CO_2 Emissions Reduction by Solar Reflective Coating for Automobiles

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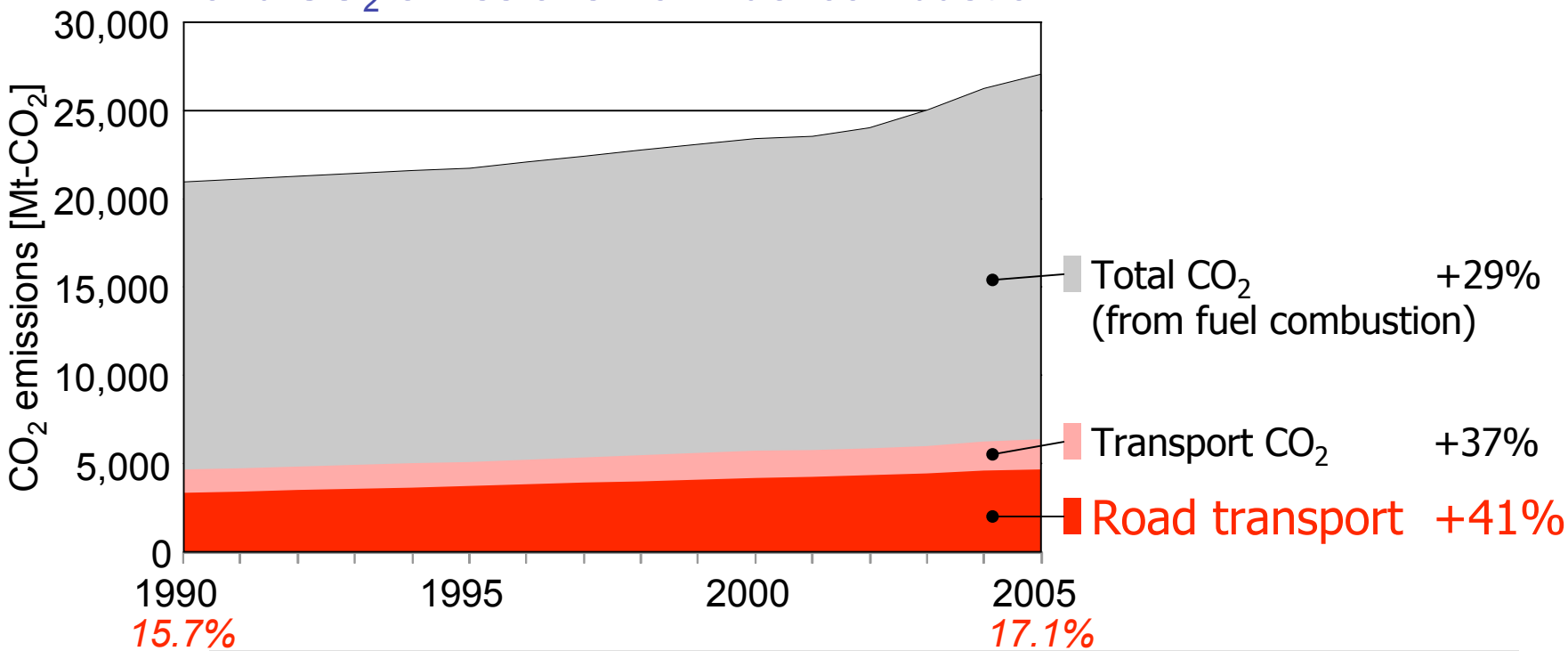
1. Introduction

- Global warming mitigation (= CO_2 reduction) is one of urgent problems.
- CO_2 from road transport is not small. (15.7% → 17.1%)
- The value is rapidly increasing. (3,300 → 4,600 Mt-CO_2)

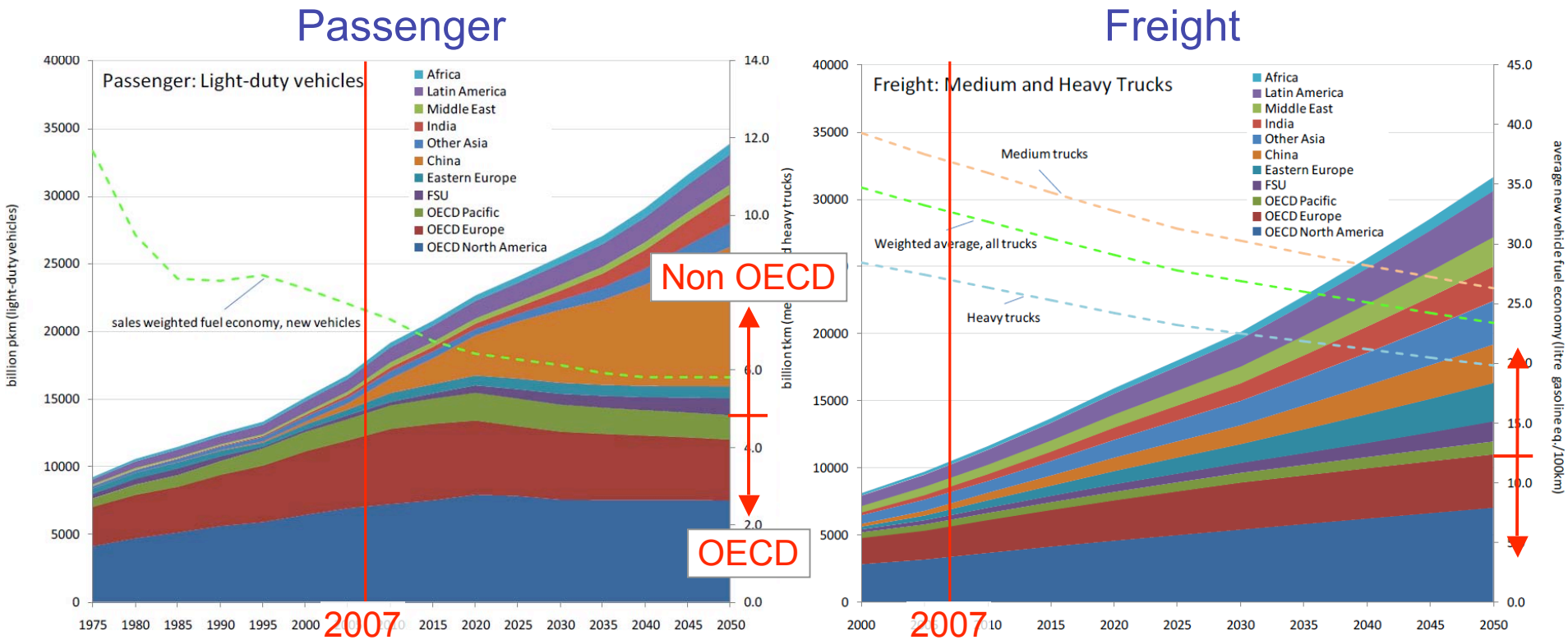
World CO_2 emissions from fuel combustion



OECD/ITF. Greenhouse Gas Reduction Strategies in the Transport Sector: Preliminary Report, 2008.
http://www.internationaltransportforum.org/Topics/c02emissions.html

1. Introduction

◆Past trend & projection of road transport



OECD/ITF. Greenhouse Gas Reduction Strategies in the Transport Sector: Preliminary Report, 2008.
http://www.internationaltransportforum.org/Topics/c02emissions.html

Road transport will continue to increase in the future, particularly in non OECD countries including China, India, FSU, etc.
Much demand will induce much CO_2 emissions.

1. Introduction

◆To reduce CO_2 from road transport...

