



THE UNIVERSITY *of* EDINBURGH  
School of Engineering

# **Timber updates from Edinburgh**

**Angus Law MEng PhD CEng MIFireE RPEQ**

Senior Lecturer in Fire Safety Engineering

The University of Edinburgh



**Requirement B1: Means of warning and escape**

**Requirement B2: Internal fire spread (linings)**

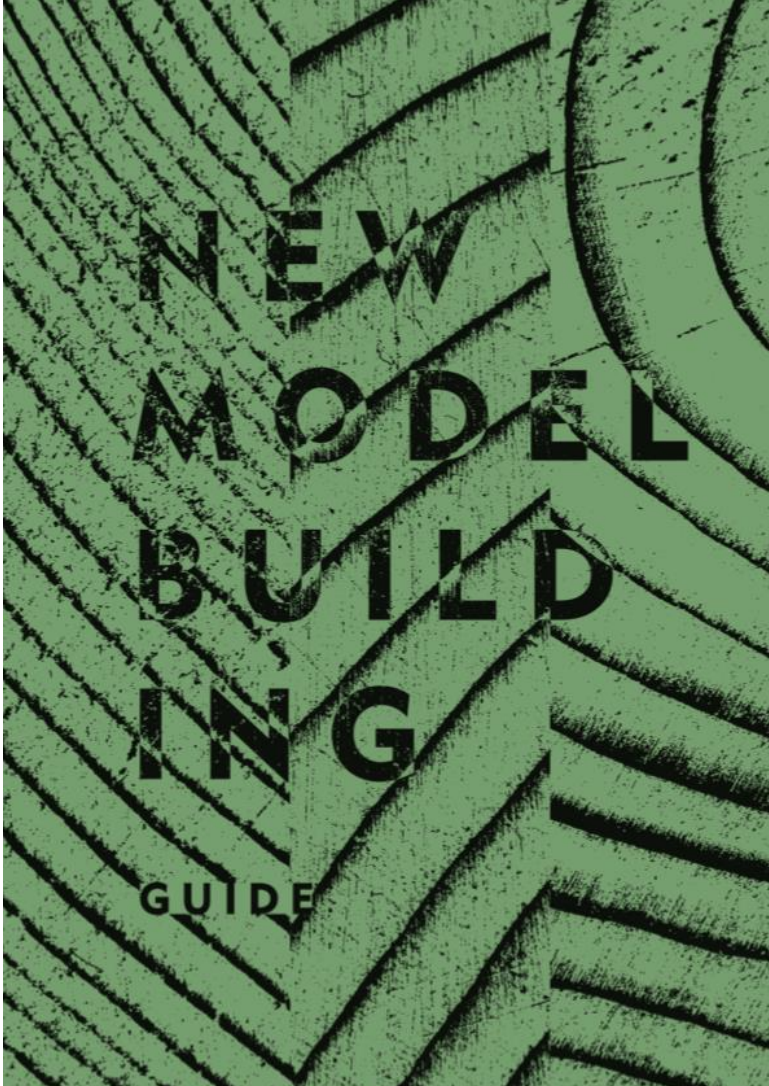
**Requirement B3: Internal fire spread (structure)**

**Requirement B4: External fire spread**

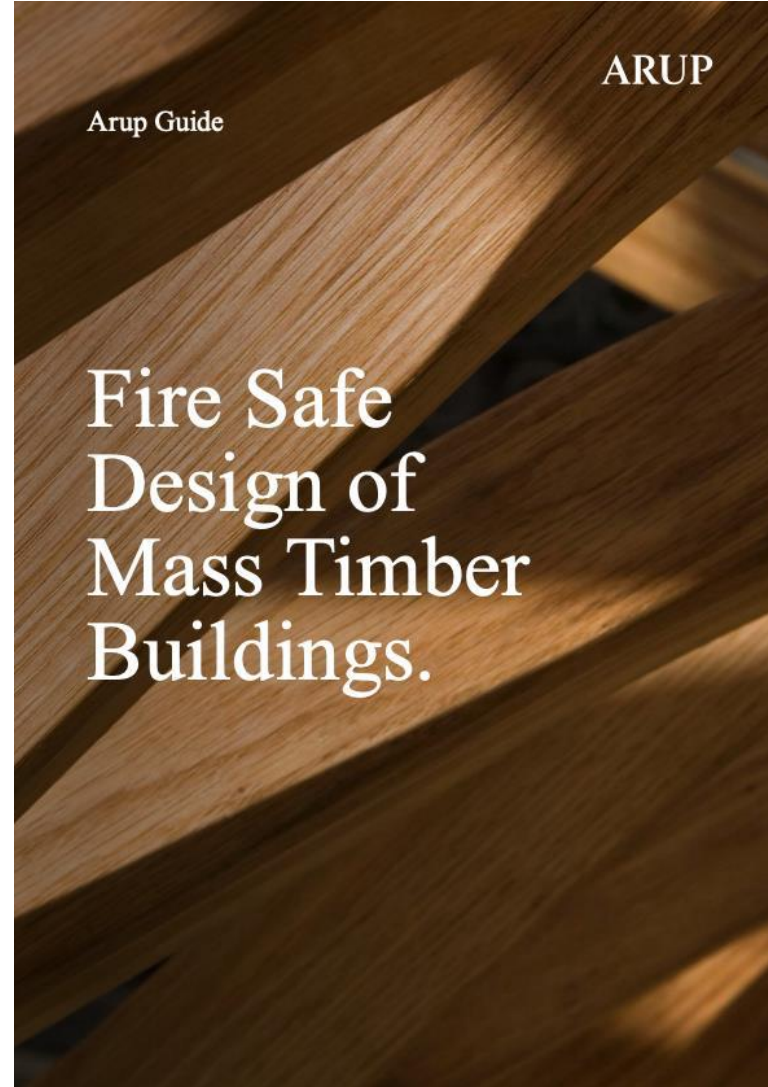
**Requirement B5: Access and facilities for the fire service**

**Regulations: 6(3), 7(2) and 38**

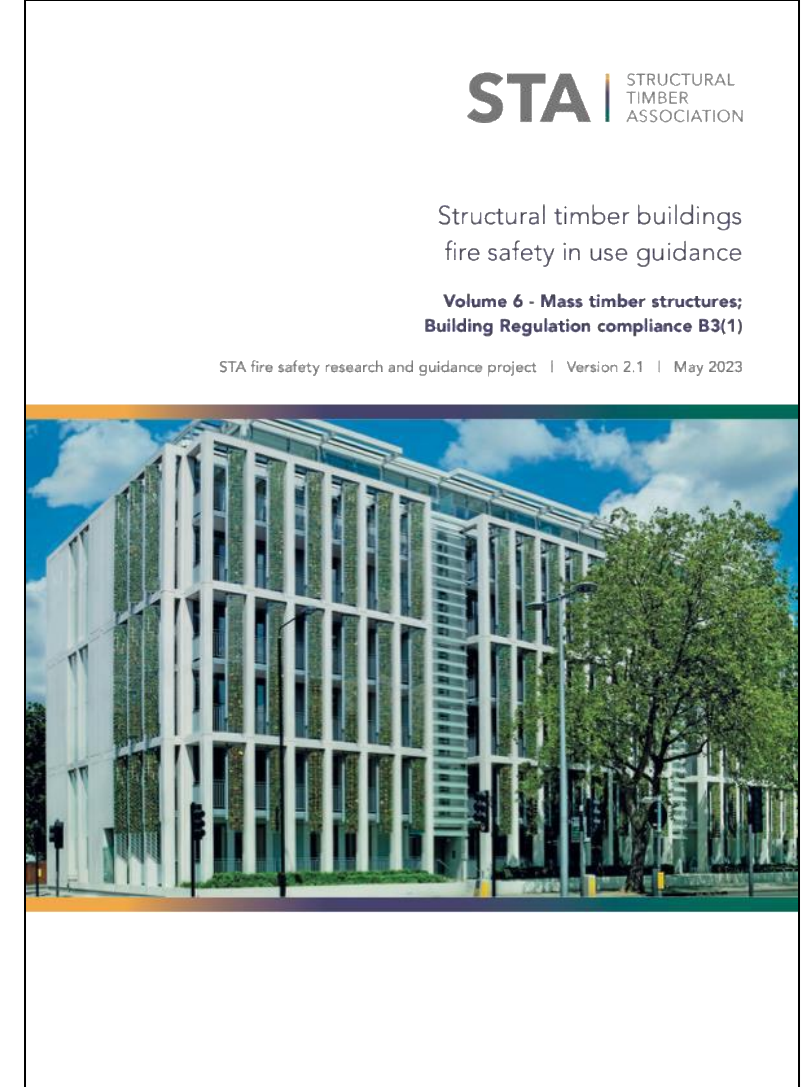
# Industry have been busy.



<https://timberdevelopment.uk/resources/new-model-building-guide/>



<https://www.arup.com/insights/fire-safe-design-of-mass-timber-buildings/>



<https://www.structuraltimber.co.uk/libraries/technical-documents/>



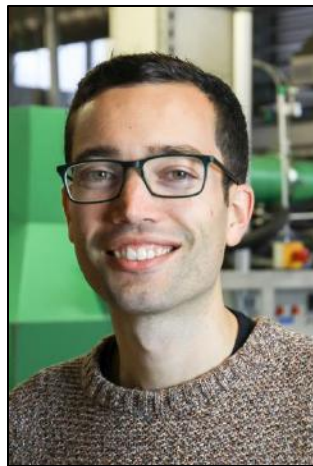
# We have also been busy!



Ali Ahmed  
Awadallah



Luke  
Bisby



Zak Campbell-  
Lochrie



Antonela  
Colic



Swagata  
Dutta



James  
Greer



Rory  
Hadden



Angus  
Law



Cameron  
MacLeod



David  
Morrisset



Mark  
Partington



Ian  
Pope



Laura  
Schmidt

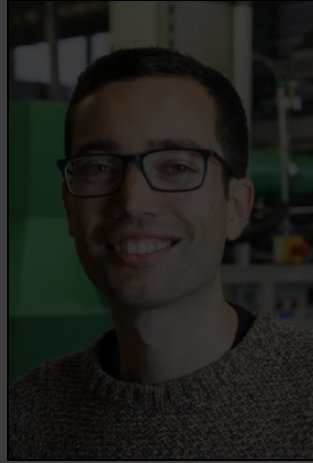
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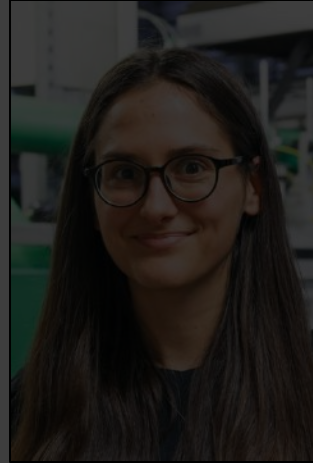
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Awadallah



Luke  
Bisby



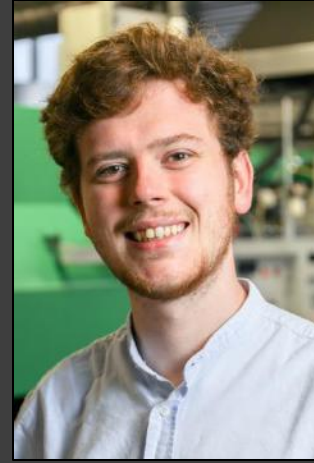
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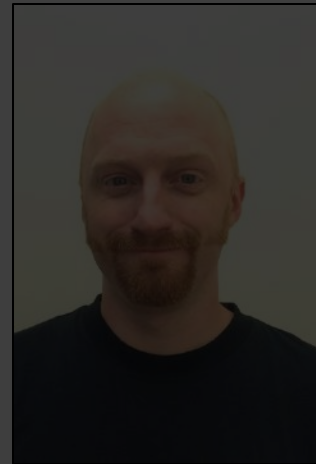
Angus  
Law



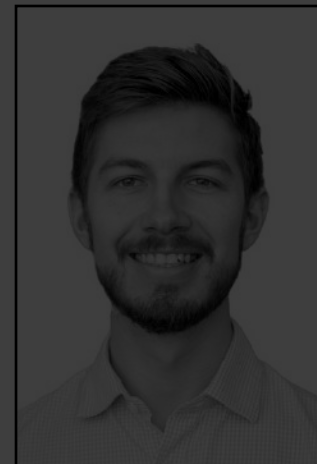
Cameron  
MacLeod



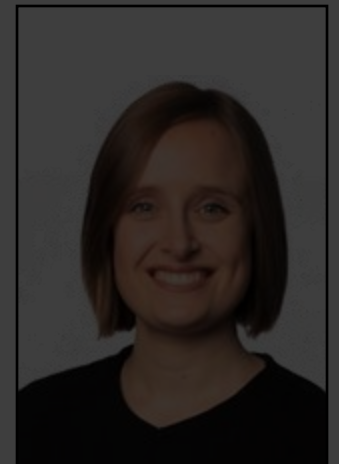
David  
Morrisset



Mark  
Partington



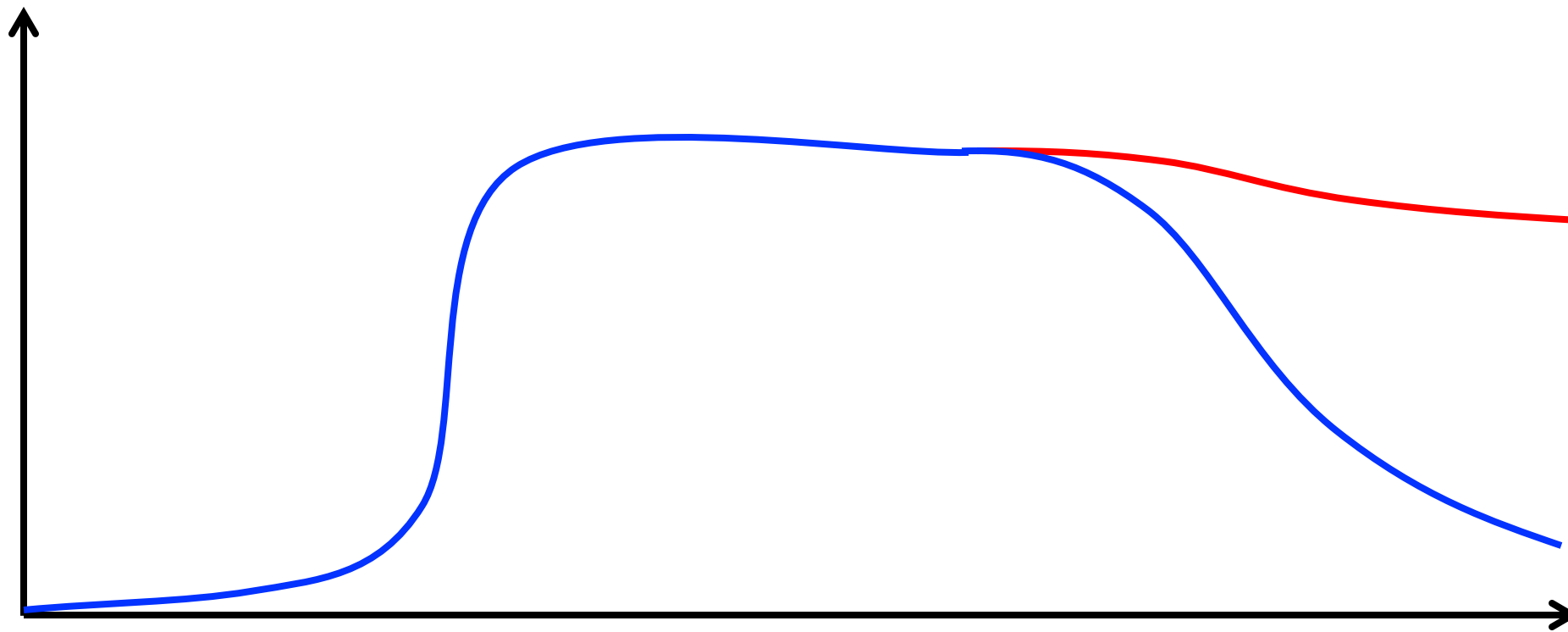
Ian  
Pope



Laura  
Schmidt

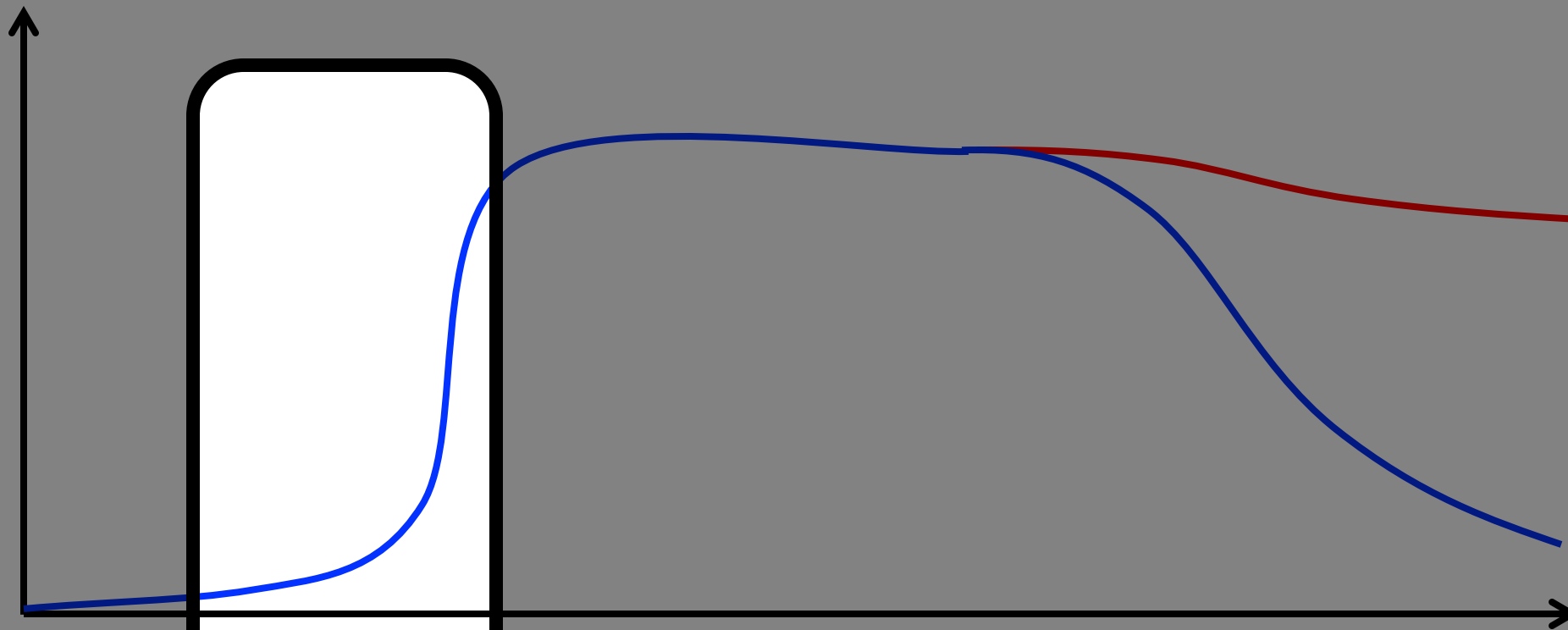
Why should we care?!

Fire size



Time

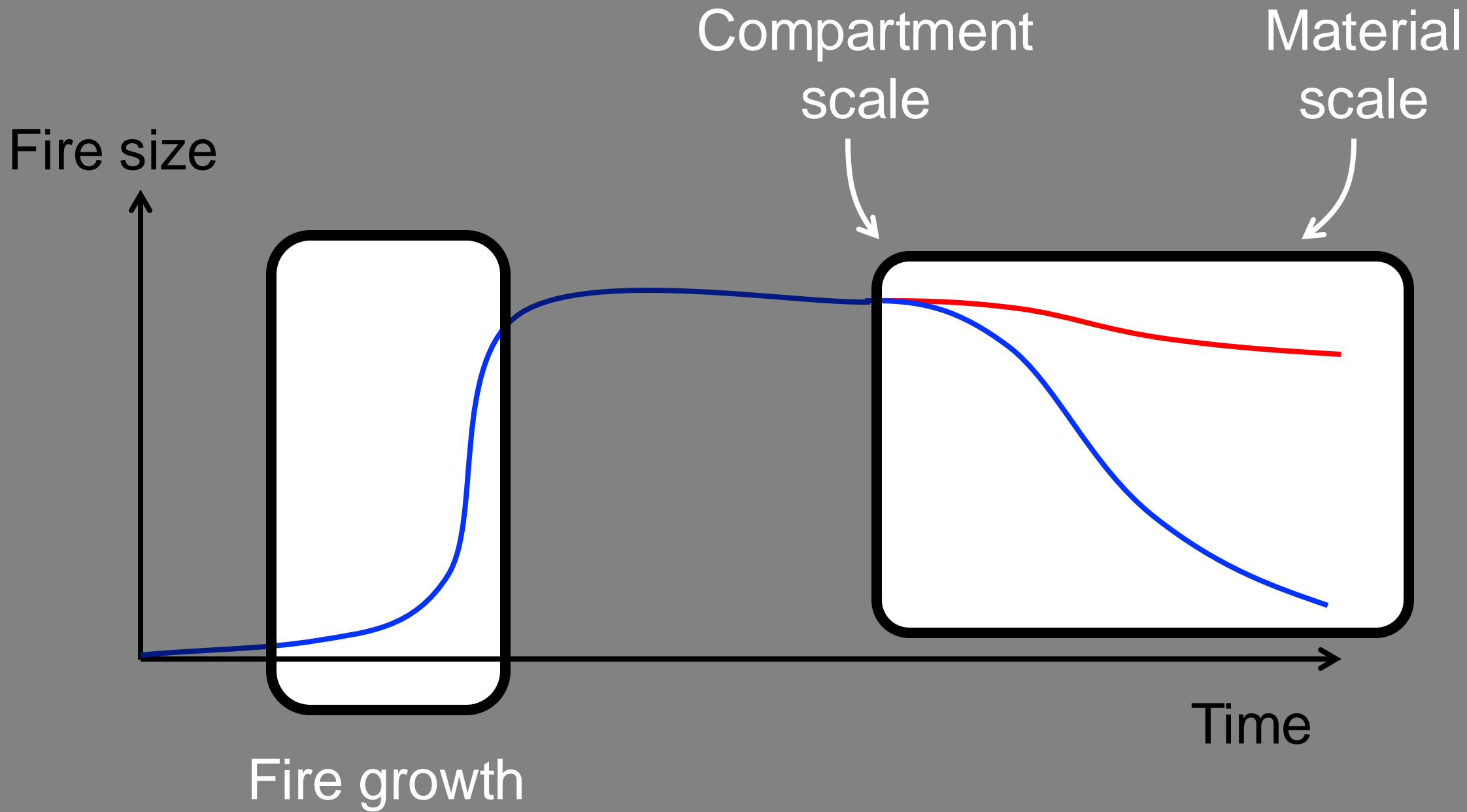
Fire size

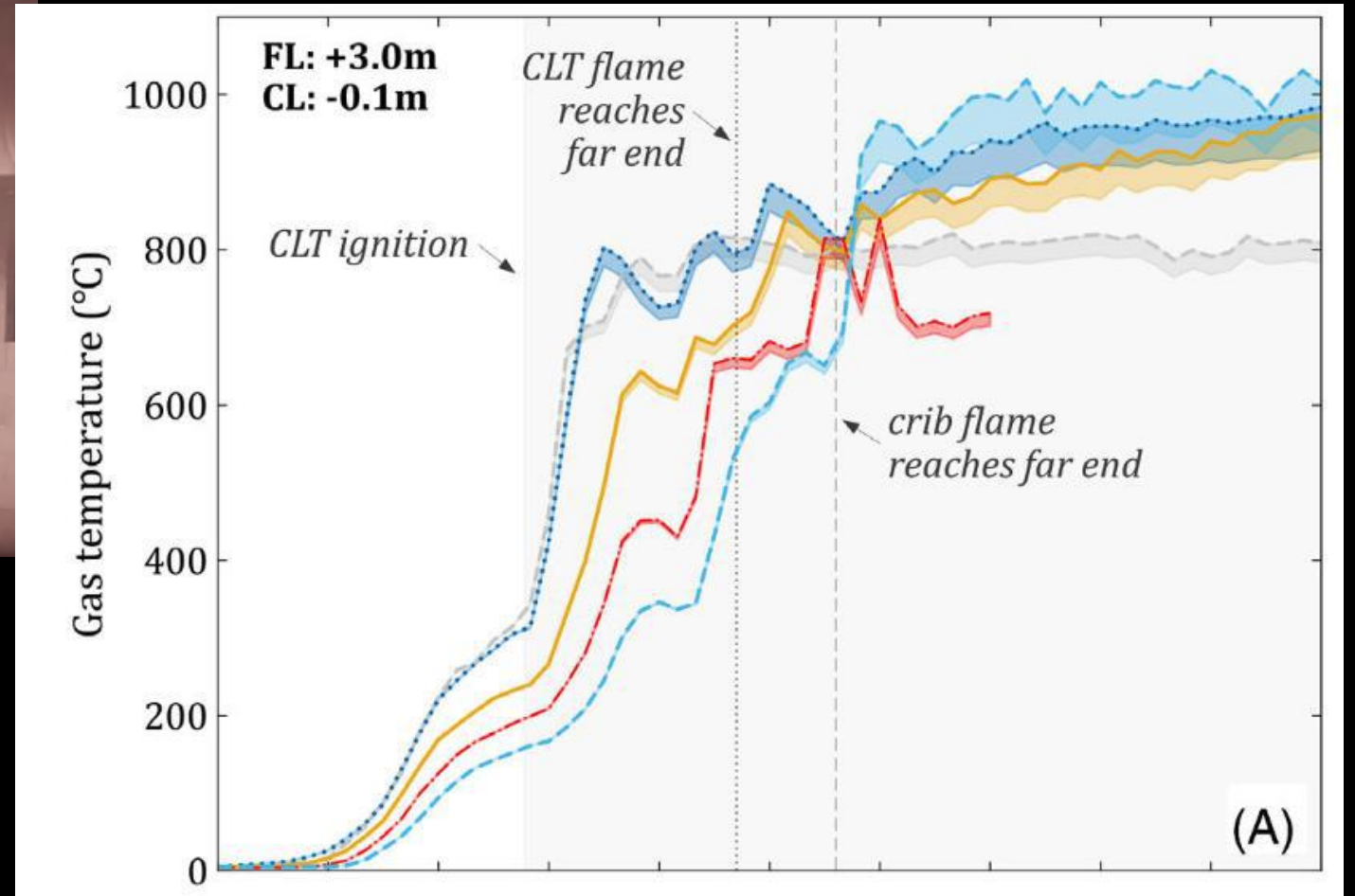
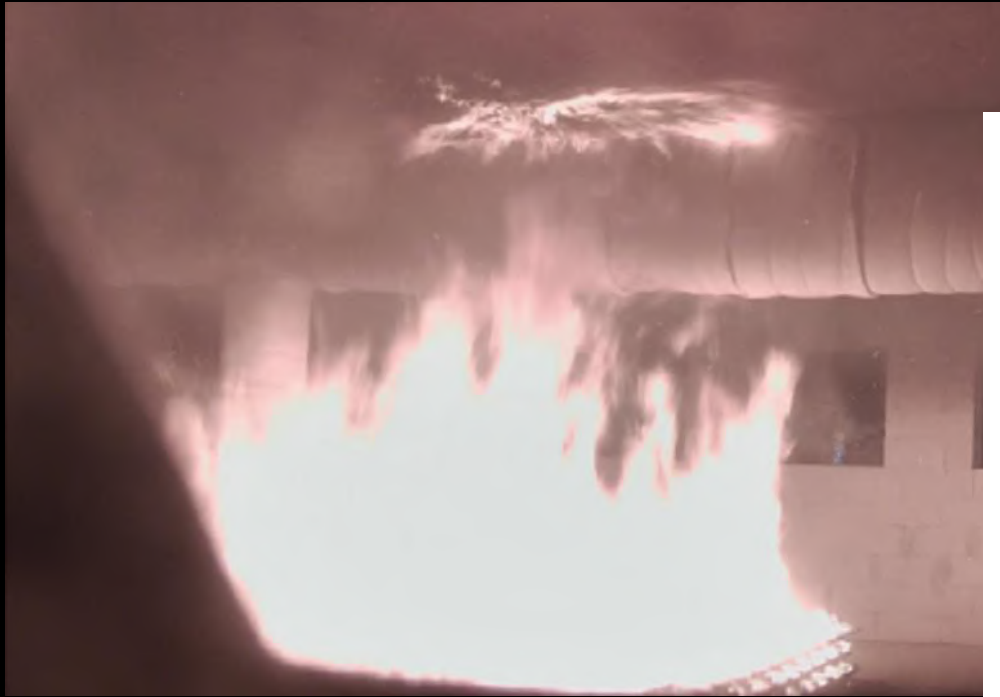


