PV-Powered Vehicle Strategy Committee
Interim Report (2)
- Preliminary Study on Solar Irradiation of PV-Powered Vehicles -

April 2019

New Energy and Industrial Technology Development Organization

Interim Report of PV-Powered Vehicle Strategy Committee (2): Table of Contents

Introduction

The Paris Agreement, adopted at COP21 in December 2015, has a goal of keeping the rise in global average temperature well below 2°C above preindustrial levels and of pursuing efforts to limit the increase to 1.5°C. In October 2018, the IPCC issued "Special Report on Global Warming of 1.5°C", which summarized the situation and impact on society if the temperature rise were kept to 1.5°C above preindustrial levels. This special report emphasized that limiting global warming to 1.5°C rather than 2°C or higher would greatly reduce climate disruption. The Summary for Policymakers was approved by the signatory countries.

At present, emissions of greenhouse gases are falling in the power generation sector due to the accelerated introduction of renewable energy, such as solar (hereinafter, photovoltaics or "PV") and wind. In the transport sector however, which relies on fossil fuel for most of its energy needs, a presently unforeseeable level of technological development will be required to outperform current greenhouse gas reduction targets. The number of automobiles, which account for over half of transport emissions, is forecast to grow rapidly mainly in Asia. This makes it vital to reduce greenhouse gas emissions from cars.

To reduce greenhouse gas emissions from cars, initiatives aiming at a rapid rollout of electric vehicles (EV) and plug-in hybrid vehicles (PHV) have begun in countries across the world. However, unless clean power derived from renewable energy sources can be supplied, such vehicles will have a limited effect in reducing greenhouse gas emissions.

In response to this situation, the New Energy and Industrial Technology Development Organization (NEDO) has established a PV-Powered Vehicle Strategy Committee (secretariat: Mizuho Information & Research Institute, Inc.). This committee investigated potential benefits and outstanding issues for installing high-efficiency PV on automobiles and reported in January 2018 on its potential for reducing the CO2 emissions in the transport sector[i]. This report also indicated that solar irradiation and generated power differ between PV on vehicle and PV installed on the roof or rooftop of a building, and stressed the need for quantitative analysis into this difference. In keeping with this recommendation, the solar irradiation of vehicles was measured at two locations in Japan.

This report summarizes the results of the PV-Powered Vehicle Strategy Committee's preliminary study into the solar irradiation of PV-powered vehicles.

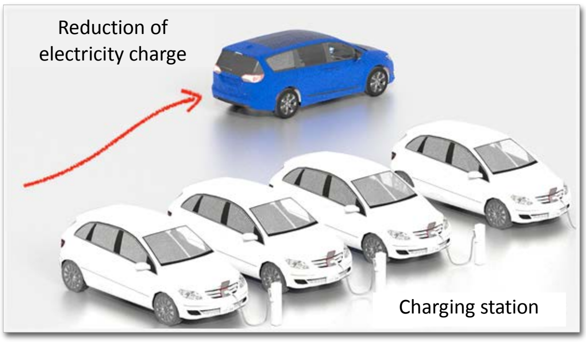

Fig. Images of PV-powered vehicles

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[i] NEDO, PV-Powered Vehicle Strategy Committee Interim Report, January 2018

1. Trends in PV-Powered Vehicles

Moves toward the development and commercialization of PV-powered vehicles have begun in several countries, though still nascent. This is underpinned by a global movement promoting the electrification of automobiles, in the form of electric cars, plug-in hybrids, and the like.

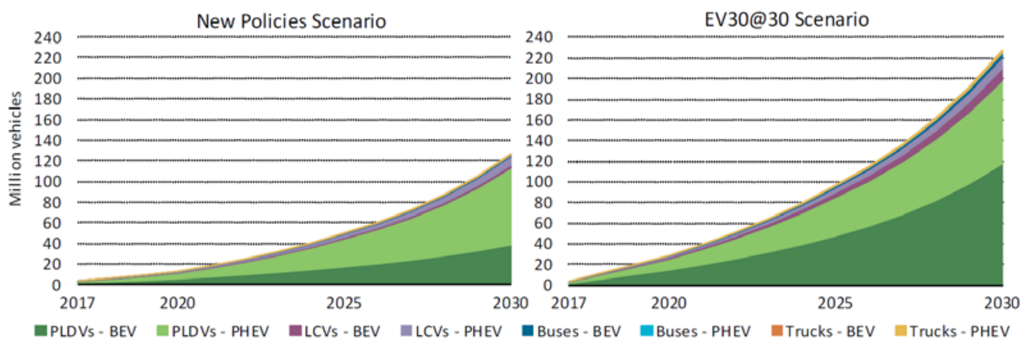
The movement toward electrification of automobiles and the trend toward development and commercialization of PV-powered vehicles are summarized below.

1.1. Movement toward Electrification of Automobiles

To reduce greenhouse gas emissions in the transport sector, increasing efforts at electrifying vehicles are being made around the world. As shown in Table 1-1, many countries have set 2020 or 2030 targets for introducing electric vehicles, such as electric cars[1]. Hereinafter, the expression "electric cars" is used to represent all electric vehicles.

The Electric Vehicles Initiatives (EVI) is an international multi-government policy forum to promote widespread introduction of electric cars. The "EV30@30" campaign was launched at the 8th Clean Energy Ministerial held in 2017. This campaign has a goal of a 30% market share (excluding motorcycles) for electric cars in EVI member countries by 2030.

Fig. 1-1 shows the cumulative numbers of electric cars in 2030 for the New Policies Scenario in the IEA World Energy Outlook 2017[2] (hereinafter, "WEO 2017") and the EV30@30 campaign. While the WEO 2017 scenario foresees around 130 million electric cars on the road, the number jumps to 228 million for the EV30@30 scenario. Achieving the target of the EV30@30 campaign will increase the number of electric cars by about 100 million, with most of this increase being in passenger cars (PLDV: Passenger Light Duty Vehicles).



Notes: PLDVs = passenger light duty vehicles; LCVs = light commercial vehicles; BEVs = battery electric vehicles; PHEV = plug-in hybrid electric vehicles.

Source: IEA analysis developed with the IEA Mobility Model (IEA, 2018a).

Fig. 1-1 Global EV stock in the New Policies and EV30@30 scenarios, 2017-30[1]
(Left: WEO2017 New Policies Scenario, Right: EV30@30 Scenario)

Table 1-1 Country targets and objectives for EV deployment[created from 1]

Country or region	EV 30@30[a)]	2020-30 EV target or objective
China	√	- 5 million EVs by 2020, including 4.6 million PLDVs, 0.2 million buses and 0.2 million trucks - New energy vehicle (NEV)[b)] mandate: 12% NEV credit sales of passenger cars by 2020[c)] - NEV sales share: 7-10% by 2020, 15-20% by 2025 and 40-50% by 2030
European Union		- Post 2020 proposed CO_2 targets for cars and vans include benchmarks: 15% EV sales by 2025 and 30% by 2030 (exceeding these benchmarks allows for less stringent specific emissions targets to be met by OEMs)
Finland	√	- 250,000 EVs by 2030
India	√	- 30% electric car sales by 2030 - 100% BEV sales for urban buses by 2030
Ireland		- 500,000 EVs and 100% EV sales by 2030
Japan	√	- 20-30% electric car sales by 2030
Netherlands	√	- 10% electric car market share by 2020 - 100% EV sales in PLDVs by 2030 - 100% electric public bus sales by 2025 and 100% electric public bus stock by 2030
New Zealand		- 64,000 EVs by 2021
Norway	√	- 100% EV sales in PLDVs, LCVs and urban buses by 2025 - 75% EV sales in long-distance buses and 50% in trucks by 2030
Korea		- 200,000 EVs in PLDVs by 2020
Slovenia		- 100% electric car sales by 2030
United Kingdom		- 396,000 to 431,000 electric cars by 2020
United States (selected states)		- 3,300,000 EVs in eight states combined by 2025[d)] - ZEV mandate in ten states[e)]: 22% ZEV credit sales in passenger cars and light-duty trucks by 2025[f)] - California: 1.5 million ZEVs and 15% of effective sales by 2025, and 5 million ZEVs by 2030
Other European Union[g)]		- 450,000 to 760,000 electric cars by 2020 - 5.42 million to 6.27 million electric cars by 2030

a) The countries that joined the EV30@30 Campaign set a collective aspirational goal to reach a 30% sales share for EVs by 2030.
b) "New energy vehicles" include BEVs, PHEVs and FCEVs.
c) The 12% sales mandate includes multipliers depending on vehicle technology and range. Most current models are eligible for multipliers between 2 and 4.
d) California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, Vermont.
e) Eight above-cited States plus Maine and New Jersey
f) The 22% sales mandate includes multipliers depending on vehicle technology and range. Most current models are eligible to receive credits between 0.5 and 3.
g) These include: Austria, Belgium, Bulgaria, Czech Republic, Hungary, Italy, Latvia, Lithuania, Luxemburg, Poland, Portugal, Slovak Republic and Spain.

1.2. Potential of PV Systems in Transport Sector

The market for PV systems for residential, commercial buildings, and ground-mounted power generation projects is rapidly expanding across the globe.

At present, there is relatively little use of PV systems in the transport sector, in limited applications such as installation on noise barriers, street lights, and other lighting. However, in some countries, there are clear signs of new markets emerging. In the Netherlands for example, infrastructure such as roads is identified as a main field in the road map for 2050[3]. Specific projects relating to PV-powered vehicles have also begun[4]. In Japan, in discussions conducted in November 2018, the installation of PV systems on automobiles was indicated as a new market predicted for 2030 onward[5].

In an ambitious mid-to-long term vision where energy needs in 2050 are 100% covered by renewable energy[6], the installed amount of PV generation for the transport sector in 2050 is 19.1TW, which would supply about 80% of transport sector demand. Of this, about 40% is supplied directly to electric cars.

1.3. Movements toward Development and Adoption of PV-Powered Vehicles

1.3.1. Initiatives toward Development of PV-Powered Vehicles

The installation of PV on automobiles was originally proposed in the 1980s and early 1990s. At that time, use was limited to interior air conditioning and charging of electrical equipment. After Ford announced a concept car that uses PV as an energy source in January 2014, other car manufacturers began to investigate the potential of PV as a power source for driving an electric vehicle[7].

TOYOTA MOTOR CORPORATION launched a plug-in hybrid vehicle equipped with a 180W crystalline Si PV panel as a power source, though not a solar car exclusively powered by PV, in 2016. Projects into developing a PV-powered vehicle that uses PV as a main power source have begun in various countries around the world, with the twin aims of creating a new market for PV systems and of developing next-generation vehicles.

Sono Motors of Germany has announced plans to sell passenger cars with PV mounted on all surfaces of the vehicle[7], while in the Netherlands, development of PV-powered vehicles has begun as a joint venture between a research institute and venture capital[4,8]. In Japan, in addition to the PV-Powered Vehicle Strategy Committee project, research is being conducted by car manufacturers[9]. China and South Korea are also developing PV-powered vehicles and have announced concepts.

Projects relating to PV-powered vehicles are not limited to passenger cars and have also started for commercial vehicles, such as trucks. In Germany for example, studies measuring power generation of onboard PV are being conducted using trucks on the road[10], in Japan also, there are initiatives for equipping trucks with thin film PV[11,12].

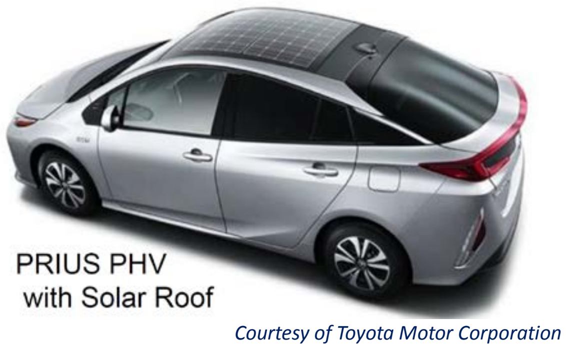


Fig. 1-2 Examples of PV-Powered vehicles (1)[13]

Fig. 1-3 Examples of PV-Powered vehicles (2)

1.3.2. International Discussions into Adoption of PV-Powered Vehicles

In addition to development projects by individual countries and enterprises, to promote such efforts and foster a base for introduction into the real market, international discussions into the adoption of PV-powered vehicles have begun.

（1） IEA PVPS Task17: PV and Transport

The IEA PVPS (International Energy Agency - Photovoltaic Power Systems Programme, Technology Collaboration Programme) is an international framework that operates under the IEA to hold discussions and share information toward the introduction and adoption of PV systems[14].

Under this program, proposals were made, with Japan as leader and based on the results of discussions and interim reports by Japan's PV-Powered Vehicle Strategy Committee, to expand initiatives toward the realization and adoption of PV-powered vehicles onto the global stage. As a result, at the 50^{th} IEA PVPS Executive Committee (a committee composed of representatives of the countries participating in IEA PVPS) held in December 2017, a new project, "Tas 17 (PV for Transport)" to promote international discussions was approved by the IEA PVPS. After discussions with experts from countries participating in Task 17 and "IEA HEVs (Hybrid and Electric Vehicles)", another technology collaboration program under the IEA that focuses on electric cars, activities of Task17 officially began in the fall of 2018. Activities under the work plan, corresponding to the actions to be taken, are expected to continue for three years.

Task17 is chaired by Japan, and among the countries participating in IEA PVPS, Australia, China, Germany, and the Netherlands have officially announced their participation. Also, many other countries in Europe and Asia have expressed an interest and the number of participants is expected to increase.

Fig. 1-4 shows the concept of Task17. In the future, more electricity for driving electric vehicles will become necessary, and to mitigate CO_2 emissions related to electric cars, it will be essential to use renewable energy such as solar power. Although there are various methods for supplying power to charge vehicles, to use solar energy more efficiently, it would be possible to supply power directly from PV mounted on the vehicle and to supply power from a charging station that uses PV.

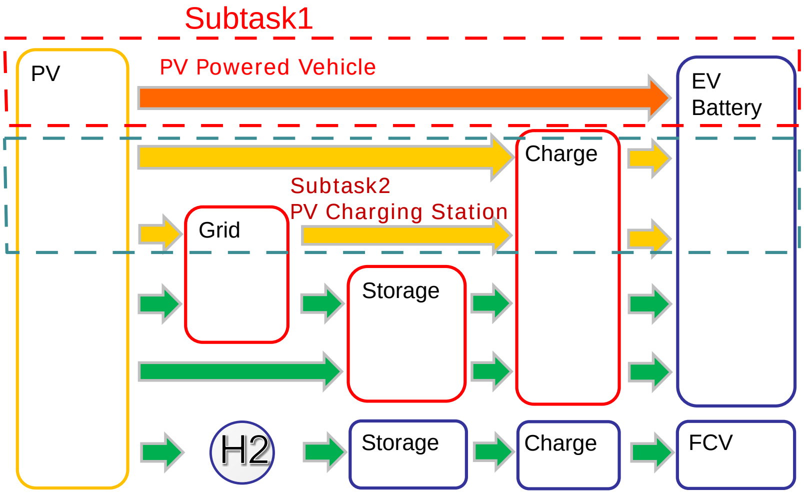


Fig. 1-4 Concept of IEA PVPS Task17: PV and Transport[15]

Task17 consists of the four Subtasks shown in Fig. 1-5 and Table 1-2. Subtask 1 involves discussions into the commercialization of PV-powered vehicles, not only passenger cars but also commercial vehicles. Subtask 2 involves discussions about charging infrastructure that uses PV power. Although the supplying of power from electric vehicles to nearby facilities or the grid, so-called “V2X”, is also possible, the present focus is on charging stations. In parallel with these discussions, Subtask 3 involves discussions into effects of the commercialization and adoption of PV-powered vehicles and PV-based charging infrastructure, and will consider a road map or the like into the expansion of PV use in the transport sector. Subtask 4 involves global dissemination of the results obtained by the activities of Task17 and public relations activities to form a bridge between the PV industry and the automotive industry.

