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LCCP Evaluation for Air-to-Air Heat Pumps using Next-Generation Refrigerants - Residential Air Conditioners -

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Abstract

In Japan, a two-step process is applied to the LCCP evaluation of heat pump-type air conditioners with next-generation refrigerants. This report mainly describes the first step of the process through to the LCCP evaluation methods, together with the concept of the study utilizing field data and hypotheses. In particular, a representative model is selected as an example of general split-type air conditioners, and it is considered in two ways, one of which is only as evaluation for a system drop-in of candidate refrigerants replacement while the other is in terms of system optimization, both using the candidate refrigerants to be examined R290, R32, R454C (and R22, R410A). On the basis of such systems, this report explains a calculation method using the performance simulation that is adopted as a standard tool by the Japan Refrigeration and Air Conditioning Industry Association (hereinafter referred to as “JRAIA”).

The report also presents an overview of a project to establish a new concept and hypothesis for LCCP evaluation in which field data related to air conditioners is adopted.

Keywords: LCCP,Air-to-Air,Heat Pump,Next-Generation refrigerant,COP,Residential A/C

1. Introduction

The main issues of recent urgent environmental efforts to address global warming in relation to air conditioners (hereinafter referred to as “AC”) are the Kigali Amendment to the Montreal Protocol in globally, the F-Gas Regulation in Europe, and the Act on Rational Use and Proper Management of Fluorocarbons in Japan.

The Kigali Amendment is a regulation aimed at gradually reducing the production and consumption amounts of refrigerants used in CO2 equivalents. This regulation is a global warming countermeasure to be promoted worldwide by focusing on a transition to lower GWP refrigerants. For actual global warming countermeasures, it is important not only to reduce the GWP of the refrigerant, but also to improve the performance of equipment by reducing the amount of greenhouse gas emissions derived from power consumption.

Report of IEA gives an overview of the forecast of demand for residential AC cooling by 2050 by country/region based on the Future of Cooling report published by the International Energy Agency (hereinafter referred to as “IEA”) [1]. As can be seen, the chart indicates that the world’s demand for residential AC cooling will expand rapidly by 2050. The use of AC in the United States and Japan will increase at a gradual pace. On the other hand, due to growing demand in India, Indonesia, Brazil, China, and EU countries, the world’s AC demand is projected to rise considerably – by more than three times – by 2050.

It is anticipated that such an increase in AC demand will not only cause refrigerants to have a direct impact on global warming but also possibly give rise to an increase in the indirect impact on global warming due to the power consumption of AC equipment. Therefore, in addition to the direct impact of refrigerants, the energy efficiency and power consumption of equipment will become the focus of even greater attention in the years to come.

For this reason, we believe the LCCP evaluation to be studied in Task 3 is an important evaluation for selecting the most suitable refrigerants because it takes into account the transition to lower GWP refrigerants

Table 1. Comparison of Refrigerant Properties

	R410A	R32	R454C	R290	R22
Composition	R32/R125 (50/50 wt%)	Pure fluid	R32/R1234yf (21.5/78.5 wt%)	Pure fluid	Pure fluid
GWP	2090	675	148	3	1810
Safety Label	A1	A2L	A2L	A3	A1

and the environmental impact of power consumption. To make the evaluation more realistic, based on the concept of S+3E (Safety, Environment Performance, Energy Efficiency, Economic Feasibility) advocated by JRAIA, it is desirable to conduct a comprehensive evaluation from multiple perspectives, including safety, cost, sustainability, and infrastructure development, in addition to environmental assessment through the LCCP evaluation.

The study conducted by JRAIA in December 2008 [2] is introduced as a previous case study relating to the LCCP evaluation. The LCCP evaluation in this case was based on a simplified simulation, with climate and other conditions set in accordance with Japanese Industrial Standards (hereinafter referred to as “JIS”).

There is also a case study concerning IEA-related LCCP evaluation, which was presented by the University of Maryland in the United States (hereinafter referred to as “UMD”) [3]. In this paper, mainstream residential ACs in the United States are evaluated; therefore, it is necessary to conduct an evaluation for the split-type heat pump ACs that are in conventional residential use in Japan and Asia.

Accordingly, in Japan, a new LCCP evaluation is carried out in two steps for heat pump-type ACs that use next-generation refrigerants. The first step (this report) examines the LCCP evaluation methods, and the second step to be implemented in the future will mainly describe a new evaluation applying performance simulation and the concept and hypothesis of the study utilizing market data.

In the evaluation in this report, a representative model of typical split-type ACs is selected, and refrigerants R290, R32, R454C, R454C, R22, and R410A are examined. Since the indirect impact of power consumption varies significantly depending on the market and factors such as climate condition and lifestyle, the first step evaluates this under the standard conditions in Japan. The performance evaluation method verified jointly by JRAIA and Waseda University is used. As the second step, evaluation will be conducted on the basis of the possibility of the application of actual market data that varies according to local climate conditions, and Report 2 will explain the established concept and hypothesis about this approach.

