GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF STRUCTURAL ENGINEERING AND BUILDING MATERIALS
FIRE SAFETY SCIENCE AND ENGINEERING (FSSE)

NUMERICAL MODELLING OF WATER SPRAY IMPINGEMENT COOLING

Cédric Van de Vondel

24th of May 2023

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

INTRODUCTION

INTRODUCTION

- Spray surface cooling is important for preventing pyrolysis and thus controlling the fire development
- Experimental paper [1]:

WATER SPRAYS COOLING OF A HOT METALLIC PLATE

Acem* Z.[1], Mehaddi R.[1], Dréan V.[2], Laumesfeld J.[2], Parent G.[1], Collin A.[1], Proal N.[2], and Wilhelm A.[2]

[1] Université de Lorraine, CNRS, LEMTA, F-54000 Nancy, France
[2] EFECTIS, France.
**Corresponding author's email: zoubir.acem@univ-lorraine.fr*

ABSTRACT

In the present work, experiments were performed in order to assess the spray cooling efficiency of a hot steel plate for three different nozzles. For this purpose, special cares were taken for both the measurement of the surface temperatures and the characterization of the sprays. Firstly, the surface temperatures were measured thanks to K-type thermocouple wires directly welded onto the surfaces of the plate in a separated contact. This technique provides an accurate measurement of the surface temperature during the cooling. Secondly, the spray characteristics of each nozzle were also thoroughly investigated. It was found that droplets size and velocity distributions of each nozzle follow a lognormal law. Corresponding Sauter Mean diameter (SMD) and Mean velocity range respectively from 170 to 230 μm and from 5.6 to 22.4 $m.s^{-1}$.

- Validation study of CFD modelling
- FDS version 6.7.7-intel-2021b

[1] See References slide

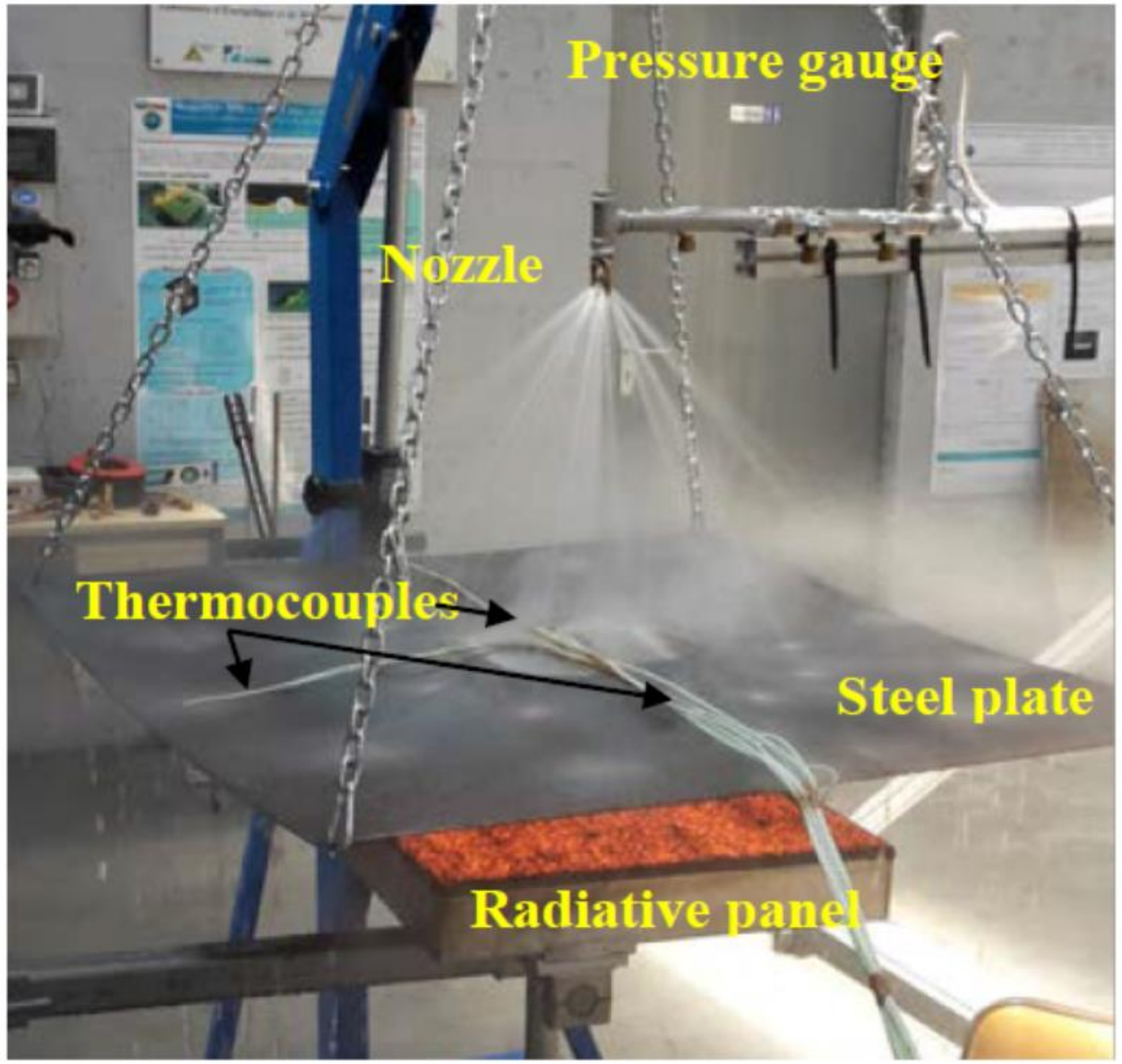
GHENT UNIVERSITY

MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING . INTERNATIONAL

EXPERIMENTAL SET-UP

EXPERIMENTAL SET-UP

- SU42 nozzle
- Water volume flow rate: 4.6 l/min
- Water pressure: 6.2 bar
- Air pressure: 4.5 bar
- Sauter mean droplet diameter: 171 µm
- Mean droplet velocity: 22.4 m/s



Set-Up from experiment [1]

[1] See References slide

GHENT UNIVERSITY

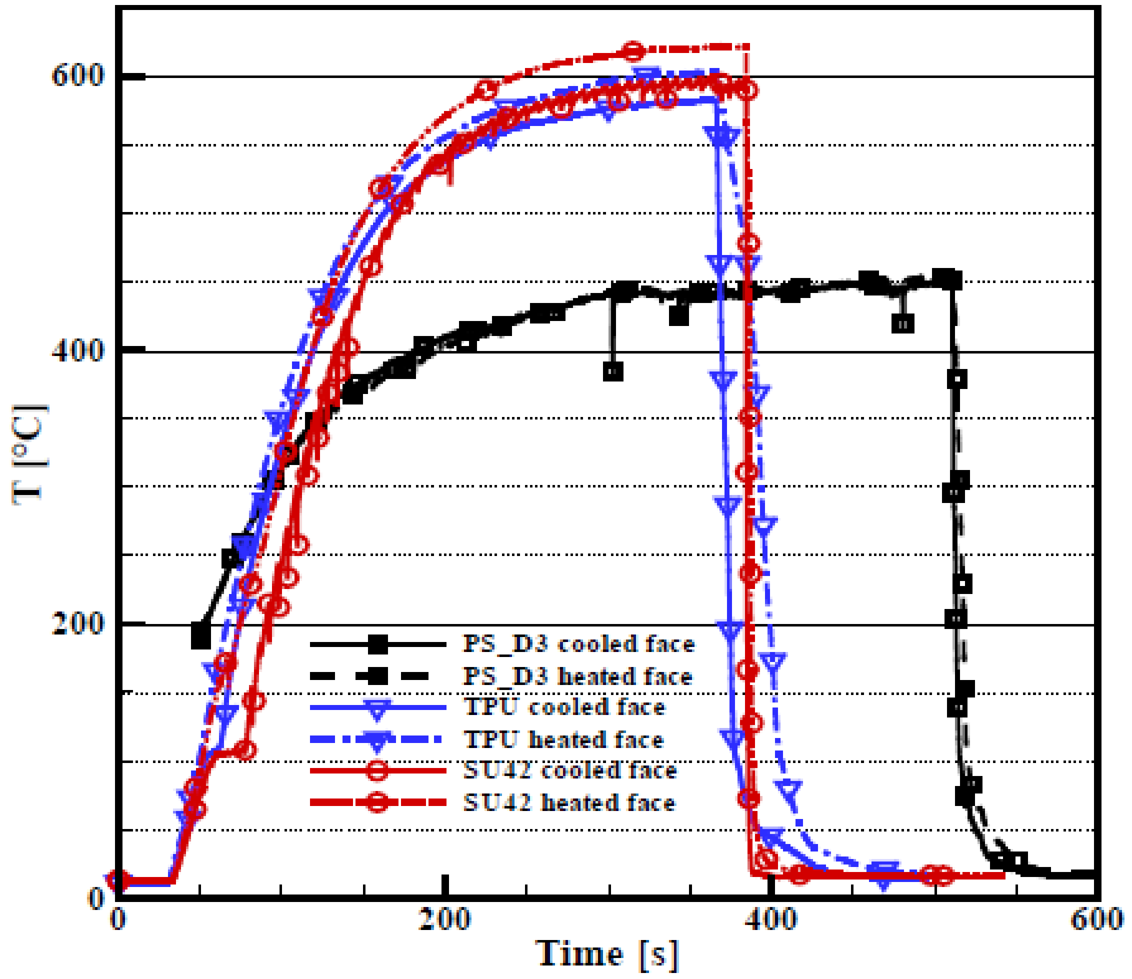
EXPERIMENTAL RESULTS

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

EXPERIMENTAL RESULTS

- Heating up to 600 °C
- At 384.4 seconds, activation of the spray and shutting down of the radiative panel
- Cooling down from 600 °C to 20 °C in 4 seconds



