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Québec

SUSTAINABLE WINTER SERVICE FOR ROAD USERS

The use of phase change materials to delay pavement freezing

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INTRODUCTION

- In winter situations, certain areas with a peculiar thermal behaviour are more sensitive to icing and rime frosting

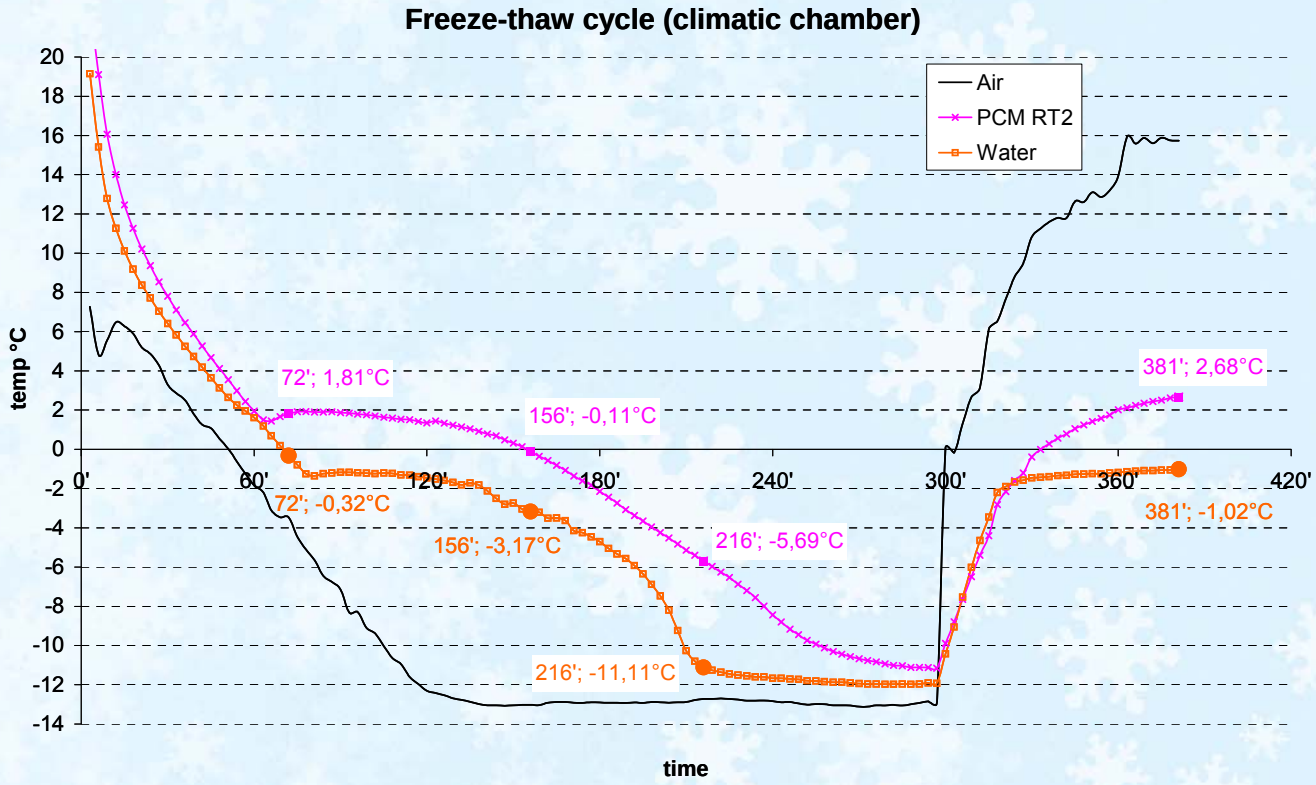
  → may easily develop into unsafe spots that are liable to surprise the road user.



- Alternative - to the traditional method "to spread anti-icing materials"- investigated in the research : Incorporate phase change materials (PCMs) into the surface courses of road pavements, mainly in sensitive areas.

