Experimental performance of a phase change material-based road/rail container for cold chain transportation

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Part I. Introduction

- **Diesel power;**
- **Inefficient and highly polluting;**
- **The limited capacity of the fuel tank can not meet the long-distance transportation;**
- **Risk of high operation cost and cargo loss when compressor failure occurs.**

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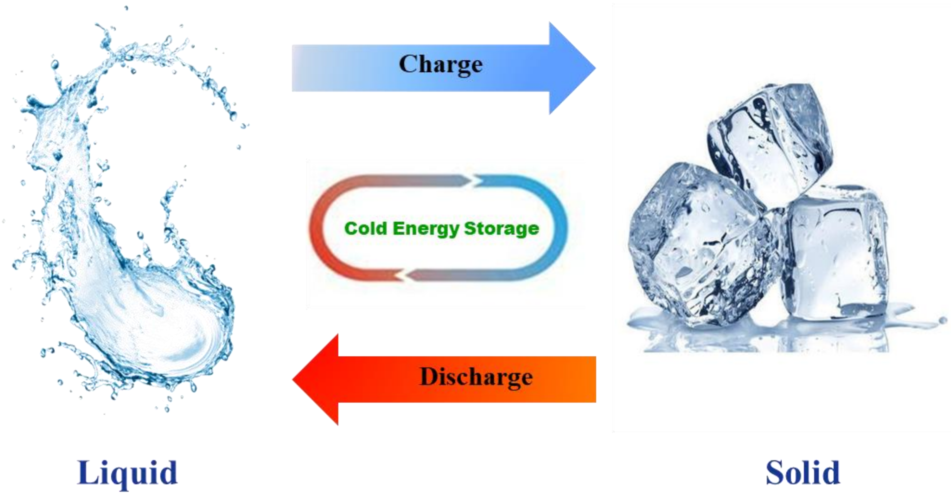
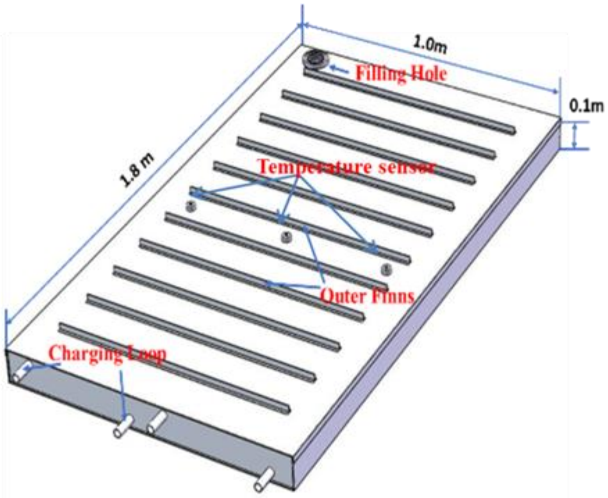
Part I. Introduction



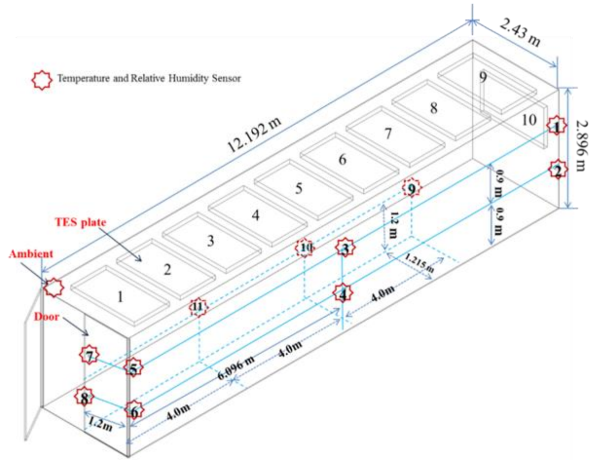
Principle of the Cold Energy Storage

- High Energy Storage Density(Volumetric);
- Low super-cooling;
- High thermal conductivity;
- Suitable viscosity;
- Low cost;
- Food and environmentally friendly;
- Long cycle life.