- Energy saving measures
  - Vehicle
    - Improvement of fuel economy
    - LEV

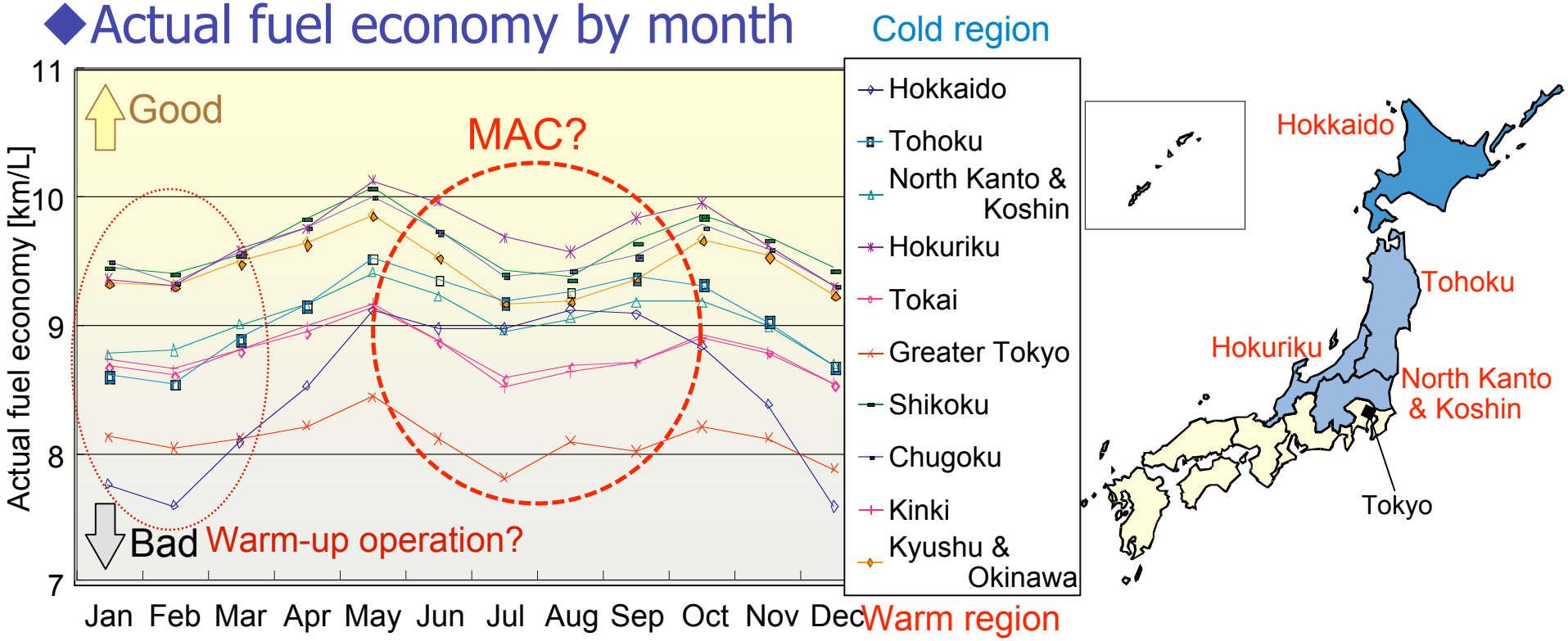
    etc.
  - Traffic flow
    - ITS

    etc.
  - Physical distribution
    - Improvement of the efficiency of physical distribution

    etc.
- Fuel economy (Actual fuel economy)
  - One of lowering factors is mobile air conditioning (MAC) in the sun. Some previous reports said,
    "MAC in summer lowers fuel economy by around 20%."

1. Introduction

◆Actual fuel economy by month



Made from the literature below by Kudoh
•Kudoh Y, et.al. *Journal of the Japan Institute of Energy*, Vol.87, pp.930-937, 2008. [in Japanese]
http://www.jstage.jst.go.jp/article/jie/87/11/930/_pdf/-char/ja/

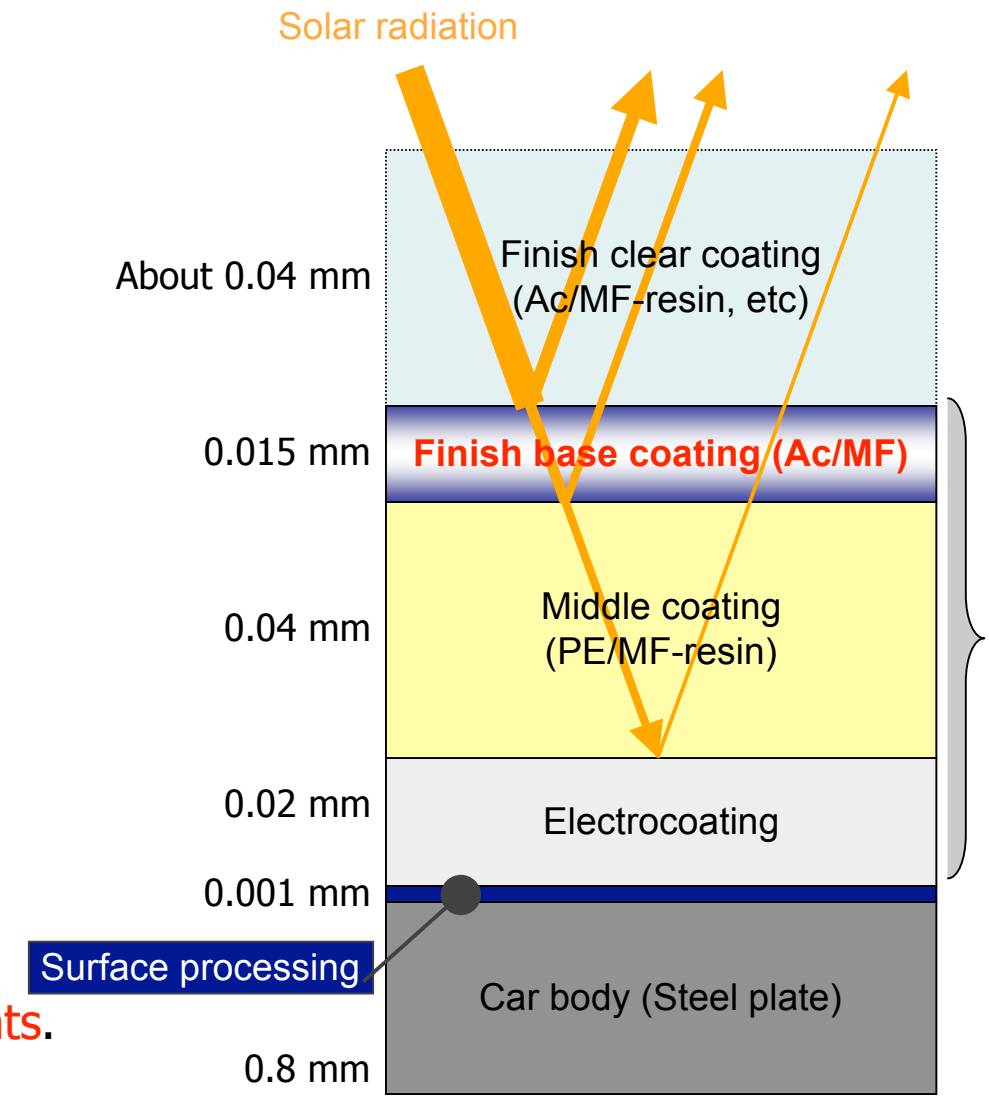
MAC affects actual fuel economy.

Improvement of the thermal environment in car can lead to reduction in actual fuel consumptions?

1. Introduction

◆How is the cabin thermal environment improved?

