



JAPANESE
INDUSTRIAL
STANDARD

Translated and Published by
Japanese Standards Association

JIS C 8851 : 2013

(JEMA)

**Measurement methods for 11 mode
energy efficiency of small fuel cell
power systems and for annual
energy consumption of standard
residence**

ICS 27.070

Reference number : JIS C 8851 : 2013 (E)

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Date of Establishment: 2013-12-20
Date of Public Notice in Official Gazette: 2013-12-20
Investigated by: Japanese Industrial Standards Committee
Standards Board
Technical Committee on Electricity Technology

JIS C 8851:2013, First English edition published in 2016-02

Translated and published by: Japanese Standards Association
Mita MT Building, 3-13-12, Mita, Minato-ku, Tokyo, 108-0073 JAPAN

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Printed in Japan

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal for establishment of Japanese Industrial Standard submitted by the Japan Electrical Manufacturers' Association (JEEMA) with the draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law.

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Measurement methods for 11 mode energy efficiency of small fuel cell power systems and for annual energy consumption of standard residence

1 Scope

This Japanese Industrial Standard specifies the test method for measuring the 11 mode energy efficiency when a stationary small polymer electrolyte fuel cell power generation unit and small solid oxide fuel cell power generation unit (hereafter referred to as “power generation unit”) are operated by an 11-mode operation pattern in which the power consumption of a standard residence including starting and stopping is simulated, and the test method for measuring the annual energy consumption when a stationary small polymer electrolyte fuel cell system and small solid oxide fuel cell system (hereafter referred to as “fuel cell system”) are installed in a standard residence.

This Standard covers the fuel cell systems applicable to the following a) to g).

- a) **Type of fuel cell** Polymer electrolyte fuel cell and solid oxide fuel cell
- b) **Output** Rated transmission output, under 10 kW
- c) **a.c. output voltage** 220 V or under
- d) **Operation state** Grid-connected operation, grid-independent operation or stand-alone operation
- e) **Raw fuel** Gaseous fuel (city gas, liquefied petroleum gas, etc.), liquid fuel (kerosene, etc.) or hydrogen
- f) **Operating pressure** Under 0.1 MPa in maximum working pressure for the portion through which gaseous fuel passes, and under 1.0 MPa for the portion through which liquid fuel passes
- g) **System configuration** Stationary power generation dedicated system or cogeneration system housed in package

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS C 8800 *Glossary of terms for fuel cell power system*

JIS C 8823 *Testing methods for small polymer electrolyte fuel cell power systems*

JIS C 8841-1 *Small solid oxide fuel cell power systems—Part 1: General rules*

JIS K 2201 *Gasoline for industrial purpose*

JIS K 2202 *Motor gasoline*

JIS K 2203 *Kerosine*

JIS K 2240 *Liquefied petroleum gases*

JIS K 2279 *Crude petroleum and petroleum products—Determination and estimation of heat of combustion*

JIS K 2301 *Fuel gases and natural gas—Methods for chemical analysis and testing*

JIS S 2093 *Test methods of gas burning appliances for domestic use*

JIS S 3031 *General rules for test methods of oil burning appliances*

3 Terms and definitions

For the purpose of this Standard, the terms and definitions given in JIS C 8800, and the following apply.

3.1 fuel cell system

system that electrochemically transforms chemical energy into electric energy (d.c. or a.c.) and thermal energy

Normally, it consists of a power generation unit and a hot-water storage unit.

NOTE : The basic configuration of general fuel cell system is shown in Figure 1.

3.2 power generation unit

unit consisting of a cell stack or module, power conditioner, fuel reformer, air supply system, water treatment equipment, exhaust heat recovery equipment, controller, etc.

3.3 hot-water storage unit

unit that stores heat recovered from a power generation unit as warm water, and supplies it to outside as necessary

It consists of a hot-water storage tank, a back-up heater, etc. The back-up heater has a heating function by gaseous fuel, liquid fuel, electricity, etc.

3.4 package

container in which the device constituting a power generation unit, auxiliary equipment, etc. are housed

The container in which a power conditioner and others are housed may be separated from the package of the power generation unit.

