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Electric Radiant Warmers for Energy Saving and Improved Comfort in EVs

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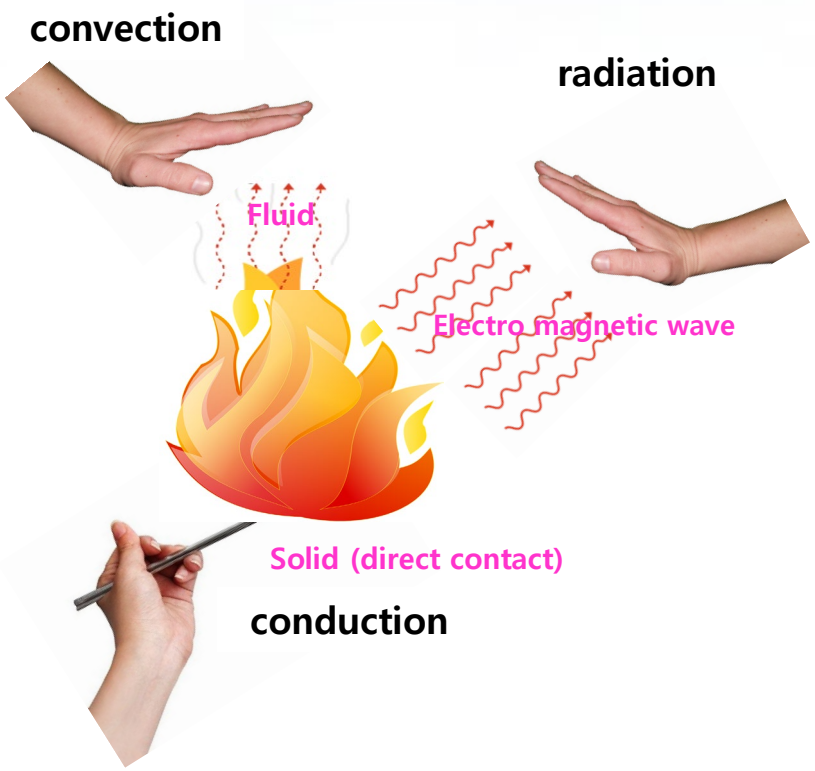
CONTENTS

What is Radiation?

3 Type of heat transfer mode

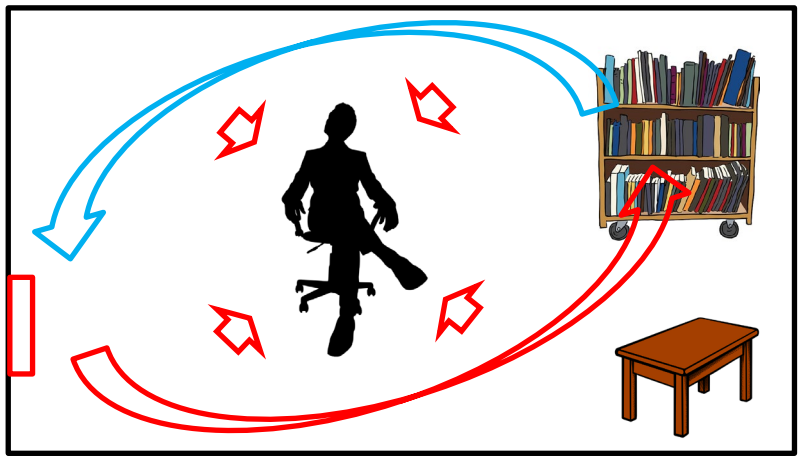


Comparison of heater transfer mode

Type	Medium	Heating rate	Efficiency for body warm-up	Heating range
Convection	Fluid	Low	Bad at initial stage	Whole space
Radiation	-	High	Good at local area	Local body
Conduction	Solid	High	Very good at contact area	Local body

Convection

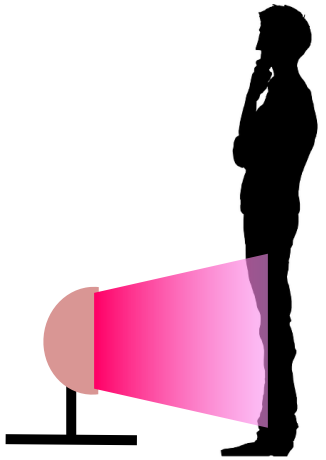
- It takes time to heat up the medium and things
- Heating range is widen up easily



Radiation

- Direct heating up body
- Effective in only local body part

→ Good performance at initial heating



Why is the Radiation Important in EVs?