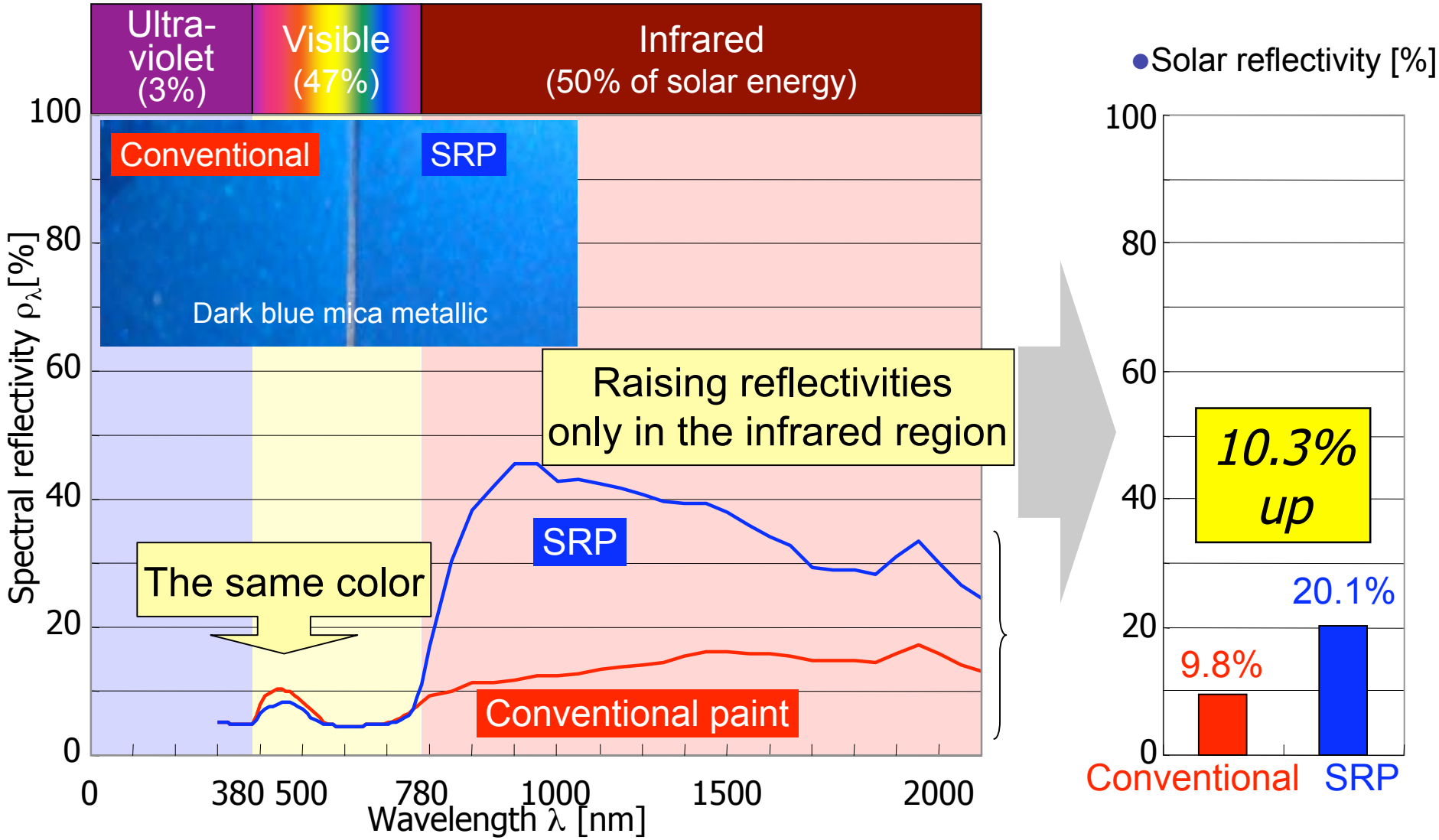
- Air ventilation
- Glazing (Windows)
  - Solar reflective film
- Body
  - Heat shielding sheet
    - A PVC sheet including special pigments
  - Solar reflective paint (SRP) (cool paint)
    - A special paint which reflects infrared radiation at a higher rate by replacing its normal pigments with special pigments.



1. Introduction

◆Solar reflectivity and color of SRP

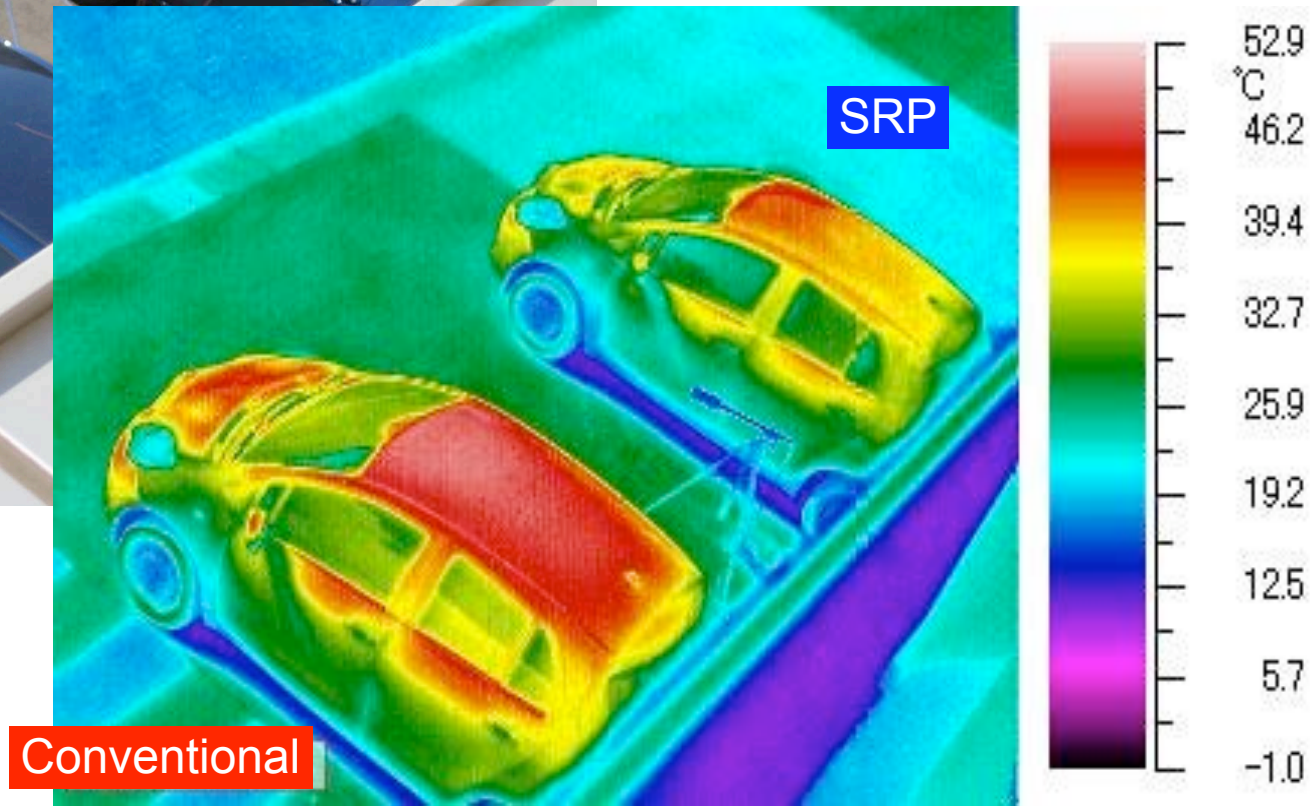
In this case, only middle and finish base coatings were replaced by SRP. If electrocoating is also replaced, its reflectivity will be more improved.



1. Introduction

◆Parking test for evaluating the effect of SRP

Surface temperature was suppressed.



1. Introduction

◆Our findings and tasks in the past

- Feature of SRP
  - Not large improvement of fuel economy itself by SRP
  - Lower cost than other CO_2 mitigating technologies
  - Not technically difficult application to cars

➡ These features make SRP easy to apply even on a mass basis.

- CO_2 reduction potential = 210,000 tons per year (to private cars in Japan)

