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

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Acknowledgements :Activity Members

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Contents

1.Introduction: Background & Purpose

■The main issues of recent urgent environmental efforts to address global warming in relation to air conditioners 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 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 reduce the amount of greenhouse gas emissions derived from power consumption by improving the performance of equipment.

■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 IEA.

- 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.

⇒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.

1.Introduction: Background,purpose

	1987	1997	2012	2016	2023 current
	•Montreal Protocol	•Kyoto Protocol	•Kigali Amendment		

CFC R12	HCFC R22	HFC R410A	HFC R32	NEXT?

To save Ozone Layer

	CFC R12	HCFC R22	HFC R410A	HFC R32	NEXT?
ODP	1.0	0.05	0	0	
GWP	10,900	1,810	2,090	675	Low

■Transition to the next-generation refrigerant is required.

■Purpose：

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

2. Concept of LCCP Evaluation:
2.1. Concept of Candidate Refrigerants

■The representative model is selected as an example of general split-type air conditioners.
■Consideration of evaluation are following :

1. Evaluation for a system drop-in tests of refrigerant replacement candidates:
2. Evaluation of system optimization:

■ 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 JRAIA .

● Table 1 shows the properties of each refrigerant.

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

2. Concept of LCCP Evaluation:

2.1. Concept of Candidate Refrigerants

■To make the evaluation of candidate refrigerants 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 LCCP evaluation in this case was based on a simplified simulation, with climate and other conditions set in accordance with Japanese Industrial Standards.
⇒It is necessary to conduct an evaluation for the split-type heat pump ACs (reversible air to air heat pumps) that are in conventional residential use in Japan and Asia.

2. Concept of LCCP Evaluation:
2.1. Concept of Candidate Refrigerants

■The new LCCP evaluation is carried out in two steps for heat pump-type ACs that use next-generation refrigerants in Japan.

1st Step :Examines the LCCP evaluation methods
- Evaluates under the standard conditions in Japan.

2nd Step : To be implemented in the future will mainly describe a new evaluation applying performance simulation

The concept and hypothesis of the study utilizing market data

- Educted on the basis of the possibility of the application of actual market data that varies according to local climate conditions.
- Report 2 will explain the established concept.

●Representative model of typical split-type ACs :R290, R32, R454C, R22, R410A are examined.

●The indirect impact of power consumption varies significantly depending on the market and factors such as climate condition and lifestyle.

●The performance evaluation method verified jointly by JRAIA and Waseda University is used.

2. Concept of LCCP Evaluation:

2.1. Concept of Candidate Refrigerants

■The analysis model (standard model) with a rated cooling capacity of 4kW was created for the examination.
■The selected AC is equivalent to a high-end unit.
⇒ 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.