1. Effects of cabin heating on the EV range*

- Low waste heat to use in convectional HVACs → Driving rage decreases dramatically in heating condition

Combined Driving range (km) *

EV type	24℃ (climate control off)	-6.7℃ (climate control on)	35℃ (climate control on)
EV model 1 (2017)	204	101	161
EV model 2 (2018)	389	208	315
EV model 3 (2018)	225	154	198
EV model 4 (2017)	385	238	323
EV model 5 (2017)	200	127	163

Driving range reduction rate (%)

EV type		-6.7℃ (climate control on)	35℃ (climate control on)
EV model 1 (2017)	-	-50.4	-21.3
EV model 2 (2018)		-46.7	-19.0
EV model 3 (2018)	-	-31.4	-12.1
EV model 4 (2017)		-38.1	-15.9
EV model 5 (2017)		-36.3	-18.5

*Electric Vehicle Range Testing, American Automobile Association(2019)

the Average the range reduction rate @cooling condition : 17%

the Average the range reduction rate @heating condition : 41%

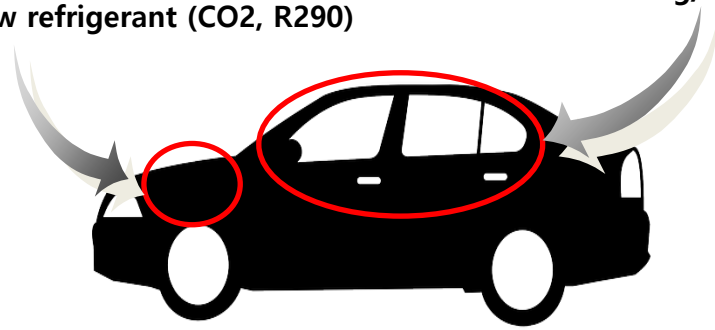
Cabin heating energy is more than 3 time of that of cabin cooling

→ Significant reduction of driving range

We need new ways to solve it
→ radiation heating

Heat pump
- New refrigerant (CO2, R290)

Cabin
- Local heating/cooling



Why is the Radiation Important in EVs?

2. Thermal characteristics of vehicle cabins

Non-uniform distribution

Low thermal insulation
(windshield, door glass)
→ large amount of heat loss
→ Non-uniform temperature field

Complex interior space (seat, handle)
→ Non-uniform wind speed

⇨ Uncomfortable feeling

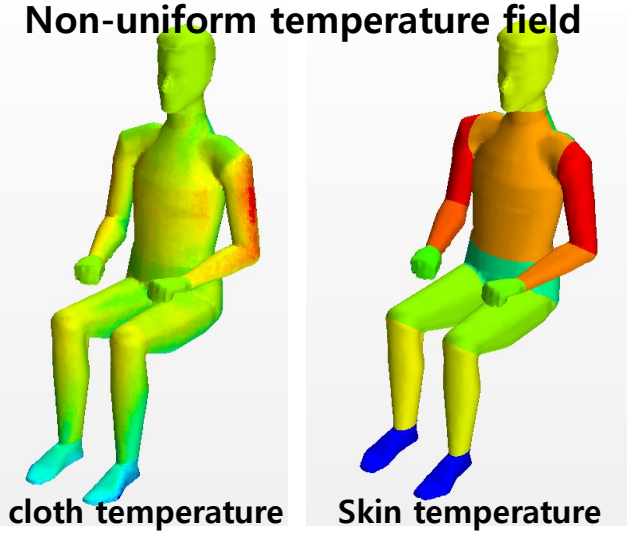
Slow response time

Heat capacity effect of cabin and HVACs

→ Time required to reach room temperature after soaking at -7 ℃ or 35 ℃ : 20~30min

⇨ Increasing occupant discomfort

Non-uniform temperature field



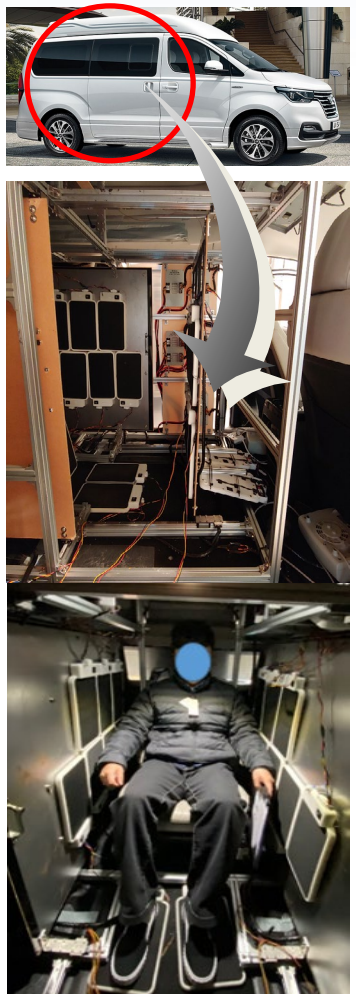
Vehicle cabins require high heating performance (~6kW) compared to its interior space
→ 41% decrease in driving range