- Tasks
  - Parking test
  - Simple simulation conditions

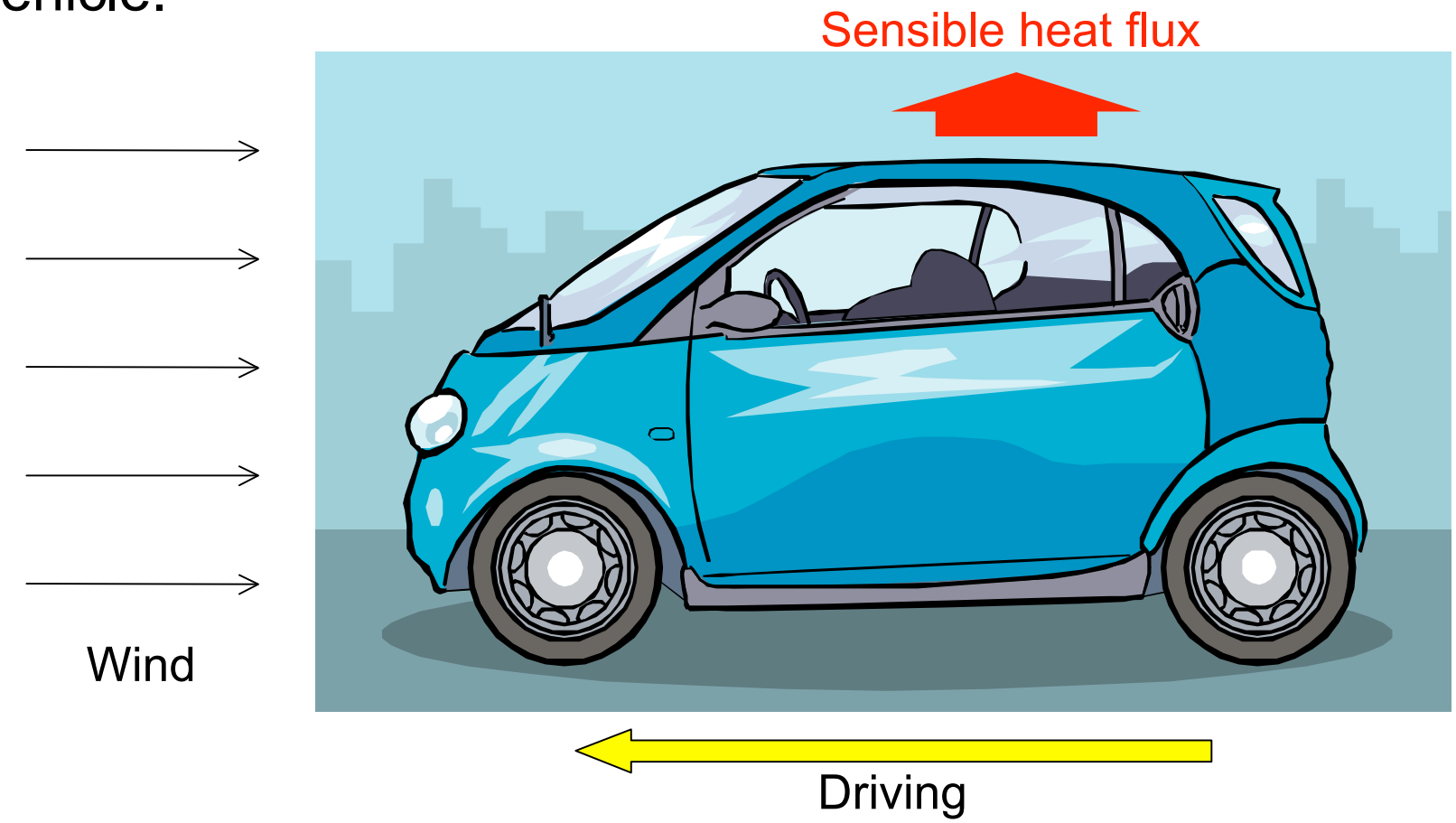
⬇

  - Driving test
  - Simulation under various conditions

1. Introduction

◆Why driving test?

Wind by driving removes sensible heat from a top plate of a vehicle.



Temperature test when driving is needed.

2. Temperature test

- Methodology
  - To evaluate cabin thermal mitigating effects while driving, we performed parking and driving tests.
  - Two cars were prepared for the test. Both cars were colored with dark blue mica metallic, but one was coated with SRP and the other was conventionally coated.
  - Surface temperatures, air temperatures in cars and weather conditions were measured.

2. Temperature test

◆Outline of temperature test

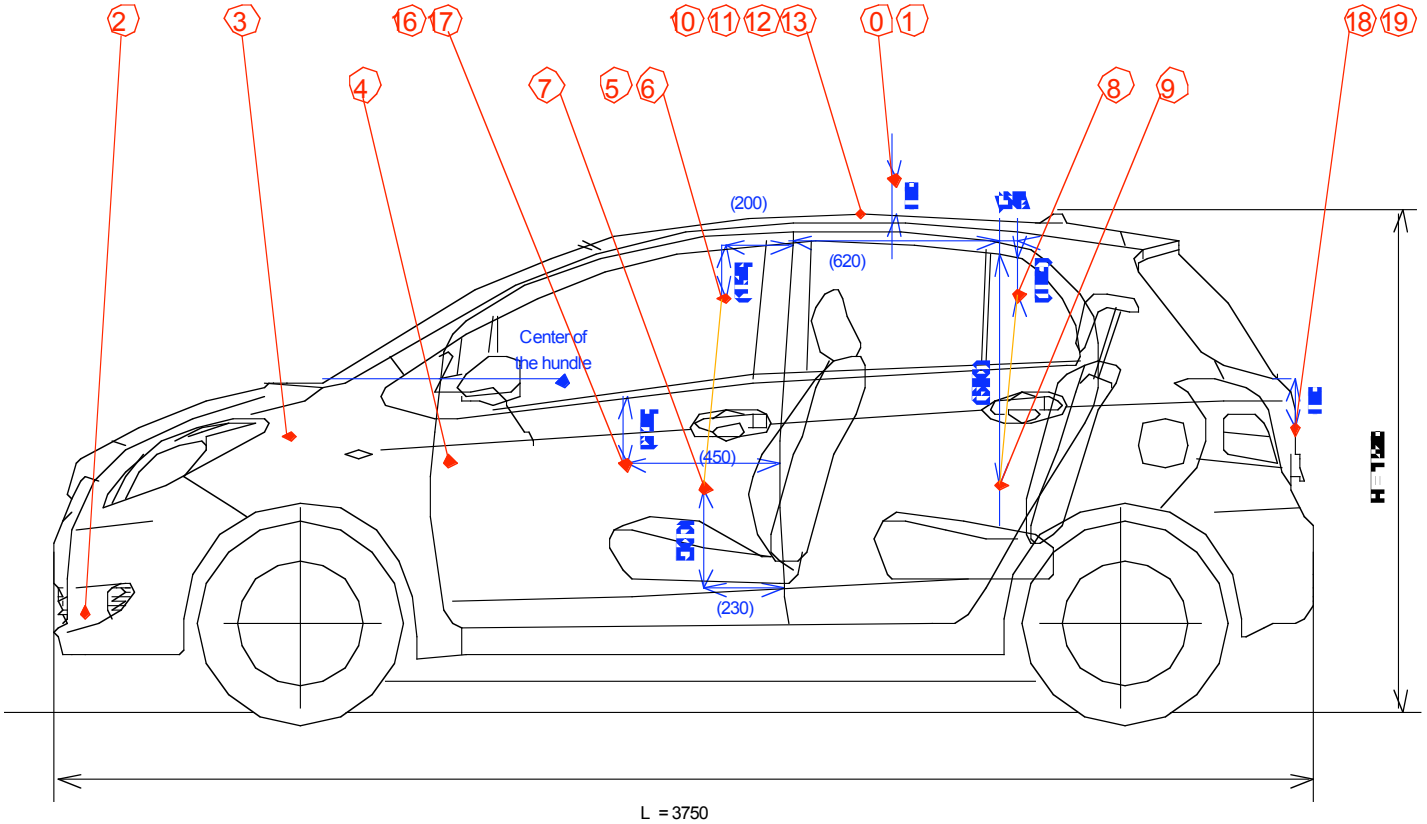
- Parking test
  - AIST West (Tsukuba)
  - 25 straight days in August and September, 2008
  - Parking without engine idling

- Driving test
  - AIST North driving test course (Tsukuba)
  - Six days in August, 2008
  - Every 20 minutes of 10:00-11:40/13:00-16:00
  - Driven with constant speed (20, 30, 50, 100 km/h)
  - A/C on (25 °C) and off
  - No ventilation with the all car windows closed
  - 11 test drivers

2. Temperature test

◆Measured items & points

- Solar radiation
- Outdoor air temperature (3 points)
- Cabin air temperatures (6 points)
- Inside/outside surface temperatures (10 points)



Ch.2

Air temperature inside here

Ch.3

Surface temperature on the sleep plate (behind the heat insulating material)

2. Temperature test

◆AIST North driving test course (Tsukuba)

The course is 3.2 km long.

