Energy Conservation and Urban Heat Island Mitigation Effects by Solar Reflective Coating to an Automobile

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Overview

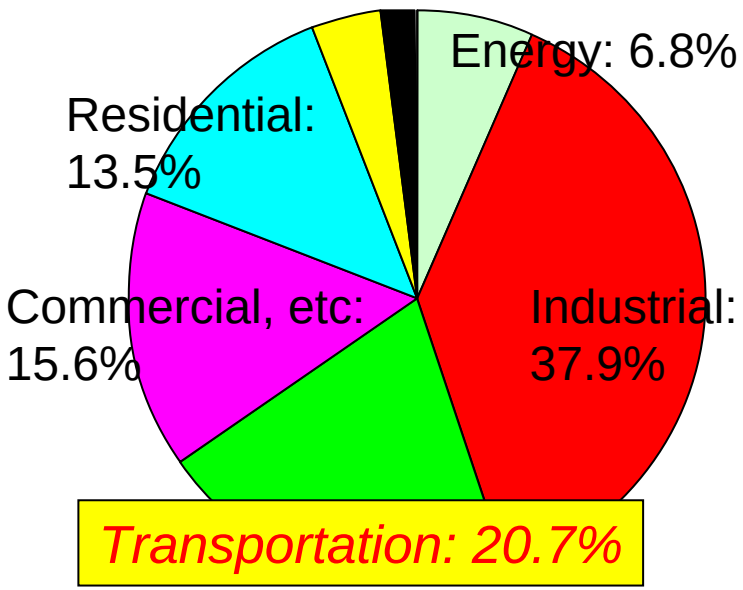
1. Introduction
2. Solar reflective paint (SRP)
3. Application of automobile body coating
4. Evaluation of energy conservation effect
5. Evaluation of urban heat island mitigation effect
6. Conclusion

1. Introduction

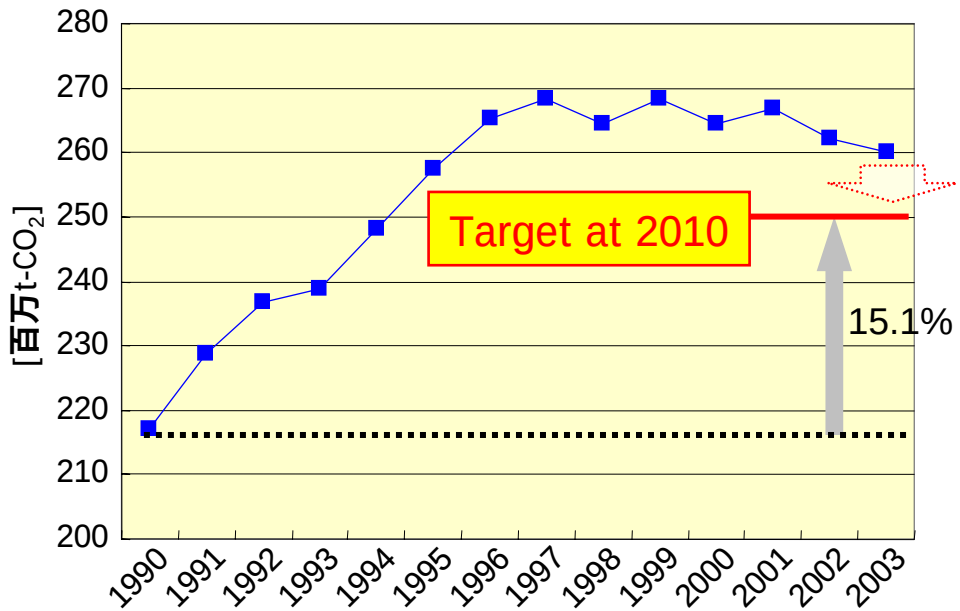
In Japan...

- Kyoto Protocol Target: To reduce GHG emissions by 6% from 1990 level.
- CO_2 emissions from the transportation sector occupied 20% of the total.

The transportation sector also must make more efforts to achieve the target.



CO_2 emissions in 2003



CO_2 emissions from the transportation sector

1. Introduction

◆Energy-saving measures in the transportation sector

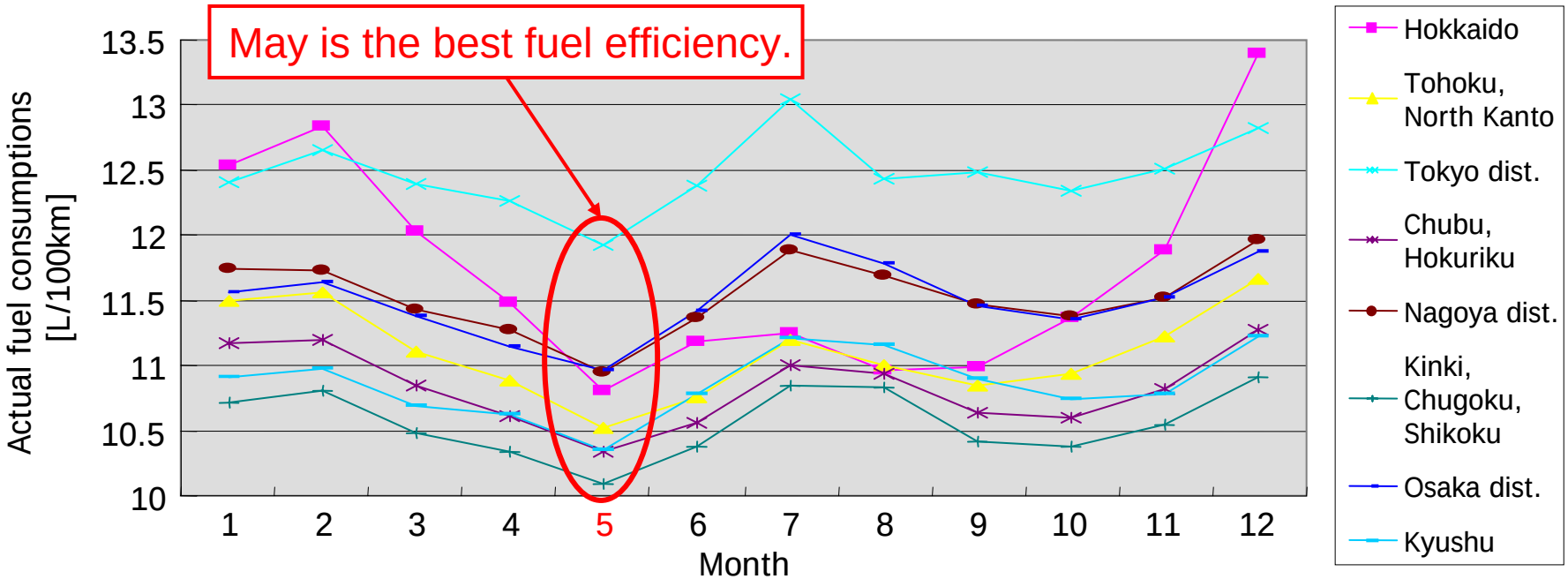
- Automobile
  - Improvement of actual fuel efficiency (energy consumptions)
  - Spread of low emission vehicles
    - Electric vehicle
    - Hybrid electric vehicle
- Traffic flow
  - Introduction of intelligent transportation system (ITS)
  - Efficiency of distribution systems
- Modal shift
  - Railway transport
  - Marine transport

etc.

1. Introduction

◆Actual fuel efficiency

Ref : Y. Kudoh, el al. Current status of actual fuel-consumptions of petrol-fuelled passenger vehicles in Japan. Applied Energy, No.79, 2004.



Seasonal change of actual fuel consumptions in Japan

Use of air-conditioner exacerbates actual fuel efficiency.
(May is not an air-conditioning season)

Improvement of thermal environment in cars will bring about actual fuel consumptions reduction?

2. Solar reflective paint

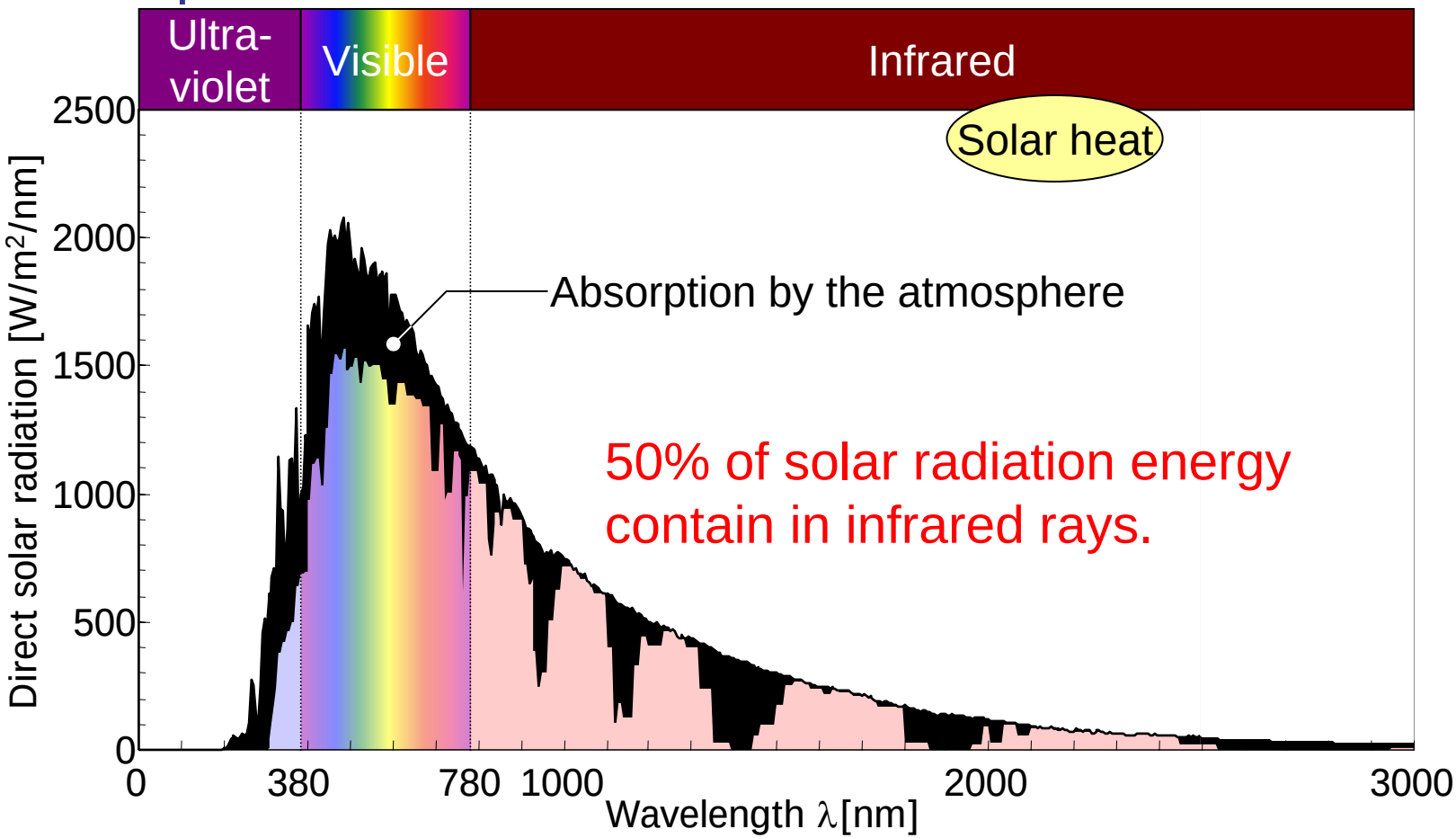
We focused on "Solar reflective paint"
as one of technologies which improve thermal environment in cars.