Part II. The Container



Three-dimensional view of the TES plate



Locations of the temperature & relative humidity sensors of the container

Photo of the container and charging facility

Part III. Performance index

- **Charging rate**

$$q_{HTF} = c_{p,HTF} * \dot{m}_{HTF} * (T_{r,HTF} - T_{i,HTF})$$

- **Charging efficiency**

$$\eta_{ch} = \frac{Q_{PCM}+Q_{Al}+Q_{ma}+Q_{EG,inside}}{Q_{EG}} *100\%$$

- **System COP**

$$COP = \left|\frac{Q_{PCM} + Q_{Al} + Q_{m} + Q_{EG,inside}}{W}\right|$$

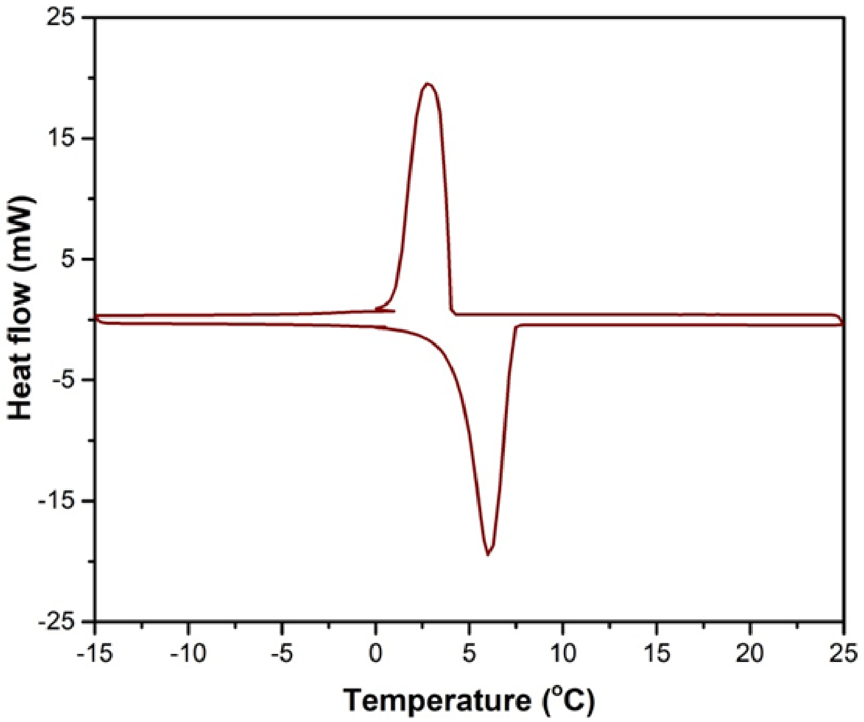
- **Energy consumption decrease and cost-saving**

$$E_s = \left(\frac{Q_{Diesel} - Q_{PCM}}{Q_{Diesel}}\right) * 100\% \qquad C_S = \left(\frac{C_{Diesel} - C_{PCM}}{C_{Diesel}}\right) * 100\%$$