INTRODUCTION

- Hypothesis : the heat released by a PCM during solidification may delay the decrease in surface temperature. How ?



- Key considerations: type of PCM ; mode of conditioning ; pavement incorporation ; amount of PCM

METHODOLOGY

- <u>What road weather phenomenon?</u>

→ The energy released by PCMs may be adequate to counteract 3 types of icing:

  – freezing of existing water
  – solid condensation
  – freezing fog

= Small amount of water – Limited temperature variation

"Latent heat" Ice-Water: ΔH = 333kJ/kg <u>*Theoretically:*</u>

• **Wet road surface :** 500g.H_2O/m² → need 165kJ/m² to counteract freezing of existing water ; a PCM can deliver around 110kJ/kg when solidifying

→ ***need <u>1,5 kg</u> PCM / m² pavement***

• **1 cm wet snow** (density 150kg/m³) → need 495kJ/m² to melt

→ ***need <u>4,5 kg</u> PCM / m² pavement***

METHODOLOGY

- What PCMs?
  - Working temperature / Latent heat ΔH (kJ/kg)
  - Selected PCMs : n-tetradecane-type paraffin waxes with a phase change temperature higher than, but close to 0 °C
  - Paraffins:
    → no tendency for segregation ; chemically inert ; slow oxidation → encapsulation ; stable thermal properties after repetitive melting-freezing cycles
    → low thermal conductivity in their solid phase ☹

Characteristics of the phase change materials investigated in the research project (*: supplier's data; **: ASC results)

PCM	Physical presentation	Congealing point	Heat storage capacity
RT2	Liquid	2 °C	156 kJ/kg *
RT5	Liquid	5 °C	156 kJ/kg *
PX2	Powder (60 % RT2 bounded to SiO_2)	2 °C	118 kJ/kg **
PX5	Powder (60 % RT5 bounded to SiO_2)	5 °C	107 kJ/kg **
GR5	Granulate 1-3 mm (35 % RT5 bounded to SiO_2)	5 °C	75 kJ/kg **

METHODOLOGY

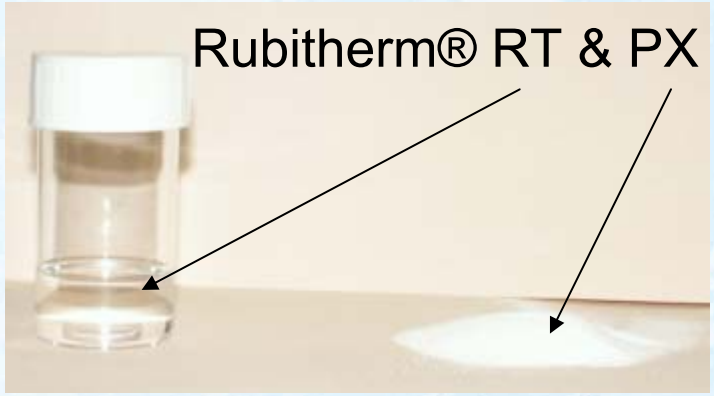
- <u>What encapsulation?</u>
  - Flash point RT2 & RT5 (112°C & 122°C) → no « hot » encapsulation methods like cross linked polyethylene thermoplastic

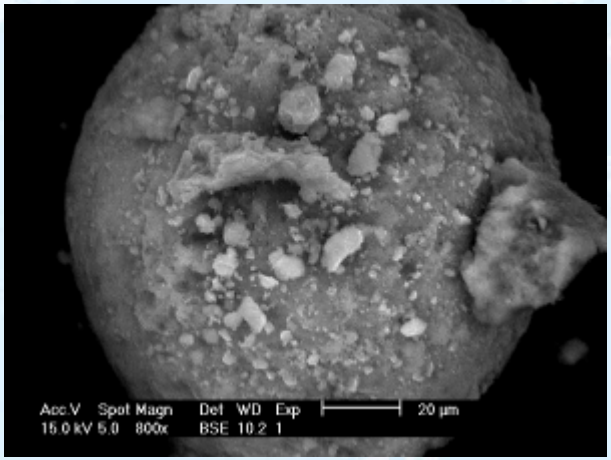
  - Solution tested: thermosetting resin
    - Incompatible with a liquid paraffin
    - Possible with a “solid form” of the paraffin, like PX2®