3.5 transmission output

electric output taken out from a power generation unit to outside at the output terminal, which is the electric output at the generator terminal from which the auxiliary equipment power is subtracted

3.6 cold state

state where the power generation unit has stopped at near the ordinary temperature and energy is not supplied from outside

3.7 storage state

state where the power generation unit has stopped but energy is supplied from outside in order to protect the devices in it and/or to apply the current to controllers

3.8 stand-by state

state where the power generation unit is maintained at such a temperature capable of outputting power to outside and readily switching to the operation mode of transmission output, but not currently generating any transmission output to outside

3.9 start-up time

time required until the transmission output is generated from the cold state in the power generation unit that does not need external energy to maintain the storage state

In the power generation unit that needs external energy to maintain the storage state, it is the time required until the transmission output is generated from the storage state.

3.10 response time up to rated output

in the stand-by state of the power generation unit, time from the start of shift operation toward the rated output until the moment when the rated output is generated

3.11 stop time

in the rated output of the power generation unit, time from the start of stop operation to the end of stop operation specified by the manufacturer

3.12 11 mode operation pattern

operation pattern used for the measurement of energy efficiency of power generation unit

3.13 power load pattern

test pattern of the average power load in units of one day of a standard residence used for the measurement of energy consumption concerning the power of fuel cell system

There are three power load patterns: summer period, intermediate period and winter period in consideration of the seasonally usage status of electricity.

3.14 hot-water supply and thermal insulation load pattern

test pattern of the average hot-water supply and the thermal insulation load in units of one day of a standard residence used for the measurement of energy consumption concerning the hot-water supply of a fuel cell system

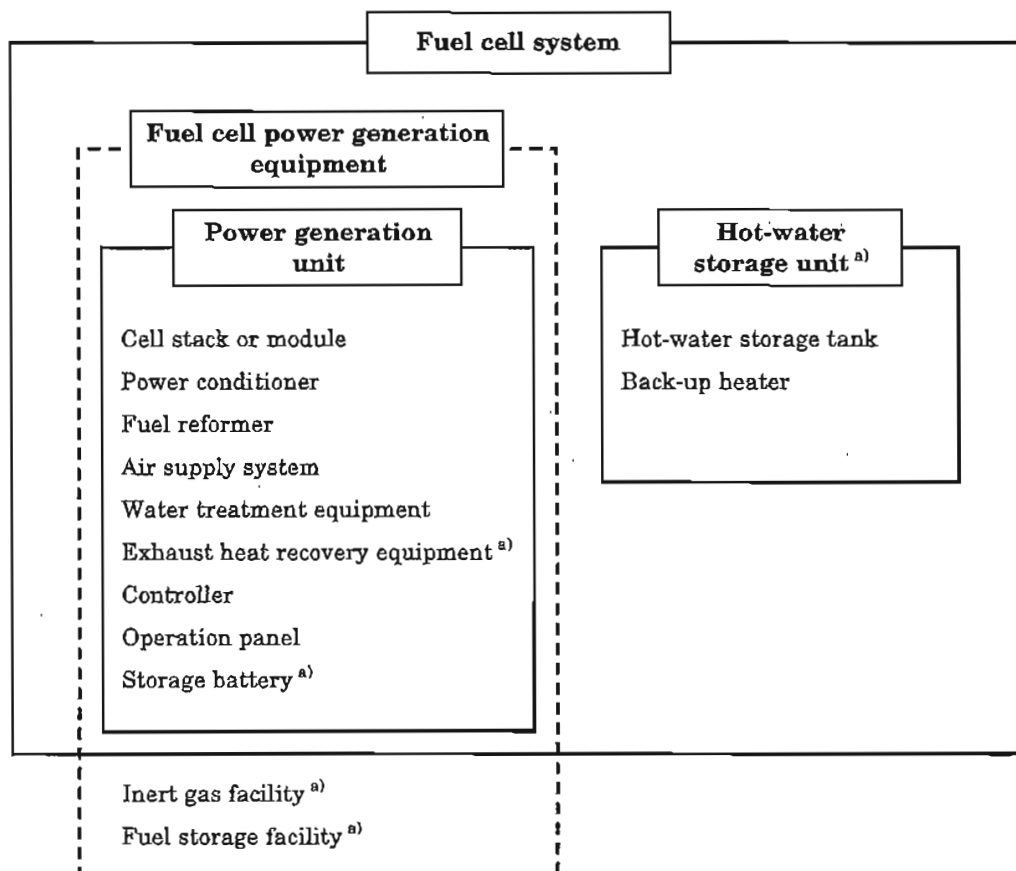
The hot-water supply and thermal insulation load pattern is expressed by the hot-water supply and thermal insulation mode (56 modes) and the intensive hot-water supply and thermal insulation mode (20 modes) when the action of the same use is put together in this mode. It simulates the loads in summer period, intermediate period and winter period according to the temperature conditions.