2. Concept of LCCP Evaluation

This chapter explains the concept of the LCCP evaluation. Basically, the calculations of LCCP are carried out in accordance with the guidelines published by the International Institute of Refrigeration (hereinafter referred to as “IIR”) [4]. The components to be evaluated for LCCP are shown in the report of IIR [4].

This chapter describes how to calculate the amount of refrigerant charge and annual energy consumption.

Table 2. Comparison of Theoretical COP

		Cooling					Heating				
		R410A	R32	R454C	R290	R22	R410A	R32	R454C	R290	R22
Evaporating Pressure	MPa	1.087	1.107	0.591	0.637	0.681	0.799	0.813	0.432	0.474	0.498
Condensing Pressure	MPa	3.067	3.141	1.691	1.713	1.943	2.142	2.190	1.177	1.218	1.355
Temperature glide	K	0.1	0.0	5.6	0.0	0.0	0.1	0.0	6.2	0.0	0.0
Suction Temperature	°C	15.1	15.0	18.5	15.0	15.0	5.1	5.0	8.7	5.0	5.0
Discharge Temperature	°C	71.6	84.3	59.4	58.5	71.7	55.4	67.7	44.5	43.8	56.1
Theoretical COP	-	5.49	5.63	6.02	5.88	5.94	6.72	6.58	7.93	7.61	7.27
Volume Capacity	kJ/m^3	6,404	7,045	3,700	3,737	4,456	5,516	5,749	3,450	3,478	3,826

*Condensing temperature Cooling50/Heating35°C,

Evaporation temperature Cooling10/Heating0°C,

Suction superheat 5K, Sub-cooling 10K

Saturation temperature of zeotropic refrigerants is midpoint temperature of two -phase region under constant pressure.

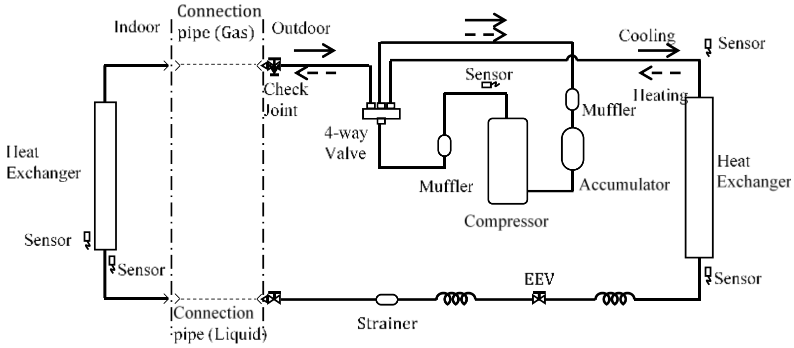


Figure 1. Refrigerant circuits for Split type Air conditioner

2.1. Concept of Candidate Refrigerants

This section explains the concept of candidate refrigerants for examination in the LCCP evaluation in this project.

The candidate refrigerants include R410A, a pseudo- azeotropic refrigerant mixture of an HFC refrigerant, and R32, an HFC single refrigerant, both of which are used in current AC units. In addition, R454C was selected as a zeotropic mixture of HFO and HFC refrigerant with relatively large temperature glide, which is attracting attention as a low-GWP refrigerant. We also selected the natural refrigerant R290, which has a lower operating pressure than R410A and R32, and the HCFC refrigerant R22, which is still adopted in many current ACs in emerging nations and is an important refrigerant for comparison with R290.

Table 1 shows the properties of each refrigerant [5] and Table 2 shows the theoretical COP calculated based on the thermodynamic properties of the refrigerants.

As described above, five refrigerants were selected for the study from the perspective of comprehensively covering the properties of the next-generation refrigerants in relation to system performance: R410A, R32, R454C, R290, and R22.

2.2. Examined AC and Performance Simulation

The AC to be examined is a split-type heat pump AC. Widely distributed ACs are diverse according to the manufacturer and development year; therefore, in this project, we decided to examine a residential AC for which JRAIA defined the standard specifications.