  → Physical forms finally used:

    - Powder (60% RT bound to SiO_2) = PX2 & PX5 ®
    - Granulate 1-3 mm (35% RT5 bound to SiO_2) = GR5 ®
    - PX powder into a thermosetting resin

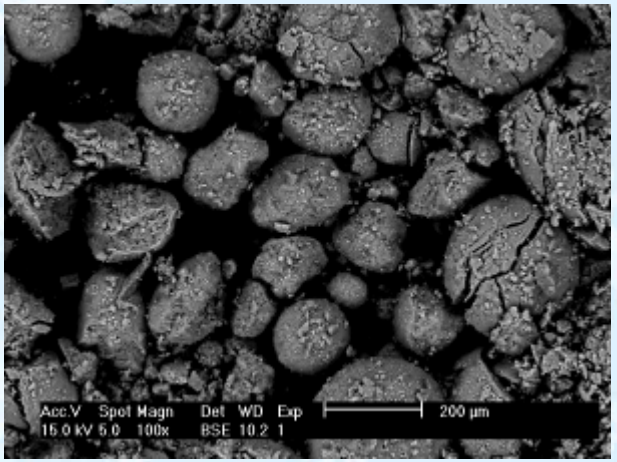
METHODOLOGY





Rubitherm® PX2
(Microscopy SEM XL 30)

Rubitherm® GR



+ PX powder into a thermosetting resin

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METHODOLOGY

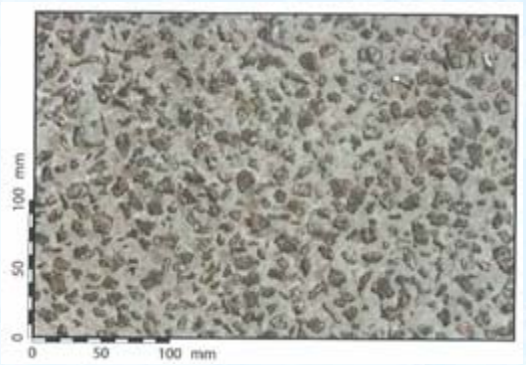
- What type of pavement?

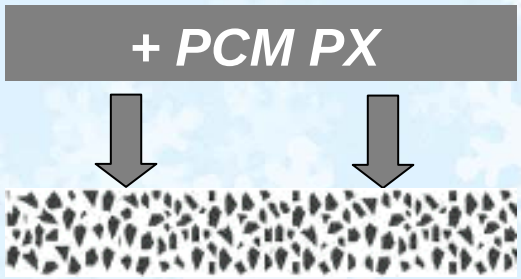
Mainly "cold-laid" pavements (due to low flash point of paraffin PCMs):

- ↑ Grouted asphalt
- ↓ Slurry surfacing → Lab trials to add GR5 to the aggregates → No breaking of emulsion due to paraffin
- ↓ Surface dressing → No sand fraction / hot bitumen emulsion → no opportunities to add PCMs
- ↑ Two-layer concrete pavements