3.15 net generated electricity

net generated electricity of power generation unit obtained by subtracting the received electricity from the transmitted electricity

4 Configuration and range

The basic configuration of the fuel cell system shall be as shown in Figure 1.



Installation location of device, etc. is not limited to that in one package.

Fuel reformer is not used when raw fuel is hydrogen.

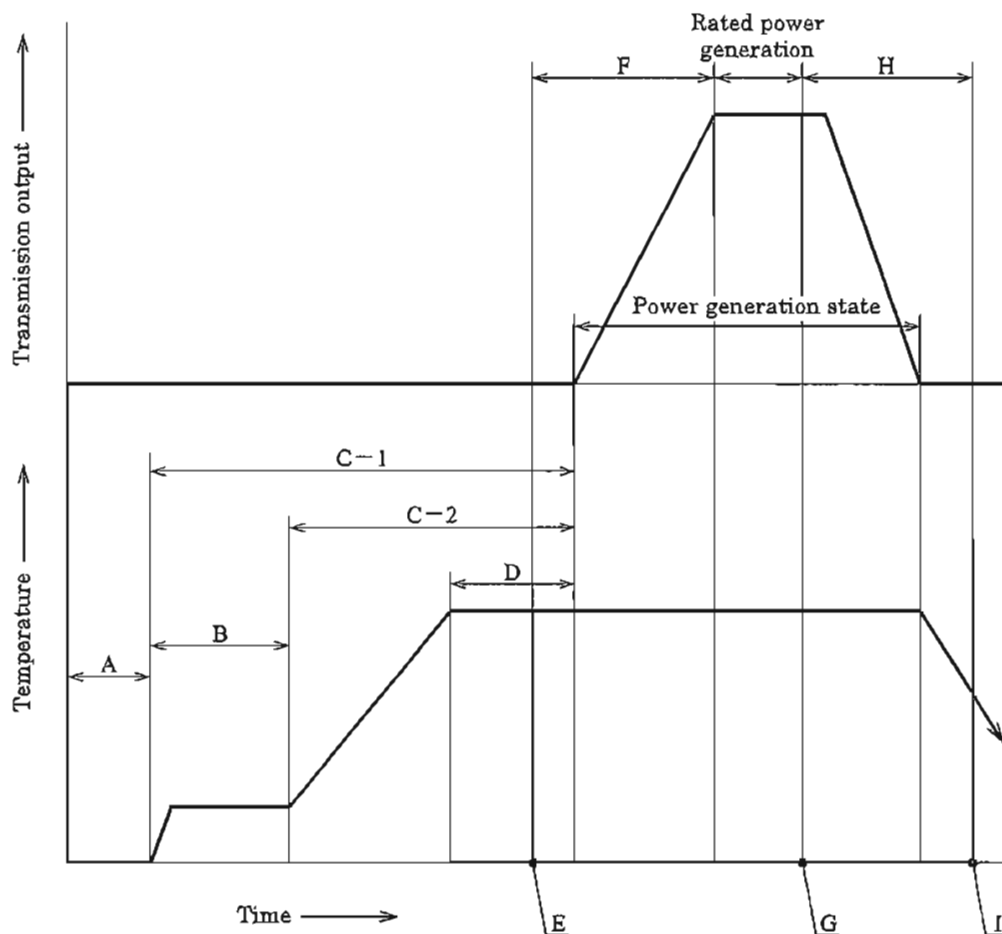
In the case of the power generation dedicated system, the hot-water storage unit and the exhaust heat recovery equipment are not installed.

Note ^{a)} Equipment or unit installed as necessary.

Figure 1 Basic configuration of fuel cell system

5 Operation process

The typical operation process of power generation unit is shown in Figure 2. Figure 2 illustrates the change with time of a series of operating conditions from the cold state to the start-up, rated output and stop of the power generation unit.



