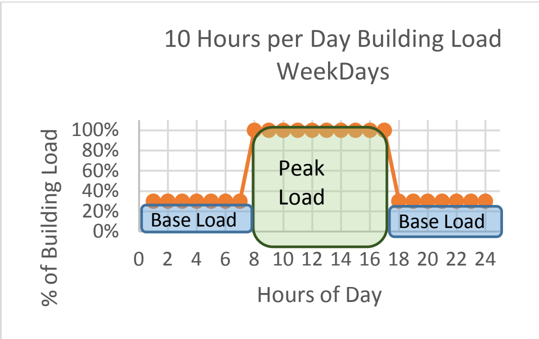

Figure 2-1: Building energy load scenario with 10 hours per day during weekdays

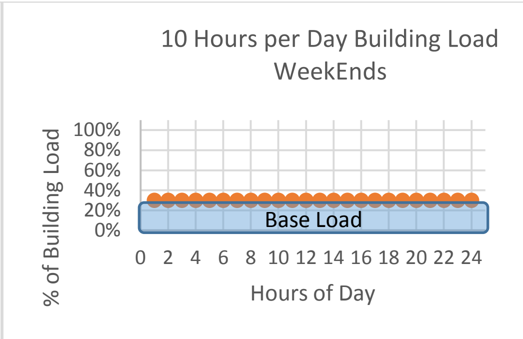

Figure 2-2: Building energy load scenario with 10 hours per day during weekends

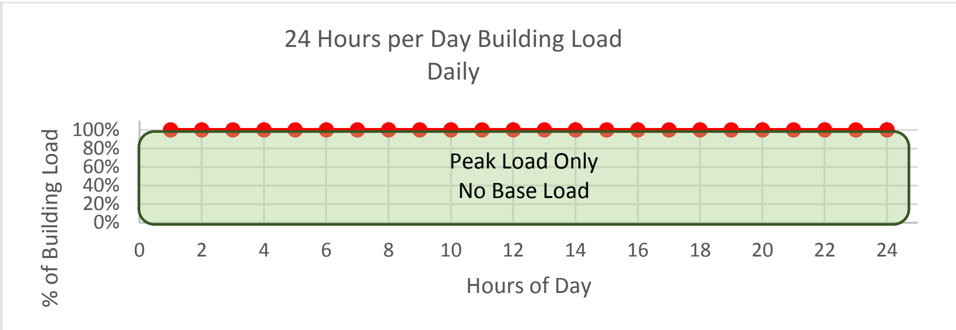

Figure 2-3: Building energy load scenario that operates 24 hours a day

To illustrate the base load effect (ignoring the thermal mass effect for now), a set of BEI computation are provided for 3 scenarios of operating hours: 50, 85 and 168 hours per week following the charts provided. The following assumptions were used on all 3 scenarios modelling a building that is exactly the same, with the only exception of different operating hours; thereby different base load hours:

a) Building Size: 1,000 m²
b) Peak Load Power: 21.65 kW
c) Base Load Power: 6.5 kW

Table 2-1: Computed BEI based on Linear Normalization

Operating Hours per Week	50 (Base)	85	168
Default Linear BEI, kWh/(m².year)	100	76	58
Error from Base	0%	-24%	-42%

Table 2-2: Computed BEI based on Logarithmic Normalization

Operating Hours per Week	50 (Base)	85	168
Logarithmic BEI, kWh/(m².year)	99	87	78
Error from Base	0%	-11%	-21%

The computed BEI with Linear Normalization is shown in Table 2-1 and it showed an error up to 42% for building operating 24 hours daily. Table 2-2 showed the computed BEI with Logarithmic Normalization Factor used and it reduces the maximum error down to 21% for the same building operated 24 hours daily.

However, this set of calculation ignored the effect of thermal mass that is also occurring on the building due to the differences of building operational hours. Therefore, the error computed here, by the Proposed Logarithmic Normalization Factor, seems to be large at 21%.

3. THERMAL MASS EFFECT

The thermal mass of a building caused peak cooling load to be different due to the different operational hours. In a building that operate 5 days a week, the building mass will absorb heat during the weekends and cause a peak cooling load to occur on Monday morning. However, in a building that operates 24 hours daily, this thermal mass effect is not relevant anymore as it does not have any hours where the building mass is allowed to heat up.