METHODOLOGY

- Grouted asphalt





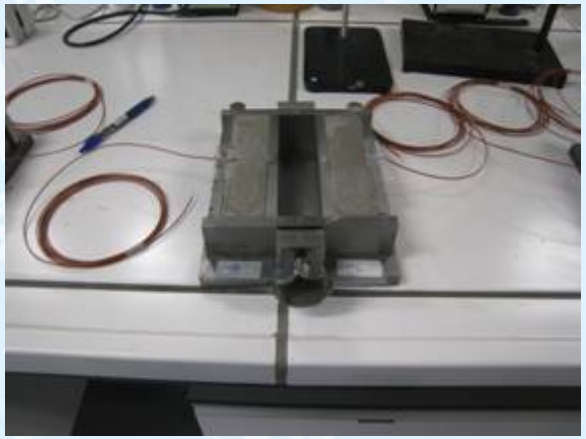
Cementitious grout (mineral filler, cement, polymer resins, water)

Highly porous bituminous mixture
0/6 to 0/20
3 to 5 cm / 20 to 30% voids

Specimens of grout (bars 4 x 4 x 16 cm) -- different amounts of PX2 and/or PX5 (10 %, 20 %, 30 % of the dry components)

-- fitted with a thermocouple

-- freeze-thaw testing in a climatic chamber



METHODOLOGY

- Grouted asphalt

Test slabs (60 x 40 x 4 cm in size) → outdoor site to assess their thermal behaviour under real conditions

-- porous asphalt with 25 % of voids

-- grout: ready-to-use powder GAMA-FLEX® + PCMs PX2 and PX5 ®

20% PCM

Slab	Ready-to-use powder	Water	PCM PX2	PCM PX5	Plasticizer
Reference	4,400 g	1,925 ml			
PX2	3,520 g	2,860 ml	880 g		132 g
PX5	3,520 g	2,860 ml		880 g	132 g
PX2/PX5	3,520 g	2,860 ml	660 g	220 g	132 g

Total masses of the test slabs and masses of grout (after two days of setting)

Slab	Mass of grout	Total mass of the slab
Reference	3.63 kg	25.39 kg
PX2	2.79 kg	24.52 kg
PX5	2.75 kg	24.29 kg
PX2/PX5	3.06 kg	24.36 kg

METHODOLOGY

- Two-layer concrete pavements

5-cm top layer with fine aggregates
18-cm bottom layer

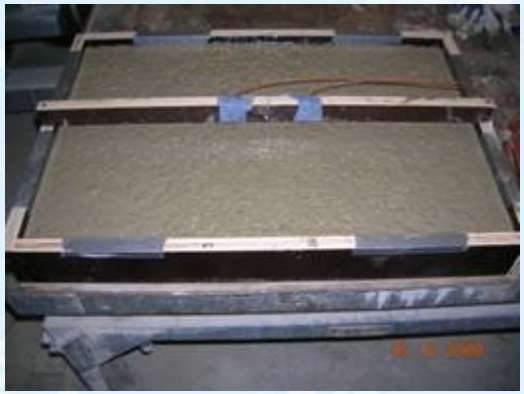
+ PCM GR

A concrete mix design with GR5 granulates replacing part of the sand fraction (0/4 mm) ; for the top layer.

Amounts of PCM correspond with 3 % and 9 %, respectively, of the mass of the sand fraction.

Test slabs (60 x 40 x 5 cm in size)