Fire growth

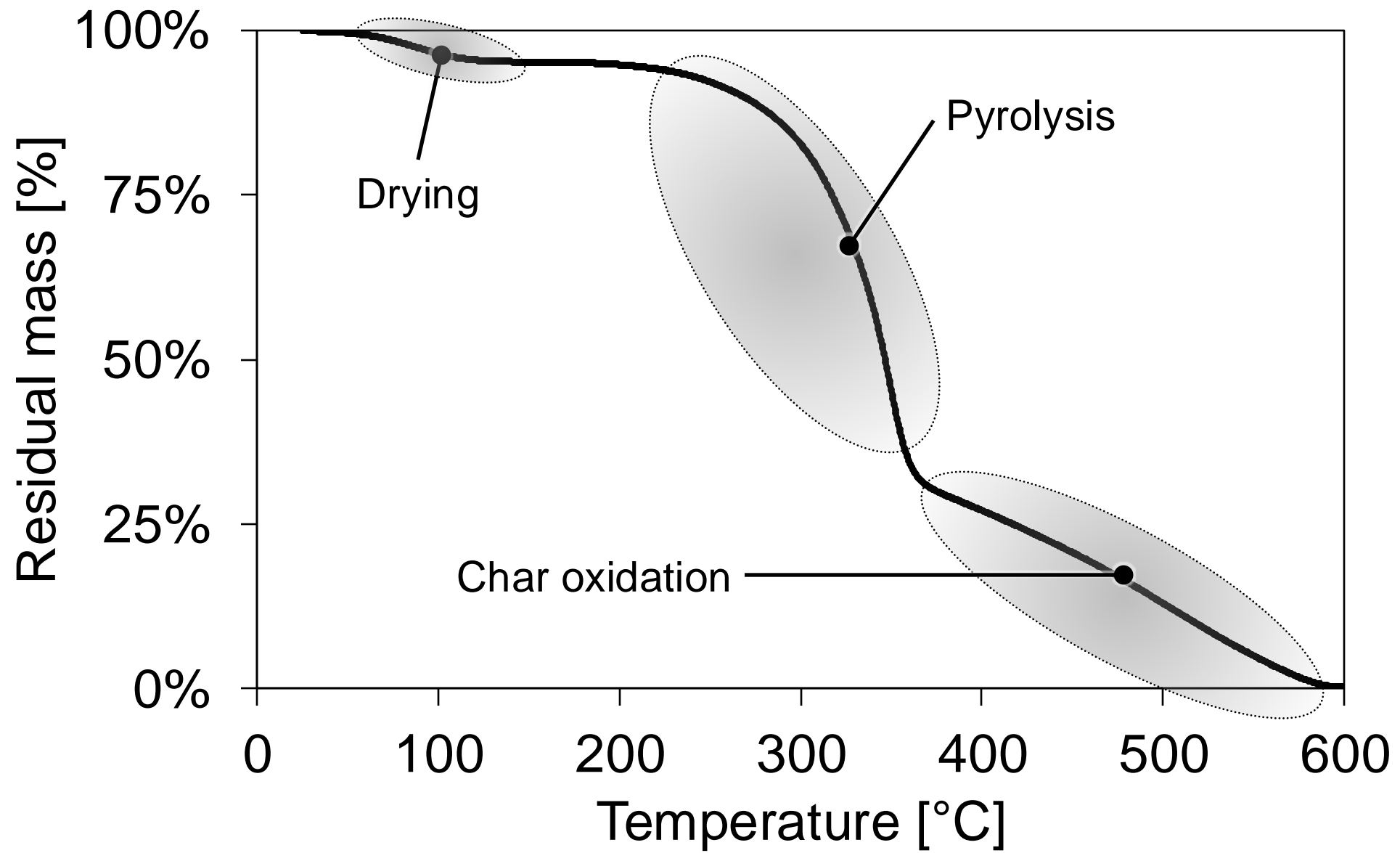
Time







Kotsovinos P, Rackauskaite E, Christensen E, et al. Fire dynamics inside a large and open-plan compartment with exposed timber ceiling and columns: *CodeRed #01*. *Fire and Materials*. 2023; 47(4): 542-568. doi:[10.1002/fam.3049](https://doi.org/10.1002/fam.3049)





An Introduction to

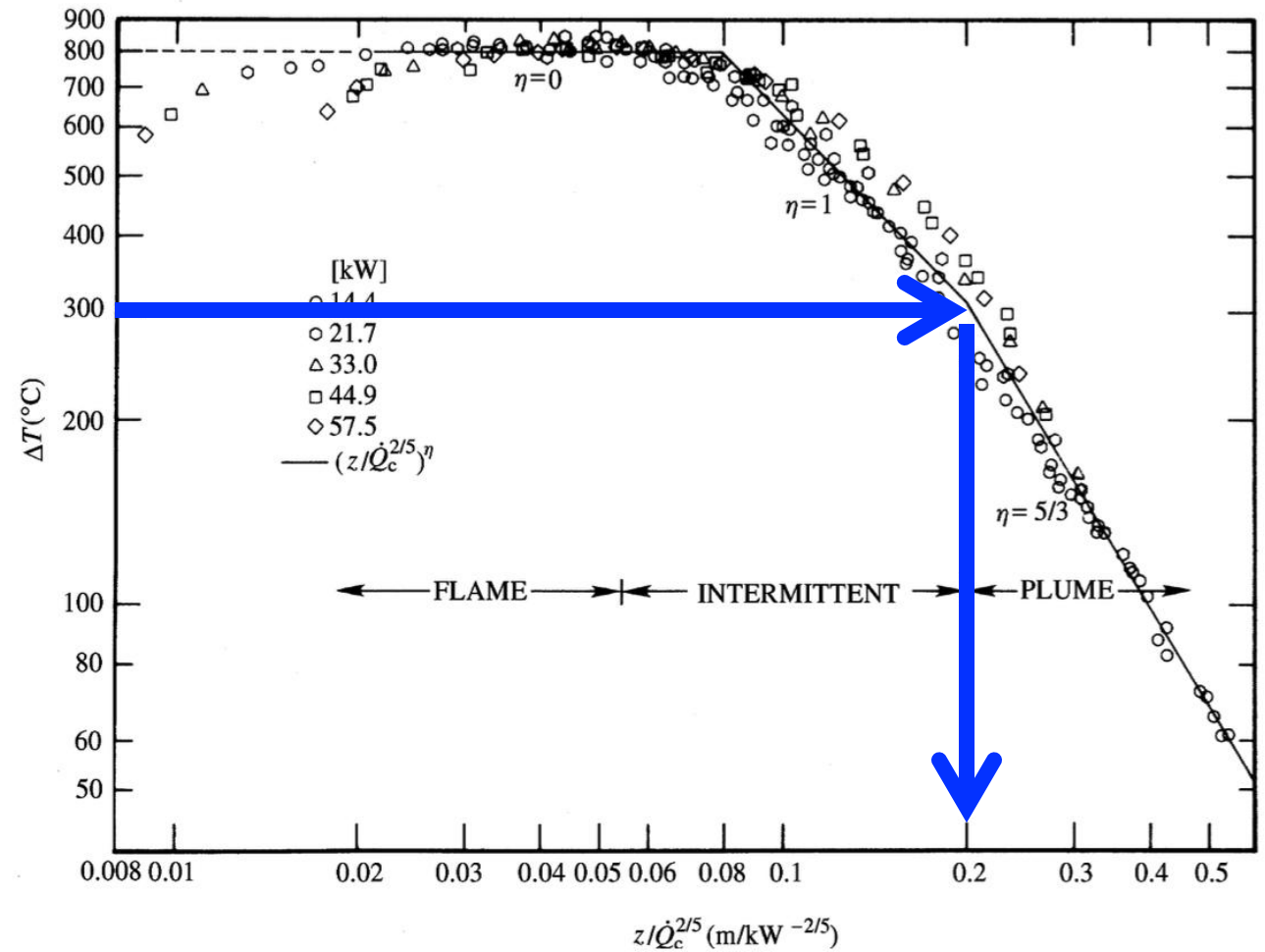
# FIRE DYNAMICS

Third Edition



Dougal Drysdale

 WILEY





Timber ceiling

Inert walls

Inert walls

Inert walls

Timber floor



t = 60 s

t = 120 s

t = 360 s

Exp. 2

NI

$A = 56.3 \text{ cm}^3$

$\dot{Q} = 1.9 \text{ kW}$



Exp. 7

FS

Slow Ign.

$A = 100 \text{ cm}^3$

$\dot{Q} = 3.0 \text{ kW}$



Exp. 12

FS

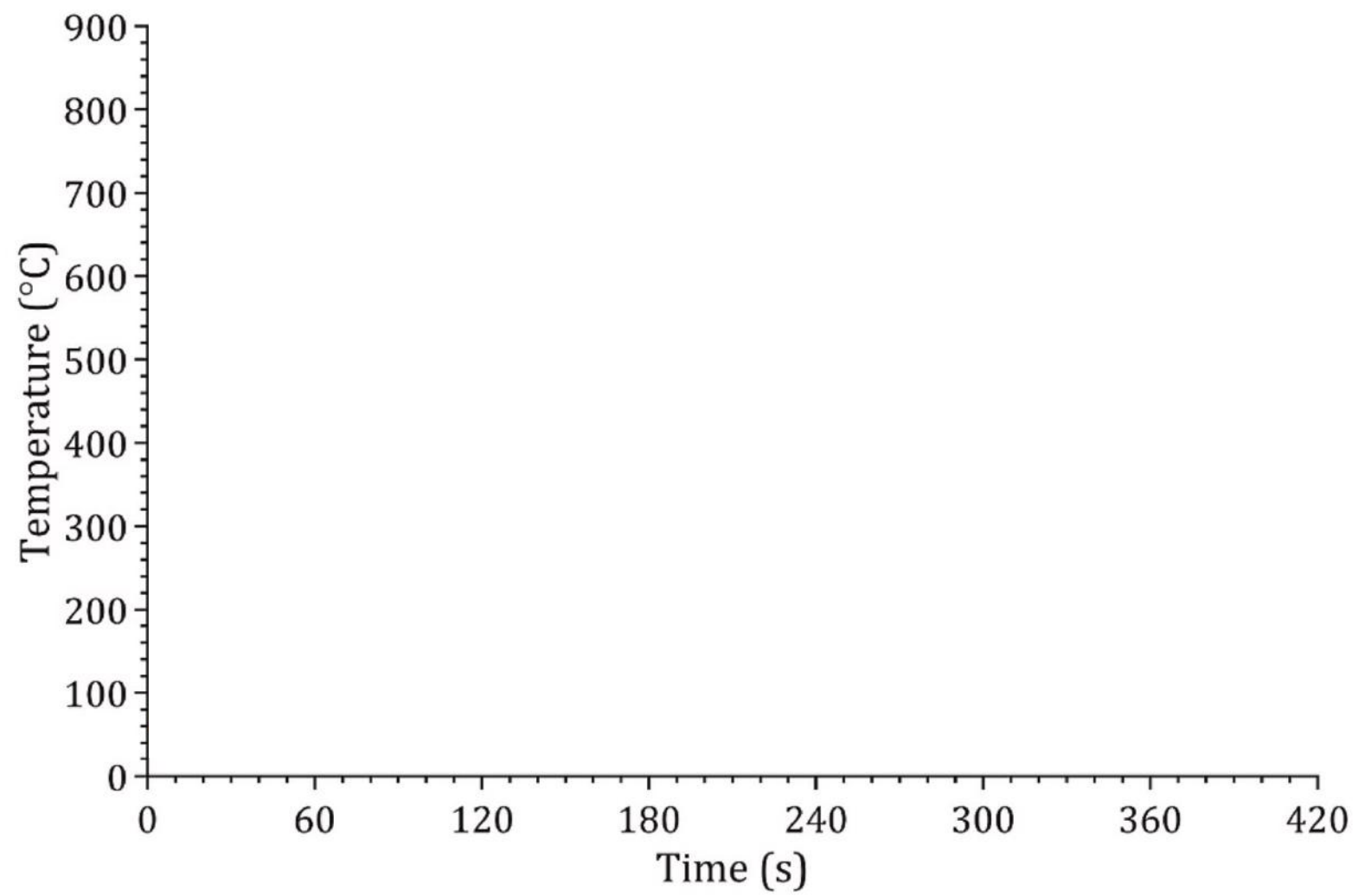
Rapid Ign.

