Simplified heat transfer modelling for temperature prediction in an insulated box equipped with PCM

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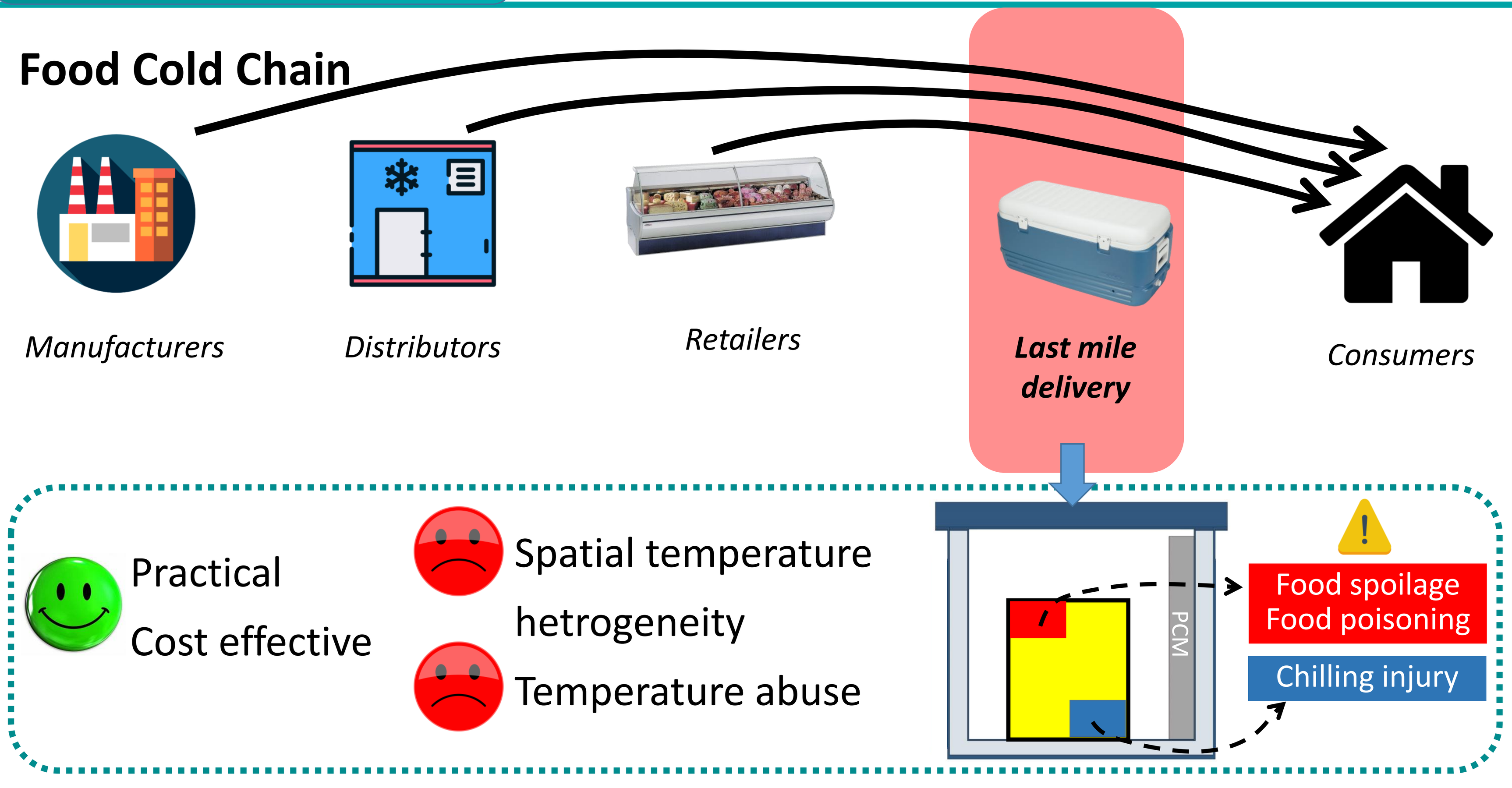
Background