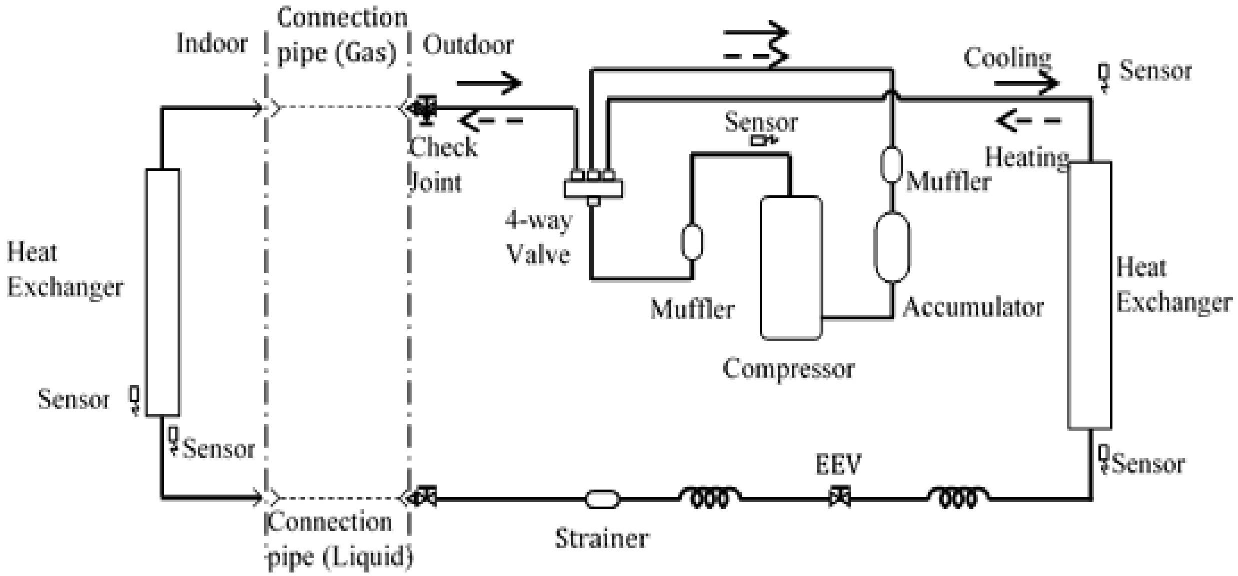


Figure 1. Refrigerant circuits for Split type Air conditioner

2. Concept of LCCP Evaluation:

2.1. Concept of Candidate Refrigerants

■The calculations of LCCP are carried out in accordance with the guidelines published by the International Institute of Refrigeration .

■The components to be evaluated for LCCP are shown in the report of IIR .
⇒**How to calculate the amount of refrigerant charge and annual energy consumption.**

●Table 2 shows the theoretical COP calculated based on the thermodynamic properties of the refrigerants.

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.

2. Concept of LCCP Evaluation :

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;
  ⇒We decided to examine a residential AC for which JRAIA defined the standard specifications.
- The performance simulation was conducted using the simulation software Energy Flow +M (Waseda University).
- Figure 2 shows the refrigerant circuit diagram of the standard model constructed with this performance simulation software.