2. Temperature test

◆Driving test

2. Temperature test

◆Driving test

2. Temperature test

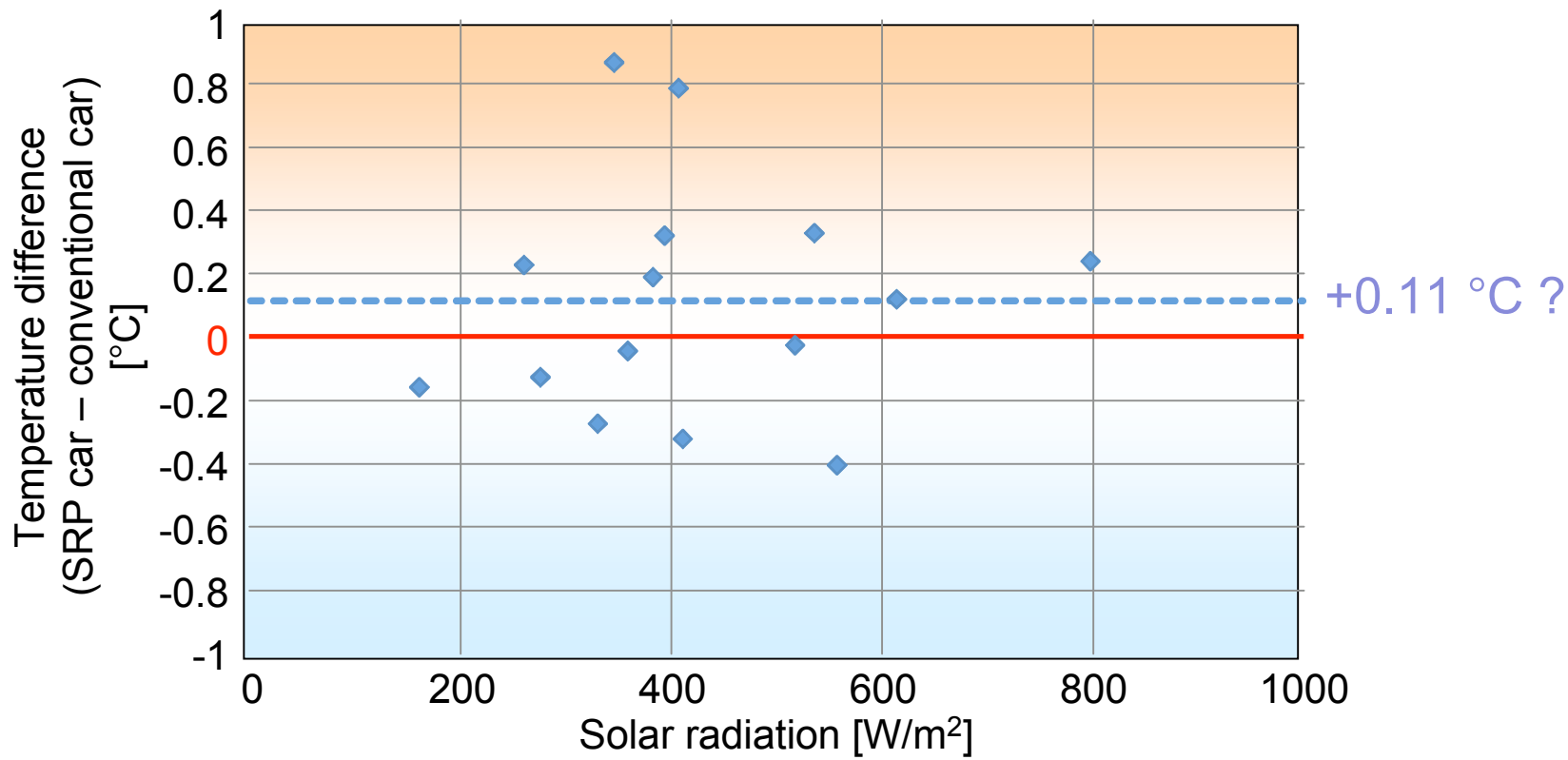
◆Driving test

2. Temperature test

◆Driving test

2. Temperature test

◆Result: Temperature difference at Ch.5 (20 km/h without A/C)



- From comparison of the same time driving, we can NOT find the relationship between solar radiation and temp. difference.
- SRP has higher temperature than the conventional one by 0.11 °C on an average.

2. Temperature test

◆Removing driving factors

- Factors to affect temperature at Ch.5
  - Solar radiation
  - Outdoor air temperature
  - Sensible heat release from the drivers (9 drivers when 20 km/h)
  - A/C on or off, Vehicle speed

- Analyzing contribution factors

$$y = a_1 x_1 + a_2 x_2 + x_3$$

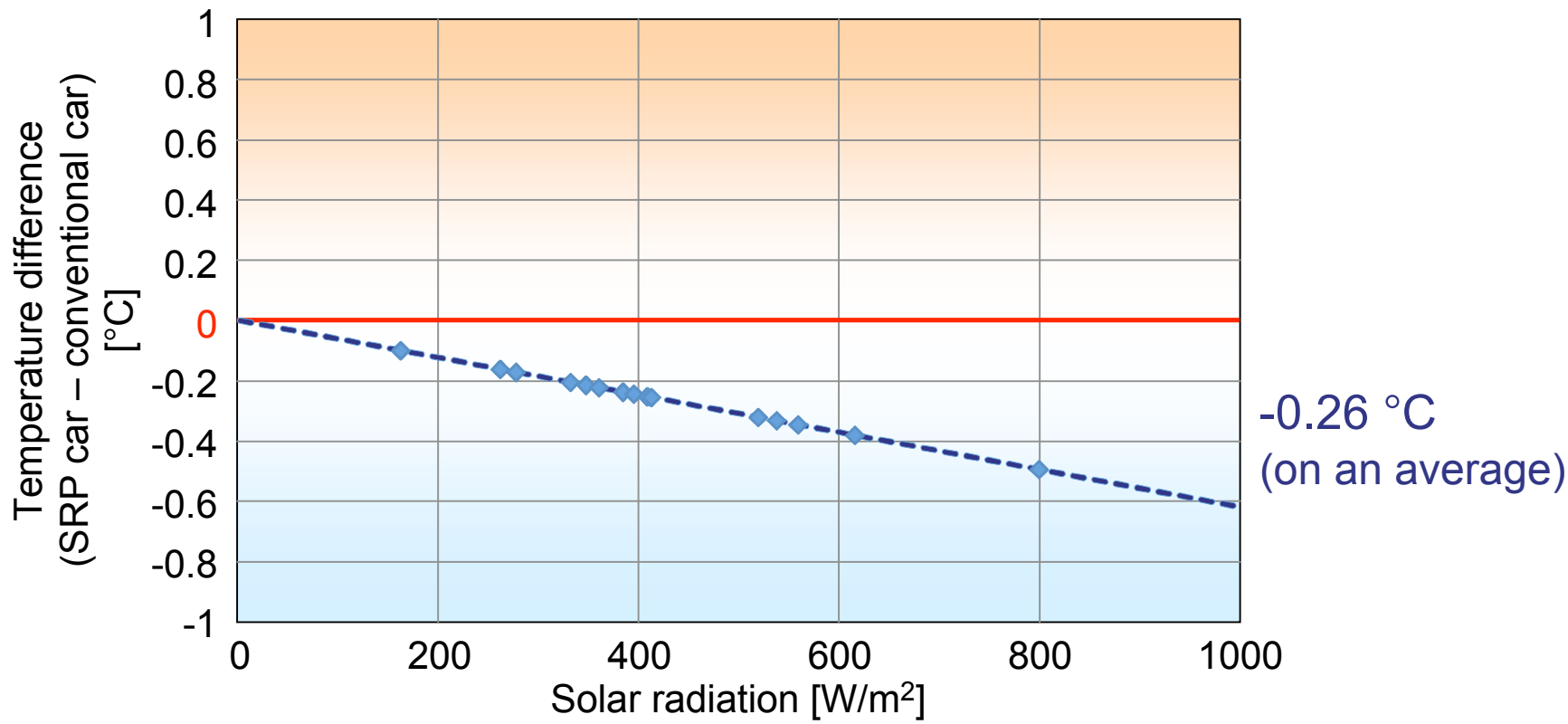
- y : Cabin air temperature (measured)
- x_1, a_1 : Solar radiation (measured), a_1 is factor (this factor is different between SRP and conventional)
- x_2, a_2 : Outdoor air temperature (measured), a_2 is factor
- x_3 : Sensible heat release from the drivers

Blue letters are unknown variables (2+1+9 = Total 12)

With the least-square method, these variables are solved.