◆Solar reflective paint (SRP)

- About solar reflective paint
  - SRP has high solar reflectivity and brings about cooling load reduction. (High reflectivity against near-infrared ray)
  - It contributes both of
    energy conservation by cooling demand reduction and
    urban heat island mitigation.
- Introduction to buildings, mainly
  - Especially, to plants and warehouses
  - SRP is often called as "Heat shield paint" or "High albedo paint".

2. Solar reflective paint

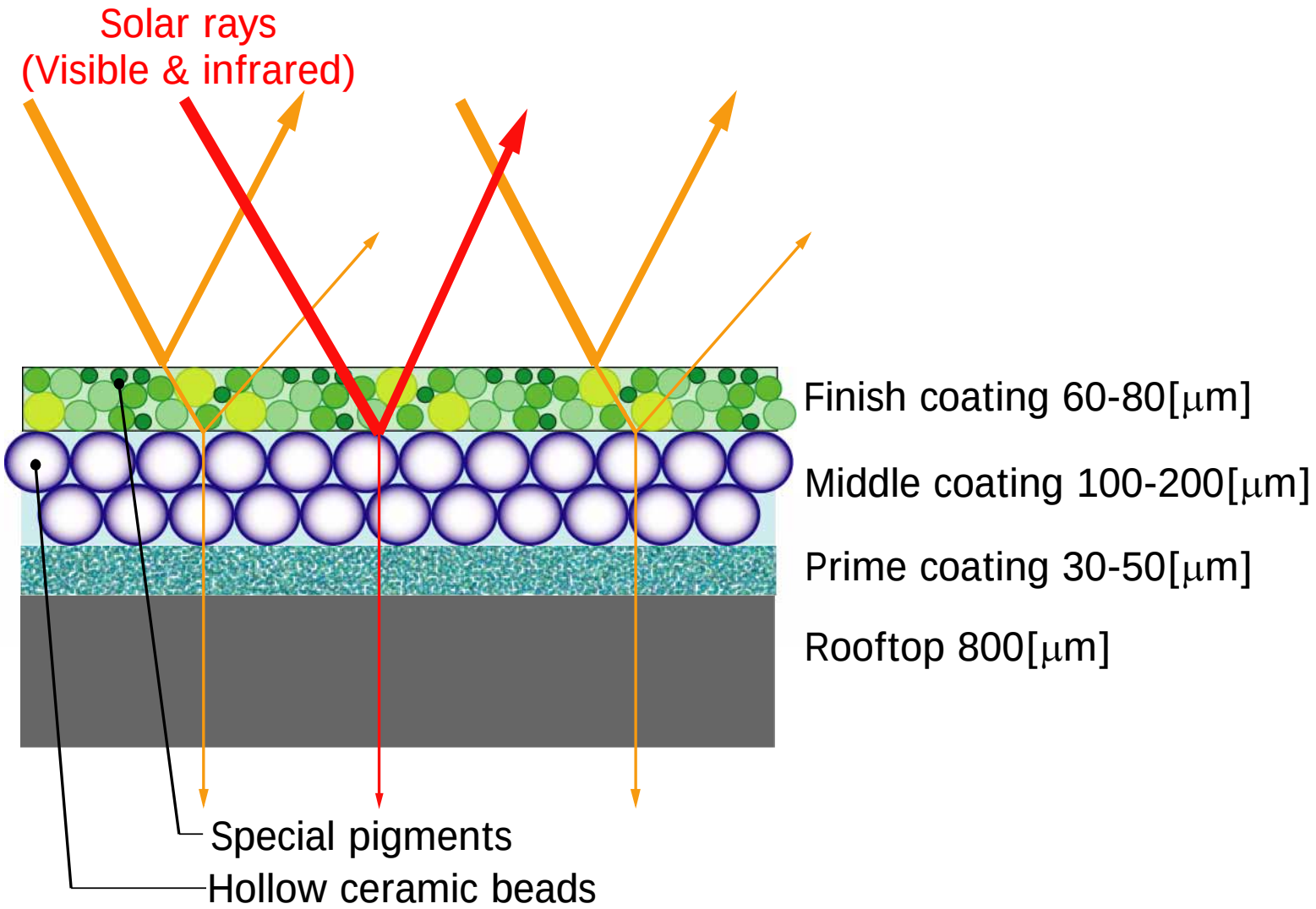
◆Solar spectrum



If reflectivities in a visible region is the same and only ones in a infrared region is raised, a reflective paint with same color can be made.

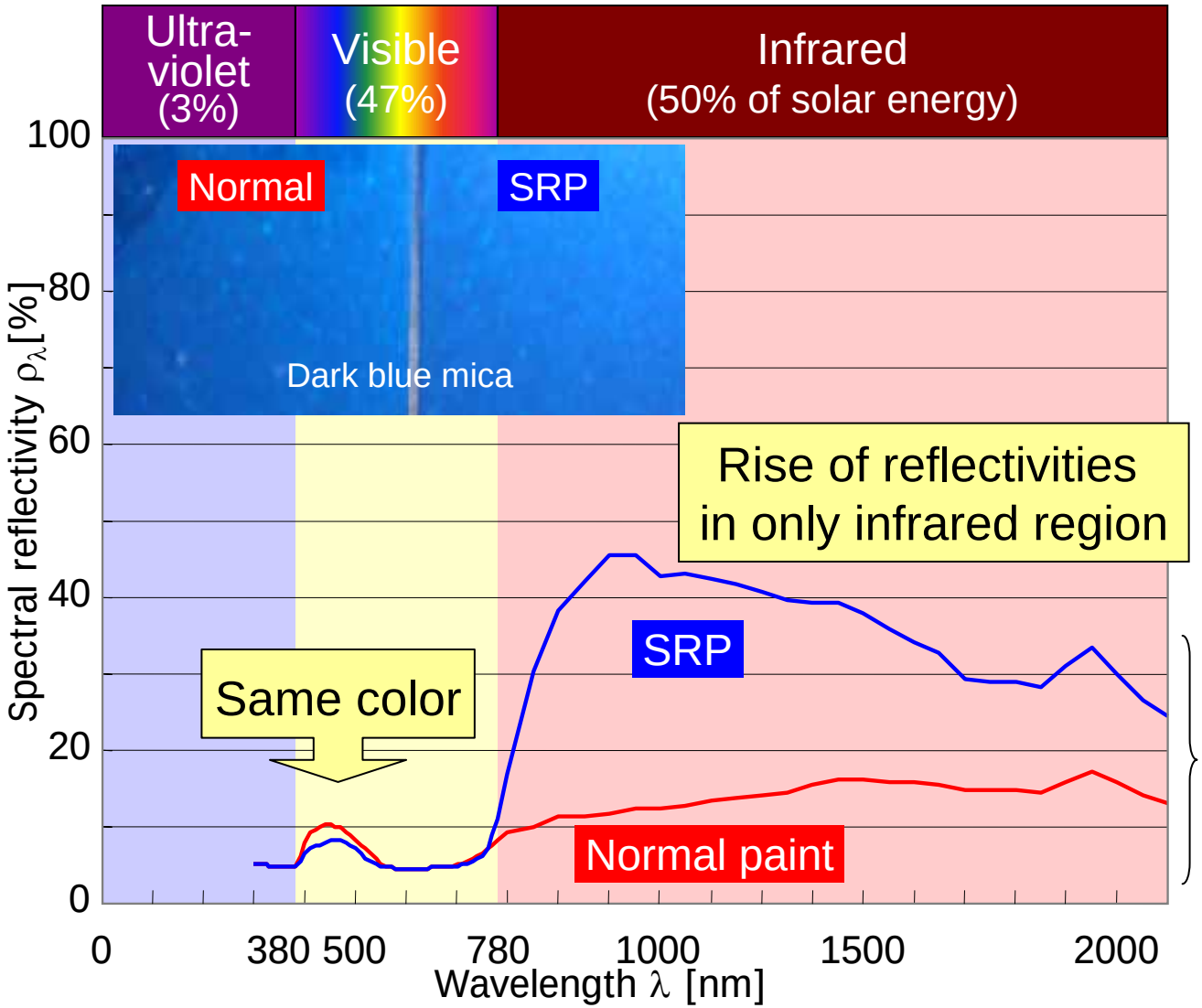
2. Solar reflective paint

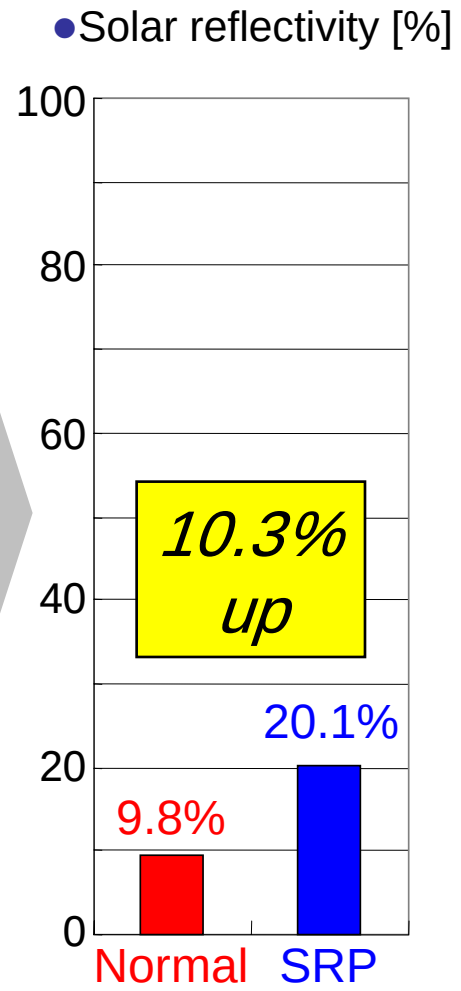
◆Application of SRP to a building surface



2. Solar reflective paint

◆Solar reflectivity and color of SRP

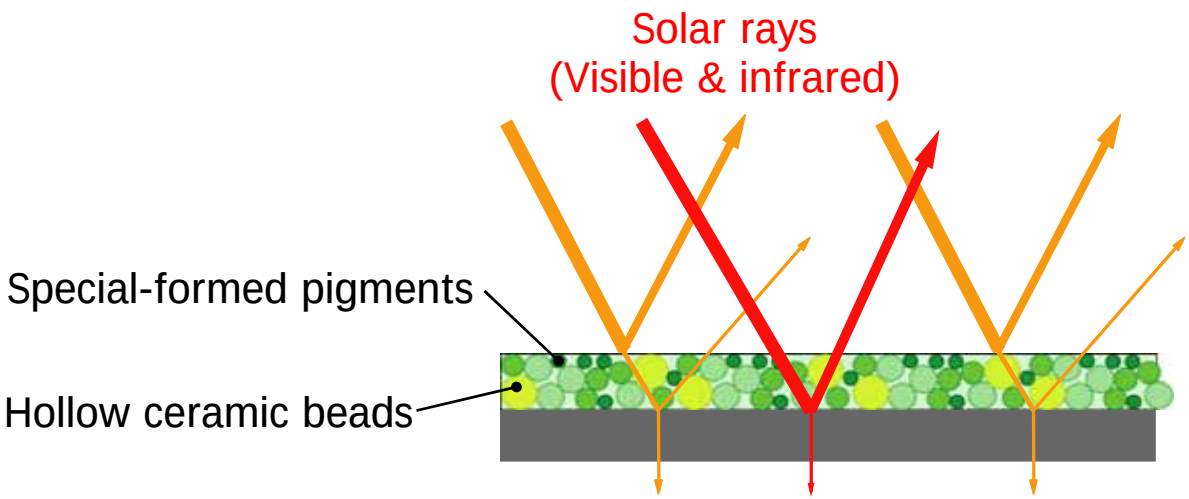




3. Application of automobile body coating

◆How to apply SRP to an automobile body?