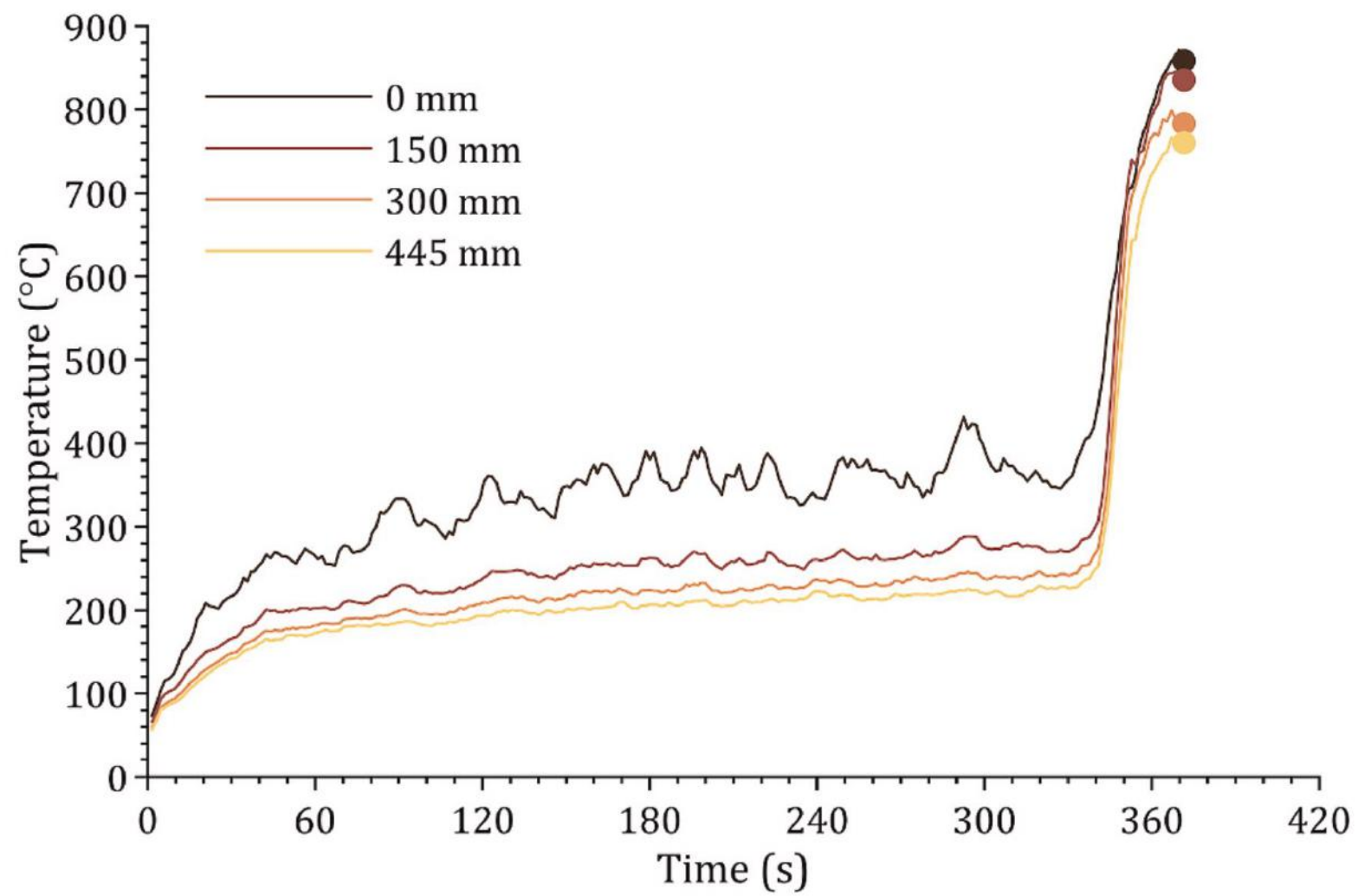
$A = 154 \text{ cm}^3$

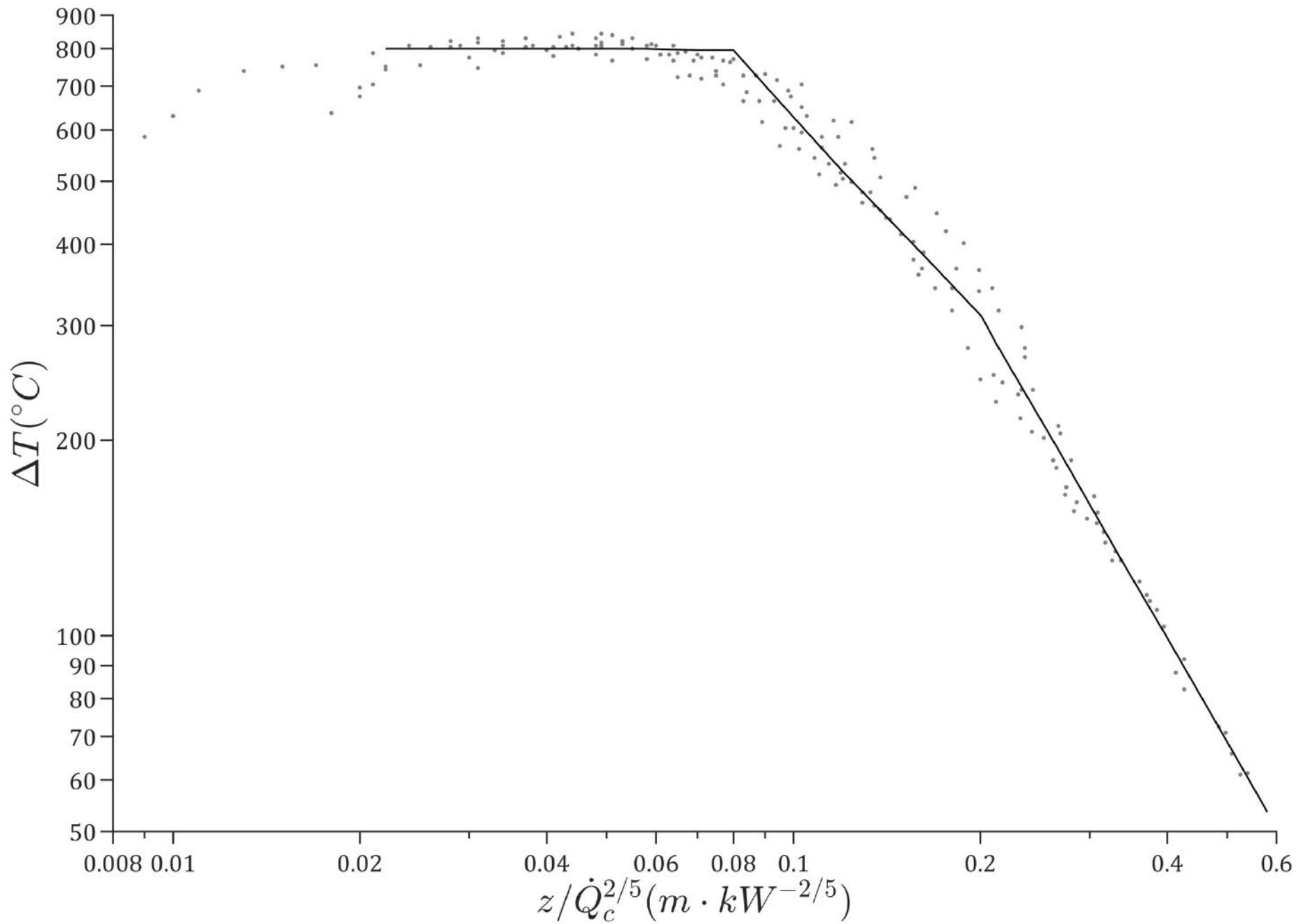
$\dot{Q} = 4.7 \text{ kW}$



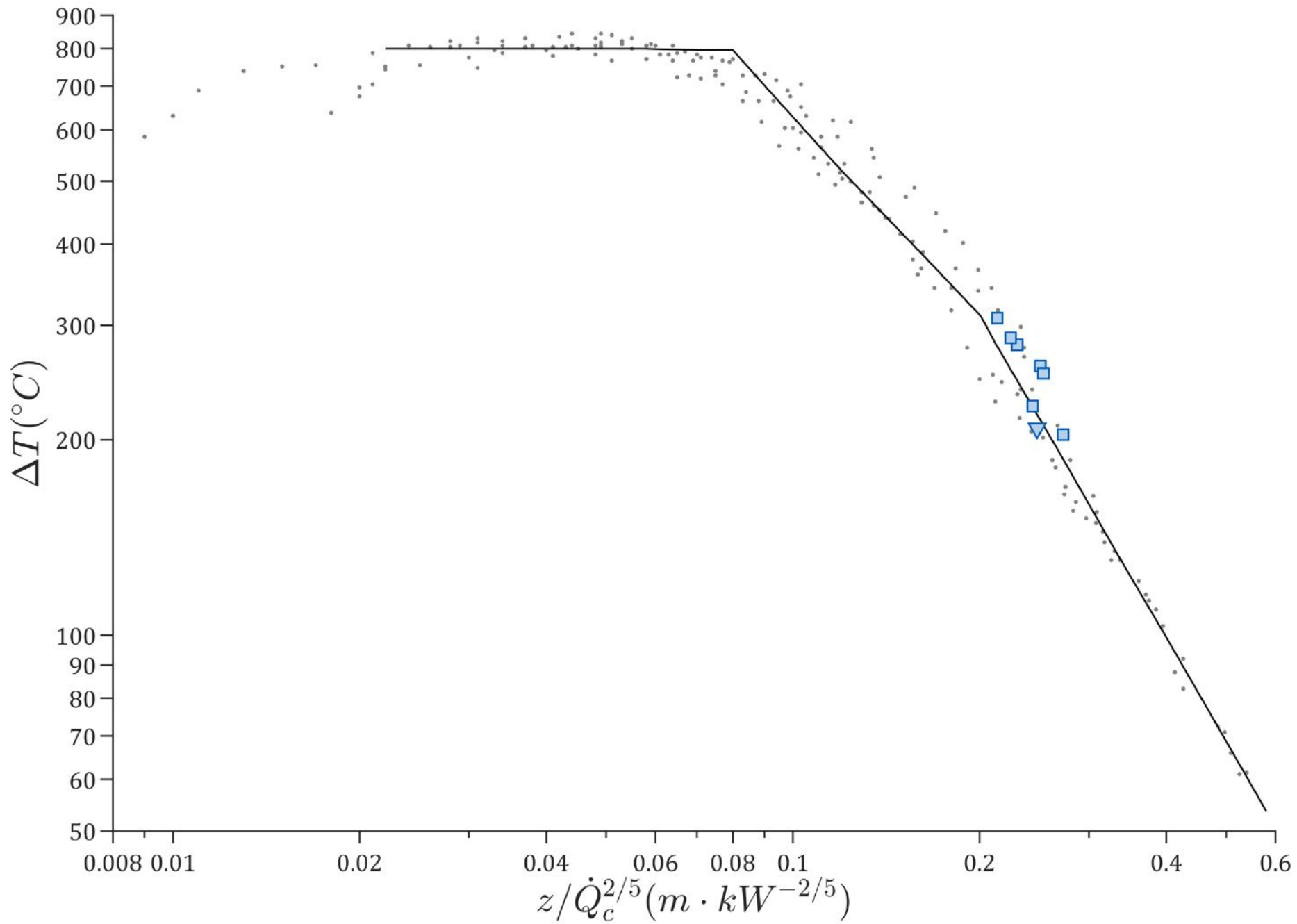


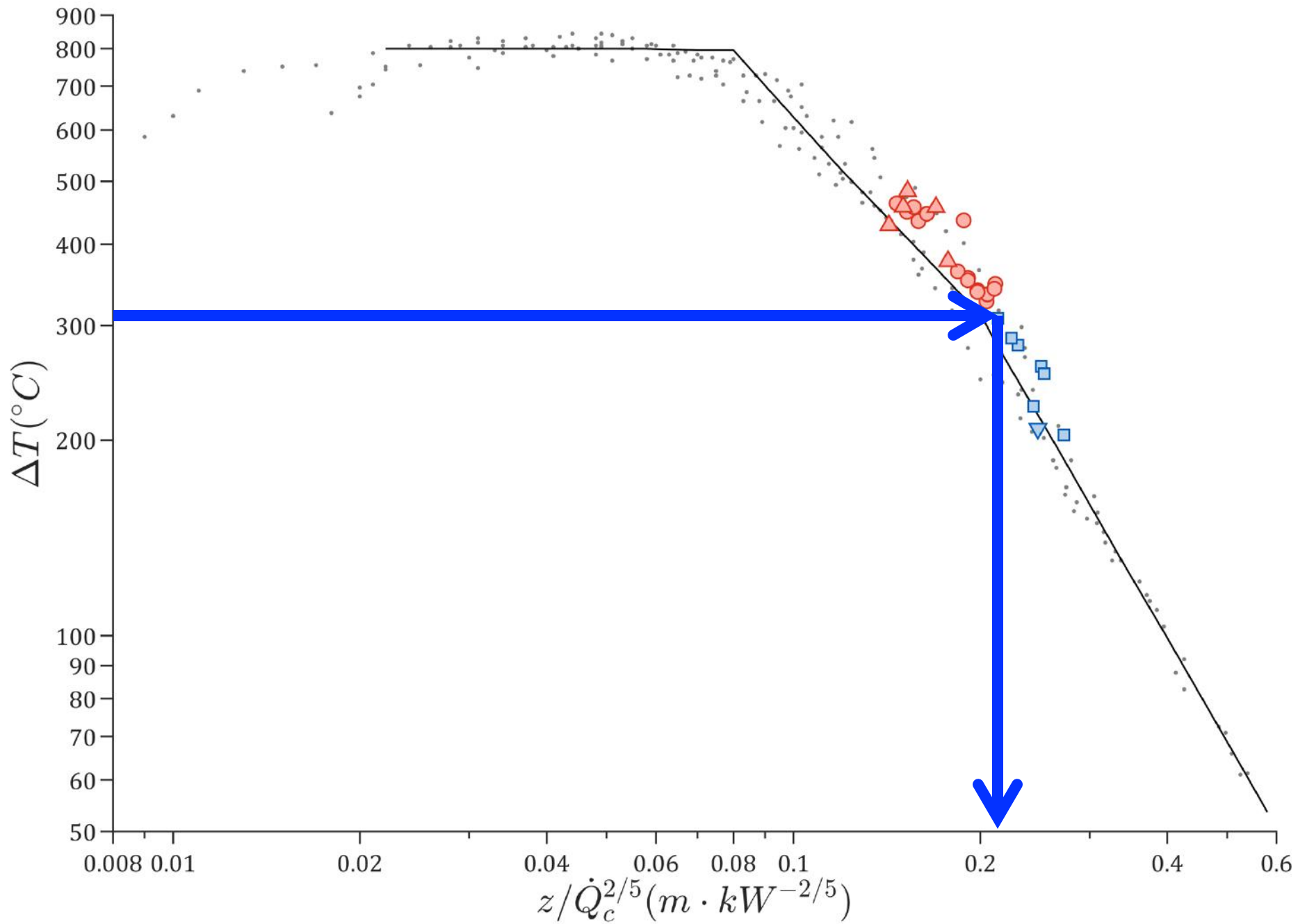












### 6.9.3 Calculation of flame height

The larger the flame or the surface that is radiating heat, the larger will be the total heat that is emitted. This implies that larger flames give larger values of  $\phi$ . Therefore, the estimation of flame heights is a crucial part of the calculation process.

For most fires away from walls, the plume can be considered to be axisymmetric. The mean flame height of luminous flames for fires is given by

$$z_f = 0.2 Q_t^{2/5} \quad (6.55)$$

where  $Q_t$  is the total heat output of the fire (kW) and  $z_f$  is the mean flame height of the luminous flame (m) (Cox and Chitty, 1980) (see Figure 6.8).

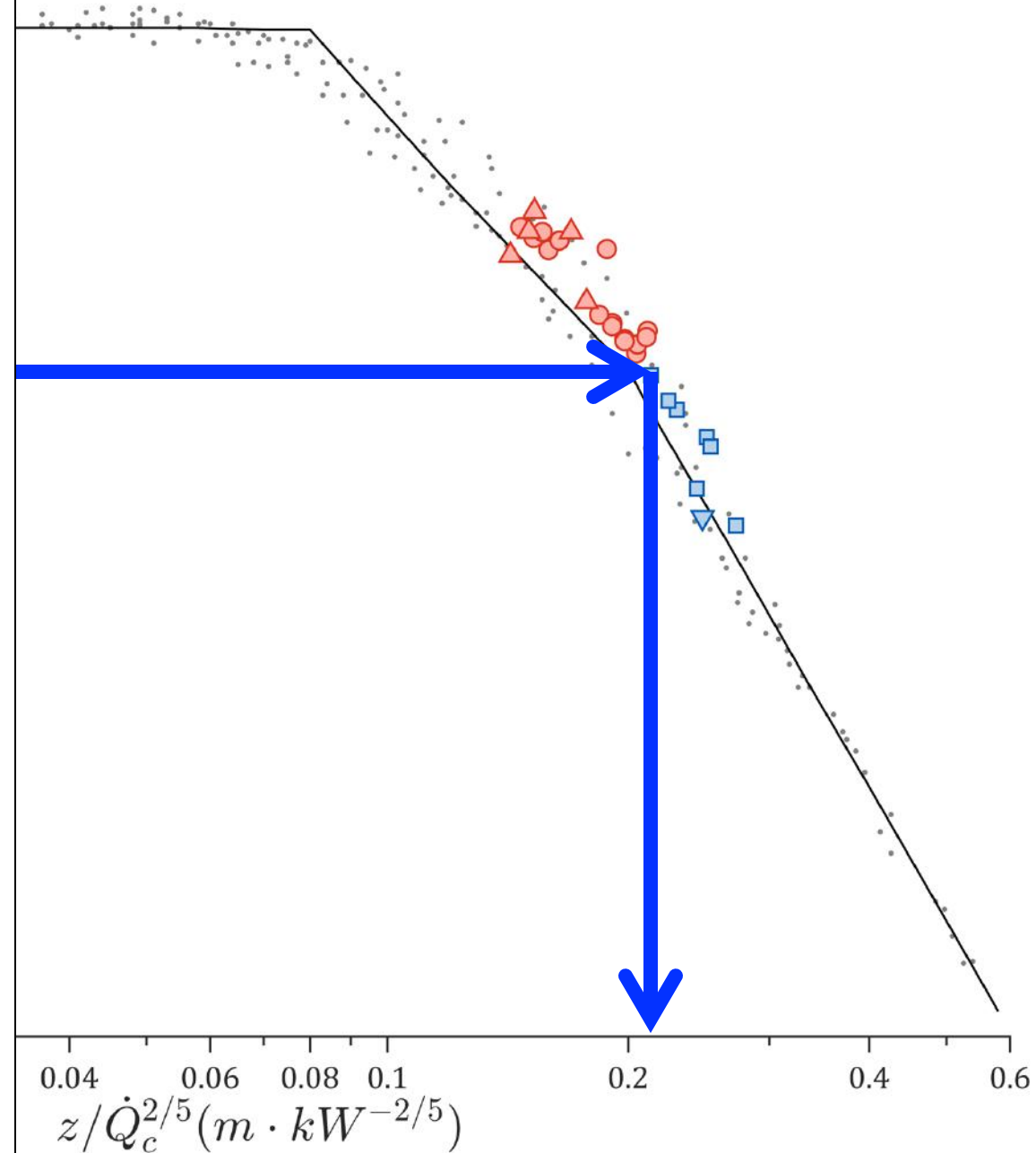
As an alternative to equation 6.55, the mean flame height is also given by

$$z_f = 0.235 Q_t^{2/5} - 1.02 D_f \quad (6.56)$$

where  $D_f$  is the fire diameter (m) (SFPE, 2016). If unknown, the fire diameter may be estimated from the heat output by assuming an average fire load density and then calculating the area of burning.

As equations 6.55 and 6.56 do not perfectly agree, the more conservative choice should be made if there is any doubt.

The above relationships do not apply to hydrocarbon fires. The calculation of such fires is complex and attention is





### 6.9.3 Calculation of flame height

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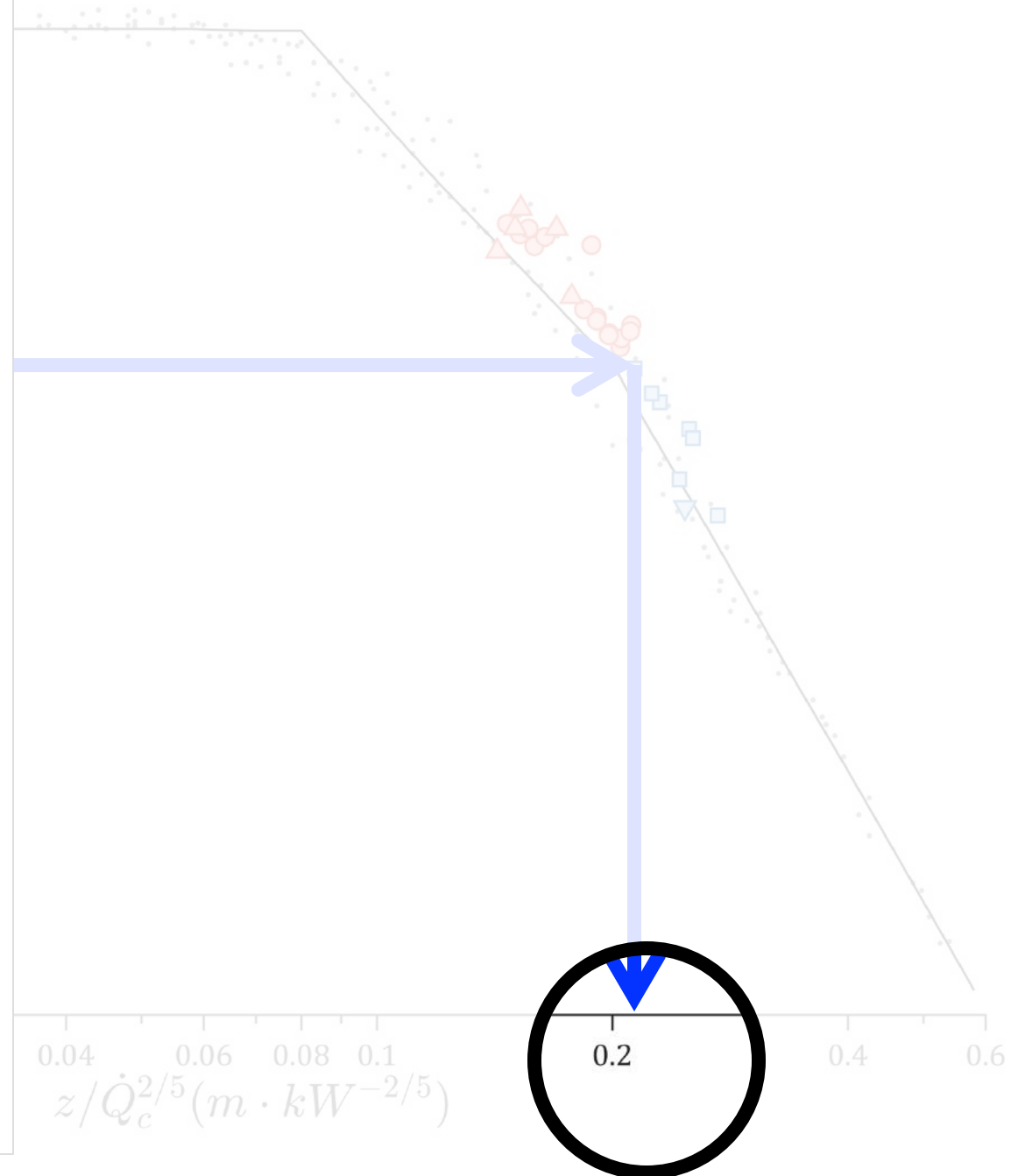
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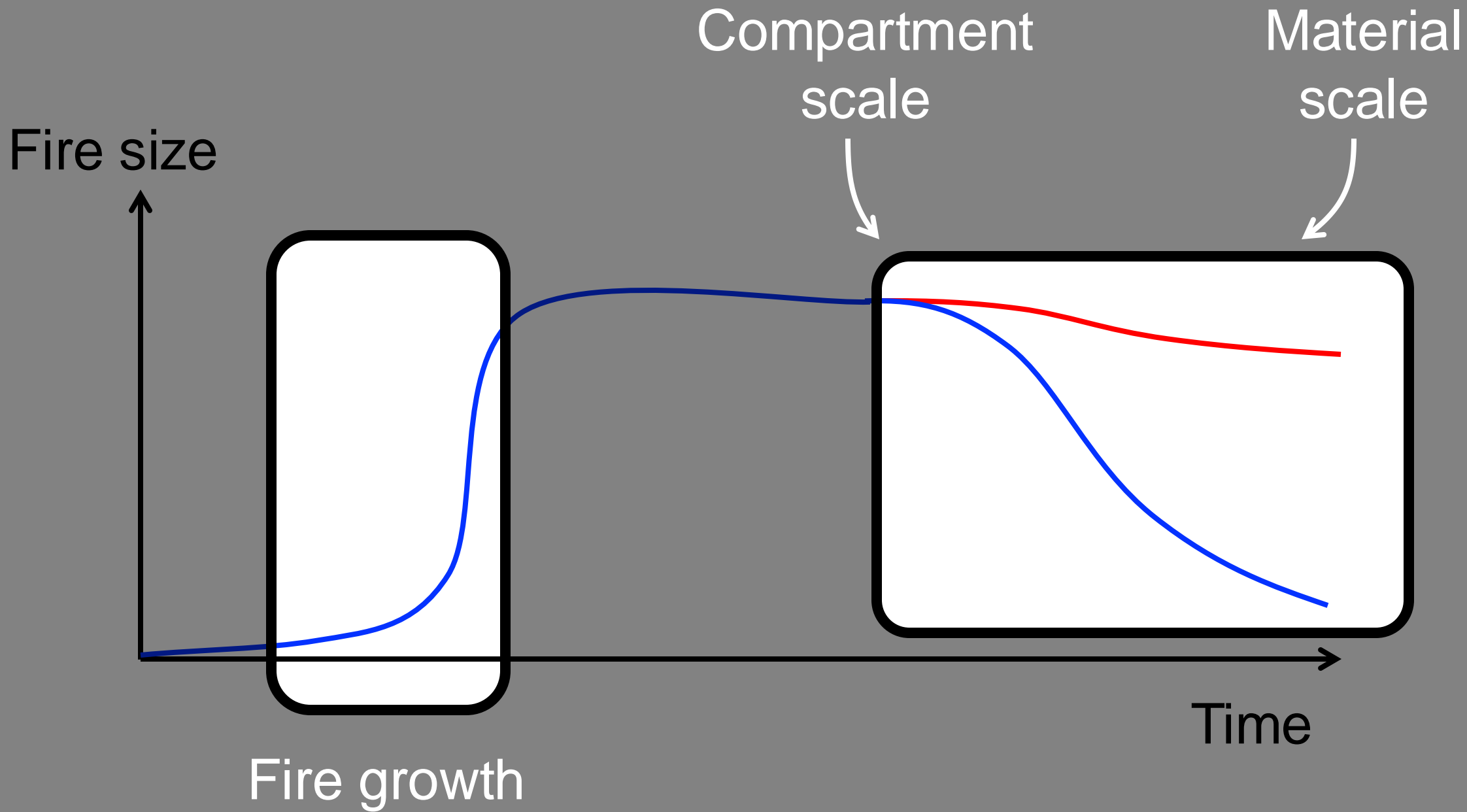
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# Problems with studying the decay phase:

Fuel takes a while to  
“burn out”

Delamination makes it  
stochastic.

Local failures of fire  
protection systems.