Results from experiment [1]

SU42 = RED

[1] See References slide

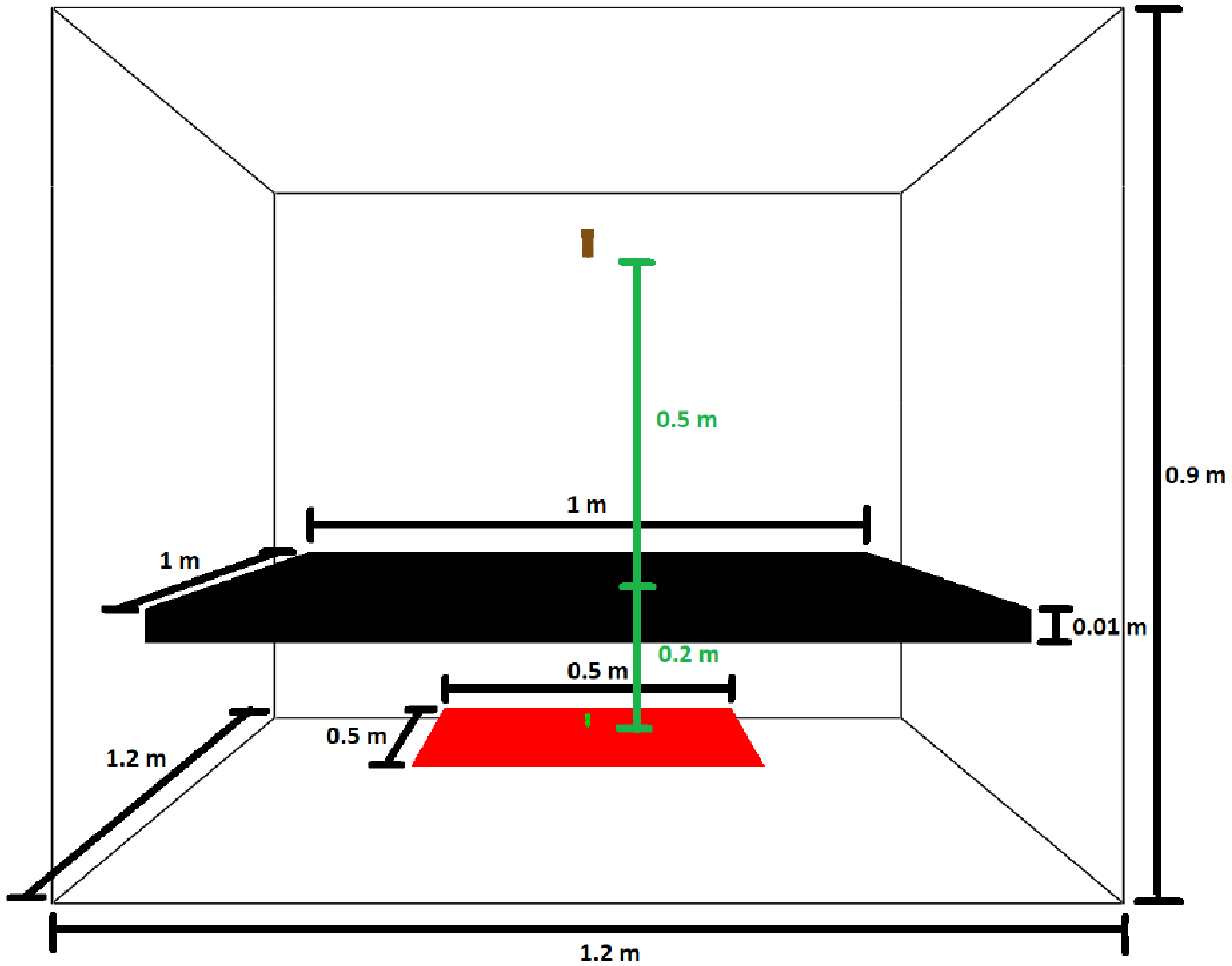
FDS SET-UP

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

FDS SET-UP

1. Hot metallic plate
2. Water spray
3. Combined simulation

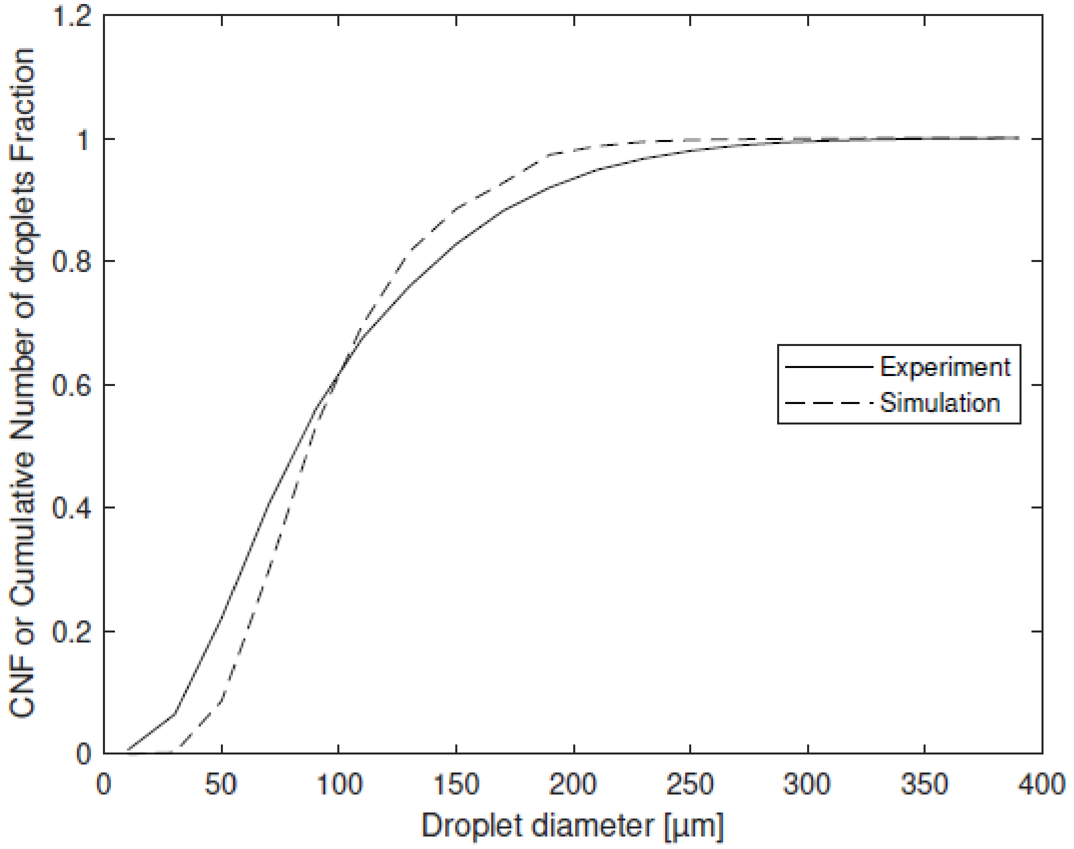


Set-Up in FDS

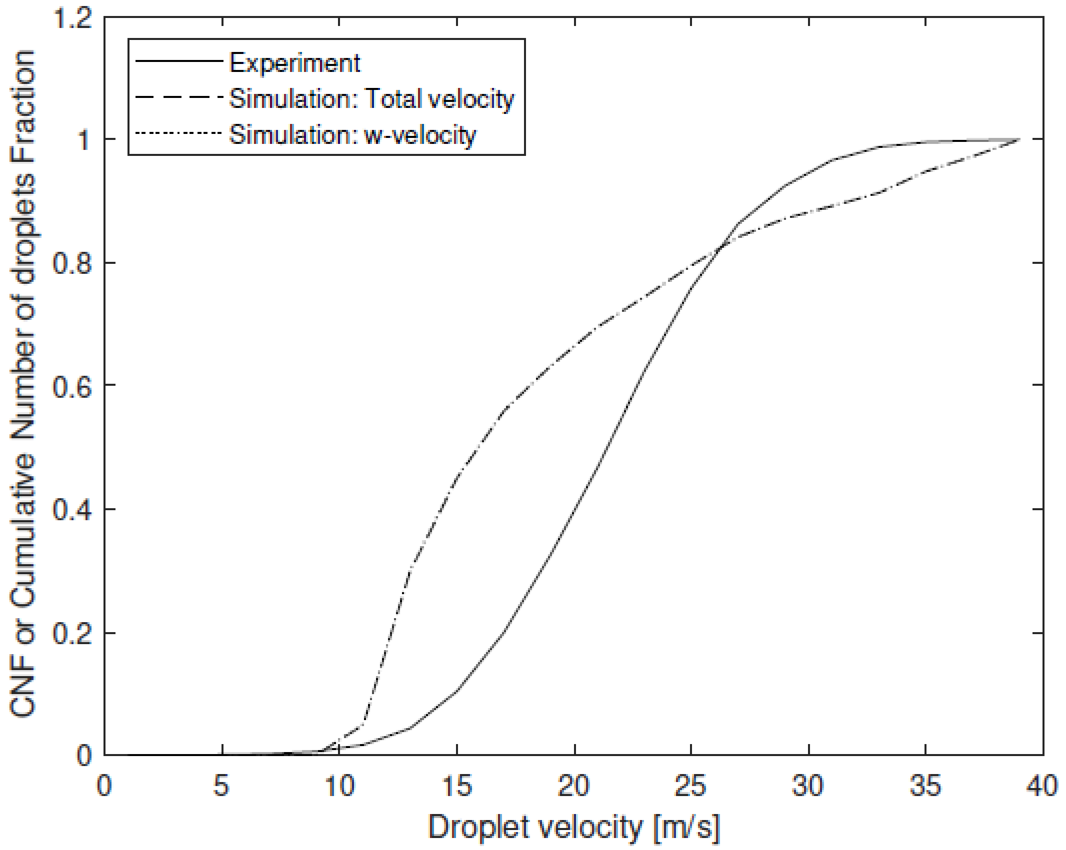
GHENT UNIVERSITY

FDS SET-UP

- Water spray nozzle: SU 42 nozzle
- Size distribution: Rosin-Rammler-Log-Normal



Size distribution



Velocity distribution

FDS SET-UP

- Some points that were analyzed:
- Variation of conductivity and specific heat for the steel
- Mono- vs poly-disperse
- Sensitivity analyses for: mesh size, number of particles per second and number of radiation angles
- Weber number, Sauter mean diameter and mean vertical velocity
- Coverage area, Boiling curve