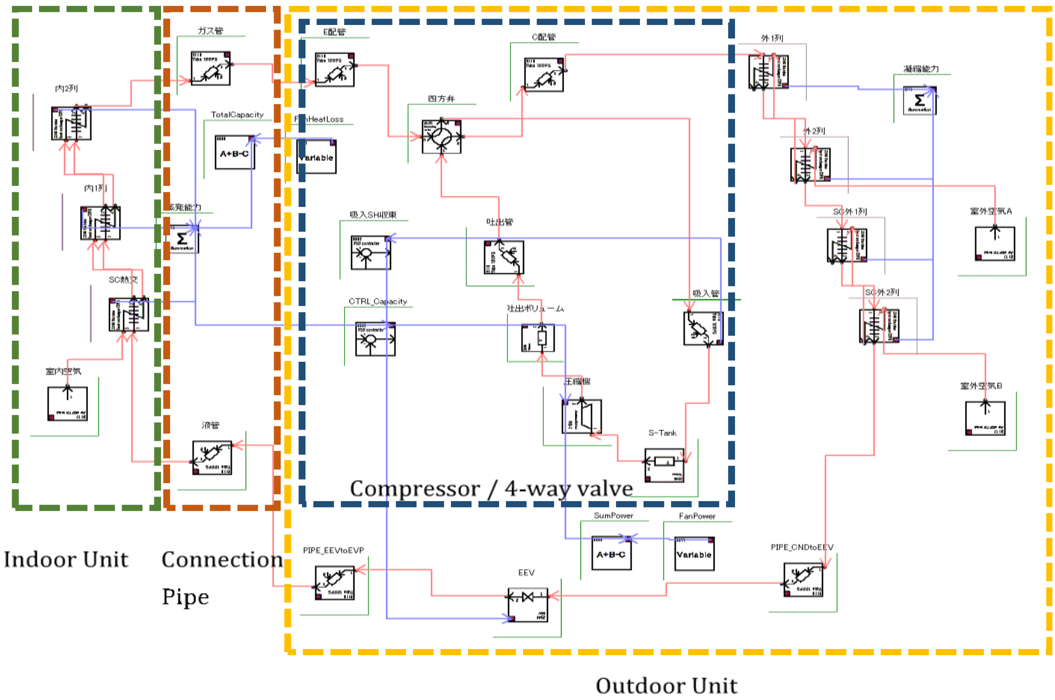


Figure 2. Project Layout for Standard model

Table 3. Calibration results of Standard model

		Cooling		Heating	
		Actual	Calculated	Actual	Calculated
Capacity	%	100	95	100	99
Power consumption	%	100	111	100	102

More specifically, the selected AC is equivalent to a high-end unit, and an analysis model (standard model) with a rated cooling capacity of 4kW was created for the examination. An overview of the AC's refrigerant circuits is shown in Figure 1.

The performance simulation was conducted using the simulation software Energy Flow +M, which was developed by Professor Saito's Laboratory at Waseda University and is used by JRAIA as a standard tool. Figure 2 shows the refrigerant circuit diagram of the standard model constructed with this performance simulation software.

To examine this standard model with greater accuracy, a comparative verification was made between the performance simulation results and the actual equipment test results for the case where the R410A was used for operation. Table 3 shows a comparison with the actual equipment test results. To implement more advanced performance simulation, each element device consisting of the refrigeration cycle was calibrated so that both the capacity and power input in Table 3 have an accuracy of ±10%.

2.3. Performance Simulation Conditions

This section describes the calculation conditions for performance simulation shown in Table 4.

The performance test conditions for ACs have been evaluated by means of JIS C 9612 (2013). Its performance evaluation method is carried out through a relative comparison under the predetermined conditions for the balance point (condensation and evaporation temperatures, suction superheating degree, and subcooling degree), which is the operating status point.

AC performance is evaluated by calculating an Annual Performance Factor (hereinafter referred to as "APF"). To calculate the APF, operation modes are set for each of cooling and heating, and the capacity is set for each of the test conditions and a Coefficient of Performance (hereinafter referred to as "COP") is calculated. AC performance is evaluated based on a relative comparison using the APF.

These evaluations are conducted for each case of using a single refrigerant and using an azeotropic (including pseudo-azeotropic) refrigerant mixture, and for the latter performance is evaluated using a technique called the "cycle midpoint protocol (boiling point/dew point)" as specified in JIS B 8623 (2019), which defines condensation and evaporation temperatures.

In addition, the expansion valve opening degree is adjusted so that the suction superheating degree (= compressor suction gas temperature – saturation temperature in compressor suction gas) is 5°C, and performance is evaluated using the same methods described above. Regarding the subcooling degree, the amount of refrigerant charge is adjusted so that the maximum COP is achieved for each refrigerant.