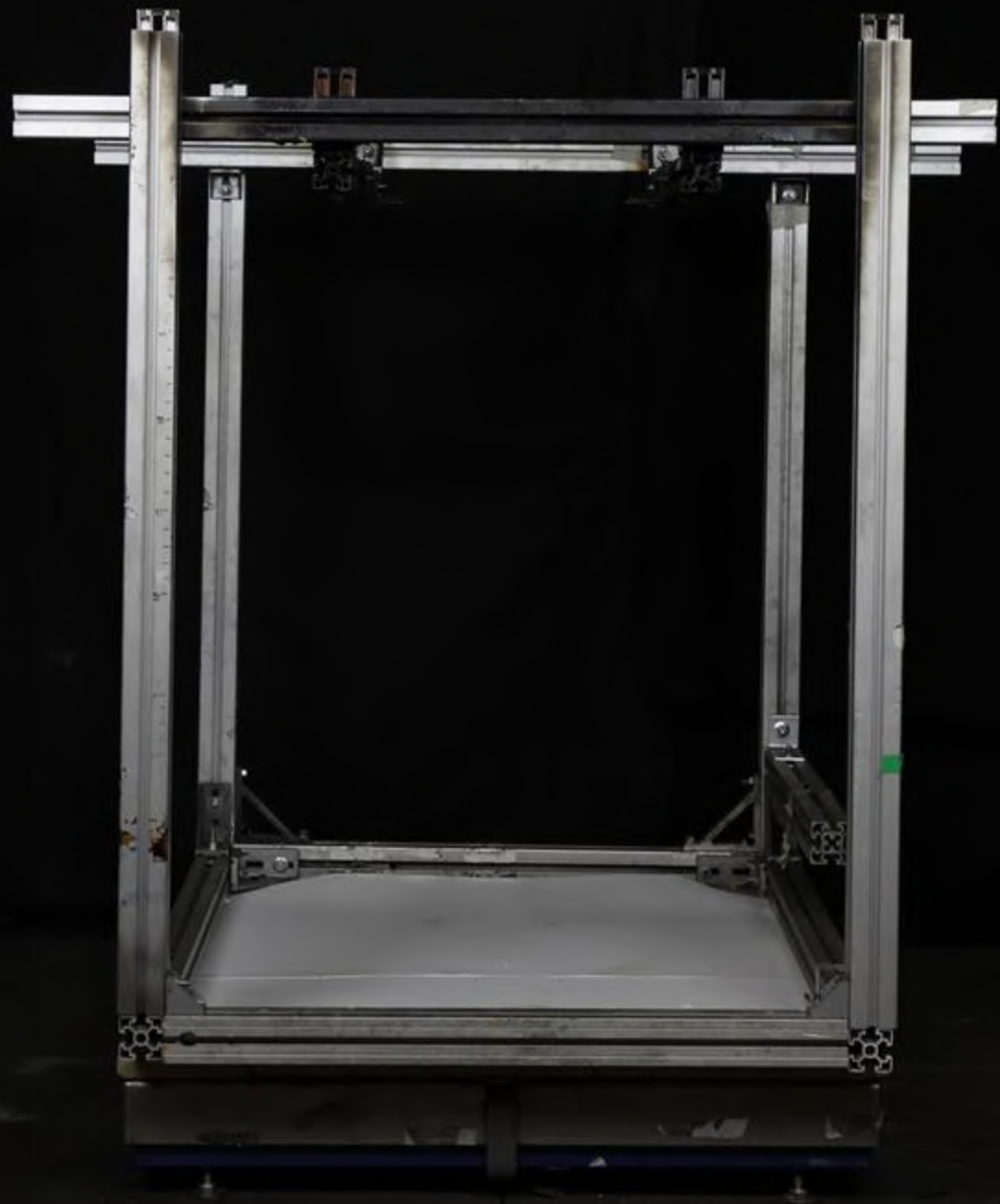


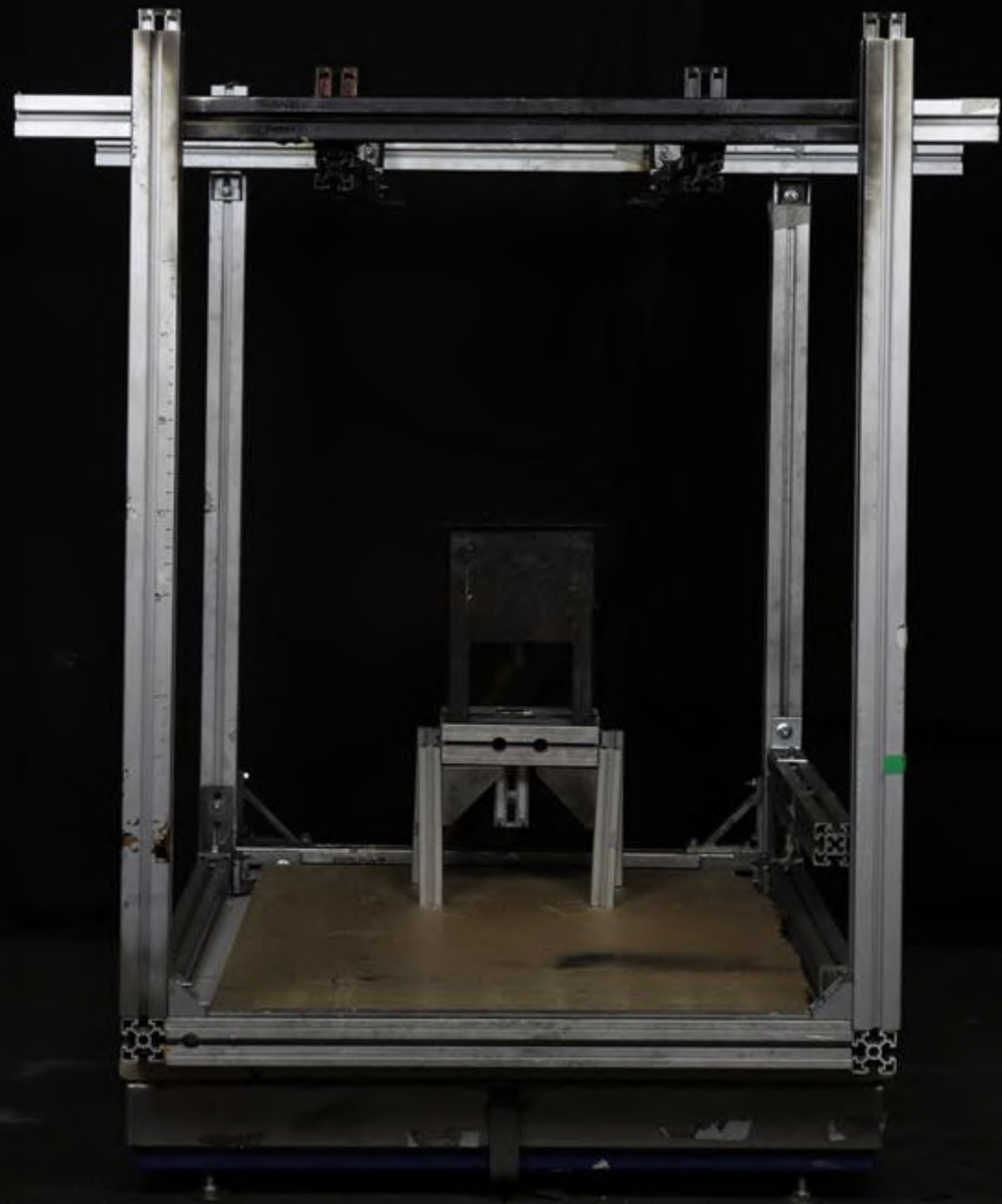


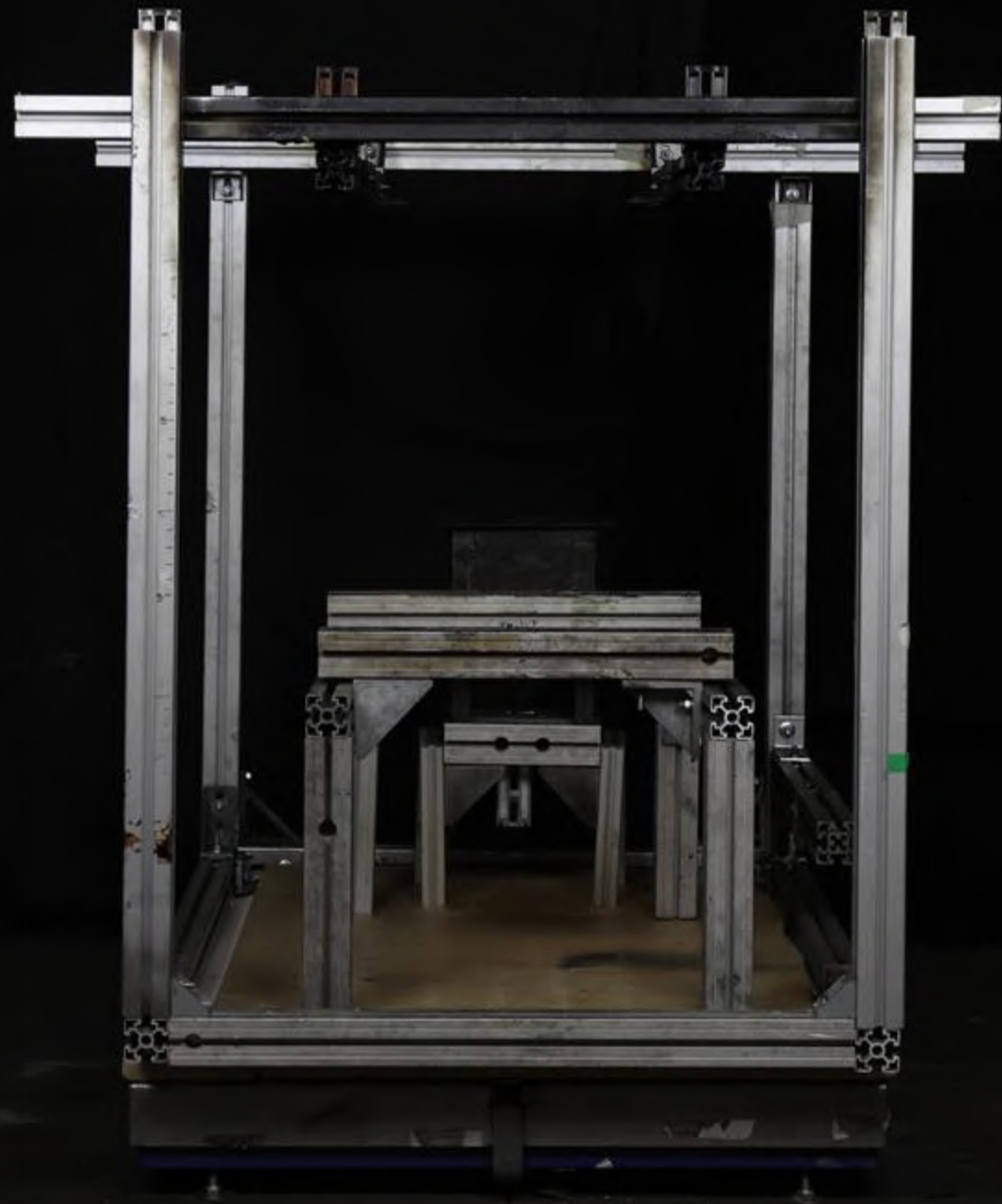




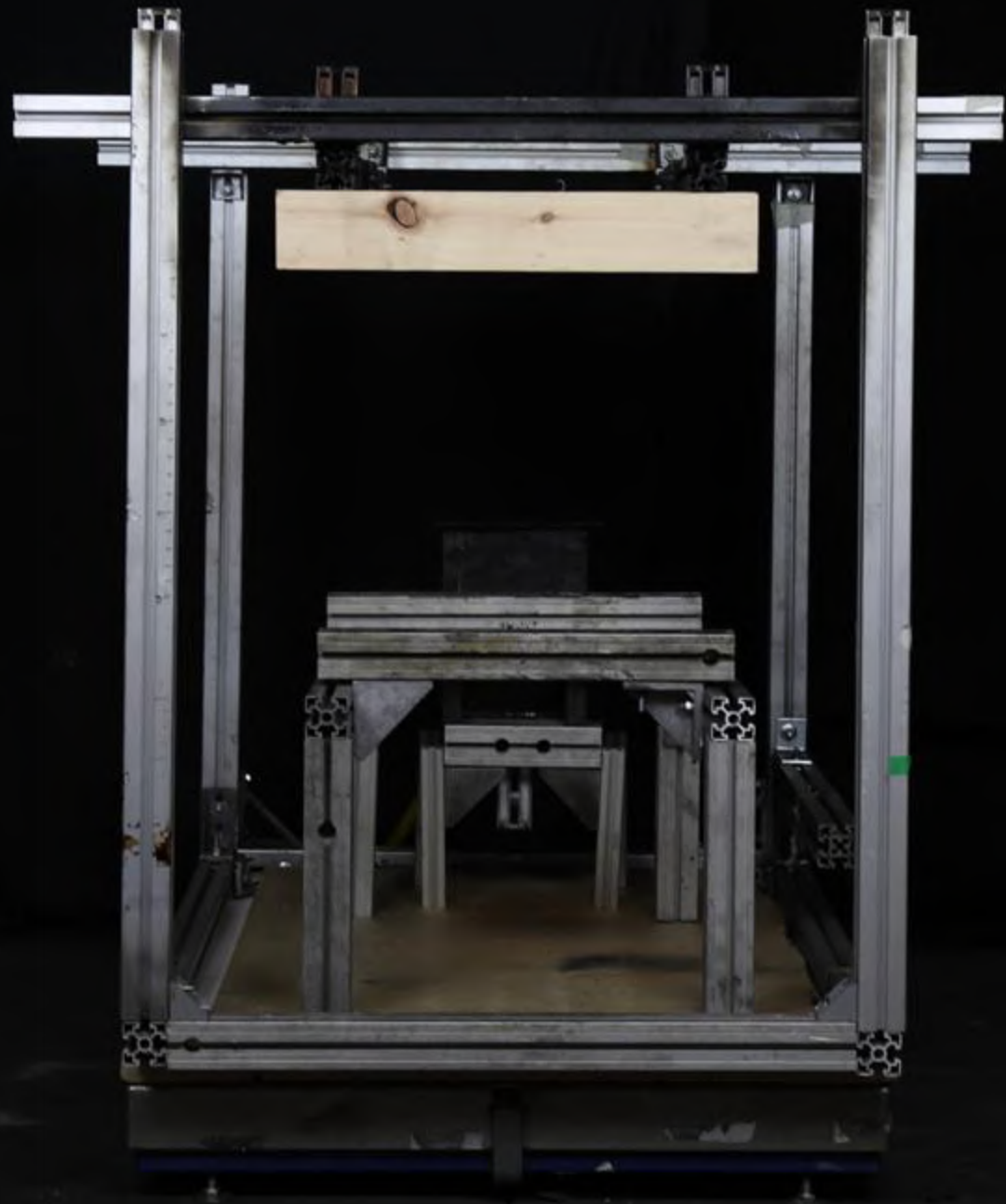








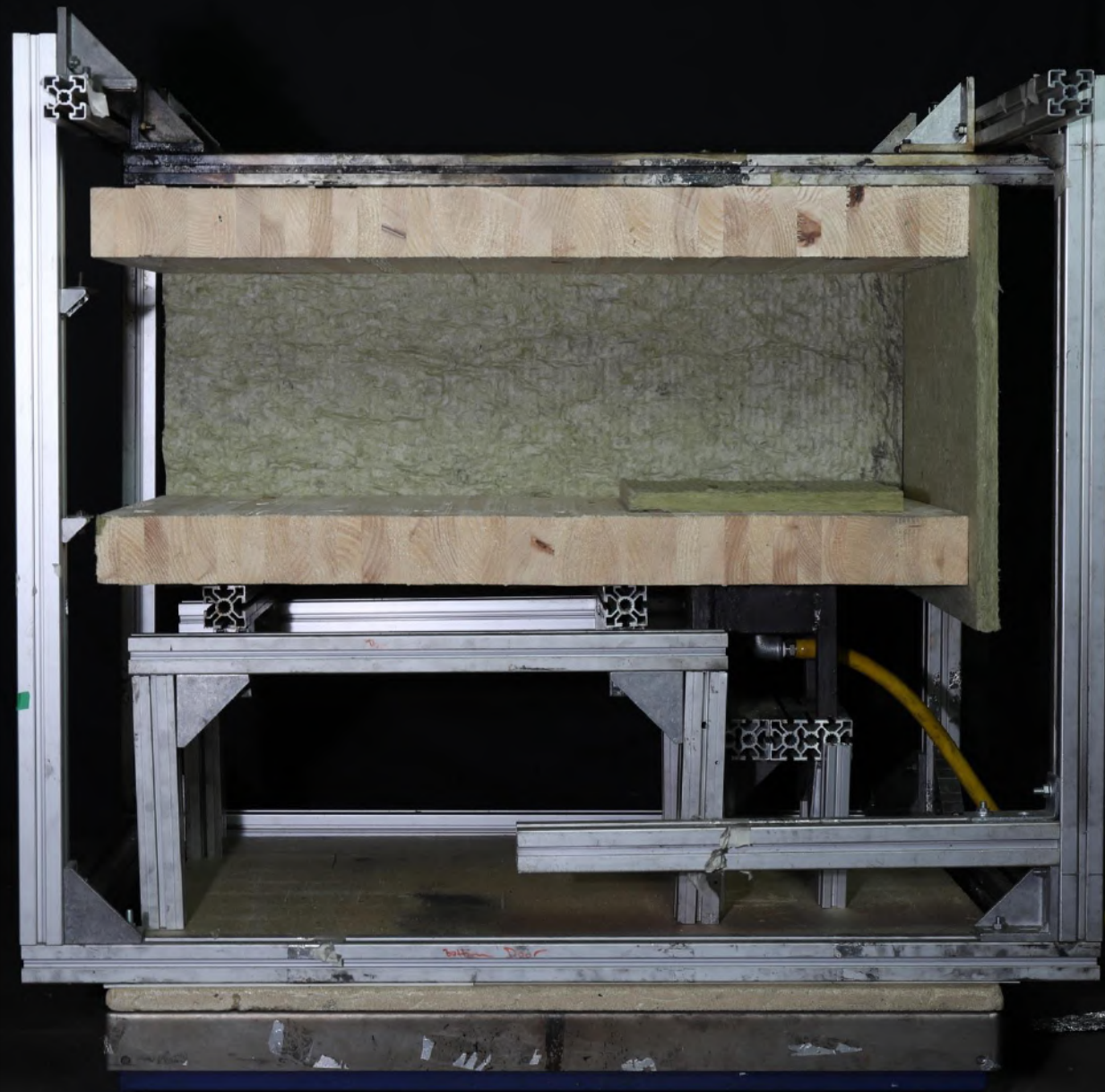




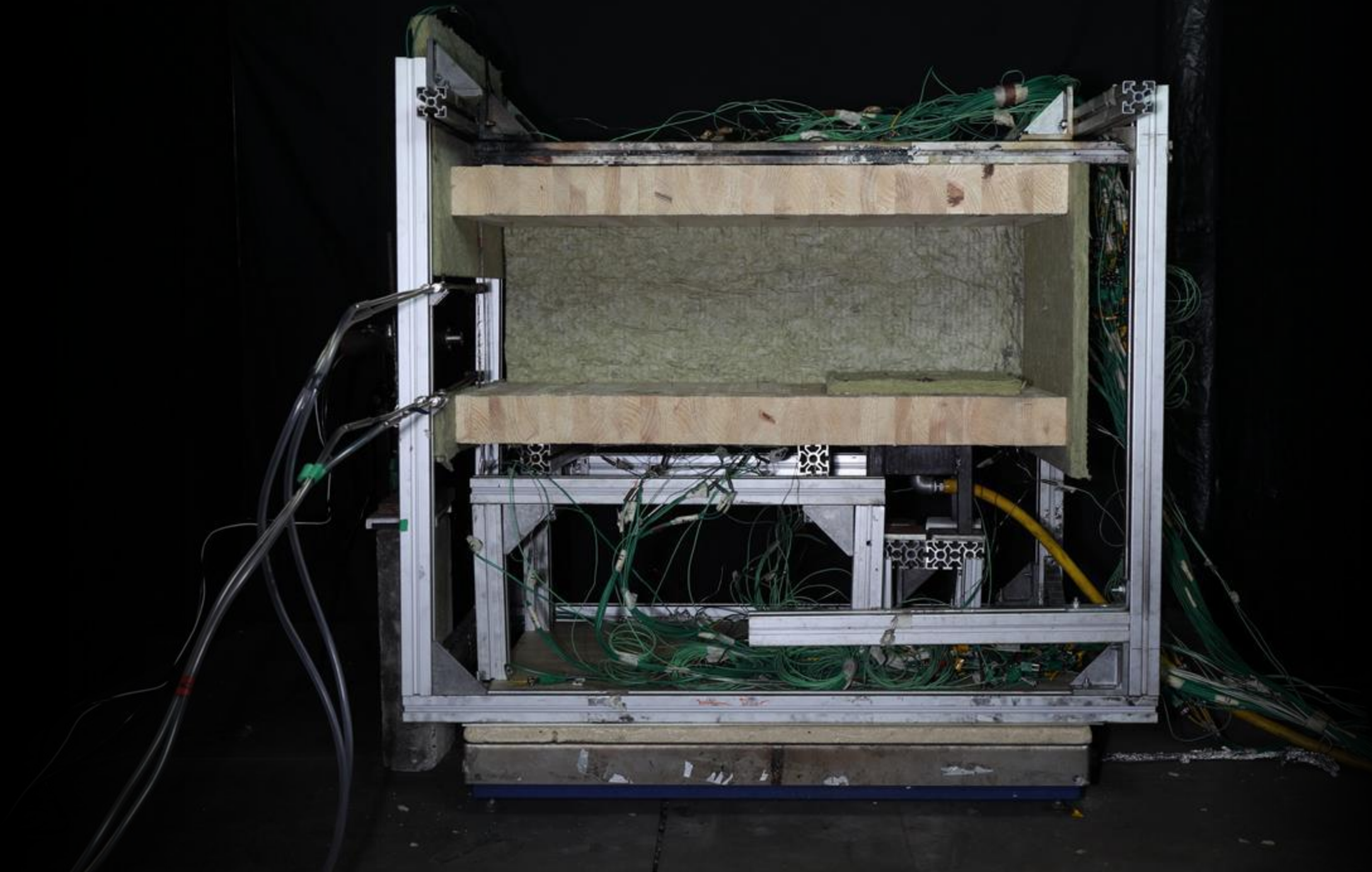






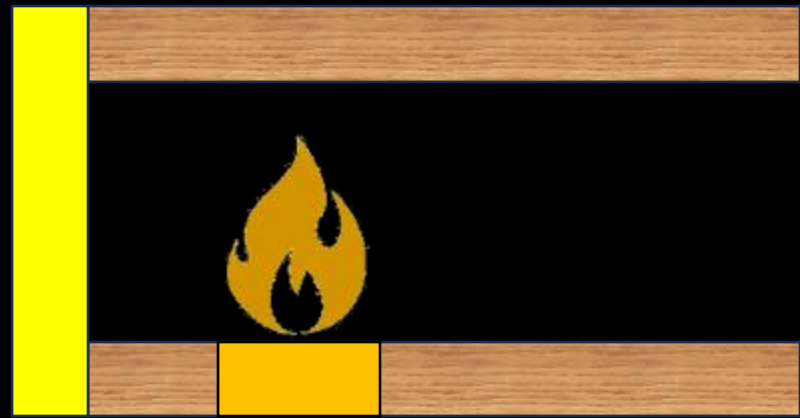
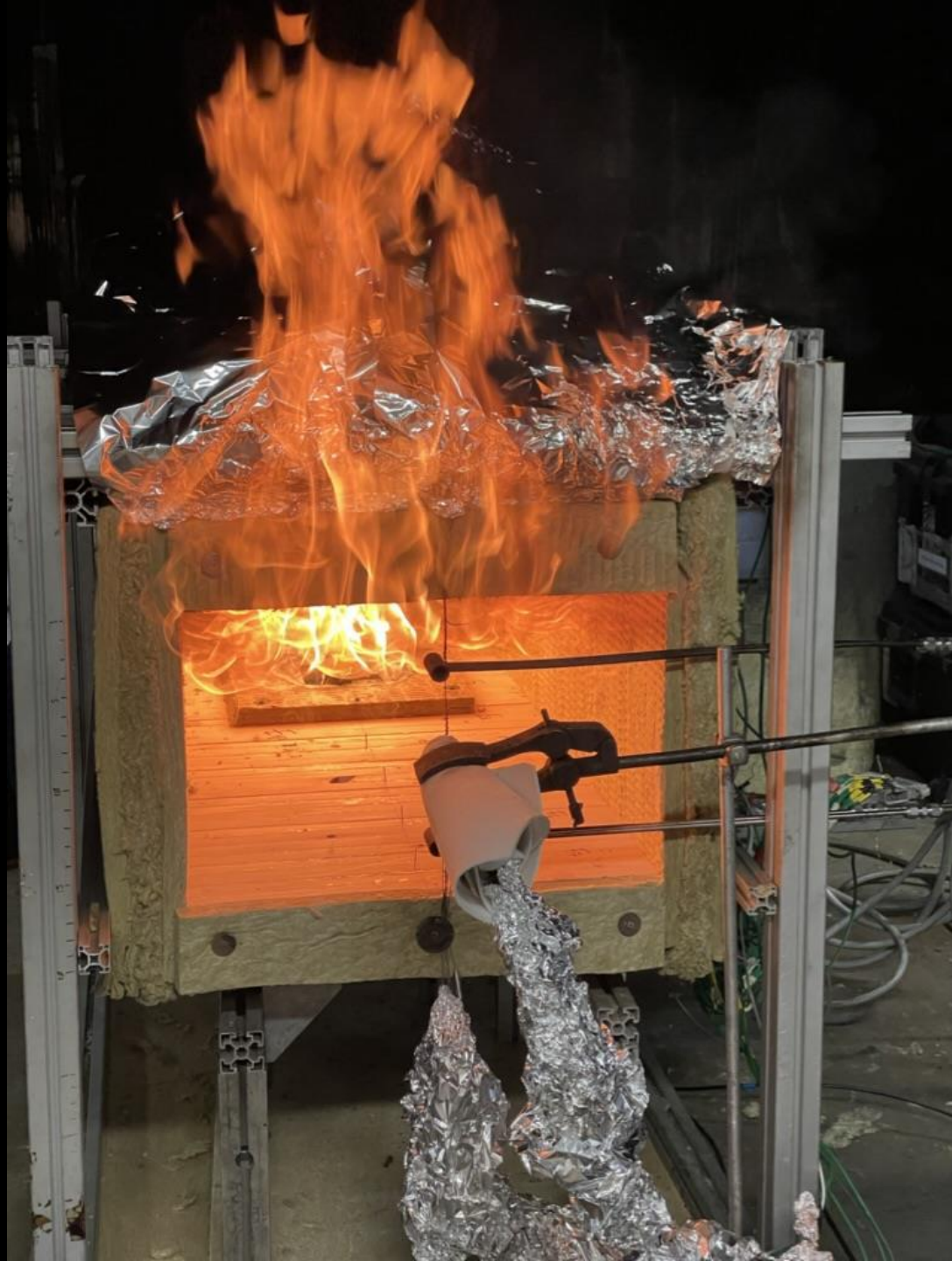


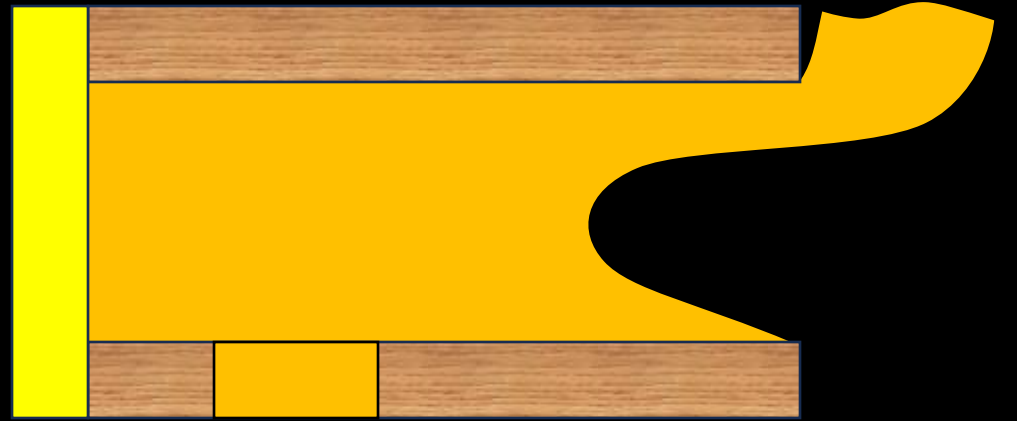
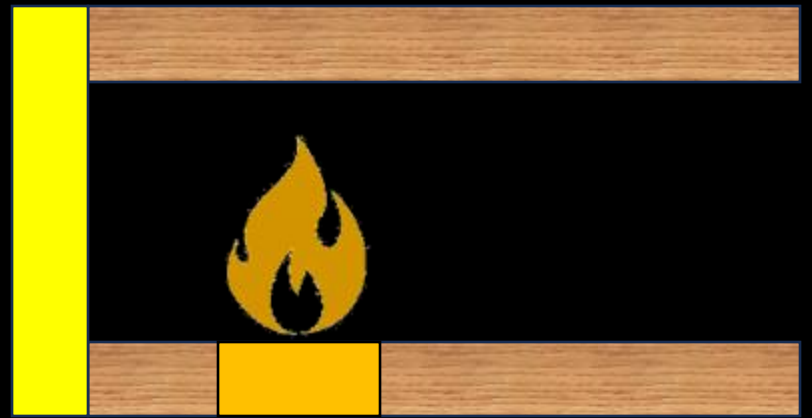




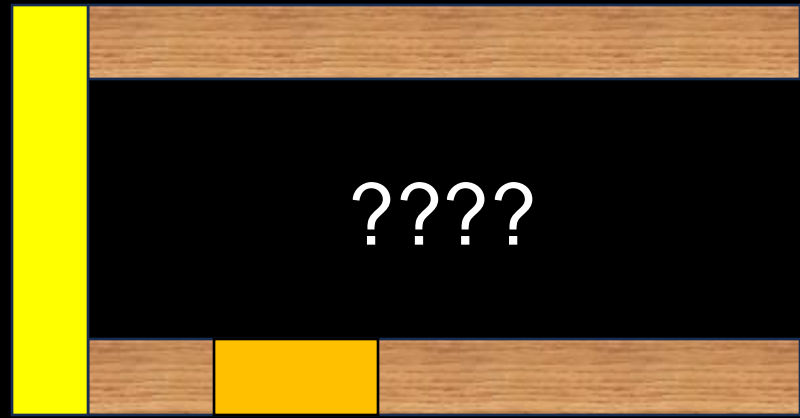
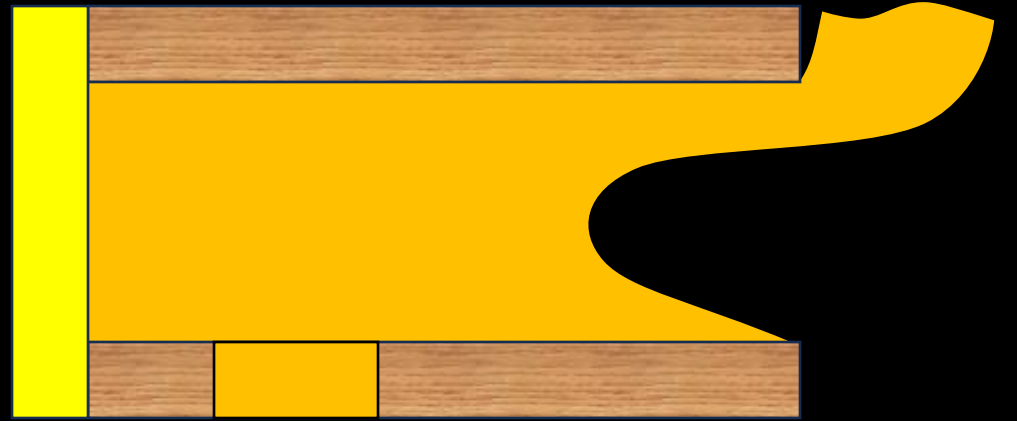
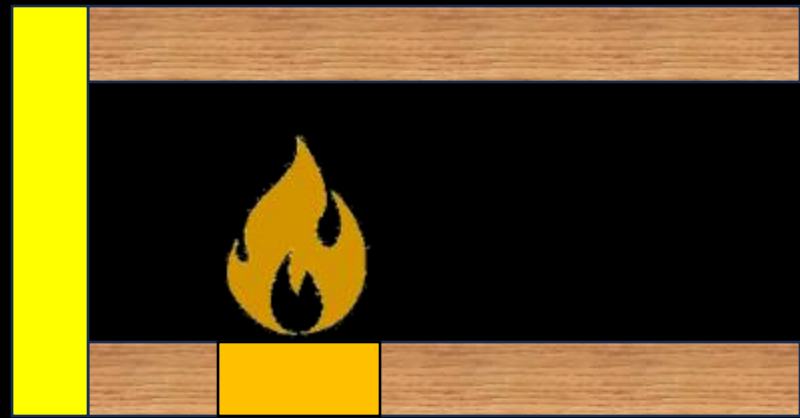


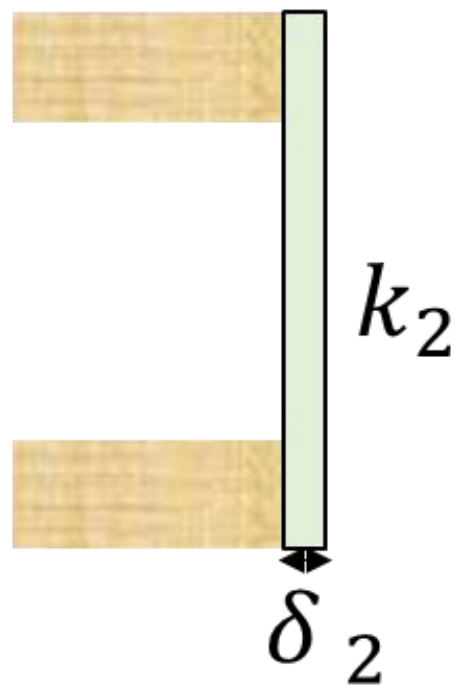


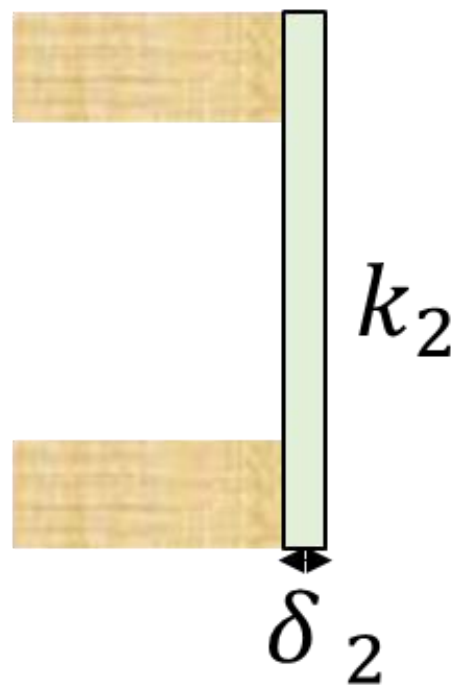
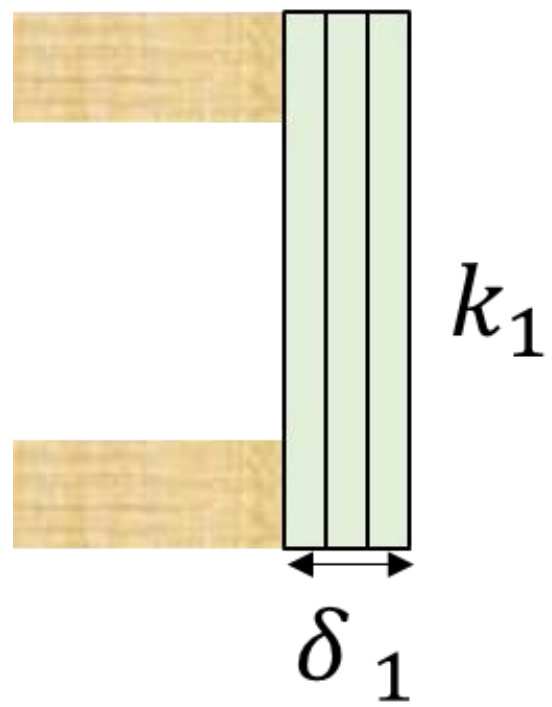