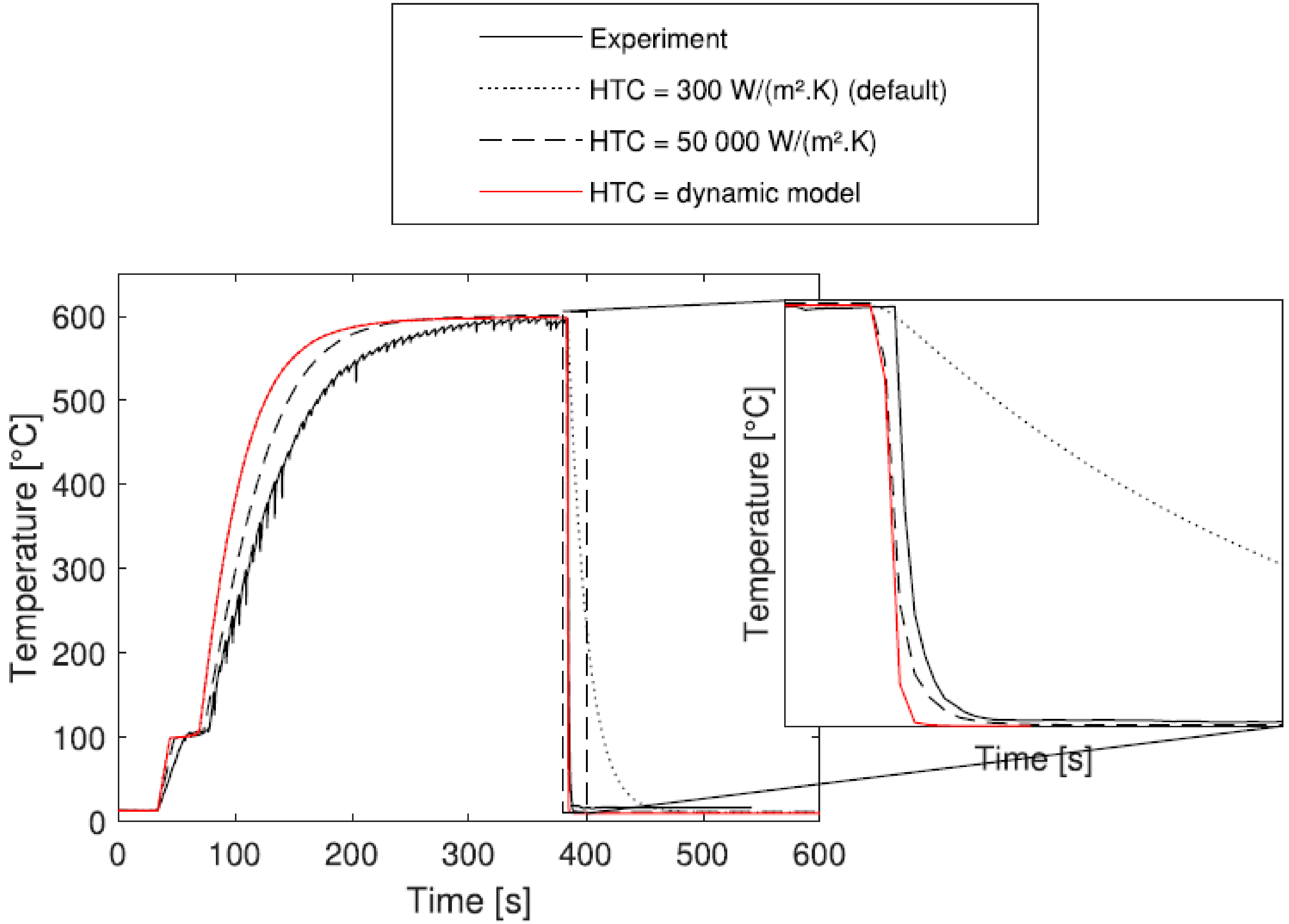
GHENT UNIVERSITY

RESULTS

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

RESULTS



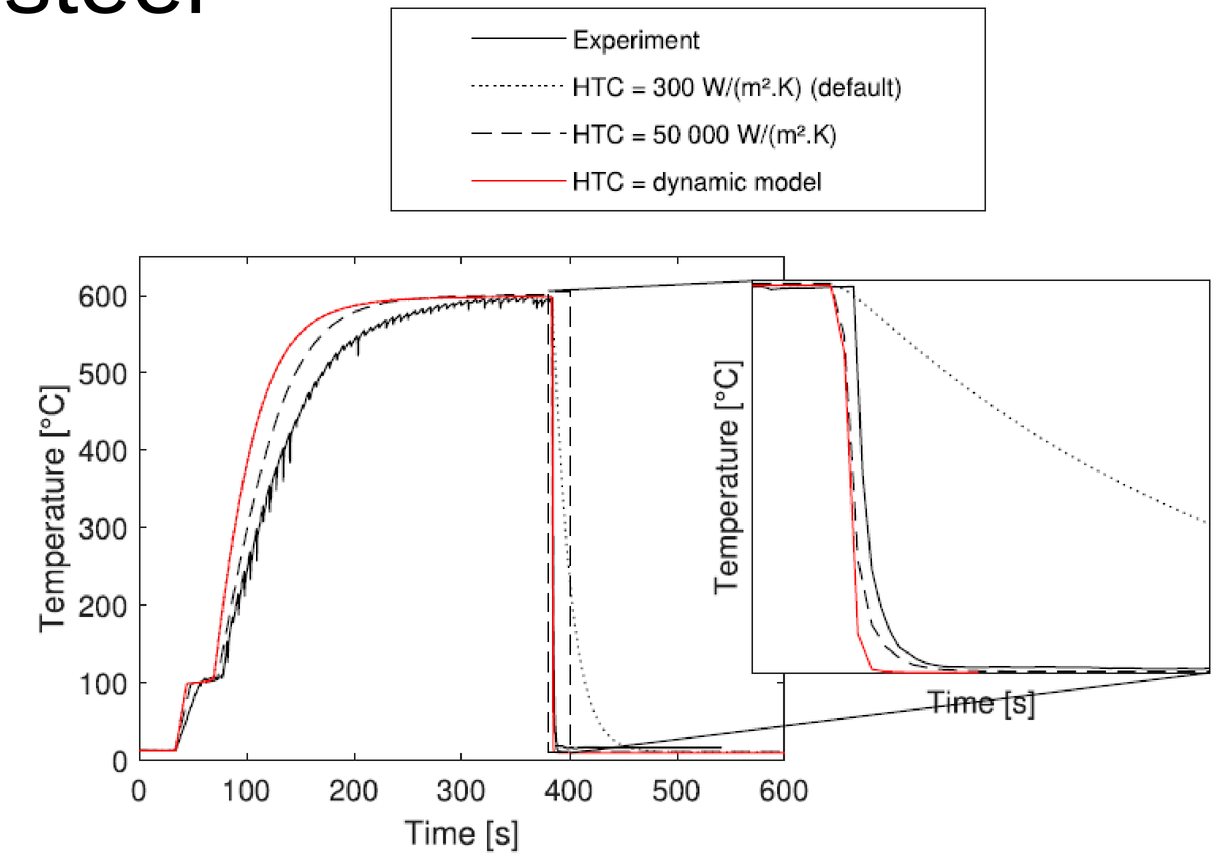
Temperature evolution

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

RESULTS

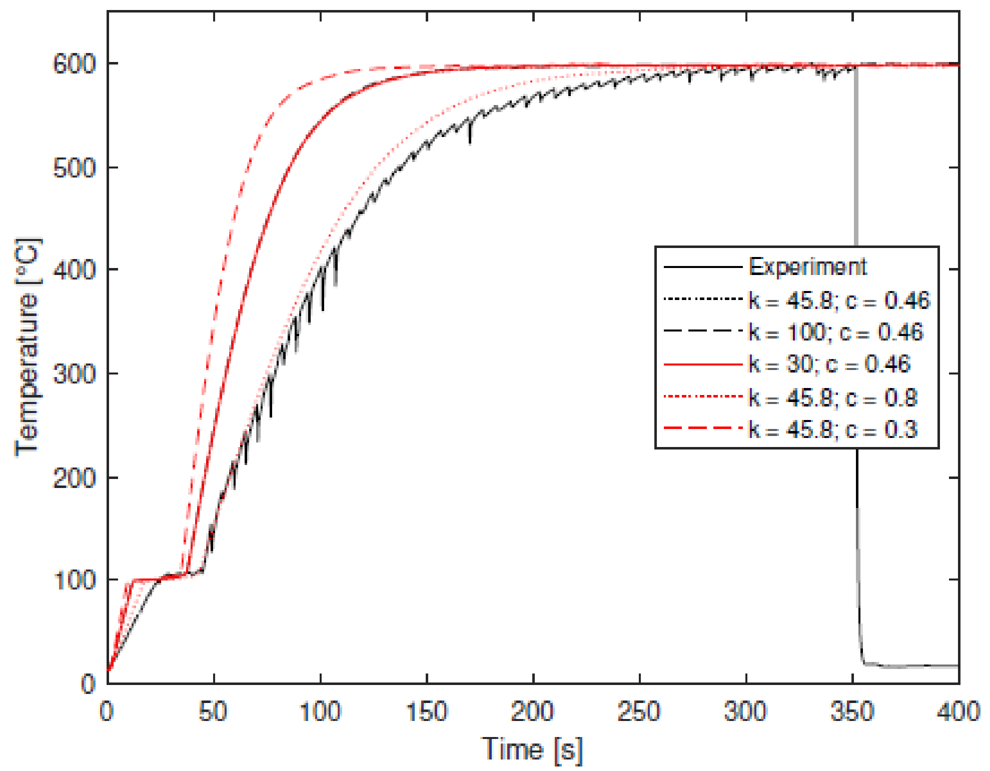
- **Important factors:**
- Thermal properties of steel