- **Emission reduction**

$$F_R = \left(\frac{F_{Diesel} - F_{PCM}}{F_{Diesel}}\right) * 100\%$$

Part IV. Results--Phase change materials



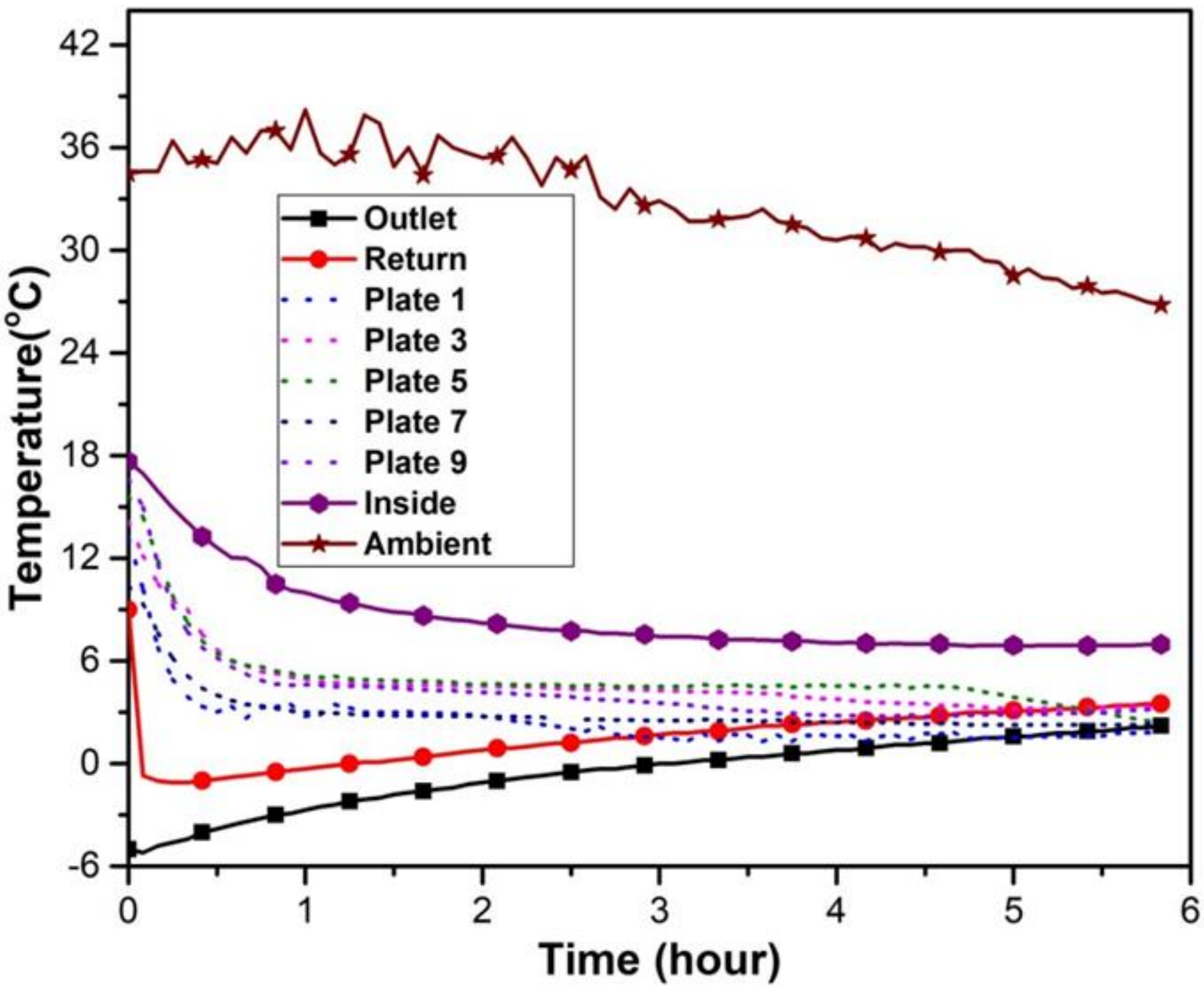
DSC of the phase change material

Thermo-physical properties of the PCM

Density kg/m^3	Latent heat kJ/kg	Melting/freezing point °C
880(l)/770(s)	180	4.96/4.84

Specific heat capacity kJ/kg·K	Thermal conductivity W/(m·K)
2.0 ±0.2	0.2

Part IV. Results--Charging performance



Time evolution of the average temperature inside the container and the plates during the charging process