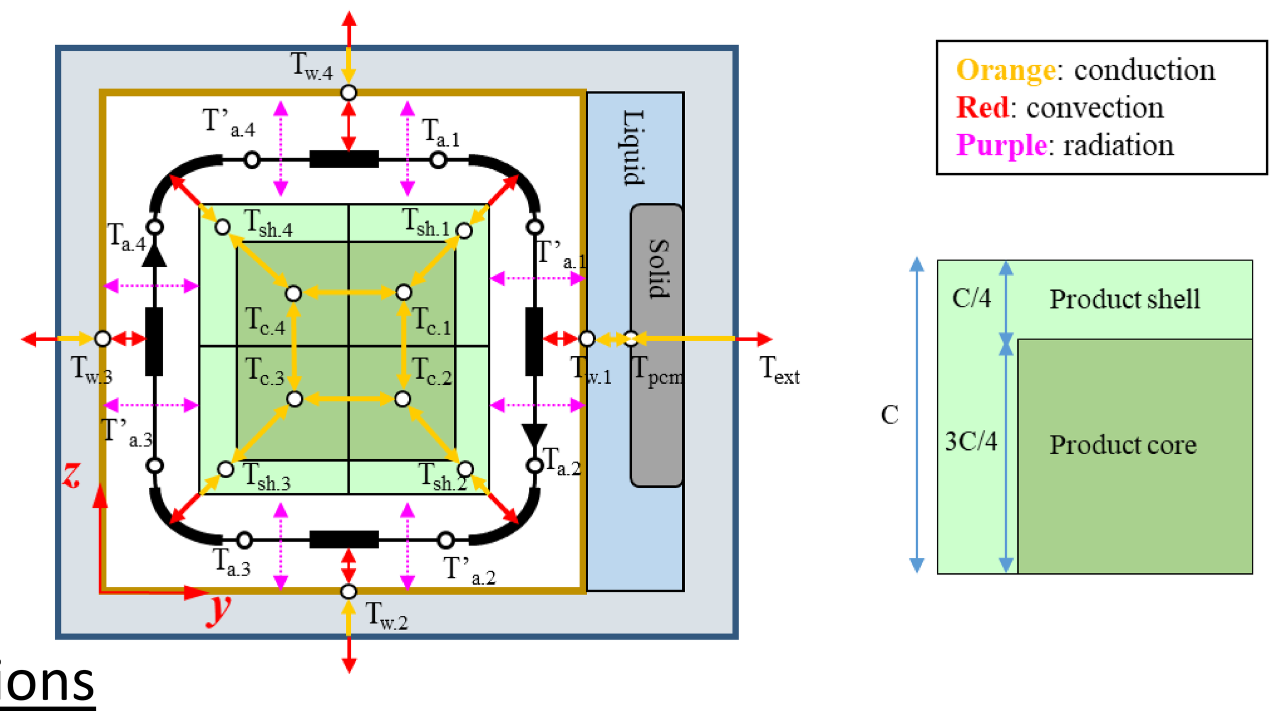
Model development

Assumption

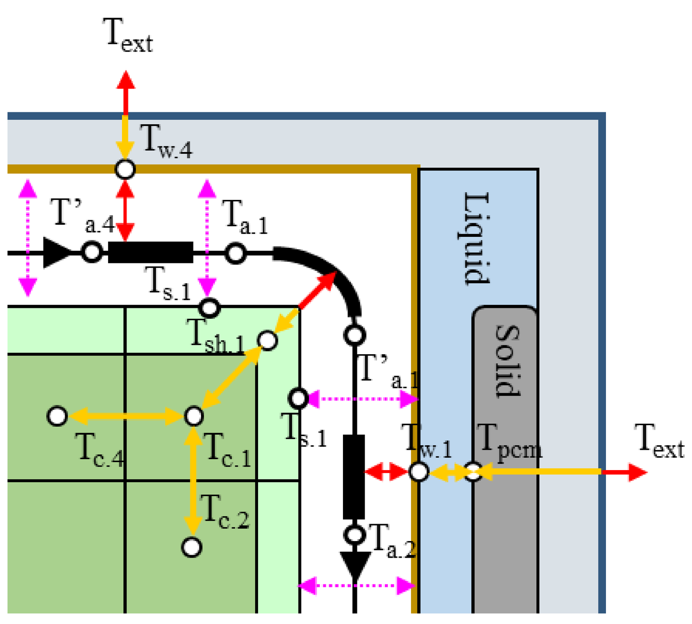
❖2D heat transfer and airflow

❖Air thermal inertia is negligible

Model structure



Governing equations



At steady state: $T_{pcm} = T_m = 0°C$ (PCM is ice)

Heat exchange between internal air and