- Accounting for water evaporation from the steel
- Heat Transfer Coefficient (HTC)



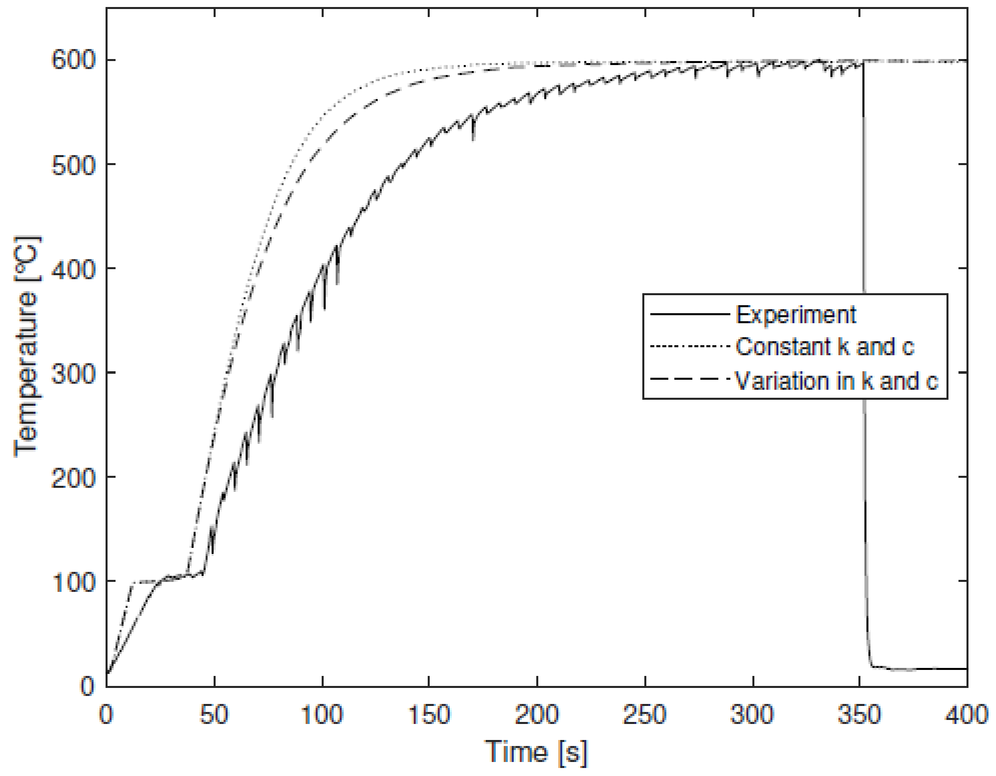
Temperature evolution

RESULTS

– Thermal properties of steel



Temperature evolution



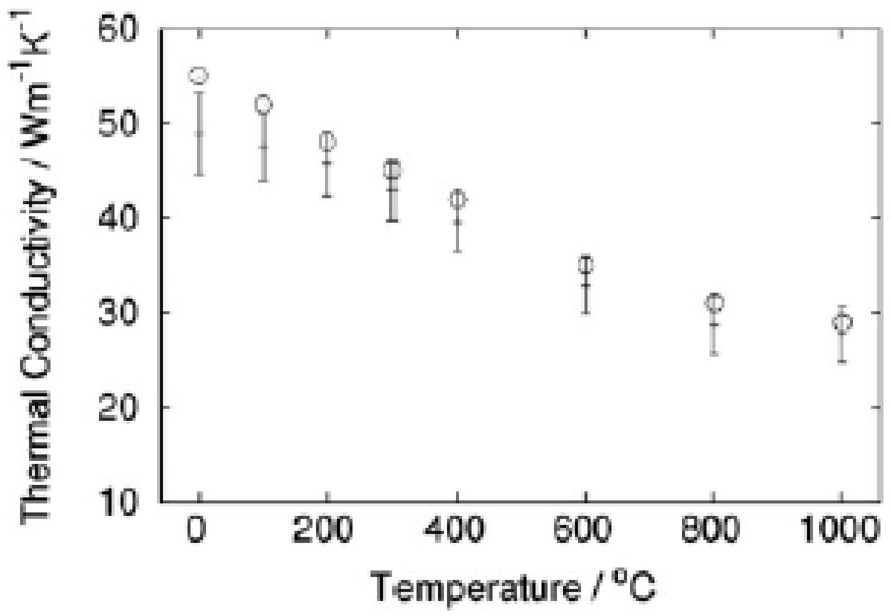
Temperature evolution

GHENT UNIVERSITY

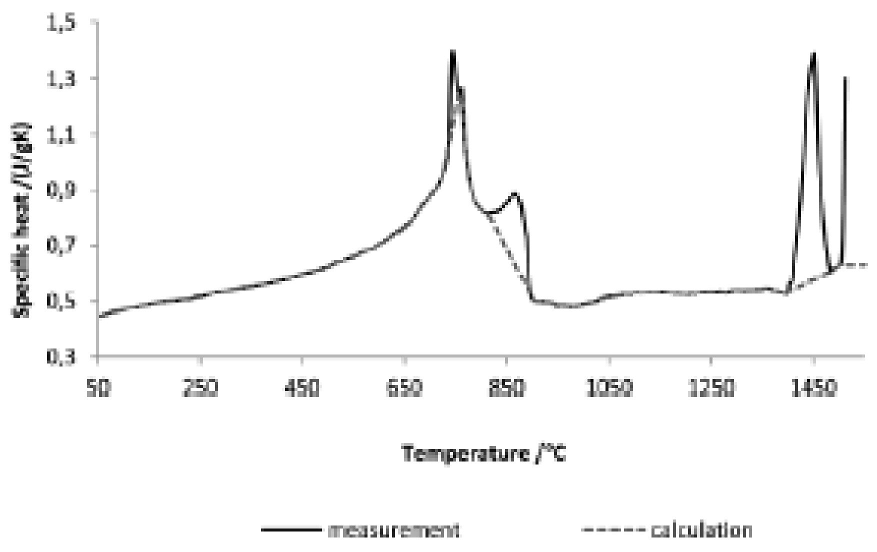
INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