The symbols in the chart are as follows.

- A : cold state
- B : storage state
- C-1 : time required until transmission output is generated from cold state in power generation unit that does not need external energy to maintain storage state
- C-2 : time required until transmission output is generated from storage state in power generation unit that needs external energy to maintain storage state
- D : stand-by state
- E : start of rising operation of power generation output from module
- F : response time up to rated output
- G : start of stop operation of module
- H : stop time
- I : end of stop operation (condition of end of stop determined in specification)
- C-1 or C-2 to H : operating condition (from start of start-up operation to end of stop operation)

Figure 2 Operation process chart of power generation unit

6 Conditions on tests

6.1 Test fuel

6.1.1 Gaseous fuel

The types of gaseous fuel shall be the liquefied petroleum gas, city gas or other gaseous fuel, and the quality shall be as follows.

- a) **Liquefied petroleum gas** Specified in Table 1 of **JIS K 2240**.
- b) **City gas** Specified in Table 42 of **JIS S 2093**.
- c) **Other gaseous fuel** Subjected to the manufacturer's specification.

The test gas and the conditions of test gas shall be in accordance with 5.2.1 of **JIS C 8823** or 14.2.1 of **JIS C 8841-1**.

6.1.2 Liquid fuel

The types of liquid fuel shall be the gasoline for industrial purpose, motor gasoline, kerosine or other liquefied fuels, and the quality shall be as follows.

- a) **Gasoline for industrial purpose** Specified in Table 1 and Table 2 of **JIS K 2201**.
- b) **Motor gasoline** Specified in Table 1 of **JIS K 2202**.
- c) **Kerosine** Specified in Table 1 and Table 2 of **JIS K 2203**.
- d) **Other liquid fuel** Subjected to manufacturer's specification.

6.2 Basis and calculation of heating value

6.2.1 Basis of heating value

The basis of heating value shall be as follows.

- a) The lower heating value (LHV) or the higher heating value (HHV) shall be used for the heating value of fuel. Normally, lower heating value (LHV) should be used.
- b) When the lower heating value is used, it is not necessary to add the subscript of LHV in front of the numerical value of heating value, fuel consumption heating value, power generation efficiency, heat recovery efficiency and overall energy efficiency.

NOTE 1 LHV is an abbreviation of Lower Heating Value or Low Heating Value.

- c) When the higher heating value (HHV) is used, the subscript of HHV shall be added in front of the numerical value of heating value, fuel consumption heating value, power generation efficiency, heat recovery efficiency and overall energy efficiency.

NOTE 2 HHV is an abbreviation of Higher Heating Value or High Heating Value.

Example : Description example when higher heating value is used

Heating value (HHV) 12 000 MJ/kg, efficiency (HHV) 40 %, etc.

6.2.2 Calculation of heating value

The heating value of test fuel shall be obtained as follows.

- a) **Case of gaseous fuel** Near the connection part of power generation unit, the sampling and the composition analysis of fuel gas shall be performed according to **JIS K 2301** and **JIS K 2240**, and the lower heating value per unit volume H_G (kWh/m³) shall be obtained according to Formula (1).

$$H_G = \sum Q_a \times \frac{V_a}{100} \dots\dots\dots (1)$$

where, H_G : lower heating value per unit volume of gaseous fuel (kWh/m³)

Q_a : lower heating value of each component at 15 °C in temperature and at 101.3 kPa in absolute pressure (kWh/m³)

V_a : volume percentage of each component (%)

NOTE 1 In the case of gaseous fuels except liquefied natural gas, the heating value at 0 °C in temperature and at 101.3 kPa in absolute pressure can be obtained according to clause 8 of **JIS K 2301**.

- b) **Case of liquid fuel** The lower heating value per unit mass H_L (MJ/kg) shall be obtained according to **JIS K 2279**.

NOTE 2 In **JIS K 2279**, lower heating value is written as the true specific energy.

NOTE 3 The round numbers of the lower heating value of kerosene fuel are shown in Table A.1 of **JIS K 2203**.

6.3 Measuring instruments for test and test apparatus

The measuring instruments for test and the test apparatus shall be as follows.