The solar irradiation of a vehicle studied in this report is data that is essential in investigating the issues toward commercialization of PV-powered vehicles and their expected benefits. The results of this report and follow-up activities will also contribute to activities under Task 17.

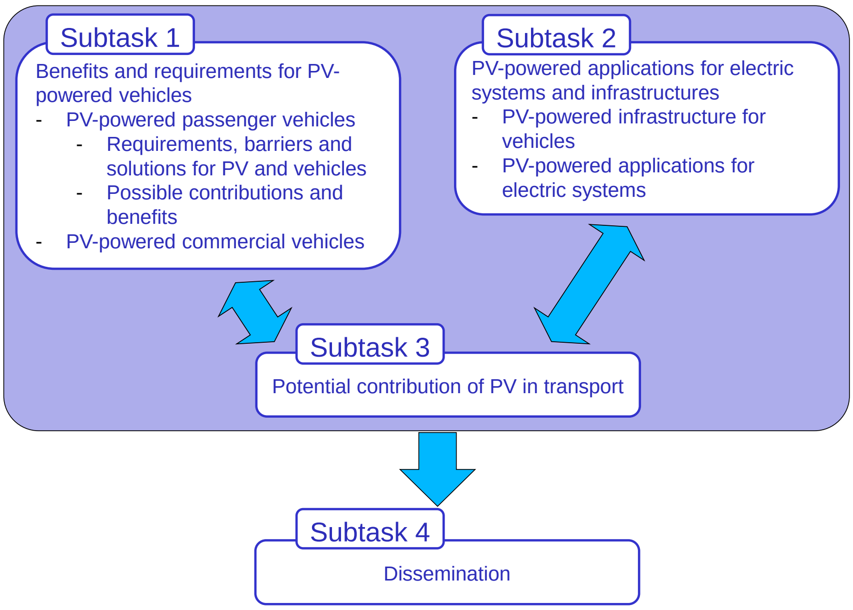


Fig. 1-5 Structure of IEA PVPS Task17: PV and Transport

Table 1-2 Outline of IEA PVPS Task17's Subtasks: PV and Transport[16]

Subtask 1： Benefits and requirements for PV-powered vehicles	In order to deploy PV-powered vehicles, Subtask 1 will clarify expected/possible benefits and requirements for utilizing PV-powered vehicles for driving and auxiliary power. Targeted PV-powered vehicles are passenger cars (PHVs and EVs) and commercial vehicles currently, and other vehicles (buses, trains, ships, airplanes, etc.) may be included in the future.
Subtask 2： PV-powered applications for electric systems and infrastructures	For promoting electrification of vehicles, not only charging electricity by itself on board, but also charging renewable electricity at the environmental friendly infrastructure, e.g. PV-powered charging stations, will be feasible. Subtask 2 will discuss energy systems to design PV-powered infrastructures for EVs charge.
Subtask 3： Potential contribution of PV in transport	For reducing CO_2 emissions from the transport, changing energy sources from conventional to renewable energy, especially PV which have a good track record in supplying electricity by utility-scale, should be accelerated. Also, new social models by innovative 'PV and Transport' are expected. In parallel with Subtask 1 and Subtask 2, Subtask 3 will develop a roadmap for deployment of PV-powered vehicles and applications.
Subtask 4： Dissemination	A considerable amount of new knowledge is expected to be developed under this task. It is important that this knowledge is disseminated to the public and end users in a timely manner. Subtask 4 will focus on information dissemination procedures that effectively release key findings to stakeholders such as PV industry, transport industry such as automobile industry, battery industry, and energy service provider.

（2） Other Initiatives

Aside from IEA PVPS, other international discussions into the adoption of PV-powered vehicles have commenced.

As one example, in Europe, Solar Power Europe, an industry association related to solar power and solar energy, launched the Solar Mobility Task Force in the summer of 2018 and started discussions into expanding the use of solar power in the transport sector. It is expected that a report (white paper) into business models and opportunities, produced via workshops with experts from the automotive industry and focusing on reductions in CO_2 emissions in the transport sector, the importance of infrastructure for promoting fuel conversion, and the potential of the PV market, will be announced in spring 2019.

The 1st Solar Mobility Forum was also held as a side event of the 35th European Photovoltaic Solar Energy Conference and Exhibition (35th EU-PVSEC) held in September 2018. The forum was organized by SOLAR

UNITED, an industry group in Europe, and featured experts in Europe and Japan describing electrification projects by car manufacturers, the potential and expectations of solar power in the transport sector, and also their experience and current projects of installing PV on cars. A summary of international activities was also given by IEA PVPS Task 17. The 2nd Solar Mobility Forum will be scheduled to be held in September 2019 in conjunction with the 36th European Photovoltaic Solar Energy Conference and Exhibition (36th EU-PVSEC).

The International Electrotechnical Commission (IEC), which discusses standardization of performance evaluations of industrial products including PV, has also started to discuss the installation of PV on vehicles. Although various initiatives into the development and adoption of PV-powered vehicles have begun, to achieve widespread adoption across the world, a certain level of standardized guidelines for product development will be necessary. For this reason, discussions are being conducted with an awareness that it will be necessary to provide a standard method for evaluating product performance.

2. Preliminary Study on Solar Irradiation of PV-Powered Vehicles

2.1. Objective

When a PV system is installed on an electric vehicle (including a plug-in hybrid vehicle) and the generated power is used to run the car, there are expected benefits such as a reduction in CO_2 emissions compared to when the vehicle is externally charged using the grid and a reduction in the frequency of external charging operations[17]. The significance of these effects is influenced by the amount of power generated by the PV system, the driving mode of the vehicle, the balance between generated and consumed power, and the capacity of the onboard battery.

Although the amount of power generated by a PV system depends on factors such as solar irradiation and temperature, the most important of these factors is solar irradiation. The solar irradiation of a PV-powered vehicle depends on the environments during parking and driving. The solar irradiation during driving fluctuates according to the surrounding environment of the route, such as whether buildings and structures are shading the vehicle. As a result, solar irradiation may fall compared to roof or rooftop solar radiation on a building, with large fluctuations in short cycles. To promote development and adoption of PV-powered vehicles, it is necessary to understand the effects of onboard PV in view of such factors and appropriately design the system.

In response to this situation, as a preliminary study on solar irradiation of a PV-powered vehicle, the solar irradiation acquired by actual vehicles in motion was measured. The features and tendencies of this insolation amount were identified, and a comparison with the solar irradiation of roof or rooftop PV on a building was performed.

2.2. Method of Measuring Acquired Insolation

Fig. 2-1 shows the measurement locations of the solar irradiation by vehicles in this preliminary study, and Table 2-1 shows the method for measuring solar irradiation. In this study, solar irradiation was measured at two locations, Sapporo City in Hokkaido (hereinafter, simply “Sapporo”) and Miyazaki City in Miyazaki Prefecture (hereinafter, simply “Miyazaki”). These locations are positioned in the north and south of the Japanese archipelago that extends in the north-south direction. Measurement in Sapporo was conducted in cooperation with the Japan Weather Association. Measurement in Miyazaki was performed in cooperation with University of Miyazaki. Note that since this is a preliminary study that precedes a full-scale investigation, to make effective use of existing equipment, there were some differences in measurement methods and measurement conditions between the two locations.

Solar irradiation was measured at one position on the roof of a car in Sapporo using three pyranometers that have different response speeds. In Miyazaki however, measurement was performed at a total of five positions which were the four sides of the vehicle, that is, the front, rear, right and left, in addition to the roof. The sampling interval of the measurement data was set at 0.1 seconds in Sapporo and at 1 second in Miyazaki. Measurement was conducted in the fall of 2018, and solar irradiation was measured three times a day (sometimes just once a day in Miyazaki) to investigate the influence of solar elevation.

To examine the influence of the environment (i.e., the car being shaded by buildings and the like), a measurement route including an urban section, a high-rise section, and an open-air section was chosen. The measurement route in Sapporo also included an underpass section. Note that the detailed measurement routes and their environments are shown together with the measurement results in the next section (2.3).

Fig. 2-1 Irradiation measurement locations in preliminary study[18]

Table 2-1 Method of measuring solar irradiation of vehicles

Measurement Location	Sapporo City, Hokkaido (near N43°04', E141°21')	Miyazaki City, Miyazaki Prefecture (near N31°53', E131°25')
Insolation Measurement Positions	One (Horizontal irradiation on vehicle roof)	Five (Horizontal irradiation on vehicle roof and four upper side surfaces of vehicle: on front, rear, left, and right sides)
Pyranometer (See Table 2-2)	- Secondary standard (x1) - Second class (x1) - Silicon type (x1) (Data produced by these pyranometers were compared.)	- Second class (x5)
Sampling Interval	0.1 seconds	1 second
Measurement Period	Mid-September to late October, 2018	Mid-September to early October, 2018
Measurement Time Zones	First run: around 08:15 to around 09:15 Second run: around 11:15 to around 12:15 Third run: around 14:15 to around 15:15	First run: around 09:00 to around 10:00 Second run: around 11:30 to around 12:30 Third run: around 15:00 to around 16:00
Measurement Route	About 18km including the following: - Urban section - High-rise section - Open-air section - Underpass section	About 30km including the following: - Urban section - High-rise section - Open-air section
Insolation reference Point	Japan Meteorological Agency (JMA), Sapporo Regional Headquarters - Kita 2-Jo Nishi 18-Chome, Chuo-ku, Sapporo - near N43°3.6', E141°19.6' - Pyranometer type: secondary standard *Data produced as one-minute totals for every-second measurements (one-minute values of surface observation data produced by JMA)	University of Miyazaki (National University Corporation) - 1-1 Gakuen Kibanadai-nishi, Miyazaki - near N31°49', E131°24' - Pyranometer type: second class *Data produced as 10-second averages for data measured every second
Measured by	Japan Weather Association	University of Miyazaki

Table 2-1 Main specifications of pyranometers used to measure solar irradiation of vehicles[19]

Pyranometer Type	Secondary Standard	Second Class	Silicon Type	
Response time (Output: 95%)	<0.5s	1s	<1ms	Time taken for output to reach 95%
Stability	±0.5%/5 years	±1%/ year	±2%/year	Change in output due to changes in sensor over time
Directional Characteristics	±10W/m^2	±25W/m^2	±2% (45°), ±5% (75°)	Output error when light with an intensity of 1,000W/m^2 is incident from all directions and angles
Temperature characteristics	<1% (⊿T50)	<3% (-10°C to +40°C)	-0.4 ±0.04%/°C	Output error due to change in temperature
Range of measurement wavelengths	285 to 3,000nm	285 to 3,000nm	360 to 1,120nm	Wavelength range that can be detected by the sensor

2.3. Measurement Results

Measurement results for Sapporo and Miyazaki are given below.

2.3.1. Measurement Results in Sapporo, Hokkaido

(1) Measurement Conditions and Measurement Route

The measurement conditions used in Sapporo are shown in Table 2-3. In Sapporo, measurements were taken on five days between September 20, 2018 and October 22, 2018. Solar irradiation acquired by a vehicle is influenced by the shadows of surrounding buildings and the like. Since it was assumed that this influence depends on solar elevation, measurements were taken three times a day in different time zones.

To identify the fall in solar irradiation due to shadows and the like, comparisons were performed with the insolation at a reference point (JMA Sapporo Regional Headquarters). Since it was assumed that this fall would also be affected by irradiation components (whether direct solar irradiation or diffuse solar irradiation), measurement was performed on both fine and cloudy days. Solar irradiation at the reference point on the measurement dates is shown in Fig. 2-2, and the solar elevation and solar orientation during the measurement time zones are shown in Table 2-4.

In addition, to identify differences that depend on the direction in which the vehicle is traveling (that is, the orientation of the sun viewed from the vehicle), measurement was also performed for both clockwise travel and anticlockwise travel on the measurement route shown below.

Table 2-3 Measurement dates and weather in Sapporo[19]

Date of measurement	Route	Weather		
		First run (around 8:15 to around 9:15)	Second run (around 11:15 to around 12:15)	Third run (around 14:15 to around 15:15)
Sep. 20, 2018 (Thursday)	Clockwise	Sunny	Sunny	Clear
Sep. 25, 2018 (Tuesday)	Anticlockwise	Slightly cloudy	Slightly cloudy	Cloudy
Sep. 28, 2018 (Friday)	Clockwise	Sunny, partly cloudy	Cloudy, occasionally scattered showers	Cloudy, occasionally scattered showers
Oct. 19, 2018 (Friday)	Anticlockwise	Very clear	Clear	Clear
Oct. 22, 2018 (Monday)	Clockwise	Clear	Clear	Clear

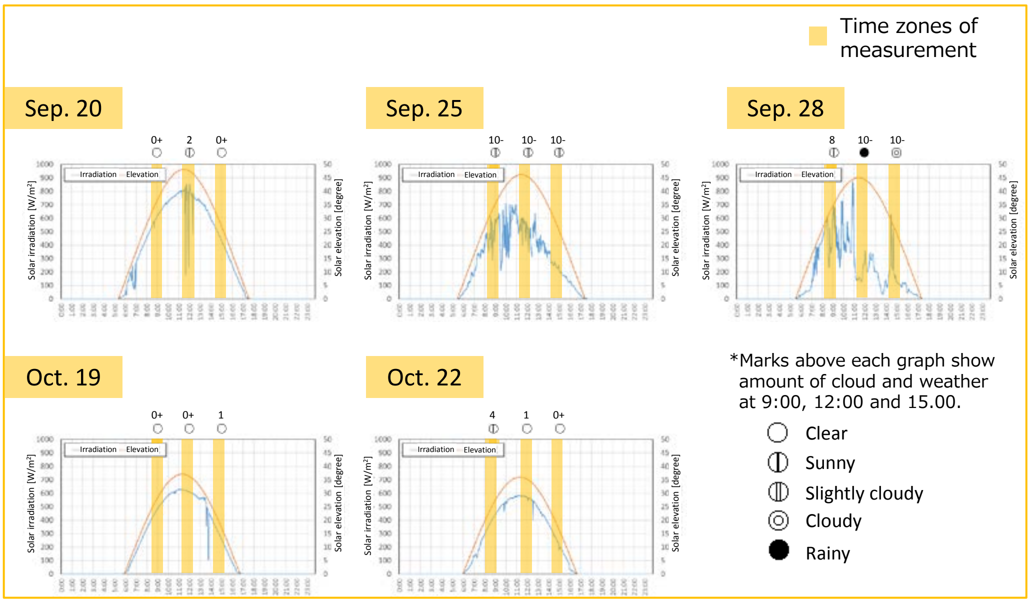


Fig. 2-2 Solar Irradiation at JMA Sapporo regional headquarters (reference point)[19]

Table 2-4 Solar elevation and solar orientation during measurement time zones in Sapporo[19]

Date of measurement	Solar elevation※1		
	First run (around 8:15 to around 9:15)	Second run (around 11:15 to around 12:15)	Third run (around 14:15 to around 15:15)
Sep. 20, 2018 (Thu.)	31.6 to 40.2	47.9 to (48.1) to 46.3	33.7 to 22.8
Sep. 25, 2018 (Tue.)	29.0 to 37.5	46.1 to (46.2) to 44.9	31.8 to 22.7
Sep. 28, 2018 (Fri.)	27.1 to 37.1	45.0 to (45.0) to 43.0	30.9 to 20.4
Oct. 19, 2018 (Fri.)	24.2 to 31.7	37.0 to (37.0) to 35.4	23.8 to 14.5
Oct. 22, 2018 (Mon.)	19.7 to 28.3	(36.0) to 36.0 to 33.8	23.1 to 13.9
Date of measurement	Solar Orientation※2		
	First run (around 8:15 to around 9:15)	Second run (around 11:15 to around 12:15)	Third run (around 14:15 to around 15:15)
Sep. 20, 2018 (Thu.)	122.7 to 138.7	173.2 to 200.1	233.8 to 248.7
Sep. 25, 2018 (Tue.)	122.5 to 137.6	175.2 to 196.9	232.9 to 245.6
Sep. 28, 2018 (Fri.)	121.9 to 139.7	177.0 to 200.9	232.1 to 246.6
Oct. 19, 2018 (Fri.)	132.6 to 148.4	178.0 to 197.4	227.9 to 241.0
Oct. 22, 2018 (Mon.)	127.5 to 142.9	181.2 to 200.2	226.9 to 240.0

※1: (Solar elevation) Value in brackets for the second run is elevation when the sun is due south

※2: (Solar orientation) East: 90°, South-east: 135°, South: 180°, South-west: 225°, West: 270°

Fig. 2-3 and Table 2-5 show the route of travel in Sapporo, and Table 2-6 shows the road width of each section on the route. The route included an urban section, a high-rise section, an open-air section, and an underpass section, and it was assumed that solar irradiation in the urban section and the high-rise section would be affected by surrounding buildings. The open-air section was assumed to be less affected, while the underpass section is a section where solar irradiation is not acquired. The directions in which the vehicle travels are approximately east-west (both east to west and west to east) and north-south (both south to north and north to south).