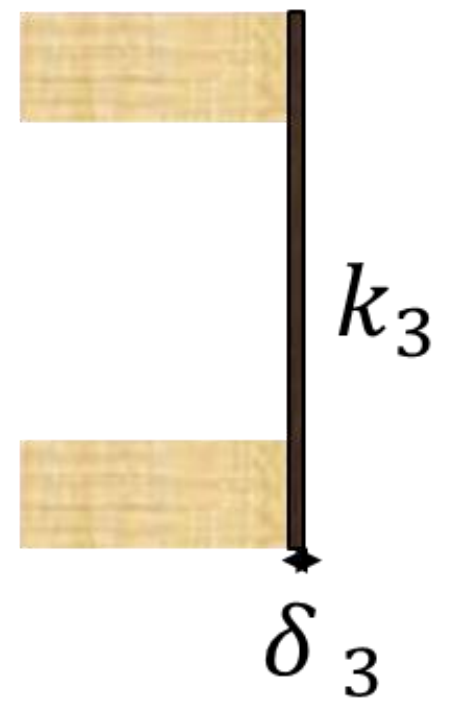
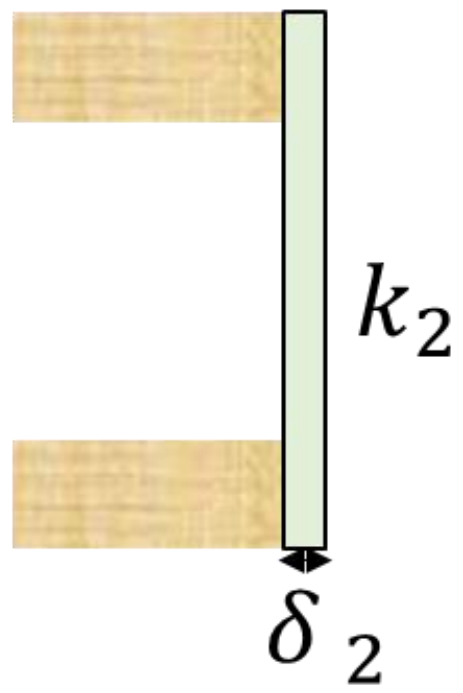
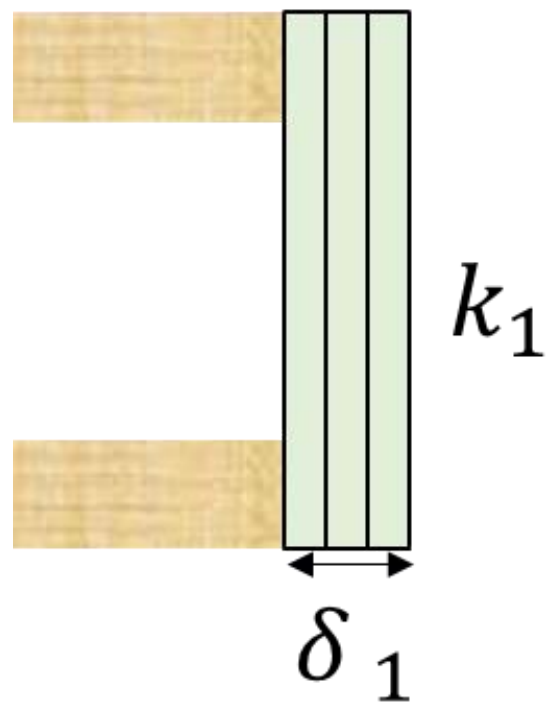




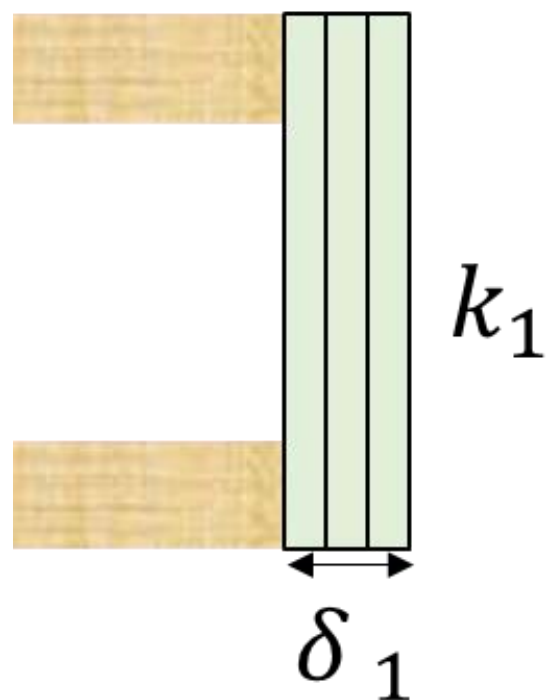




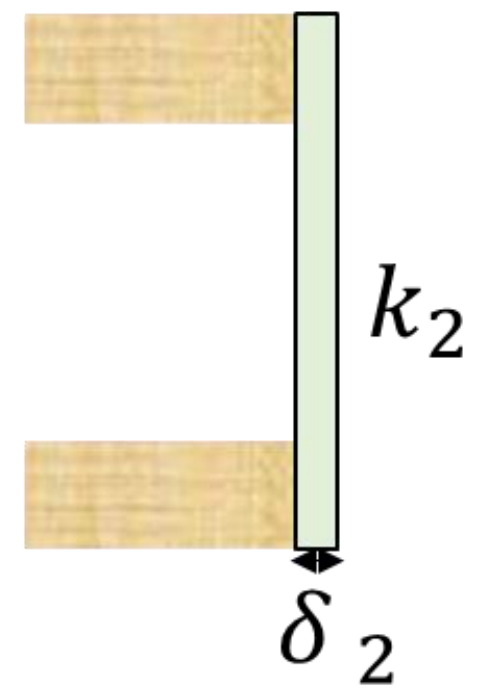




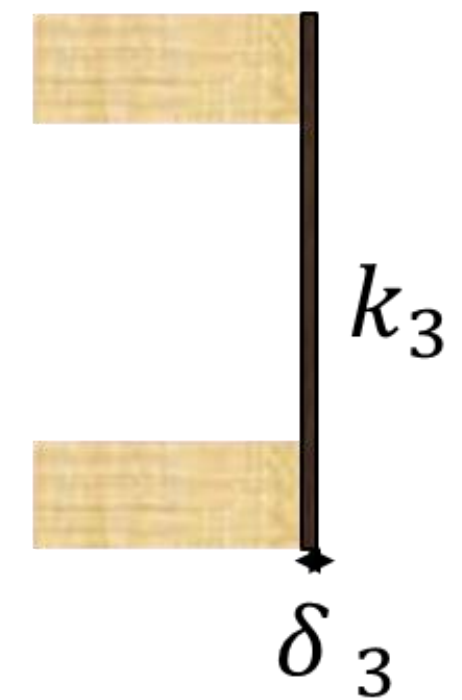




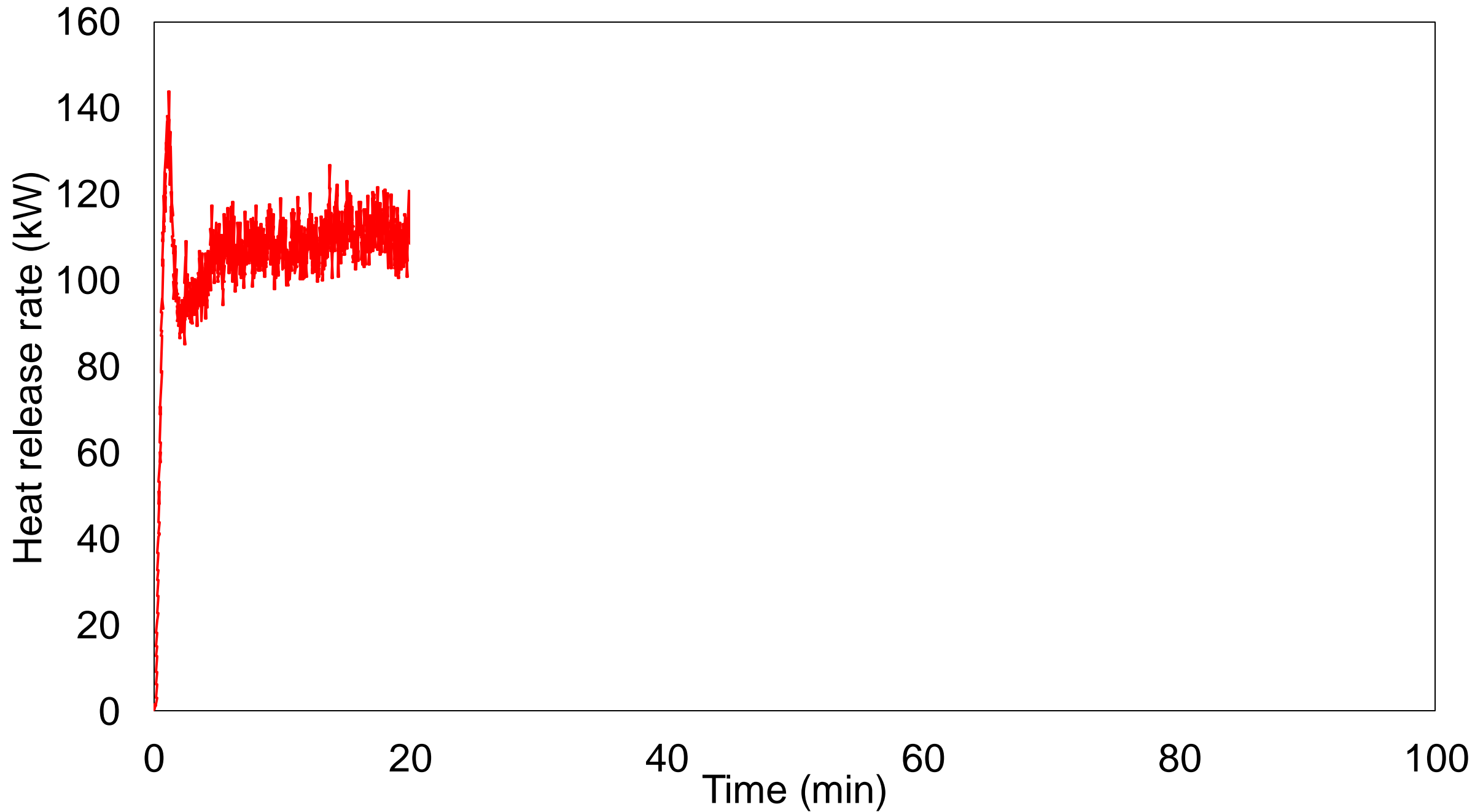
*3-layer  
Rockwool*



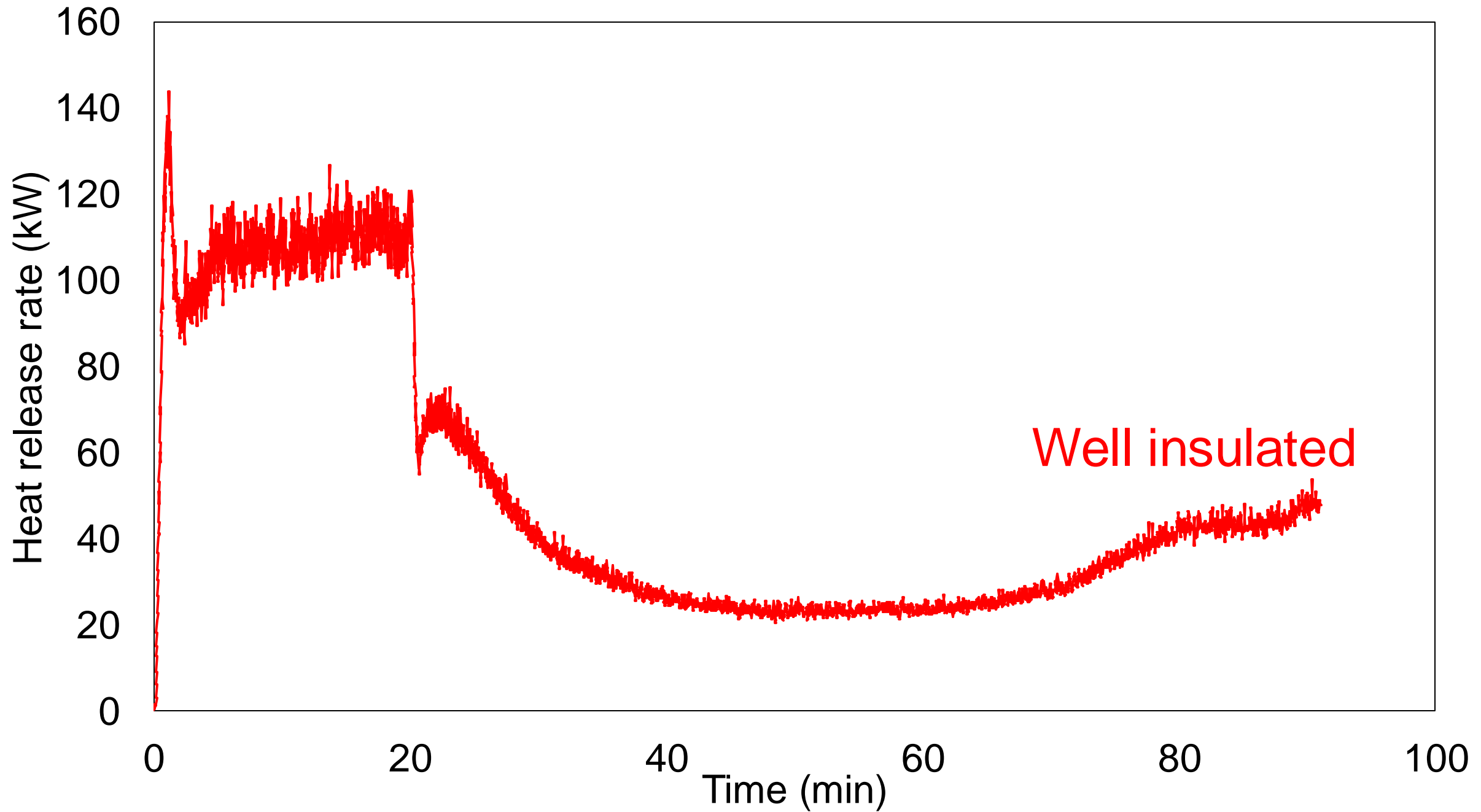
*1-layer  
Rockwool*



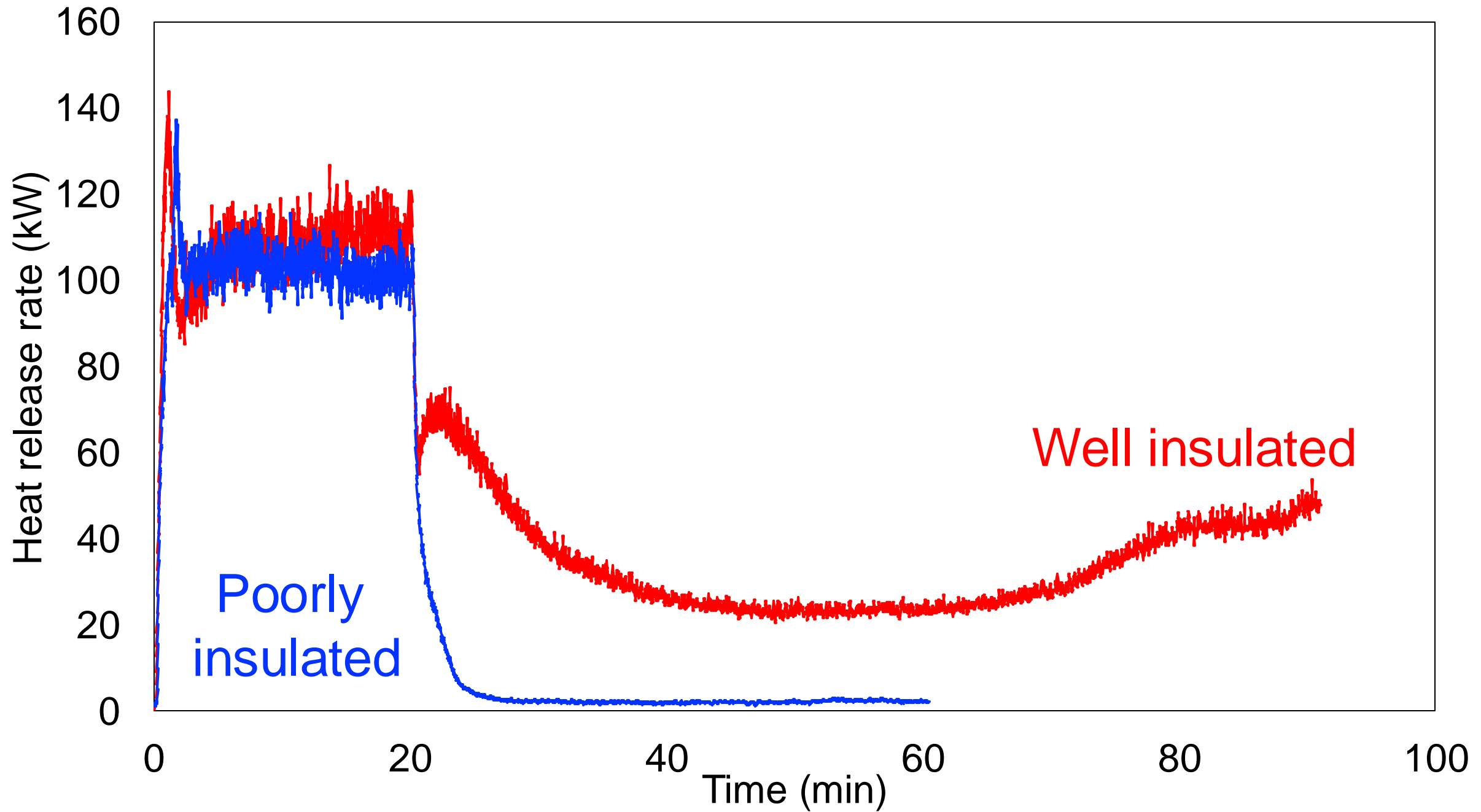
*Metal  
plate*



Data: Ali Ahmed Awadallah (UoE PhD student)