- a) **Power generation unit using gaseous fuel** The measuring instruments for test and the test apparatus shall be the equipment specified in Table 43 and Table 44 of **JIS S 2093** or the equipment equivalent to this.
- b) **Power generation unit using liquid fuel** The measuring instruments for test and the test apparatus shall be the equipment specified in Table 2 of **JIS S 3031** or the equipment equivalent to this.

6.4 Simulated power load

The simulated power load shall be connected with the grid-connected condition. The power factor shall be 1.

7 Measuring method of fuel consumption heating value and net generated electricity

7.1 Fuel consumption heating value

The fuel consumption heating value shall be as follows.

- a) **Gaseous fuel consumption heating value** Measure the observed fuel consumption F_1 , calculate the fuel consumption F after correction of temperature and pressure at 15 °C in temperature and at 101.3 kPa in atmospheric pressure (absolute pressure) according to Formula (2), and calculate the integrated fuel consumption heating value I according to Formula (3) based on F . For fuel temperature, fuel pressure (gauge pressure) and atmospheric pressure (absolute pressure), use the average during the measurement time, respectively. Perform the measurement of atmospheric pressure (absolute pressure) once or more per day, and use the average for the calculation by Formula (2).

$$F = \frac{F_1}{1000} \times \frac{288.2}{273.2 + T_1} \times \frac{P_1 + P_2}{101.3} \dots\dots\dots (2)$$

where, F : fuel consumption after correction of temperature and pressure (m³)
 F_1 : observed fuel consumption (L)
 T_1 : average of fuel temperature (°C)
 P_1 : average of fuel pressure (gauge pressure) (kPa)
 P_2 : average of atmospheric pressure (absolute pressure) (kPa)

$$I = F \times H_G \dots\dots\dots (3)$$

where, I : integrated fuel consumption heating value (kWh)
 F : fuel consumption after correction of temperature and pressure (m³)
 H_G : fuel heating value per unit volume (kWh/m³)

- b) **Liquid fuel consumption heating value** Measure the mass of a fuel tank at the test start and the test end, and calculate the integrated fuel consumption heating value according to Formula (4). When it is difficult to measure the mass, attach a flowmeter or integrating flowmeter to the fuel tank outlet, measure the integrated flow amount and calculate according to Formula (6).

In the fuel cell system to which the fuel is intermittently supplied, when 20 times the interval of fuel supply exceeds a measurement time, calculate according to Formula (5) in consideration of the remaining fuel in the fuel cell system. When it is difficult to measure the mass, attach a flowmeter or integrating flowmeter to the buffer tank outlet and hot-water storage tank fuel supply line in the system, measure the integrated flow amount, respectively, and after totalling, calculate according to Formula (6).

$$I = (M_t - M_t') \times \frac{H_L}{3.6} \dots\dots\dots (4)$$

where, I : integrated fuel consumption heating value (kWh)
 M_t : mass of fuel tank at test start (kg)
 M_t' : mass of fuel tank at test end (kg)
 H_L : fuel heating value per unit mass (MJ/kg)

$$I = (M_i - M_i' + M_b - M_b') \times \frac{H_L}{3.6} \dots\dots\dots (5)$$

where, I : integrated fuel consumption heating value (kWh)
 M_i : mass of fuel tank at test start (kg)
 M_i' : mass of fuel tank at test end (kg)
 M_b : remaining fuel mass in fuel cell system at test start (kg)
 M_b' : remaining fuel mass in fuel cell system at test end (kg)
 H_L : fuel heating value per unit mass (MJ/kg)

$$I = F_L \times \rho \times \frac{H_L}{3.6} \dots\dots\dots (6)$$

where, I : integrated fuel consumption heating value (kWh)
 F_L : integrated fuel consumption (m³)
 ρ : fuel density (kg/m³)
 H_L : fuel heating value per unit mass (MJ/kg)

7.2 Net generated electricity

Measure FC transmitted electricity¹⁾ and FC received electricity¹⁾, and calculate FC integrated net generated electricity¹⁾ according to Formula (7).

$$W_{FC} = W_{outFC} - W_{inFC} \dots\dots\dots (7)$$

where, W_{FC} : FC integrated net generated electricity (kWh)
 W_{outFC} : integrated value of a.c. transmitted power at transmitting terminal of power generation unit (kWh)
 W_{inFC} : integrated value of a.c. received power at receiving terminal of power generation unit (kWh)

Note ¹⁾ Here, FC means the power generation unit.