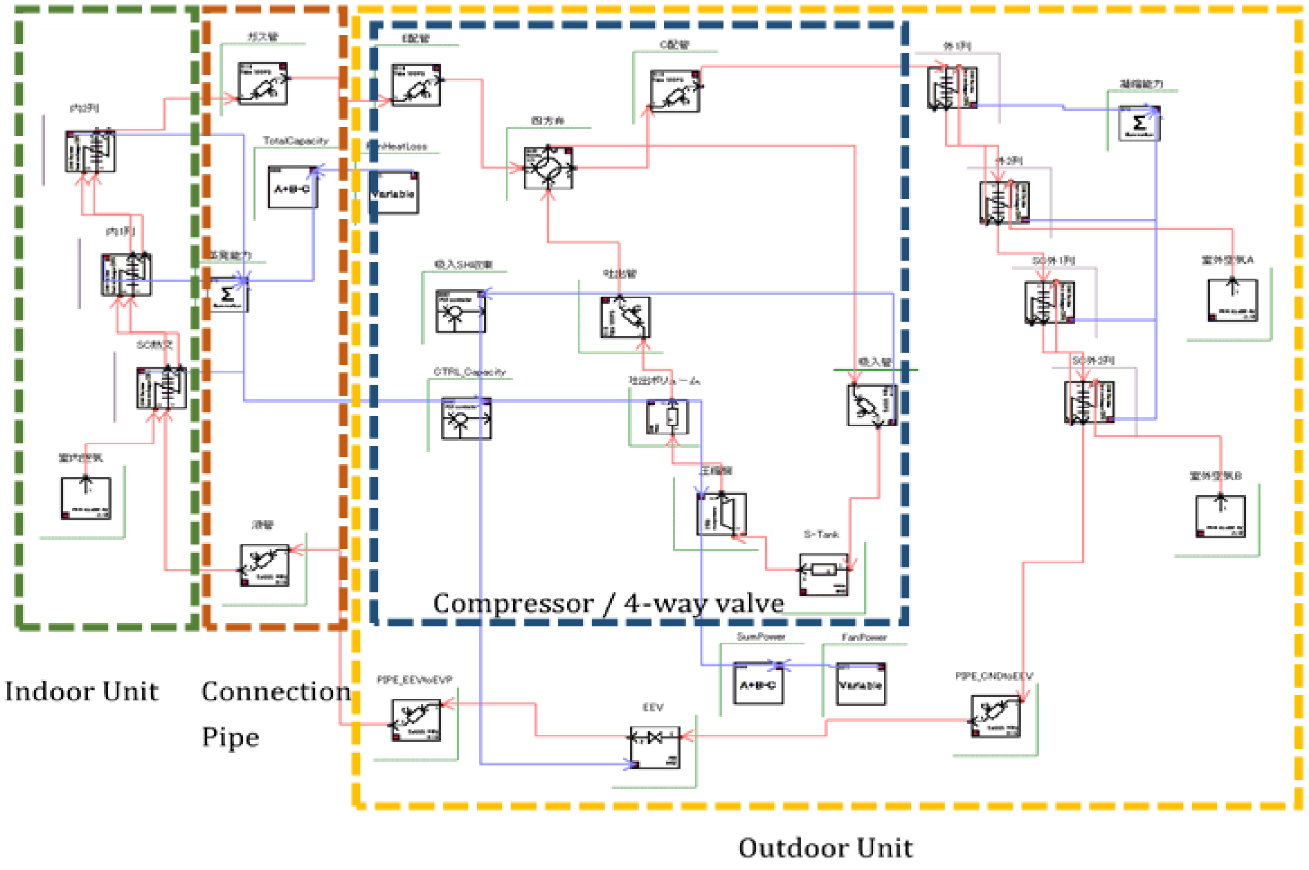


Figure 2. Project Layout for Standard model

2. Concept of LCCP Evaluation :

2.2. Examined AC and Performance Simulation

■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.

■To implement more advanced performance simulation, each element device of the refrigeration cycle was calibrated so that both the capacity and power input in Table 3 have an accuracy within ±10%.

●Table 3 shows a comparison with the actual equipment test results.

Table 3. Calibration results of Standard model

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

2. Concept of LCCP Evaluation:
2.3. Performance Simulation Conditions

■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 (Tc ,Te, SH and SC), which is the operating status point.

・AC performance is evaluated by calculating an Annual Performance Factor (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 (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 the 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.

・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(SC), the amount of refrigerant charge is adjusted so that the maximum COP is achieved for each refrigerant.

2. Concept of LCCP Evaluation ：

2.4. Calculation of LCCP

■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
(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.

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	

3. LCCP Evaluation Conditions and Specifications:

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 .
  ⇒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.

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

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

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

3. LCCP Evaluation Conditions and Specifications:
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.

⇒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.

⇒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.

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.LCCP Evaluation Conditions and Specifications:
3.3. Evaluation Applying Performance Simulation

■To take into account the design concept for actual ACs, the performance is predicted assuming drop-in (DI) .
■Soft optimization (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.
⇒Regarding equipment mounted with an inverter compressor and electronic expansion valve, the compressor frequency is changed with the same AC capacity, and the expansion valve opening degree is changed with the same suction superheating degree.

■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.

3.LCCP Evaluation Conditions and Specifications:

3.3. Evaluation Applying Performance Simulation

■Table 7 shows the concept of the assumed specification changes.

(a);Compared with the base AC

(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.

(c);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.

(d);While maintaining the size of the heat exchanger, the path was changed to achieve the maximum efficiency.

(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) Base model	(b) Drop in	(c) Soft optimization	(d) Optimization (Same size)	(e) 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