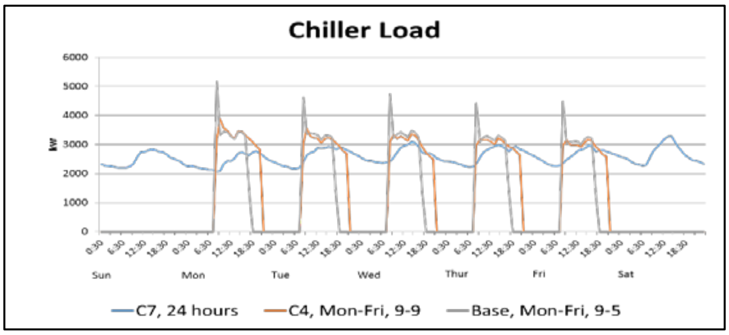

Figure 3-1: Chiller load due to different operating hours

Fundamentally, the longer the operating hours of the air-conditioning system, the less hours the building mass is exposed to heat gain, reducing the relevancy of thermal mass effect on the peak cooling load.

Building energy simulation studies were conducted to capture the effect of building thermal mass effect on the BEI computation. A range of simulation studies were made to calibrate the BEI to account for the base load effect and thermal mass effect at the same time, for buildings with different operational hours.

The dampening of cooling load effect due to longer operational hours of a building is shown in Figure 3-1 above.

4. DERIVATION OF THE MERIT LOGARITHMIC NORMALIZATION FACTOR

The logarithmic normalization factor was derived from a set of 72 cases of simulation study of a typical office building of 17 floors with these conditions:

Part 1: Different Energy Use Intensity

Three (3) basic building scenarios were created to model the influence of operating hours on the BEI computation. These three (3) building scenarios represents the followings:

a) Low Energy Building:

This is a model of a building that is reasonably well optimized for energy efficiency. It has good building fabric, low lighting power density, low small power density and efficient air-conditioning equipment. This building is modelled with variable air volume system and variable chill water flow.

b) Medium Energy Building:

This is a model of a building that has standard efficiency. It has moderate building fabric, medium level of lighting power density, medium level of small power density and average efficiency air-conditioning equipment. This building is modelled with variable air volume system and variable chill water flow.

c) High Energy Building:

This is a model of a building that has poor energy efficiency. It has poor building fabric, high lighting power density, high small power density and poor efficiency air-conditioning equipment. This building is modelled with constant air volume system and constant chilled water flow.

The lighting and air-conditioning equipment in these three (3) buildings remain exactly the same for all the simulation cases based on the building scenario. The objective of this study is to model the same building with same equipment and occupant density. The only difference that made to the building is the operational hours which impacts the hours of occupancy, hours of small power use, hours of lighting power use and air-conditioning hours.

Part 2: Different Base Loads

In addition to the above, three (3) different base loads were simulated for each building scenario. These three (3) base loads were selected to study the influence of different base load on BEI and operational hours of the building. The following assumption on base load were made:

a) Small Power base load of 10%
b) Small Power base load of 35%
c) Small Power base load of 50% (65% for High Energy Building).

Part 3: Different Operating Hours

Finally, eight (8) cases of different operating hours of a building were made. These cases modelled building with operating hours of 2080 to 8760 per year. The details of the operating hours are as shown in Table 4-1 below:

Table 4-1: List of Operating Hours Simulated

Cases	Operating hours (Mon-Fri)	Operating Hours (Sat)	Operating Hours (Sun)	Weekly Operating Hours
Base Case	9am to 5pm	Off	off	40
Case 1	9am to 6pm	Off	off	45
Case 2	8am to 6pm	Off	off	50
Case 3	8am to 6pm	8am to 1pm	off	55
Case 4	9am to 9pm	Off	off	60
Case 5	9am to 9pm	9am to 9pm	9am to 9pm	85
Case 6	9am to 12 midnight	9am to 12 midnight	9am to 12 midnight	105
Case 7	24 hours	24 hours	24 hours	168

The simulation studies were conducted using IES<VE> building simulation software, with full modelling of the air-conditioning system. Conventional building material and power consumption was obtained from the building industry professional through stakeholder’s engagement; via the Building Sector Energy Efficiency Project in Malaysia to represent the common building industry practise [2].

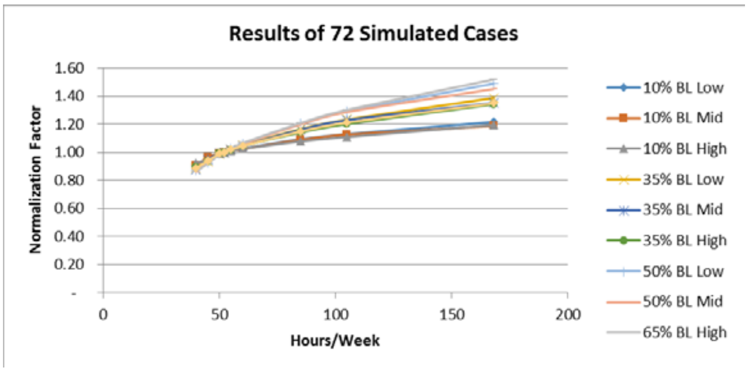

Figure 4-1: Results of 72 simulated cases

Table 4-2: Confidence Interval of Proposed Normalization Factor

Hours/week	Average Normalization Factor	Potential Error of Computed BEI (±) Confidence Interval		
		80%	95%	99%
40	0.89	1.1%	1.7%	2.2%
45	0.94	0.6%	0.9%	1.2%
50	0.99	0.2%	0.2%	0.3%
52	1.00	0.0%	0.0%	0.0%
55	1.02	0.2%	0.4%	0.5%
60	1.04	0.6%	1.0%	1.3%
85	1.15	1.9%	2.9%	3.8%
105	1.21	2.7%	4.1%	5.3%
168	1.35	4.0%	6.1%	8.0%