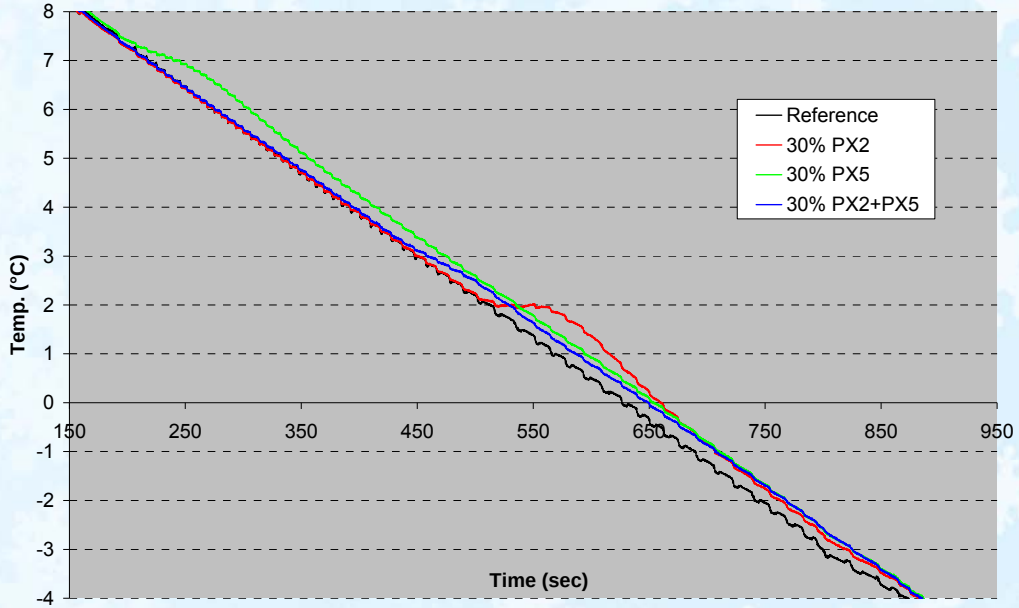
→ outdoor site

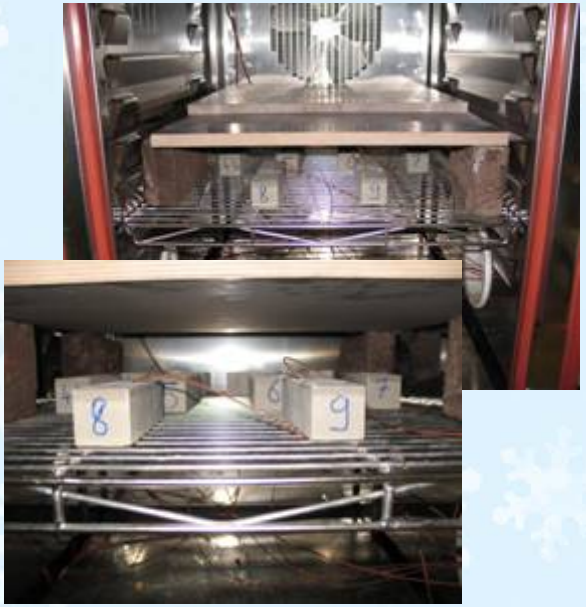


RESULTS

- Freeze-thaw tests on the grout specimens in a climatic chamber

- to demonstrate the effect of the PCMs on the development of temperatures





- larger deviations from the reference grout: recorded for the three mixtures with 30 % of PX-type PCM.