Heating by Radiation
- Good at local heating
- Quick response time

Reduce required heating load

Energy Consumption Experiment : HVAC vs Radiant Warmers

1. Experiment conditions (Convection vs Radiation)



- Test car
- Rear seat remodeling for surrounding radiant warmer

- Drive mode : idle
- Ambient T : -7℃

- Cloth & Skin T Energy consumption measurement

- Thermal sensation & comfort checking by 10 persons

HVAC mode

Warmer : off
HVAC : on
- FATC 32℃
Seat warmer on
Foot heater on

VS

RAD Warmer mode

Warmer : on
- Ts=const
HVAC : off
Seat warmer on
Foot heater off

- Excluding all forced convection Effect

Energy Consumption Experiment : HVAC vs Radiant Warmers

2. Heating rate comparison

Number and gender : male 10
Age : 20s~ 50s
Averaged weight : 77kg
Pre Soaking time : 1hr
Clothing insulation : 1.45clo (total)

Time to reach a specific point

	Chest Cloth Temperature 0℃→15℃	Chest Skin Temperature 32℃→33℃	Thermal Sensation Cold → neutral	Thermal Comfort Very Uncomfortable →neutral
HVAC 	10 min	30 min	22 min	21 min
Warmer 	7 min	20 min	19 min	16 min

※ X minute = Time taking X minute to reach to the specific point after HVAC or Warmer is turned on
Ex) Cloth Temperature, HVAC → 10 min : It takes 10 minute to reach 15℃ after heating start

Energy Consumption Experiment : HVAC vs Radiant Warmers

3. Energy consumption up to neutral point of thermal sensation

Energy consumption (kWh) – Ambient Temperature -7℃

No.	Case	Time @neutral (min)	Power consumption @HVAC [kWh]	Power consumption @ RAD warmer [kWh]	Power consumption @foot auxiliary heater [kWh]	Power consumption @ climate seat [kWh]	Sum [kWh]
1	HVAC mode (auto max 32℃)	22	2.1	-	0.6	0.02	2.72
2	Radiant Warmer mode	19	-	0.7	-	0.02	0.72

→ Consumption in warmer mode ~ 26% HVAC mode

Power consumption (kW) – Ambient Temperature -7℃

No.	Case	Time @neutral (min)	Time averaged power consumption @HVAC [kW]	Time averaged power consumption @ RAD warmer [kW]	Time averaged power consumption @foot auxiliary heater [kW]	Time averaged Power consumption @ climate seat [kW]	Sum [kW]
1	HVAC mode (auto max 32℃)	22	5.81	-	1.65	0.06	7.52
2	Radiant Warmer mode	19	-	2.21	-	0.06	2.27

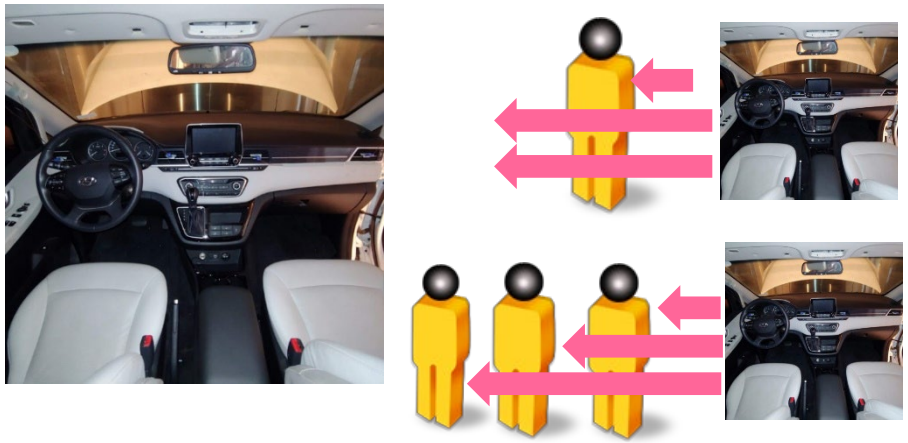
※ typical small vehicles require 3~5kW power consumption for cabin heating