The result of the simulation studies indicated that the proposed calibration factors are very accurate for weekly operational hours between 45 to 60 hours per week, as it is within 99% confidence interval that the computed BEI will have a maximum error of less than 2.2%. Longer operating hours have higher uncertainties due to the ambiguity of the actual base load during non-occupancy hours. The uncertainty of the base load also impacts the building thermal mass, causing further uncertainty.

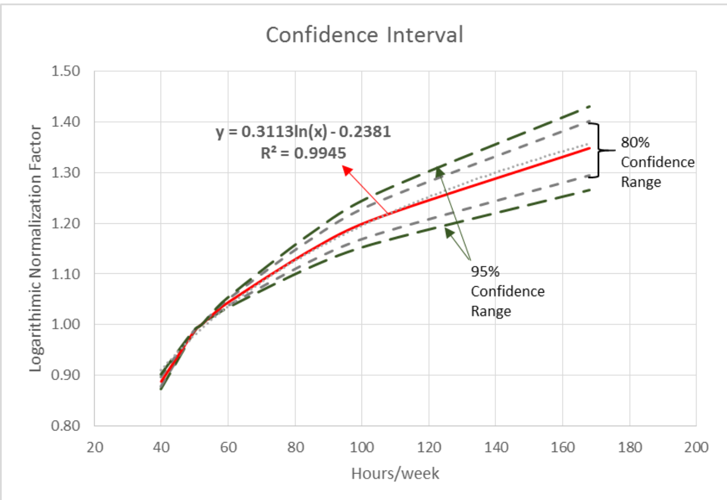

Figure 4-2: Confidence interval of proposed logarithmic normalization factor

Although there are uncertainties, the results from this simulation study showed that the proposed normalization factor will provide a maximum of ±6% error, within a

95% confidence interval in the worst case scenario. This result is deemed accurate enough for such tool to be used by the building industry.

5. VALIDATION BY EXERGY SDN BHD

Exergy Sdn Bhd has completed a verification study on the proposed MERIT logarithmic normalization factor by conducting building energy simulation studies using a different software (EnergyPlus) on four (4) of their actual office building projects. These buildings have BEI ranging from 135 to 180 kWh/(m².year) at 52 hours/week operational hours and has different Gross Floor Area (GFA), different air-conditioned space ratio to GFA, different building orientation, different building heights and different windows to wall ratio for each of the project. The results of Exergy studies are as summarized in the tables below:

Table 5-1: Comparison of Building 1 Normalization Factor (NF)

Bldg 1	Hr/wk	Act BEI *	Def. BEI**	BEI @ 52 Hr/wk	NF for Bldg 1	MERIT NF	Diff (%)
C1	40	127	164	146	0.89	0.89	**0.0%**
C2	45	135	156	146	0.93	0.94	**-1.1%**
C3	50	143	149	146	0.98	0.99	**-1.0%**
C4	55	152	143	146	1.02	1.02	**0.0%**
C5	60	161	140	146	1.04	1.04	**0.0%**
C6	85	204	126	146	1.16	1.15	**0.9%**
C7	105	241	119	146	1.23	1.21	**1.7%**
C8	168	349	108	146	1.35	1.35	**0.0%**

Where:

*;

$$Act\ BEI = \frac{Total\ Building\ Energy\ Consumption}{Building\ Gross\ Floor\ Area}$$

**;

$$Def\ BEI = \frac{Act\ BEI\ x\ 52\ Hours/Week}{Rated\ Hours}$$

Table 5-2: Comparison of Building 2 Normalization Factor (NF)

Bldg 2	Hr/wk	Act BEI *	Def. BEI **	BEI @ 52 Hr/wk	NF for Bldg 2	MERIT NF	Diff (%)
C1	40	151	196	180	0.92	0.89	**3.4%**
C2	45	162	187	180	0.96	0.94	**2.1%**
C3	50	180	186	180	0.97	0.99	**-2.0%**
C4	55	193	182	180	0.99	1.02	**-2.9%**
C5	60	196	170	180	1.06	1.04	**1.9%**
C6	85	255	157	180	1.15	1.15	**0.0%**
C7	105	301	148	180	1.22	1.21	**0.8%**
C8	168	447	138	180	1.31	1.35	**-3.0%**