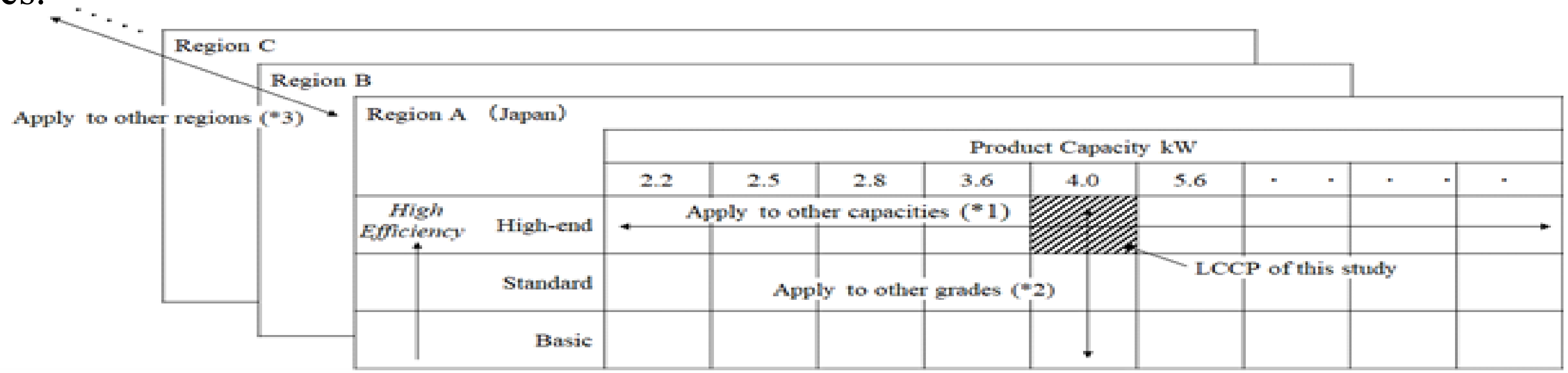
3.LCCP Evaluation Conditions and Specifications:

3.3. Evaluation Applying Performance Simulation

■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.

⇒We will study the LCCP evaluation through this task, having in mind that there may be technological spillovers from this research to other countries.



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

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

■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.

⇒We will explain the key points of the LCCP evaluation.
The LCCP evaluation is basically examined by utilizing field data in addition to the past study by JRAIA .

4. Application of LCCP Evaluation and Consideration

4.2. Application of the Project's LCCP Evaluation

(1) Impact of equipment specifications

・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.

・There is a wide variety of ACs on the Japanese market, and they are even more diversified in other countries.

・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

・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.

4. Application of LCCP Evaluation and Consideration

4.2. Application of the Project's LCCP Evaluation

(2) Influence of regional characteristics

- **Figure 4 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.**
  ⇒ 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 to the building from outdoors also increases, and the room temperature tends to rise.**
  ⇒It is necessary to select an AC with a higher capacity.
- **Larger heat exchangers are required as the load increases, leading to the problem of an increase in the amount of refrigerant used.**
  ⇒It is anticipated that there will be demand for highly efficient refrigerants suitable for large capacity and other influences.

