Aerothermal Energy Use by Heat Pumps in Japan

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Summary

This paper quantifies the amount of aerothermal energy captured by heat pumps, which is categorized as renewable energy in the European Union. Although several assumptions have to be made, the designed COP leads to the estimation that 5,000 kTOE of aerothermal energy, which equals 40 % of the current renewable energy supply, was used in Japan for space heating in the residential and tertiary sector in 2007, accompanied by 4,800 kTOE of primary energy consumption incurred by electricity input to heat pumps.

While there still remain discussions as to whether the aerothermal energy can be conceptually defined as renewable energy, it can be physically regarded as renewable energy used by consumers without recognition through air conditioners equipped with heat pump technology. In Japan, heat pumps with an annual average COP exceeding 2.7 guarantee a reduction of primary energy consumption and those with a COP higher than 3.7 are able to capture more aerothermal energy than the primary energy they consume.

The improvement of heat pump performance means that a decrease in electricity input, which equates to energy efficiency, and an increase in captured energy are simultaneously achieved and the further improvement in COP is expected. It is, however, important to prevent misunderstanding by clearly describing electricity consumption along with aerothermal energy or by subtracting electricity consumption from aerothermal energy, when aerothermal energy is treated as renewable energy. As the actual performance in situ of a heat pump differs from the designed performance, the actual COP should be monitored and assessed for improvement in the method of aerothermal energy estimation. The EU is currently deliberating the establishment of a methodology for collecting heat pump data statistics and a guideline for estimating the heat captured by a heat pump, in accordance with the "Directive on the promotion of the use of energy from renewable sources, April 2009," known as the EU Renewable Energy Directive. Japan also needs to establish a guideline taking into account the characteristics of Japan's climate conditions, energy consumption and heat pump market.

Introduction

In 2009, the EU Renewable Energy Directive stipulated the inclusion of aerothermal and hydrothermal energy in the category of renewable energy in addition to geothermal energy. Since these thermal energies existing in the environment can be used more effectively by heat pumps than

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by direct use, heat pump technology is drawing larger attention in Europe. The EU set the target of 20 % of final energy demand coming from renewable energy sources by 2020, and targets for thermal energies are also identified in the action plans of member countries. In Japan also, the law on the Promotion of the Use of Non-fossil Energy Sources and Effective Use of Fossil Energy Source Materials by Energy Suppliers (July 2009) stipulates the thermal energy (ground heat, aerothermal energy and hydrothermal energy) used by energy suppliers as renewable energy sources.

Japanese heat pumps, with their state-of-the-art technology, have been and are categorized in the energy efficiency sector. Regardless of the difference between Japan and the EU in the background and recognition that heat pumps are energy efficiency technology or technology using a renewable energy source, heat pumps can contribute to a reduction of fossil fuel consumption if the annual average performance is high enough.

Although it is inferred that a great amount of aerothermal energy is used in Japan, no studies on the estimation of aerothermal energy have been seen, and issues concerning how aerothermal energy is regarded as a renewable energy source are not being clearly discussed. This study clarifies the viewpoints on categorizing aerothermal energy into renewable energy and estimates the amount of aerothermal energy captured by heat pumps, which is compared with other renewable energy sources. The issues for improvement in estimation are also addressed.