RESULTS

– Thermal properties of steel



Thermal conductivity

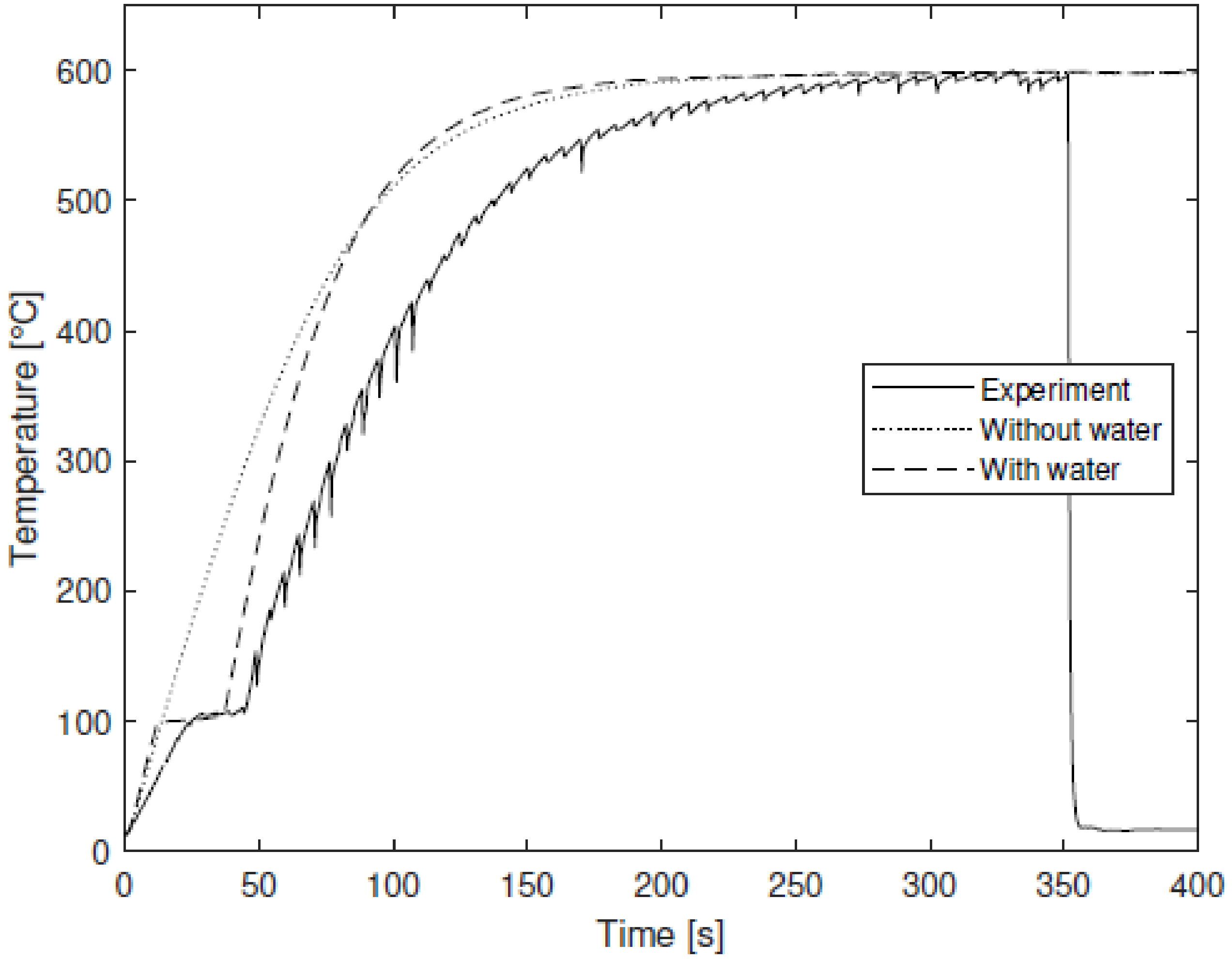


Specific heat

GHENT UNIVERSITY

RESULTS

– Accounting for water evaporation from the steel

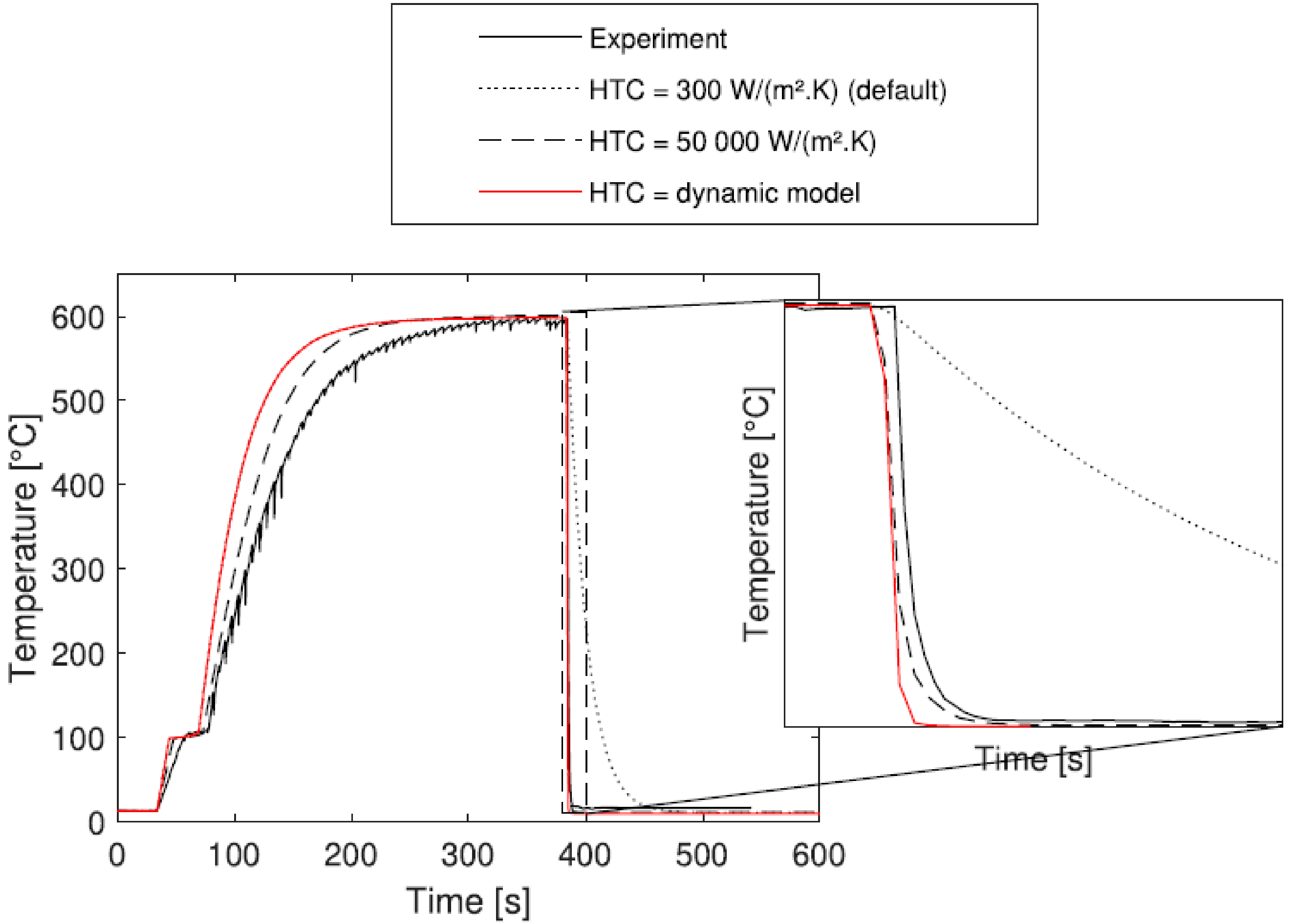


Temperature evolution

GHENT UNIVERSITY

RESULTS

– Heat Transfer Coefficient (HTC)



Temperature evolution

RESULTS

– Mono- vs poly-disperse:

– Mono-disperse saves 12% CPU time compared to poly-disperse.

– Poly-disperse is 12% closer to the experimental data.

– Weber number, Sauter mean diameter and mean velocity

	SMD (µm)	Mean velocity (m/s)	Weber number
Experiment	171	22.4	1175
Simulation	147	20.0	824

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

CONCLUSION

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

CONCLUSION

- FDS can provide accurate results
- **But:** Some FDS settings need modification!
- For example: Heat transfer coefficient
- The mesh is always an important factor in every FDS simulation

REFERENCES

REFERENCES

– Acem Z., Mehaddi R., Dréan V., Laumesfeld J., Parent G., Collin A., Proal N., and Wilhelm A. ”Water sprays cooling of a hot metallic plate”, 10th international Seminar on Fire and Explosion Hazards, 10th may at 11:10.

