Installation of separate-type inverter-controlled fridge showcase
for convenience store(s)
Additional Information

1. Introduction

This methodology evaluates the reference emission of separate type fridge showcase, taking into account the impact of the difference of the coefficient of performances (COPs) and performance degradation effect of ON/OFF cycles of the constant speed compressor. In calculating the performance degradation effect of incremental electricity consumption caused by frequent of ON/OFF cycles by the absence of the inverter, Part load fraction (PLF) is applied considering the condition called “part load conditions” under which the cooling load is smaller than the rated cooling load. On the other hand, the effect of the inverter at the part load condition where separate type fridge showcases frequently operate and the efficiency drastically improved against reference non-inverter separate type fridge showcase is not considered. Therefore the methodology achieves the net emission reductions.

2. Estimation of emissions from reference separate-type fridge showcase using Part Load Fraction

Reference emissions of the separate type fridge showcase is calculated by the multiplying electricity consumption of the reference separate type fridge showcase and CO_2 emission factor for the consumed electricity.

$$RE_{i,j,p} = EC_{ref,i,j,p} \times EF_{elec} \cdots (1)$$

Where,

$EC_{ref,i,j,p}$	Electricity consumption of the reference separate type fridge showcase *j* at store *i* during the monitoring period *p* [MWh/p]
EF_{elec}	CO_2 emission factor for consumed electricity [tCO_2/MWh]
i	Identification number of the convenience store [-]
j	Identification number of the separate type fridge showcase [-]

Therefore, the formula for calculating the reference emissions of the reference separate type fridge showcase is as follows.

$$RE_p = \sum_i \sum_j \left[EC_{ref,i,j,p}\right] \times EF_{elec} \cdots (2)$$

In this methodology, the reference electricity consumptions are calculated by considering PLF which is a coefficient of part load ratio (PLR). PLR is generally calculated by the ratio of cooling load to rated cooling capacity as follows. Since cooling load can be replaced by cooling capacity, the basic concept is shown in Equation (3).

$$PLR = \frac{Cooling\ load[\mathrm{k}W]}{Rated\ cooling\ capacity[\mathrm{k}W]} \cong \frac{Cooling\ capacity[\mathrm{k}W]}{Rated\ cooling\ capacity[kW]} \cdots (3)$$

Cooling capacity required for the monitoring period is calculated by multiplying the averaged electricity consumption and the COP of the project separate type fridge showcase as shown in Equation (4)

$$Cooling\ capacity_{pj,i,p} = \frac{EC_{pj,i,j,p}}{t_{pj,i,j,p}} \times COP_{pj,i,j} \cdots (4)$$

As the result, Equation (3) can be converted to Equation (5)

$$PLR_{i,j,p} = \frac{EC_{pj,i,j,p} \times 10^3}{t_{pj,i,j,p}} \times \frac{COP_{pj,i,j}}{Cap_{ref,i,j}} \cdots (5)$$

Where,

$PLR_{i,j,p}$	Part Load Ratio of the separate type fridge showcase *j* in convenience store *i* during the monitoring period *p*[-]
$Cooling\ capacity_{pj,i,j,p}$	Cooling capacity of the separate type fridge showcase *j* in convenience store *i* during the monitoring period *p* [kW]
$EC_{pj,i,j,p}$	Electricity consumption of the project separate type fridge showcase *j* in convenience store *i* during the monitoring period *p*[MWh/p]
$t_{pj,i,j,p}$	Operating time of the project separate type fridge showcase *j* in convenience store *i* during the monitoring period *p*[hour]
$COP_{pj,i,j}$	Energy efficiency of the project separate type fridge showcase *j* in convenience store *i*
$Cap_{ref,i,j}$	Rated capacity of the reference separate type fridge showcase *j* in convenience store *i* [kW]

Rated capacity of the reference separate type fridge showcase is assumed to be same as the rated capacity of project separate type fridge showcase, therefore the following equation can be obtained.

$$Cap_{ref,i,j} = Cap_{pj,i,j} \cdots (6)$$

Where,

$Cap_{pj,i,j}$	Capacity of the project separate type fridge showcase *j* at store *i* during the monitoring period *p*[kW]

According to the manual of EnergyPlus(1), a typical part load fraction (PLF) correction is calculated as follows.

$$PLF_{i,j,p} = \frac{part\ load\ efficiency}{steady - state\ efficiency} = 1 - C_D\left(1 - PLR_{i,j,p}\right) \cdots (7)$$

Where,

$PLF_{i,j,p}$	Part Load Fraction of the separate type fridge showcase *j* in convenience store *i* during the monitoring period *p*
C_D	Degradation Coefficient is a parameter used in calculating the part load fraction-]

As shown in the equation (7) above, PLF is led by the formula using degradation coefficient (C_D). The degradation due to ON/OFF cycles by the absence of the inverter is assumed to be equivalent since the separate type fridge showcase is similar with the air conditioner in terms of the operation except for the setting of evaporating temperature. As shown in **Table 1**, the survey of air conditioner standard in the countries indicated in Table 1, the values of degradation coefficient C_D are identified from 0.20 to 0.25. Therefore, in this methodology, C_D is set to be 0.15, which is applied in Energy Plus, in order to achieve net emission reductions.