1. How Aerothermal Energy Can be Regarded as Renewable Energy

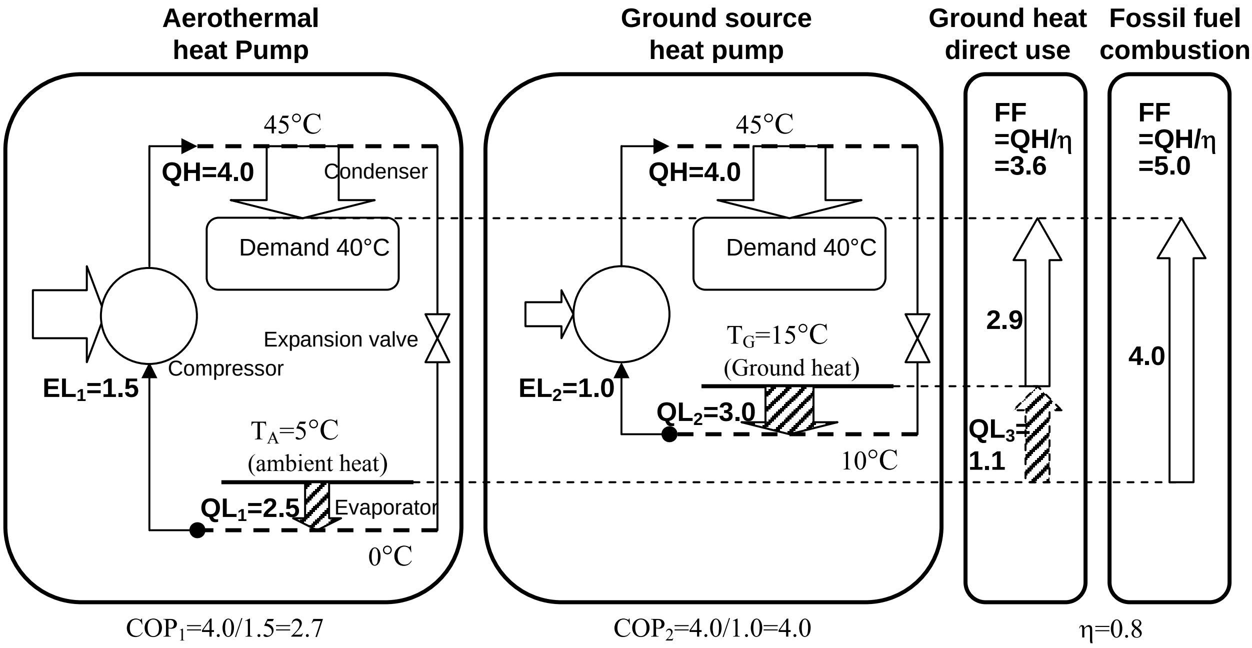
1-1 Principle of The Heat Pump

Aerothermal energy, unlike geothermal (ground heat source) and hydrothermal energy, has the same temperature as the environment and does not contain energy that can be extracted without any work on it. The following shows the mechanism by which aerothermal energy can be transformed to useful energy only by means of heat pump technology.

Four systems used as heat supply for space heating and water heating are compared in Fig. 1-1: the fossil fuel combustion boiler, ground heat direct use, ground heat use by electrical heat pump and aerothermal energy use by electrical heat pump. When heat QH = 4.0 (at 40°C) is needed, 5.0 of fossil fuel is consumed in the fossil fuel combustion boiler with a thermal efficiency of 80% (rightmost of Fig.1-1). If ground-thermal energy (15°C) is used when the ambient temperature is 5°C, the fossil fuel can be reduced to 3.6 (=4.0×25/35/0.8). The ground heat is expressed as QL_3.

The heat pump is a technology that lowers the refrigerant temperature below the ambient temperature through an expansion valve, absorbs the heat from the ambience and elevates the refrigerant temperature, by compressing, to a temperature higher than the demand temperature. An aerothermal heat pump can absorb the heat QL_1 by inputting energy EL_1 and supply the heat QH ($=QL_1+EL_1$) to the demand (leftmost in Fig.1-1). The most remarkable feature of aerothermal energy use by a heat pump is that the originally useless aerothermal energy can be transformed into valuable energy by promoting heat transfer (QL_1) with the help of energy input, which otherwise could not happen. In the case of a ground source heat pump, since the ground heat temperature is higher than the ambient temperature, the heat pump can absorb heat more easily than an aerothermal heat pump, leading to greater heat captured (QL_2) and a decrease in electricity consumption (EL_2).

Fig. 1-1 Comparative Illustration of Different Heat Supply Systems



Note : FF is fossil fuel, η the efficiency of the fossil fuel combustion boiler, and COP the coefficient of performance of the heat pump. Numerical values are just examples and there is no theoretical consistency between temperature and heat quantity.

It is evident that QL_3 is regarded as renewable energy, since the ground heat has a different temperature than the ambient temperature and is evaluated as valuable. However, when the heat pump is used, it becomes very difficult to interpret which energy is to be regarded as renewable energy. In the case of ground heat use by the heat pump, there are mainly two interpretations, one of which is that the only amount corresponding to the heat existing in the natural state (QL_3) is renewable energy, based on the concept that QL_2 is the amount that can be captured only if the heat pump is used, and the other one is that the total of QL_2 is renewable energy. According to the former interpretation, the aerothermal energy that is not available as it is can not be regarded as renewable energy. On the other hand, the latter interpretation leads to the conclusion that the aerothermal energy is also renewable energy. In any case, unlike ground heat, aerothermal energy can be used only if heat pump technology works on it.

The performance index of the heat pump, COP (Coefficient of Performance), is expressed in the case of heating supply as [heat supplied by the heat pump]/[energy input to the heat pump] (=QH/EL). The COP of a ground heat pump (COP_2) is in general 30 to 50 % higher than that of an aerothermal heat pump.

In the case of using the heat pump for heating supply, the heat supplied by the heat pump equals the sum of energy input to the heat pump and the energy captured by the heat pump, so the energy flow of the heat pump is similar to that of a biomass mixing combustion system that adds biomass to fossil fuel for incineration.

1-2 Types of Heat Pumps

The thermodynamic cycle of the heat pump with all types of heat source is categorized principally into two cycles: the vapor-compression cycle and the absorption cycle. The heat pump shown in section 1-1 uses the vapor-compression cycle, capturing and releasing heat by compressing, condensing, expanding and evaporating the refrigerant. The absorption cycle uses the characteristics of refrigerant vapor, whose solubility in a solution varies depending on the temperature. Heat, including gas combustion heat, exhaust heat, and solar heat, is generally used for the driving source of an absorption heat pump. The energy input to and output from a vapor-compression cycle heat pump is the driving source necessary to operate the heat pump (EL), the heat captured from the low temperature heat source (QL) and the heat released from the heat pump to the high temperature heat source (QH). Electric power is the most dominating driving source in the market, though gas engines are also used.

The heat pump is defined precisely as a machine for heating purposes, and the machine for cooling purposes is called a refrigerating machine. Residential and commercial air conditioners use a reversible cycle heat pump which can operate for both heating and cooling purposes.