- Heat shield sheet
  - PVC sheet including special pigments and ceramics beads.
  - A case in which SRP was installed to rooftops of buses, container trucks, etc., already exists.
    - In a case in which SRP was installed to a daytime expressway bus, air temperature in the bus was reduced by the maximum of 5 degrees C.
  - Making sheets from paints costs very much than simple coating.



3. Application to automobile body coating

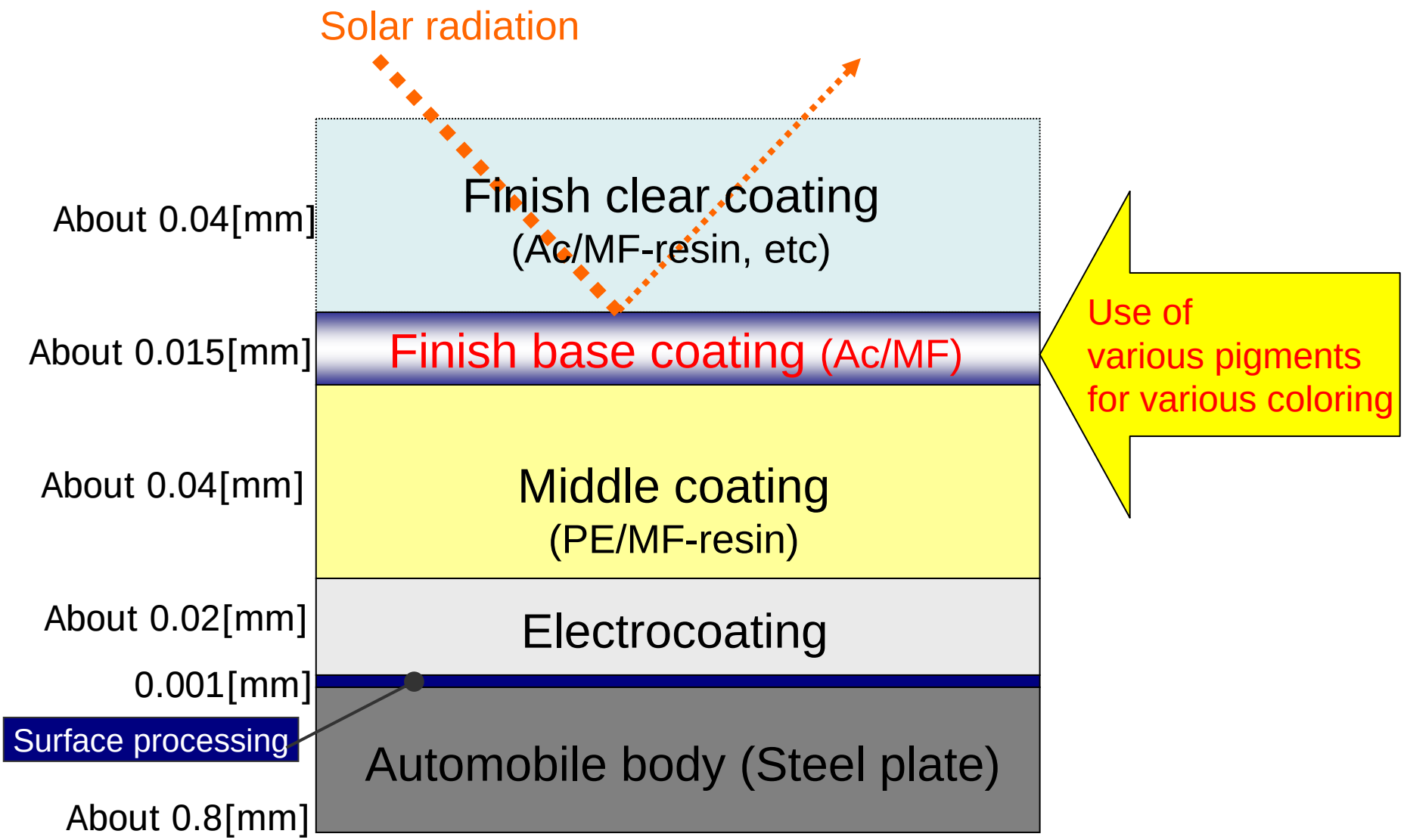
◆How to apply SRP to an automobile body?

- Heat shield sheet

- Simple coating
  = Solar reflective coating to an automobile body
  - Replacement from normal pigments to special-formed pigments in automobile body paints
  - Hollow ceramic beads are not included.

3. Application to automobile body coating

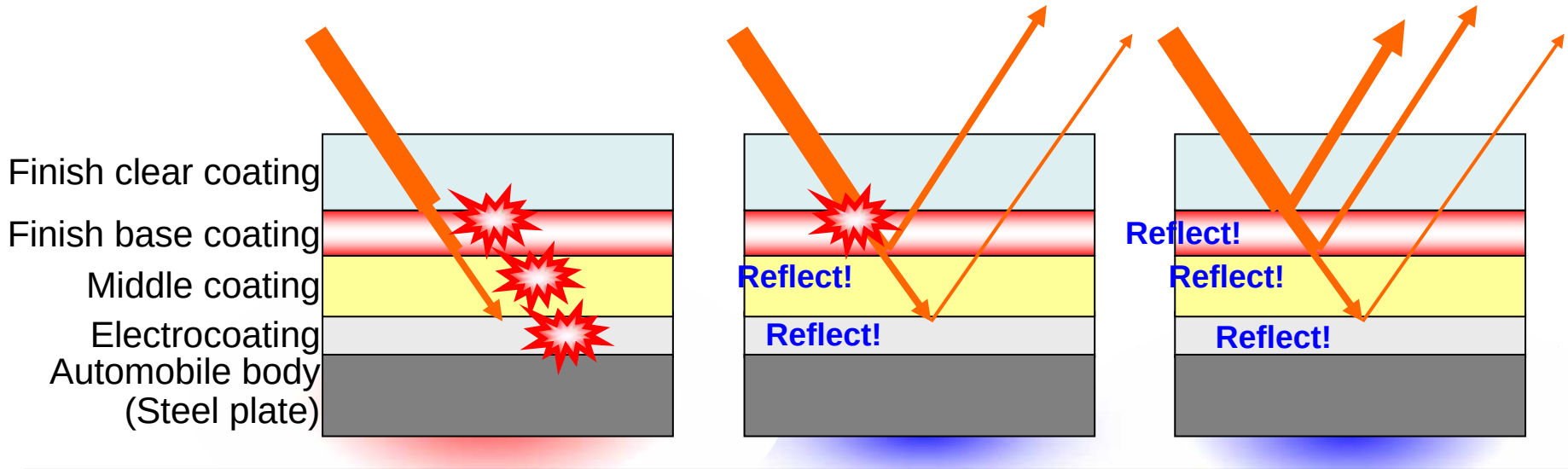
◆Composition of automobile body coating



3. Application to automobile body coating

◆Solar reflective coating to automobile body

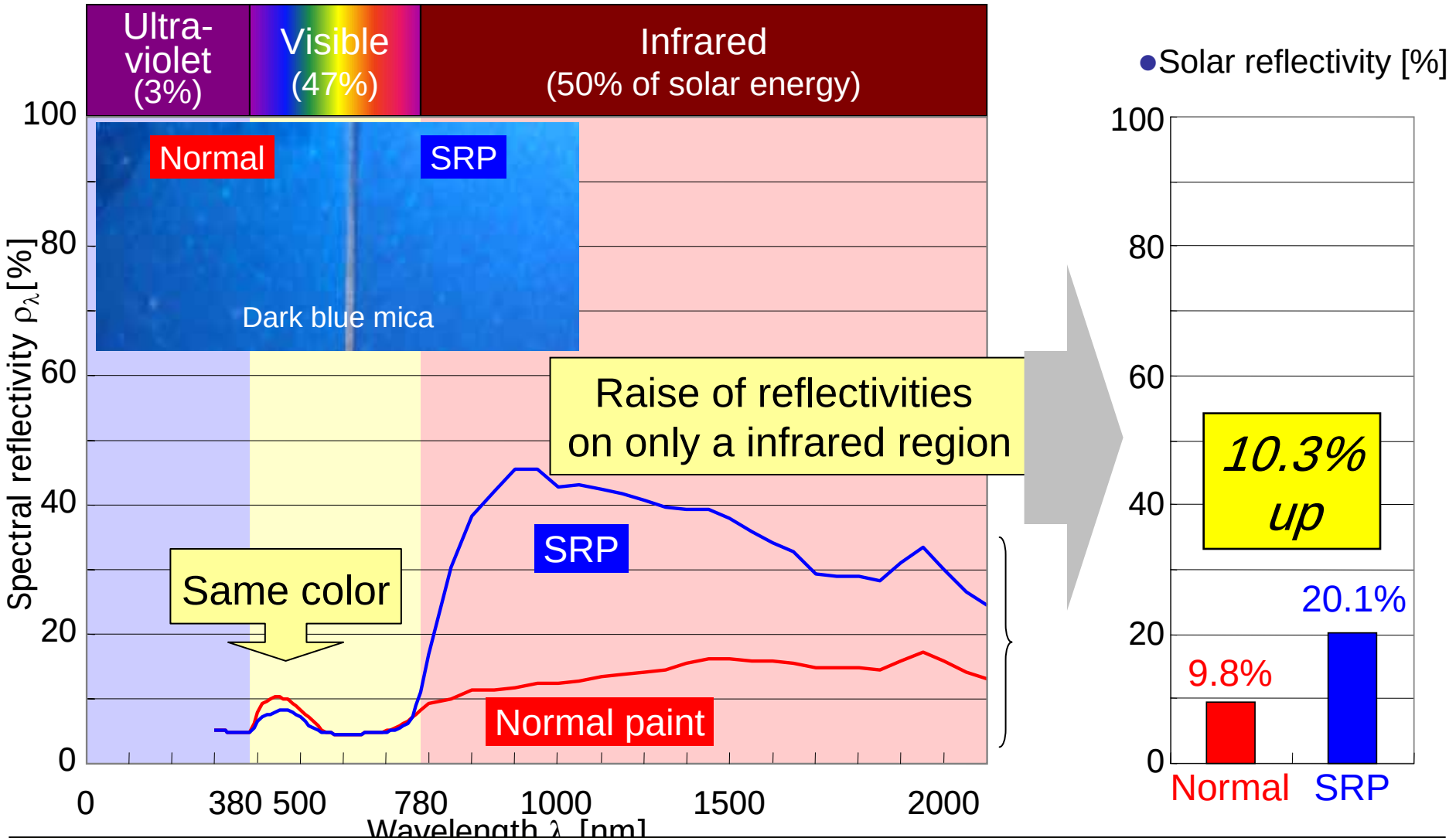
Normal paints	Replacement to SRP in electrocoating and middle coating	Replacement to SRP in electrocoating, middle coating and finish coating



- Hollow ceramic beads are NOT available, because automobile body coating consists of thin films.
- Normal pigments in each coating layer are replaced to special pigments. (Below layers' reflectivity also have some effects to a total reflectivity, because each layers' transmittance is not zero.)