2. Temperature test

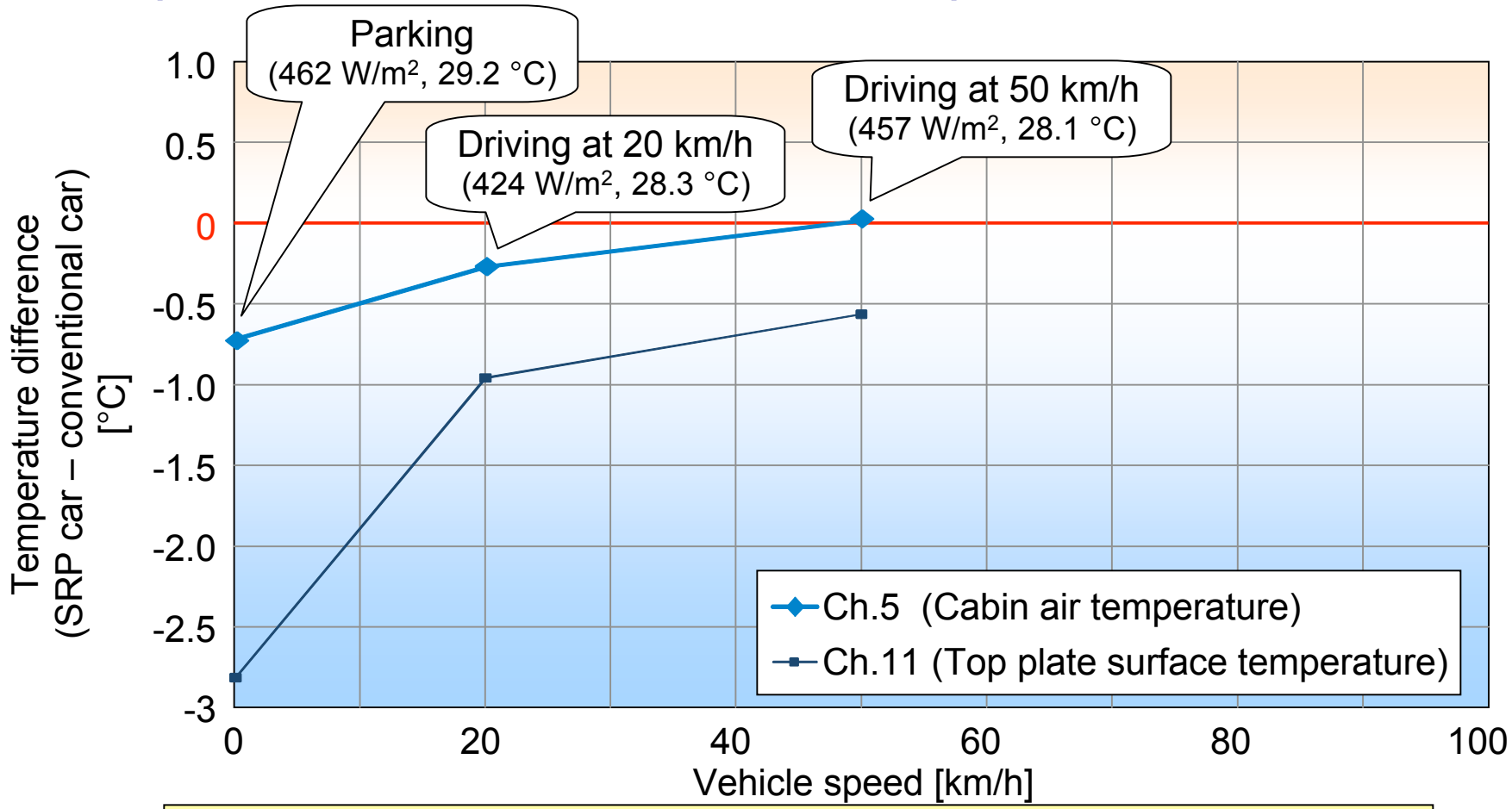
◆Result: Analyzed temperature difference at Ch.5



- Some factors might remain. (*e.g.* use of many drivers and correlation of solar radiation with outdoor air temperature).
- Even if so, It was found that SRP reduced cabin air temperature by 0.26 °C.

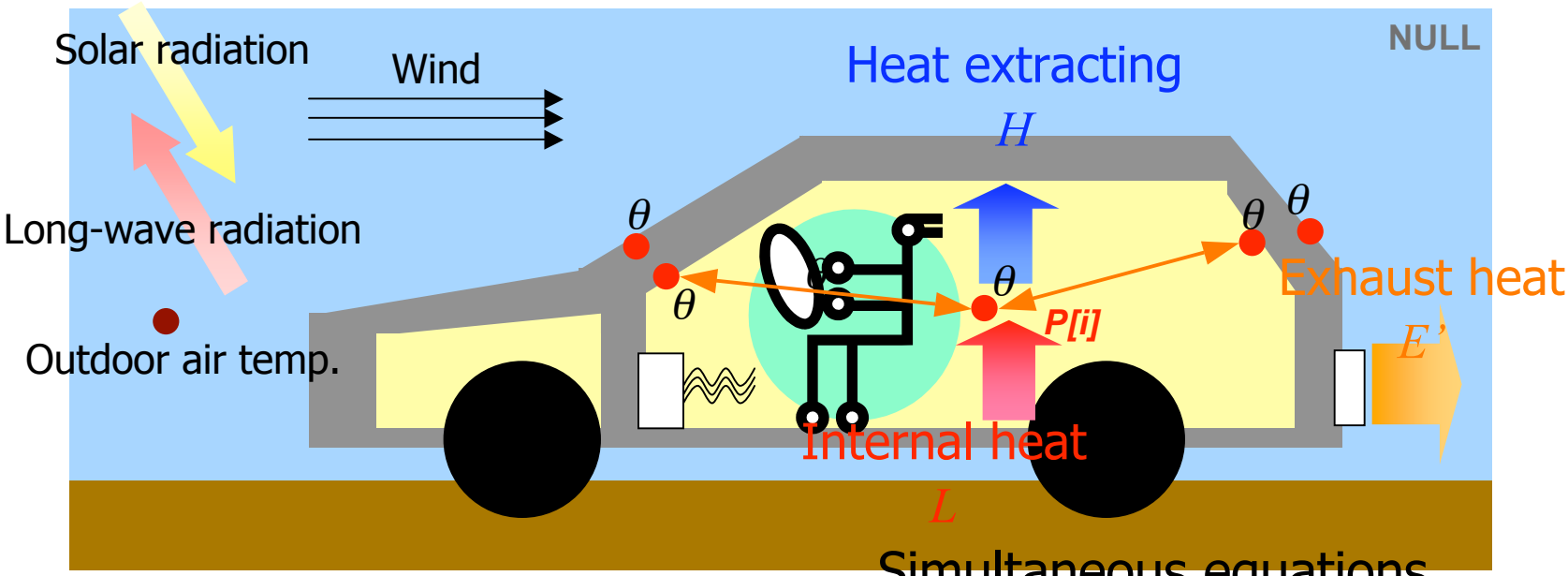
2. Temperature test

◆Temperature reductions vs. Vehicle speed



SRP effect disappeared when driving at 50 km/h, but it surely existed when driving at 20 km/h.
(Cf. Average vehicle speed in Tokyo = 18.8 km/h)

3. Numerical simulation (under working)



- Revision of a building program
- Output: Air temp./heat extracting

Input:

- Weather conditions
- Automobile specification
- Schedules (air-conditioning, etc.)