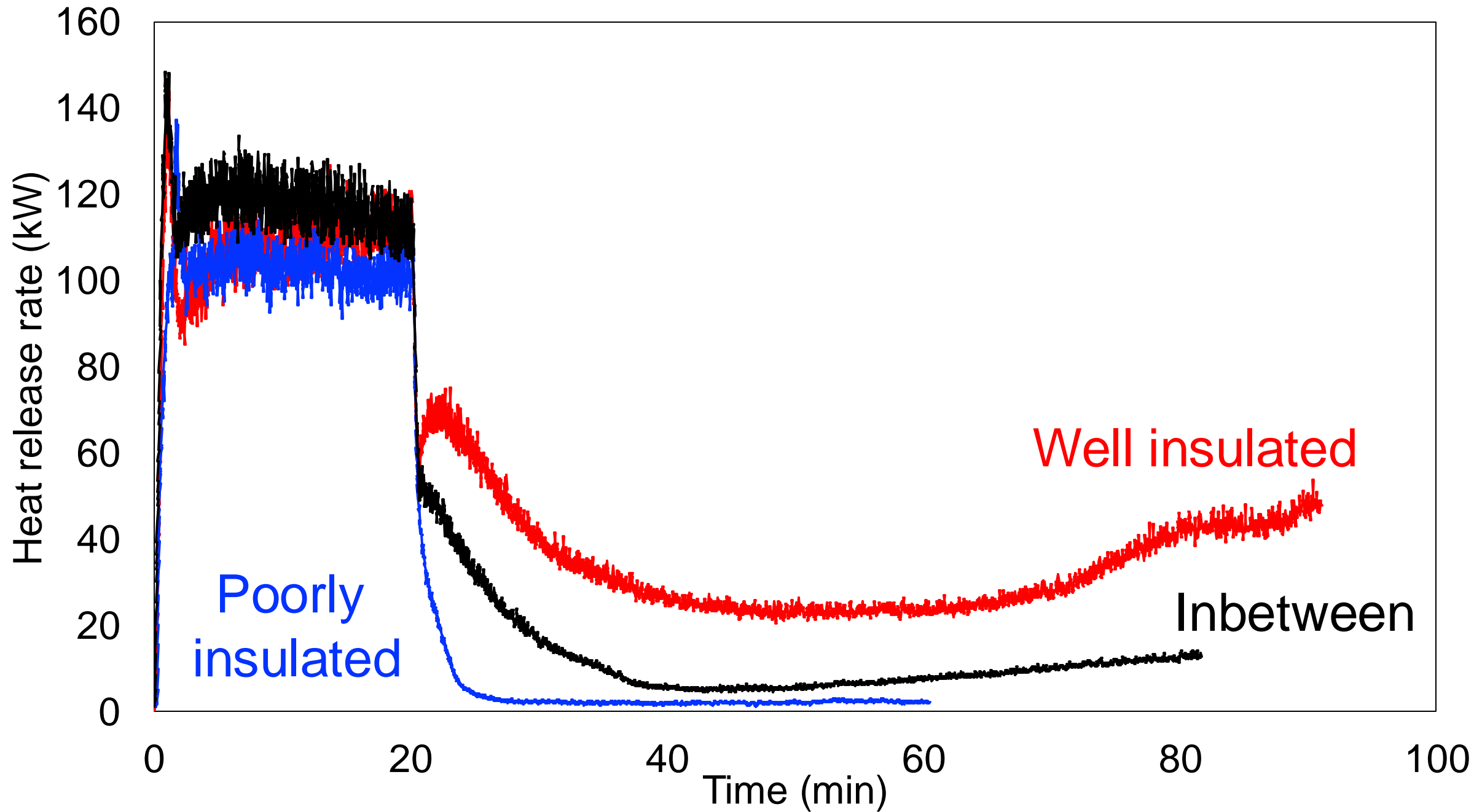


Well insulated

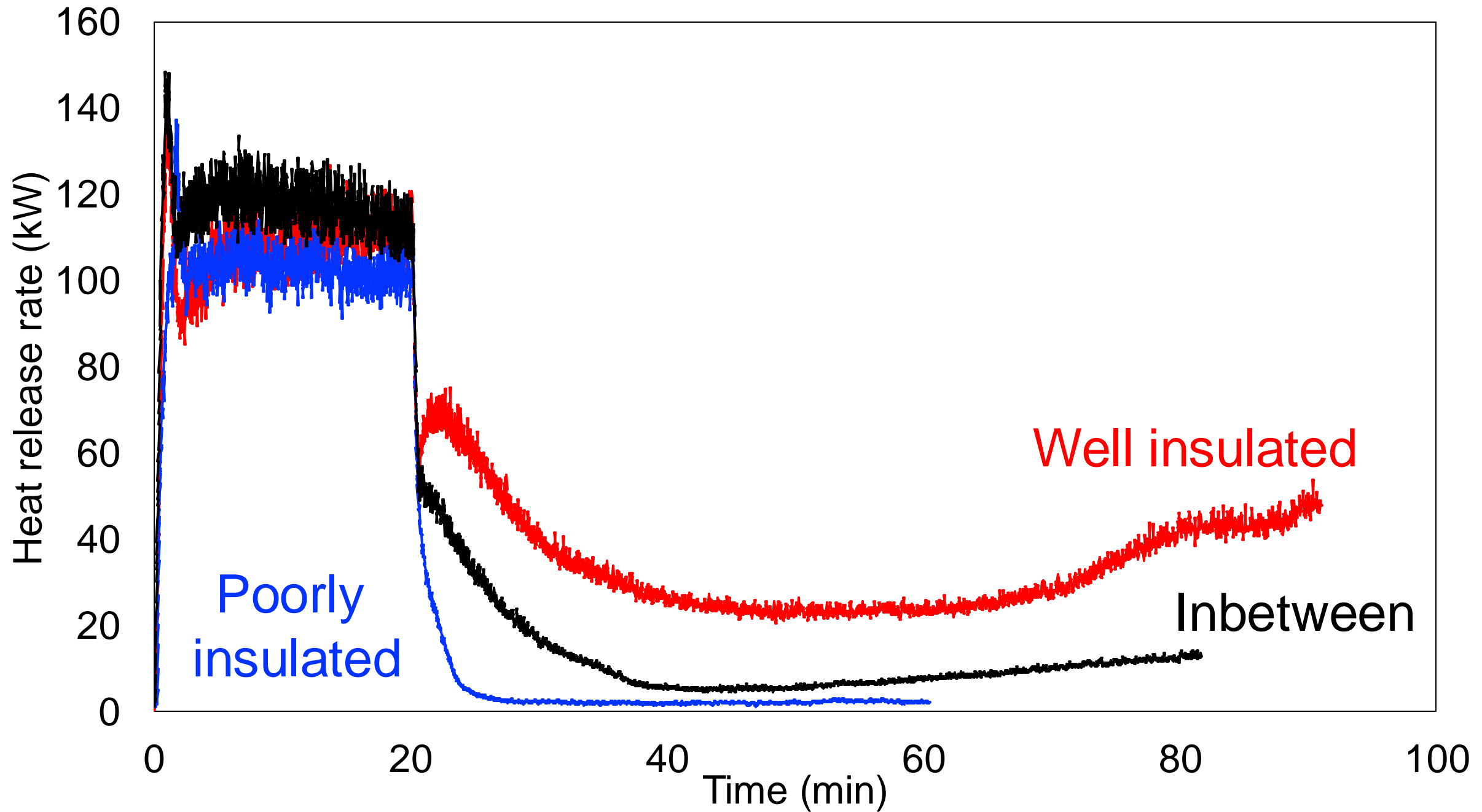


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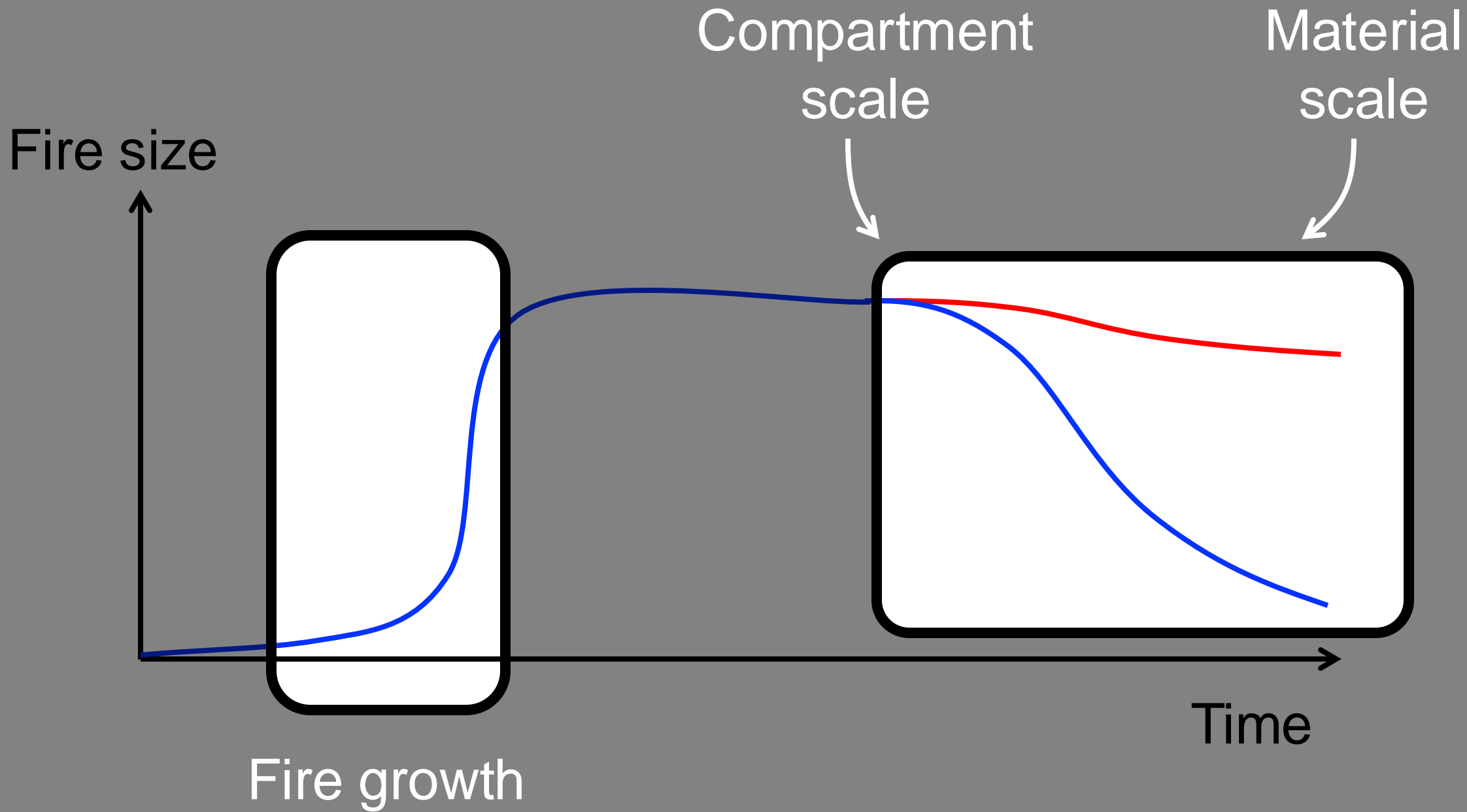
Data: Ali Ahmed Awadallah (UoE PhD student)

# How do building geometry and materials influence outcome?

Thermal properties

Openings

Exposed surfaces





$$\dot{m}_f'' = \frac{1}{L_v} \left[ \dot{q}_E'' + \dot{q}_f'' + \dot{q}_{ch}'' - \dot{q}_{Loss}'' - \left( -k \frac{dT}{dx} \Big|_{x=x_{ch}} \right) - \frac{\partial(\delta q''')}{\partial t} \right]$$

External heat flux

Flame heat feedback

Heat released by char oxidation

Losses from the surface

Conductive losses

Energy stored in the char

$$\dot{m}_f'' = \frac{1}{L_v} \left[ \dot{q}_E'' + \dot{q}_f'' + \dot{q}_{ch}'' - \dot{q}_{Loss}'' - \left( -k \frac{dT}{dx} \Big|_{x=x_{ch}} \right) - \frac{\partial(\delta q''')}{\partial t} \right]$$

External heat flux

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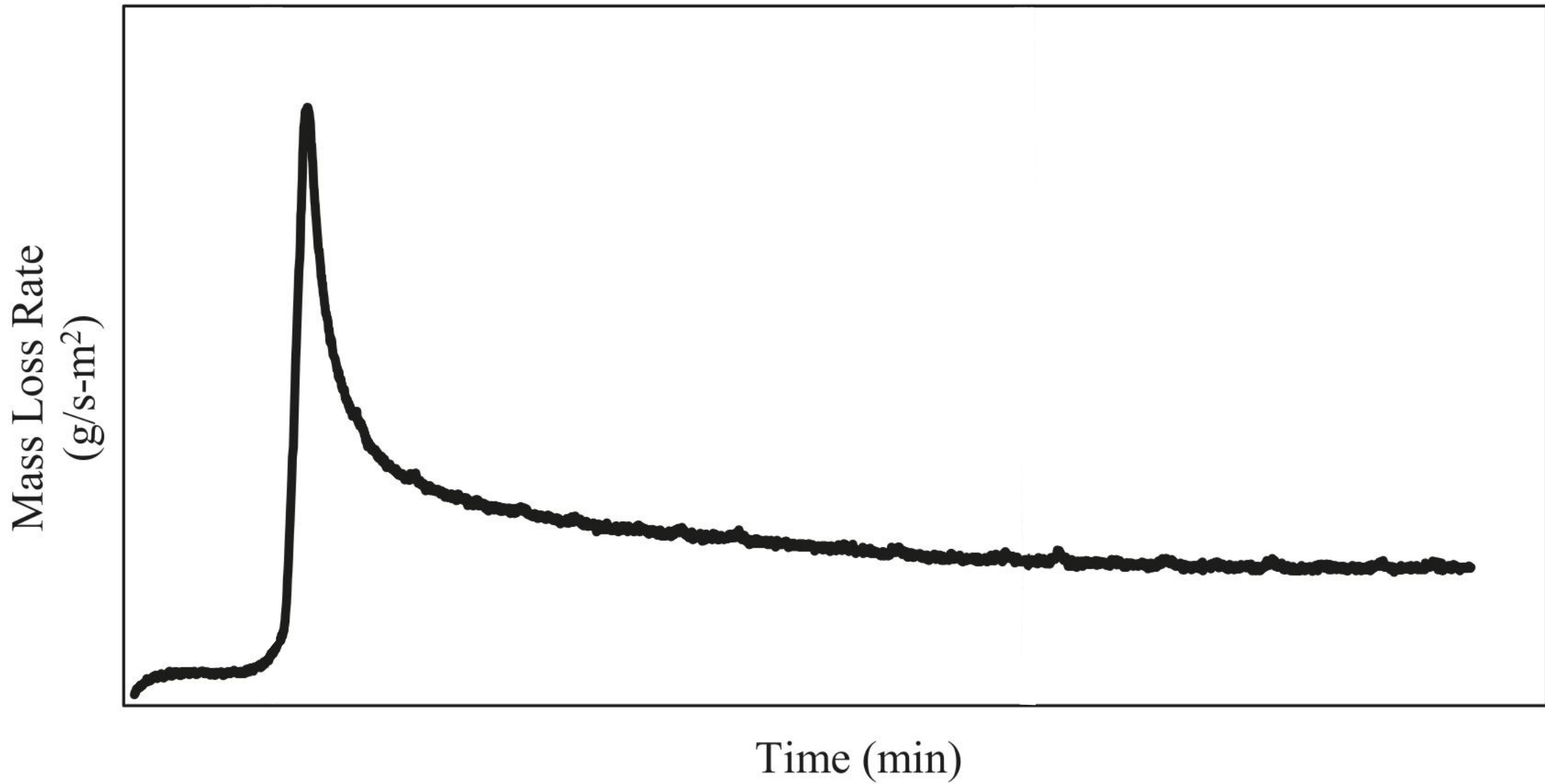
Heat released by char oxidation

Losses from the surface

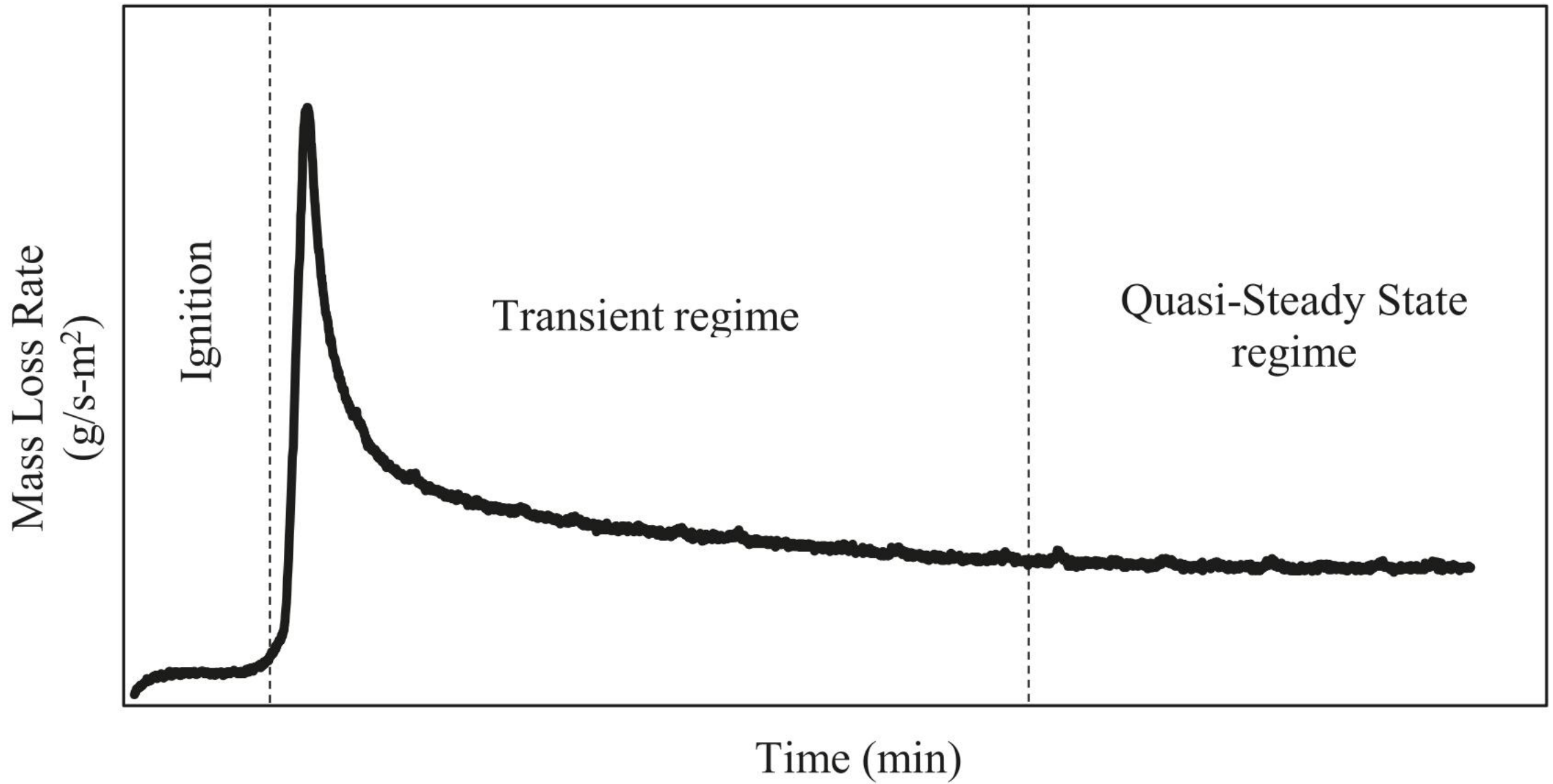
Conductive losses

Energy stored in the char

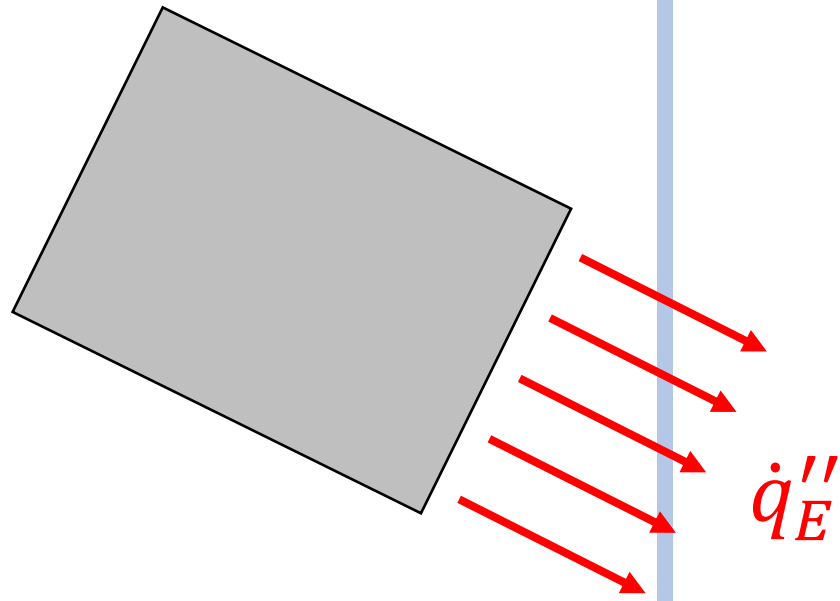




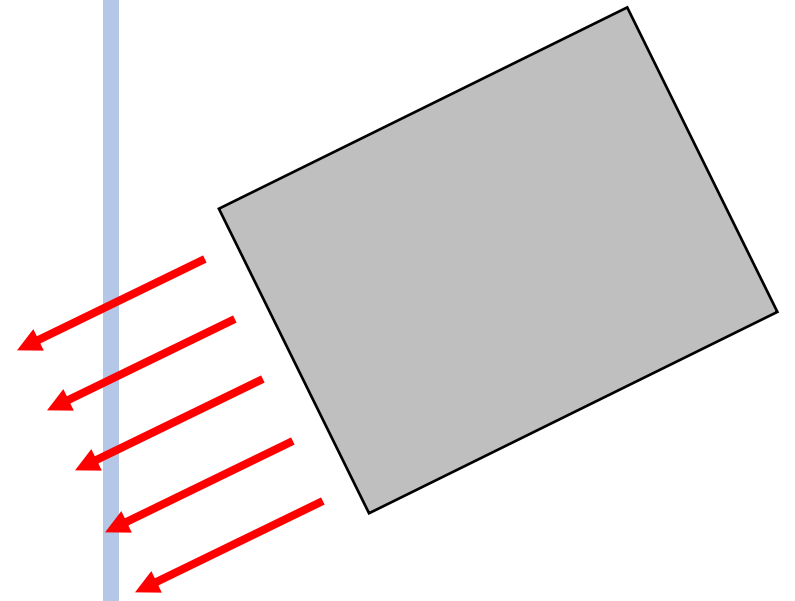




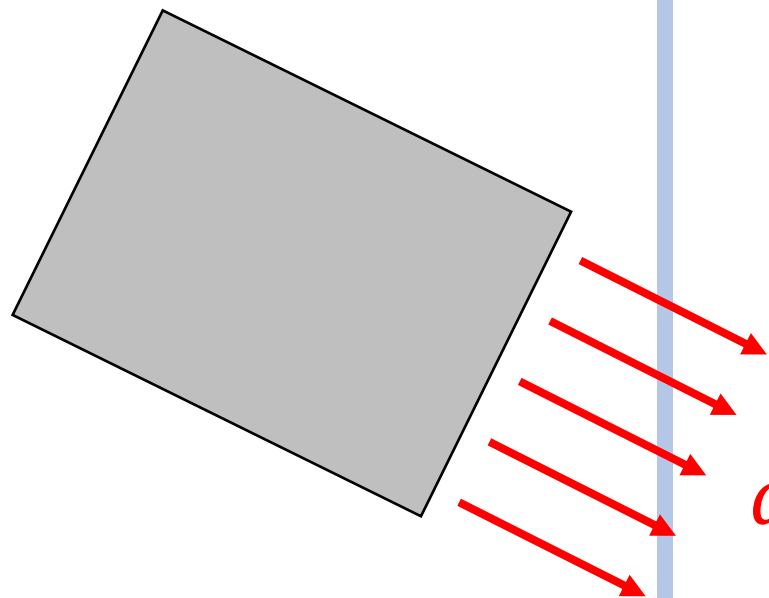
Air



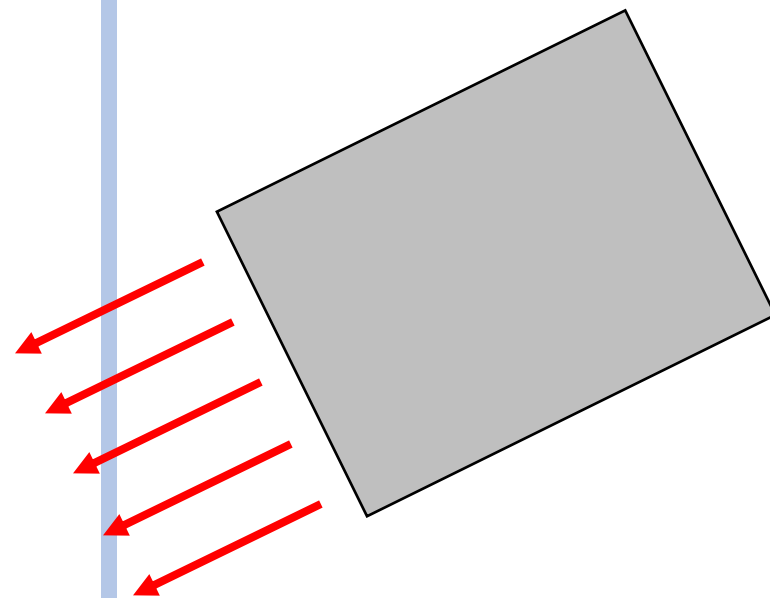
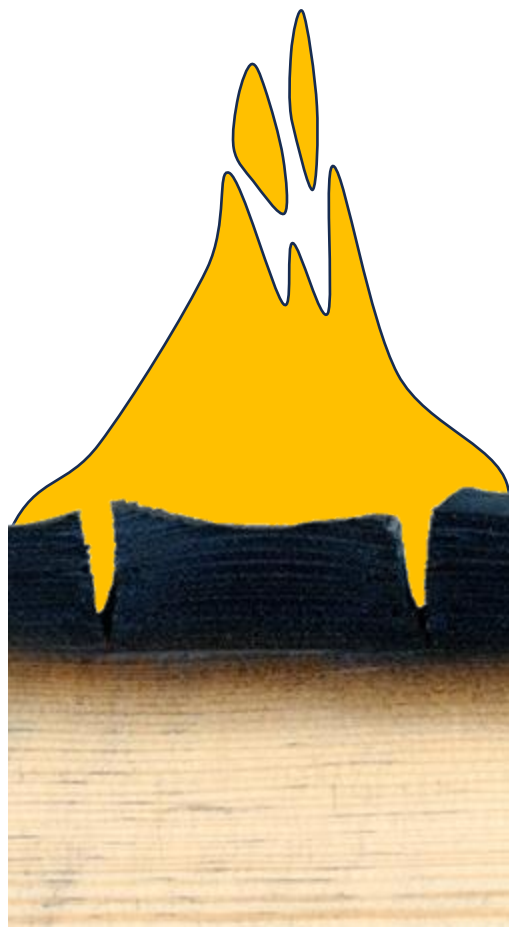
$$\dot{q}_E''$$