3. Application to automobile body coating

◆Solar reflectivity and color of SRP



Color is well reproduced. (Special pigments of the carbon black is found.)

3. Application to automobile body coating

◆Increase of solar reflectivity by replacement to SRP

Color	Normal	Replacement to SRP in electro- and middle coatings		+ Replacement to SRP in finish base coating	
	Reflectivity	R	ΔR	R	ΔR
#040	69.0%	76.0%	+7.0%	83.6%	+14.6%
#1C3	18.4%	19.3%	+0.9%	48.5%	+30.1%
#1D9	51.9%	52.7%	+0.8%	60.8%	+8.9%
#1E7	57.5%	59.0%	+1.5%	64.3%	+6.8%
#209	1.5%	2.3%	+0.8%	48.4%	+46.9%
#3P1	46.7%	50.1%	+3.4%	50.2%	+3.5%
#3P2	9.9%	12.1%	+2.2%	54.3%	+44.4%
#6R4	3.5%	4.9%	+1.4%	45.2%	+41.7%
#8P4	8.0%	10.9%	+2.9%	50.4%	+42.4%
#8Q3	39.1%	40.7%	+1.6%	54.4%	+15.3%
...	...	...	...	...	...
Average	46.7%	50.4%	**+3.7%**	64.2%	**+17.5%**

A solar reflectivity in a standard type of car will increase an average of 17.5%.

4. Evaluation of energy conservation effect

◆Measurement of thermal environment in cars

- Purpose
  - Evaluation of thermal environment in a car coated with SRP, really
  - Investment of automobile heat load simulation program
- Methodology
  - Two cars colored with dark blue mica, one is coated with SRP and another is normal coated, were fixed on a sunny place of Tokyo.
  - Surface temperatures, air temperatures in a car and weather conditions were measured.

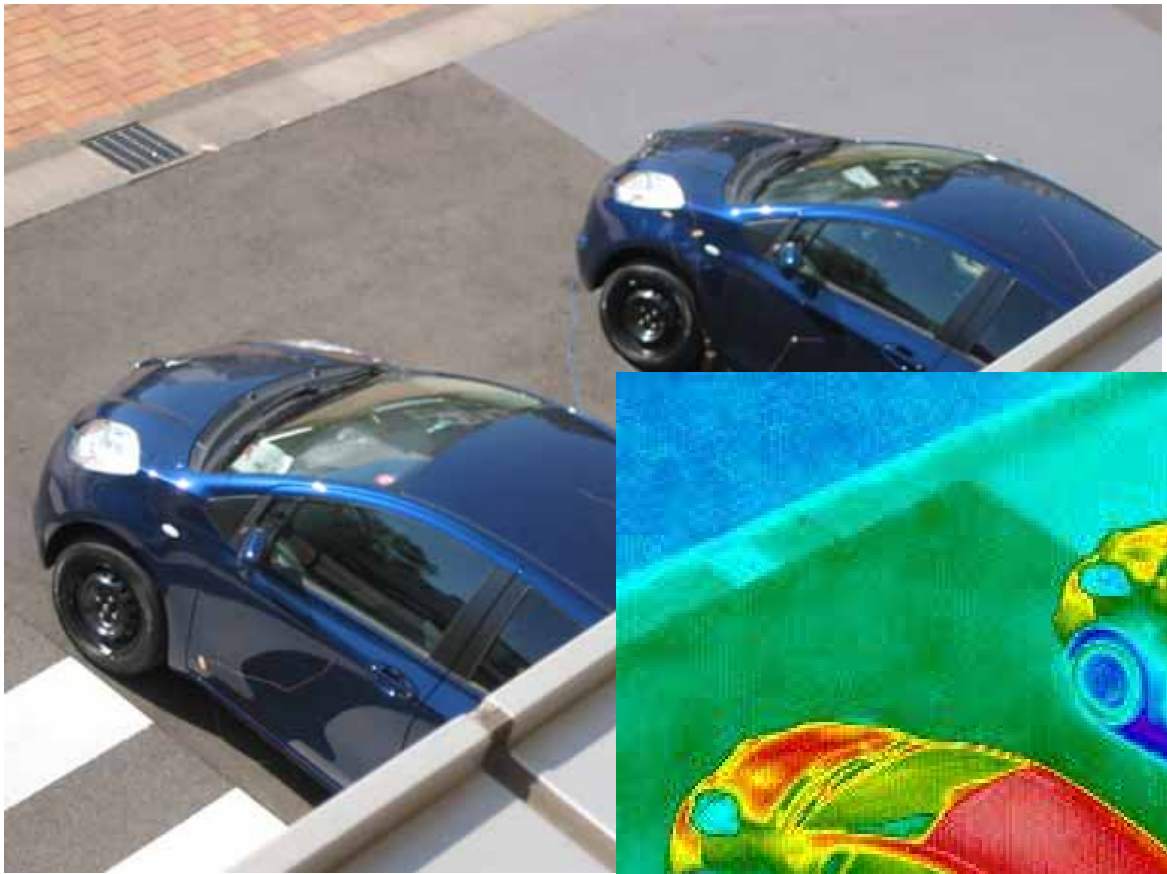
4. Evaluation of energy conservation effect

◆Measurement of thermal environment in cars

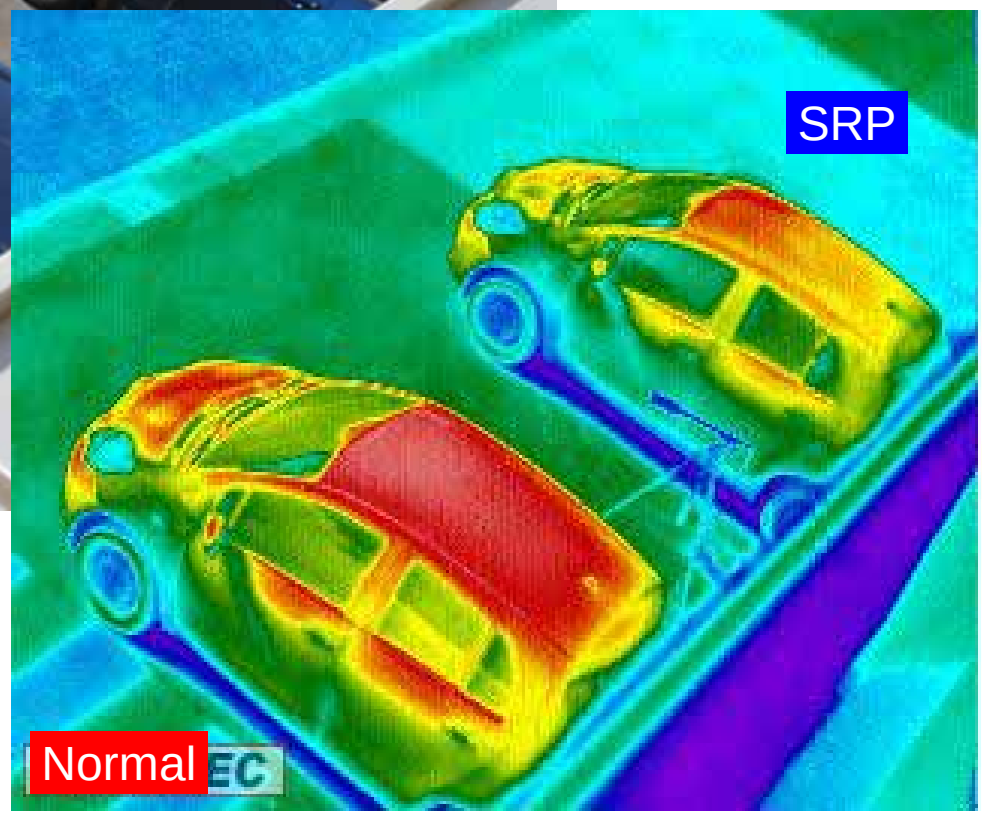
- Measurement system
  - Measuring
    - Radiometer: EKO MR-40
    - Anemometer: EKO MA-130
    - Thermocouples: Yamari DT20TT
  - Data logging
    - EKO DATAMARK LS-3000PtV, DATAMARK LS-3300PtV
    - EKO CADAC21 9220A, SOLAC V
- Measured item
  - Cars
    - Inside/outside surface temperatures
    - Air temperatures in cars
  - Weather conditions
    - Solar radiation & atmospheric radiation
    - Wind direction & velocity
    - Outdoor air temperature

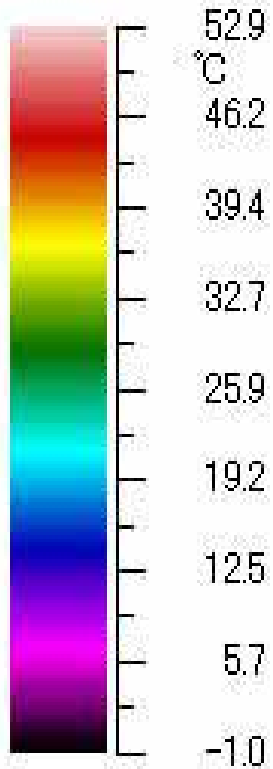
4. Evaluation of energy conservation effect

◆Measurement: Thermograph (2006/01/29)