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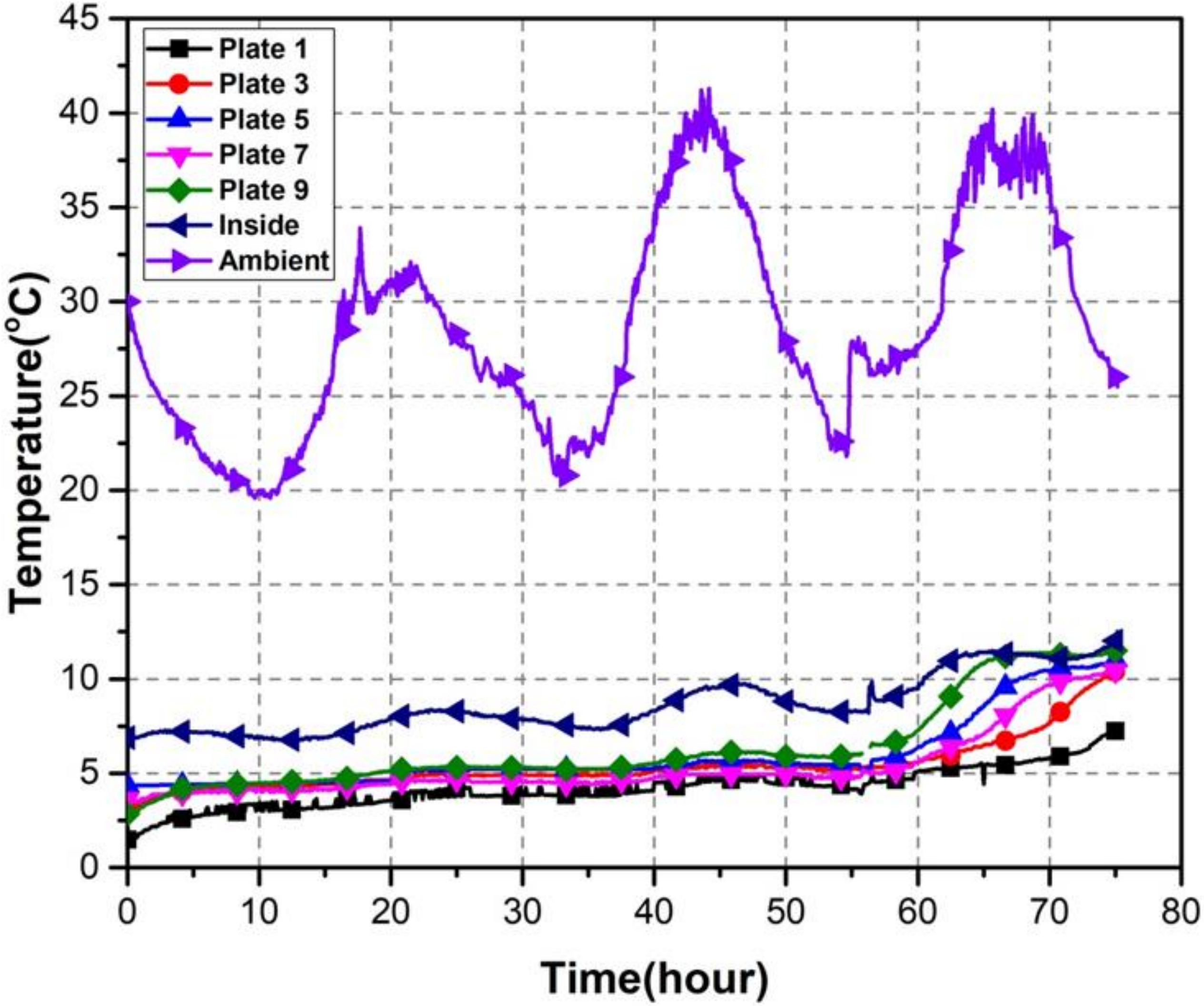
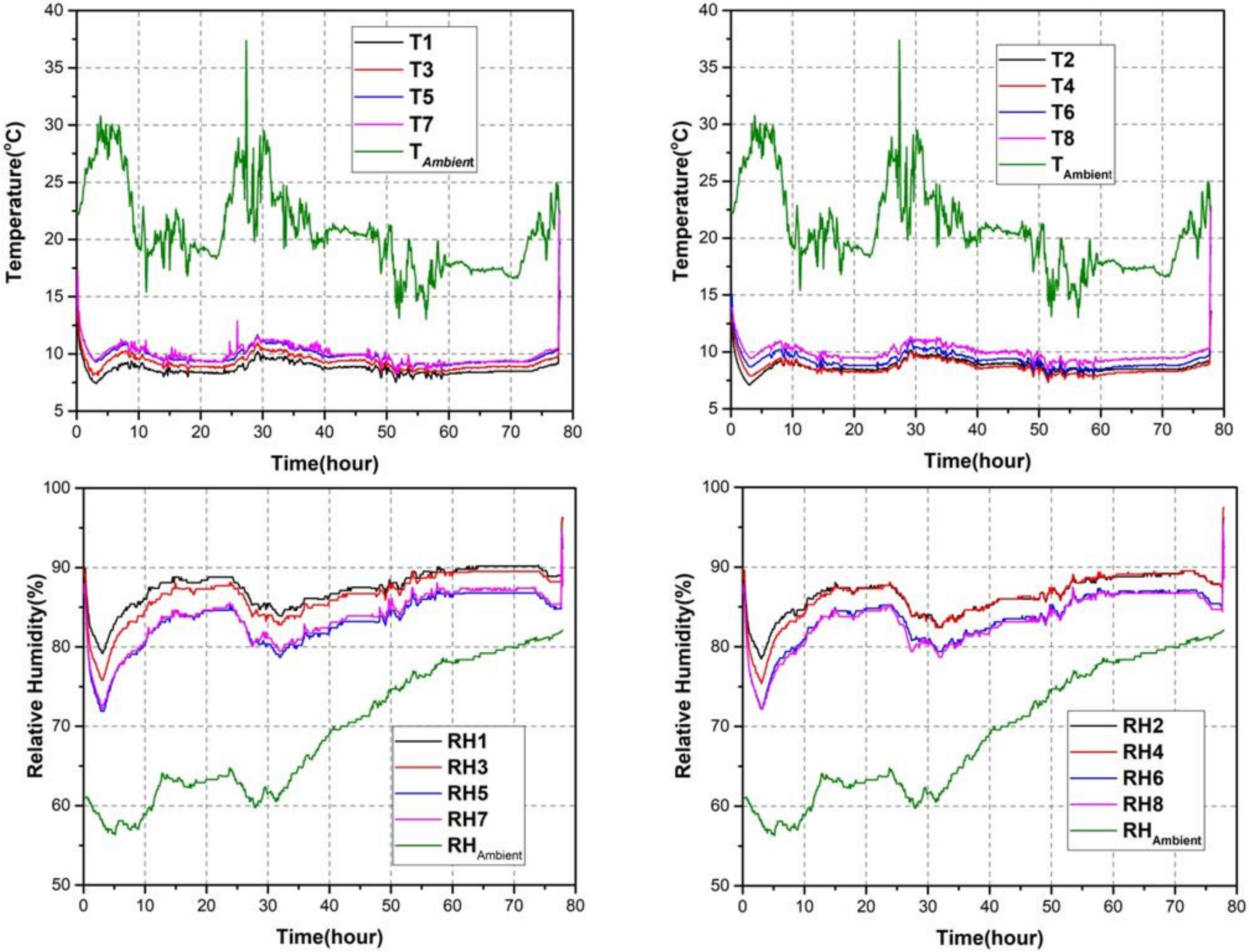
Part IV. Results--Discharging performance