Table 1 The comparison with C_D in each country

Country	Standards	Degradation coefficient (C_D)
Japan	JIS B 8616:2015	0.25
USA	ARI 210/240,	0.2
Canada	ASHRAE 116-1995	
EU	BS EN 14825	0.25
China	GB/T 7725-2004	0.25
Hong Kong	Voluntary Energy Efficiency Labelling Scheme for Room Air Conditioners	0.25
Chinese Taipei	Draft-2008	0.25
Korea	KS C 9306-2007	0.25
New Zealand	AS/NZS 3823.4.1:2014	0.25

(Source)

- APEC Energy Working Group, Reducing Barriers to Trade through Development Of A Common Protocol For Measuring The Seasonal Energy Efficiency (SEER) Of Air Conditioners.
- JIS B 8616：2015 Package Air Conditioners
- BS EN 14825:2016 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling. Testing and rating at part load conditions and calculation of seasonal performance

In addition, the part-load fraction correction should be normalized to a value of 1.0 when the PLR equals to

1 EnergyPlus is an open-source whole building energy simulation program funded by the U.S. Department of Energy's (**DOE**) Building Technologies Office (BTO), and managed by the National Renewable Energy Laboratory (NREL). https://energyplus.net/

1.0 (i.e., no efficiency losses when the compressor run continuously). For PLR values between 0 and 1(0<PLR<1), the following rule applies.

$$PLF_{i,j,p} \geq 0.7 \quad , \quad PLF_{i,j,p} \geq PLR_{i,j,p}$$

In the case of the calculation of the electricity consumption of the reference separate type fridge showcase without consideration of the incremental electricity consumption caused by frequent ON/OFF switching control of constant speed compressor, it is calculated by the multiplying ratio of COPs of the project and reference separate type fridge showcase. The formula for obtaining the power consumptions of the reference separate type fridge showcase is as follows.

$$EC_{ref,continous,i,j,p} = EC_{pj,i,j,p} \times \frac{COP_{pj,i,j}}{COP_{ref,i,j}} \cdots (8)$$

Where,

$EC_{ref,continous,i,j,p}$	Electricity consumption of the reference separate type fridge showcase *j* in convenience store *i* with operating continuously during the monitoring period *p* [MWh/p]

Therefore if PLR is equal to and larger than 1 (PLR≧1), the formula for obtaining the power consumptions of the reference separate type fridge showcase is as follows since the constant speed compressor of the reference separate type fridge showcase runs continuously.

$$EC_{ref,i,j,p} = EC_{ref,continous,i,j,p} = EC_{pj,i,j,p} \times \frac{COP_{pj,i,j}}{COP_{ref,i,j}} \cdots (9)$$

Where,

$EC_{pj,i,j,p}$	Electricity consumption of the project separate type fridge showcase *j* in convenience *i* during the monitoring period *p* [MWh/p]

On the other hand, if PLR is less than 1 (PLR<1), the electricity consumption of the reference separate type fridge showcase is calculated by dividing electricity consumption of the reference separate type fridge showcase by PLF. The formula for obtaining the power consumptions of the reference separate type fridge showcase in case that PLR is less than 1 (PLR<1) is as follows.

$$EC_{ref,i,j,p} = EC_{ref,continous,i,j,p} \div PLF_{i,j,p}$$

$$= EC_{pj,i,j,p} \times \frac{COP_{pj,i,j}}{COP_{ref,i,j}} \times \frac{1}{PLF_{i,j,p}} \cdots (10)$$

3. Research on reference COP values for separate-type fridge showcase

Table 2 shows the market share of convenience store companies in Thailand. It is observed that Company X and Y are dominant in the convenience store market. In addition, according to the survey, convenience stores in Thailand install lightings, air conditioners, and fridge showcases including condensing units that are made by domestic companies, e.g. condensing unit equipped with constant-speed compressor. Furthermore, floor area of convenience store is mostly less than 200 square meters in Thailand.