Table 4. Calculation conditions

TEST		Cooling	Heating
Air Entering of Indoor unit	Dry Bulb[°C]	27.0	20.0
	Wet Bulb[°C]	19.0	15.0
Air Entering of Outdoor unit	Dry Bulb[°C]	35.0	7.0
	Wet Bulb[°C]	24.0	6.0
Cycle Point	Capacity	Same at each operation point	
	SH	5.0 K at Suction Temperature	
	SC	At Optimum Performance	

2.4. *Calculation of LCCP*

Basically, LCCP is calculated in accordance with the guidelines published by the IIR.
The calculation methods for the amount of refrigerant charge, annual energy consumption, and other items are arranged and implemented as follows.
(1) Equipment: JRAIA AC standard model (H/P split type) equivalent to high-end unit with a rated cooling capacity of 4kW
(2) Tool: JRAIA standard tool Energy Flow +M (Prof. Saito's Lab at Waseda University)
(3) Comparison: Optimization is performed for each refrigerant to calculate the amount of refrigerant charge and the annual energy consumption.
(4) Selection of refrigerant types: Five refrigerants (R410A, R32, R454C, R290, and R22) were selected based on the above-mentioned concept.
(5) Calculation conditions: As described above, the power consumption in a refrigeration cycle with the same capacity is calculated under the conditions shown in Table 4.

3. LCCP Evaluation Conditions and Specifications

This chapter describes the evaluation conditions and specifications for LCCP.

3.1. *Definitions of LCCP Equations:*

The definitions of the LCCP equations are stipulated as the LCCP evaluation conditions. LCCP is calculated by obtaining the sum of the direct and indirect emissions according to the method proposed by Dr. Hwang of UMD [3]. The method of calculating the direct emissions is shown in Equation (1). Indirect emissions are calculated using Equation (2). The following is a brief summary of the LCCP calculation.

$$\mathrm{LCCP} = Direct\ Emissions + Indirect\ Emissions$$

$$Direct\ Emissions = C \times (L \times ALR + EOL) \times (\mathrm{GWP} + Adp.\mathrm{GWP}) \quad (1)$$

$$\begin{aligned} Indirect\ Emissions = \ & L \times AEC \times EM + \sum(m \times MM) + \sum(mr \times RM) \\ & + C \times (1 + L \times ALR) \times RFM \\ & + C \times (1 - EOL) \times RFD \end{aligned} \quad (2)$$

The symbols in the evaluation equations are shown in Table 5.

Table 5. Symbol Description

C	kg	Refrigerant Charge
L	yr	Average Lifetime of Equipment
ALR	% of Ref. Charge	Annual Leakage Rate
EOL	% of Ref. Charge	End of Life Refrigerant Leakage
GWP	$kgCO_2e/kg$	Global Warming Potential
$Adp.\ GWP$	$kgCO_2e/kg$	GWP of Atmospheric Degradation Product of the Refrigerant
AEC	kWh	Annual Energy Consumption
EM	$kgCO_2e/kWh$	CO2e Produced / kWh
m	kg	Mass of Unit
MM	$kgCO_2e/kg$	CO2e Produced / Material
mr	kg	Mass of Recycled Material
RM	$kgCO_2e/kg$	CO2e Produced / Recycled Material
RFM	$kgCO_2e/kg$	Refrigerant Manufacturing Emissions
RFD	$kgCO_2e/kg$	Refrigerant Disposal Emissions

Table 6. Assumption parameters used for LCCP calculation

Symbol	unit
C	kg
L	yr
ALR	% of Ref. Charge
EOL	% of Ref. Charge
GWP	$KgCO_2e/kg$
AEC	kWh
EM	$KgCO_2e/kWh$

3.2. *Influential Factors of LCCP:*

This section describes influential factors when calculating LCCP.

Table 6 summarizes the calculation items used in Equation 1 for the direct emissions and in Equation 2 for the indirect emissions in the LCCP calculation. Table 6 indicates that LCCP involves various influential factors. Therefore, when evaluating LCCP, it is necessary to clarify its influential factors and parameterize them for the study. There is particular concern that the evaluation may significantly differ depending on the country or region.

For example, with regard to energy conversion, since the power generation systems vary by country or region, the data that comes under Equation 1 for the direct emissions and Equation 2 for the indirect emissions are deemed to be influential factor parameters for energy conversion. By replacing these influential factor parameters as appropriate for each country or region, it is possible to estimate valid LCCP.

3.3. *Evaluation Applying Performance Simulation:*

To predict the performance of AC equipment, which will have a major impact on the LCCP evaluation, newly constructed performance simulation with improved prediction accuracy is used in the study.

Figure 4 shows the schematic configuration of the standard model used for performance simulation in this study. The standard model was created based on the specifications of a common commercially available heat pump AC.