RESULTS

- Monitoring of the temperatures of the slabs on the outdoor site

Concrete slabs

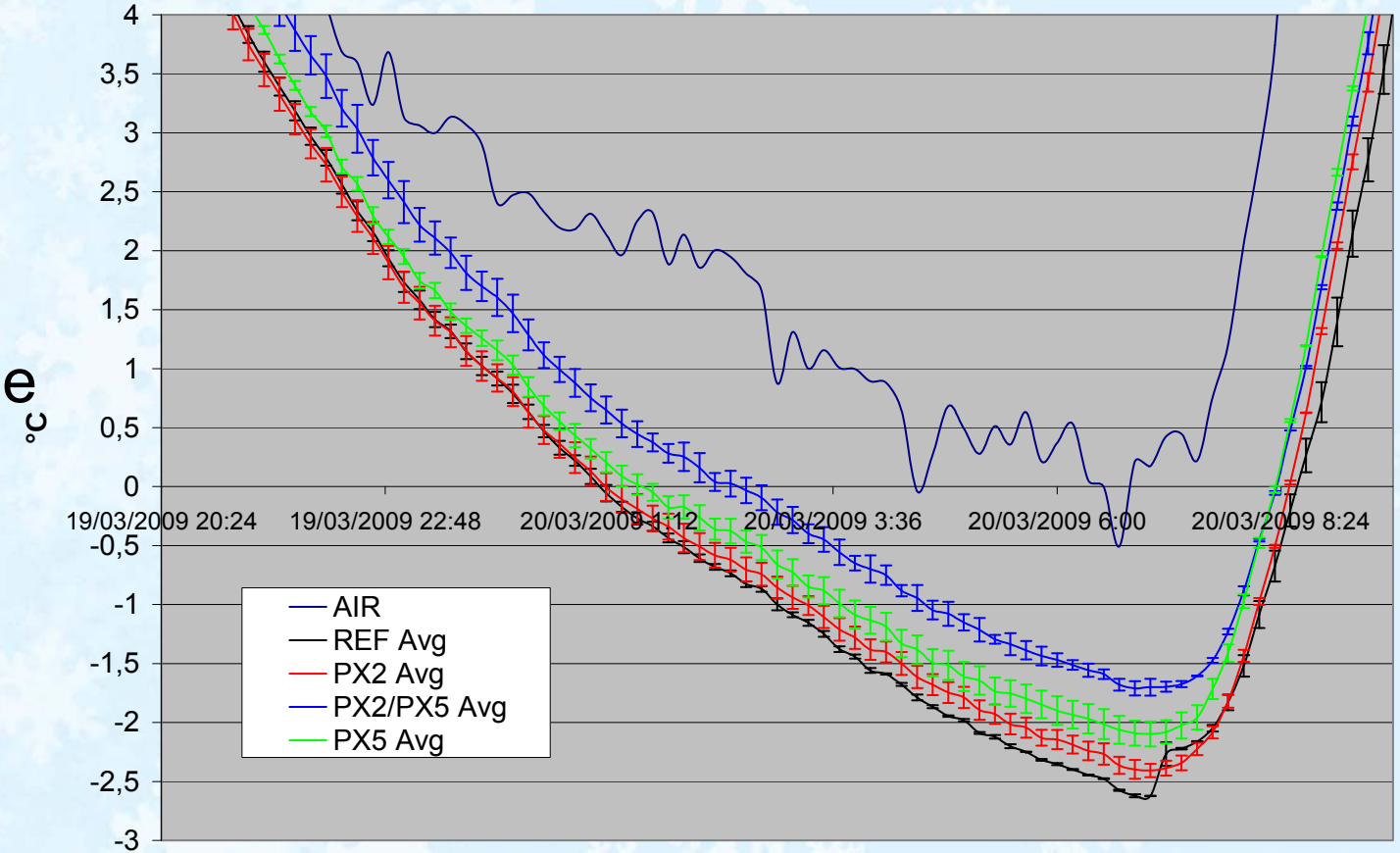
Grouted asphalt

RESULTS

- Monitoring of the temperatures of the slabs on the outdoor site - <u>Grouted asphalt</u>

  - 4 spells of ground frost during period between 19th & 31st March 2009

  - Slab with PX2/PX5 blend differs most from the reference slab



RESULTS

- Monitoring of the temperatures of the slabs on the outdoor site - Grouted asphalt

Behaviour of the slabs with PCMs compared to that of the reference slab without PCM

	PX2		PX2/PX5		PX5	
	i. (min)	**ii.** (min)	**i.** (min)	**ii.** (min)	**i.** (min)	**ii.** (min)
19/03	10	20	90	150	30	50
20/03	0	0	60	70	20	20
29/03	-20	-10	30	40	0	10
30/03	0	0	70	60	10	10

Indicators

i. the advance (sign –) or delay (sign +) of the slabs with PCMs in dropping below 0 °C, in comparison with the reference slab;