Table 2 Market size of convenience store in Thailand

Company	Number of stores	Market share
X	8,618	76.8%
Y	1,117	10.0%
Other	1,483	13.2%
Total	11,218	100.0%

(Source) Interview with convenience store Y (2015)

According to the interview from Company B, condensing units of fridge showcase installed in a convenience store in Thailand are generally separate type showcase equipped with compressors whose output are generally 6 HP or 8 HP （1HP = 0.7457kW） depending on the number of open showcases or walk-in showcases provided by store design. When determining the reference condensing units of separate-type fridge showcase, the standard conditions shown in Table 3 is applied. And also, the range of cooling capacity including the condensing unit whose output of the compressor is 6 HP and 8 HP are widely selected. It is noted that the refrigerant of which ODP is zero is also considered.

Table 3 The rated condition of condensing unit

Condition	
Refrigerant	R404A
Temperature condition	Ambient temperature 32° C Evaporating temperature -10°C

(source) Spec sheet, Engineering document, brochure from show case manufacturer

The interview results show that there are four companies, the Company A and Company B and C and D, which sell the condensing unit for separate type fridge showcase in Thailand. The Company A and Company B accounts for about 90% share of the estimated market of refrigerators in Thailand. Company A, Company B, and Company D provide condensing units equipped with constant speed compressor. Among them, Company A provides the catalog of condensing unit for convenience stores. Taking the temperature standardization of COP values into consideration, COP values of condensing unit are collected from the catalog data shown in Figure 1 below. However, the 8 HP model is not available on the market in Thailand, so Company A’s models with the same refrigerant, similar compressor’s horsepower band including 6 HP that are used for the same purpose and distributed in other areas are selected and are illustrated with light blue and blue dots in the figure. These units are versatile and introduced in Europe where the introduction of high-efficiency condensing unit is progressing, and are considered to be reasonable as reference equipment.

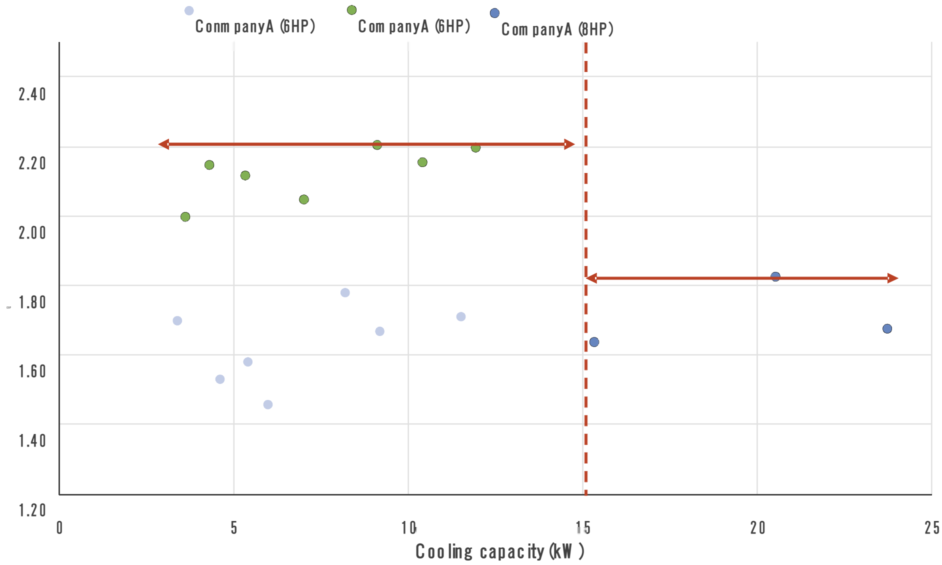

Figure 1 COP values of non-inverter type condensing unit for fridge showcase in Thailand

Two cooling capacity ranges, namely “3.0 ≤x≤ 15.0” and “15.0 <x≤ 25.0” are set to determine the reference COP values for each range. The highest value of COP obtained from the survey with green dots for the range of “3.0 ≤x< 15.0” are set as a reference COP value for the 6 HP model. In addition, the highest COP value with blue dots for the range of “15.0 <x≤ 25.0” is set conservatively as a reference value for 8 HP model. Accordingly, the COP values depending on the cooling capacity range shown in Table 4 below are applied as the reference COP value in this methodology (x indicates the unit freezing capacity).

Table 4 Established COP of reference condensing unit for the proposed methodology

Cooling capacity [kW]	Reference COP
3.0 ≤x≤ 15.0	2.20
15.0 <x≤ 25.0	1.83