In this study, to take into account the design concept for actual ACs, the performance is predicted assuming drop-in (hereinafter referred to as “DI”) and soft optimization (hereinafter referred to as “SO”) in the performance simulation. Specifications optimized with greater awareness of AC product capabilities (e.g., size equivalence and energy efficiency equivalence) are also examined. The DI evaluation in this study refers to performance evaluation where the same AC equipment is used but only the refrigerant is replaced. However, regarding equipment mounted with an inverter compressor and electronic expansion valve, the compressor frequency is changed (change of refrigerant mass flow rate) with the same AC capacity, and the expansion valve opening degree is changed with the same suction superheating degree. In addition, the SO evaluation refers to performance evaluation with minor modifications added on the AC’s hardware, such as changing the diameter of the connection pipe so that almost the same pressure drop occurs in the circuit even when different refrigerants are applied. Table 7 shows the concept of the assumed specification changes.

As shown in Table 7, compared with the base AC (a), in (b) the charged refrigerant (R410A) was changed, the refrigerant amount was adjusted to equalize the subcooling degree, and the compressor frequency was also changed to equalize the capacity before comparison. In (c), for the connection pipes of the liquid side and gas side that connect the indoor and outdoor units, the pipe diameter was optimized so that the pressure drop is equal to that of the current refrigerant. In (d), while maintaining the size of the heat exchanger, the path was changed to achieve the maximum efficiency. In (e), the size of the heat exchanger was changed to equalize the energy efficiency.

The refrigerant used for the base model is R410A.

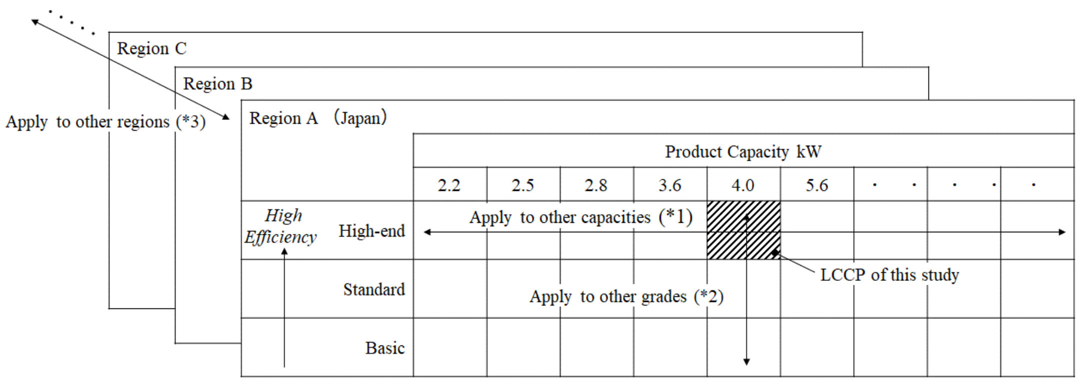
Based on these studies, the values for the refrigerant charge amount, C, and the annual energy consumption, AEC, which are factors affecting the LCCP evaluation, are calculated, and a comparative assessment is made using the obtained values.

Table 7. Specification of refrigeration cycle

		(a)	(b)	(c)	(d)	(e)
		Base model	Drop in	Soft optimization	Optimization (Same size)	Optimization (Same efficiency)
Outdoor unit	Row	2	←	←	←	Optimize
	Column	35	←	←	←	Optimize
	Cooling path	6-3-1	←	←	Optimize	Optimize
Indoor Unit	Row	3	←	←	←	Optimize
	Column	21	←	←	←	Optimize
	Cooling path	1-3	←	←	Optimize	Optimize
Connection pipes	Liquid	Φ6.35	←	Optimize (*1)	Same as (c)	Same as (c)
	Gas	Φ9.52	←	Optimize (*1)	Same as (c)	Same as (c)
Refrigerant charge [kg]		1.1	COP Maximum (*2)	COP Maximum (*2)	COP Maximum (*2)	COP Maximum (*2)
Capacity vs base model [%]		100	←	←	←	←
Expansion valve		As it is	Same as Base model SH	Same as Base model SH	Same as Base model SH	Same as Base model SH

※Note 1： Same as temperature-equivalent pressure drops of base model

※Note 2： Proposal under consideration



How to apply：

※Note 1, ※Note 2： Modify the simulation model (Figure 4)

※Note 3： Modify the assumption parameters (Table 6)

Figure 3. Outline of how to apply the LCCP of this study to various product specifications and global areas

4. Application of LCCP Evaluation and Consideration

With regard to the LCCP evaluation, this chapter formulates a hypothesis for the study with a view to the influential factors and the study of regions both in Japan and abroad, and describes a consideration of these.

4.1. *Key points of the Project in the LCCP Evaluation:*

Firstly, we will explain the key points of the project in the LCCP evaluation.

The LCCP evaluation is basically examined by utilizing field data in addition to the past study by JRAIA [2] and the paper by UMD [3].

The results of evaluation based on the actual operating conditions will be reported next time in the final report.