- Red line: Measurement route
- In case of clockwise: passing open-air section (east) twice and open-air section (west) once
- In case of anticlockwise: passing open-air section (east) once and open-air section (west) twice

Fig. 2-3 Route used for measurement in Sapporo[created from 18]

Table 2-5 Route used for measurement in Sapporo[19]

Clockwise					Anticlockwise				
Section	Type	Direction	Distance from start (km)	Section distance (km)	Section	Type	Direction	Distance from start (km)	Section distance (km)
1-a	Urban section 1	West to east	0.00 to 1.56	1.56	2-a	Urban section 1	West to east	0.00 to 1.56	1.56
1-b	High-rise section 1	West to east, north to south	1.56 to 2.90	1.34	2-b	High-rise section 2	West to east, north to south, east to west	1.56 to 4.51	2.95
1-c	Underpass section	North to south	2.90 to 3.79	0.88	2-c	Urban section 3	North to south, east to west	4.51 to 6.27	1.75
1-d	Urban section 2	North to south	3.79 to 4.19	0.40	2-d	Open-air section (west)	South to north	6.27 to 8.37	2.10
1-e	Open-air section (east)	West to east, north to south, east to west	4.19 to 6.75	2.57	2-e	Open-air section (east)	West to east, north to south, east to west	8.37 to 10.94	2.57
1-f	Open-air section (west)	South to north	6.75 to 8.85	2.10	2-f	Open-air section (west)	South to north	10.94 to 13.04	2.10
1-g	Open-air section (east)	West to east, north to south, east to west	8.85 to 11.42	2.57	2-g	Urban section 2	South to north	13.04 to 13.44	0.40
1-h	Urban section 3	East to west, south to north	11.42 to 13.18	1.76	2-h	Underpass section	South to north	13.44 to 14.32	0.88
1-i	High-rise section 2	West to east, south to north, east to west	13.18 to 16.13	2.95	2-i	High-rise section 1	South to north, east to west	14.32 to 15.66	1.34
1-j	Urban section 1	East to west	16.13 to 17.69	1.56	2-j	Urban section 1	West to east	15.66 to 17.22	1.56

Table 2-6 Estimated road width of route sections in Sapporo[19]

Section		Type	Section distance (km)	Estimated road width	Comments
1-a	2-j	Urban section 1	1.56	15 to 17m	
1-b	2-i	High-rise section 1	1.34	18 to 21m 50m	This section passes the high-rise buildings in front of Sapporo Station. Four-lane road on both sides of the Sousei River and drainage space
1-c	2-h	Underpass section	0.88	9m	Two lane underpass
1-d	2-g	Urban section 2	0.40	50m	
1-e	2-e	Open-air section (east)	2.57	12m 7 to 12m 16m	Minami 7-jo Ohashi bridge There are buildings and trees to the east Minami 19-jo Ohashi Bridge
1-f	2-d, 2-f	Open-air section (west)	2.10	7 to 10m	There are buildings and trees to the west
1-g	(2-e)	Open-air section (east)	2.57	12m 7 to 12m 16m	Same as 1-e
1-h	2-c	Urban section 3	1.76	20m 15m	(First half) Ring road (Second half) Tramline in center of road
1-i	2-b	High-rise section 2	2.95	16 to 17m 13 to 14m 20 to 24m	Kikusui Asahiyama Park Street South of Susukino intersection North of Susukino intersection: There are trees on the central division
1-j	2-a	Urban section 1	1.56	15 to 17m	Same as 1-a

(2) Characteristics of Solar Irradiation According to Route Section and Time Zone

The characteristics of the solar irradiation on the vehicle roof according to route section and time zone are summarized here based on the measurement results on September 20, 2018 (Day 1). A comparison of cumulative values of solar irradiation and the reference point, including other measurement days, is given in Section (3).

Figs. 2-4 to 2-6 show the measurement results of the first to third runs on September 20, 2018 (Day 1).

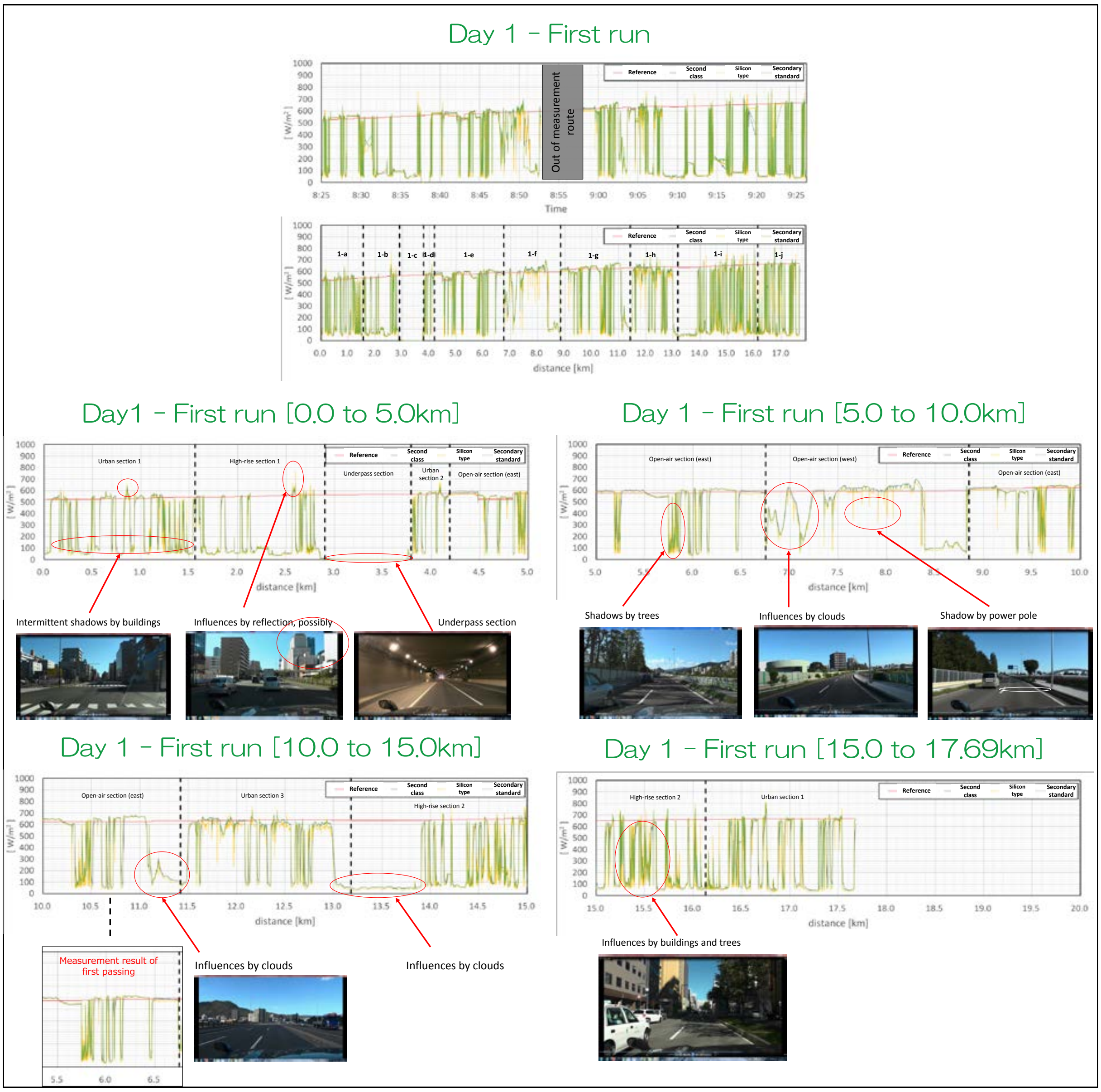


Fig. 2-4 September 20, 2018 (Day 1) in Sapporo: Measurement results for solar irradiation during the First run[19]

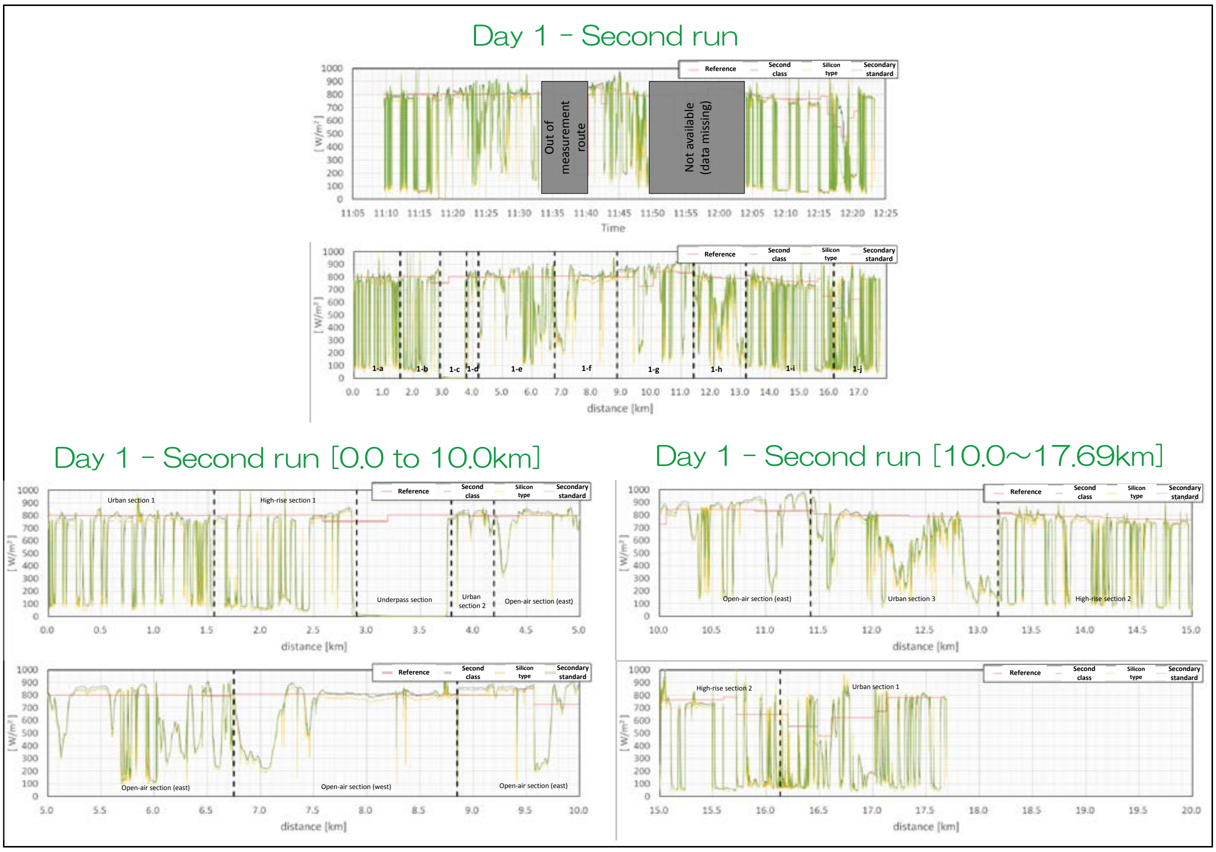


Fig. 2-5 September 20, 2018 (Day 1) in Sapporo: Measurement results for solar irradiation during the Second run[19]

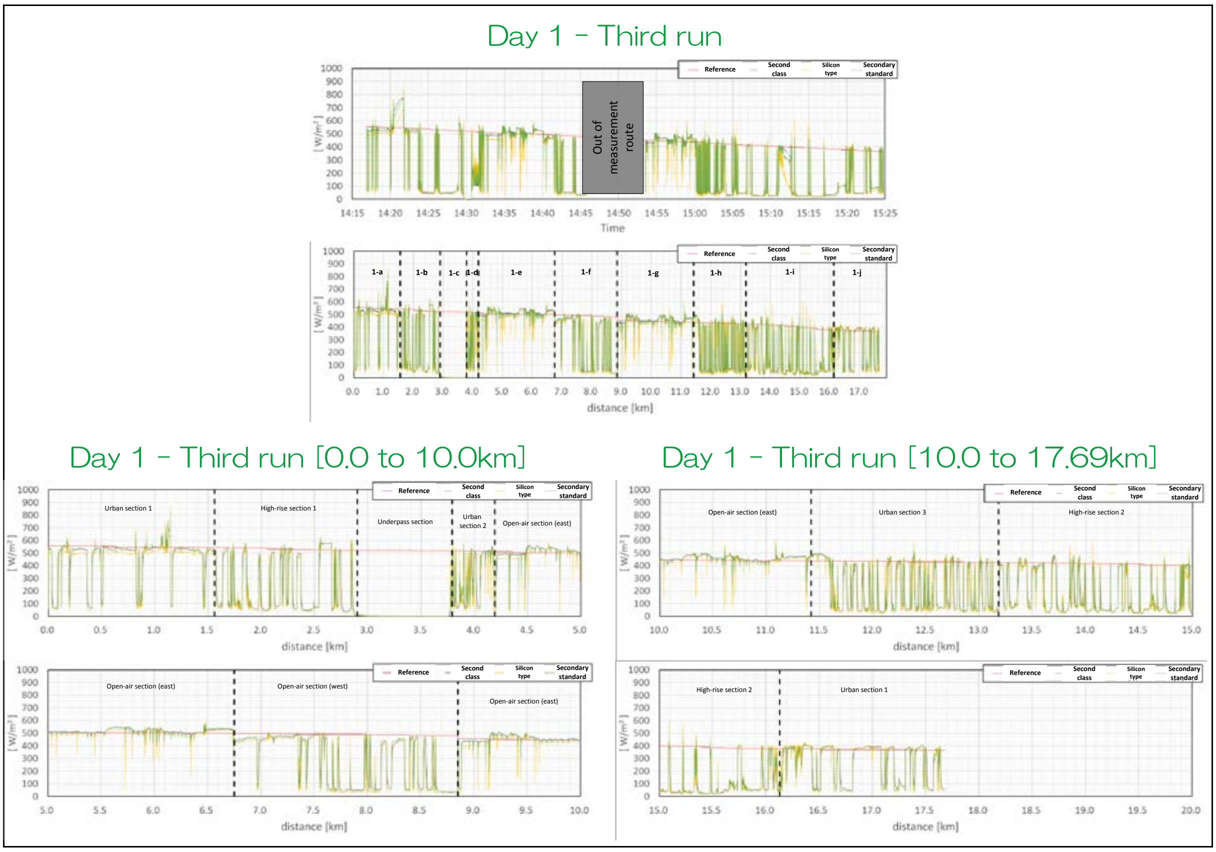


Fig. 2-6 September 20, 2018 (Day 1) in Sapporo: Measurement results for solar irradiation during the Third run[19]

<Characteristics according to route section>

In urban sections and high-rise sections, solar irradiation fell and fluctuated due to the shadows of buildings and trees along the road, with this especially frequent in high-rise sections. Even in open-air sections, solar irradiation sometimes fell due to the shadows of buildings, trees, and power poles along the road.