GHENT UNIVERSITY

FACULTY OF ENGINEERING
AND ARCHITECTURE

Cédric Van de Vondel

Department of Structural Engineering and Building Materials

E Cedric.VandeVondel@ugent.be
M +32 499 39 97 31

Universiteit Gent
@ugent
@ugent
Ghent University

GHENT UNIVERSITY

INTERNATIONAL MASTER OF SCIENCE IN FIRE SAFETY ENGINEERING

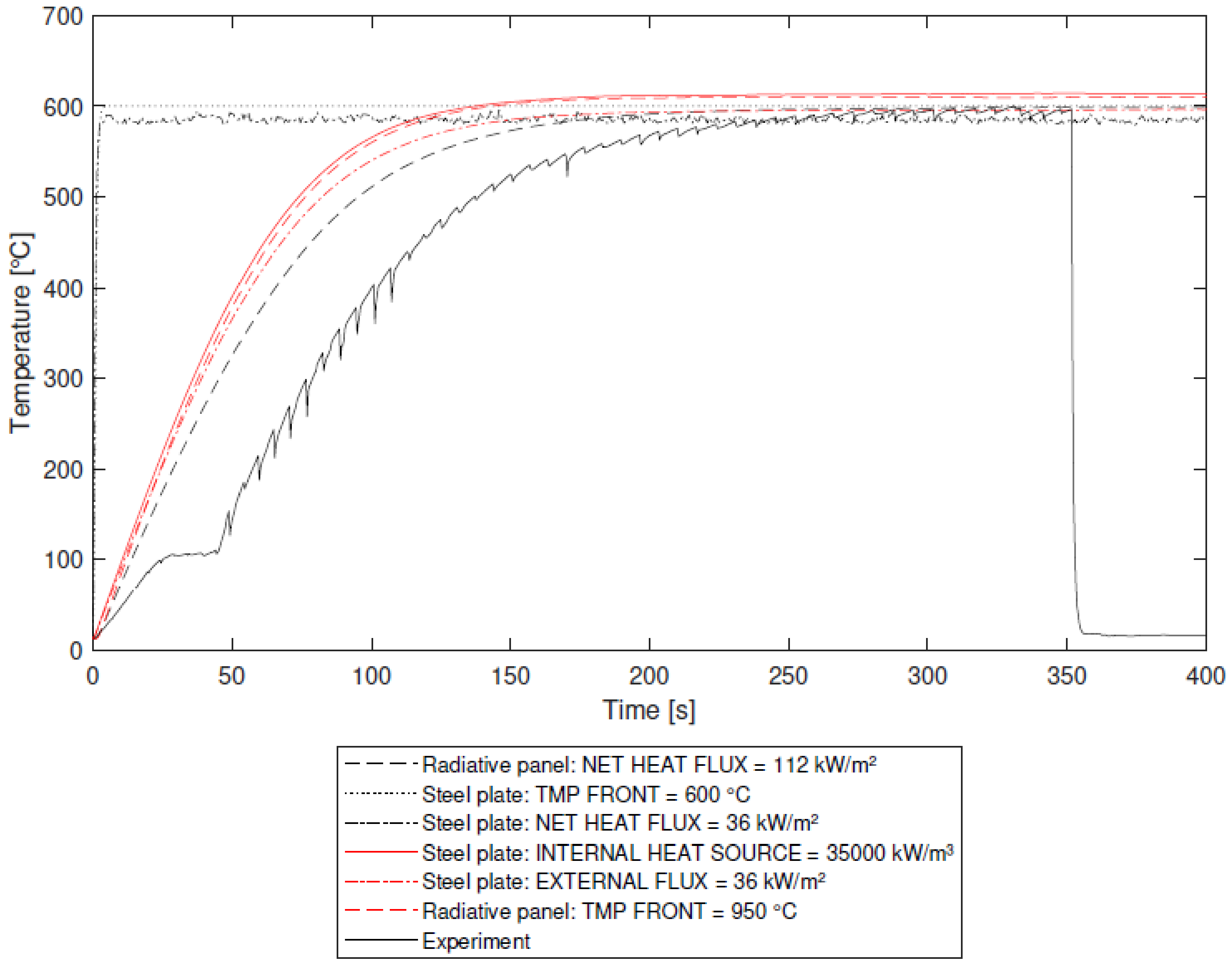


Figure 4.1: Wall temperature of cooled side steel plate with different heating methods in FDS

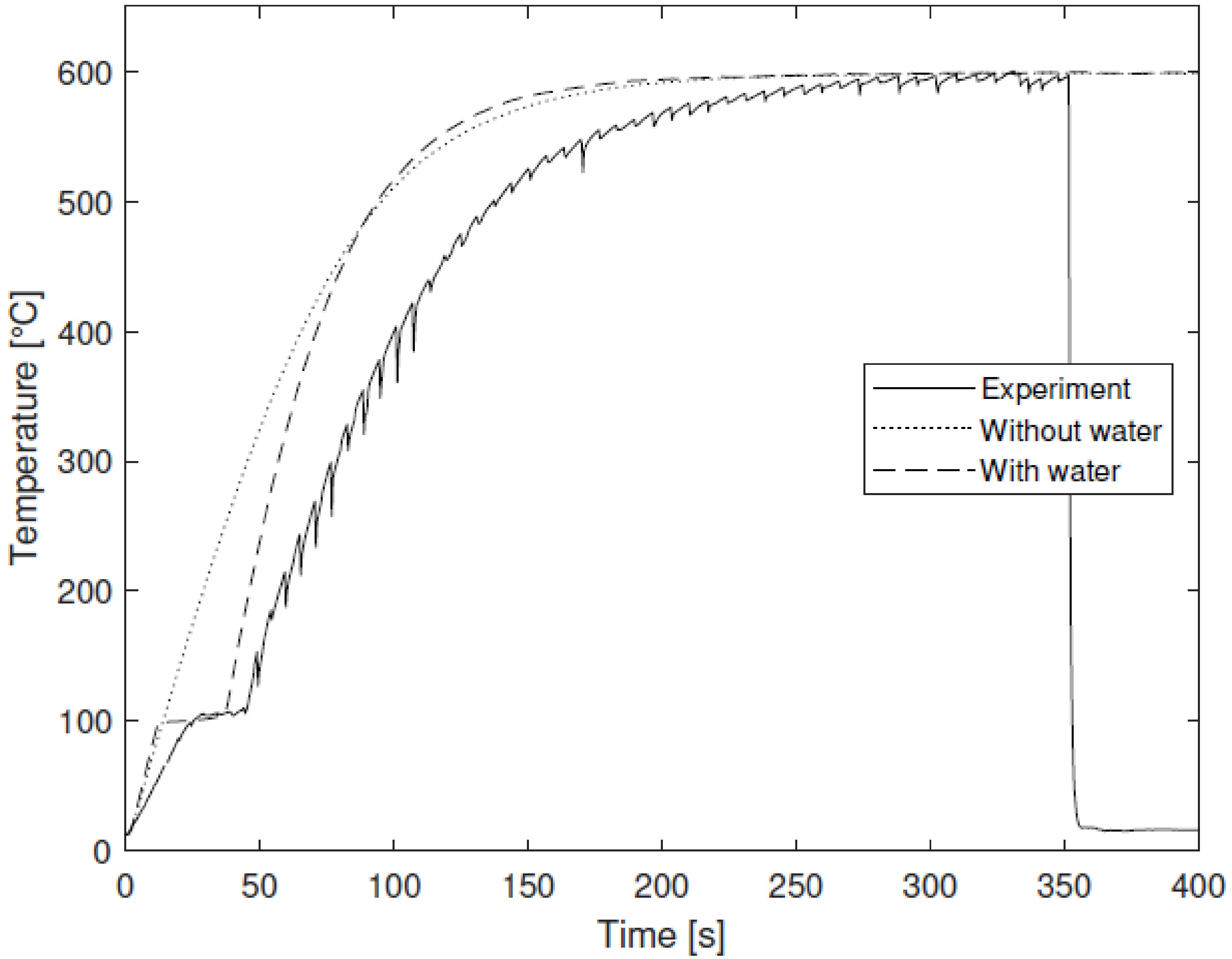
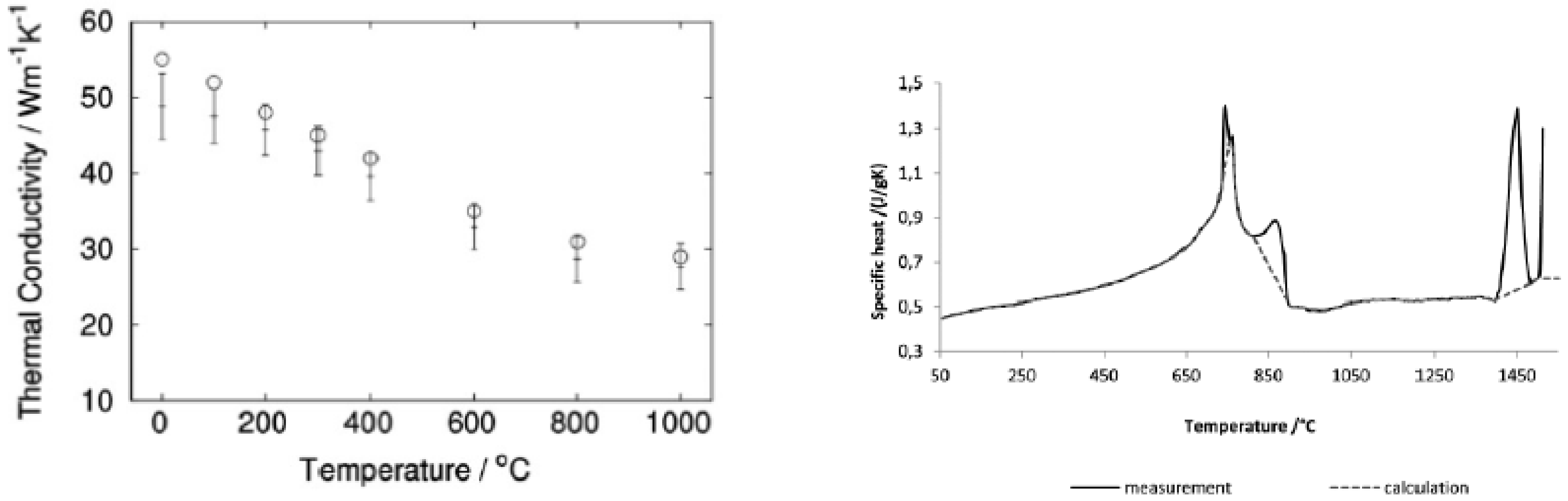


Figure 4.2: Difference in wall temperature of cooled side steel plate with and without the presence of water inside the solid



(a) Thermal conductivity from [20] (b) Specific heat from [22]