4.2. *Application of the Project's LCCP Evaluation*

The concept of the LCCP evaluation in this project is shown in Figure 3, and the following explains how to apply the evaluation and other matters. The final report of the project will classify and study the regional characteristics of ambient air temperatures and other influential factors in Japanese regions that affect the LCCP evaluation. Therefore, we will study the LCCP evaluation through this task, having in mind that other countries will be able to make broad and general speculation.

(1) Impact of equipment specifications

As explained in Chapter 4, the LCCP values in this project are calculated for the standard model based on a high-end AC unit with a cooling capacity of 4kW that is commercially available in Japan.

However, there is a wide variety of ACs on the Japanese market, and they are even more diversified in other countries. In our view, for such diverse equipment, it is possible to calculate the annual power consumption, namely the indirect emissions in the LCCP evaluation, by modifying the specifications in the refrigeration cycle simulation shown in Figure 2.

(2) Influence of regional characteristics

In addition to the modification of the equipment specifications mentioned in (1), the annual power consumption, namely the indirect emissions in the LCCP evaluation, also requires modifications of the estimation parameters according to environmental characteristics including the temperatures in the region, users' usage conditions, differences in power generation systems, and other factors.

For reference, Figure 6 shows a comparison of the changes of monthly average temperatures around the world in 2020. Climates vary depending on the assumed regional environment, which results in differences in the ambient air temperatures and humidity, operating hours, and required load. These differences strongly affect the annual power consumption during the use of an AC – the indirect emissions of LCCP. For example, in a region where ACs are required to operate throughout the year, annual power consumption is projected to increase throughout the life of the equipment. Regarding the load on the equipment, the higher the ambient air temperature during the cooling mode, the higher the condensing pressure in the refrigeration cycle, increasing the load on the compressor. The heat load entering the building from outdoors also increases, and the room temperature tends to rise; therefore, it is necessary to select an AC with a higher capacity.

Moreover, larger heat exchangers are required as the load increases, leading to the problem of an increase in the amount of refrigerant used. Therefore, it is anticipated that there will be demand for highly efficient refrigerants suitable for large capacity and other influences.

Figure 5 shows the composition of power generation systems in five countries in 2016. Power resources are classified into fossil fuels, such as petroleum, natural gas, and coal, and non-fossil fuels, such as hydraulic power, other renewable energies, and nuclear power, and they are compared in percentage terms. As indicated in Table 6, according to the resource of power generation means, LCCP is affected by EM, which is the amount of CO2 [kgCO2] generated per unit power consumption [kWh]. The EM varies greatly depending on the major power generation systems in each country. For example, in countries where the major systems are renewable energy power generation, such as hydraulic power, and nuclear power generation, the power consumed by

ACs will be unlikely to lead to CO2 emissions, and the indirect emissions will be negligible. On the other hand, in countries where power generation is mainly derived from fossil fuels such as petroleum and natural