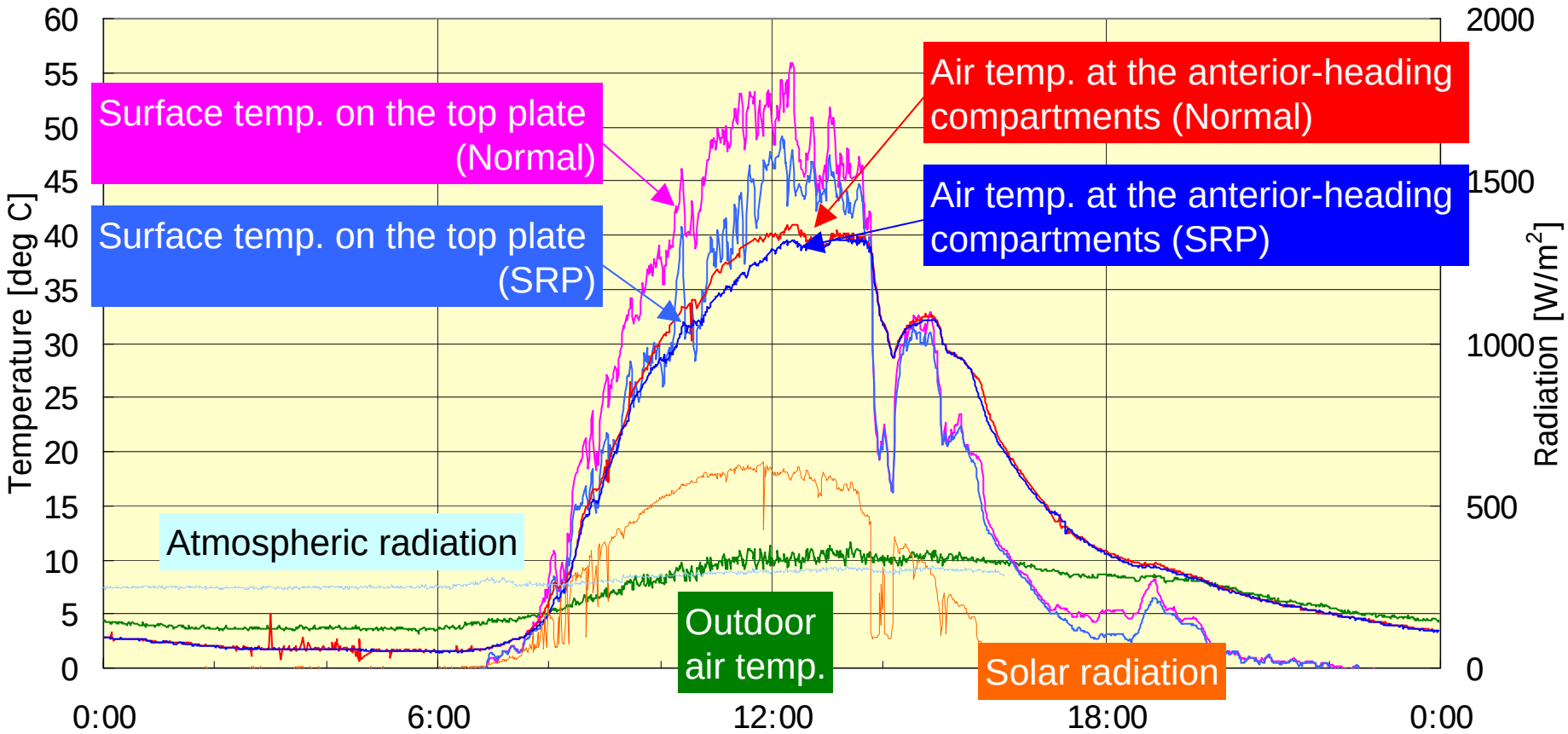
Temperature increase was repressed.





4. Evaluation of energy conservation effect

◆Measurement: Air temperature in cars (2006/01/27)

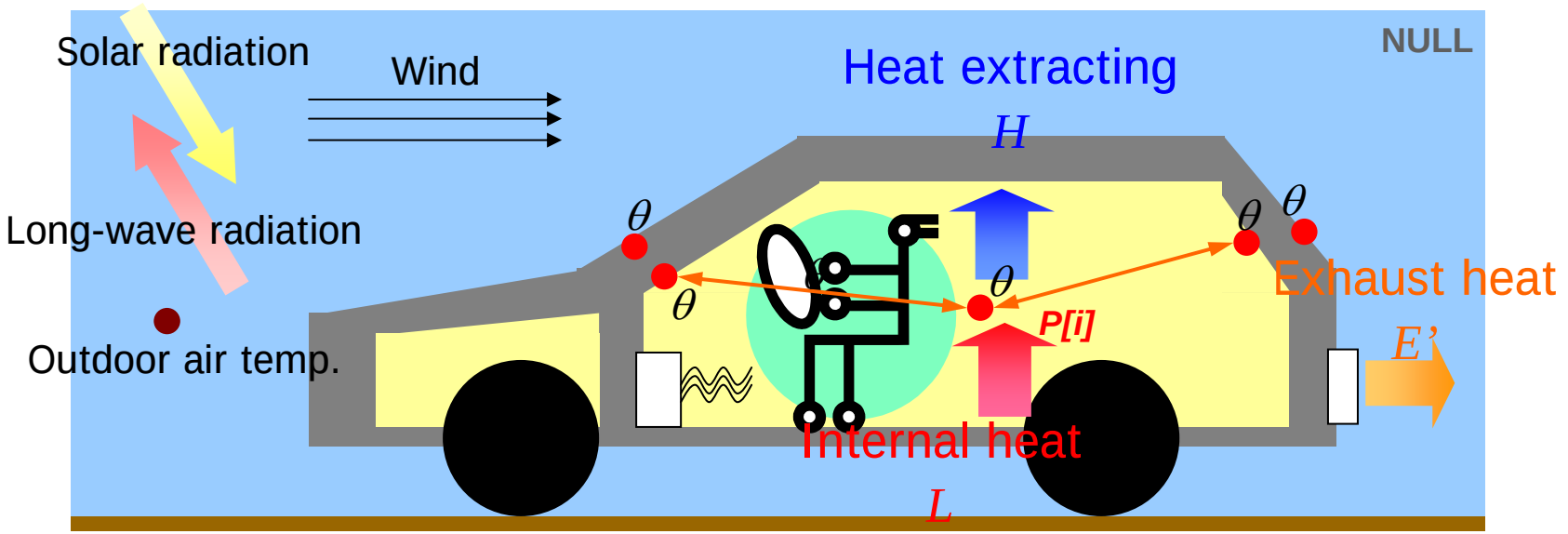


- Air temp. in the normal car was the maximum of 40 deg C in the daytime.
- The SRP car brought about surface temp. by 5~10 deg C.
- Air temp. in the SRP car also were reduced the maximum of 3.9~1.6 deg C.

4. Evaluation of energy conservation effect

◆Automobile heat load simulation program

EDSDHL



- Revising from a building program
- Output: Air temp./heat extracting

Input:

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

Simultaneous equations

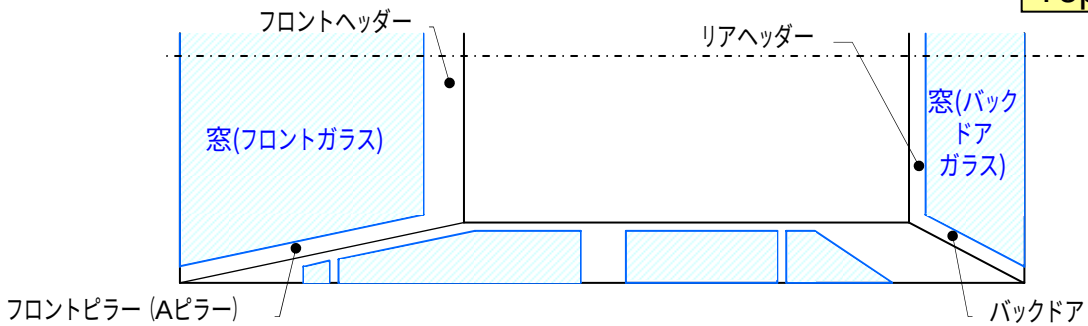
$$\left[\quad M \quad\right]\left\{\theta^{K}\big|_{P[i]}\right\}=\left\{V\right\}$$

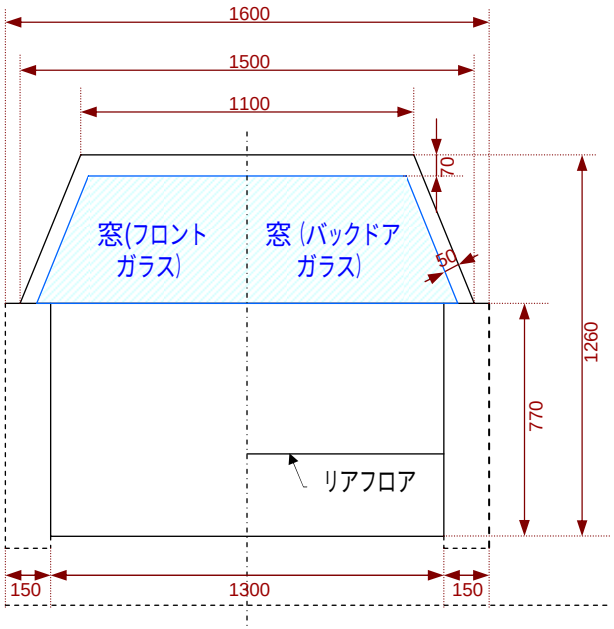
- Differential equations about θ are solved by the backward difference method.
- M and V are constants.