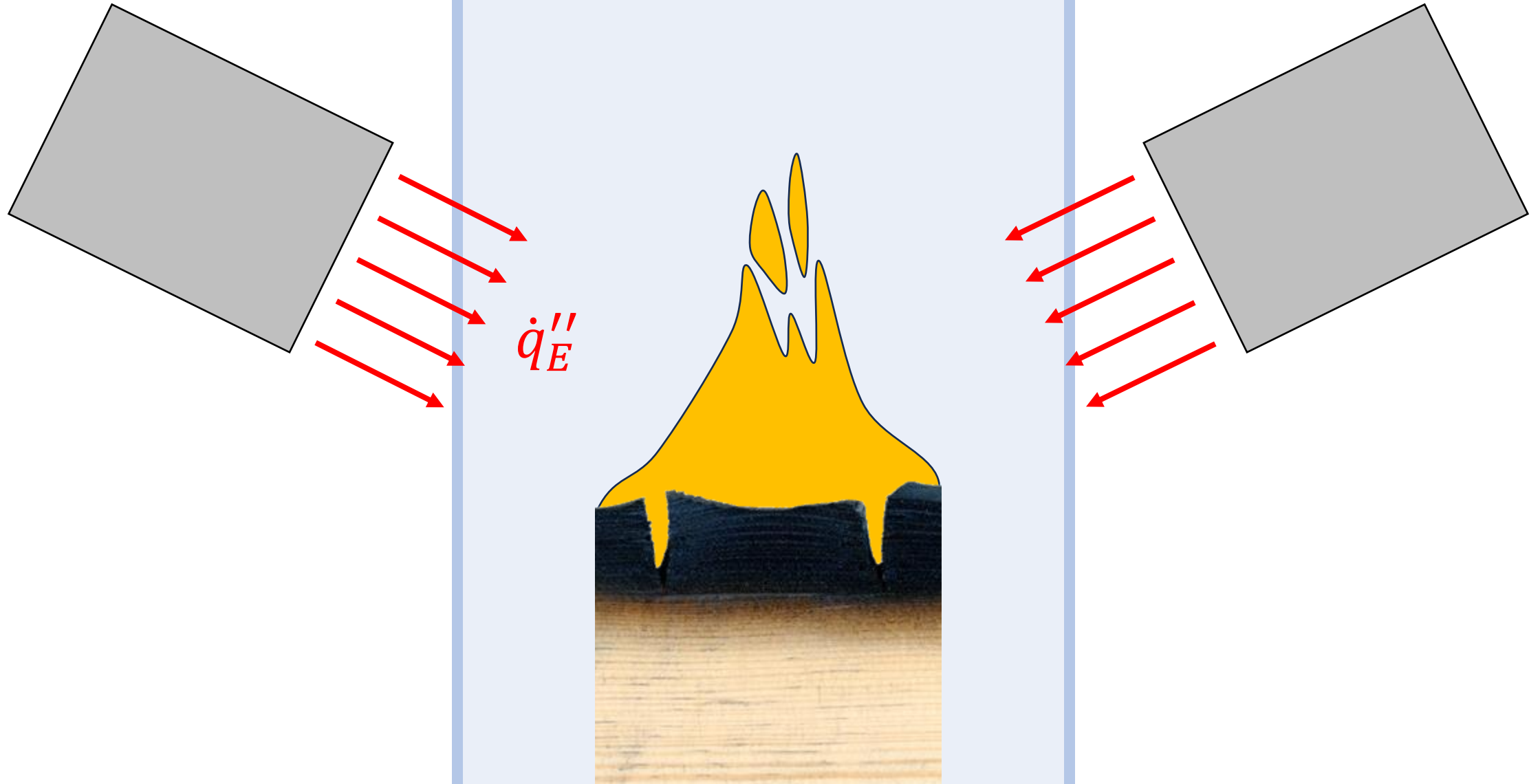
Air



$$\dot{q}''_E$$

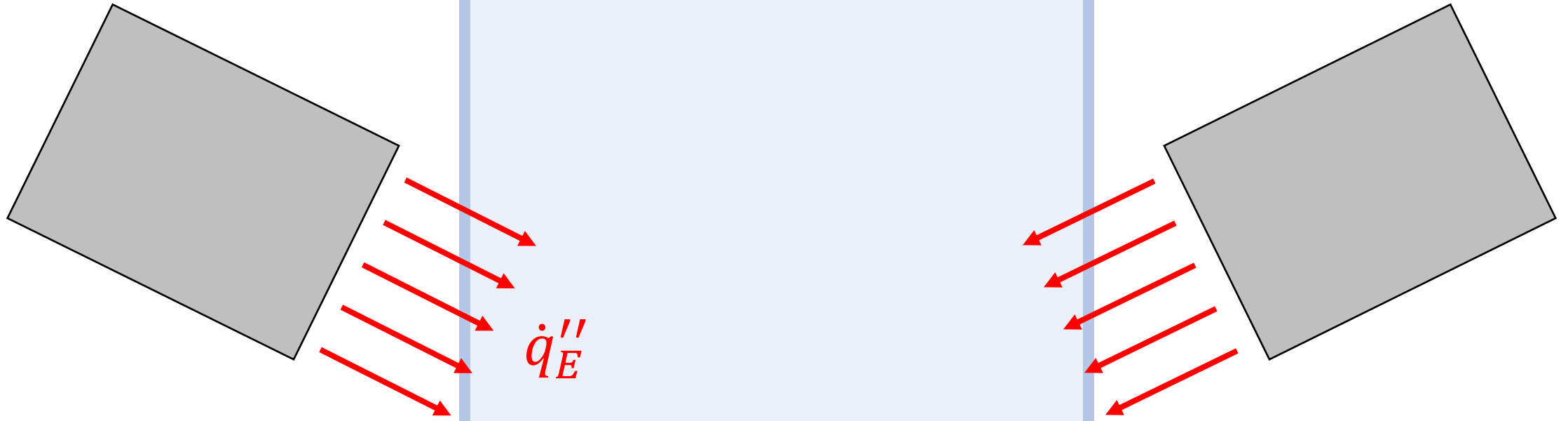


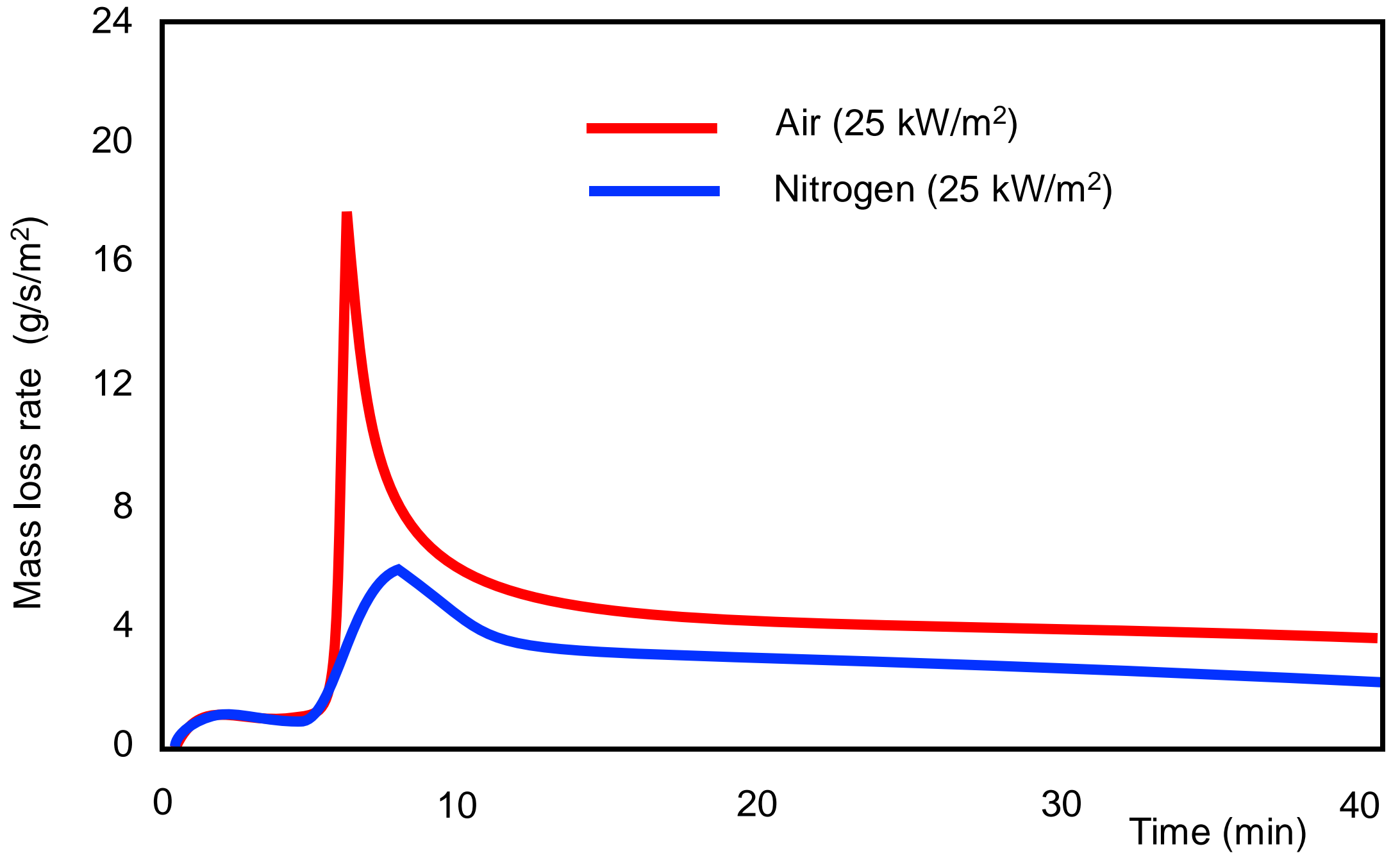
Nitrogen













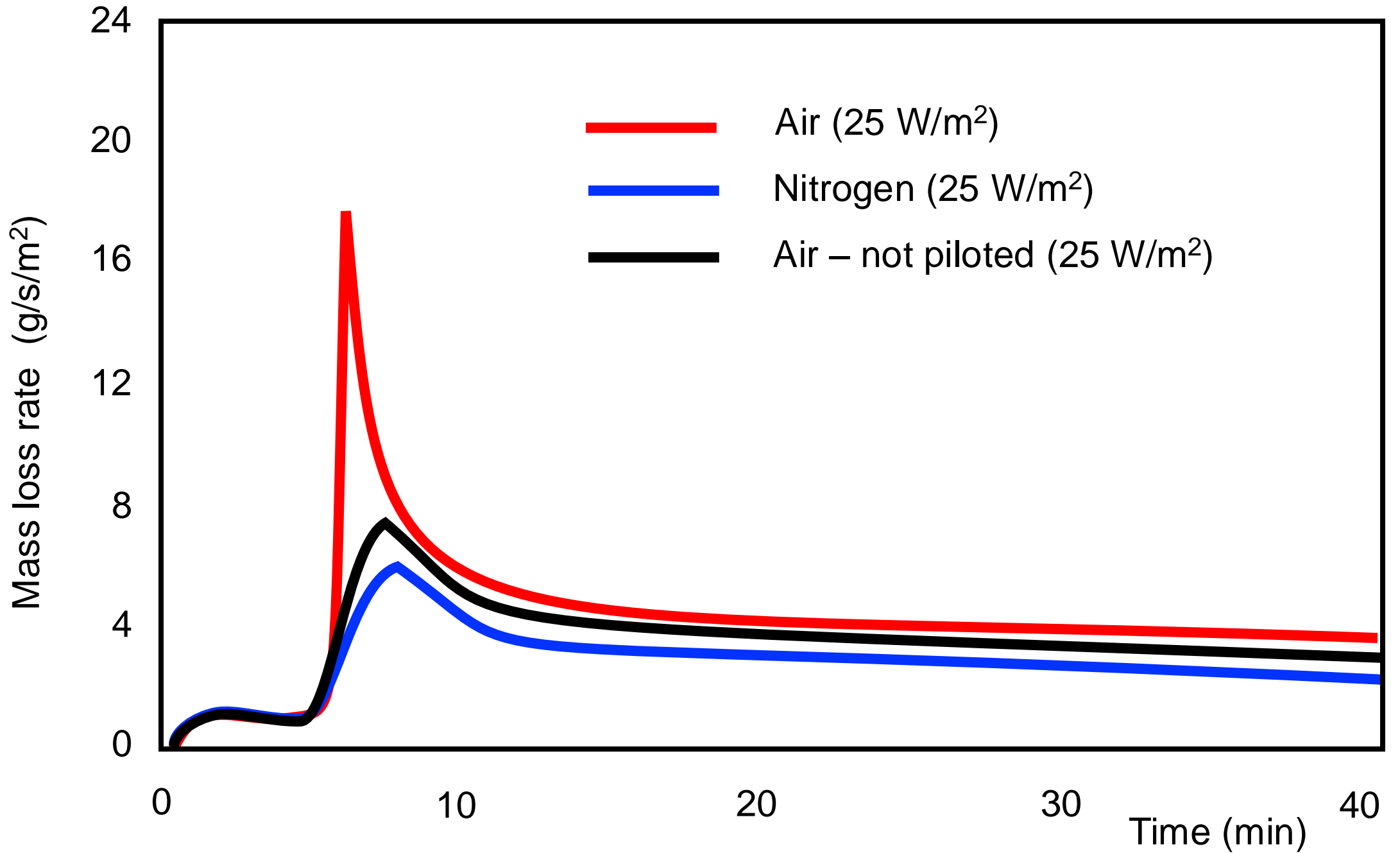


Nitrogen

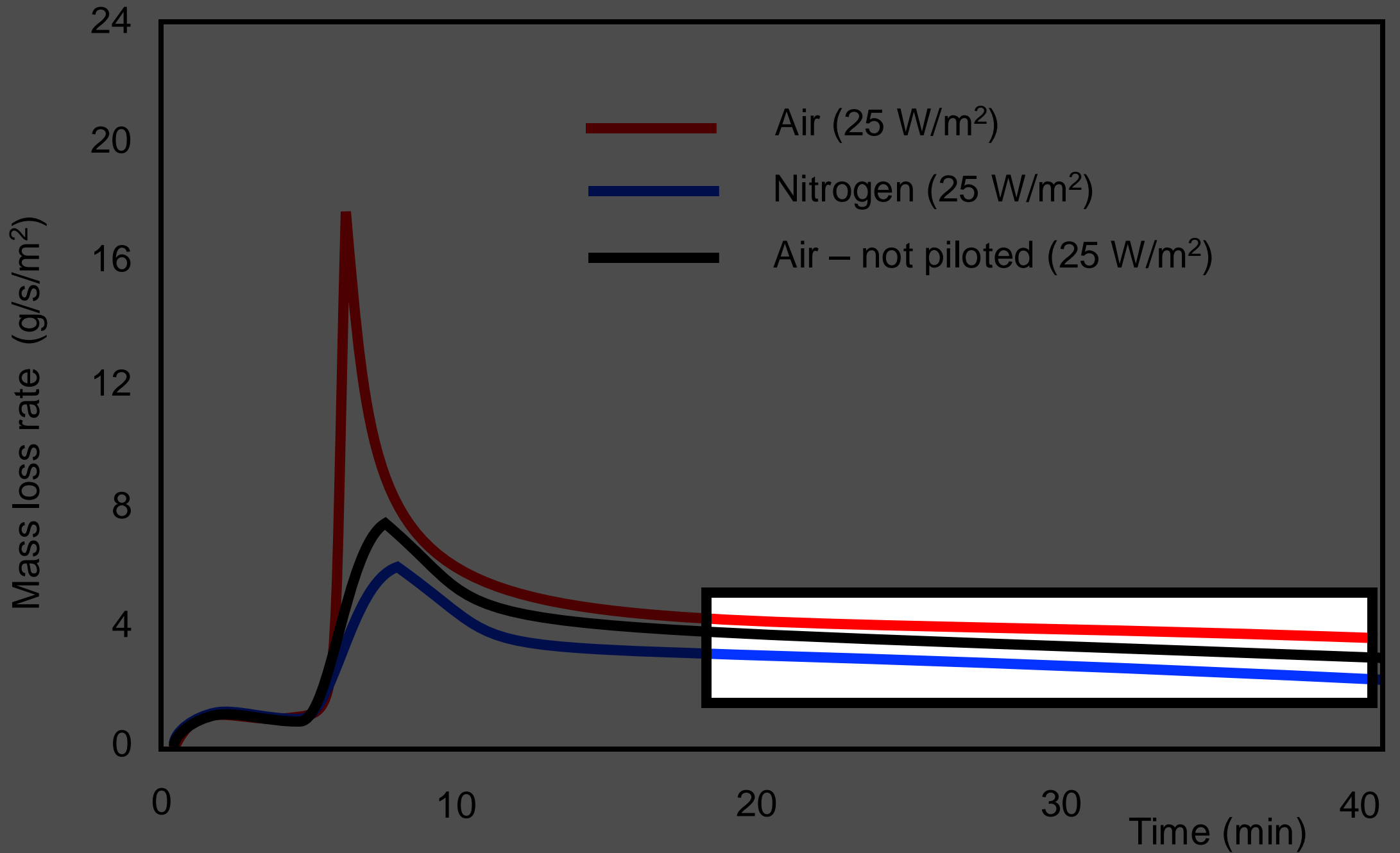


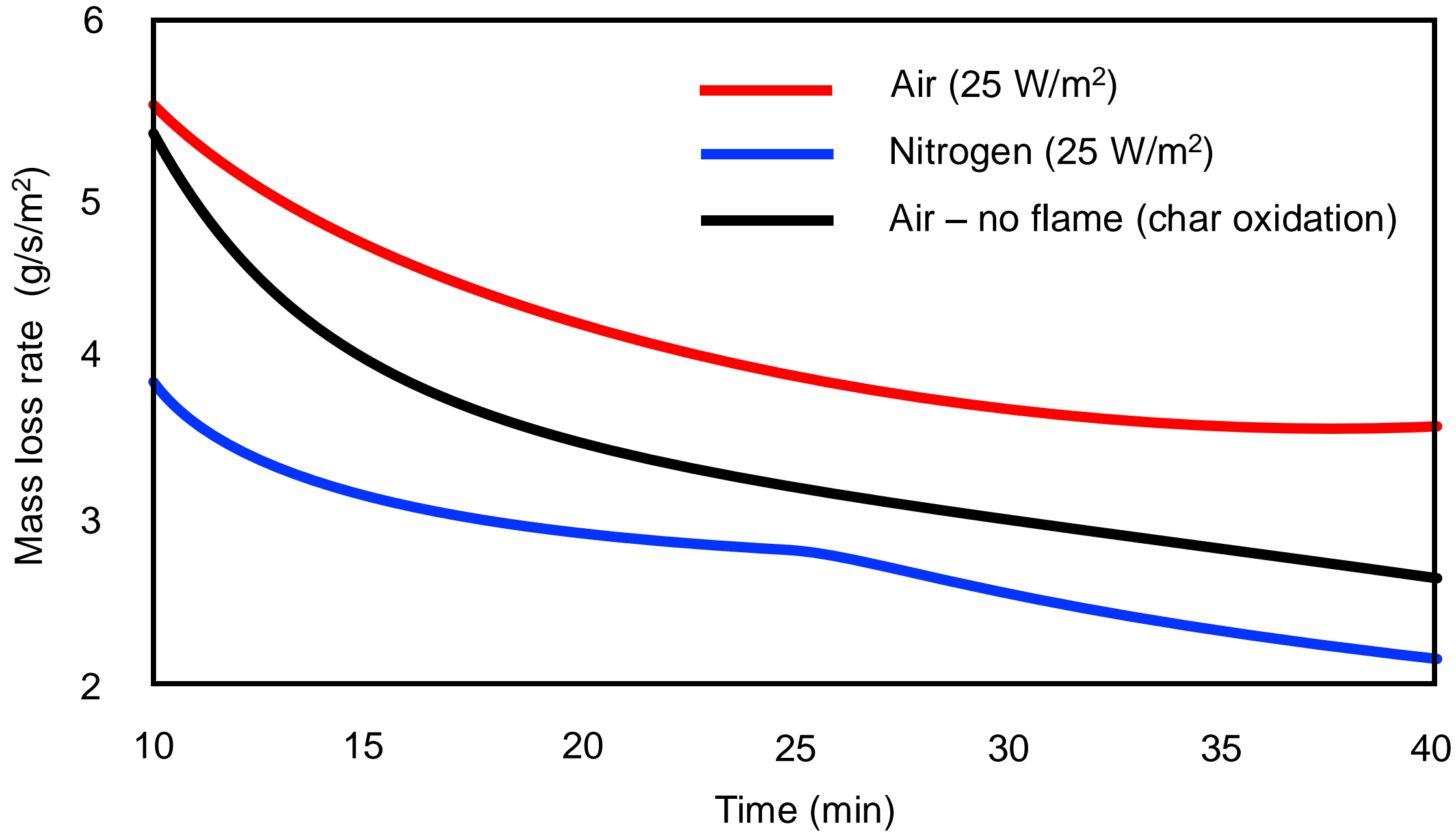


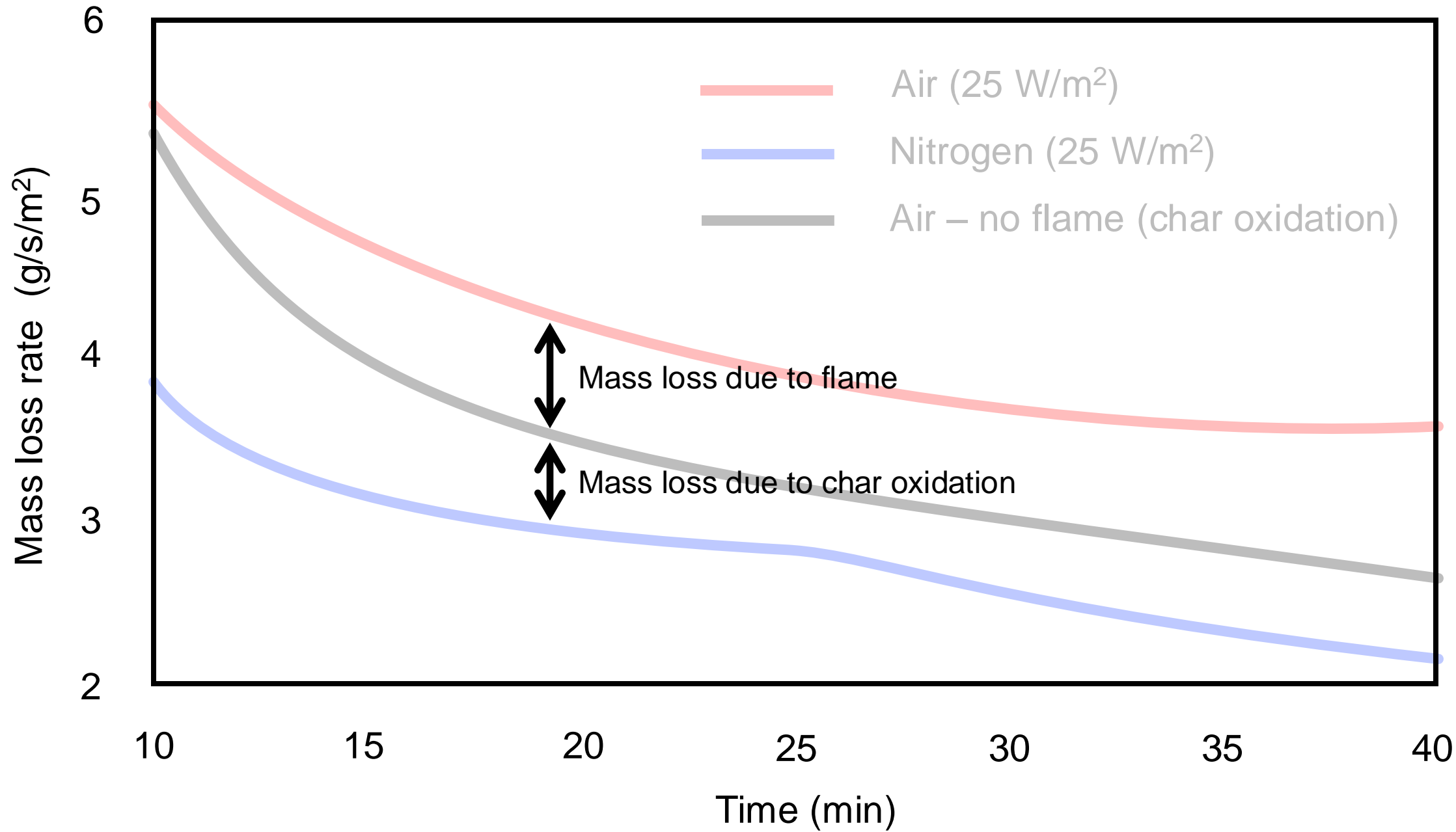
	Air		Nitrogen
	Piloted	Non-piloted	
20 kW/m <sup>2</sup>			
25 kW/m <sup>2</sup>			
40 kW/m <sup>2</sup>			
60 kW/m <sup>2</sup>			











$$\dot{m}_f'' = \frac{1}{L_v} \left[ \dot{q}_E'' + \dot{q}_f'' + \dot{q}_{ch}'' - \dot{q}_{Loss}'' - \left( -k \frac{dT}{dx} \Big|_{x=x_{ch}} \right) - \frac{\partial(\delta q''')}{\partial t} \right]$$

$$\dot{m}_f'' = \frac{1}{L_v} \left[ \dot{q}_E'' + \dot{q}_f'' + \dot{q}_{ch}'' - F(T_s) \right]$$