Table 1-1 shows heat pumps by type of cycle. The most widely used vapor-compression heat pump is the air conditioner for residential and commercial use. Most of the vapor-compression heat pumps in Japan use aerothermal energy, while few installations in commercial buildings use ground heat or hydrothermal energy.

The absorption cycle is mainly used for absorption refrigerator and absorption cooling and heating systems in commercial buildings. The principal driving source is combustion heat from city gas and other fossil fuels, but exhaust heat from co-generation systems is also used.

In addition, refrigerators, freezers, dehumidifiers, vending machines, car air conditioners and recent clothes dryers also use heat pump technology.

Table 1-1 Types of Heat Pumps

Thermodynamic cycle	Equipments
Vapor-compression	Air conditioning: room air conditioner, commercial air conditioner turbo freezer, gas engine heat pump air conditioner Water heating: heat pump water heater (residential and commercial use) Refrigeration & freezing: refrigerator, freezer, vending machine
Absorption	Air conditioner: absorption refrigerator, absorption cooling and heating system

Fig. 1-2 classifies heat pumps by cycle, heat source and end use. The amount of aerothermal energy in the residential and tertiary sector, which presumably accounts for a large part of aerothermal energy in Japan, will be estimated in the latter part of this study.

Fig. 1-2 Classification of Heat Pumps and Category for Estimation (Shaded Area)

		Vapor compression		Absorption
		Aerothermal	Hydrothermal Groundthermal	
Air conditioning	Residential	Scope of this study		
	Tertiary			
Water heating	Residential			
	Tertiary			

1-3 Viewpoints in Estimation of Heat Captured by Heat Pump

There are some issues to be discussed in order to categorize the heat captured by heat pumps into renewable energy, such as which end-use purpose is covered and what is the criterion for a COP that can realize net energy consumption reduction. These issues are addressed in this section based on the vapor-compression heat pump technology, which is dominating the market. All kinds of heat sources are covered.

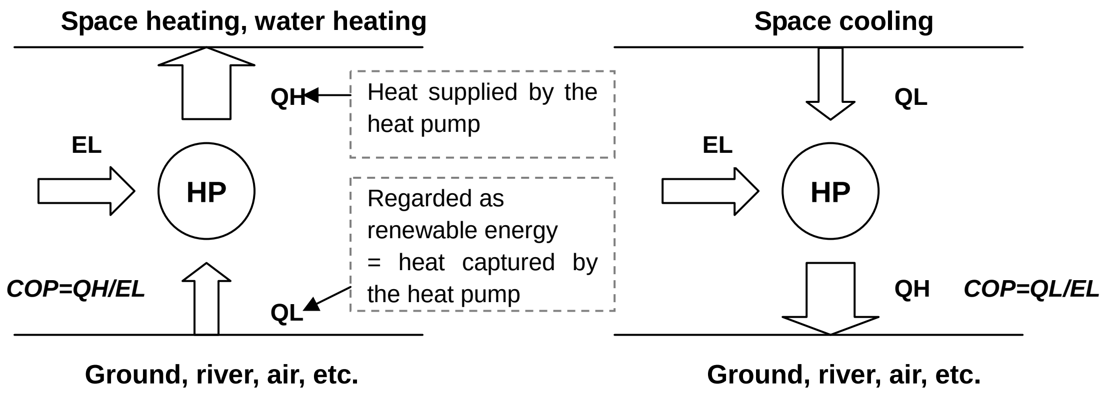
1-3-1 Driving Source

The driving source is not always electric power, and the gas engine can also be included. However, since the market share of heat pumps driven by a gas-engine is small, this study does not cover this type of heat pump.

1-3-2 Scope of End Use

In the case of use for heating purposes, the heat captured by a heat pump (QL) can be counted as renewable energy, regardless of the heat source (left of Fig.1-3). However, in the case of use for cooling purposes, heat flows reversibly and the heat released (QH) to the high temperature source (ground, water, ambient) can not be regarded as renewable energy since this heat includes electricity input (right of Fig.1-3). The removed heat (QL) also can not be regarded as renewable energy, because this heat is identified as cooling demand.

Fig. 1-3 Energy Flow of a Heat Pump



Although the EU Renewable Energy Directive in 2009 covers renewable energies for heating and cooling, the heat estimation formula for a heat pump (as described later) stipulated in this directive is applicable only to heat pumps for heating purposes.

1-3-3 Minimum Standard for COP

For the sake of simplification, the following addresses only electric heat pumps for heating purposes. As a heat pump always needs energy input to drive itself, the reduction effect of primary energy depends on the magnitude of the relation between the heat captured by the heat pump and the energy input to the heat pump.