4. Evaluation of energy conservation effect

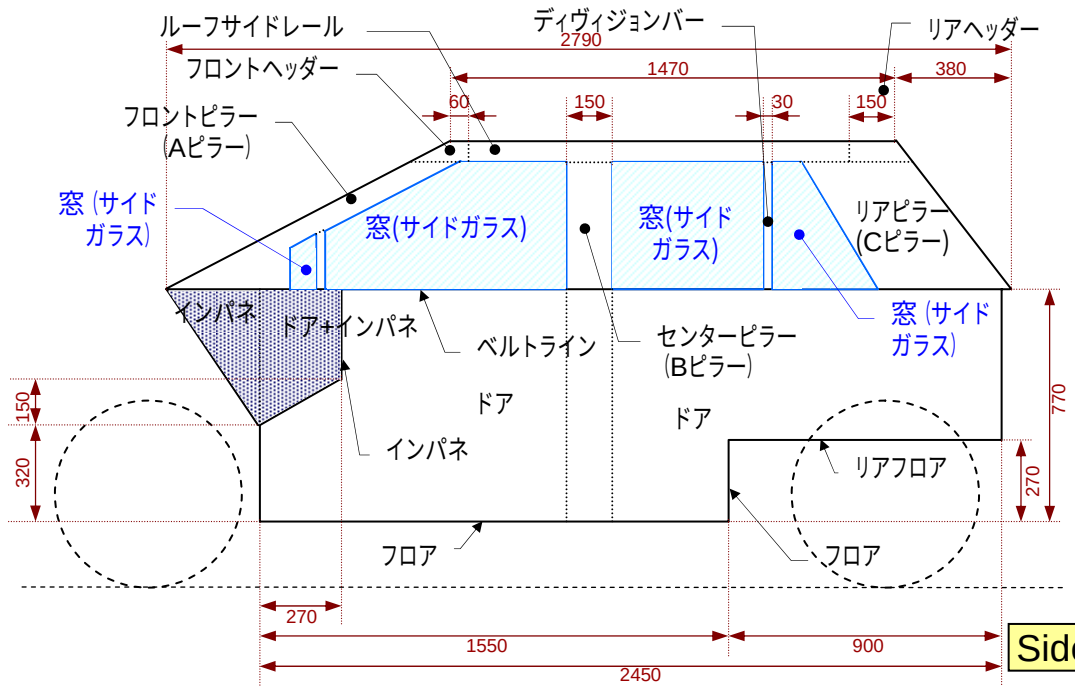
◆Conditions of automobile specification

Top view





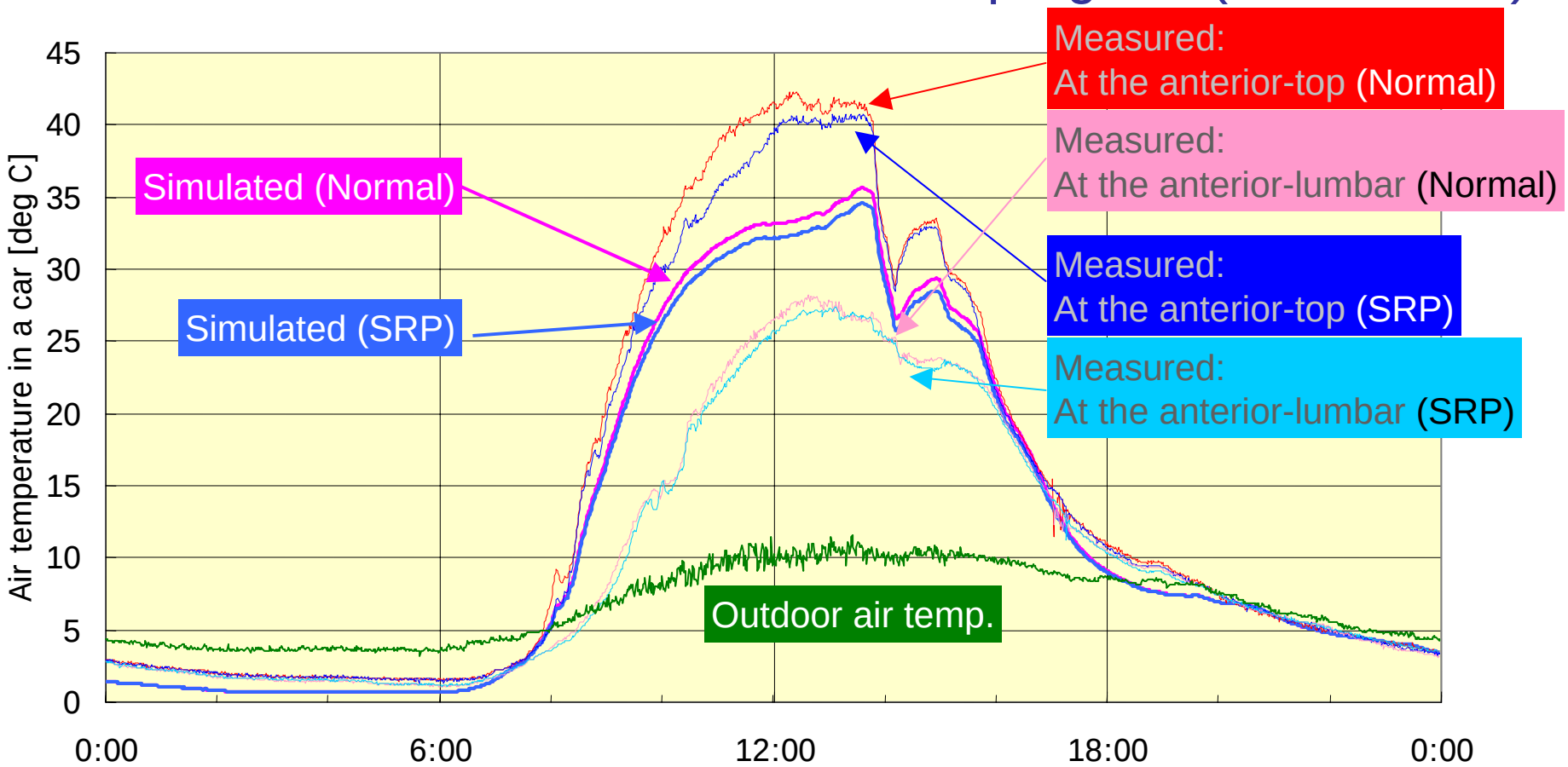
Back/front view



Side view

4. Evaluation of energy conservation effect

◆Simulation: Investment of simulation program (2006/01/27)



- Measured data in Jan. 27th were used as simulation conditions of weather.
- Simulation results reproduced air temperatures measured in two cars.

➡ Automobile simulation program reproduced actual thermal environment.

4. Evaluation of energy conservation effect

◆Fuel consumptions simulation

- Simulation conditions
  - Automobile specification
    - Cars which are used in this experiment.
    - Normal car & SRP car about “Dark blue mica” & “Dark blue” (two colors)
  - Weather conditions
    - Tokyo, Typical year (ref. “Expand AMeDAS Weather data” (AIJ))
  - Driving conditions
    - Two types such as a private vehicle and a commercial vehicle

Driving conditions	Private vehicle	Commercial vehicle
Yearly mileage [km/y]	10,575	63,113
Daily mileage [km/d]	43.5	216.9
Driving time	Mon. ~ Fri., 1.82[h/d]	Mon. ~ Sat., 9.07[h/d]
	Drop-off 7:30~7:45	Working 8:45~17:45
	Shopping 11:30~12:00	
	Shopping 15:00~15:45	
	Pickup 19:15~19:30	
Setting air temp. [deg C]	20(Lower) ~ 25(Upper)	

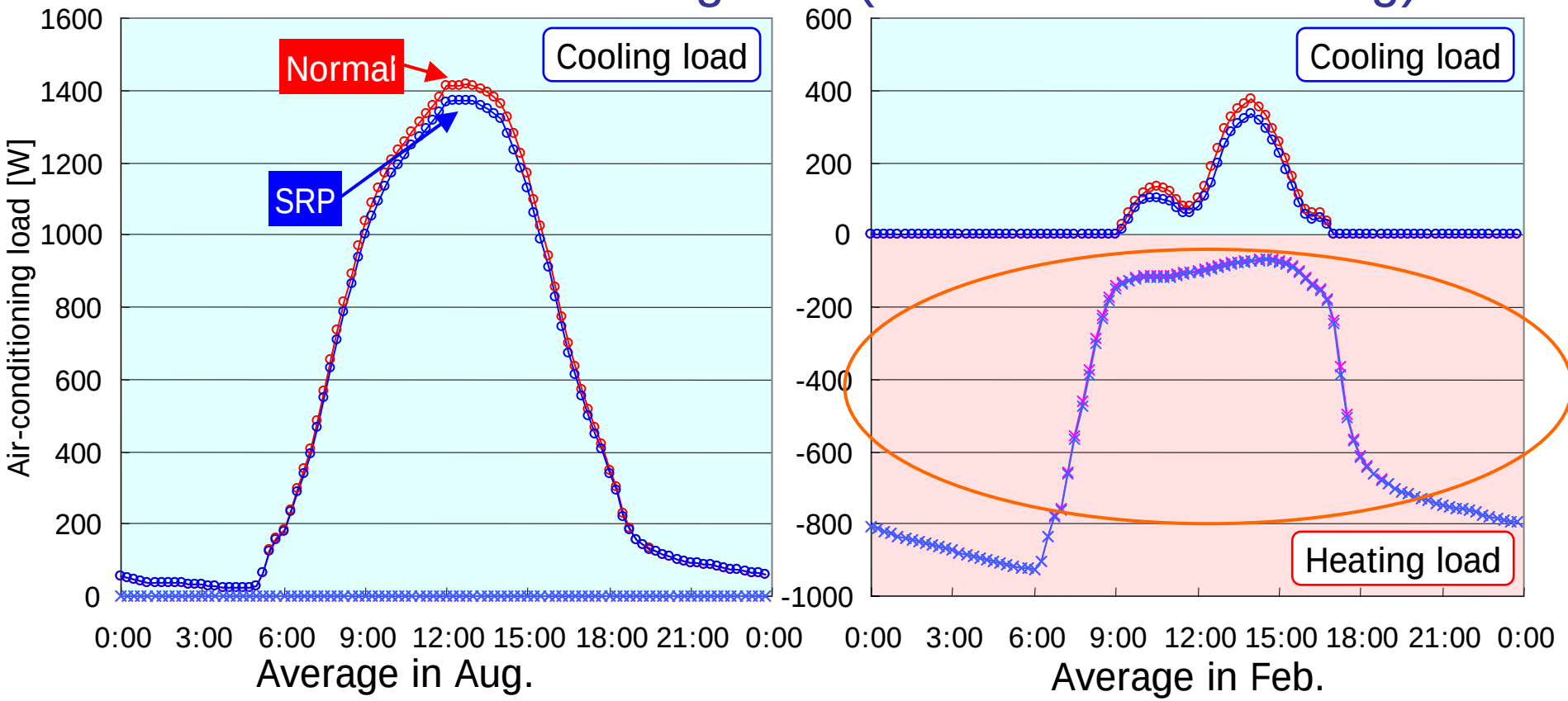
Statistics of yearly average mileage (MLIT)

Average speed in Tokyo pref. 23.9[km/h] (MLIT)

Default schedule from “SCHEDULE” (SHASEJ)

4. Evaluation of energy conservation effect

◆Simulation: air-conditioning load (when 24-hours driving)



An increase in heating load which is one of demerits on SRP is very small!

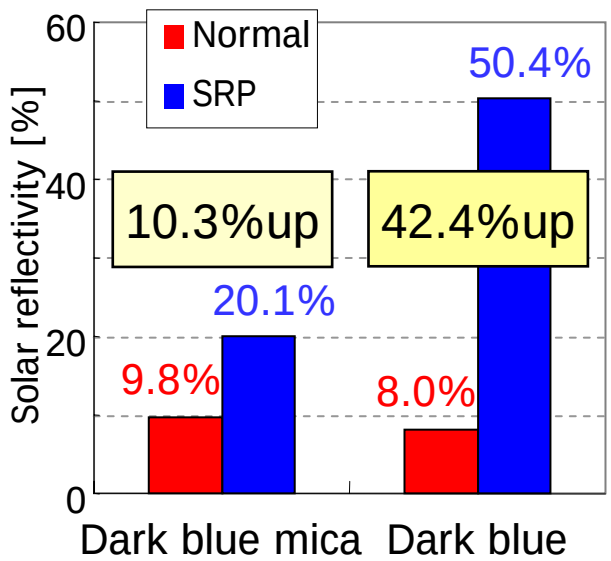
- A hermetic body & large ratio of windows in a body
- A small heat capacity

SRP is suitable for automobile body.

4. Evaluation of energy conservation effect

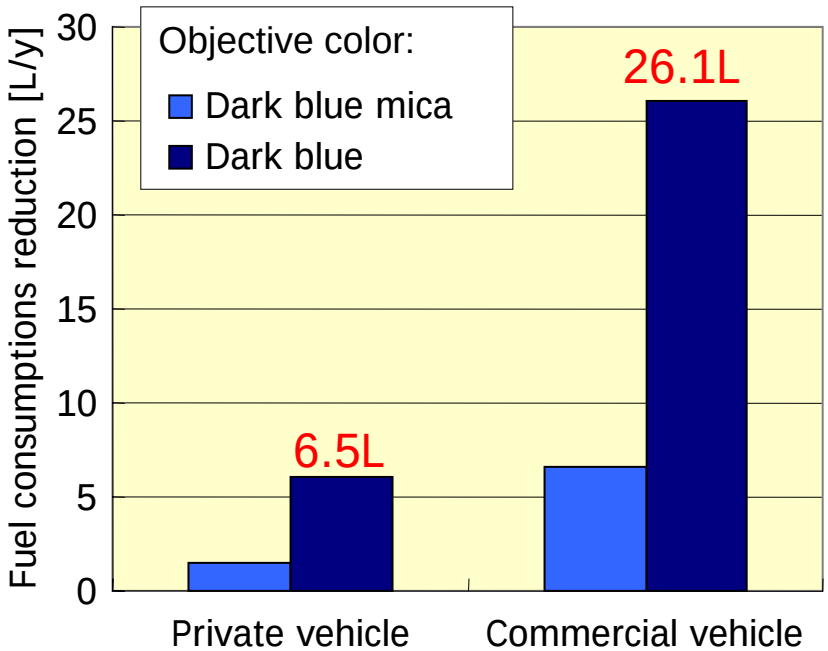
◆Simulation: fuel consumptions

Objective color:



A raise in reflectivity is different in color.
(Average: +17.5%)

Fuel consumptions reduction by SRP



Translating to actual fuel efficiency...