Although the fall in solar irradiation due to the shadows of buildings, trees, and the like may be smaller than the influence of clouds in terms of cumulative solar irradiation over a certain period, the variations in solar irradiation that occur on a vehicle roof have a characteristic of occurring at extremely short cycles and with a large range of fluctuation.

In urban sections and high-rise sections, solar irradiation sometimes exceeded the solar irradiation at the reference point, and it is thought that this could be due to an increase in acquired insolation caused by reflections from buildings.

Table 2-7 Measurement results of solar irradiation of vehicle roof in Sapporo: Characteristics according to route section

Urban sections	- Shadows of buildings and trees occur intermittently, so that solar irradiation fluctuates. - Solar irradiation may exceed irradiation at the reference point, and it is thought that this could be due to an increase in solar irradiation caused by reflections from buildings.
High-rise sections	- Large fall in solar irradiation due to shadows from buildings and trees. - Solar irradiation may exceed irradiation at the reference point, and it is thought that this could be due to an increase in solar irradiation caused by reflections from buildings.
Underpass sections	- These sections are underground, so there is no solar irradiation.
Open-air sections	- Surrounding buildings have little effect compared to urban and high-rise sections. However, short-cycle fluctuations (falls) in solar irradiation still occur due to buildings, trees, and power poles along the road.

<Characteristics according to time zone>

Shadows from buildings, trees, power poles, and the like occur in urban sections, high-rise sections, and partly in open-air sections, causing a fall in solar irradiation. During the second run (when the sun is substantially due south), the solar elevation is high, which means that the frequency of falls in solar irradiation due to shadows is low. The range of fluctuations in solar irradiation though is larger.

During the first and third runs when the solar elevation is low, solar irradiation falls frequently due to shadows, but when the sun is oriented close to the direction of the road (i.e., the direction of travel), shadows that affect solar irradiation are produced less frequently.

Table 2-8 Measurement results of solar irradiation of vehicle roof in Sapporo: Characteristics according to time zone

Urban sections	Urban section 1: East-west direction - During both the first and second runs, shadows appeared intermittently, but there was no large difference in the frequency of shadows. The road runs in the east-west direction, and the lack of difference is believed to be caused by the high solar elevation during the second run. However, the range of fluctuations in solar irradiation was larger during the second run. - During the third run, there were fewer fluctuations due to shadows. It is thought that this is because the solar orientation is closer to the direction of the road (the direction of travel) than in the first and second runs. Urban section 2: (Mostly) South-north direction to East-west direction - There was little fluctuation during the second run, where the solar elevation is high and the solar orientation is close to the direction of the road. - There was some fluctuation during the first run, and very large fluctuations during the third run. It is thought that this is caused by the low solar elevation and the difference between the orientation of the sun and the direction of the road. Urban section 3: East-west direction → (mostly) North-south direction - The overall tendency was the same as in Urban section 2, but the fluctuations and falls in solar irradiation during the second run were larger.
High-rise sections	High-rise section 1: (Mostly) East-west direction to North-south direction - There were large falls in solar irradiation due to the shadows of buildings and trees during all of the first to third runs. - During the second run where the solar elevation was high, there were slightly more areas where the vehicle was not shaded, but the range of fluctuations in solar irradiation was large. High-rise section 2: East-west direction to North-south direction to East-west direction) - The overall tendency was the same as in High-rise section 1, however, during the second run where the solar elevation is high and the orientation of the sun was close to the direction of the road, irradiation was less affected by shadows.
Open-air sections	Open-air section (east): East-west direction to (mostly) North-south direction to East-west direction - There was no large difference in the frequency of shadows due to buildings, trees, and power poles between the first and second runs, but the locations of shadows differed, which is believed to be due to the orientation of the sun. - Shadows were infrequently encountered during the third run, which is thought to be due to buildings being located on the east side (or east-southeast side). Open-air section (west): North-south direction - Shadows were most frequently encountered during the third run and were infrequent during the first and second runs. It is thought that this is due to buildings being located mainly on the west side (west-north-west side).
Other observations (common to all sections)	- The range of fluctuation in solar irradiation due to shadows was greatest on the second run where the solar elevation and solar intensity were high.

(3) Comparison between Acquired Insolation on Vehicle Roof and at the Reference Point

The results of measurements taken three times daily for five days in Sapporo are given here.

Table 2-9 shows, for the measurement results produced on September 20, 2018 (Day 1) given in (2), the solar intensity and cumulative solar irradiation at the reference point (JMA Sapporo Regional Headquarters), the cumulative value of solar irradiation on the vehicle roof, and ratios between the cumulative values.

A certain fall in solar irradiation due to shadows of buildings, trees, power poles and the like was confirmed. When the cumulative value for the acquired insolation on the vehicle roof was compared with the irradiation at the reference point, while some of the difference will be due to the difference in pyranometer used for measurement, the ratio was about 54% for the first run, about 69% for the second run, and about 56% for the third run. The main factors that affect the fall in solar irradiation are thought to be the frequency of shadows and the intensity of solar irradiation when no shadows are present, so that the fall in solar irradiation during the second run where the solar elevation and solar intensity were high (the sun was almost due south) was lower than for the other runs.

Table 2-9 Measurement results of solar irradiation on September 20, 2018 (Day 1) in Sapporo (Summary)[19]

Measurement date: Sep 20, 2018 (Tuesday)		First run (Sunny) (around 8:15 to around 9:15)	Second run (Sunny) (around 11:15 to around 12:15)	Third run (Clear) (around 14:15 to around 15:15)
Reference point	Solar intensity	Around 550 to 650 W/m^2 (increasing over time)	Around 800 W/m^2	Around 550 to 400 W/m^2 (decreasing over time)
	Cumulative solar irradiation	564.2 Wh/m^2	666.4 Wh/m^2	462.2 Wh/m^2
Vehicle roof irradiation (for each pyranometer)	Secondary Standard (ratio to reference point)	308.0 Wh/m^2 (54.6%)	462.5 Wh/m^2 (69.4%)	264.6 Wh/m^2 (57.2%)
	Second Class (ratio to reference point)	298.6 Wh/m^2 (52.9%)	469.7 Wh/m^2 (70.5%)	264.2 Wh/m^2 (57.2%)
	Silicon Type (ratio to reference point)	302.8 Wh/m^2 (53.7%)	445.6 Wh/m^2 (66.9%)	246.9 Wh/m^2 (53.4%)

Table 2-10 shows the cumulative solar irradiation per section of route and per pyranometer, which was measured on September 20, 2018 (Day 1). Figs. 2-7 to 2-8 and Table 2-11 depict a chart of the measurement results, and for measurement results produced using a secondary standard pyranometer out of these solar irradiation values, the ratio of solar irradiation on a section of the route to irradiation at the reference point.

Table 2-10 Measurement results for solar irradiation on September 20, 2018 (Day 1) in Sapporo[19]

<First run (8:25 to 9:27): Sunny>

Sec.	Type	Distance from start (km)	Secondary standard (Wh/m²)	Second class (Wh/m²)	Silicon type (Wh/m²)	Reference point (Wh/m²)
1-a	Urban section 1	0.00 to 1.56	37.4	37.5	36.6	48.0
1-b	High-rise section 1	1.56 to 2.90	17.9	17.4	16.3	66.6
1-c	Underpass section	2.90 to 3.79	0.1	0.0	0.1	10.2
1-d	Urban section 2	3.79 to 4.19	15.1	15.2	15.2	16.8
1-e	Open-air section (east)	4.19 to 6.75	60.8	60.5	59.5	67.8
1-f	Open-air section (west)	6.75 to 8.85	30.5	34.0	32.8	49.7
1-g	Open-air section (east)	8.85 to 11.42	46.5	46.7	45.6	58.8
1-h	Urban section 3	11.42 to 13.18	37.1	36.4	35.0	59.3
1-i	High-rise section 2	13.18 to 16.13	39.6	37.8	38.3	139.6
1-j	Urban section 1	16.13 to 17.69	23.0	13.1	23.4	47.3
Total		0.00 to 17.69	308.0	298.6	302.8	564.2

<Second run (11:09 to 12:23): Sunny>

Sec.	Type	Distance from start (km)	Secondary standard (Wh/m²)	Second class (Wh/m²)	Silicon type (Wh/m²)	Reference point (Wh/m²)
1-a	Urban section 1	0.00 to 1.56	37.5	37.6	35.6	46.2
1-b	High-rise section 1	1.56 to 2.90	33.9	33.9	32.4	63.4
1-c	Underpass section	2.90 to 3.79	0.9	0.8	0.9	13.1
1-d	Urban section 2	3.79 to 4.19	9.4	9.5	9.2	9.6
1-e	Open-air section (east)	4.19 to 6.75	90.6	91.2	88.6	106.8
1-f	Open-air section (west)	6.75 to 8.85	48.0	47.7	45.7	51.1
1-g	Open-air section (east)	8.85 to 11.42	73.2	73.9	71.5	84.4
1-h	Urban section 3	11.42 to 13.18	38.7	38.7	38.1	57.8
1-i	High-rise section 2	13.18 to 16.13	93.1	92.0	89.4	170.8
1-j	Urban section 1	16.13 to 17.69	37.3	44.4	34.2	63.4
Total		0.00 to 17.69	462.5	469.7	445.6	666.4

<Third run (14:17 to 15:25): Clear＞

Sec.	Type	Distance from start (km)	Secondary standard (Wh/m²)	Second class (Wh/m²)	Silicon type (Wh/m²)	Reference point (Wh/m²)
1-a	Urban section 1	0.00 to 1.56	50.1	50.1	46.0	50.9
1-b	High-rise section 1	1.56 to 2.90	22.4	21.8	20.5	64.1
1-c	Underpass section	2.90 to 3.79	0.1	0.0	0.1	8.6
1-d	Urban section 2	3.79 to 4.19	6.4	5.9	6.5	13.6
1-e	Open-air section (east)	4.19 to 6.75	66.8	67.1	64.3	66.4
1-f	Open-air section (west)	6.75 to 8.85	19.3	18.9	17.8	45.3
1-g	Open-air section (east)	8.85 to 11.42	44.6	45.0	43.1	44.2
1-h	Urban section 3	11.42 to 13.18	13.5	13.3	12.9	28.2
1-i	High-rise section 2	13.18 to 16.13	29.7	30.2	24.5	114.3
1-j	Urban section 1	16.13 to 17.69	11.7	11.8	11.2	26.7
Total		0.00 to 17.69	264.6	264.2	246.9	462.2

As can be seen in Figs. 2-7 to 2-8 and Table 2-11, the ratio of the solar irradiation acquired by the vehicle to the irradiation at the reference point was high for the open-air sections and low for the high-rise sections (the underpass section was excluded). Urban sections were in the middle of these, with no great difference between urban section 1 (1-a) and urban section 2 (1-d) and the open-air section.

Among the ratios for the first to third runs, the ratios were fundamentally highest for the second run where the solar elevation is high and shadows are short and unlikely to shade the car. However, for urban section 1 (1-a) and open-air section (east) (1-e and 1-g), the ratios in the third run were the highest. This suggests that the relationship between the solar orientation and the direction of the road has a great effect, even in the open-air section.

Figs. 2-9 to 2-16 and Tables 2-12 to 2-15 are charts of measurement results for the second to fifth days and show the results of comparisons between the measurement results produced by the secondary standard pyranometer, with irradiation at the reference point for each route section.

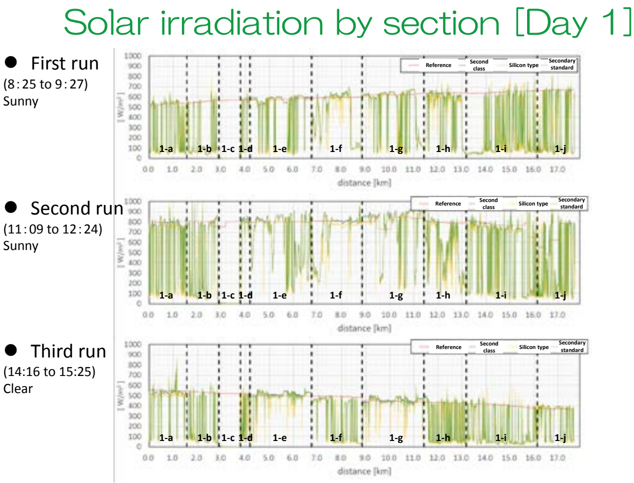


Fig. 2-7 Measurement results for solar irradiation on September 20, 2018 (Day 1) in Sapporo[19]

Table 2-11 Measurement results for solar irradiation on September 20, 2018 (Day 1) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

Sec.	Type	Distance from start (km)	First run (8:25 to 9:27)		Second run (11:09 to 12:24)		Third run (14:16 to 15:25)	
			(Wh/m^2)	(ratio to reference point)	(Wh/m^2)	(ratio to reference point)	(Wh/m^2)	(ratio to reference point)
1-a	Urban section 1	0.00 to 1.56	37.4	77.9%	37.5	81.2%	50.1	98.4%
1-b	High-rise section 1	1.56 to 2.90	17.9	26.9%	33.9	53.5%	22.4	34.9%
1-c	Underpass section	2.90 to 3.79	0.1	1.0%	0.9	6.9%	0.1	1.2%
1-d	Urban section 2	3.79 to 4.19	15.1	89.9%	9.4	97.9%	6.4	47.1%
1-e	Open-air section (east)	4.19 to 6.75	60.8	89.7%	90.6	84.8%	66.8	100.1%
1-f	Open-air section (west)	6.75 to 8.85	30.5	61.4%	48.0	93.9%	19.3	42.6%
1-g	Open-air section (east)	8.85 to 11.42	46.5	79.1%	73.2	86.7%	44.6	100.9%
1-h	Urban section 3	11.42 to 13.18	37.1	62.6%	38.7	67.0%	13.5	47.9%
1-i	High-rise section 2	13.18 to 16.13	39.6	28.4%	93.1	54.5%	29.7	26.0%
1-j	Urban section 1	16.13 to 17.69	23.0	48.6%	37.3	58.8%	11.7	43.8%
Total		0.00 to 17.69	308.0	54.6%	462.5	69.4%	264.6	57.2%

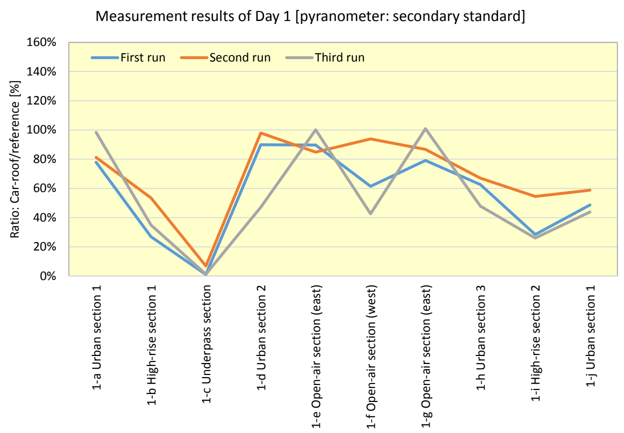


Fig. 2-8 Measurement results for solar irradiation on September 20, 2018 (Day 1) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