The energy balance and COP in Fig.1-3 are expressed as (1) and (2), and the COP for heating necessarily exceeds 1.0.

$$QH = EL + QL \tag{1}$$

$$COP = \frac{QH}{EL} \quad \text{(for heating)} \tag{2}$$

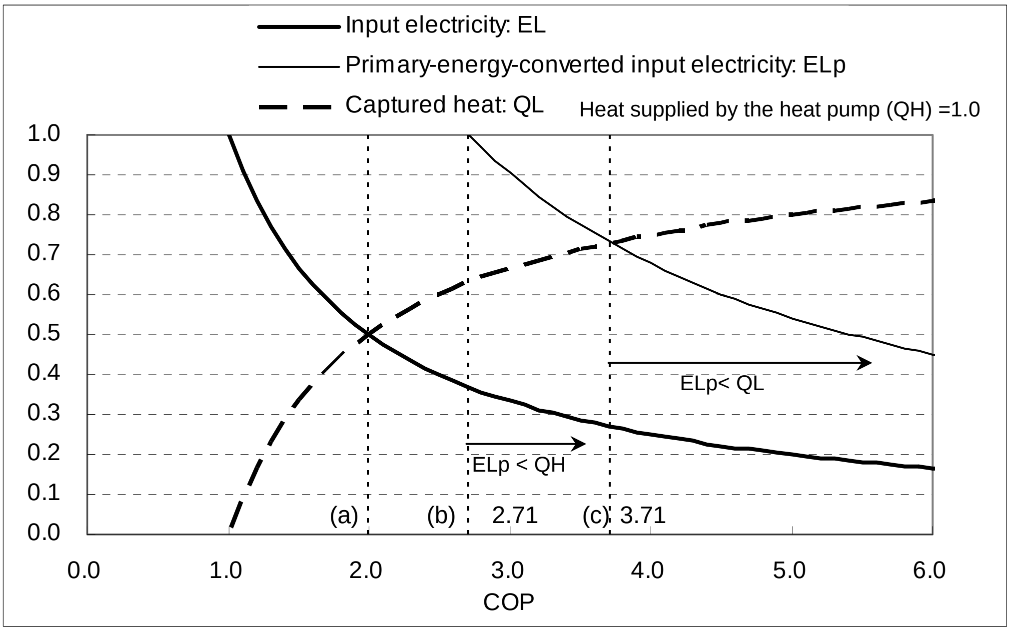
The minimum standards which COP should exceed are described below.

(a) Input electricity < captured heat

[EL<QL : COP>2] (See Fig.1-4)

This is the requirement that captured heat (QL) should exceed the electricity input to the heat pump (EL), which means that the COP should be higher than 2.0 according to equations (1) and (2). This is a sine qua non condition.

Fig. 1-4 COP, Electricity Input and Captured Heat in Case of Heating Operation



Note : Figures are normalized by heat supplied from HP (QH=1.0). The primary energy conversion factor of electricity is assumed to be 9.76 kJ/kWh (η_g=3.6/9.76=0.369) in Japan.

(b) COP based on the primary-energy-converted electricity > 1

[COP*η_g>1] (See Fig.1-4)

This requirement means that the primary-energy-converted COP should exceed 1.0 (η_g is power generation efficiency, which is 0.369 (=9.76 kJ/kWh) in Japan according to the Energy Conservation Law). Meeting this criterion guarantees that the replacement of a conventional fossil combustion boiler with a heat pump can necessarily realize a reduction in primary energy consumption. The criterion is expressed as "COP > 2.71" in Japan. However, this requirement does not always mean that captured heat exceeds the primary-energy-converted electricity input into the heat pump.

(c) Primary-energy-converted input electricity < captured heat

[EL/η_g<QL : COP>1+1/η_g] (See Fig.1-4)

This is the most stringent requirement that the captured heat should exceed the primary-energy-converted electricity input into the heat pump. The criterion is expressed as "COP > 3.71" in Japan. The net energy balance of a heat pump with a COP higher than this threshold always becomes positive.

(d) Concept in the EU

The EU Renewable Energy Directive 2009 stipulates a formula below to calculate the energy captured by a heat pump, in which the minimum performance standard (annual average of COP) of the heat pump is specified.

$$E_{RES} = Q_{usable}*(1-1/SPF)$$

－Q_{usable} is the heat supplied by the heat pump. Only heat pumps for which SPF > 1.15*1/η are taken into account. η is the power production efficiency and is calculated as an EU average based on Eurostat data.

－SPF is the "Seasonal Performance Factor" (APF [Annual Performance Factor], used for air conditioners in Japan, is the average performance factor for the total of heating and cooling).

E_{RES} and Q_{usable} are identical to QL and QH in this paper, respectively, and replacing COP in equations (1) and (2) by SPF yields the formula above. It should be noted that this formula can be applicable only to heat pumps for heating supply, but not to cooling supply (in the case of cooling, QH= (1+1/COP)*QL).

The EU's criterion is interpreted as 15 % more stringent than requirement (b). If SPF > 1.15*1/η is applied in Japan, the threshold of COP becomes 3.12, milder than condition (c).

By January 2013, the Commission of EU will establish guidelines on how member states are to estimate the values of Q_{usable} and SPF for different heat pump technologies and applications, taking into consideration differences in climatic conditions, especially very cold climates.