In dark blue mica
Private: +0.2%
Commercial: +0.2%

In dark blue
Private: +0.9%
Commercial: +0.2%

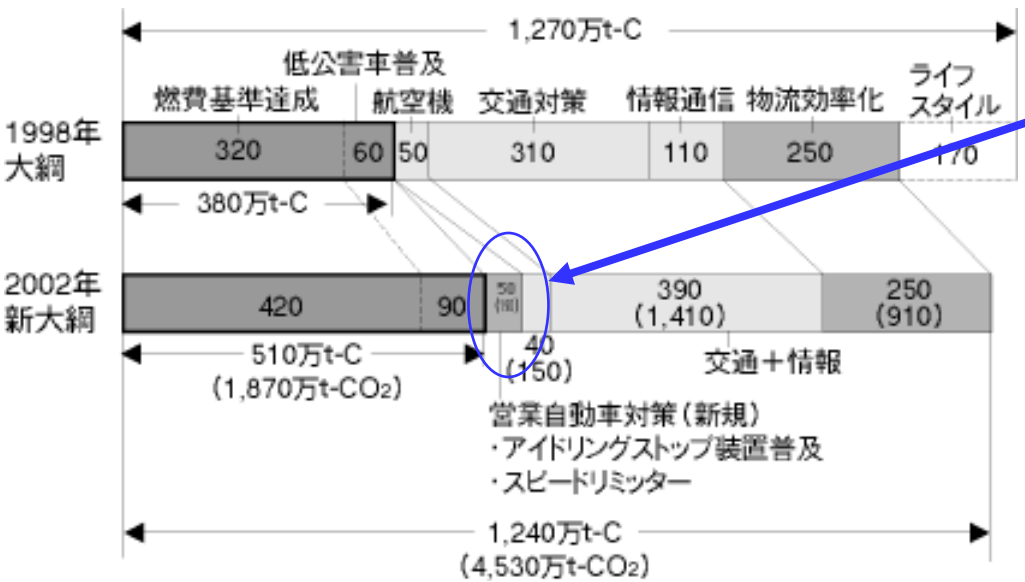
will be improved!

4. Evaluation of energy conservation effect

◆Potential of CO_2 emissions reduction in Japan

Actual fuel improving effect in Tokyo are applied to Japan.
A raise in solar reflectivity by SRP is 17.5%.

In Japan: 150,000 t-CO_2/y



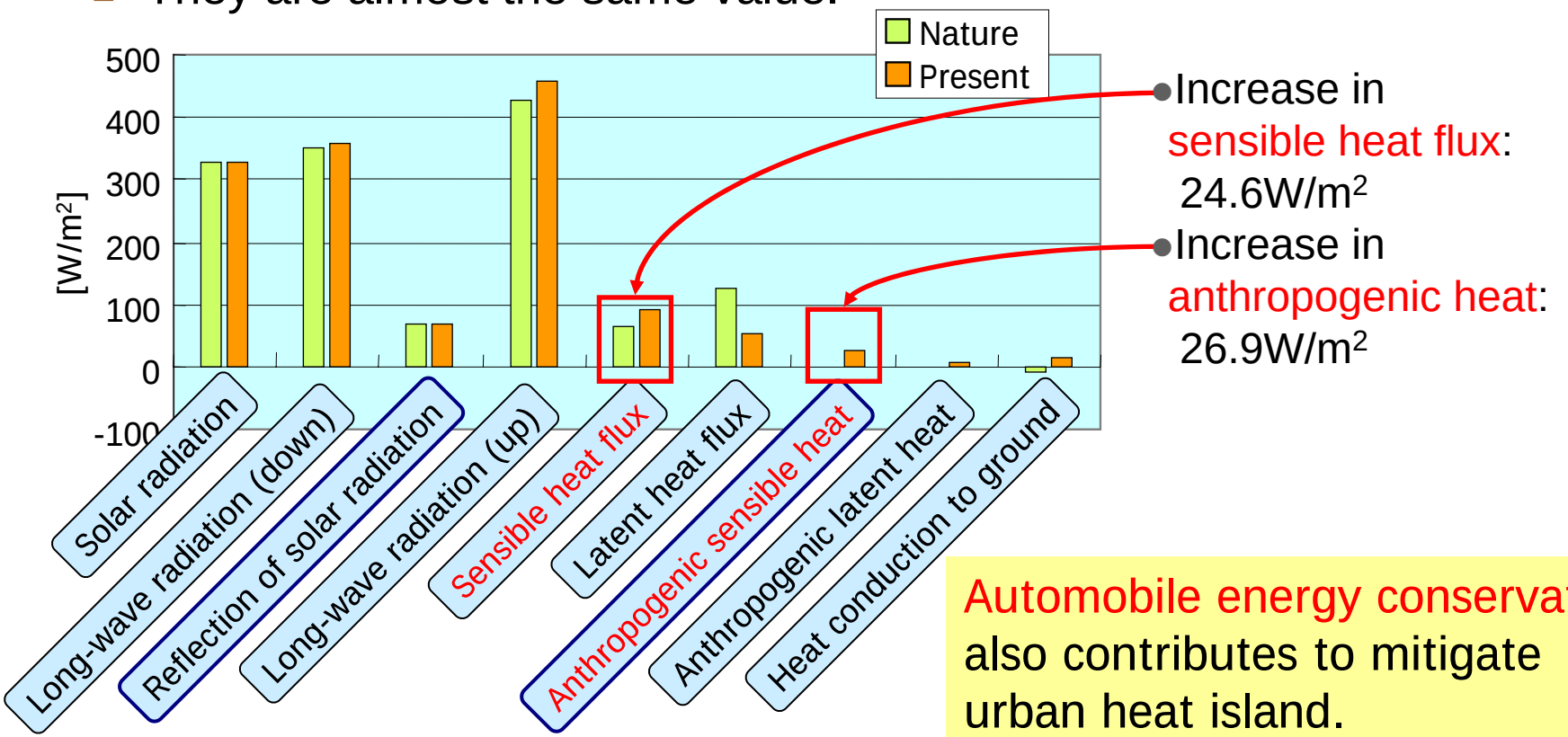
Spread of idling-stop equipments, speed-limiters, etc.
→ 1,100,000 t-CO_2/y
(ex. Idling-stop equipments
Added cost: ¥80,000/car)

SRP which can be introduced under existed plants, is very reasonable.
(Added cost: ¥0~40/car)

5. Evaluation of urban heat island mitigation effect

◆Urban heat island (UHI) in Tokyo

- Heat budget
  - Increase in sensible heat flux (←Road asphalting, decrease in water)
  - Increase in anthropogenic heat (←From buildings and cars)
  - They are almost the same value.



Automobile energy conservation also contributes to mitigate urban heat island.

5. Evaluation of urban heat island mitigation effect

◆Urban heat island mitigation effect by SRP

In previous researches

Increase in solar reflectivity of building surface by installation of SRP

→

- Increase in reflection of solar radiation (by increasing albedo in building area)
- Decrease in anthropogenic sensible heat (by reducing energy for air-conditioning in buildings)

Apply to cars

Spread of cars coated with SRP

→

- Increase in reflection of solar radiation (by increasing albedo in road area)
- Decrease in anthropogenic sensible heat (by reducing energy for air-conditioning in cars)

To invest the above UHI mitigation effects...

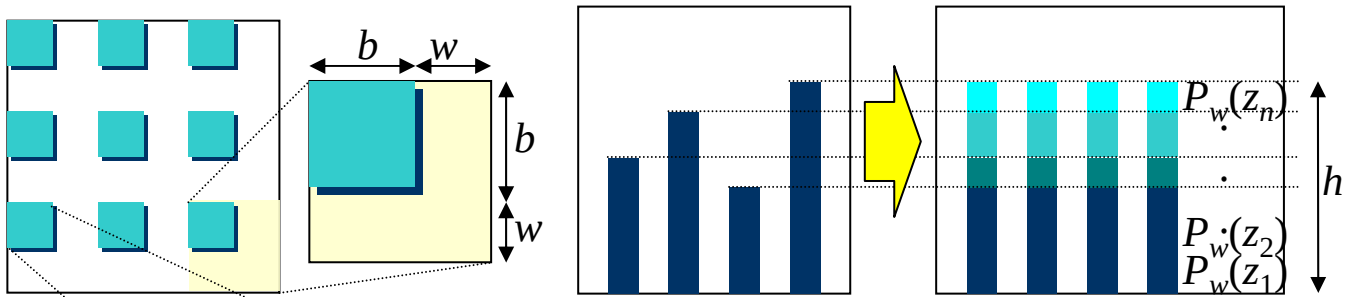
We evaluated a change of urban thermal environment by solar reflectivity of cars.

5. Evaluation of urban heat island mitigation effect

◆Urban canopy-building energy simulation program

AIST-CM-BEM

1-D urban canopy model (CM)



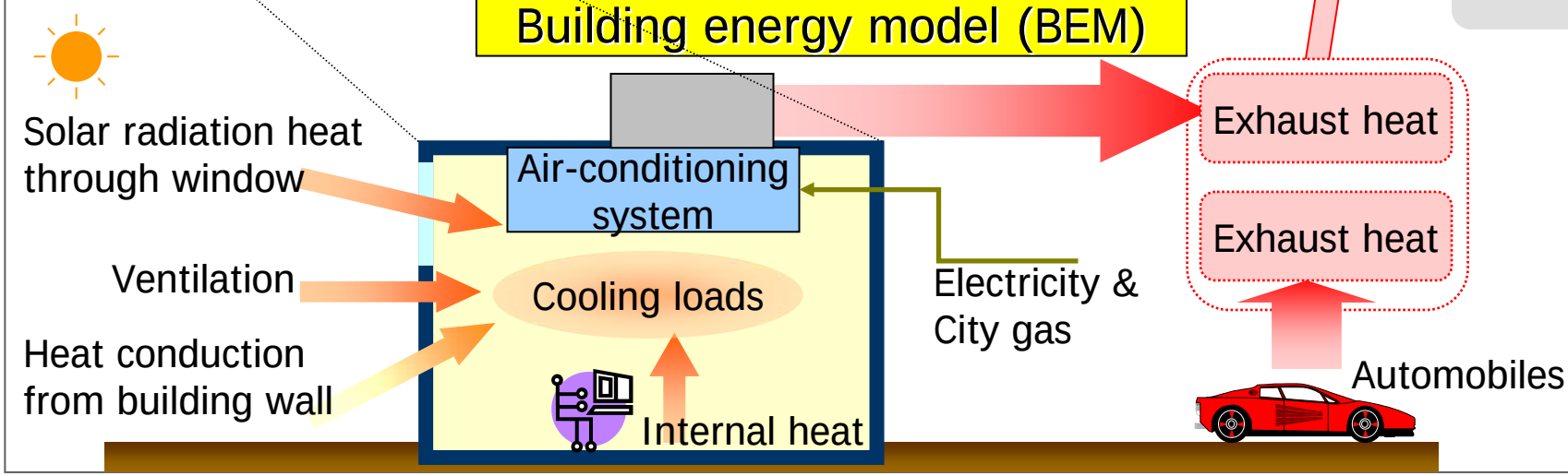
b : Average building width
w : Average road width

$P_w(z)$: Building existence ratio at each vertical mesh level

Air temperature
Air humidity
Wind direction & speed

Feedback

Building energy model (BEM)