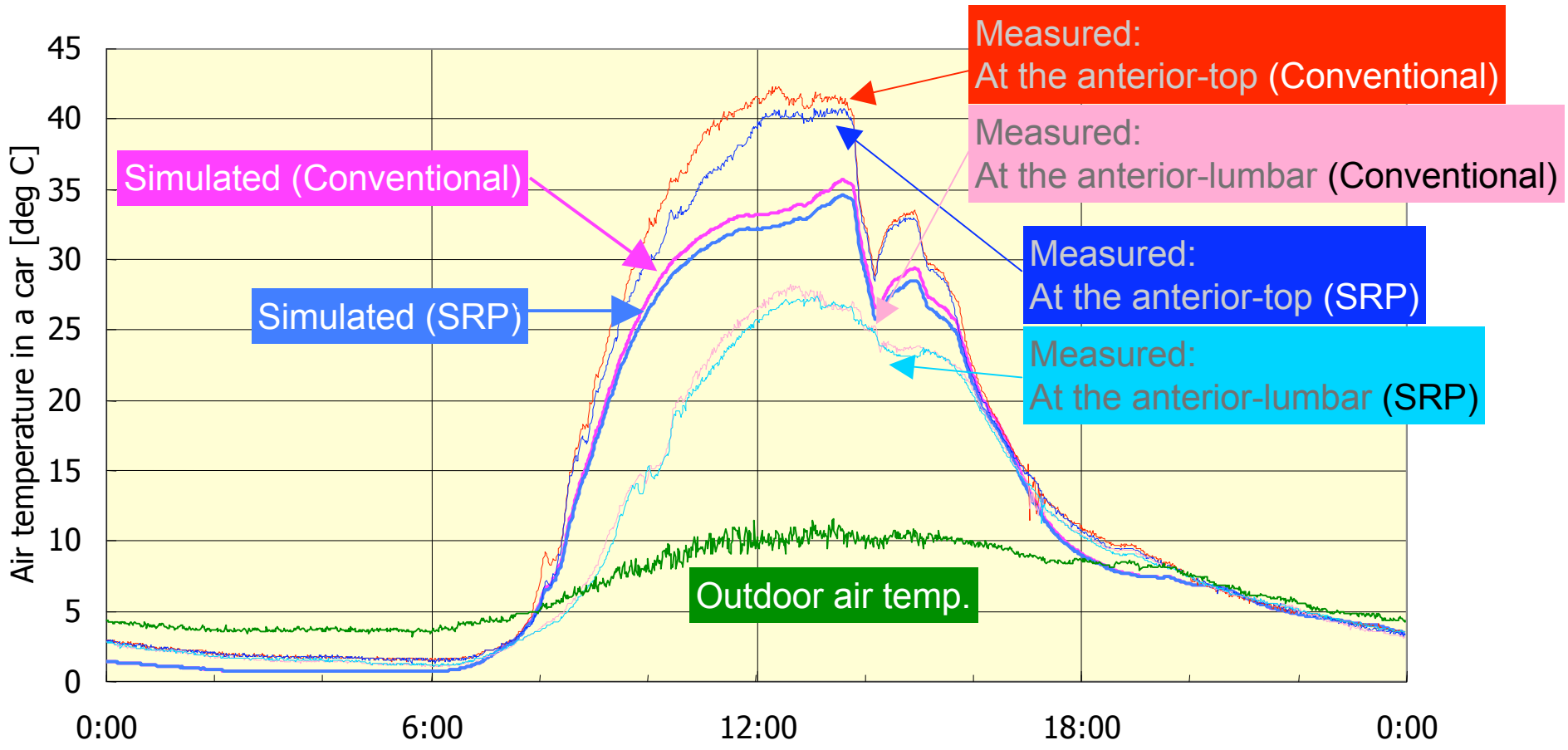
Simultaneous equations

$$\begin{bmatrix} & M & \end{bmatrix} \left\{ \theta^K \Big|_{P[i]} \right\} = \left\{ V \right\}$$

- Differential equations about θ are solved according to the backward difference method.
- M and V are constants.

3. Numerical simulation (under working)

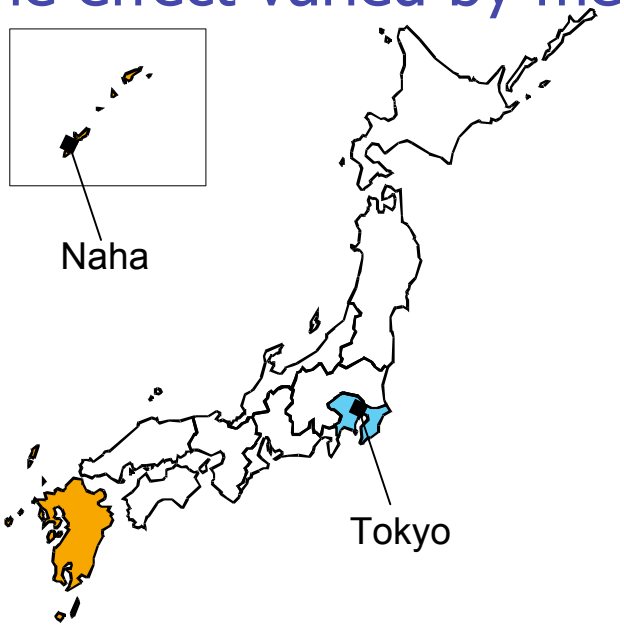
◆Effect of SRP using simulation model

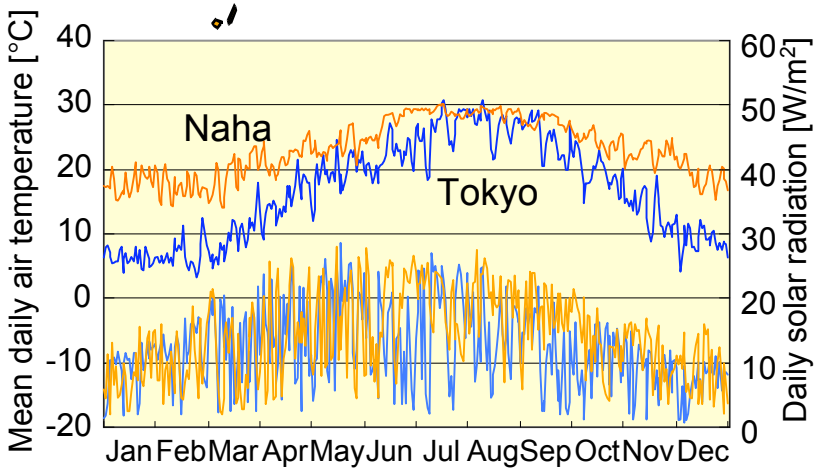


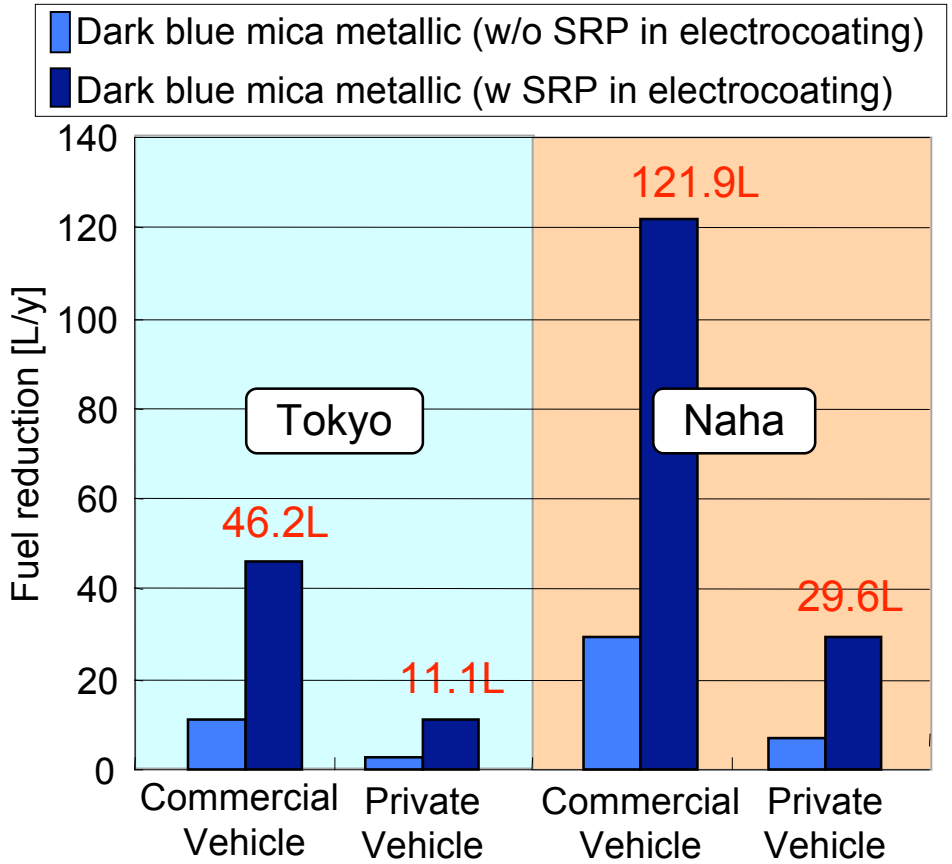
Thermal environment improves by applying SRP.

3. Numerical simulation (under working)

◆The effect varied by meteorological condition







Fuel consumption reduction is greater in a warmer area.

4. Conclusion

- Thermal environment surely improves by applying SRP.
  = Fuel consumption by use of A/C is sure to improve.