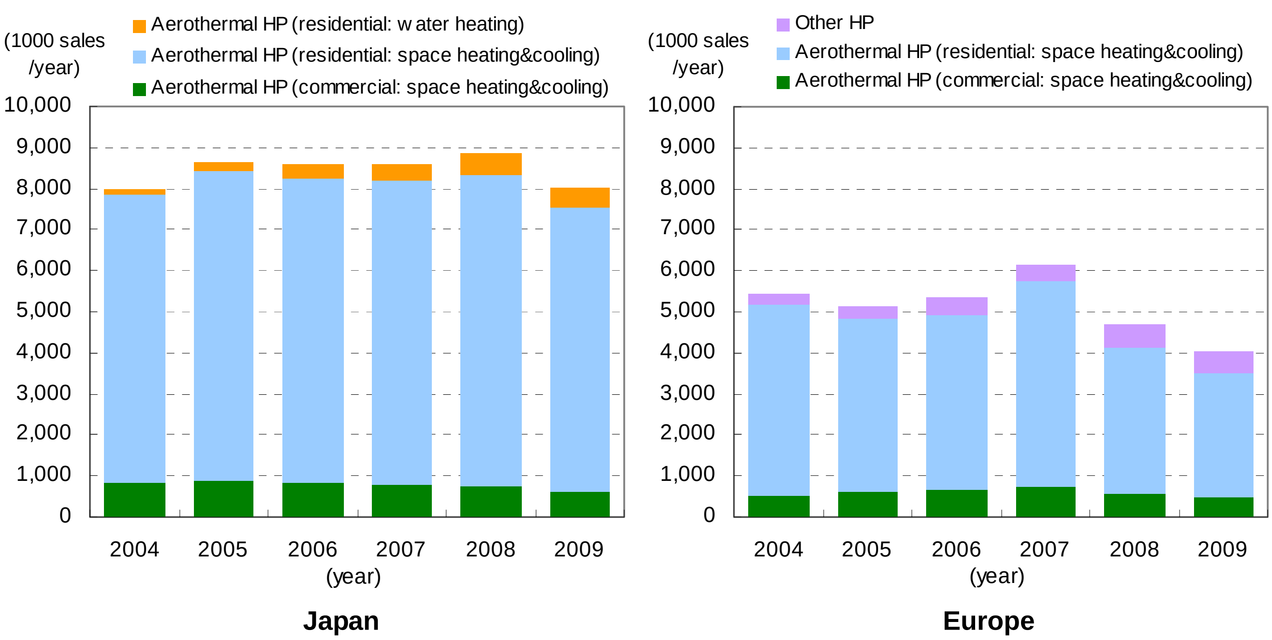
As seen above, there are multiple criteria for the COP of heat pumps that can be regarded as technology able to contribute to a reduction in primary energy consumption. There might also be a viewpoint, in terms of exergy[1], that heat and electricity should not be added or subtracted, as they are totally different in terms of energetic quality. However, as far as COP exceeds 1.0, the heat pump captures heat from the low temperature heat source.

2. Heat Pump Market Statistics

2-1 Market Scale in Japan and Europe

In Japan, with its relatively mild climate, aerothermal heat pumps can operate efficiently and provide heat sufficiently, so there is little demand for ground source heat pumps. In addition, there is not as much heating demand in Japan as to be able to pay back the expensive installation cost including ground boring and maintenance. In this context, the inexpensive aerothermal heat pumps have historically developed the heat pump market in Japan.

Fig. 2-1 Market Development of Heat Pumps for Air Conditioning (Sales)



Note : "Aerothermal heat pumps" means air conditioners. Commercial aerothermal heat pumps include packaged air conditioners, chilling units, turbo refrigeration, and gas engine heat pumps. The other thermal heat pumps, "Other HP", in Europe includes ground thermal heat pumps, hydrothermal heat pumps and aerothermal heat pumps except for room air conditioners and packaged air conditioners.

Note : "Europe" refers to the geographical whole of Europe. The other heat pump, "Other HP", in Europe includes only those in Austria, Finland, France, Germany, UK, Italy and Sweden in the EU, as well as Switzerland and Norway.

Source : Estimated based on the data of The Japan Refrigeration and Air Conditioning Industry Association and European Heat Pump Association.

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[1] Exergy is the maximum useful work as mechanical energy that can be extracted from a system, and is also called "Available energy." The exergy content of energy is the exergy coefficient and is used for the index of energetic quality of energy. The exergy coefficient of electricity is 1.0 and around 0.95 for fossil fuels. The coefficient of heat varies according to temperature. The higher the temperature, the larger the exergy coefficient is. The coefficient of heat of 100°C in an ambient temperature of 15°C is 0.23.

Fig. 2-1 compares the scales and developments of the heat pump markets in Japan and Europe. The Japanese heat pump market is dominated by aerothermal heat pumps (operating ground or hydrothermal heat pumps number only in the thousands) and the sales volume of 8 million per annum, including residential and commercial air conditioners and residential heat pump water heaters, doubles the amount of the European market. What characterizes the EU market is the ground and hydrothermal heat pumps (shown as “Other HP” in Fig. 2-1), which represent more than 10 % of the market.