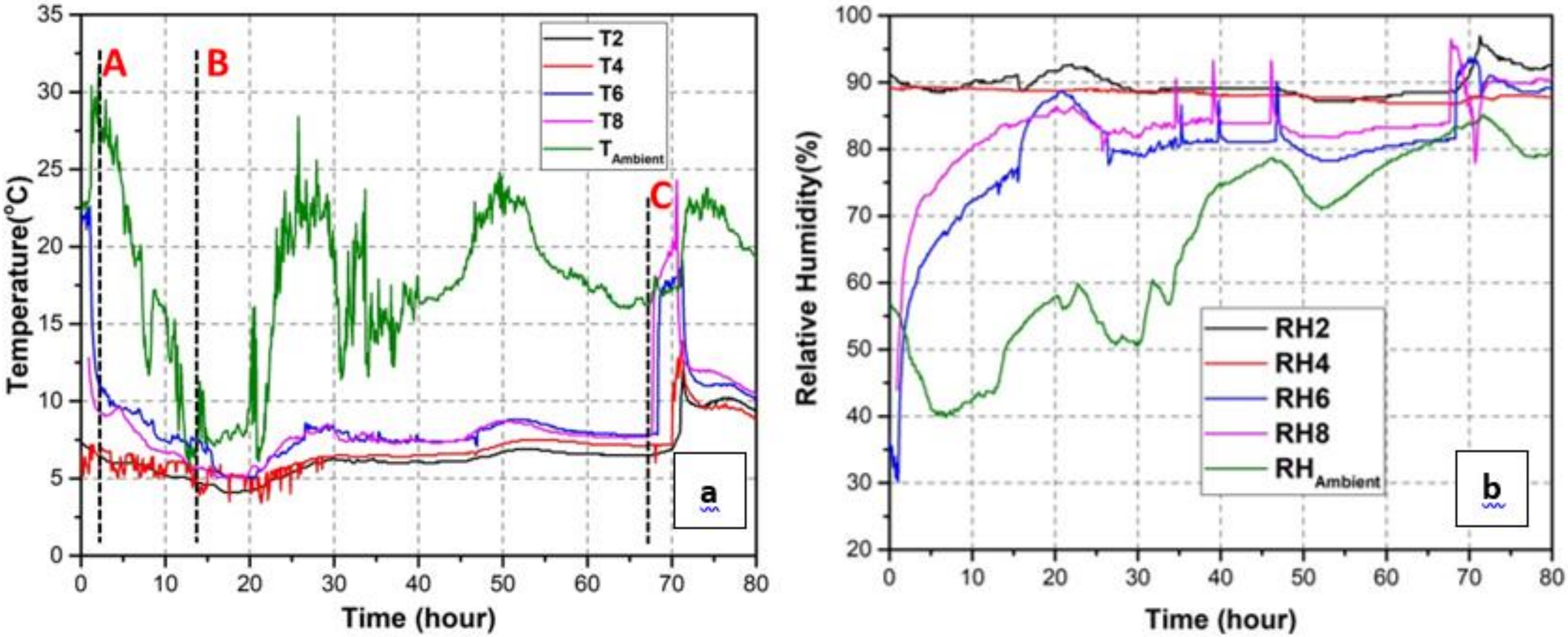
Time evolution of the average temperature inside the container and the plates under static condition

