THE UNIVERSITY of EDINBURGH
School of Engineering

Timber updates from Edinburgh

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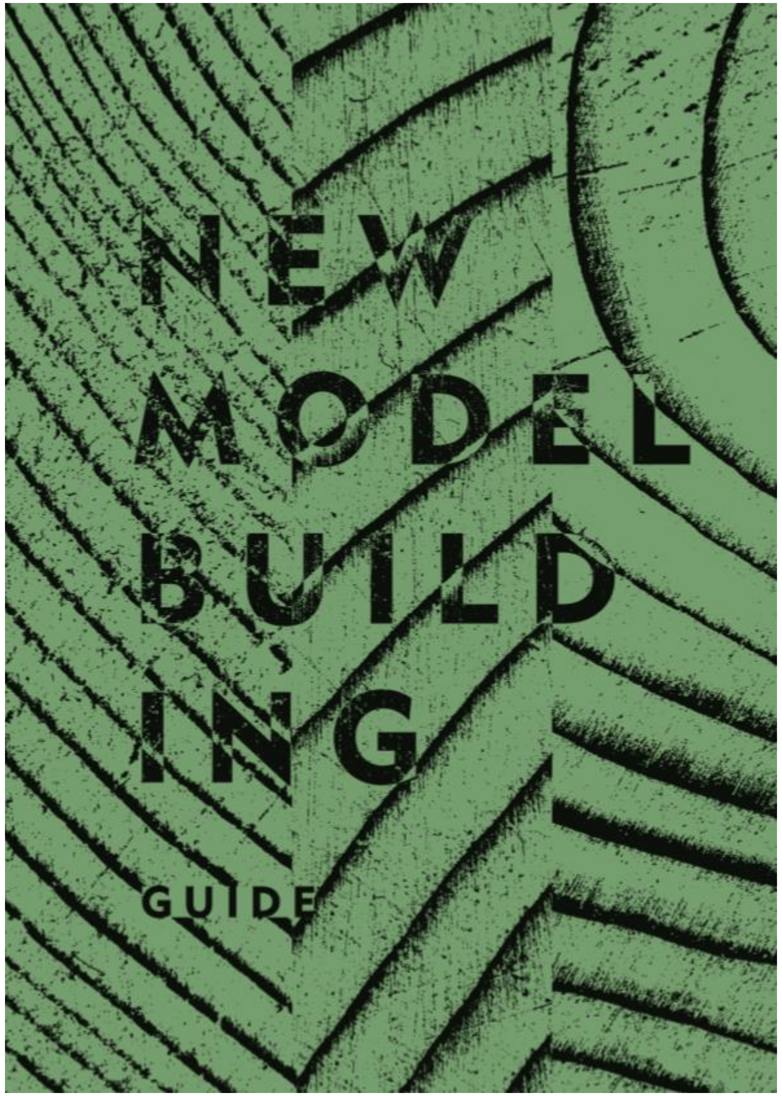
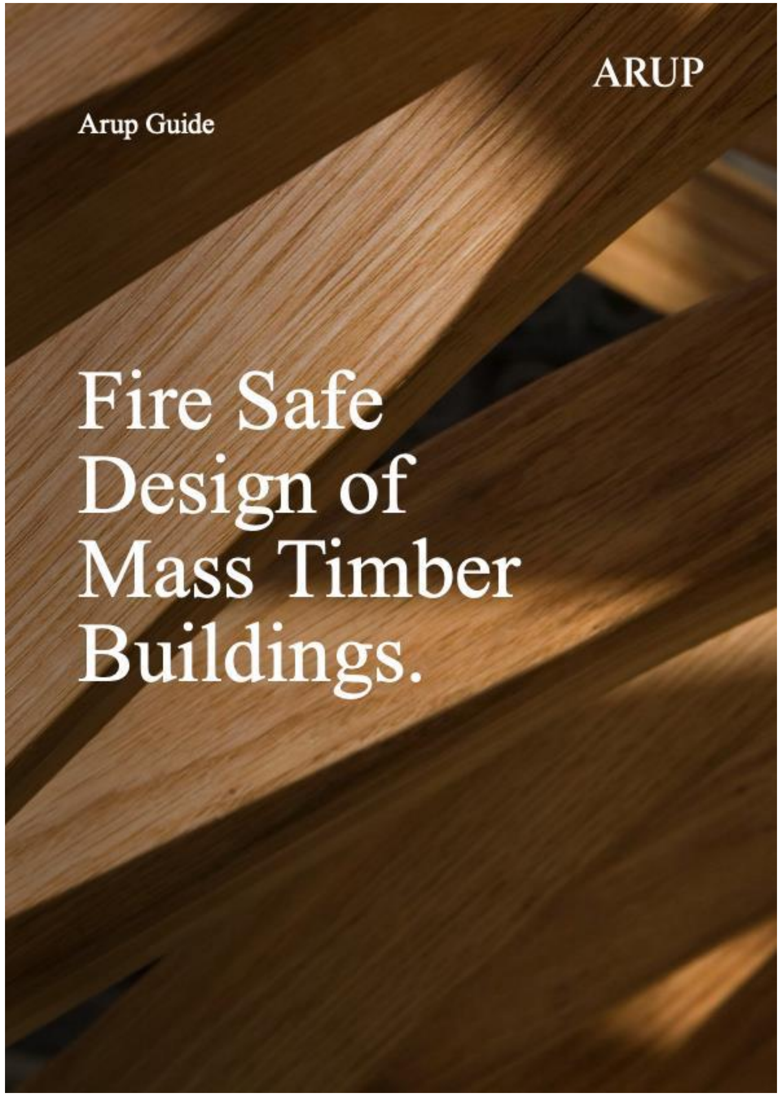
Senior Lecturer in Fire Safety Engineering
The University of Edinburgh