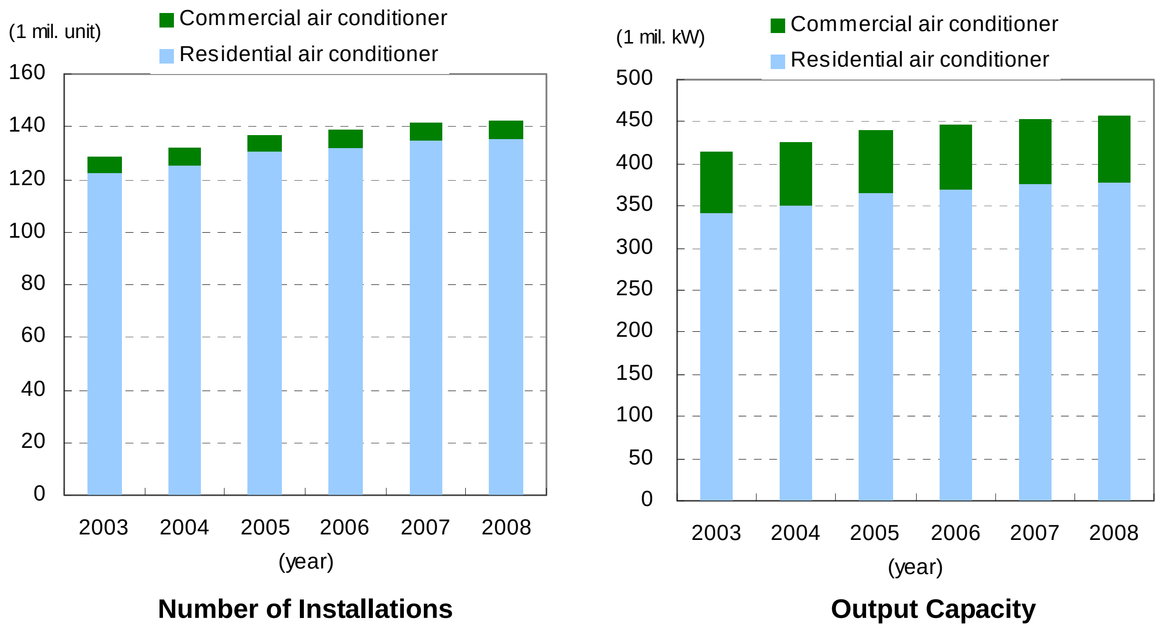
Unlike Japan, where air conditioners (aerothermal heat pump) have been penetrating the market for cooling purposes, Europe has a limited number of installations of air conditioners, due partly to the climate with low cooling demand and partly to the fact that the absence of an aerothermal heat pump that can operate in Europe’s very cold climate has forced consumers to choose ground source heat pumps. However, the air conditioner market in Europe is expected to grow in the future, driven by the recent hot spell in summer and also by the technology development which has recently realized the commercialization of aerothermal heat pumps that can work in cold climates, even at 25 degrees below zero.

The standpoints regarding to what extent the output capacity of heat pumps can be categorized as renewable energy, in particular those of the small air conditioners widely used in Japan, differ among member countries and a consensus has not been reached.

2-2 Installation of Aerothermal Heat Pumps in Japan

The cumulative number of aerothermal heat pumps in Japan is presented in Fig.2-2. Although the sales of heat pumps for water heaters have been growing recently, the installation of heat pumps

Fig. 2-2 Installation of Aerothermal Heat Pumps in Japan



Source : Estimated based on the data from “Consumer confidence (Cabinet Office)” and “White Paper of Heat pump and Thermal storage (Heat Pump & Thermal Storage Technology Center of Japan)”. “Commercial air conditioners” include package air conditioners and chilling units. Only electric heat pumps are covered.

only for air conditioning, which are still dominating, is shown. The total number of residential air conditioners is estimated from ownership per household multiplied by the number of households. The average air conditioner output capacity for residential use is assumed to be 2.8 kW, and 12 kW for commercial use, though these capacities greatly differ among households and business types where heat pumps are installed. As of 2008, 140 million (95% in residential use) air conditioners are installed and their total output capacity amounts to 450 million kW (83% in residential use).

3. Simplified Estimation of Aerothermal Energy Captured by Heat Pumps

While discussions continue on how the aerothermal energy captured by heat pumps is treated as renewable energy, this section tries to quantify the aerothermal energy in Japan. The criterion of COP is not taken into account. Only space heating in the residential and tertiary sectors is included (water heating is excluded), due to limited availability of statistical data.

3-1 Methodology

As indicated in equations (1) and (2), the captured aerothermal energy (QL) and the heat supplied from a heat pump (QL) are obtained by an equation (3) for the given input electricity (EL) and COP.

$$QL = EL(COP - 1) = QH\left(1 - \frac{1}{COP}\right) \quad \text{(for heating)} \qquad (3)$$

As the COP distribution of installed heat pumps is unknown and setting a COP criterion is still controversial, the aerothermal energy captured only by heat pumps with a COP exceeding a certain criterion (1-3-3) is not estimated, but the aerothermal energy of total installation is. The methodology that estimates the aerothermal energy based on the heat supplied from the heat pump (QH) obtained by multiplying the total installation output capacity (Fig.2-2) by the operating hours is one of the candidates (bottom-up approach). However, since difficulty in assuming the operating hours of the heat pump persists, the other methodology that obtains an estimation using electricity input (top-down approach) is chosen here. The conditions of calculation are shown in Table 3-1.