5. Evaluation of urban heat island mitigation effect

◆Simulation conditions about albedo & anthropogenic heat

■ Road albedo & anthropogenic heat by automobiles

Hourly road albedo [-] =
(Cars-occupied area[m²] x Car albedo[-] + Other road area[m²] x Road albedo[-])
/ Total road area[m²]

Hourly cars-occupied area [m²]
= Traffic density [car/km] x Length of road [km] x One car-occupied area [m²/car]

Hourly anthropogenic heat on roads [kW/m²]
= Traffic density [car/km] x Length of roads in an area [km/m²]
x Anthropogenic heat exhausted from one car [kW/car]

■ Traffic density

$$\begin{cases} Q = KV \\ Q = K_{\text{jam}} V \exp\left(\dfrac{-K_{\text{jam}} V}{eQ_{\max}}\right) \end{cases}$$

Q : Traffic volume [car/h]
K : Traffic density [car/km]
V : Car velocity [km/h]
K_{jam} : Maximum traffic volume [car/km]
$Q_{\max}$: Maximum traffic density [car/h]

Road conditions

Road traffic census (MLIT)

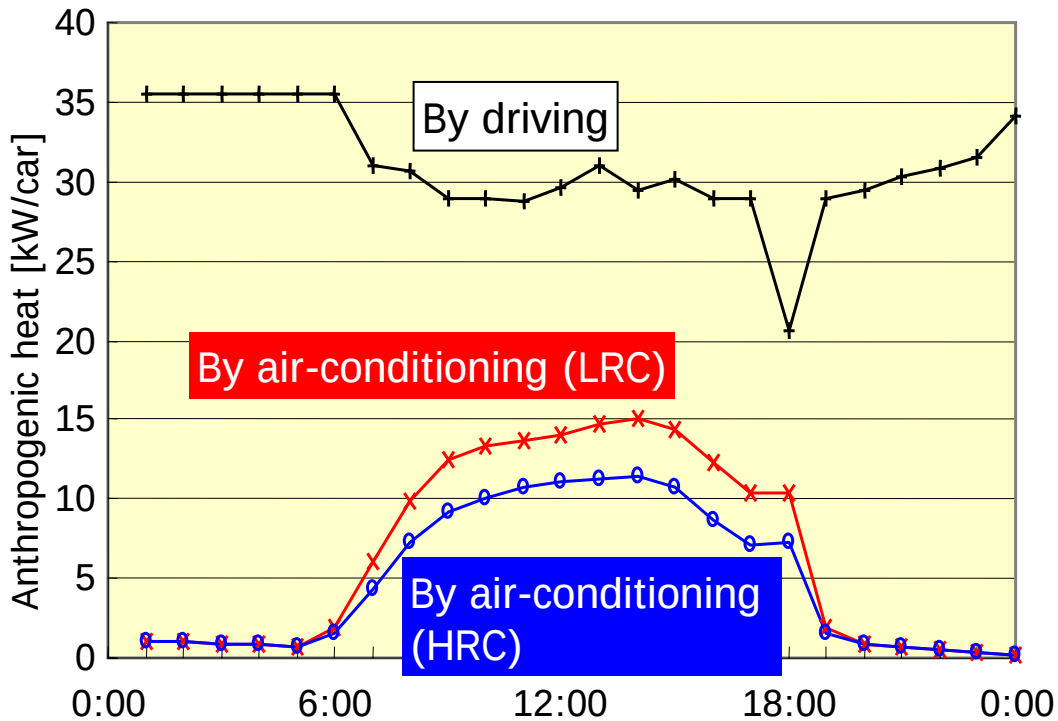
5. Evaluation of urban heat island mitigation effect

◆Anthropogenic heat exhausted from a car

Conditions:

- Automobiles
  - High-reflective car, HRC (Reflectivity: 73.69%)
  - vs.
  - Low-reflective car, LRC (Reflectivity: 6.43%)
- Area
  - Otemachi (Central Tokyo)
- Duration
  - 2002/07/28 ~ 2002/08/14

Anthropogenic heat exhausted from a car



Anthropogenic heat by air-conditioning from HRC was 5 [kW] smaller.
Even if heat by driving is taken into consideration, it is NOT negligible.

5. Evaluation of urban heat island mitigation effect

◆Simulation: Anthropogenic heat on roads (in Otemachi)

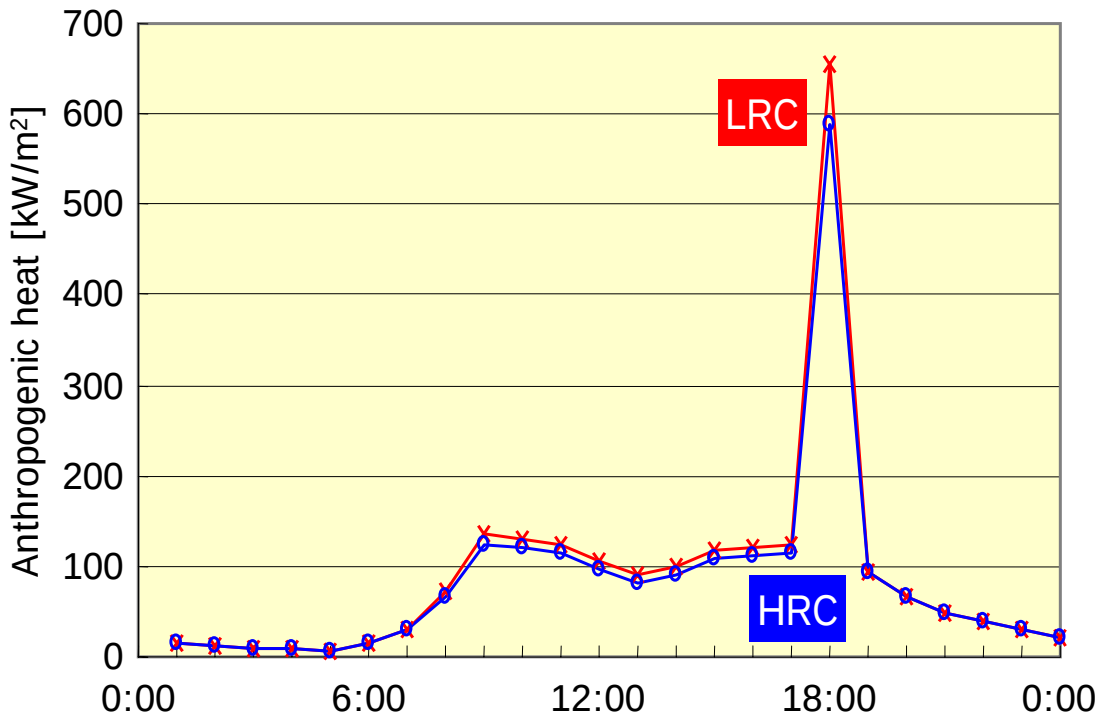
Traffic density
[car/km]

Length of roads
in the area
[km/m^2]

Anthropogenic heat
exhausted from one car
[kW/car]

*All cars in the area are LRC or HRC.

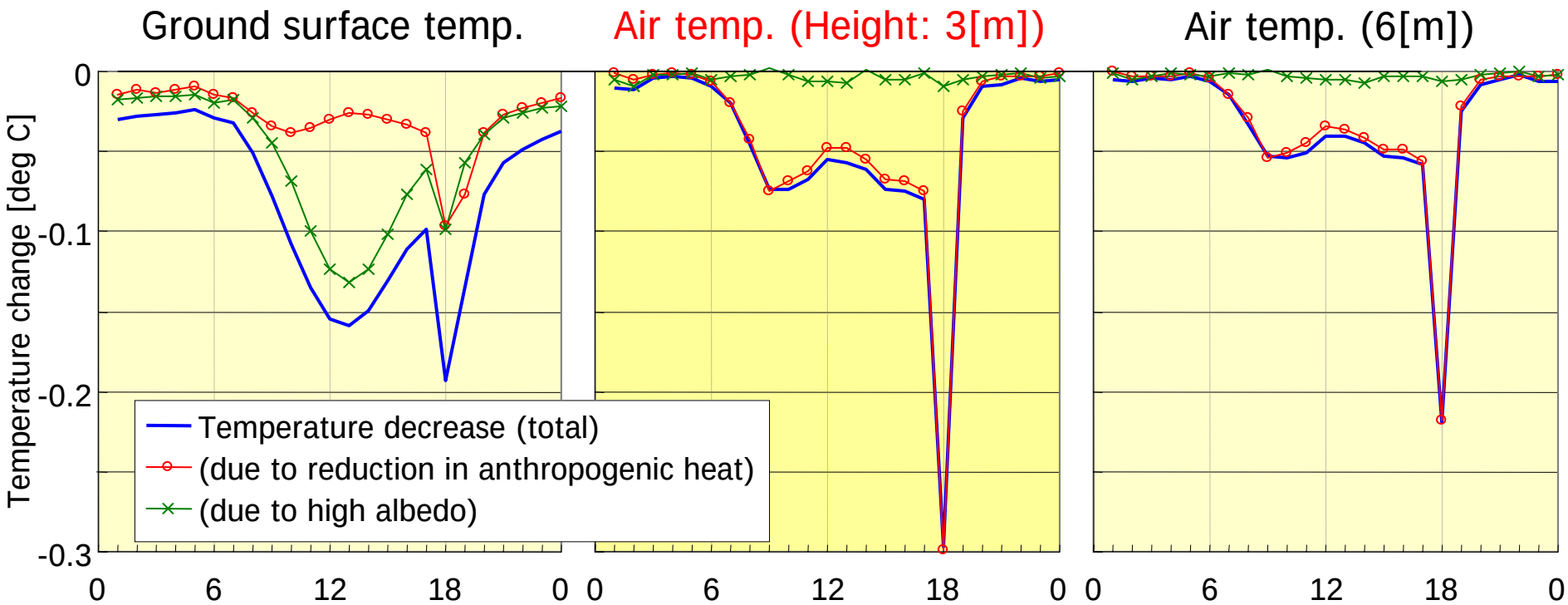
Anthropogenic heat on roads in the area



By an increase in a solar reflectivity of cars in the area, anthropogenic heat was reduced by a maximum of 70 [W/m^2]

5. Evaluation of urban heat island mitigation effect

◆Simulation: Temperature decrease (HRC vs. LRC)



- By raising solar reflectivity of automobile body (6.43% → 73.69%), air temperature in Otemachi was reduced by the maximum of 0.3 deg C.
- Air temperature decrease in a pedestrian space was large.
- Air temperature decrease was mainly due to a reduction in anthropogenic heat from car air-conditioners.

6. Conclusion

◆Application of solar reflective paint (SRP) to an automobile

- SRP is installed as heat shield sheets on an automobile body.
- Simple coating by SRP actualizes by replacement of pigments.
- SRP raises a solar reflectivity in an typical car by an average of 17.5%, without a change of color.

◆Energy conservation effect by SRP

- SRP is suitable technology for an automobile which has very small heating load or does NOT use air-conditioners when heating.
- SRP will bring about small improvement of actual fuel efficiency which is about 0.2% to 0.9%.
- Because SRP is one of low-cost technologies, an introduction of SRP contributes the reduction in CO_2 emissions from a transportation sector.

◆Urban heat island mitigation effect by SRP

- An installation of SRP also reduces air temperature in business districts, especially pedestrian spaces.

Thank you for your attention.