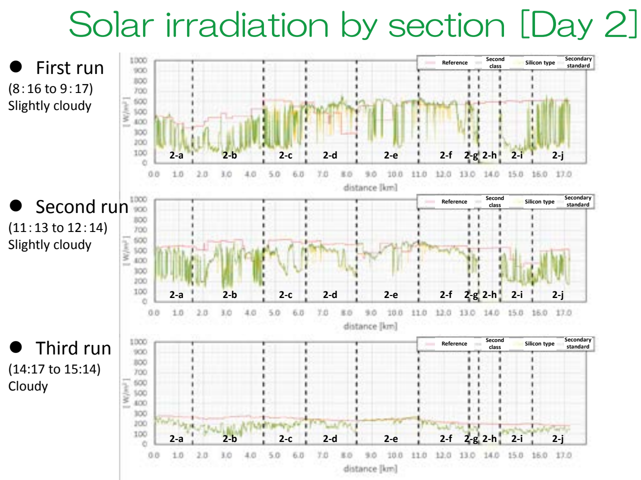


Fig. 2-9 Measurement results for solar irradiation on September 25, 2018 (Day 2) in Sapporo[19]

Table 2-12 Measurement results for solar irradiation on September 25, 2018 (Day 2) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

Sec.	Type	Distance from start (km)	First run (8:16 to 9:17)		Second run (11:13 to 12:14)		Third run (14:17 to 15:14)	
			(Wh/m²)	(ratio to reference point)	(Wh/m²)	(ratio to reference point)	(Wh/m²)	(ratio to reference point)
2-a	Urban section 1	0.00 to 1.56	26.4	76.1%	28.6	60.9%	17.4	76.7%
2-b	High-rise section 2	1.56 to 4.51	37.3	49.6%	92.3	70.9%	31.9	58.5%
2-c	Urban section 3	4.51 to 6.27	20.9	47.9%	38.5	74.2%	14.8	72.5%
2-d	Open-air section (west)	6.27 to 8.37	87.9	132.8%	35.4	80.5%	11.7	83.6%
2-e	Open-air section (east)	8.37 to 10.94	57.7	94.3%	60.5	100.5%	23.9	100.0%
2-f	Open-air section (west)	10.94 to 13.04	54.8	94.3%	25.7	93.5%	14.7	84.0%
2-g	Urban section 2	13.04 to 13.44	7.6	73.1%	6.7	80.7%	5.7	70.4%
2-h	Underpass section	13.44 to 14.32	0.1	1.1%	0.0	0.0%	0.0	0.0%
2-i	High-rise section 1	14.32 to 15.66	13.9	28.5%	21.8	50.5%	12.0	67.0%
2-j	Urban section 1	15.66 to 17.22	16.5	44.2%	27.4	57.7%	11.2	77.8%
Total		0.00 to 17.22	323.1	72.7%	336.9	71.8%	143.2	72.8%

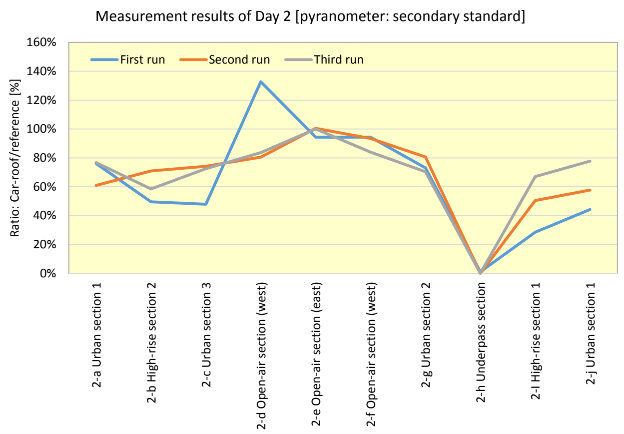


Fig. 2-10 Measurement results for solar irradiation on September 25, 2018 (Day 2) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

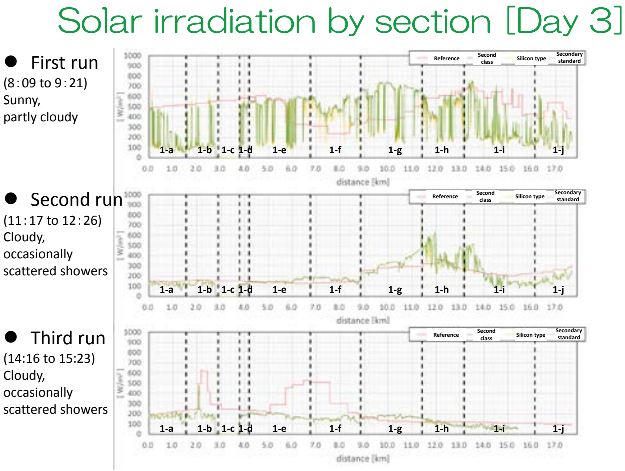


Fig. 2-11 Measurement results for solar irradiation on September 28, 2018 (Day 3) in Sapporo[19]

Table 2-13 Measurement results for solar irradiation on September 23, 2018 (Day 3) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

Sec.	Type	Distance from start (km)	First run (8:09 to 9:21)		Second run (11:17 to 12:26)		Third run (14:16 to 15:23)	
			(Wh/m²)	(ratio to reference point)	(Wh/m²)	(ratio to reference point)	(Wh/m²)	(ratio to reference point)
1-a	Urban section 1	0.00 to 1.56	20.4	42.1%	14.8	84.6%	18.8	80.0%
1-b	High-rise section 1	1.56 to 2.90	15.0	24.0%	16.1	83.9%	24.8	42.0%
1-c	Underpass section	2.90 to 3.79	0.3	1.4%	0.2	7.1%	0.6	8.0%
1-d	Urban section 2	3.79 to 4.19	4.7	70.1%	3.4	81.0%	1.8	78.3%
1-e	Open-air section (east)	4.19 to 6.75	93.3	110.0%	17.2	117.0%	23.1	53.6%
1-f	Open-air section (west)	6.75 to 8.85	60.6	159.5%	11.4	122.6%	8.8	45.6%
1-g	Open-air section (east)	8.85 to 11.42	99.2	149.2%	46.5	116.3%	25.7	108.9%
1-h	Urban section 3	11.42 to 13.18	49.5	80.2%	36.5	129.4%	8.6	81.1%
1-i	High-rise section 2	13.18 to 16.13	53.7	43.2%	42	78.2%	8.3	34.4%
1-j	Urban section 1	16.13 to 17.69	13.8	41.6%	16.5	66.5%	0.0	0.0%
Total		0.00 to 17.69	410.6	75.1%	204.6	95.5%	120.4	54.2%

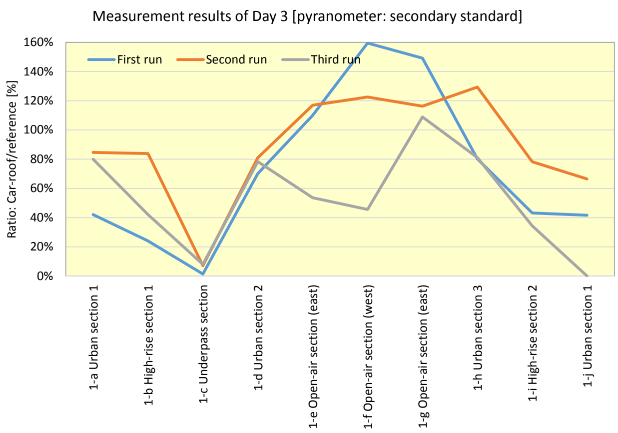


Fig. 2-12 Measurement results for solar irradiation on September 23, 2018 (Day 3) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

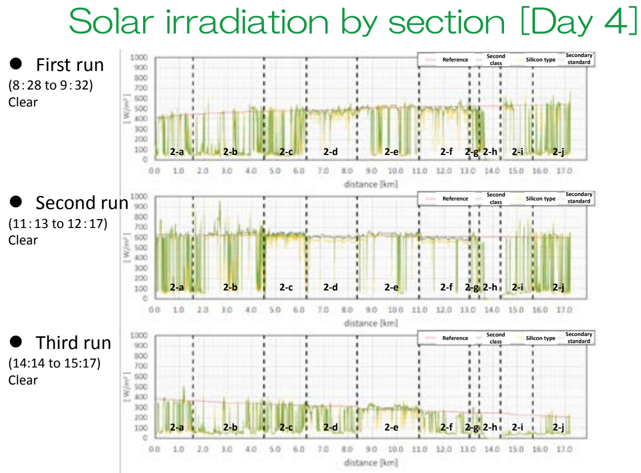


Fig. 2-13 Measurement results for solar irradiation on October 19, 2018 (Day 4) in Sapporo[19]

Table 2-14 Measurement results for solar irradiation on October 19, 2018 (Day 4) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

Sec.	Type	Distance from start (km)	First run (8:28 to 9:32)		Second run (11:13 to 12:17)		Third run (14:14 to 15:17)	
			(Wh/m²)	(ratio to reference point)	(Wh/m²)	(ratio to reference point)	(Wh/m²)	(ratio to reference point)
2-a	Urban section 1	0.00 to 1.56	40.7	43.3%	77.2	67.5%	21.5	67.2%
2-b	High-rise section 2	1.56 to 4.51	34.9	35.5%	109.6	70.7%	15.3	21.9%
2-c	Urban section 3	4.51 to 6.27	15.9	44.7%	48.3	97.2%	13.9	50.7%
2-d	Open-air section (west)	6.27 to 8.37	27.7	97.5%	49.8	96.5%	10.5	45.7%
2-e	Open-air section (east)	8.37 to 10.94	32.9	70.0%	55.5	91.3%	35.6	100.6%
2-f	Open-air section (west)	10.94 to 13.04	37.4	99.2%	38.0	96.4%	12.4	45.8%
2-g	Urban section 2	13.04 to 13.44	9.0	85.7%	8.5	85.9%	1.8	36.7%
2-h	Underpass section	13.44 to 14.32	1.4	8.0%	1.6	13.7%	0.4	9.3%
2-i	High-rise section 1	14.32 to 15.66	22.4	50.7%	9.2	15.2%	4.8	18.3%
2-j	Urban section 1	15.66 to 17.22	9.2	24.3%	32.7	73.0%	5.0	25.3%
Total		0.00 to 17.22	231.5	51.3%	430.6	72.0%	121.1	44.8%

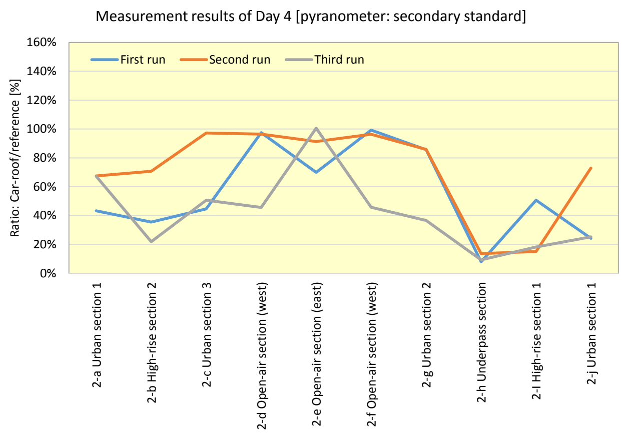


Fig. 2-14 Measurement results for solar irradiation on October 19, 2018 (Day 4) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

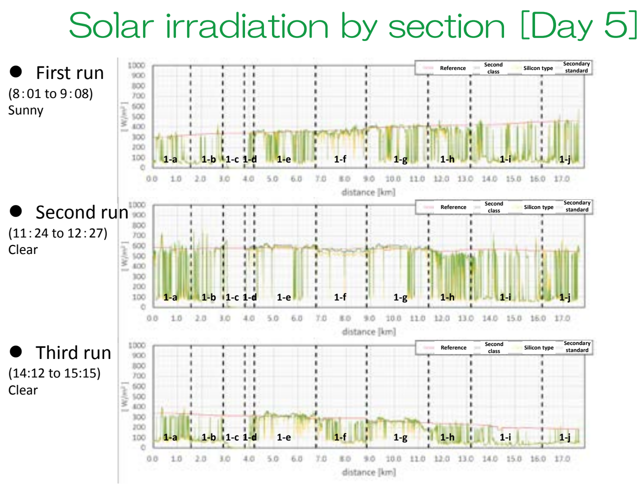


Fig. 2-15 Measurement results for solar irradiation on October 22, 2018 (Day 5) in Sapporo[19]

Table 2-15 Measurement results for solar irradiation on October 22, 2018 (Day 5) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

Sec.	Type	Distance from start (km)	First run (8:01 to 9:08)		Second run (11:24 to 12:27)		Third run (14:12 to 15:15)	
			(Wh/m^2)	(ratio to reference point)	(Wh/m^2)	(ratio to reference point)	(Wh/m^2)	(ratio to reference point)
1-a	Urban section 1	0.00 to 1.56	19.2	52.6%	26.7	59.9%	12.7	49.2%
1-b	High-rise section 1	1.56 to 2.90	6.6	21.6%	21.3	37.6%	5.3	24.7%
1-c	Underpass section	2.90 to 3.79	0.2	3.1%	2.0	19.6%	0.3	5.5%
1-d	Urban section 2	3.79 to 4.19	1.8	35.3%	13.8	85.7%	3.4	42.0%
1-e	Open-air section (east)	4.19 to 6.75	34.8	85.9%	55.5	93.0%	25.6	99.6%
1-f	Open-air section (west)	6.75 to 8.85	38.9	98.2%	50.1	97.7%	11.3	52.3%
1-g	Open-air section (east)	8.85 to 11.42	40.3	84.8%	57.0	97.9%	29.3	97.3%
1-h	Urban section 3	11.42 to 13.18	18.6	71.8%	34.7	70.4%	11.6	45.1%
1-i	High-rise section 2	13.18 to 16.13	27.8	25.6%	44.3	31.4%	12.4	24.8%
1-j	Urban section 1	16.13 to 17.69	10.3	24.4%	11.9	29.2%	5.2	29.4%
Total		0.00 to 17.69	198.4	51.8%	317.3	60.1%	117.2	50.5%

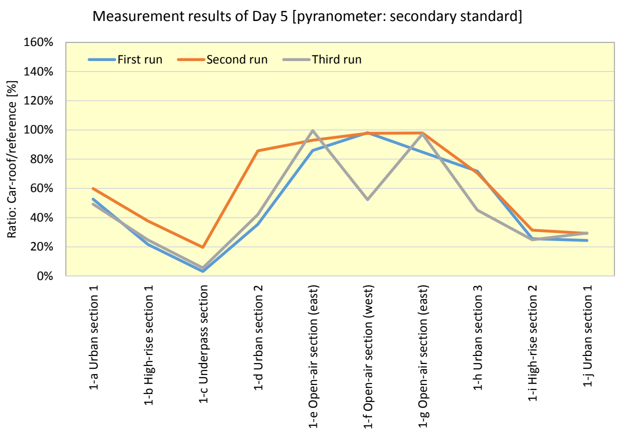


Fig. 2-16 Measurement results for solar irradiation on October 22, 2018 (Day 5) in Sapporo (Comparison with reference) (Pyranometer: Secondary standard)[19]

Table 2-16 shows the ratio between total solar irradiation in every section (measured with a secondary standard pyranometer) and irradiation at the reference point for the measurement results on Day 1 to Day 5.

On fine days, there was a tendency for a ratio of around 50% on the first and third runs and 70% on the second run. On cloudy days, the ratio was over 70% irrespective of time zone. This is thought to be due to cloudy days having a low solar intensity and a low amount of direct solar irradiation that could be shaded by buildings or the like.