Figure 4.3: Thermal conductivity and specific heat evolutions over temperature

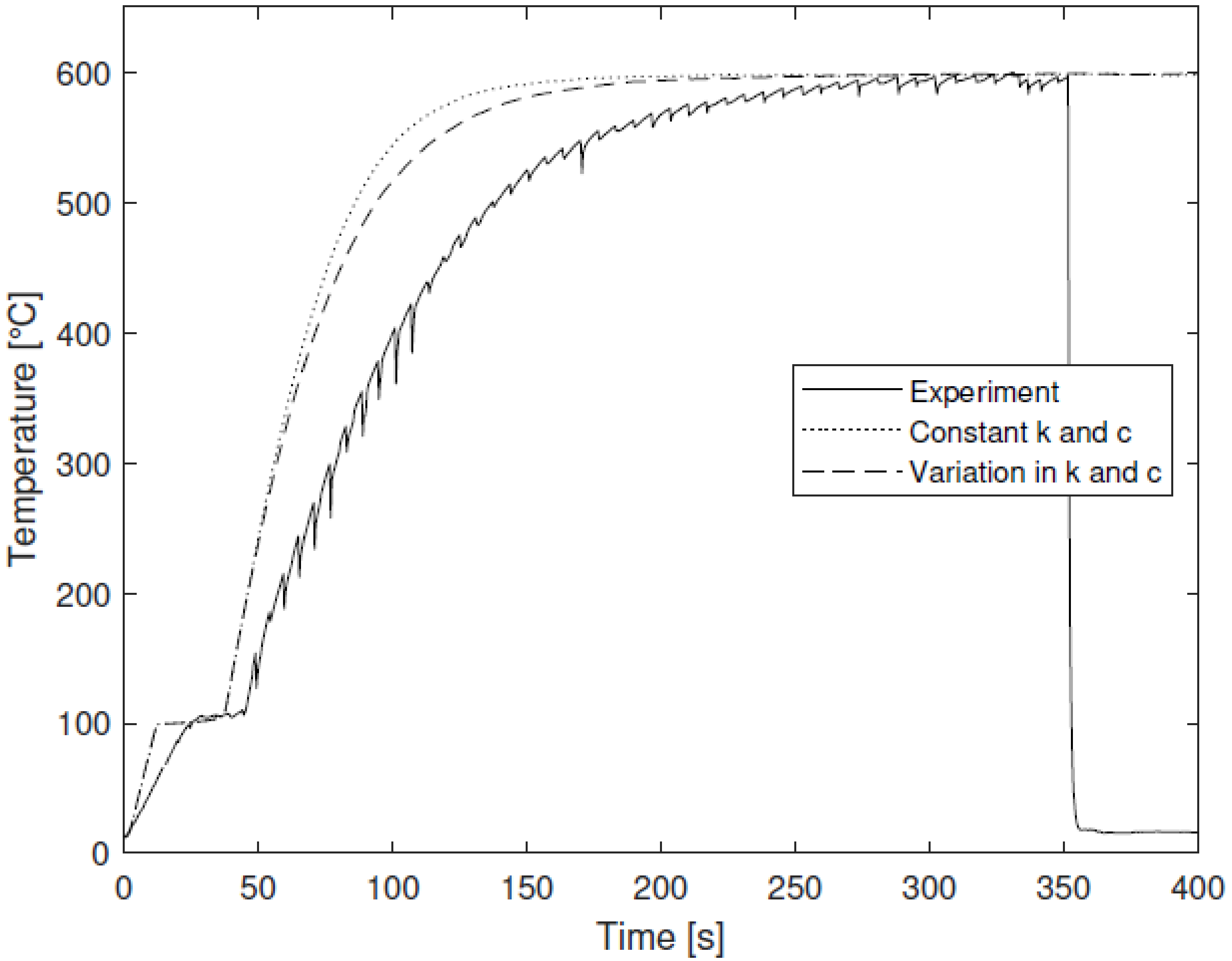


Figure 4.4: Difference in wall temperature of cooled side steel plate with and without a variation in conductivity and specific heat

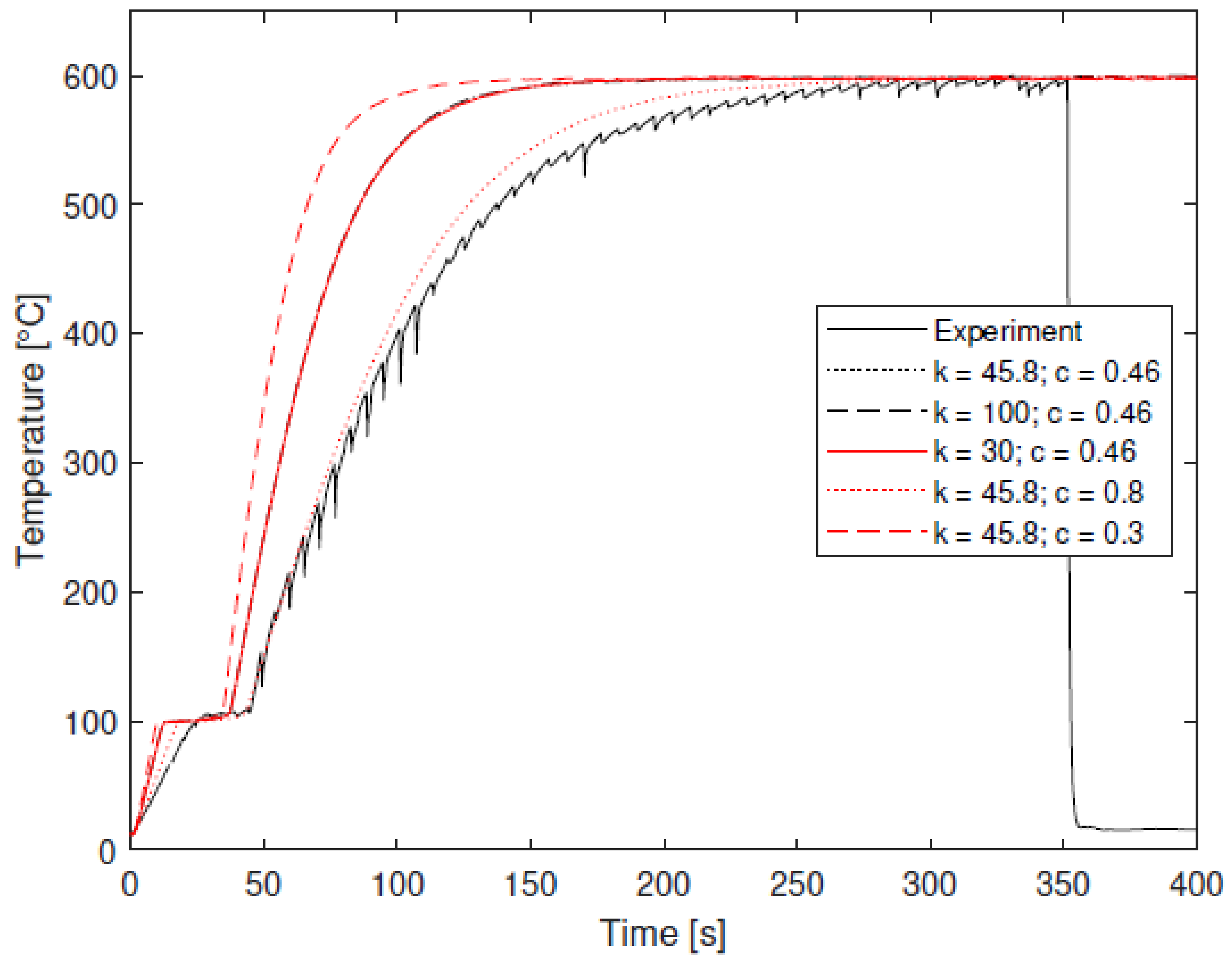


Figure 4.5: Different conductivity and specific heat simulations [k in W/(m.K) and c in kJ/(kg.K)]

Table 4.1: Times for the cooled side to reach ambient temperature and cooling rates

	Simulation					Experiment
	Poly-disperse			Mono-disperse		
HTC (W/(m².K))	300	20 000	-1	20 000	-1	4.17
Δt (s)	88.8	5.40	2.40	6.00	2.40	4
Average cooling rate (°C/s)	6.59	108	245	97.6	245	144
CPU time (s)	196300	229300	249600	201900	210000	