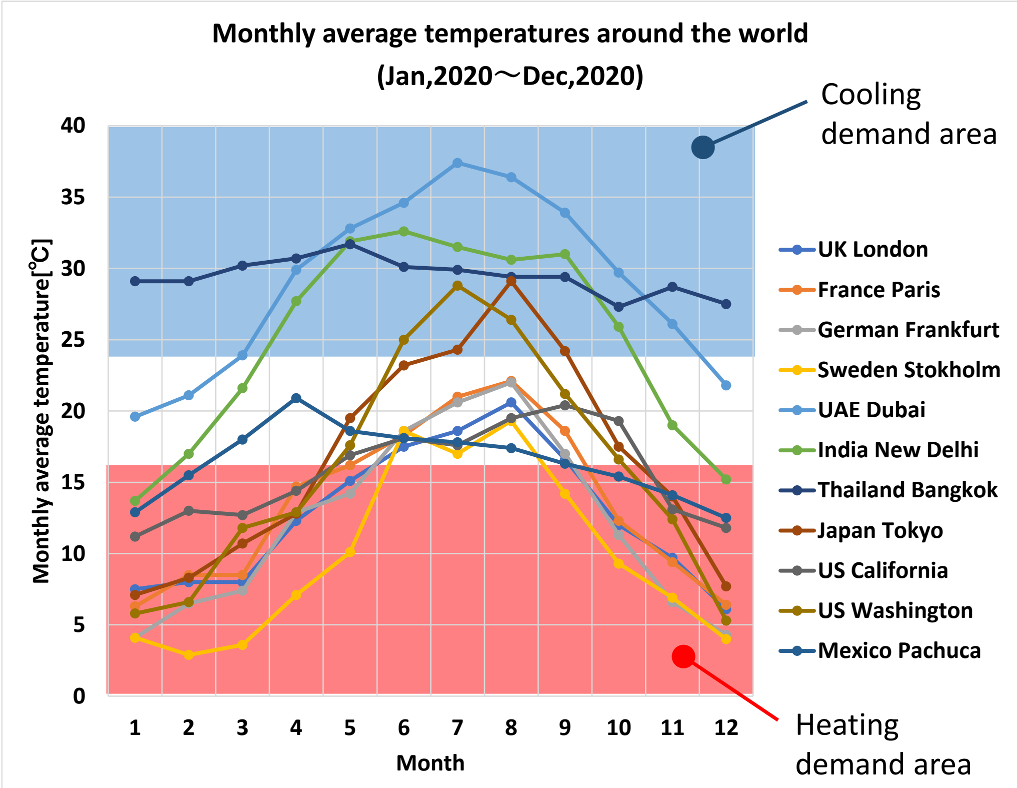


Figure 4. Example of Monthly average temperatures around the world

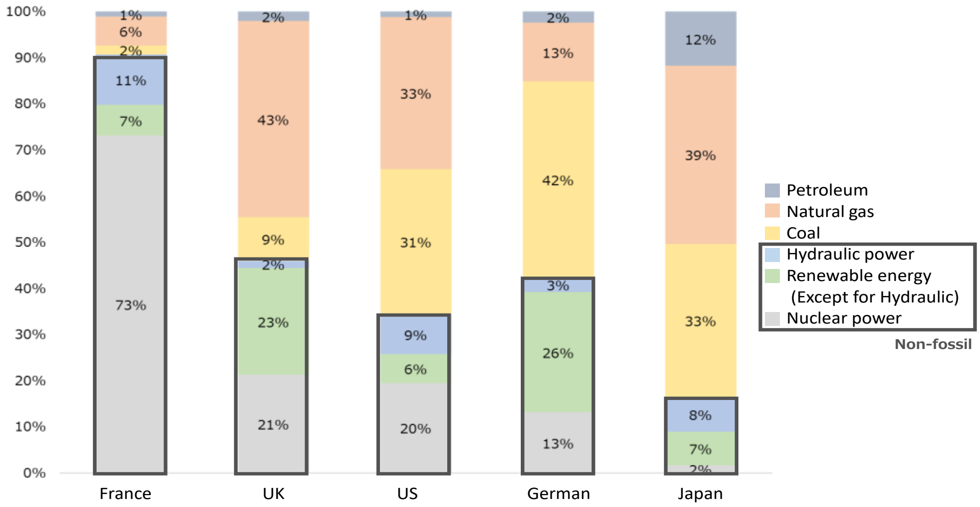


Figure 5. Comparison of non-fossil fuel power resource rates in 2016

gas, CO2 emissions from the use of AC becomes sensitive, and the indirect emissions of LCCP are strongly affected by the equipment efficiency and air-conditioning load.

Concerning the power generation systems, changes in the composition due to changes in power resource demand, shift to renewable energies and other factors may also need to be considered in future predictions.

In our view, by studying the basic values required for the LCCP calculation shown in Table 6, it is possible to apply the LCCP evaluation to the influential factors described above.

(3) Impact of the properties of various refrigerants

This section explains the concept concerning the LCCP evaluation methods for diverse candidate refrigerants.

As mentioned in Chapter 4 and this chapter, in this project, by utilizing new performance simulation with high accuracy and market data, the LCCP evaluation is expected to be closer to actual market conditions than the previous evaluation was.

The LCCP calculation for various refrigerants in this project is as described in Chapter 4. The method is to examine the factors that affect the LCCP evaluation of various refrigerants through SO or by optimizing the refrigerant circuit for each refrigerant.

For example, the values for the refrigerant charge amount, C, and annual energy consumption, AEC, which are considered major influential factors, can be calculated with high levels of accuracy. In terms of the calculation conditions, it is expected that LCCP for each refrigerant can be compared by reflecting market data and regional characteristics, such as climate and refrigerant recovery rate, which vary in different countries and regions.

5. Conclusion

In Japan, LCCP, LCCP evaluation is studied in a two-step process, and the concept (hypothesis) of the first step described in this report is summarized in the following bullet points:

- The concept (hypothesis) of the LCCP evaluation in this report was established by focusing on the consistency of the criteria of evaluation indicators.
- In the LCCP evaluation, a performance simulation evaluation will be carried out using JRAIA's standard tool (performance simulation program developed by Waseda University) to optimize the system in relation to candidate refrigerants.
- Performance evaluation will be carried out through a relative comparison for each refrigerant under the same capacity.
- A residential heat pump mini-split AC with a capacity of 4.0kW was selected as the standard model of AC equipment to be examined, and calculation will be performed.
- For the standard model, mutual correction will be made between the actual equipment test data and the performance simulation data.
- The calculation conditions of LCCP were clarified so as to share the same data recognition.

In addition, in the second step, the LCCP evaluation will be studied by utilizing the market data on ACs.