8 Measuring method of 11 mode energy efficiency of power generation unit

8.1 Overview

This test is for measuring the 11 mode energy efficiency when the operation including the starting and stopping of power generation unit is performed with an 11 mode operation pattern that simulates the power consumption of an actual standard residence. There are 11 mode power generation efficiency, 11 mode heat recovery efficiency and 11 mode overall energy efficiency in 11 mode energy efficiency.

8.2 Symbols and definitions

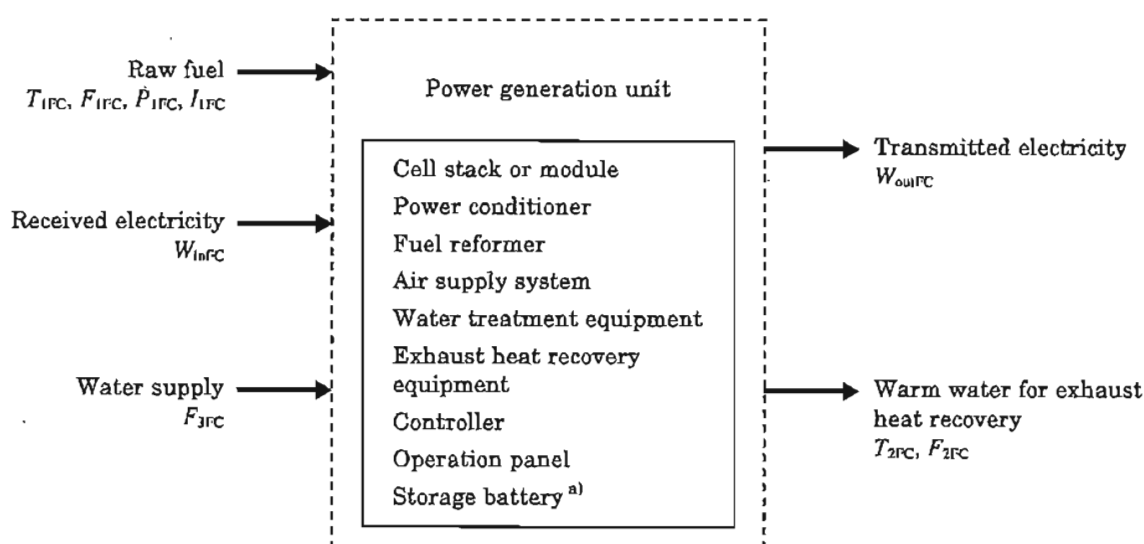
The symbols and definitions are as shown in Table 1.

Table 1 Symbols and definitions

Symbol	Meaning of symbol	Definition	Unit
F_{1FC}	FC observed fuel consumption	Observed value of fuel consumption consumed in power generation unit	L
F_{2FC}	FC flow rate of warm water for exhaust heat recovery	Flow rate of warm water for exhaust heat recovery from power generation unit	L/min
F_{3FC}	FC water supply flow rate	Flow rate of water supplied to power generation unit	L/min
I_{FC}	FC integrated fuel consumption heating value	Integrated heating value of fuel consumption consumed in power generation unit	kWh
P_{1FC}	FC fuel pressure (gauge pressure)	Gauge pressure of fuel consumed in power generation unit	kPa
P_{2FC}	FC atmospheric pressure (absolute pressure)	Atmospheric pressure around power generation unit	kPa
T_{1FC}	FC fuel temperature	Temperature of fuel consumed in power generation unit	°C
T_{2FC}	FC temperature of warm water for exhaust heat recovery	Temperature of warm water for exhaust heat recovery from power generation unit	°C
T_{3FC}	FC temperature of water supply	Temperature of water supplied to power generation unit	°C
W_{inFC}	FC received electricity	Integrated value of a.c. electricity at receiving terminal of power generation unit	kWh
W_{outFC}	FC transmitted electricity	Integrated value of a.c. electricity at transmitting terminal of power generation unit	kWh
NOTE : "FC" in the table means the fuel cell power generation unit.			

8.3 Target range to be tested

The target range to be tested is shown in Figure 3.



Note ^{a)} Device or unit installed as necessary.

Figure 3 Target range to be tested