Part IV. Results--Discharging performance



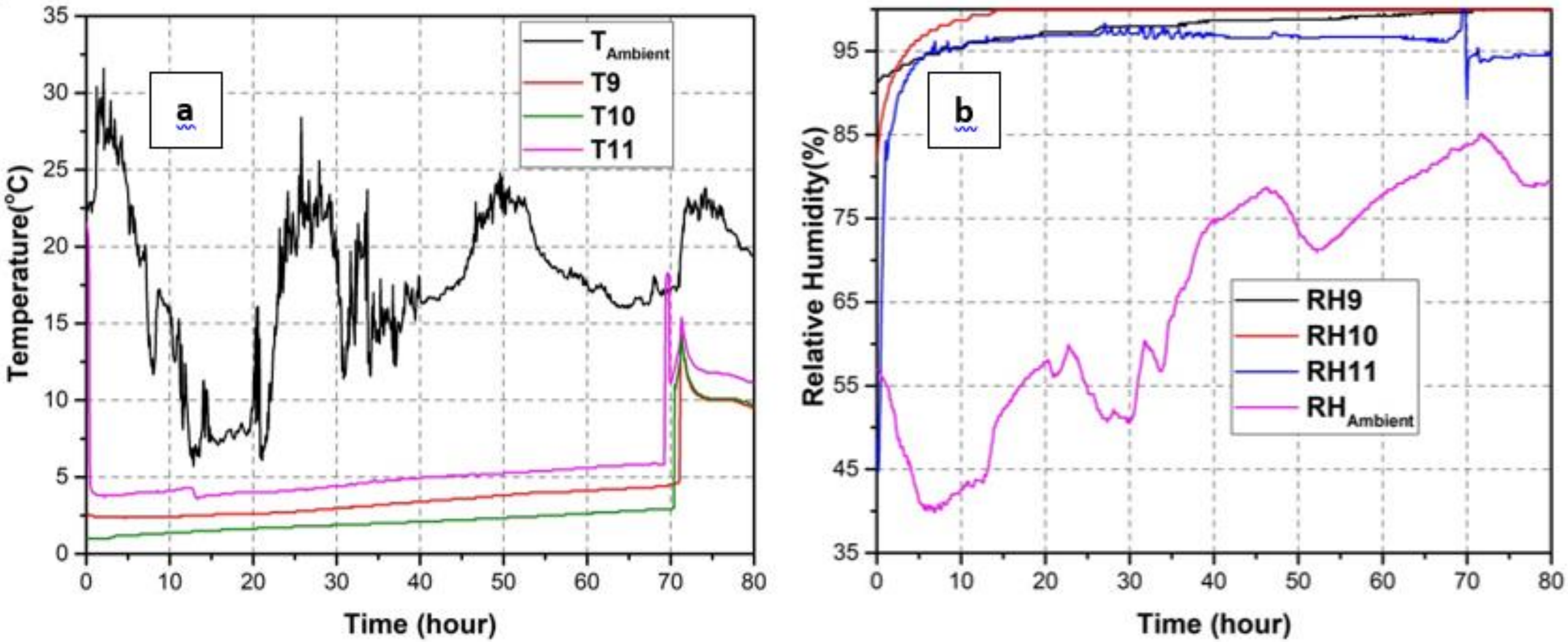
Time evolution of the temperature and the relative humidity under dynamic conditions