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

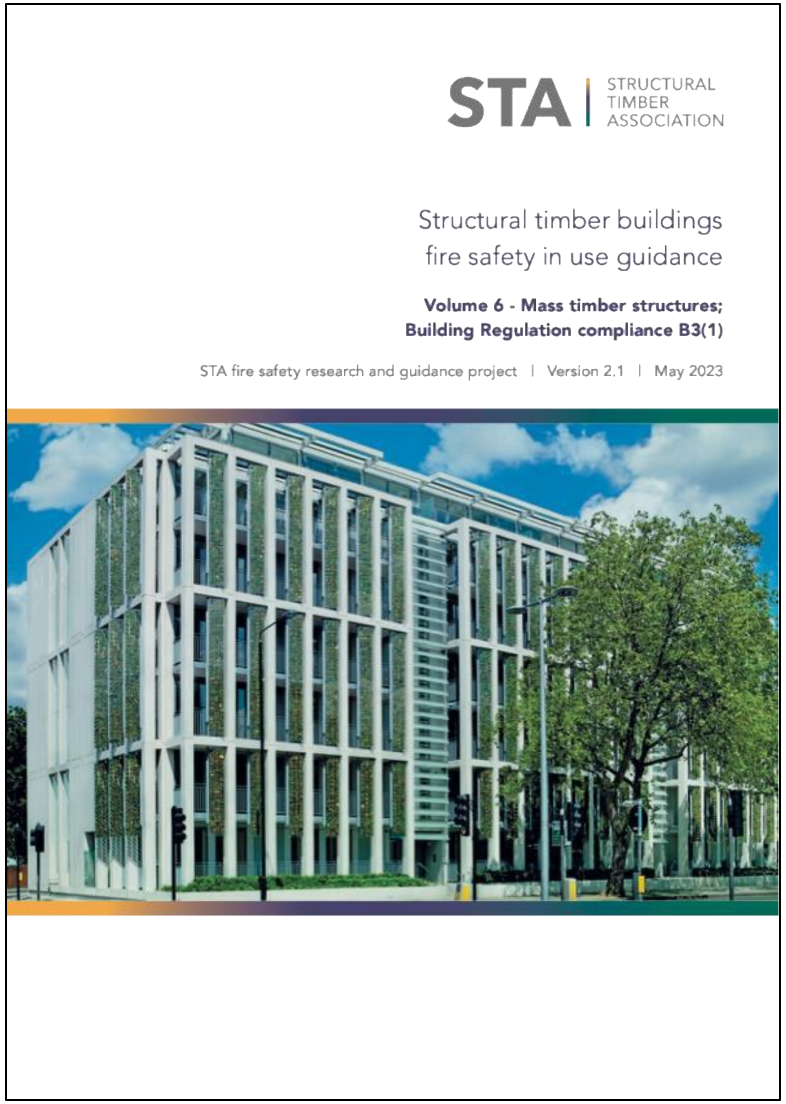
Industry have been busy.



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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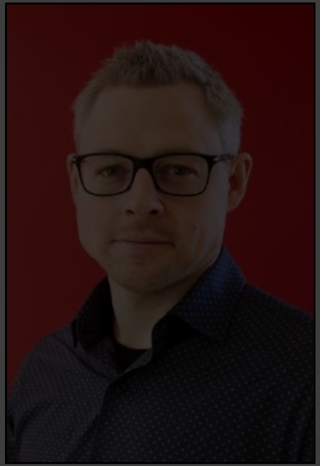
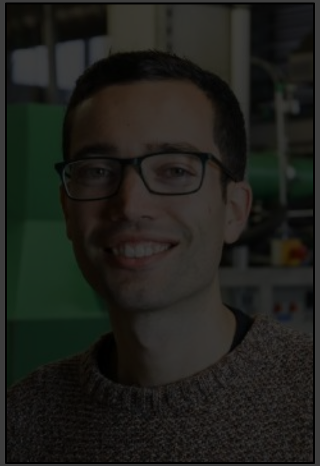
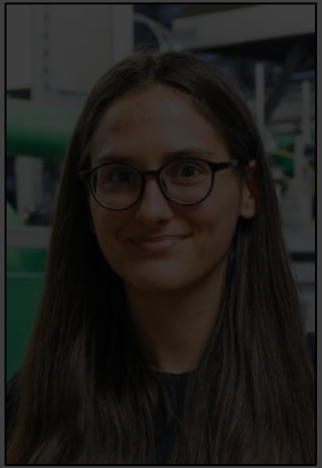