internal wall; $(T_{a.2} - T_{w.1}) = exp\left(-\frac{h_w A_{w.1}}{\dot{m}_a C_{p.a}}\right)(T'_{a.1} - T_{w.1})$

product shell; $(T'_{a.1} - T_{sh.1}) = exp\left(-\frac{A_p}{\dot{m}_a C_{p.a}\left(\frac{1}{h_p} + \frac{C}{8\lambda_p}\right)}\right)(T_{a.1} - T_{sh.1})$

Radiative heat flux; $\Phi_{s1.w1} = \varepsilon_{w.1}\sigma A_{s1.w.1}(T_{s.1}{}^4 - T_{w.1}{}^4)$

Heat balance

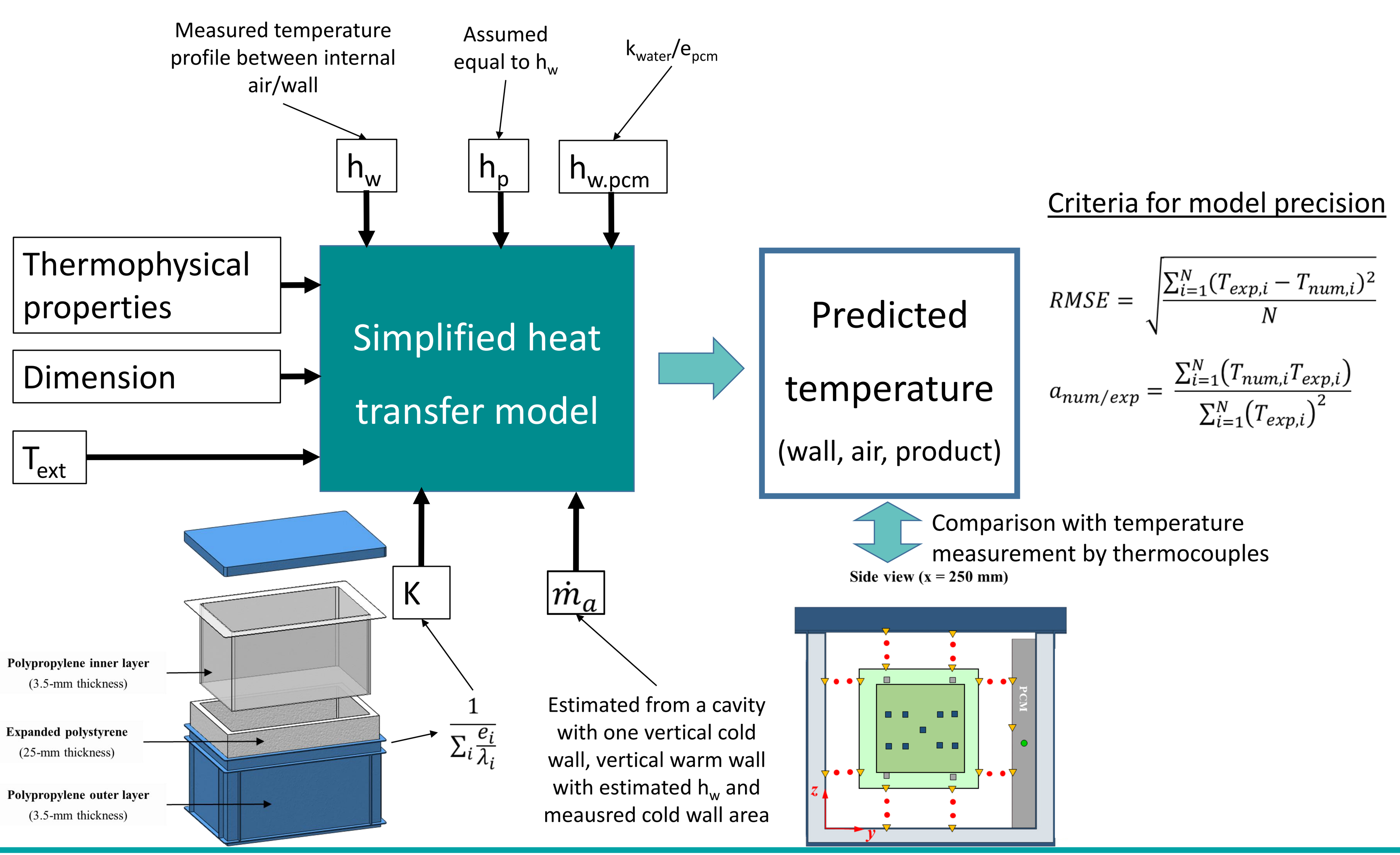
Product core ($T_{c.1}$); $\lambda_p A_{sh1.c1}\frac{(T_{sh.1} - T_{c.1})}{\frac{3C}{8}} + \lambda_p A_{c1.c2}\frac{(T_{c.2} - T_{c.1})}{\frac{3C}{4}} + \lambda_p A_{c1.c4}\frac{(T_{c.4} - T_{c.1})}{\frac{3C}{4}} = 0$