→ In case of small vehicle, A radiant warmer of about 1kW will be sufficient to increase thermal sensation level

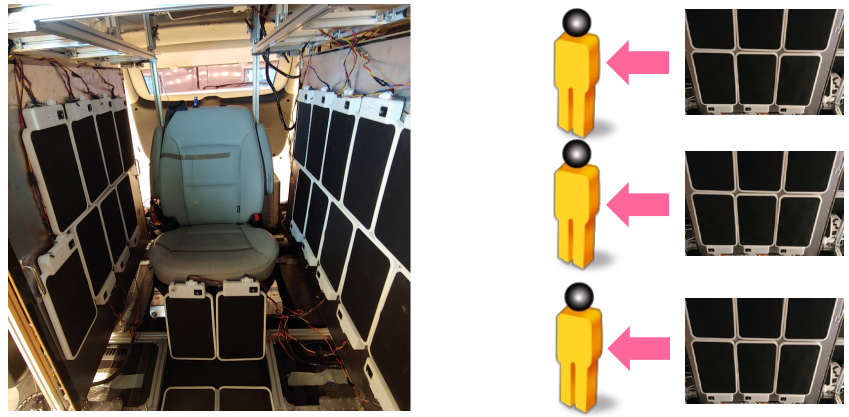
Energy Consumption Test : Convection+Radiation

1. Complementary relationship between convection and radiation

- HVAC (convection)



- Radiant Warmer (radiation)



1. The more passengers, The more efficient

- Heating energy can be delivered to every passenger not evenly, but above a certain level

2. Slow air heating due to indirect heating and heat capacity

- Energy for cabin heating is much higher than that for body heating

1. The more passengers, The less efficient

More radiant warmers are required with the number of passenger

2. Quick body heating due to direct heat transfer

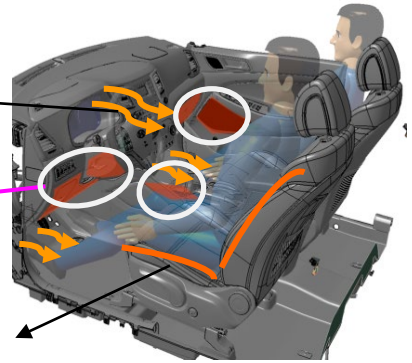
- Close installation to body can improve radiant heat transfer efficiency

→ Hybrid heating (convection + radiation) is effective for saving cabin heating energy

Energy Consumption Test : Convection + Radiation

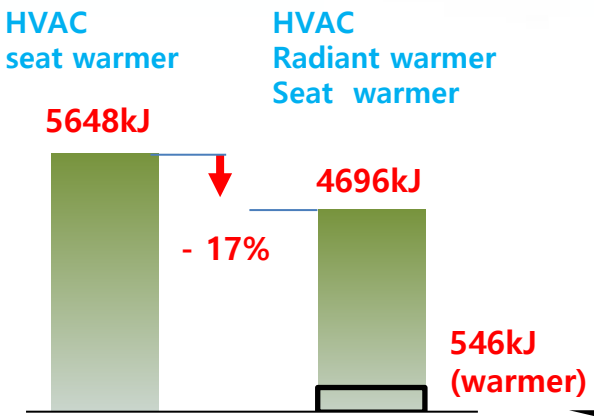
2. Test of combination heating

- Test car
- 2 occupants condition
-



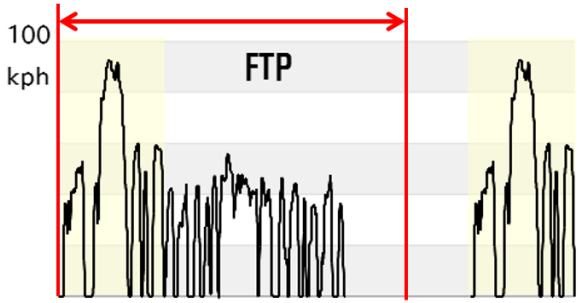
- **Cabin heating energy consumption**

HVAC mode vs Hybrid mode



- **Driving energy consumption without heating @cold FTP -7℃**

→ 6176kJ



Driving range @ No cabin heating : 450km
Driving range @ HVAC +Seat : 235km
Driving range @ HVAC + Radiant warmer + Seat : 255km

→ Driving range can be improved by 9%

→ 1kW consumption in radiation heating ~1.7kW in convection heating (@ 2 passenger condition)

→ Radiation heating will become essential option for improving the driving range of EV in cold condition

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Thank you