Luke Bisby



Zak Campbell-Lochrie



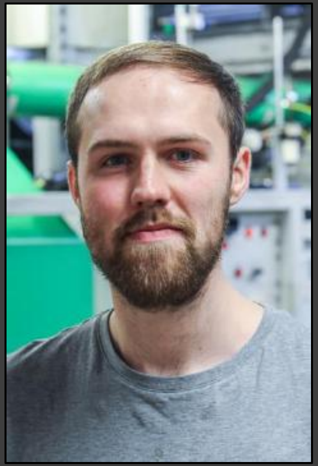
Antonela Colic

Swagata Dutta

James Greer

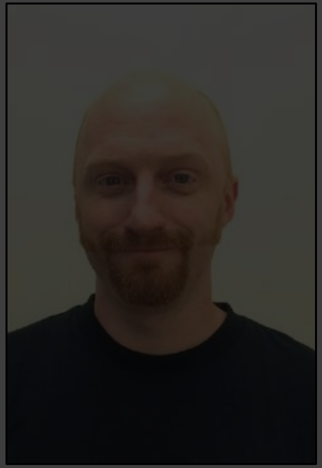
Rory Hadden

Angus Law



Cameron MacLeod

David Morrisset

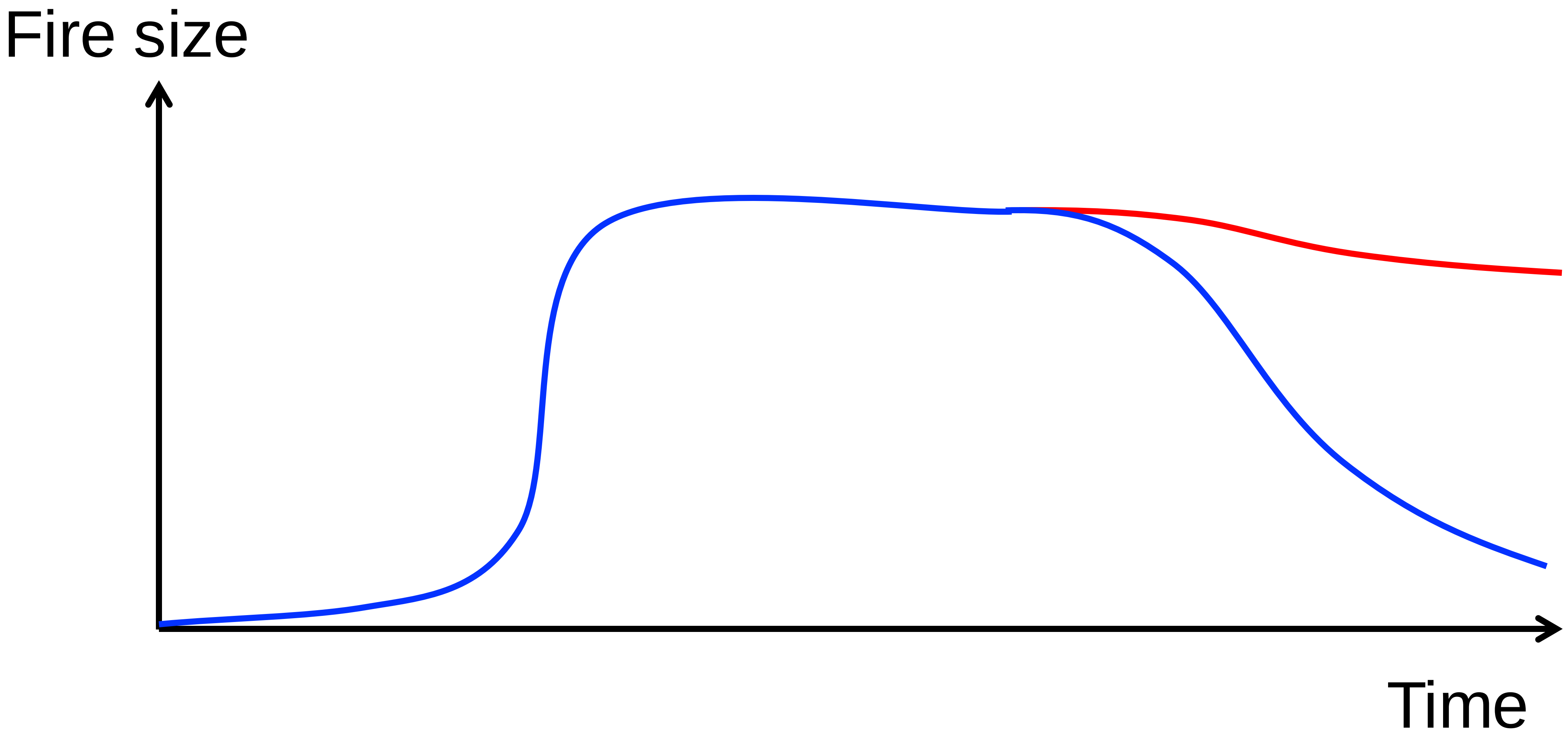


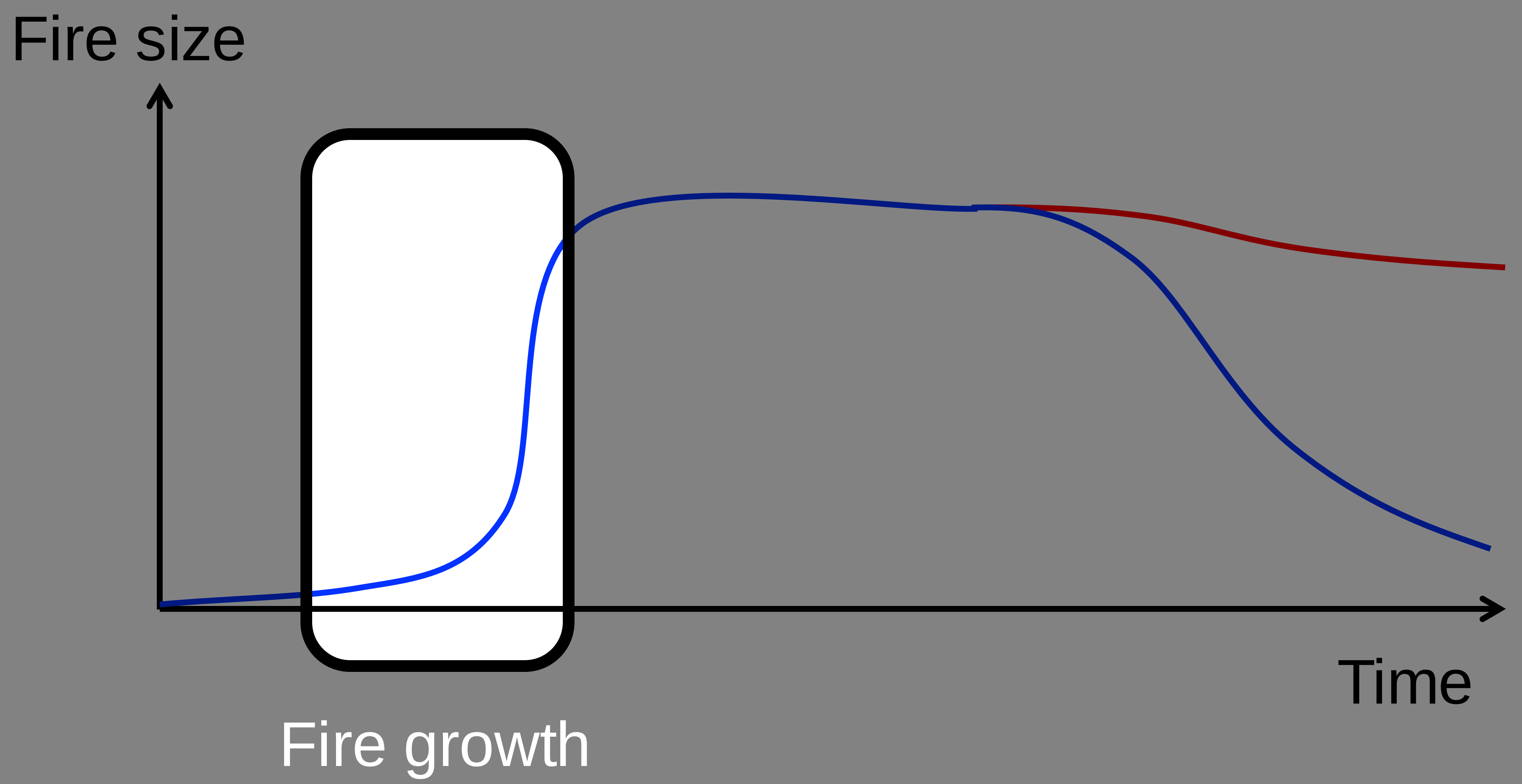
Mark Partington