Product shell ($T_{sh.1}$); $\dot{m}_a C_{p.a}(T_{a.1} - T'_{a.1}) + \lambda_p A_{sh1.c1}\frac{(T_{c.1} - T_{sh.1})}{\frac{3C}{8}} - \Phi_{s1.w1} - \Phi_{s1.w4} = 0$

Internal warm wall ($T_{w.4}$); $\dot{m}_a C_{p.a}(T'_{a.4} - T_{a.1}) + KA_{w.4}(T_{ext} - T_{w.4}) + \Phi_{s1.w4} + \Phi_{s4.w4} = 0$

PCM surface ($T_{w.1}$); $\dot{m}_a C_{p.a}(T'_{a.1} - T_{a.2}) + h_{w.pcm} A_{w.1}(T_{pcm} - T_{w.1}) + \Phi_{s1.w1} + \Phi_{s2.w1} = 0$

Modeling approach



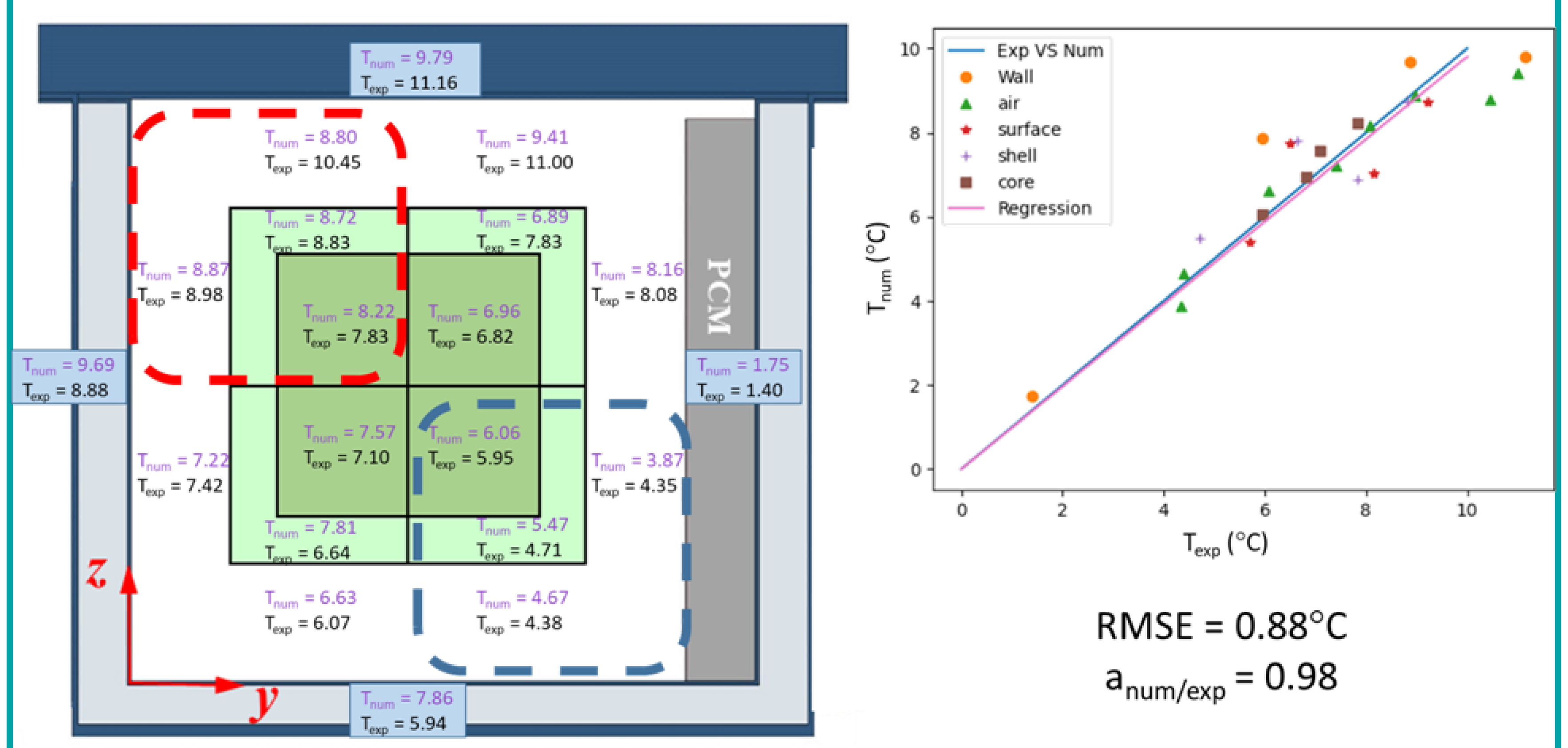
Objectives

1. To develop a simplified heat transfer model to predict spatial temperature variation under steady state in an insulated box equipped with Phase Change Material (PCM).
2. To study the influence of box geometry and operating condition on the product temperature