Table 2-16 Measurement results for solar irradiation in Sapporo (Comparison with reference: Summary) (Pyranometer: Secondary standard)[19]

			First run (around 8:15 to around 9:15)	Second run (around 11:15 to around 12:15)	Third run (around 14:15 to around 15:15)
Day 1	Sep 20, 2018	Weather	Sunny	Sunny	Clear
		Irradiation on vehicle roof	308.0 Wh/m^2	462.5 Wh/m^2	264.6 Wh/m^2
		Reference irradiation	564.2 Wh/m^2	666.4 Wh/m^2	462.2 Wh/m^2
		Vehicle roof/reference	54.6 %	69.4 %	57.2 %
Day 2	Sep 25, 2018	Weather	Slightly cloudy	Slightly cloudy	Cloudy
		Irradiation on vehicle roof	323.1 Wh/m^2	336.9 Wh/m^2	143.2 Wh/m^2
		Reference irradiation	444.5 Wh/m^2	469.3 Wh/m^2	196.8 Wh/m^2
		Vehicle roof/reference	72.7 %	71.8 %	72.8 %
Day 3	Sep 28, 2018	Weather	Sunny, partly cloudy	Cloudy, occasionally scattered showers	Cloudy, occasionally scattered showers
		Irradiation on vehicle roof	410.6 Wh/m^2	204.6 Wh/m^2	120.4 Wh/m^2
		Reference irradiation	546.8 Wh/m^2	214.3 Wh/m^2	222.3 Wh/m^2
		Vehicle roof/reference	75.1 %	95.5 %	54.2 %
Day 4	Oct 19, 2018	Weather	Clear	Clear	Clear
		Irradiation on vehicle roof	231.5 Wh/m^2	430.6 Wh/m^2	121.1 Wh/m^2
		Reference irradiation	451.3 Wh/m^2	598.1 Wh/m^2	270.3 Wh/m^2
		Vehicle roof/reference	51.3 %	72.0 %	44.8 %
Day 5	Oct 22, 2018	Weather	Sunny	Clear	Clear
		Irradiation on vehicle roof	198.4 Wh/m^2	317.3 Wh/m^2	117.2 Wh/m^2
		Reference irradiation	382.7 Wh/m^2	528.0 Wh/m^2	232.0 Wh/m^2
		Vehicle roof/reference	51.8 %	60.1 %	50.5 %

（4） Differences According to Pyranometer and Sampling Interval

Fig. 2-17 shows differences in ranking-based appearance frequency of falls according to the type of pyranometer on the first day (September 20, 2018: sunny) and the third day (September 28, 2018: cloudy).

On Day 1 when the weather was clear, the tendencies of the overall appearance frequency are similar, but the values produced by the silicon type tend to be slightly smaller. On the other hand, on Day 3 when it was cloudy, the differences due to the type of pyranometer used were small.

Table 2-17 shows the total solar irradiation in all route sections on September 20, 2018 (Day 1) for different sampling intervals.

Although the relative magnitudes of the irradiation are the same for each sampling interval, a difference of up to about 5% was observed between sampling intervals of 0.1 seconds to 1 minute. When identifying the total irradiation in all route sections, the result does not greatly change even when the sampling interval is set at one minute though, in order to observe short-cycle fluctuations caused by the shadows of buildings and the like, it is necessary to use a pyranometer with a short sampling interval and a high response speed.

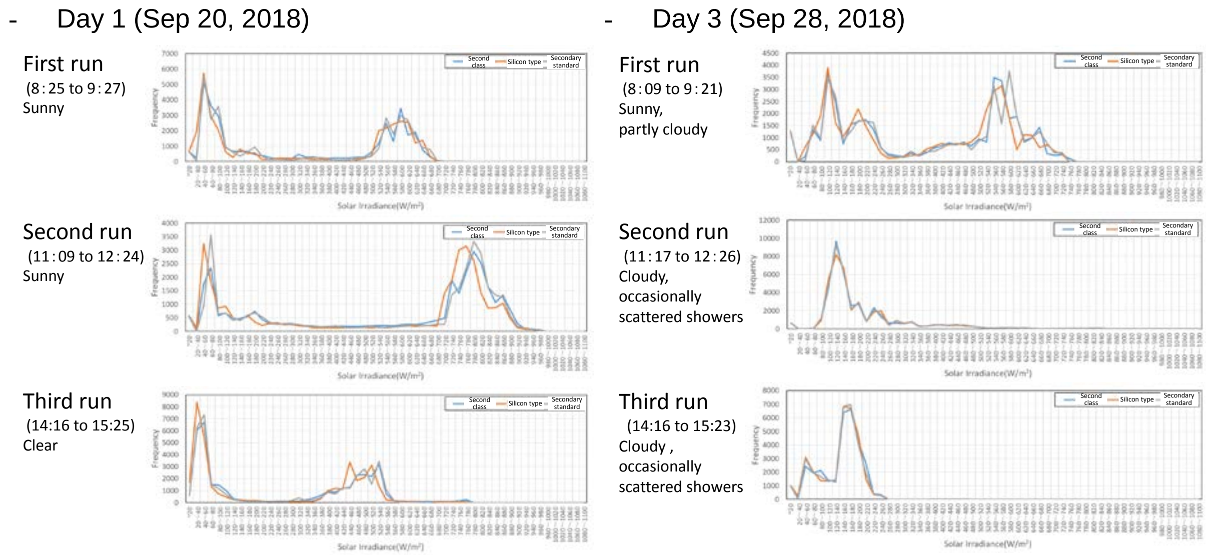


Fig. 2-17 Difference in ranking-based appearance frequency according to type of pyranometer for measurements in Sapporo[19]

Table 2-17 Total Insolation in all route sections according to sampling interval on September 20, 2018 (Day 1) in Sapporo[19]

	Sampling interval	Secondary standard (W/m^2)	Second class (Wh/m^2)	Silicon type (Wh/m^2)
First run	0.1 sec.	308.0	298.6	302.8
	1 sec.	308.6	298.8	302.9
	10 sec.	299.5	289.7	293.1
	1 minute	311.1	301.5	306.8
Second run	0.1 sec.	465.8	472.9	448.9
	1 sec.	467.2	473.6	449.9
	10 sec.	464.4	466.6	449.6
	1 minute	472.0	486.3	442.8
Third run	0.1 sec.	264.6	264.2	246.9
	1 sec.	265.1	264.4	247.1
	10 sec.	271.5	270.5	251.9
	1 minute	280.6	276.2	264.3

2.3.2. Measurement Results in Miyazaki City, Miyazaki Prefecture

（1） Measurement Conditions and Measurement Route

The measurement conditions in Miyazaki are shown in Table 2-18. In Miyazaki, measurements were taken on four days between September 13, 2018 and October 1, 2018. Solar irradiation acquired by a vehicle is influenced by the shadows of surrounding buildings and the like. Since it was assumed that this influence depends on solar elevation, measurements were taken three times a day in different time zones on two out of the four days.

To identify the fall in solar irradiation due to shadows and the like, comparisons were performed with the insolation at a reference point (the rooftop of a University of Miyazaki building). The insolation and solar elevation at the reference point on the date of measurement are shown in Fig. 2-18, as well as for the vehicle roof and side surfaces (the average of four directions).

Table 2-8 Measurement dates in Miyazaki[20]

Date of Measurement	Route	First run (around 9:00 to 10:00)	Second run (around 11:30 to 12:30)	Third run (around 15:00 to 16:00)
Sep. 13, 2018 (Thu.)	Anticlockwise	√	√	√
Sep. 16, 2018 (Sun.)	Anticlockwise	√	√	√
Sep. 22, 2018 (Sat.)	Anticlockwise	-	√	-
Oct. 1, 2018 (Mon.)	Anticlockwise	-	√	-

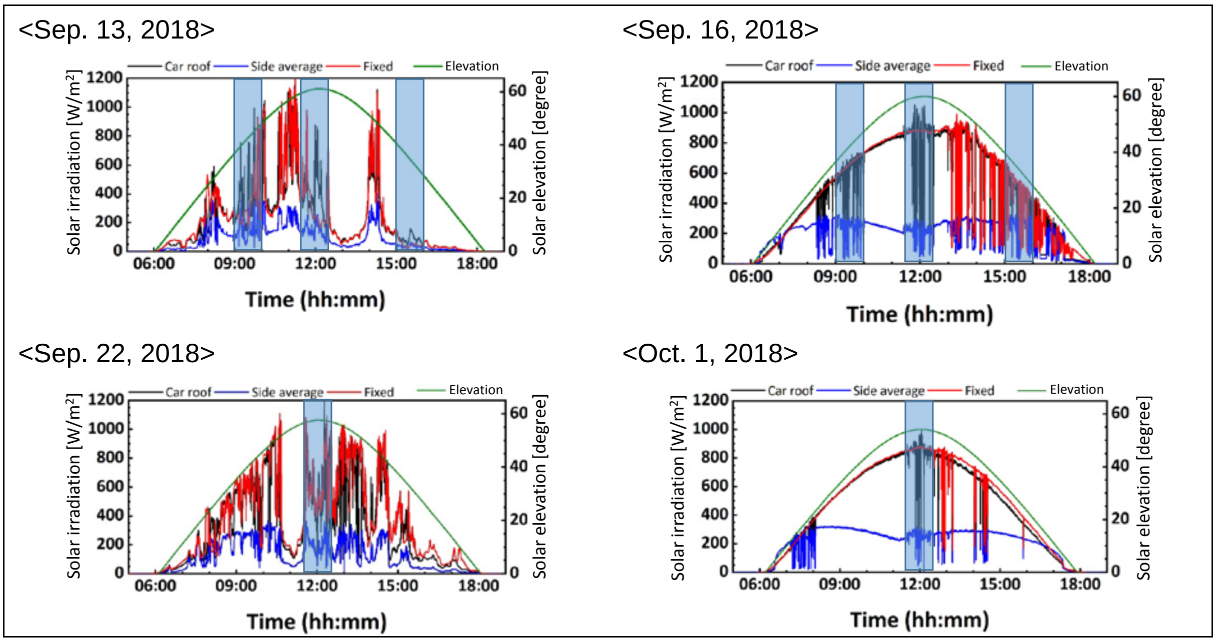


Fig. 2-18 Solar irradiation at University of Miyazaki (reference point)[20]

Fig. 2-19 shows the route of travel in Miyazaki. The route included an urban section (a residential area), a high-rise section (commercial buildings and a downtown area), and an open-air section, and it was assumed that measurements in the urban section and the high-rise section would be affected by surrounding buildings, and also assumed that the same effects would be less likely in the open-air section.

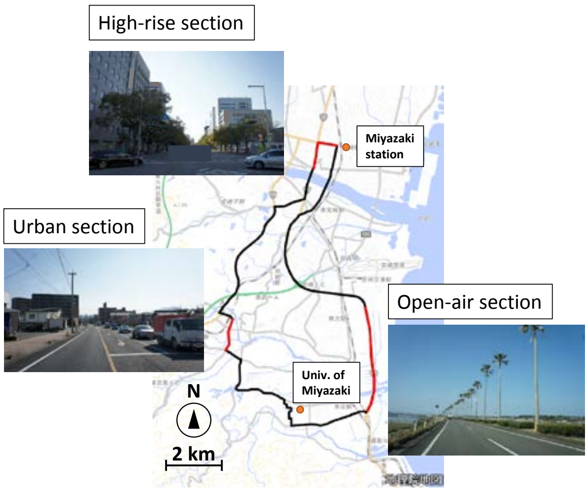


Fig. 2-19 Route used for measurement in Miyazaki[created from 18]

(2) Characteristics of Solar Irradiation According to Route Section

Based on the measurement results on September 16, 2018 (Day 2), measurements corresponding to the urban section (residential area: one lane in each direction), a high-rise section (with commercial buildings and a downtown area: three lanes in each direction) and an open-air section (two lanes in each direction) (the parts marked with red lines in Fig. 2-19) were extracted, and the features of these measurements were summarized.

<Urban section: Residential area>

Table 2-19 and Fig. 2-20 show the measurement results for solar irradiation on the vehicle roof and vehicle sides (the value for the sides is an average of four directions) in the urban section (residential area). Although the measurement periods were short at two to four minutes, vehicle roof solar irradiation relative to irradiation at the reference point was high at 92.0% in the morning (9:40-9:42) (First run) and 83.6% at mid-day (12:17-12:21) (Second run), which shows that there was little loss due to the shadows of buildings, trees, and power poles along the road. On the other hand, the ratio was rather low at 62.5% during the afternoon (15:48-15:51) (Third run).

As shown in Fig. 2-20, there were large falls in solar irradiation for 30 to 40 seconds during 12:20 to 12:21 and 15:49 to 15:51, resulting in reduced ratios to the reference. Although this is thought to be caused by the shadows of buildings, when the vehicle is stopped at an intersection or the like, the effect of shadows will continue for several tens of seconds.

Fig. 2-21 shows measurement results of the solar irradiation on the sides of the vehicle. The timing at which the falls in solar irradiation were observed were the same as for the roof of the vehicle. When the vehicle is driving on a south-to-north road, insolation is high on the east side (mainly the left side of the vehicle) in the morning, the south side (mainly the front of the vehicle) at mid-day, and the west side (mainly the right side of the vehicle) in the afternoon, with a characteristic that solar irradiation is a similar level to the vehicle roof in the morning and afternoon. The average solar irradiation in the four directions was 35% of the vehicle roof in the morning, 25% at mid-day, and around 67% in the afternoon.

Table 2-19 Measurement results for solar irradiation of vehicle roof in urban section on September 16, 2018 in Miyazaki[20]

Measurement time zone	Vehicle roof irradiation (car-roof)	Side irradiation (average of four sides)	Irradiation at reference (rooftop: fixed)	Ratio of vehicle roof irradiation to reference
9:40 – 9:42	23 Wh/m^2	8 Wh/m^2	25 Wh/m^2	92.0 %
12:17 – 12:21	51 Wh/m^2	13 Wh/m^2	61 Wh/m^2	83.6 %
15:48 – 15:51	15 Wh/m^2	10 Wh/m^2	24 Wh/m^2	62.5 %

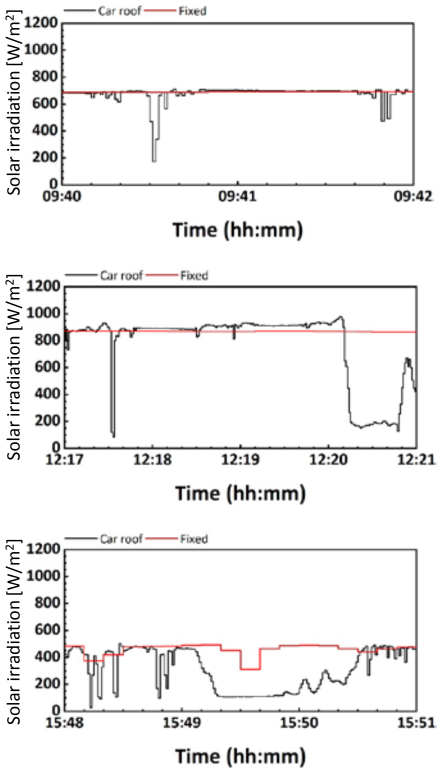


Fig. 2-20 Measurement results for solar irradiation of vehicle roof in urban section on September 16, 2018 in Miyazaki[20]

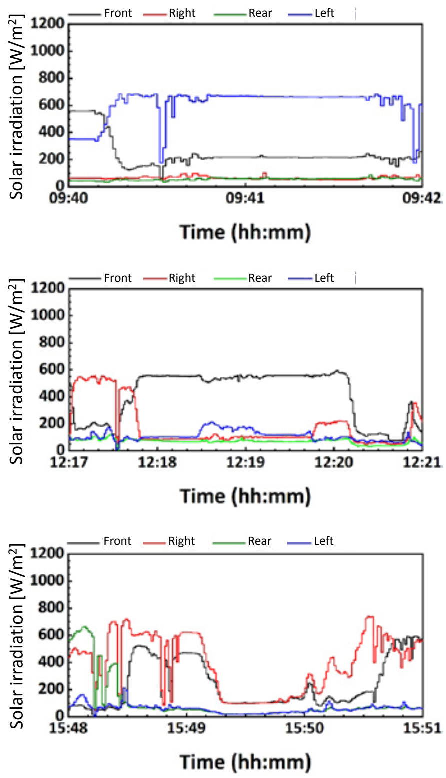


Fig. 2-21 Measurement results for solar irradiation of vehicle roof in urban section on September 16, 2018 in Miyazaki[20]

<High-rise section: Commercial buildings and downtown Area>

In the high-rise section (commercial buildings and downtown area), the vehicle traveled from east to west and then north to south on roads in the east-west direction and then north-south direction. Table 2-20 shows the measurement results for the solar irradiation on the vehicle roof and sides (the value for the sides is the average in four directions) in the high-rise section. The measurement periods were short at two to four minutes, but vehicle roof insolation relative to insolation at the reference point was 73.9% in the morning (9:22-9:24) (First run), 63.1% at mid-day (11:58-12:02) (Second run), and 58.8% in the afternoon (15:29-15:33) (Third run).