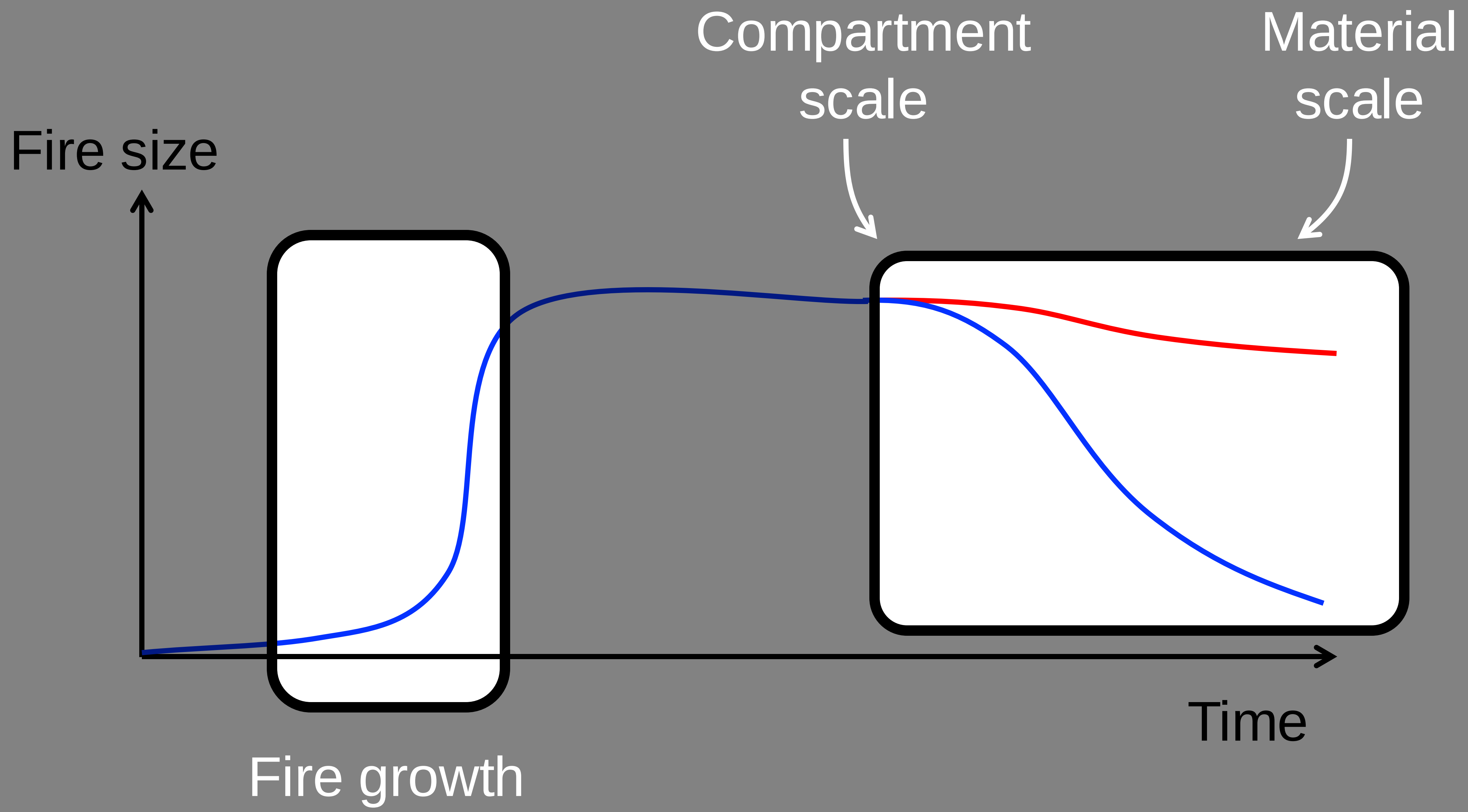
Ian Pope

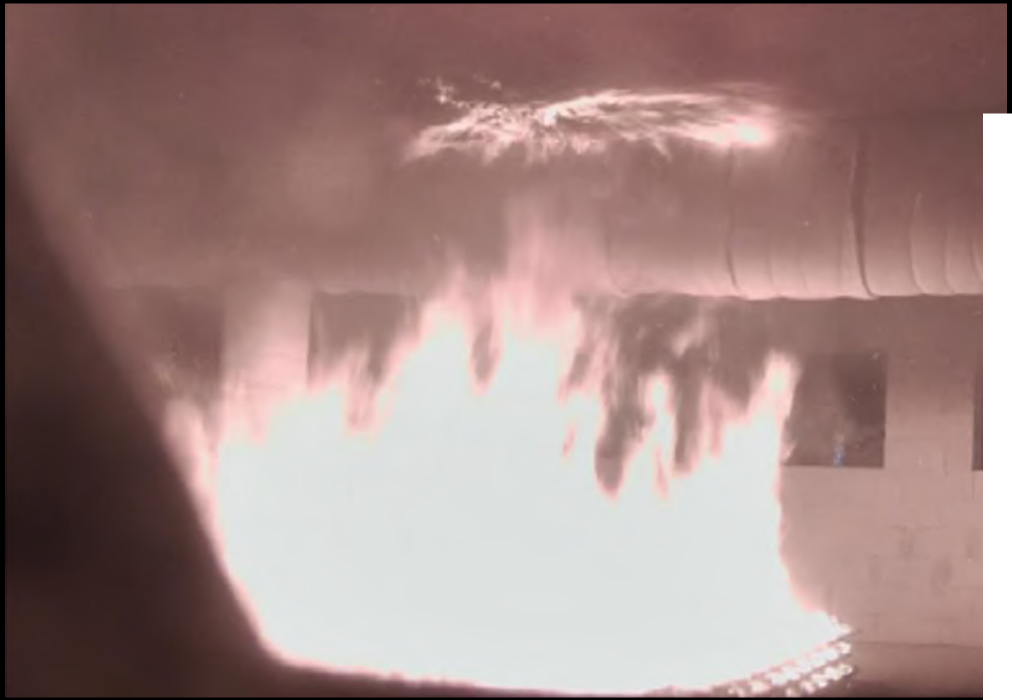
Laura Schmidt

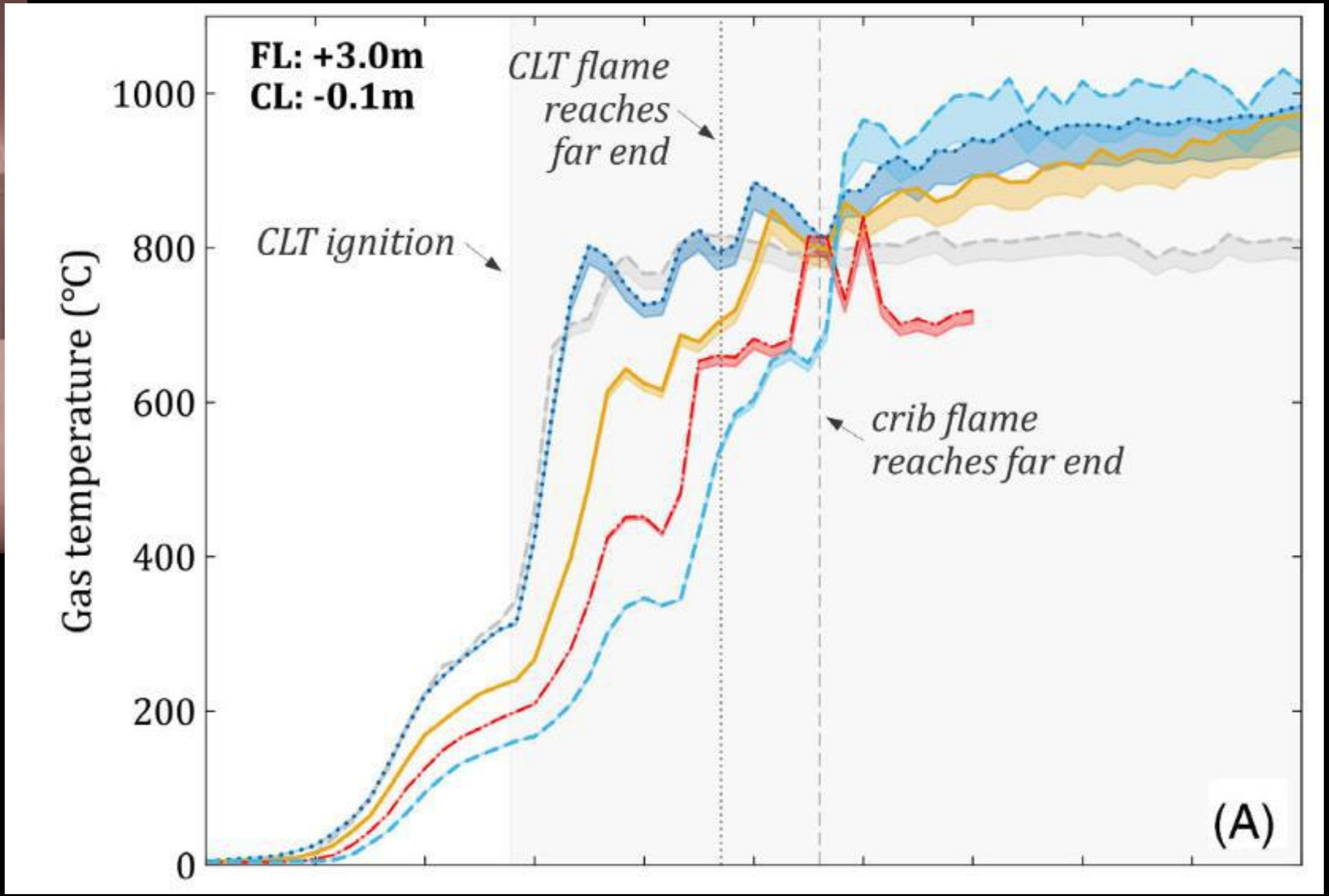
Why should we care?!