Results

Model validation

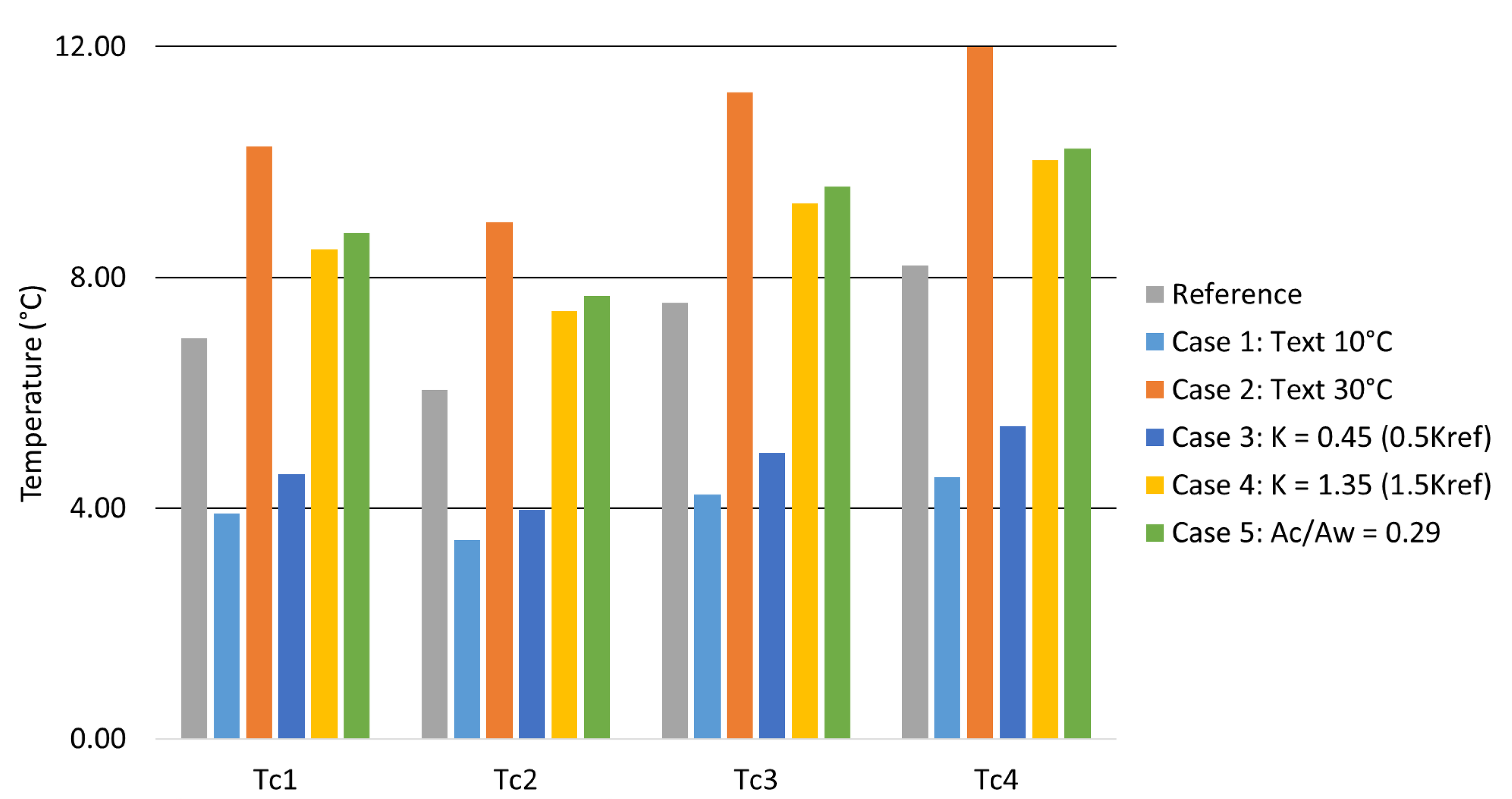
T_{ext} = 20°C (Reference condition)

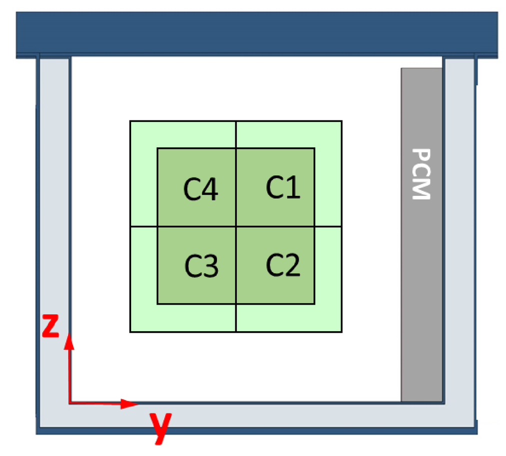


RMSE = 0.88°C

$a_{num/exp}$ = 0.98

Influence of input parameters on product core temperature





Parameter	Reference value
T_{ext} (°C)	20
K ($W \cdot m^{-2} \cdot K^{-1}$)	0.9
Ac/Aw (Cold wall area/Warm wall area)	0.43

Conclusion

✓The model can predict well temperature distribution in an insulated box with PCM.

✓It could predict the impact of box geometry and operating conditions which coud be useful for system design.

✓Combining this model with quality and safety predictive models, it could be possible to predict food quality and safety evolution along a supply chain.