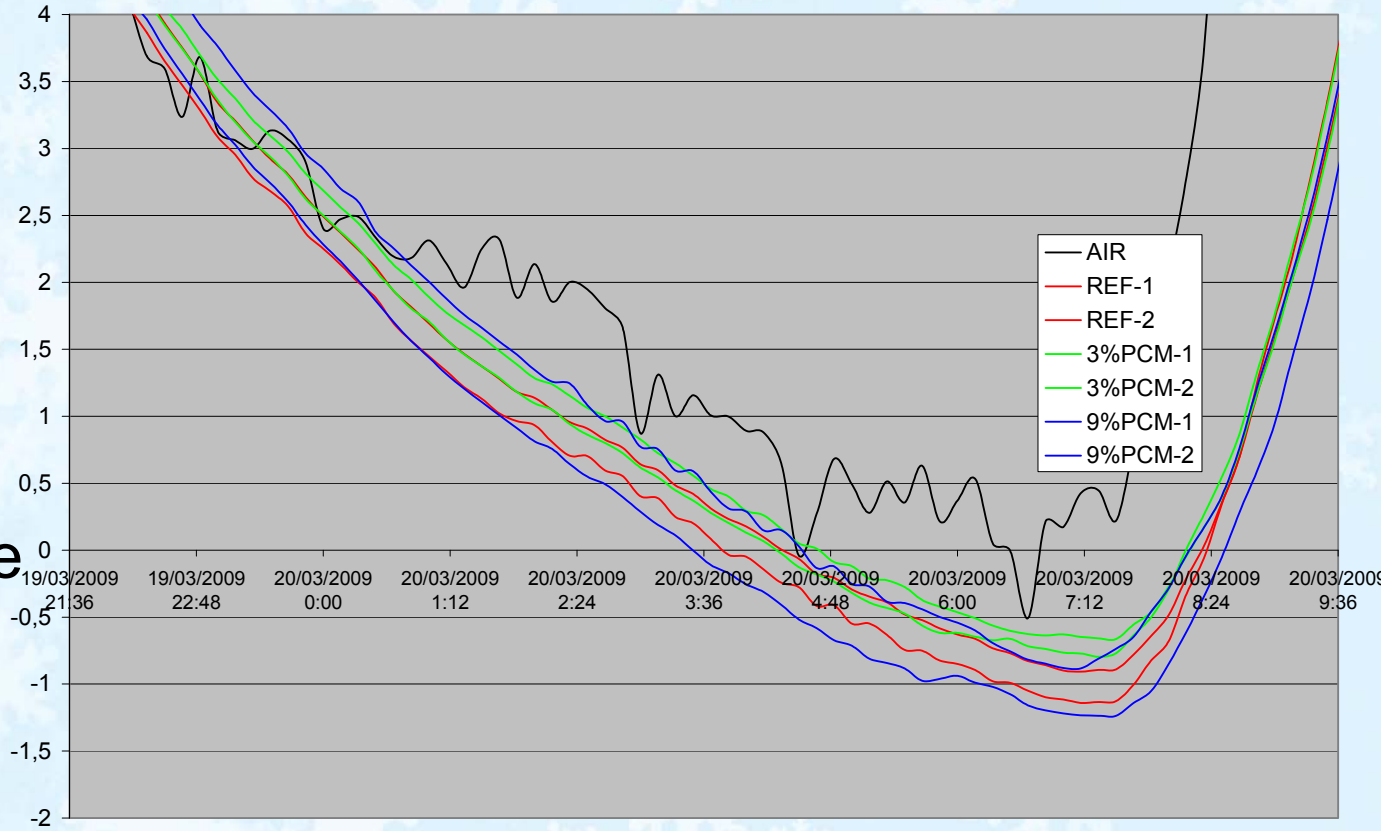
ii. the advance (sign –) or delay (sign +) of the slabs with PCMs in dropping below 0.5 °C, in comparison with the reference slab

RESULTS

- Monitoring of the temperatures of the slabs on the outdoor site – <u>Concrete slabs</u>

  - A few spells of ground frost in January, February & March 2009. Problem with the 9% PCM slab !