Fire size
Time

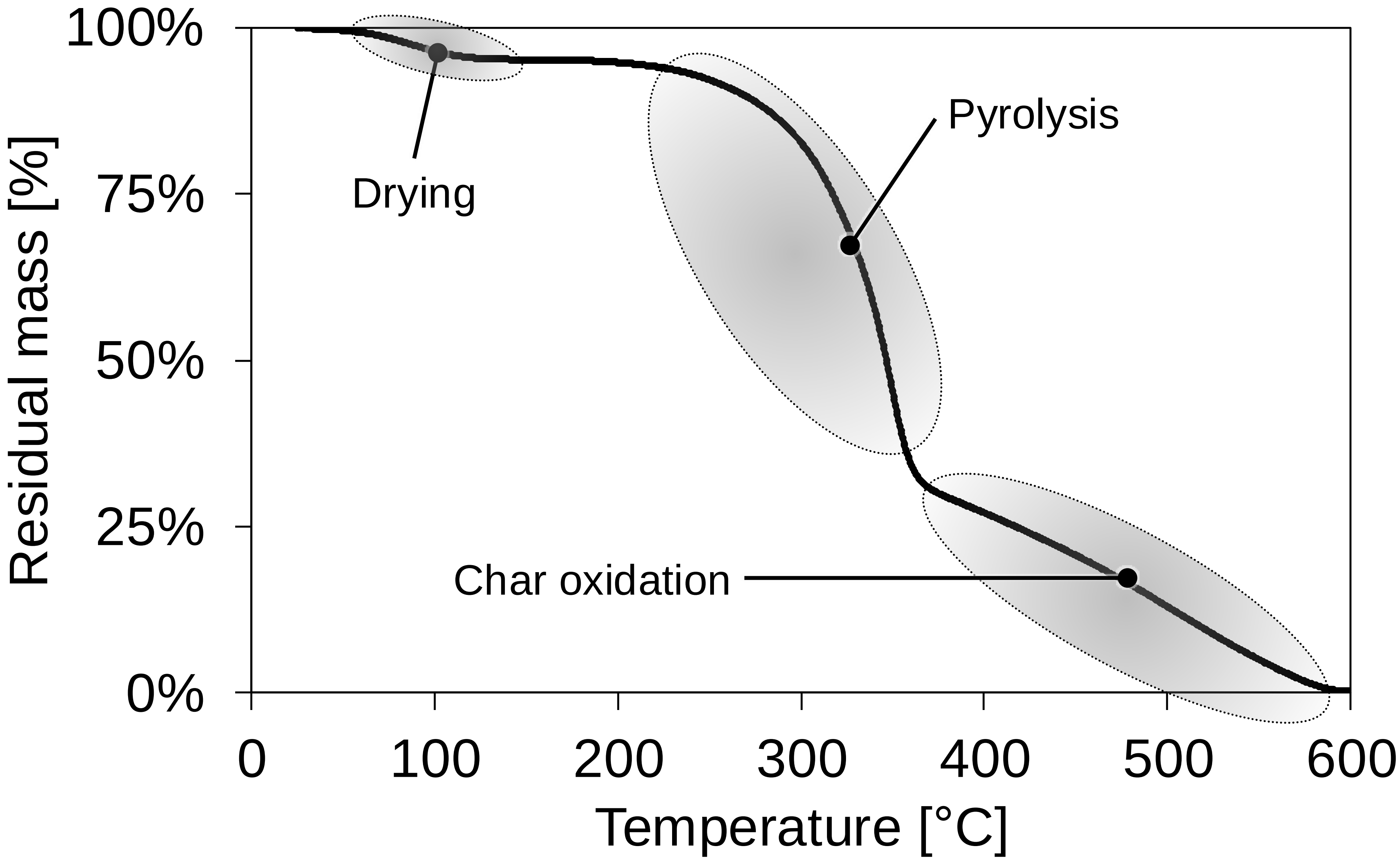

Fire size
Time
Fire growth


Compartment
scale
Material
scale
Fire size
Time
Fire growth

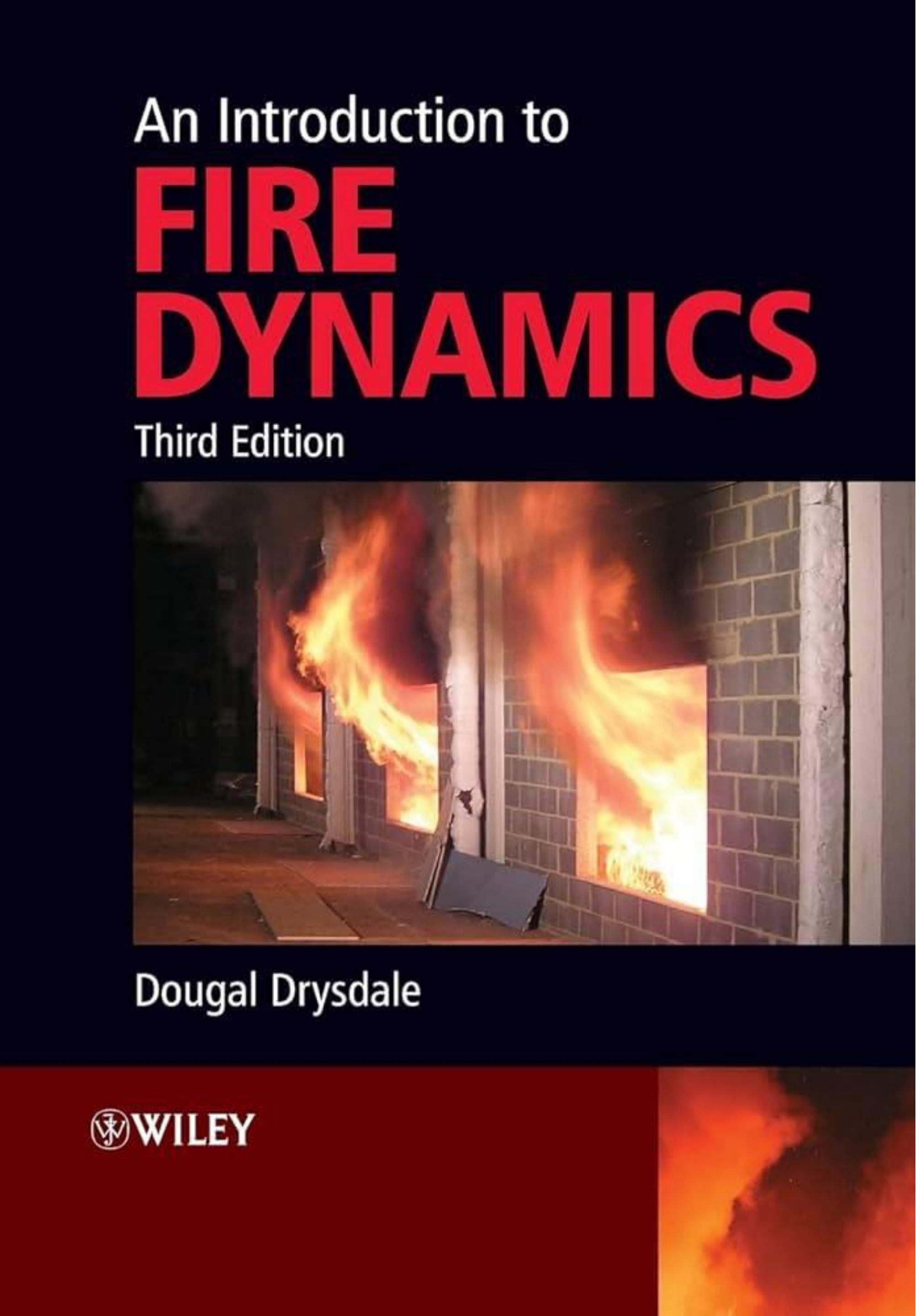


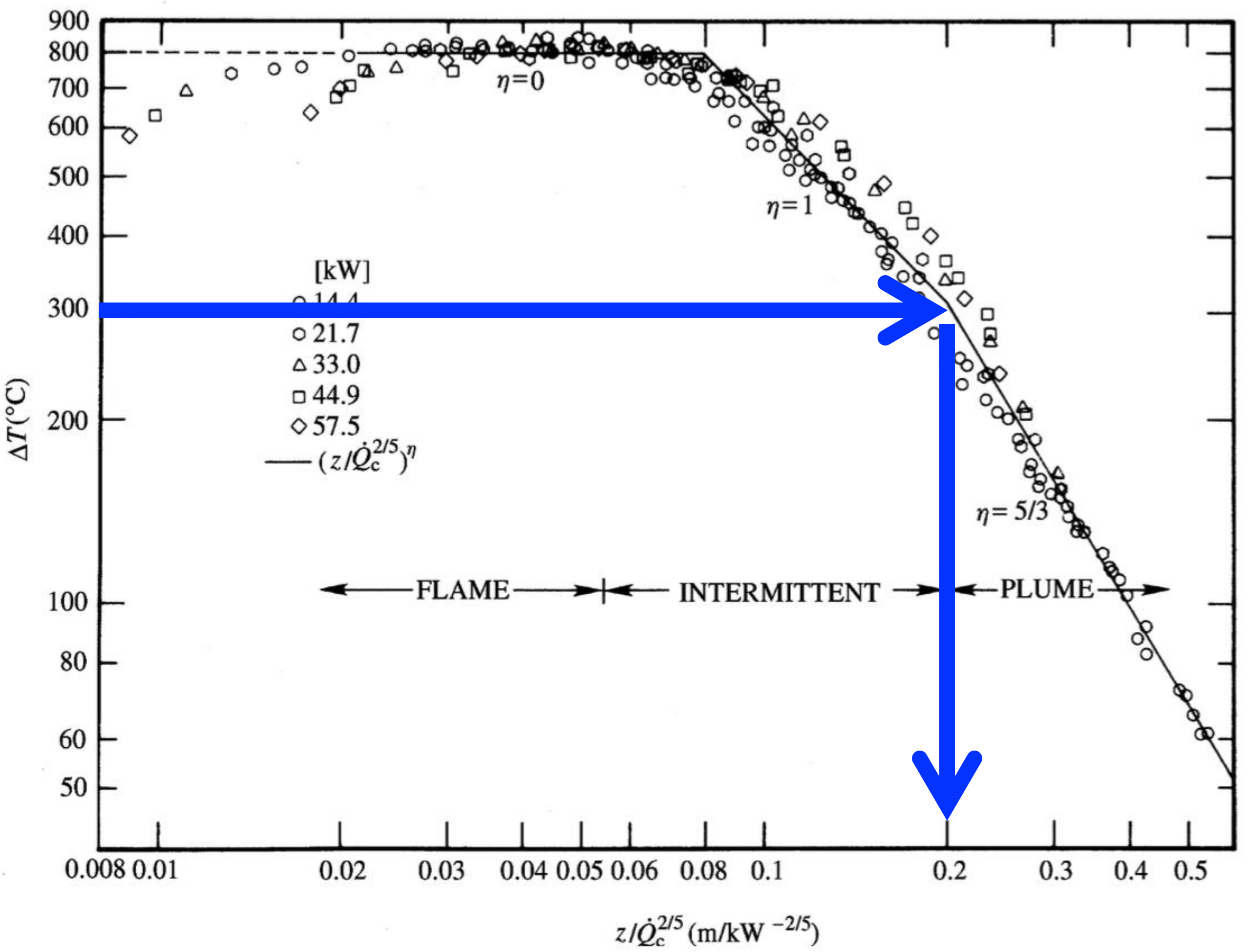


Kotsovinos P, Rackauskaite E, Christensen E, et al. Fire dynamics inside a large and open-plan compartment with exposed timber ceiling and columns: *CodeRed #01*. *Fire and Materials*. 2023; 47(4): 542-568. doi:10.1002/fam.3049