External heat flux

Flame heat feedback

Heat released by char oxidation

Losses

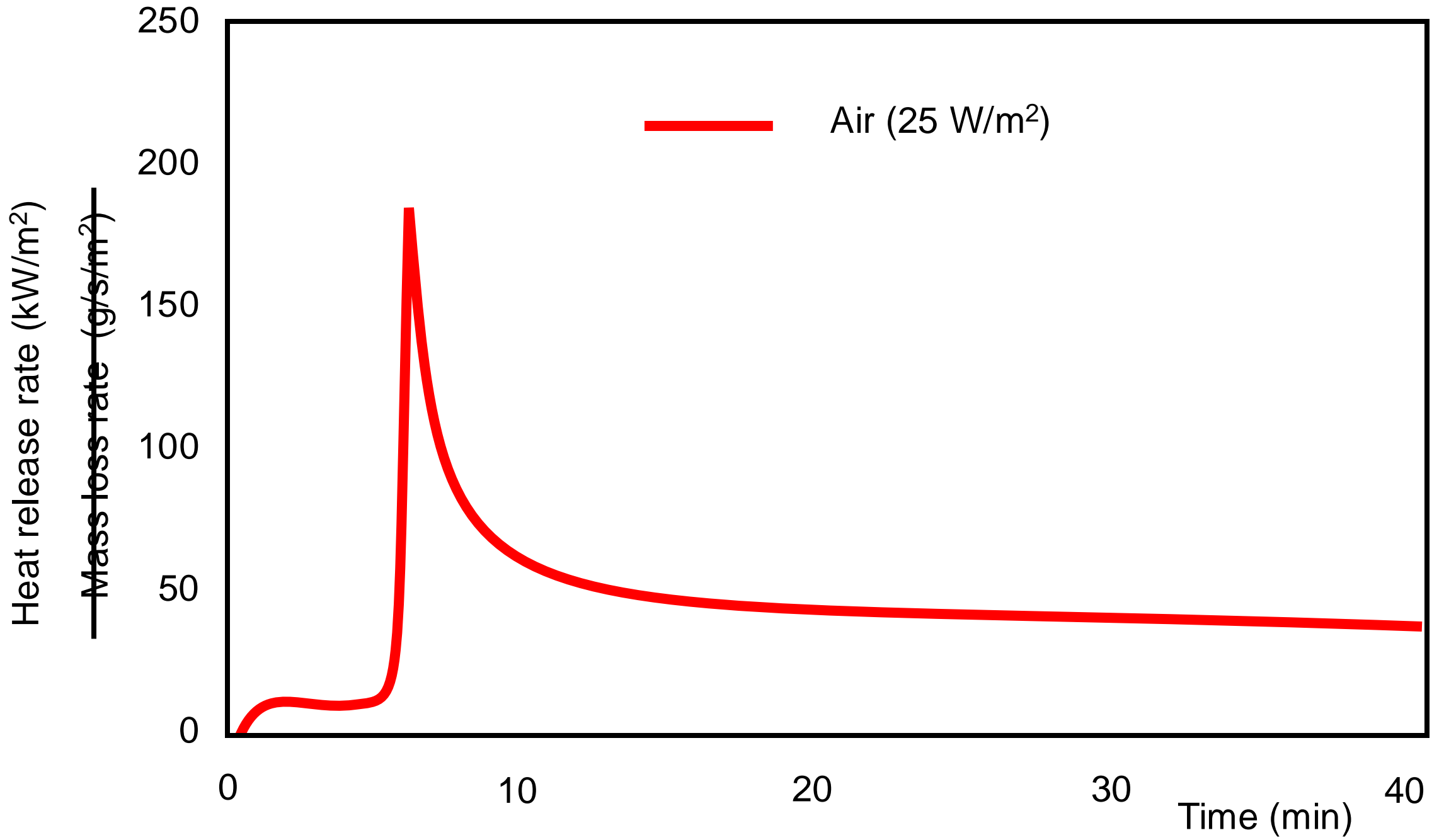
$$L_v = 1.82 \text{ MJ/kg}$$

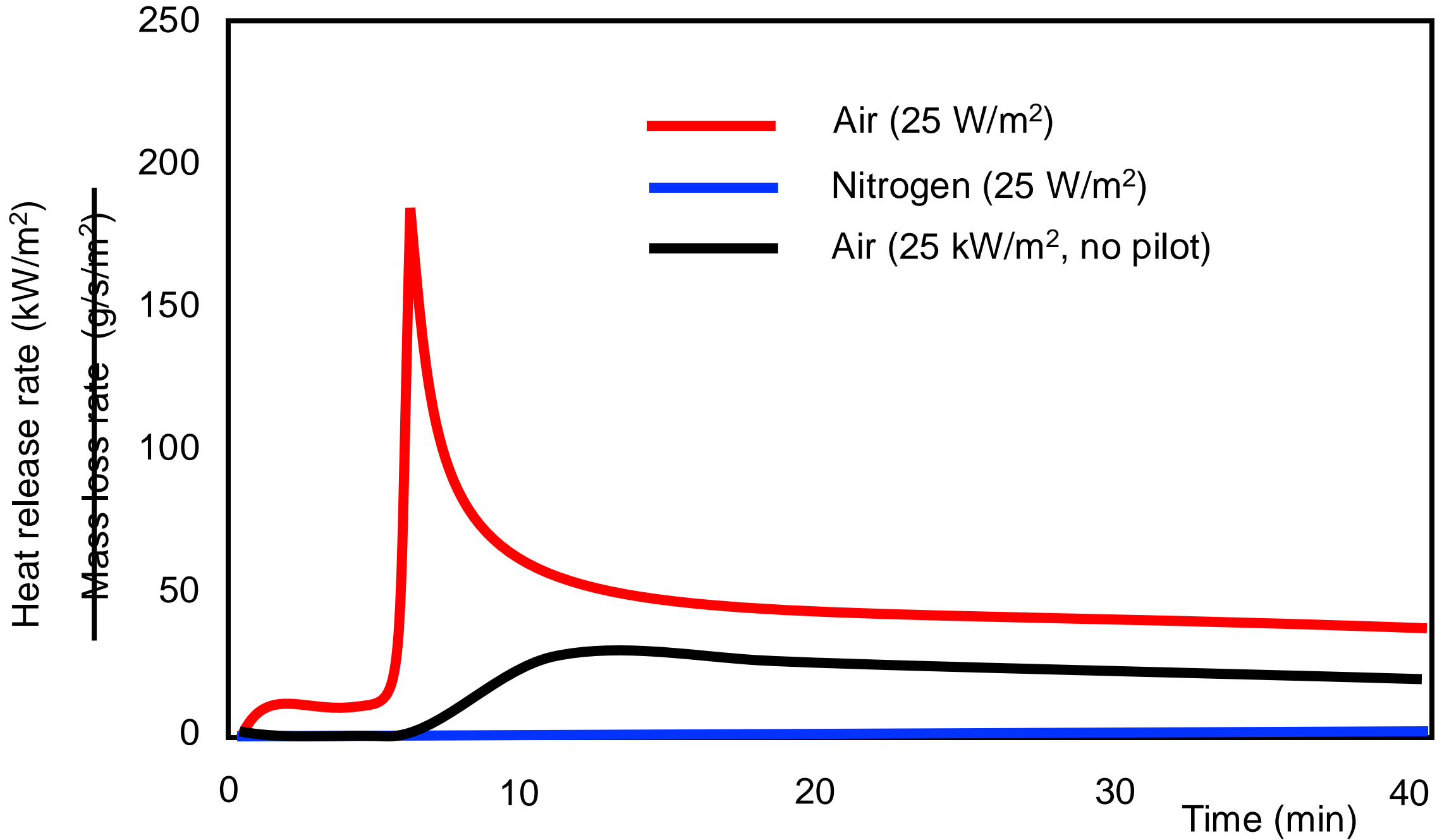


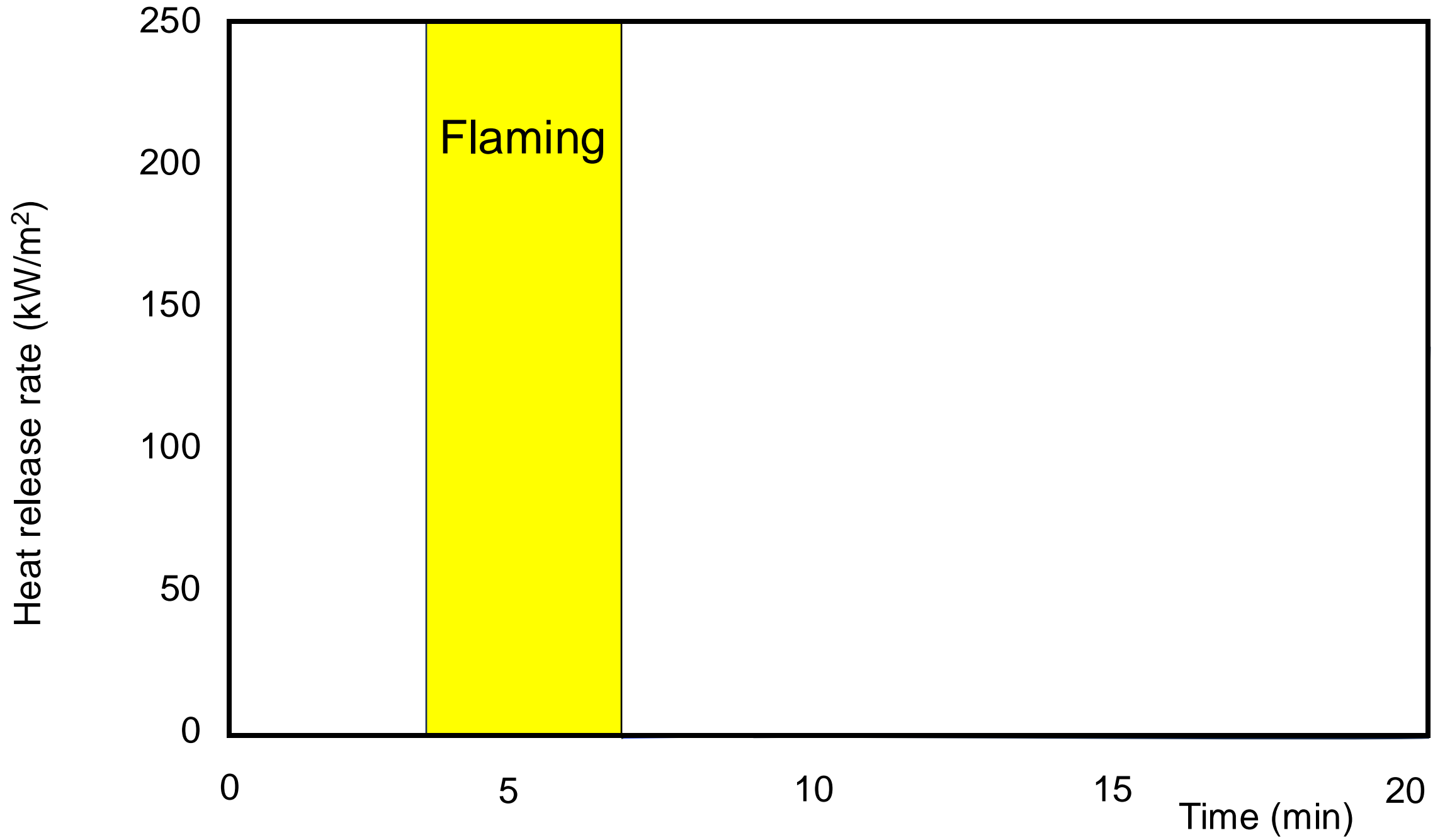
~20 kW/m<sup>2</sup> feedback from the flame  
~4 kW/m<sup>2</sup> feedback char oxidation

Total feedback around 3 kW/m<sup>2</sup> during **steady state**.

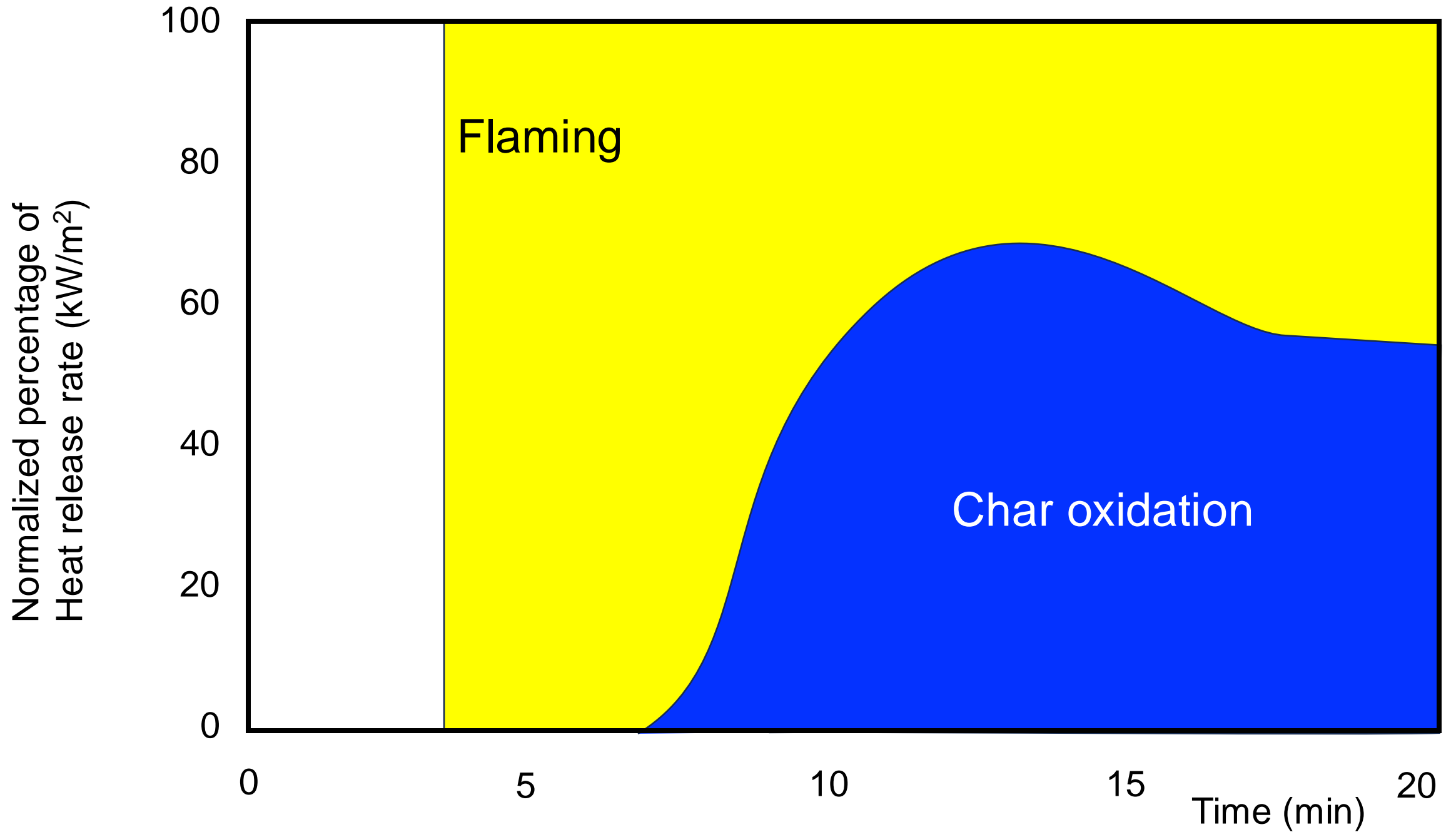
Feedback vs. heat released



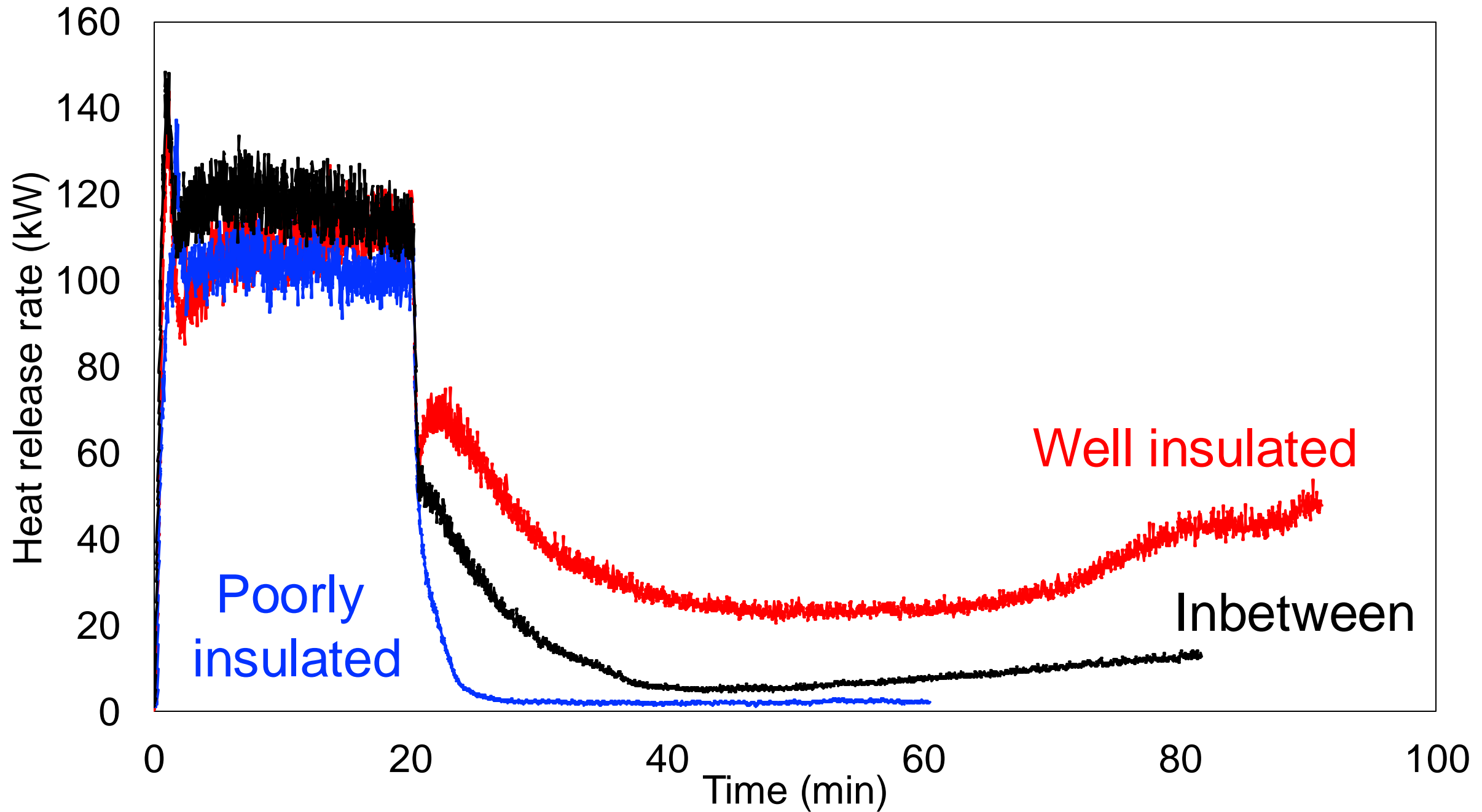




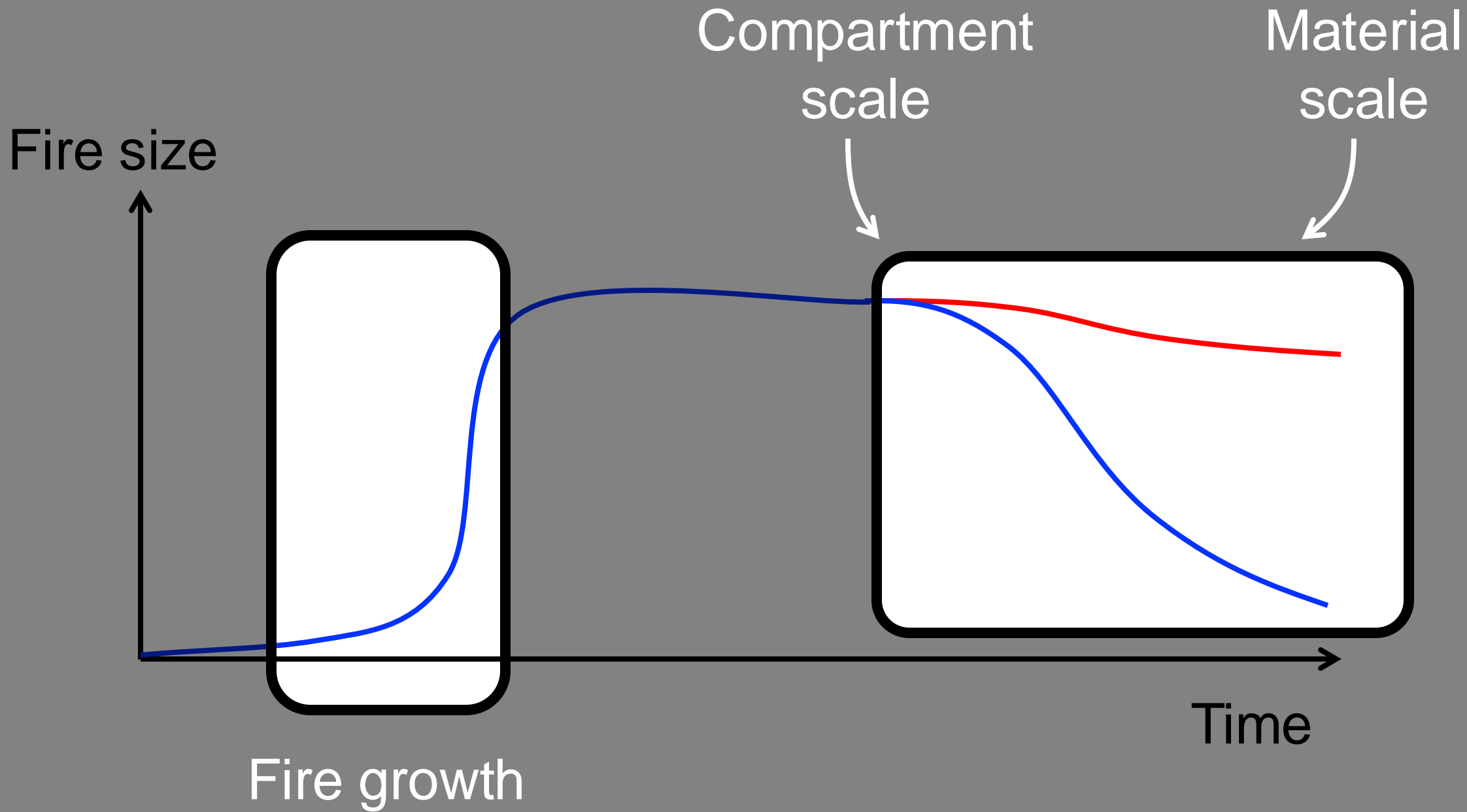




30-60% of heat release  
is from char oxidation.



Data: Ali Ahmed Awadallah (UoE PhD student)



**Ignition and behaviour of reduced scale compartments with timber ceiling**

James Greer<sup>a</sup>  
<sup>a</sup> School of Engineering,  
 The University of Edinburgh, United Kingdom

**Meta-analysis of temperature, heat release rate, delamination and auto-extinction of timber compartments**

Ahmed Ahmed Ali Awadallah<sup>a,b,\*</sup>, Rory M. Hadden<sup>a</sup>, Angus Law<sup>a</sup>  
<sup>a</sup> The University of Edinburgh, United Kingdom  
<sup>b</sup> The Institut National de la Recherche Scientifique, Canada

**1. Introduction**  
 The ignition of increasing relevant increasing use of combustible interior product within a compartment is potential to spread place limits on the characteristics of essential where fire. Timber is a main Although there are ignition and fire The material properties established (1,2). Values obtained for the ceiling configuration which char intensity despite the char as ignition of the buoyant plume fire

**Time dependent contribution of char oxidation and flame heat feedback on the mass loss rate of timber**

David Morrisett<sup>a</sup>, Rory M. Hadden<sup>a</sup>, Alastair I. Bartlett<sup>a</sup>, Angus Law<sup>a</sup>, Richard Emberley<sup>a,b</sup>  
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<sup>b</sup> School of Engineering, University of Edinburgh, UK

**1. Introduction**  
 The environment in which a material is burning plays a significant role in determining the energy balance of the material and thus dictates the burning rate of that material. This concept has been studied previously [1–3], however, at present there remains a relatively poor understanding of the processes which affect the burning of charring solids. The burning behaviour of such materials is controlled by the time dependent processes of heat feedback from the flame and char oxidation. These aspects are not explicitly addressed during material, char acceleration under standardized conditions such as the Cone Calorimeter [4] or the Fire Propagation Apparatus (FPA) [5]. In these cases, a defined heat flux is applied to the surface of a sample, and the time to ignition, mass loss rate, and total release rate are recorded. No explicit analysis of the energy balance on the material is made and hence the explicit burning behaviour is not elucidated. This lack of explicit understanding has implications when applying such data to contexts different than those in which it is measured. The key distinction between charring and non-charring material's relates to the occurrence of time-dependent char layer formation, which alters the heat transfer into the material and hence the pyrolysis rate of the volatiles material [6]. In turn, the pyrolysis rate determines whether a flammable mixture can exist and, if so, also determines the energy transferred from the flame to the surface. Finally, the char layer itself will undergo an oxidative process resulting in additional energy release. The formation of the char layer alters the energy balance on the surface of the material resulting in a decrease in the heat flux entering the pyrolysis zone. This effect is strongly dependent on time and the environment in which it is tested. In order to develop a more complete understanding of the burning of charring materials, it is essential to understand how these processes contribute to the burning of charring solids. One of the more common charring materials of interest in the context of engineering and the fire safety science is timber. The burning of timber is complicated by the heterogeneity of the material, changes to the physical dimensions of a burning sample, and thermo-mechanical processes such as shrinkage, cracking and, in the case of engineered laminated timber, char fall off. In recent years, there has been an increase in the use of timber in the built environment due to various factors such as sustainable building practices and ease of construction. Thus, timber adds a level of complexity to the design of a structure from the perspective of the fire safety. Properly characterizing the process by which

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**Quantifying the heat release from char oxidation in timber**

Cameron E. M.  
<sup>a</sup> School of Engineering,  
 The University of Edinburgh, United Kingdom

**Observations and impact of char layer formation and loss for engineered timber**

Iaura Schmidt<sup>a,b,c,\*</sup>, Rory M. Hadden<sup>a</sup>, Dilum Fernando<sup>b,c</sup>  
<sup>a</sup> The International Master of Science in Fire Safety Engineering (IMSFSE), Osnabrück University, Osnabrück  
<sup>b</sup> School of Engineering, The University of Edinburgh, United Kingdom  
<sup>c</sup> School of Civil Engineering, The University of Queensland, Australia

**1. Introduction**  
 Heat release is of material to a fire. It that results in energy and oxidation of the energy release but is characterized by low flaming, due to the high experimental, varied porosity because it is With the increase the widespread use important to understand place during all fire safety, property, zone char oxidation have the context of mass flaming, char growth and initial covers, at longer time based by charring Wisner et al. [7] considered in fire

**Application of microscale methods to study the heat-induced delamination in engineered wood products bonded with one-component polyurethane adhesives**

Colic A.<sup>a</sup>, Wiesner F.<sup>a</sup>, Hopkin D.<sup>a</sup>, Spearpoint M.<sup>a</sup>, Wu W.<sup>a</sup>, Bisby L.<sup>a</sup>  
<sup>a</sup> The University of Edinburgh, School of Engineering, Edinburgh, Scotland;  
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<sup>c</sup> The University of British Columbia, Vancouver, Canada; felix.wiesner@ubc.ca

**1. Introduction**  
 Engineered timber aesthetic benefits. Consequently, there construction [1–3] widespread adoption high-rise buildings generally make use of internal fire-fight provisions requiring the full burnout (i.e. cost well as self-extraction mass timber structure). The challenges as structure are related structure and the fire fire dynamics). The compartment size (i.e. bo

**A Review of Factors Affecting the Burning Behaviour of Wood for Application to Tall Timber Construction**

Alastair I. Bartlett<sup>a</sup>, Rory M. Hadden and Luke A. Bisby  
<sup>a</sup> School of Engineering, The University of Edinburgh, The King's Buildings, Mayfield Road, Edinburgh EH9 3JW, UK

**Abstract.** This paper presents a review of the pyrolysis, ignition, and combustion processes associated with wood, for application in tall timber construction. The burning behaviour of wood is complex. However the processes behind pyrolysis, ignition, combustion, and extinction are generally well understood, with good agreement in the fire science literature over a wide range of experimental conditions for key parameters such as critical heat flux for ignition (12 kW/m<sup>2</sup> ± 2 kW/m<sup>2</sup>) and heat of combustion (17.5 MJ/kg ± 2.5 MJ/kg). These parameters are key for evaluating the risks posed by using timber as a construction material. Conversely, extinction conditions are less well defined and understood, with critical mass loss rates for extinction varying from 2.5 g/m<sup>2</sup> to 5 g/m<sup>2</sup>. A detailed meta-analysis of the fire resistance literature has shown that the rate of burning as characterised by charring rate averaged over the full test duration is observed to vary with material properties, in particular density and moisture content which indicate a maximum 18% variability over the range expected in design. System properties are also shown to be important, with stochastic phenomena such as delamination and encapsulation failure resulting in changes to the charring rate that cannot be easily predicted. Finally, the fire exposure as defined by incident heat flux has by far the largest effect on charring rates over typical heat fluxes experienced in compartment fires. Current fire design guidance for engineered timber products is largely prescriptive, relying on fixed “charring rates” and “zero-strength layers” for structural analyses, and typically prescribing gypsum encapsulation to prevent or delay the involvement of timber in a fire. However, it is clear that the large body of scientific knowledge that exists can be used to explicitly address the fire safety issues that the use of timber introduces. However the application of this science in real buildings is identified as a key knowledge gap which if explored, will enable improved efficiencies and innovations in design.

**Keywords:** Timber, Fire, Pyrolysis, Charring, Fire safety engineering, Building design.

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- <https://doi.org/10.1016/j.firesaf.2023.103793>
- <https://doi.org/10.1007/s10694-018-0787-y>

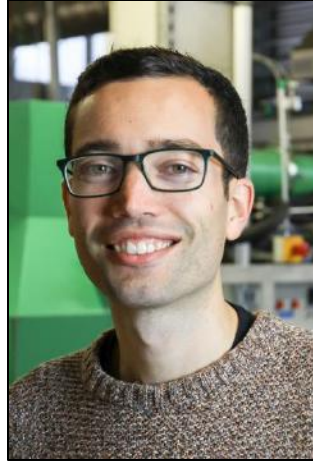
# Thanks to all involved!



Ali Ahmed  
Awadallah



Luke  
Bisby



Zak Campbell-  
Lochrie



Antonela  
Colic



Swagata  
Dutta



James  
Greer



Rory  
Hadden



Angus  
Law



Cameron  
MacLeod



David  
Morrisset



Mark  
Partington



Ian  
Pope



Laura  
Schmidt



# Questions

The background of the image is a close-up of a wooden surface with a prominent, wavy grain pattern. The wood is light-colored, ranging from pale yellow to a warm tan. The grain lines are irregular and undulating, creating a textured, organic appearance. The lighting is even, highlighting the natural texture and color variations of the wood.

# Feedback (kW/m<sup>2</sup>)

	Flame contribution	Oxidation contribution	Combined Peak (steady-state)
20 kW/m <sup>2</sup>	20.6	4.1	24.7
25 kW/m <sup>2</sup>	19.9	3.4	23.3 (2.5)
40 kW/m <sup>2</sup>			17.6 (2.6)
60 kW/m <sup>2</sup>			12.4 (2.9)