Table 3-1 Conditions of Calculation of Aerothermal Energy Use by a Heat Pump (2007)

	Electricity consumption for space heating	Number of households, Commercial floor space	Input electricity to heat pump	Annual average COP (heating)
Residential	1,595MJ/household In which 957MJ/household is for air conditioner	52.32million households	50,071 TJ	4.0
Tertiary	13MJ/m^2	1.79 billion m^2	24,031 TJ	3.5

Source : Electricity consumption comes from "Handbook of Energy & Economic Statistics in Japan (Institute of Energy Economics, Japan)". As electricity consumption for space heating also includes electric heaters, electric heating carpets and *kotatsu* (tables with an electric heater underneath and covered by a quilt), the electricity consumption of air conditioner is estimated to account for 60% based on "Power Demand and Supply (Ministry of Economy, Trade and Industry, Japan)". Average COP in operation is estimated from product catalogs and information.

3-2 Results from Estimation

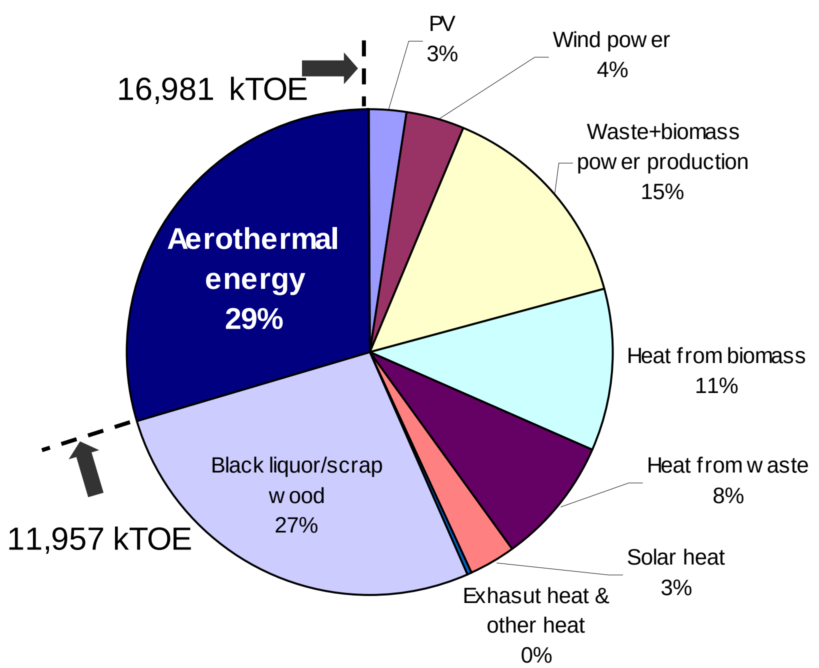
The results are shown in Table 3-2. In Japan, 150,000 TJ for residential use and 60,000 TJ for commercial use, mean that a total of 210,000 TJ (5,000 kTOE) of aerothermal energy was captured by heat pumps in 2007, equaling the supply of black liquor/scrap wood. When the aerothermal energy is included in the renewable energy category, the total renewable energy supply becomes 1.4 fold the current scale (11,957 to 16,981 kTOE) (Fig.3-1).

Table 3-2 Aerothermal Heat Pump Energy Balance (2007)

	Residential [TJ]	Tertiary [TJ]	Total [TJ]	Total [kTOE]
Heat supply from heat pump: QH	200,285	84,109	284,395	6,794
Electricity input :EL	50,071	24,031	74,103	1,770
Aerothermal energy :QL	150,214	60,078	210,292	5,024

One important observation from the result is that modifying the assumption of the COP from 4.0 to 3.0 decreases the amount of aerothermal energy by 33%, and a modification to 5.0 increases it by 33% (See equation (3)). In addition, assumption of the annual average COP as 4.0 for residential use and 3.5 for commercial use higher than the criterion presented in 1-3-3 (b) always yields the result that heat pumps contribute to reduction of the primary energy consumption. It should be noted that the assumption regarding COP is the dominating factor in estimating the amount of aerothermal energy and also the magnitude balance between the primary-energy-converted electricity input and aerothermal energy. It is therefore, as described later, very important to figure out the actual COP for improvement in estimation.

Fig. 3-1 Renewable Energy Mix Including Aerothermal Energy in Japan (FY2007)