Fig. 2-22 shows the measurement results of the solar irradiation on the vehicle roof. During the morning run, falls in solar irradiation that can be attributed to shadows were observed for both travel from east to west

(A to B) and travel from north to south (B to C), with a larger fall being observed for travel from north to south (B to C). During the mid-day run, for travel from east to west (A to B), there was a continuous fall in solar irradiation which is attributable to the influence of buildings on the south side of the road. During travel from north to south (B to C) however, there was almost no falls in solar irradiation, and instead a tendency for insolation to exceed insolation at the reference point. On the afternoon run, insolation was high when traveling from east to west (A to B).

Fig. 2-23 shows the measurement results of the solar irradiation on the vehicle sides. The timing of falls in solar irradiation coincided with the roof of the vehicle. During the morning run, solar irradiation was high on the rear (the east side of the vehicle) in the section from east to west (A to B) and on the left side of the vehicle in the section from north to south (B to C). Both were a similar level to solar irradiation on the vehicle roof. During the mid-day run, no insolation was acquired except by the left side (south side) of the vehicle in the first half of the section from east to west (A to B) due to a prominent effect of buildings and the like along the road. On the other hand, insolation was high on the front of the vehicle in the section from north to south (B to C) reaching a similar level to the vehicle roof. During the afternoon run, solar irradiation was high on the front (west) and left (south) sides of the vehicle when traveling from east to west (A to B), with solar irradiation on the front of the vehicle exceeding the solar irradiation on the vehicle roof. The average solar irradiation in the four directions was 41% of the vehicle roof in the morning, 28% at mid-day, and around 55% in the afternoon.

Table 2-20 Measurement results for solar irradiation of vehicle roof in high-rise section on September 16, 2018 in Miyazaki [20]

Measurement time zone	Vehicle roof irradiation (car-roof)	Side irradiation (average of four sides)	Irradiation at reference (rooftop: fixed)	Ratio of vehicle roof irradiation to reference
9:22 – 9:24	17 Wh/m^2	7 Wh/m^2	23 Wh/m^2	73.9 %
11:58 – 12:02	48 Wh/m^2	13 Wh/m^2	76 Wh/m^2	63.1 %
15:29 – 15:33	20 Wh/m^2	11 Wh/m^2	34 Wh/m^2	58.8 %

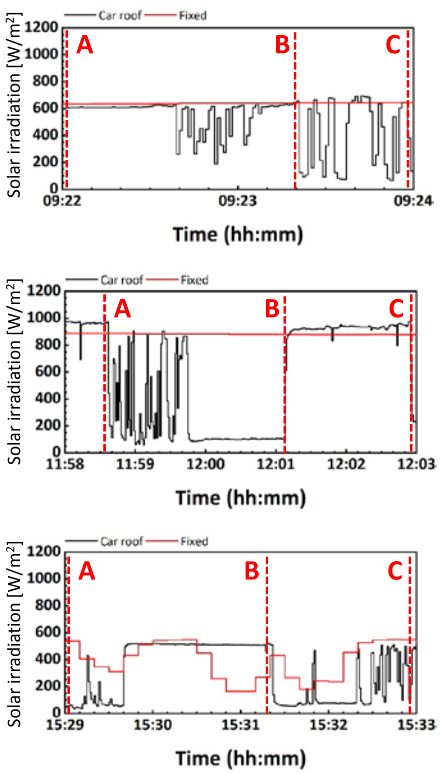


Fig. 2-22 Measurement results for solar irradiation of vehicle roof in high-rise section on September 16, 2018 in Miyazaki[20]

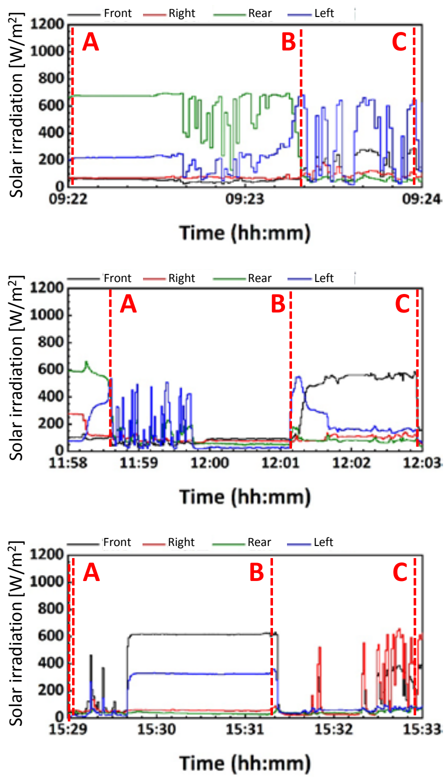


Fig. 2-23 Measurement results for solar irradiation of vehicle roof in high-rise section on September 16, 2018 in Miyazaki[20]

<Open-air section>

Table 2-21 shows the measurement results for solar irradiation on the vehicle roof and sides (the value for the sides is an average of four directions) in an open-air section. The measurement periods were short at two to four minutes, but vehicle roof solar irradiation relative to insolation at the reference point was extremely high at 95.2% in the morning (9:05-9:07) (First run) and 96.7% at mid-day (11:31-11:35) (Second run).

Fig. 2-24 shows the measurement results of the solar irradiation on the vehicle roof. Although fluctuations attributable to shadows of trees and power poles along the road were sometimes observed, the loss in solar irradiation was extremely small. On the other hand, a tendency for solar irradiation on the vehicle roof to exceed insolation at the reference point was barely observed, and it is thought that this tendency observed in urban sections and high-rise sections is due to the influence of reflections from surrounding buildings. During the afternoon run (15:04-15:08) (Third run), the ratio of solar irradiation on vehicle to the irradiation at the reference point was 124%. This is believed to be due to the reference point being cloudy while the route of travel was fine.

Fig. 2-25 shows the measurement results of the solar irradiation on the vehicle sides. The timing of falls in solar irradiation coincided with the roof of the vehicle. Insolation was high on the right (east) side of the vehicle during the morning run and on the left (west) side of the vehicle during the afternoon run, and exceeded the solar irradiation on the vehicle roof and at the reference point. The average amount of solar irradiation in the four directions was 50% of the roof in the morning and afternoon, and around 28% at mid-day.

Table 2-21 Measurement results for solar irradiation of vehicle roof in open-air section on September 16, 2018 in Miyazaki[20]

Measurement time zone	Vehicle roof irradiation (car-roof)	Side irradiation (average of four sides)	Irradiation at reference (rooftop: fixed)	Ratio of vehicle roof irradiation to reference
9:05 – 9:07	20 Wh/m^2	10 Wh/m^2	21 Wh/m^2	95.2 %
11:31 – 11:35	58 Wh/m^2	16 Wh/m^2	60 Wh/m^2	96.7 %
15:04 – 15:08	41 Wh/m^2	20 Wh/m^2	33 Wh/m^2	124.2 %

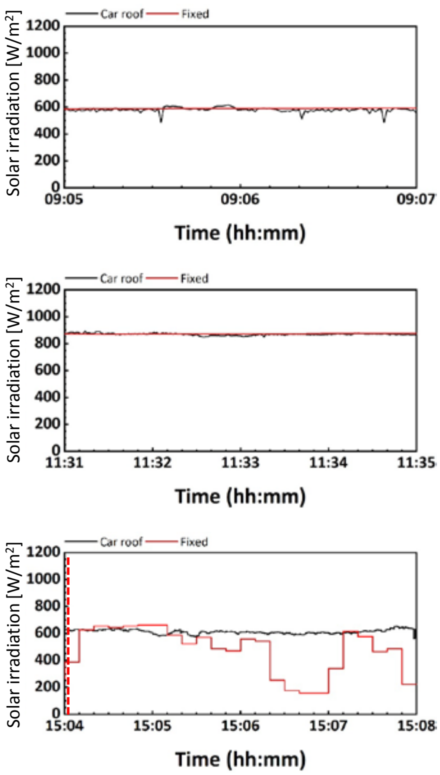


Fig. 2-24 Measurement results for solar irradiation of vehicle roof in open-air section on September 16, 2018 in Miyazaki[20]

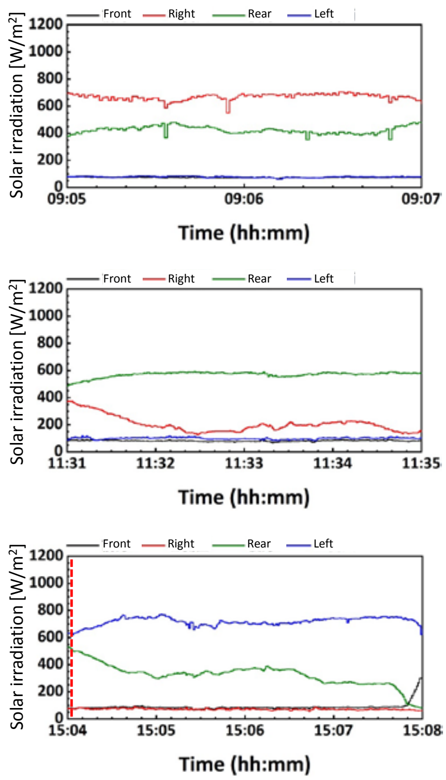


Fig. 2-25 Measurement results for solar irradiation of vehicle roof in open-air section on September 16, 2018 in Miyazaki [20]

（3） Comparison between Solar Irradiation on Vehicle and at the Reference Point

The results of measurements taken on four days (three times daily on two days, and once a day on the remaining two days) in Miyazaki are given here.

Table 2-22 shows solar irradiation on the vehicle roof and side surfaces (the value for the side surfaces is an average of four directions) for all sections of travel and the ratios with the irradiation at a reference point. The values are cumulative solar irradiation for a route including an urban section, a high-rise section, and an open-air section. Figs. 2-26 to 2-29 are charts of measurement results for solar irradiation on the vehicle roof and side surfaces (the value for the side surfaces is an average of four directions).

The weather was fine on Day 2 (September 16, 2018), if a little cloudy in the afternoon. Day 1 (September 13, 2018) was very cloudy, with very little solar irradiation in the afternoon. Out of these two days, the ratio of the solar irradiation to irradiation at the reference point was 87.5 to 92.4% for the vehicle roof on the second day, so only slightly lower than the reference point. On the first day, solar irradiation on the vehicle roof exceeded the reference point. Regarding the solar irradiation on the side surfaces of the vehicle, the ratio was higher on the first day. Although there is the possibility that there were different cloud conditions between the reference point and the route of travel, the presence of less direct irradiation and more diffuse irradiation is also believed to be a factor. In addition, the ratio with the reference point was lower on the second run (at mid-day) compared to the morning and afternoon. It is presumed that the greater difference on the second day was due to a difference in solar elevation.

Regarding the measurement of solar irradiation at mid-day, it was cloudy on Days 1 and 3 but fine on Days 2 and 4. On Days 2 and 4, there were falls in solar irradiation (short period fluctuations) that would appear to be shadows of buildings, trees, power poles, and the like along the road, but the ratio of solar irradiation on the vehicle roof to the reference point was 87.5% and 92.0% on the two days, indicating that there was little loss due to shadows. There were also times where the solar irradiation on the vehicle roof exceeded the insolation at the reference point. There is the possibility that this was due to reflections from surrounding buildings and the like, but since the conditions may have differed between the reference point and the route of travel, it is not possible to make any definite judgment on this. The solar irradiation on the vehicle sides was below 30% of the reference point on Days 2 and 4 when the weather was clear. There was also a tendency that when the ratio of the solar irradiation on the vehicle roof to the irradiation at the reference point was low, the ratio for the vehicle sides was also low.

Table 2-22 Measurement results for solar irradiation in Miyazaki (Comparison with reference: Summary)[20]

			First run (around 9:00 to around 10:00)	Second run (around 11:30 to around 12:30)	Third run (around 15:00 to around 16:00)
Day 1	Sep. 13, 2018	Vehicle roof solar irradiation	404 Wh/m^2	393 Wh/m^2	88 Wh/m^2
		Vehicle side surface solar irradiation	169 Wh/m^2	146 Wh/m^2	36 Wh/m^2
		Irradiation at reference point	346 Wh/m^2	329 Wh/m^2	51 Wh/m^2
		Vehicle roof/reference	114.3 %	118.2 %	180.0 %
		Vehicle sides/reference	48.8 %	44.4 %	70.6 %
Day 2	Sep. 16, 2018	Vehicle roof solar irradiation	617 Wh/m^2	775 Wh/m^2	450 Wh/m^2
		Vehicle side surface solar irradiation	258 Wh/m^2	205 Wh/m^2	243 Wh/m^2
		Irradiation at reference point	659 Wh/m^2	879 Wh/m^2	459 Wh/m^2
		Vehicle roof/reference	92.4 %	87.5 %	91.8 %
		Vehicle sides/reference	39.2 %	23.3 %	52.9 %
Day 3	Sep. 22, 2018	Vehicle roof solar irradiation	-	578 Wh/m^2	-
		Vehicle side surface solar irradiation		203 Wh/m^2	
		Irradiation at reference point		613 Wh/m^2	
		Vehicle roof/reference		95.1 %	
		Vehicle sides/reference		33.1 %	
Day 4	Oct. 1, 2018	Vehicle roof solar irradiation	-	804 Wh/m^2	-
		Vehicle side surface solar irradiation		248 Wh/m^2	
		Irradiation at reference point		867 Wh/m^2	
		Vehicle roof/reference		92.0 %	
		Vehicle sides/reference		28.6 %	

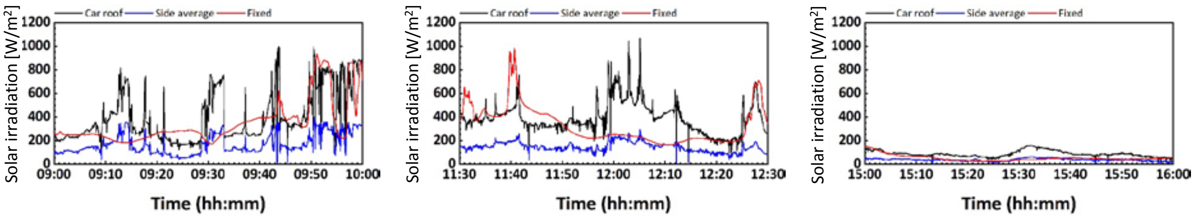


Fig. 2-26 Measurement results for solar irradiation of vehicle on September 13, 2018 (Day 1) in Miyazaki[20]

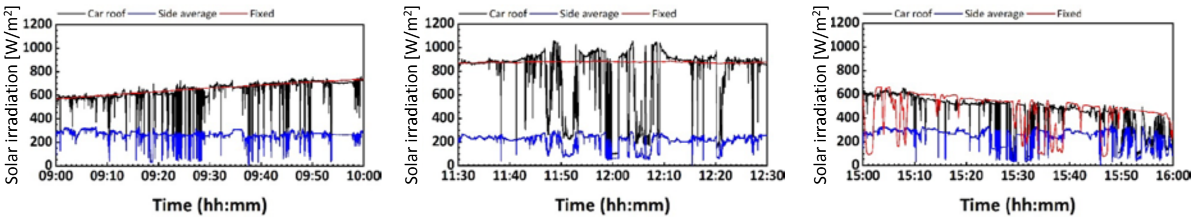


Fig. 2-27 Measurement results for solar irradiation of vehicle on September 16, 2018 (Day 2) in Miyazaki[20]

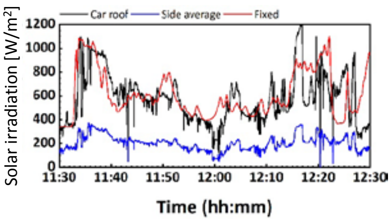


Fig. 2-28 Measurement results for solar irradiation of vehicle on September 22, 2018 (Day 3) in Miyazaki[20]

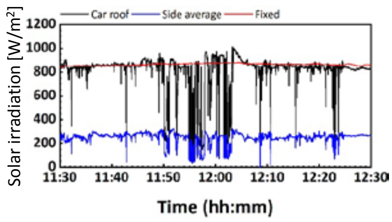


Fig. 2-29 Measurement results for solar irradiation of vehicle on October 1, 2018 (Day 4) in Miyazaki[20]

Fig. 2-30 shows the solar irradiation on the vehicle side surfaces per direction on Day 2 (September 16, 2018) when the weather was fine. Fig. 2-31 is the measurement results on Day 3 (September 22, 2018) which was intermittently cloudy.