Part IV. Results--Discharging performance



Time evolution of the temperature and RH of the loaded container under dynamic conditions (axial direction, a: Temperature, b: Relative Humidity)

Part IV. Results--Discharging performance



Time evolution of the temperature and RH inside the carrying items under dynamic conditions

Part IV. Results--Overall performance

Comparison of the energy and cost of the TES and diesel-powered container

Properties	The diesel-powered	The PCM-based
Delivery distance (km)	2362	
Delivery duration (hour)	53	
Power consumption (kW)	5.4	1.55
Energy consumption	Diesel(*53L*)	Electricity(*82kWh*)
Diesel consumption (L/h)	1[4]	0
Diesel price($ /L)[a]	0.95	
Electricity price($ /kWh)[b]	0.11	
Diesel cost ($)	63.65	0
Electricity cost ($)	0	9.02
Operation cost reduction		85.6%

a: Based on the average price in China (https://www.globalpetrolprices.com/China/diesel_prices/).
b: Based on the average price in China (https://www.ceicdata.com/en/china/electricity-price?page=4).

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Part IV. Results--Overall performance

Leaf lettuce

Lettuce

Strawberry

Mango

Category		Leaf lettuce		Lettuce		Strawberry		Mango	
		a	*b*	*a*	*b*	*a*	*b*	*a*	*b*
Hardness		2.63	2.51	2.22	2.73	0.58	0.56	3.44	4.76
Colour	**L***	45.96	45.17	44.71	44.73	34.36	34.02	34.36	34.02
	a*	-15.01	-15.18	-16.01	-16.15	34.96	34.10	-8.95	-6.53
	b*	24.50	24.69	26.35	28.13	23.11	21.87	40.13	40.92
Soluble solid content		3.67%	3.51%	3.47%	3.67%	10.05%	10.50%	15.3%	14.3%
pH		6.63	6.55	6.54	6.46	4.37	4.25	3.74	3.99

Vegetables and fruits before and after the transport(*a: before*, *b: after*)

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Part V. Conclusions

- The system COP during the discharging process was found to be 1.84;
- Once charged in 2 hours, the container can provide 2-8 ^{o}C cooling for up to 96 hours and 2,000 km;
- The emission can be reduced by 70.21% when using the PCM-based container;
- Flexible transfer between different transport modes without extra energy supply;
- Reduced water loss compared with forced air and No condensed water drop;
- Advanced information technology provides real-time monitor of locations, temperature and humidity, door opening, available cold energy;
- Movable or fixed charging facility with Internet of Things providing the real-time location and availability information.

Thank you

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