- Cost for SRP installation is small compared with other fuel consumption improvement technology.

- With some strong political support (ex. Regulations for vehicle paints), SRP can be used as de-facto paint of vehicles->CO_2 abatement

4. Conclusion

◆Increase of solar reflectivity by SRP

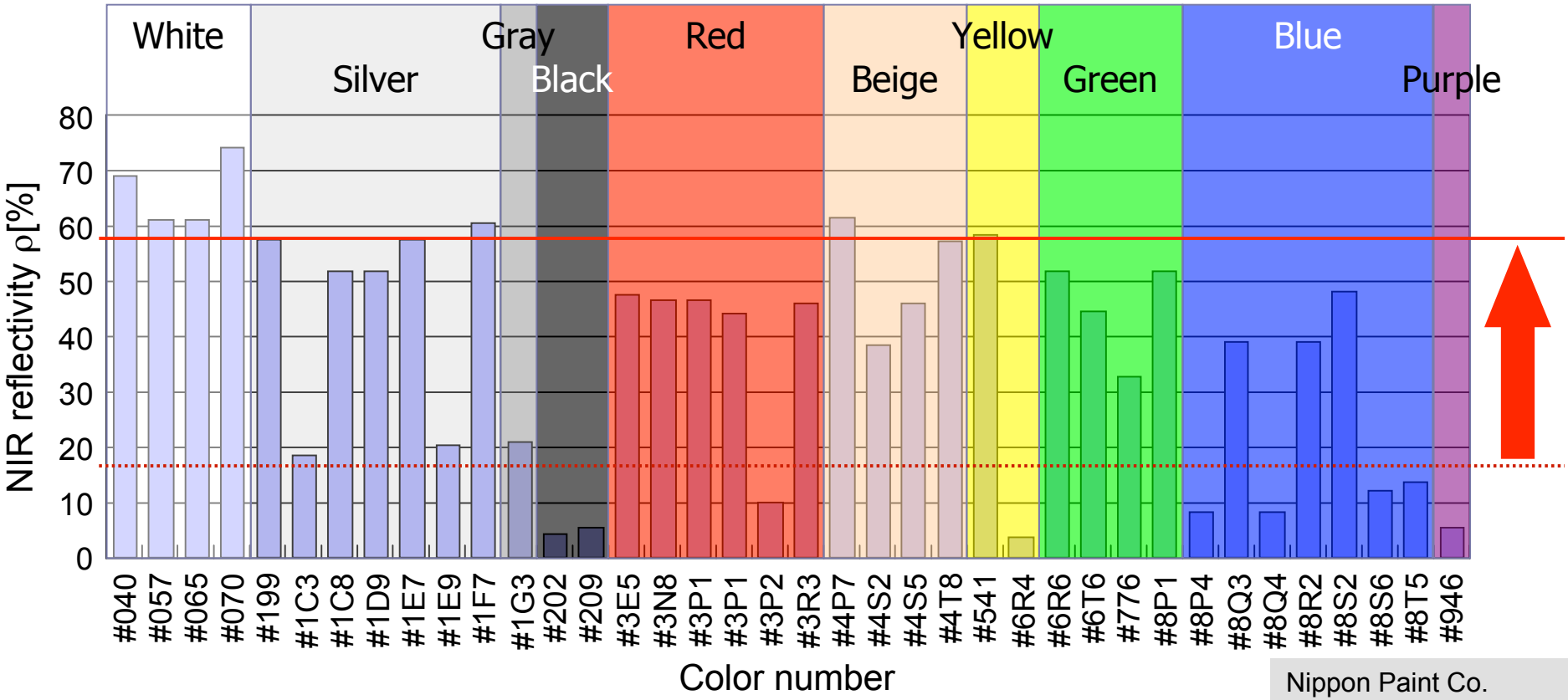
Nippon Paint Co. 2005.

Color		Conventional	Replacement by SRP	
		Reflectivity	R	ΔR
#040	Super white 2	69.0%	83.6%	+14.6%
#1C3	Gray mica metallic	18.4%	48.5%	+30.1%
#1D9	Silver metallic graphite	51.9%	60.8%	+8.9%
#1E7	Silver mica metallic	57.5%	64.3%	+6.8%
#209	Black mica metallic	1.5%	48.4%	+46.9%
#3P1	Red mica metallic	46.7%	50.2%	+3.5%
#3P2	Bordeaux mica	9.9%	54.3%	+44.4%
#6R4	Dark green mica	3.5%	45.2%	+41.7%
#8P4	Dark blue mica metallic	8.0%	50.4%	+42.4%
#8Q3	Grayish blue mica metallic	39.1%	54.4%	+15.3%
#946	Dark purple mica	5.4%	51.1%	+45.7%
…		…	…	…
Average (a standard-type car)		46.7%	64.2%	**+17.5%**

The solar reflectivity of a standard-type car will increase by an average of 17.5%.

4. Conclusion

◆Near-infrared (NIR) reflectivity of conventional paint



Nippon Paint Co. 2009.

NIR reflectivity varies by color and brightness, but every color has the lineup of reflective paint. NIR reflectivity could be increased to about 60% by coloring design.

Thank you for your attention.

4. Conclusion

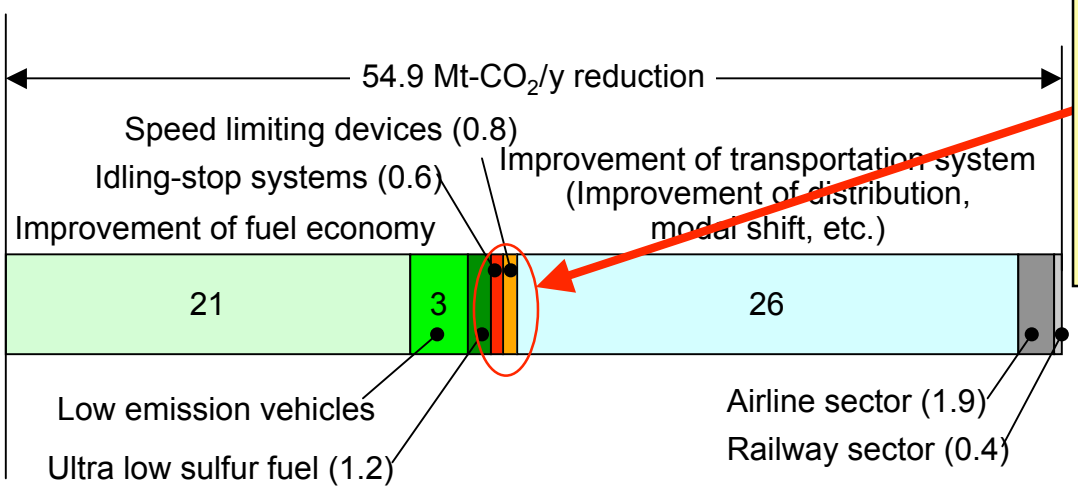
- Policy proposition
  - Although improvement of fuel economy itself by SRP is not large, results of our test show that fuel consumption reduction can be expected by applying SRP either in parking and driving condition using AC (temperature decline in 室内). = Less attractive for consumers as "environmentally friendly vehicle".
  - However, its installation cost is small.
  - Some of the vehicles with high fuel economy are already well-insulated. High effects can be expected by applying SRP to cars (1) used in places where temperature is high (usually use A/C), (2) with little insulation and (3) driven at low speeds. = SRP surely has effect to fuel consumption by using A/C.
  - From these points of view, it is recommended that policy makers (and vehicle manufactures) should promote the application of SRP.
  - It is necessary for policy makers and/or vehicle manufactures to promote the vehicle with SRP.

1. Introduction

◆Potential of CO_2 emissions reduction in Japan

A rise in solar reflectivity by SRP is 17.5%.
If this actual fuel improving effect observed in Tokyo can be extrapolated to whole Japan.

In Japan: 150,000 t-CO_2/y
(when SRP is installed to only passenger cars: ???,??? cars)



The Kyoto Target Achievement Plan
(Cabinet decision on April, 2005)

Prevail of idling-stop systems, speed limiting devices, etc. → approx. 600,000 ~ 800,000 t-CO_2/y
(ex. Idling-stop system
Added cost: \80,000/car)

SRP which can be introduced under existing car manufacturing plants, costs very reasonable.