- Influential factors of the LCCP evaluation were clarified and parameterized so that the evaluation can be applied overseas.

Finally, the basic concept on the positioning of the LCCP evaluation in the selection of refrigerants is explained as follows.

We believe that the LCCP evaluation to be studied in Task 3 is one of the important criteria for selecting optimal refrigerants. We also feel that in order to make the evaluation more realistic, it is desirable to conduct a comprehensive evaluation from multiple perspectives, including safety, cost, sustainability, and infrastructure development, in addition to the environmental assessment through the LCCP evaluation.

6. Future Plans

Regarding issues and responses to be addressed in the second step in the future, we plan to verify the concept (hypothesis) of the LCCP evaluation described in this report.

Specifically, the study will be conducted based on the results of the performance simulation to optimize ACs. In addition, the utilization of market data will also be examined.

In the second step, we plan to study the LCCP evaluation not only for Japanese regions with a temperate climate but also, by utilizing market data, for other areas in the world such as India, where ACs are used more often.

Terminology

- **Life Climate Performance (LCCP)**: An index to evaluate the global warming impact of a product throughout its life, from manufacture to disposal. Based on the TEWI, the value is calculated by adding energy consumption (indirect emissions) when manufacturing the gas to be used and the leakage of the gas (direct emissions).
- **Global Warming Potential (GWP)**: Indicates the degrees of the global warming impacts of gases released in the atmosphere. On the basis of carbon dioxide (1.0), the same gas weight and same period (100 years) are assumed to allow relative comparisons of the impact of each gas. When the HFC refrigerant used for ACs is considered with the same gas weight, its GWP is generally hundreds to thousands of times greater than that of carbon dioxide; therefore, its significant impact on global warming is regarded as a problem.

- **Optimization**: In performance simulation, compared with the performance prediction made with conventional DI and SO, optimized performance prediction takes into account the design concept of an actual product; optimization is carried out by adjusting the component parts (piping, heat exchanger, etc.) of the refrigeration circuit so that their specifications conform to the refrigerant characteristics.
- **Performance simulation**: A method to estimate the power consumption of the target equipment under various operating conditions using Energy Flow +M (Prof. Saito's Lab at Waseda University), which is a standard tool of JRAIA. Used to calculate annual power consumption.
- **Coefficient of Performance (COP)**: A factor used as a measure of the energy consumption efficiency of cooling equipment, etc. The value represents cooling/heating capacity per kW of power consumption.
- **Total Equivalent Warming Impact (TEWI)**: A method to evaluate global warming impacts in comprehensive consideration of refrigerant leakage during equipment use, emissions into the atmosphere at the time of disposal, and the amount of carbon dioxide generated from fossil fuel usage due to operating power consumption. TEWI is expressed by the following equation.

TEWI = Direct CO2 emission equivalent + Indirect CO2 emission equivalent
Direct CO2 emission equivalent = $GWP \times L \times N + GWP \times M \times (1-\alpha)$
Indirect CO2 emission equivalent = $N \times E \times \beta$

GWP: Global warming potential per kg on the basis of CO2, 100-year integration period (kg-CO2e/kg)
L: Annual amount of leakage from equipment (kg/year)
N: Service life of equipment (years)
M: Amount of charge to equipment (kg)
α: Recovery rate at equipment disposal
E: Annual energy consumption of equipment (kWh/year)
β: CO2 emissions required for 1 kWh of power generation (kg-CO2e/kWh)

- CO2 emissions: Total of the amount of carbon dioxide generated from fossil fuel usage due to power consumption and the equivalent amount of carbon dioxide using GWP to the degree of the global warming impact of the gas released into the atmosphere.

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References

[1] The Future of Cooling - Opportunities for energy-efficient air conditioning, 2018, OECD/IEA
[2] Basic Policy of JRAIA on Global Warming Prevention Measures and LCCP-Analogy for HFO1234yf Air Conditioners using a Simulation with R134a Properties, International Symposium on New Refrigerants and Environmental Technology 2008, JRAIA
[3] Y. Hwang, et al, Harmonization of Life Cycle Climate Performance (LCCP) Methodology 2016. International Refrigeration and Air Conditioning Conference. Paper 1724.
[4] IIR LCCP Working Group, Guideline for life cycle climate performance 2015, IIR
[5] TEAP XX VII/4 TEAP Task Force Report, 2016
[6] The data from homepage tool "Climate View" by Japan Meteorological Agency https://www.data.jma.go.jp/cpd/monitor/climatview/frame.php
[7] The data from webpage "Energy circumstances of each country" The Figure made by Japan Agency for Natural Resources and Energy and the original data are from "IEA World Energy Balances" https://www.enecho.meti.go.jp/about/whitepaper/2019html/1-2-3.html