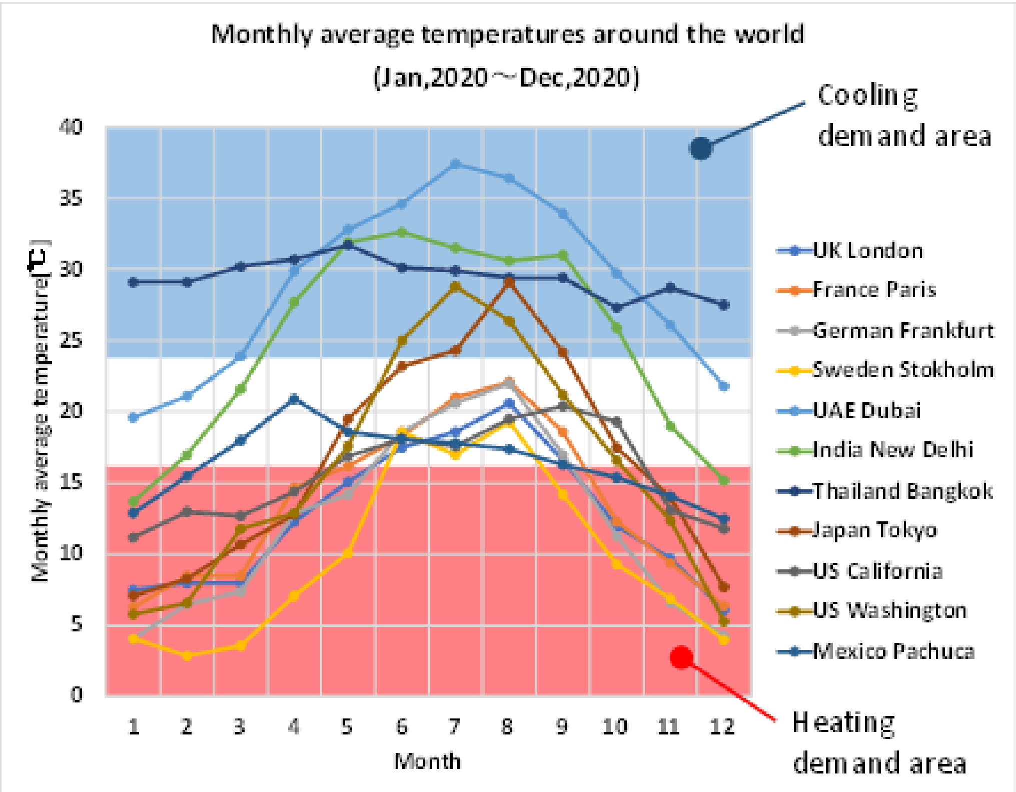


Figure 4. Example of Monthly average temperatures around the world

4. Application of LCCP Evaluation and Consideration

4.2. Application of the Project's LCCP Evaluation

● 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.

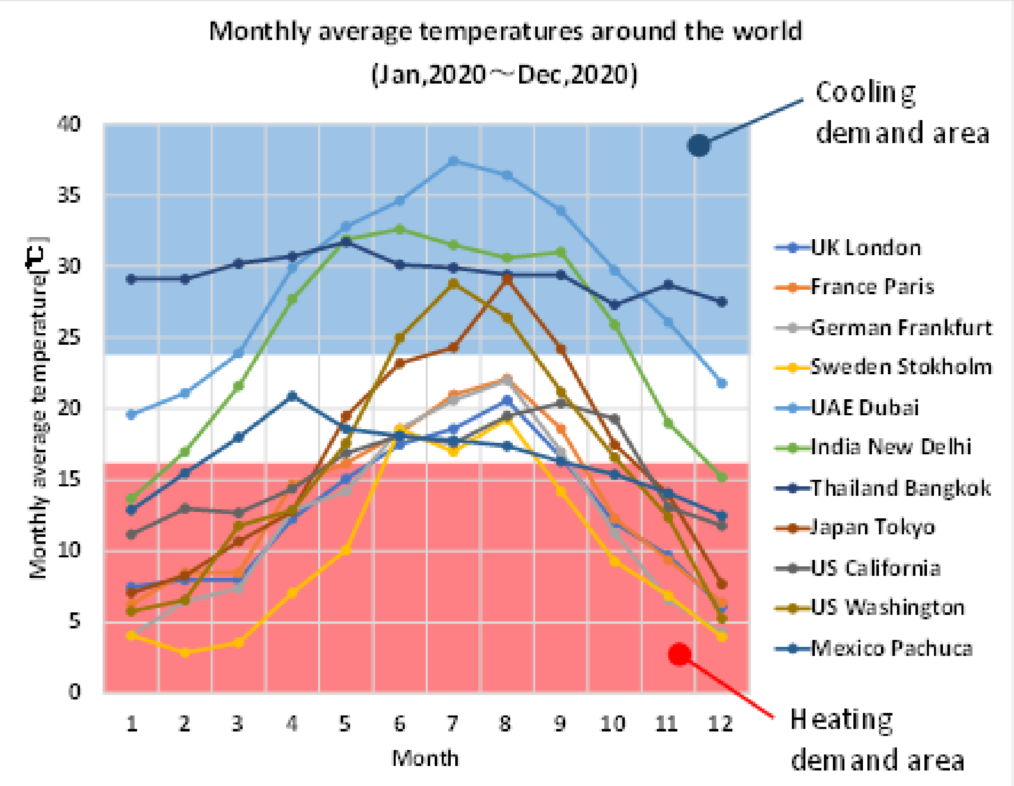


Figure 4. Example of Monthly average temperatures around the world

4. Application of LCCP Evaluation and Consideration

4.2. Application of the Project's LCCP Evaluation

- 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.