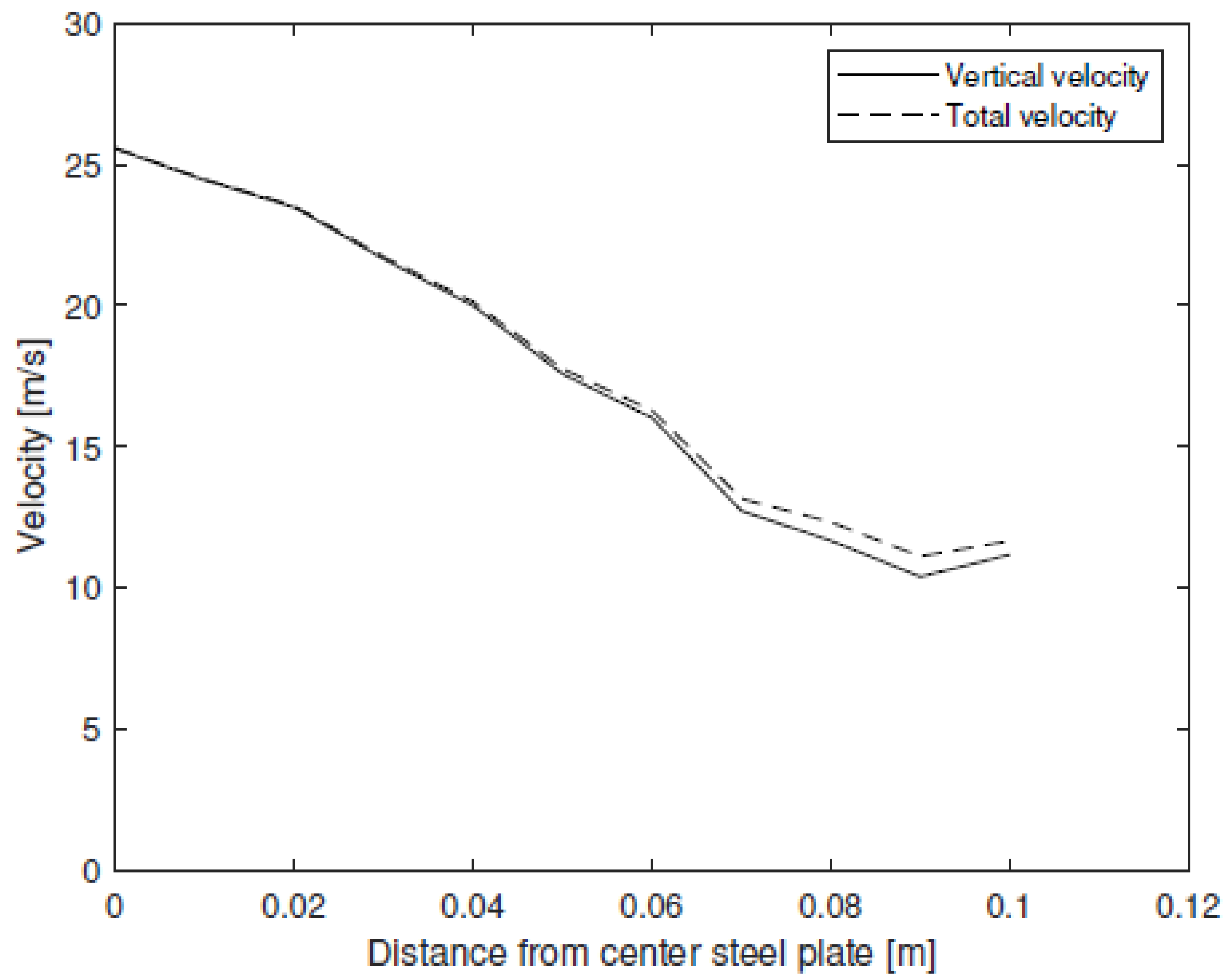


Figure 4.22: Average velocity at different distances from the center (HTC = 20 000 W/(m².K))

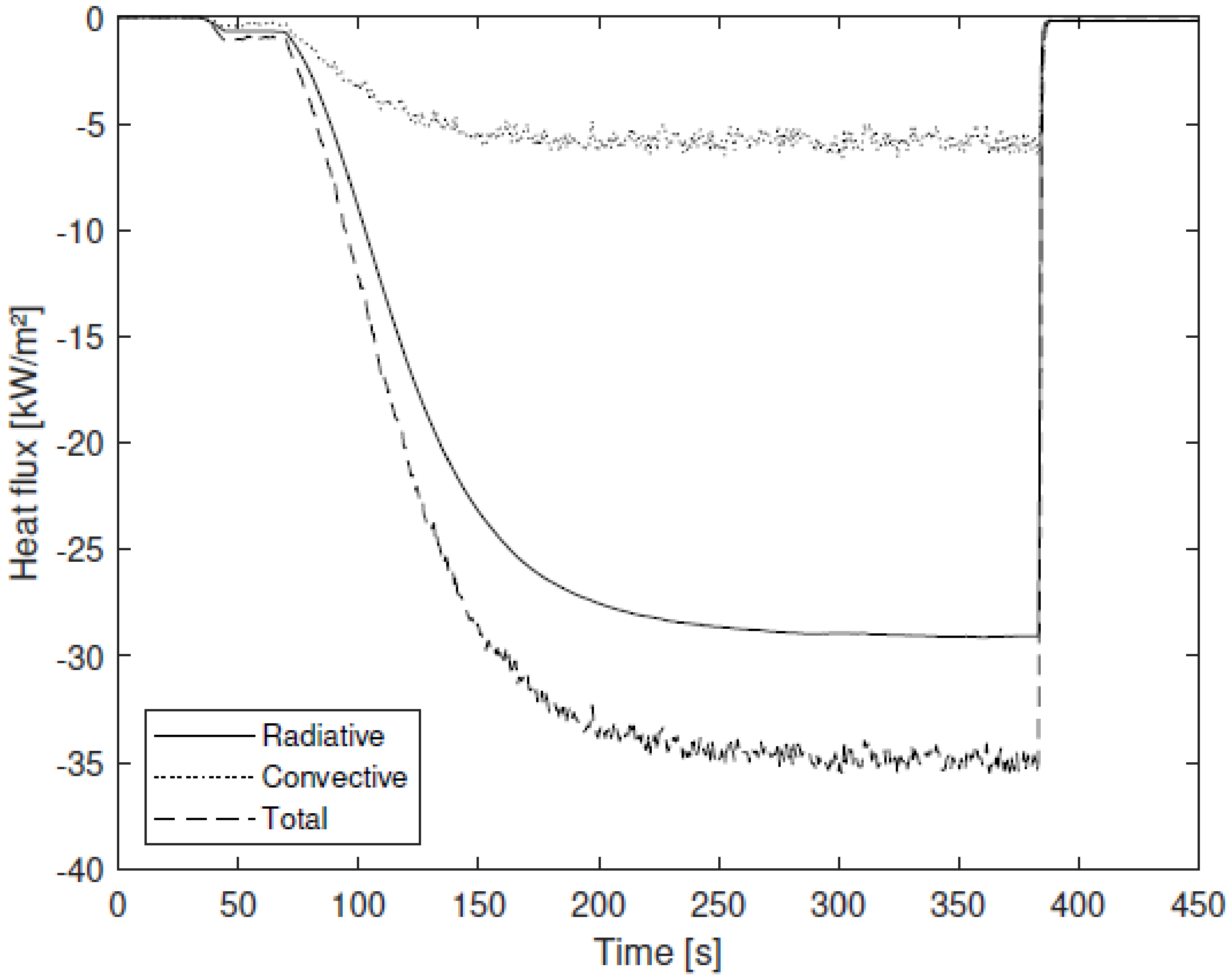


Figure 4.24: Heat fluxes at the cool side of the steel plate (HTC = 20 000 W/(m².K))

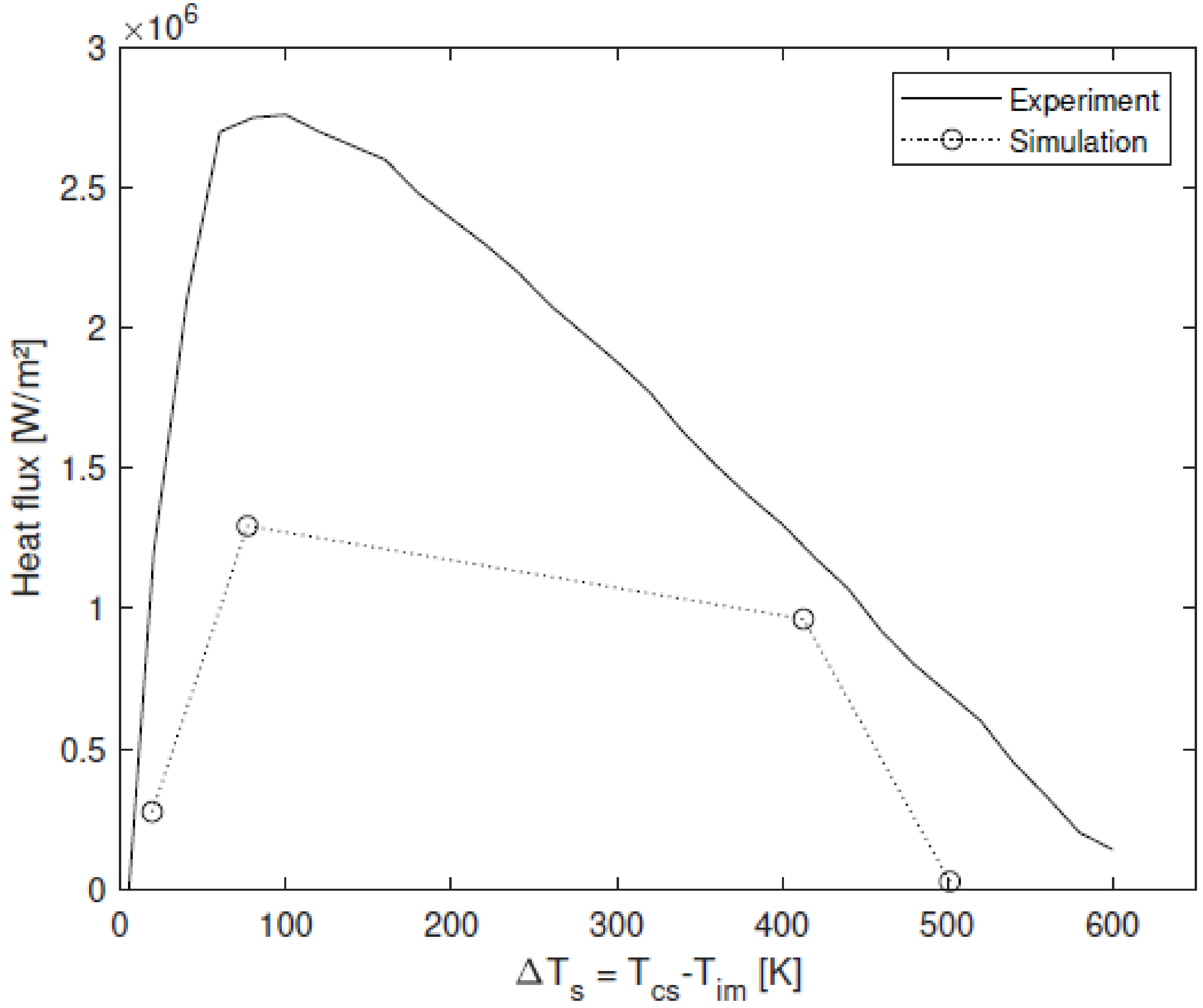


Figure 4.30: Boiling curve experiment vs simulation