  - “Intra-composition” differences recorded for the reference and the 3 % PCM slabs are more limited



RESULTS

- Monitoring of the temperatures of the slabs on the outdoor site - Concrete slabs

- Draw conclusions ?

- ASC to confirm the possible influence of PCMs

Behaviour of the slabs with PCMs in comparison with the reference slab without PCM - Concrete

	GR5	
	i. (min)	**ii.** (min)
23/01	10	10
24/01	10	10
26/01	0	10
11/02	0	10
18/02	0	10
19/03	20	30
20/03	10	30
29/03	20	20
30/03	10	20

Indicators

i. the advance (sign –) or delay (sign +) of the slabs with PCMs in dropping below 0 °C, in comparison with the reference slab;

ii. the advance (sign –) or delay (sign +) of the slabs with PCMs in dropping below 0.5 °C, in comparison with the reference slab

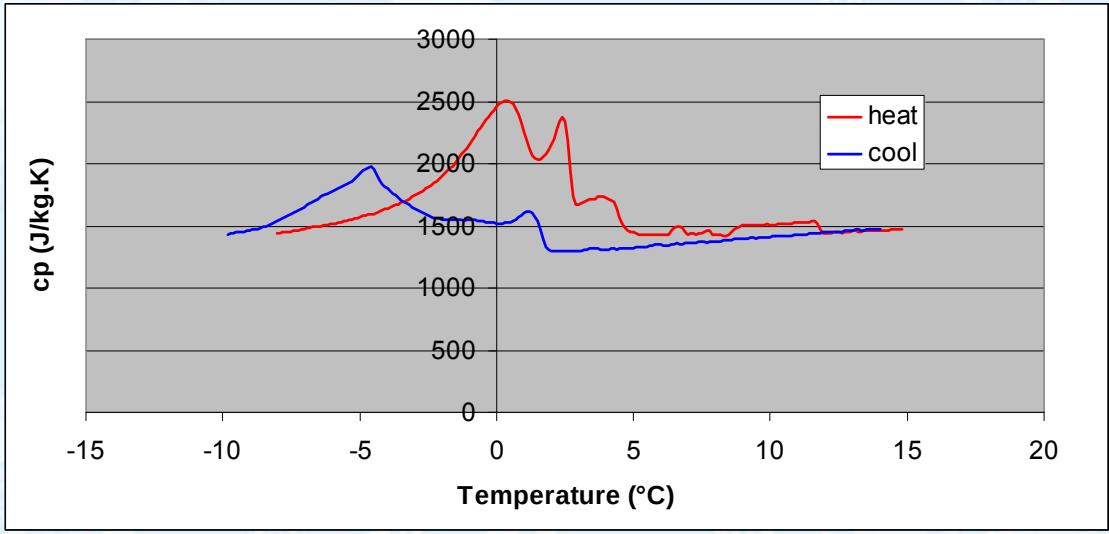
RESULTS

- Adiabatic Scanning Calorimetry

- On “pure” PCMs

- On the grout specimens

e.g. PX2/PX5 blend →
(*ΔH* 40 to 45 kJ/kg)



- On concrete slabs

CONCLUSIONS & PROSPECTS

- Partial / Encouraging results

→ the analysis of temperature data recorded on site remains to be continued

- Thermal effect of the PCMs as conditioned remains relatively limited

→ continue to investigate any technical solution which makes it possible to increase the amounts of PCMs in pavements:

  - encapsulation in epoxy resin before incorporation into a porous pavement, as developed in this project;
  - other ways to encapsulate PCMs

- Amount and type of PCM optimised through model analysis

Thanks for your kind attention

Research partners :

» *Belgian Road Research Centre – www.brrc.be*

» *Belgian Building Research Institute – www.bbri.be*

» *Centre of Technological Resources in Chemistry – www.certech.be*

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