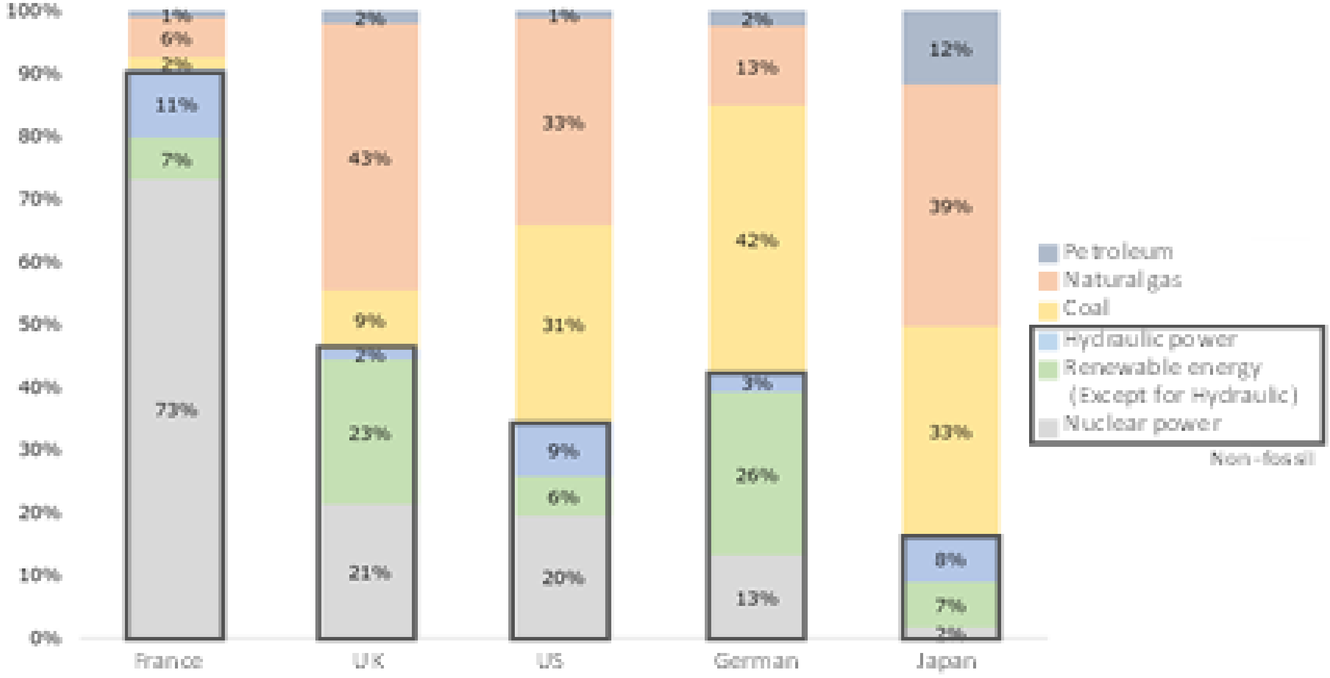


Figure 5. Comparison of non-fossil fuel power resource rates in 2016

※ https://www.enecho.meti.go.jp/about/whitepaper/2019html/1-2-3.html

4. Application of LCCP Evaluation and Consideration

4.2. Application of the Project's LCCP Evaluation

■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 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.

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	$KgCO_2e/kWh$

4. Application of LCCP Evaluation and Consideration

4.2. Application of the Project's LCCP Evaluation

(3) Impact of the properties of various refrigerants

・The concept concerning the LCCP evaluation methods for diverse candidate refrigerants.

・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 method for various refrigerants in this project is to examine the factors that affect the LCCP evaluation through SO or by optimizing the refrigerant circuit for each refrigerant.

・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.

⇒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 by country and region .

5.Conclusions

■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 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.

5.Conclusions

■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(IEA Annex54) is one of the important criteria for selecting optimal refrigerants.

■ We also feel that in order to make the evaluation of alternative refrigerants for AC equipment 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.**

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.

・The study will be conducted based on the results of the performance simulation to optimize ACs.

・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 other areas in the world as well.

Ex. India, where ACs are used more often.

・JRAIA Symposium2023

International Symposium on New Refrigerants and Environmental Technology 2023

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Thank you for your attention