Table 5-3: Comparison of Building 3 Normalization Factor (NF)

Bldg 3	Hr/wk	Act BEI *	Def. BEI **	BEI @ 52 Hr/wk	NF for Bldg 3	MERIT NF	Diff (%)
C1	40	117	152	135	0.89	0.89	**0.0%**
C2	45	126	145	135	0.93	0.94	**-1.1%**
C3	50	133	138	135	0.98	0.99	**-1.0%**
C4	55	141	133	135	1.01	1.02	**-1.0%**
C5	60	150	130	135	1.04	1.04	**0.0%**
C6	85	190	117	135	1.15	1.15	**0.0%**
C7	105	230	113	135	1.19	1.21	**-1.7%**
C8	168	309	95	135	1.41	1.35	**4.4%**

Table 5-4: Comparison of Building 4 Normalization Factor (NF)

Bldg 4	Hr/wk	Act BEI *	Def. BEI **	BEI @ 52 Hr/wk	NF for Bldg 4	MERIT NF	Diff (%)
C1	40	129	167	151	0.90	0.89	**1.1%**
C2	45	139	160	151	0.95	0.94	**1.1%**
C3	50	147	153	151	0.99	0.99	**0.0%**
C4	55	157	148	151	1.02	1.02	**0.0%**
C5	60	167	145	151	1.05	1.04	**1.0%**
C6	85	215	132	151	1.14	1.15	**-0.9%**

C7	105	255	126	151	1.20	1.21	**-0.8%**
C8	168	372	115	151	1.32	1.35	**-2.2%**

Table 5-5: Summary Comparison of 4 Buildings Normalization Factor (NF)

Hr/wk	MERIT NF	Bldg 1 % Diff	Bldg 2 % Diff	Bldg 3 % Diff	Bldg 4 % Diff	Ave % Diff
40	0.89	0.0%	3.4%	0.0%	1.1%	**1.1%**
45	0.94	-1.1%	2.1%	-1.1%	1.1%	**0.3%**
50	0.99	-1.0%	-2.0%	-1.0%	0.0%	**-1.0%**
55	1.02	0.0%	-2.9%	-1.0%	0.0%	**-1.0%**
60	1.04	0.0%	1.9%	0.0%	1.0%	**0.7%**
85	1.15	0.9%	0.0%	0.0%	-0.9%	**0.0%**
105	1.21	1.7%	0.8%	-1.7%	-0.8%	**0.0%**
168	1.35	0.0%	-3.0%	4.4%	-2.2%	**-0.2%**

The results from Exergy studies verified that the proposed MERIT logarithmic normalization factor provided a good calibration of the BEI due to the differences of operational hours on four (4) of their building projects. The average differences of BEI computation by Exergy to the MERIT proposed logarithmic normalization factor range from a low of -1% to +1%, suggesting a very good fit.

A maximum difference of 4.4% is shown to occur for a building running 24 hours daily. This result corresponded well to the statistical analysis of the proposed MERIT logarithmic normalization factor which showed that the confidence interval gets larger with longer hours of building use.

6. SUMMARY

The proposed logarithmic normalization factor for BEI computation is shown to provide a more correct comparison of energy consumption of buildings with different operational hours of use.

A table providing normalization factor was proposed as a mean of offering the building industry a simple tool for it to be adopted easily. The normalization factor proposed provided a confidence interval of 95% that the computed BEI falls within a margin of error of ±6% even on the worst case scenario.

It is therefore, proposed for Malaysia building industry to adopt this methodology to normalize BEI of buildings with different operational hours.

REFERENCES

[1] NABERS Energy and Water for offices, Validation Protocol for Accredited Ratings, 2009, Department of Environment, Climate Change and Water NSW.
[2] Tang, 2013, Report on Malaysian Building Energy Efficiency Rating System (MEERB) – Part 1 & 2; Building Sector Energy Efficiency Project (BSEEP), Malaysia.
[3] Ahmad, 2015, BEI Normalization based on Operating Hours, Exergy Sdn Bhd.
[4] Terry Sharp, 2012, Energy Benchmarking in Commercial Office Buildings, Oak Ridge National Laboratory.
[5] Green Building Index, 2011, New Construction (NRNC) Design Reference Guide & Submission Format, Malaysia.
[6] Green Building Index, BEI Formula, http://www.greenbuildingindex.org/FAQs-9.html
[7] J.J. derringer, J.F. Bush, J. Hall, K.S. Kannan, M.D. Levine, A.C. Ayub and I. Turiel (April 1987), Energy and Economic Analysis in support of Energy Conservation Standards for new Commercial Buildings in Malaysia, Lawrence Berkeley laboratory, University of California.