As with the roof of the vehicle, falls in solar irradiation (short-period fluctuations) believed to be shadows were frequently observed, with different behavior depending on the relationship between the solar orientation and the direction of the road (the direction of travel) and for each side surface (the front, rear, left, and right of the vehicle). On Day 2, there were prominent changes in solar irradiation in each direction that accompanied changes in the direction of travel. On the other hand, on Day 3, although measurement was only performed at mid-day, in the latter half of the measurement period, there was little difference in insolation between the different directions, which is believed to be due to a fall in direct solar irradiation caused by clouds.

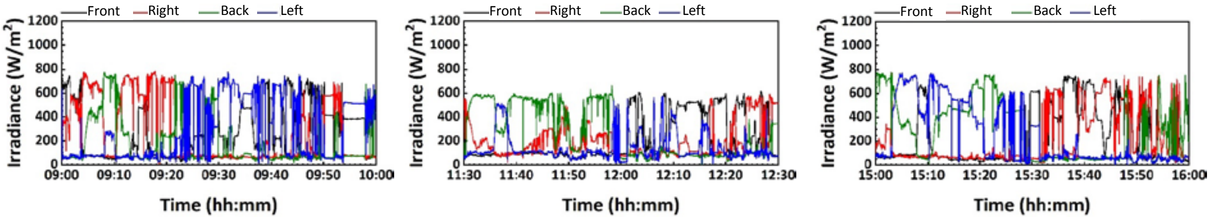


Fig. 2-30 Measurement results for solar irradiation of vehicle sides on September 16, 2018 (Day 2) in Miyazaki[20]

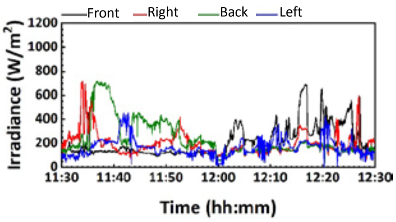


Fig. 2-31 Measurement results for solar irradiation of vehicle sides on September 22, 2018 (Day 3) in Miyazaki[20]

3. Conclusion

In this report, as a preliminary study on solar irradiation of a PV-powered vehicle, the solar irradiation acquired by a traveling vehicle was measured, the characteristics and tendencies of such irradiation were identified, and the result of a comparison with irradiation at a reference point (a roof or rooftop of a building with favorable insolation) has been shown.

The characteristics of solar irradiation acquired by a vehicle and future issues that have been suggested by this trial measurement are given below.

3.1. Characteristics of Solar Irradiation of a Vehicle

The solar irradiation on a vehicle roof and on vehicle side surfaces has the following characteristics.

(1) Horizontal Solar Irradiation on Vehicle Roof

- Shadows are occurred by buildings, trees, power poles, and the like along the road, so that compared to the reference point, solar irradiation falls in corresponding locations and sections.
- Shadows are occurred by buildings frequently in high-rise sections and intermittently in urban sections. Although infrequent, shadows are also occurred in open-air sections.
- Due to shadows from buildings and the like, fluctuations in insolation were occurred in extremely short cycles (several hundred W/m^2 in 0.1 seconds).
- Although the solar intensity has a similar level to the reference point in sections with no shadows, there is a fall of around 50 to $100W/m^2$ in sections where shadows are occurred, with the range of fluctuations in solar irradiation increasing as solar elevation increases.
- The fall in cumulative solar irradiation depends on the length of the period where shadows occur. This was longest in the high-rise section and shortest in the open-air section, with the urban section in between.
- Although the buildings along the road may cast shadows across the entire vehicle roof, shadows produced by trees and power poles do not cover the entire roof and correspond to partial shading.
- The occurrence of shadows on the vehicle largely depends on the relationship between the direction of the road (the direction in which the vehicle travels) and the orientation of the sun, and when these almost match, the influence of shadows is small, even in a high-rise section.
- The occurrence of shadows on the vehicle by buildings along the road is thought to be influenced by road width and the lane in which the vehicle is traveling.
- In high-rise sections and urban sections, solar irradiation at the vehicle may exceed irradiation at the reference point. It is believed that solar irradiation may increase due to reflections from buildings along the road.

(2) Insolation on Vehicle Sides

- Shadows are occurred by buildings, trees, and power poles along the road, and as with the roof of the vehicle, there is a fall in solar irradiation in corresponding locations and sections.

- Solar irradiation and the occurrence of shadows on the vehicle greatly depend on the relationship between the solar orientation and the direction of the road. Surfaces that face the orientation of the sun (one or two out of the front, rear, left, and right of the vehicle) are hardly affected by shadows of buildings and the like along the road, but other surfaces will receive no direct solar irradiation and irradiation is low.
- The surface(s) where insolation is high will change as the direction in which the vehicle is traveling changes.
- Although the average value (per square meter) of solar irradiation in the various directions is smaller than the vehicle roof, the solar irradiation of the surface facing the sun may exceed the solar irradiation on the vehicle roof when the solar elevation is low.
- In high-rise sections and urban sections, it is believed that solar irradiation increases due to reflections from buildings along the road. In open-air sections also, it is believed that solar irradiation increases due to reflections from the surroundings.

3.2. Future Issues

Data on solar irradiation acquired by a vehicle is a first step or gateway toward the use of PV in automobiles and is vital information for evaluating the significance and effect of mounting a PV system. It is also important for the design and operation of a control system for using generated power as power for driving the vehicle.

This preliminary study, a trial that measured the solar irradiation of a vehicle, was conducted at limited locations and times, and has therefore produced fragmentary data. Although it would not be appropriate to make generalizations on the characteristics of the solar irradiation acquired by a vehicle or to conduct quantitative evaluations into the expected level of generated power from only the results given here, the following characteristics and trends were observed as indicated in Section 3.1 above.

- Shadows of buildings, trees, power poles, and the like occur, causing a fall in solar irradiation in affected locations and sections.
- Shadows occurred by a building or the like may cover an entire surface, such as the vehicle roof, or may only partially shade the surface.
- Due to reflections from buildings and the like, the solar irradiation by a vehicle in some locations and sections may exceed the insolation on a roof or rooftop of a building.
- Fluctuations in solar irradiation due to shadows and reflections often occur with very short cycles (less than 0.1 seconds).

Although it is considered necessary to expand and enhance this research and measurement toward the full-scale development and adoption of PV-powered vehicles, to conduct such activities efficiently, it is also necessary to predict in advance how such data will be used.

（1） Enhancement of Research and Data Measurement

Table 3-1 shows examples of data desired from further research and measurement.

In this trial measurement, measurement was performed for solar irradiation in the fall (September to October) at two locations in Japan only. However, data on different regions and different seasons with other irradiation characteristics, data on solar irradiation and temperature conditions in various driving environments, and data on the output and/or current of PV cells or modules is also considered necessary. In such studies, to understand the occurrence and influence of partial shading, it is believed effective to measure solar irradiation at multiple points on the vehicle roof (as examples, the four corners and the center) and to analyze images of the sky.

Although the sampling interval was set at 0.1 seconds and at 1 second for the measurements in this study, it may be necessary to measure at even shorter intervals (that is, intervals shorter than 0.1 seconds) to estimate power generation with highly accuracy and reflect real-life conditions in system design (such as MPPT for fluctuations in solar radiation). To perform such high-precision data measurement, system performance, such as the response speed of the pyranometer, also becomes important.

Table 3-1 Examples of enhanced research and measurements

Expansion of measurement locations and times	- Regions with different irradiation characteristics (geographical conditions) - Different seasons (summer, winter, etc.) - Various driving environments (different regions of use) - Various time zones
Data that contributes to estimation of power generated by PV	- Temperature conditions - Output, current, or the like of PV cells or modules
Improving precision	- Measurement at multiple points on the vehicle roof (such as the four corners and the center) - Analysis of sky images - Measurement with sampling intervals shorter than 0.1 seconds

（2） Utilization of Enhanced Research and Data Measurement

Table 3-2 shows conceivable methods of using the data described above. The necessary precision and resolution of the data produced by enhanced research and measurement may differ according to how the data is to be used, and there are cases where instantaneous values are required at the sampling interval, and cases where values produced by integration for a certain period are required.

Table 3-2 Example of methods of using solar irradiation of vehicle

Creation of detailed power generation estimation model in keeping with solar irradiation characteristics (instantaneous values)	Insolation and generated power based on instantaneous values, spectrum analysis, etc. - Reflection in the design of 3D modules for mounting on vehicles - Reflection in design of control system for MPPT or the like
Estimation of areal potential based on cumulative solar irradiation	Creation of potential map - Data such as solar irradiation, generated power, ratio to roof or rooftop irradiation - One-hour values, for each travel section, each direction, etc. Analysis based on map data, combining with actual measurements
Estimation of power generating potential of a PV-powered vehicle	Estimation of power generating potential through combination with vehicle travel and usage patterns Derivation of generated power as a model according to typical travel and usage patterns
Analysis of effects of PV-powered vehicles	Identify effects (potential) based on the generated power - Energy savings, reduction in CO_2 emissions, reduction in cost of electrical charging, etc. Identify real-world effects by combining with vehicle travel data - Contribution of PV system based on comparison with power consumption data of vehicle - Reductions in energy consumption, CO_2 emissions, etc. - Reduction in charging frequency
Reflection in expected and required levels for PV systems	Set target levels such as coversion efficiency and cost required to realize and enhance the effect of installing a PV system

To create a detailed power generation estimation model in keeping with solar irradiation characteristics, calculation of solar irradiation and generated power based on instantaneous values and spectrum analysis are believed necessary. This is expected to be beneficial when designing 3D modules for mounting on vehicles and designing a control system for MPPT. When doing so, it is also necessary to clarify the purpose of creating and using the model and to investigate the sampling interval required to produce solar irradiation amounts based on instantaneous values.

On the other hand, evaluation of potential based on cumulative solar irradiation is performed to identify the solar irradiation that can be acquired by PV-powered vehicles on a nationwide scale. It would be conceivable to estimate based not only on direct measurements of solar irradiation and generated power, but also in combination with an existing solar irradiation database or analysis that uses map data. Here, it is desirable to prepare data in hourly units or data on each section of the route (by each usage region etc.), and to reflect data and characteristics for each road direction. It is also desirable to verify the estimated values (against actual measurements) whenever possible.

Evaluation of the power generation potential of a PV-powered vehicle makes use of the power generation estimation model or the results of evaluating potential based on solar irradiation, and seeks to evaluate the generated power of a vehicle that is actually moving. The solar irradiation and power generated by a PV-powered vehicle will change depending on the travel and usage pattern of the vehicle, but by assuming a typical driving and usage pattern, there is a goal of deriving generated power as the standard specification and a model for analyzing effects of a PV-powered vehicle.

Based on the generated power, it will be possible to analyze the reduction in energy consumption, the effect in reducing CO_2 emissions, and the effect in reducing the cost of charging as the effects of a PV-powered vehicle. By combining this data with vehicle driving and usage data (such as the power consumed by driving) on actual roads, it will be possible to make the effect of installing a PV system more persuasive to users.

It is believed that the results of these evaluations and analysis of effects could lead to the setting of targets for conversion efficiency and cost that are necessary to realize the installation of PV systems and increase the effect. These targets are levels that are expected to PV installed on vehicles.

To achieve full-scale adoption and expansion of PV-powered vehicles, in addition to the evaluations and analysis of effects described above, it is necessary to identify technical issues encountered when using PV as part of a car body and to work toward solutions. These issues include improving PV efficiency, compatibility with curved surfaces, maintaining and improving reliability and safety, and control in keeping with battery specification and charging state.

In addition to being means of transport capable of generating their own power using solar energy, PV-powered vehicles can also be regarded as extremely small-scale (around 1kW or less) movable sources of distributed power. There are also hopes for PV-powered vehicle use in highly flexible applications that support regions and communities, such as compatibility with changing power needs with the rollout of IoT and introduction of self-driving cars, diversification of modes of travel and transport, and usage as independent power supplies during natural disasters. It is therefore important for studies into the effects and value of PV-powered vehicles to also include the effects and value of PV-powered vehicles for regions and society.

3.3. Future Initiatives

To solve the above issues, we will continue to conduct studies on PV-powered vehicles.

In addition to identifying technical problems, gathering the required data and evaluating benefits through the activities of NEDO, we will support IEA PVPS Task17 to expand activities on an international scale.

PV-Powered Vehicles Strategy Committee

<List of committee members (as of 31 March 2019: the end of FY2018)>

Chair of committee	Masafumi Yamaguchi	Professor Emeritus, Senior Research Scholar, Research Center for Smart Energy Technology, Toyota Technological Institute, Japan
Committee member	Yuzuru Ueda	Associate Professor, Department of Electrical Engineering, Faculty of Engineering, Tokyo University of Science, Japan
	Akinori Sato	Group Manager, Energy Group No.2, F Mobility Infrastructure Research Dept., S-Frontier Dev., Frontier Research Center, TOYOTA MOTOR CORPORATION, Japan
	Yusuke Zushi	Ph.D., Manager, EV System Laboratory, Research Division, Nissan Motor Co., Ltd., Japan
	Tatsuya Takamoto	Ph.D., Division Manager, Compound Business Promotion Division, Business Solutions BU, Sharp Corporation, Japan
	Toshio Hirota	Ph.D., Guest Professor, Environmental Research Institute, Waseda University, Japan
Special Cooperation	Japan Weather Association	
	University of Miyazaki	
Secretariat	Hiroyuki Yamada	Ph.D., Director, Solar Energy Systems, New Energy Technology Development, New Energy and Industrial Technology Development Organization, Japan
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	Shouhei Namikawa	Chief Consultant, Environment and Energy Division 2, Mizuho Information & Research Institute, Inc., Japan
	Takafumi Sato	Consultant, Environment and Energy Division 2, Mizuho Information & Research Institute, Inc., Japan

<Schedule of committee meeting>

7th meeting : 9 November 2017
8th meeting : 8 February 2018
9th meeting : 5 November 2018
10th meeting : 5 February 2019

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(In Fig. 2-1, geographic point names have been added to an outline map from GSI Maps (Electronic Land web), in Fig. 2-3 the route of travel has been added to the relevant region map from GSI Maps (Electronic Land web). In Fig. 2-19, the route of travel and photographs have been added to a region map from GSI Maps (Electronic Land web))

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