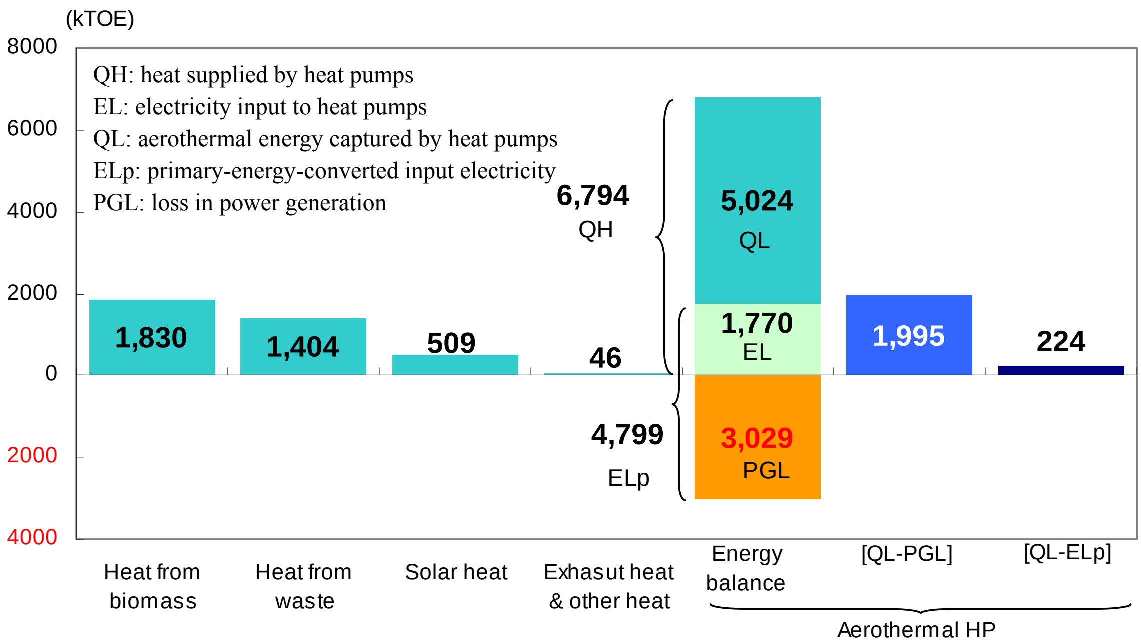


Note： The data of renewable energies other than aerothermal energy come from the documents in the Advisory Committee of Renewable Energy, Ministry of Economy, Trade and Industry, Japan.

Fig. 3-2 shows the energy balance of aerothermal heat pumps, along with the supply of renewable energy sources for heat. The amount of aerothermal energy used in the heat pumps reaches as much as 5,024 kTOE, equivalent to 2.7 times biomass heating and 10 times solar water heating. Subtracting the power production loss (3,029 kTOE) caused by the electricity input to the heat pump (1,770 kTOE) from the aerothermal energy results in 1,995 kTOE, and subtracting the primary energy of electricity input (4,799 kTOE) results in 224 kTOE. When categorizing aerothermal energy into renewable energy, what is the primary energy reduction effect of aerothermal energy has not yet been clearly defined and should be discussed further.

A greater degree of attention should be given to the fact that only heat pumps with a significantly higher COP can cause a reduction in primary energy reduction by replacing fossil fuel combustion boilers. In other words, in a comparison of aerothermal energy with the other renewable energy sources for heat, one should not neglect to include the electricity input to the heat pump. This context resembles the discussion on whether biofuel is classified into renewable energy, depending on the energy input amount required to produce biofuel. The aerothermal energy used by heat pumps is completely different in terms of impact on net primary energy conservation than the renewable energies that do not need any input of electricity or fossil fuels and hence can unconditionally contribute to reducing primary energy consumption.

Fig. 3-2 Renewable Heat and Aerothermal Energy in Japan (2007)



3-3 Issues to be Addressed for Improvement in Estimation

The results from the estimation by simplified methodology revealed that a considerable amount of aerothermal energy is being used for space heating in the residential and tertiary sectors in Japan. However, there are still issues to be addressed for further improvement in estimation, which are presented below.

－COP varies in relation to the ambient temperature and demand (indoor) temperature. In general, since the designed (rated) COP and the actual (in situ) COP differs, a methodology to estimate the actual COP as opposed to designed COP based on field test results should be established.

－Distribution data regarding the COP of heat pump installation is required, when setting a criterion for COP.

－If data on energy consumption by type of use and energy source are not available, a bottom-up approach would be an alternative. The bottom-up methodology requires data on output capacity and operation hours of each heat pump by type of room (for residential use) or business category (for commercial use) in which it is installed. In order to collect these data, an additional survey is needed, along with the use of existing statistical data and studies.

－Heat pumps for water heaters and industrial use, out of the scope of this study, would be addressed.

4. Concluding Remarks

Aerothermal energy can be regarded as renewable energy that is used by consumers without recognition through air conditioners equipped with heat pump technology. Although several assumptions have to be made, the designed COP leads to the estimation that 5,000 kTOE of aerothermal energy, which equals 40 % of current renewable energy supply, was used in Japan for space heating in the residential and tertiary sector in 2007, accompanied by 4,800 kTOE of primary energy consumption incurred by electricity input to heat pumps.

In Japan, heat pumps with an annual average COP exceeding 2.7 guarantee a reduction of primary energy consumption, and a heat pump with a COP higher than 3.7 can capture an amount of aerothermal energy that is greater than the amount of primary energy consumed by the heat pump.

Improvement of heat pump performance means that a reduction in electricity input, which means energy efficiency, and an increase in captured energy are simultaneously achieved, and further improvement in COP is expected. It is, however, important to prevent misunderstanding by clearly describing electricity consumption along with aerothermal energy or by subtracting electricity consumption from aerothermal energy, when aerothermal energy is treated as renewable energy. Although the highest designed COP for heating of air conditioners in Japan is presently reaching 7.0, the actual performance in situ of heat pump differs from the designed performance, so the actual COP should be monitored and figured out for improvement in the method of estimation of aerothermal energy. The EU is currently considering the establishment of methodology for heat pump statistical data collection and guidelines for estimation of heat captured by heat pumps, in accordance with the “Directive on the promotion of the use of energy from renewable sources, April 2009.” Japan also needs to establish guidelines, taking into account the characteristics of Japan’s climate, energy consumption, and heat pump market.

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