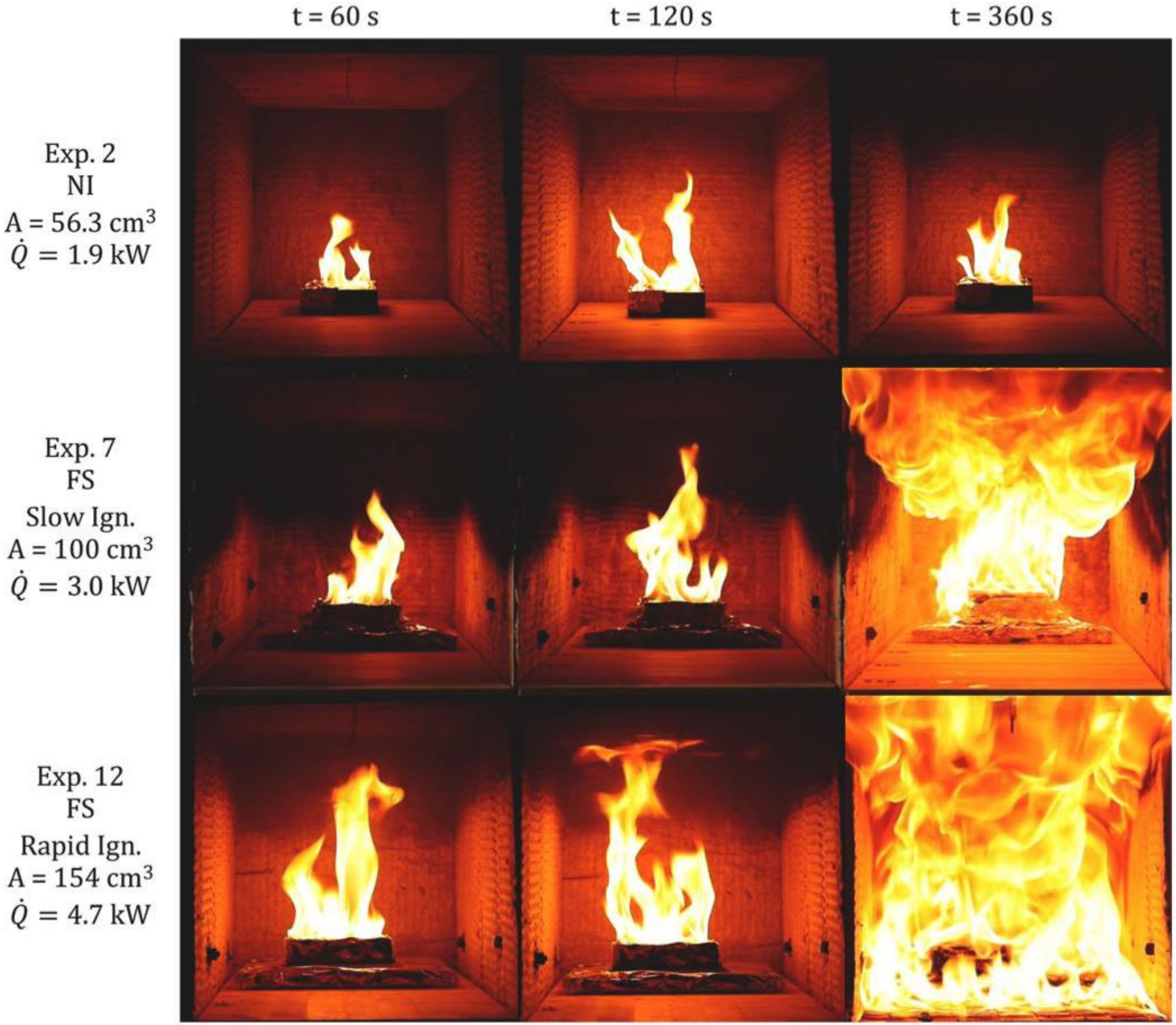


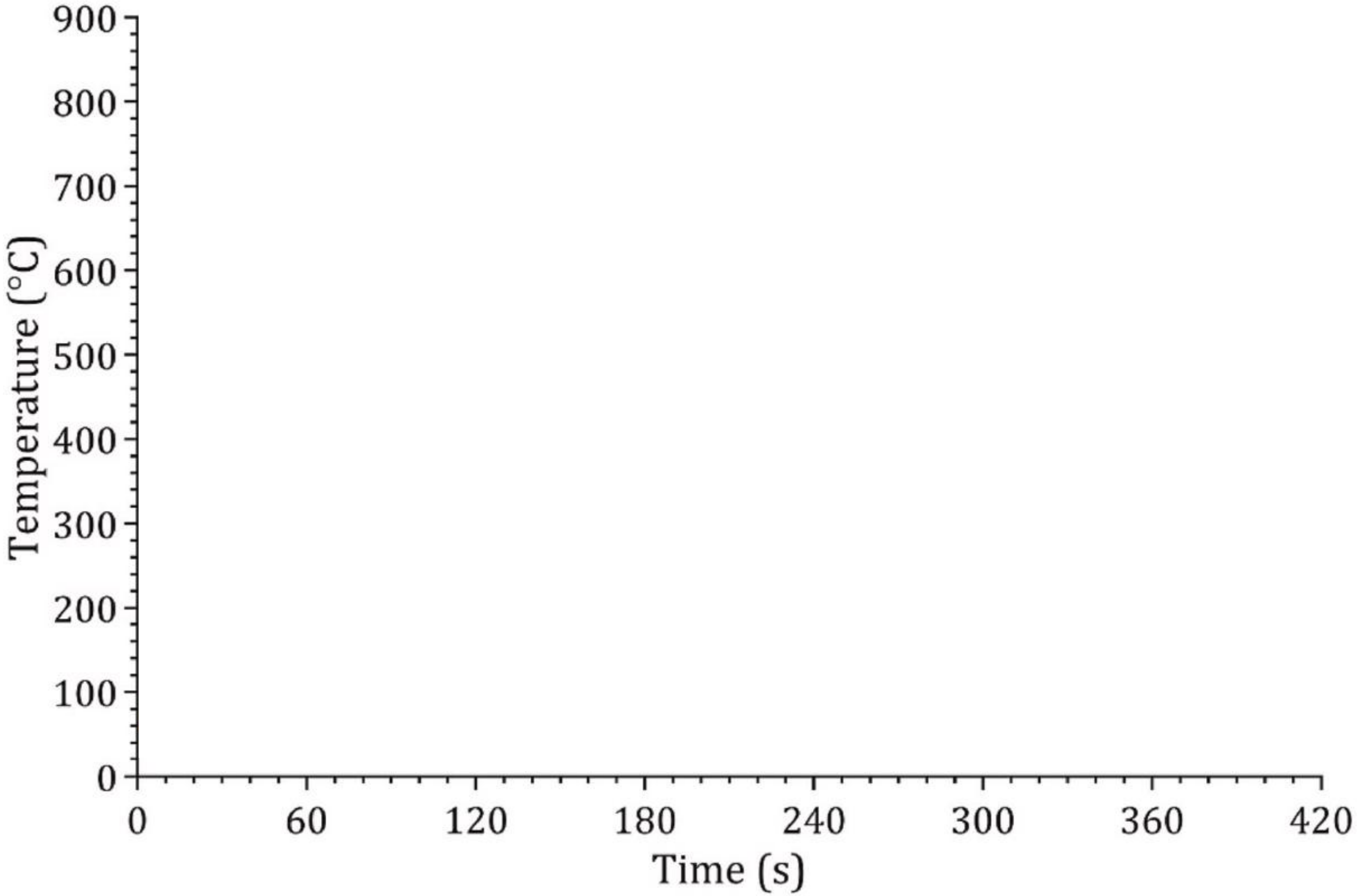
100%
75%
50%
25%
0%
Residual mass [%]
0
100
200
300
400
500
600
Temperature [°C]
Drying
Pyrolysis
Char oxidation

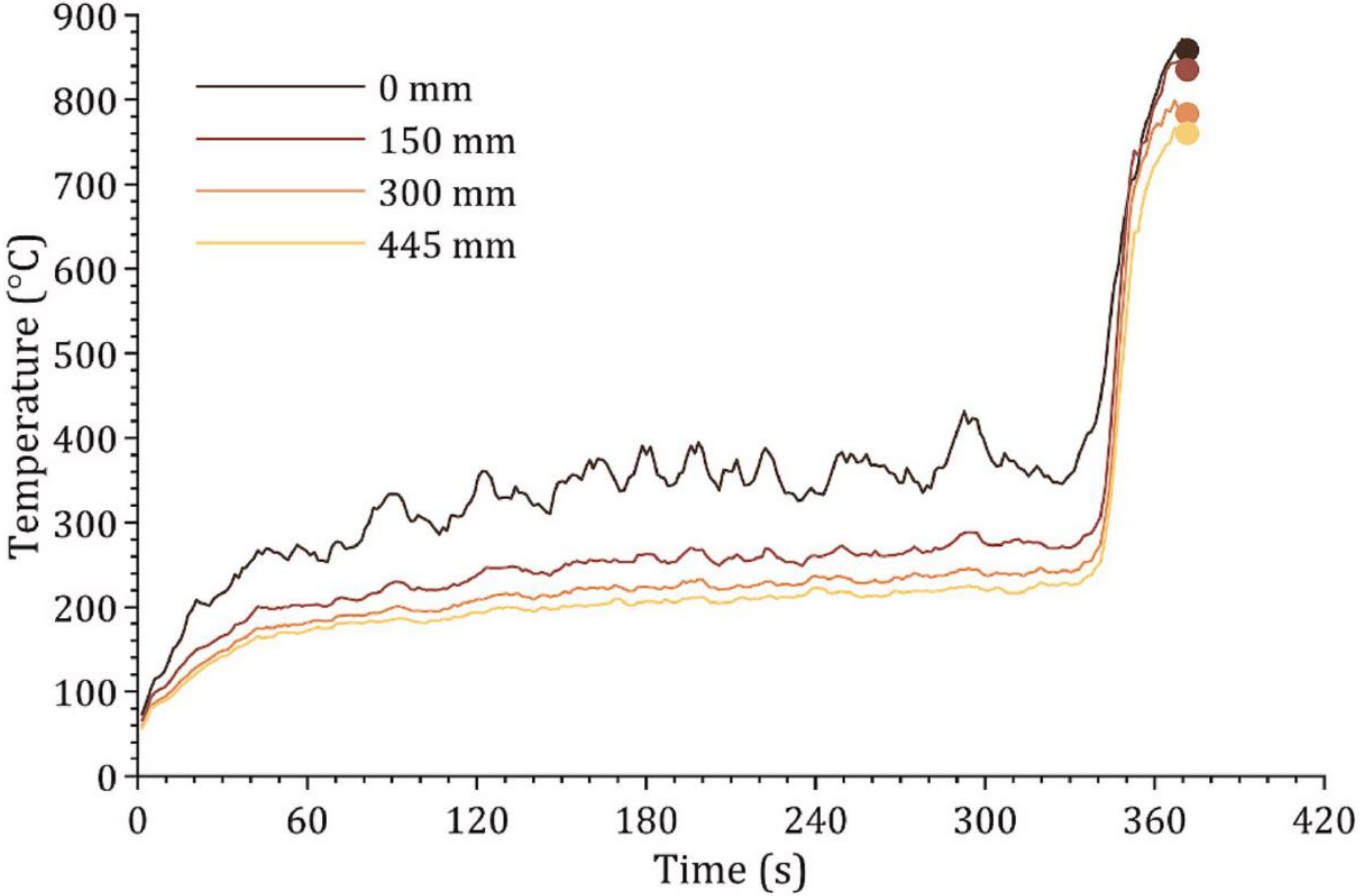

An Introduction to
FIRE
DYNAMICS
Third Edition
Dougal Drysdale
WILEY


ΔT(°C)
900
800
700
600
500
400
300
200
100
80
60
50
η=0
η=1
η= 5/3
[kW]
21.7
33.0
44.9
57.5
(z/Q̇c^2/5)^η
FLAME
INTERMITTENT
PLUME
0.008 0.01
0.02
0.03
0.04 0.05 0.06
0.08 0.1
0.2
0.3
0.4
0.5
z/Q̇c^2/5 (m/kW^-2/5)

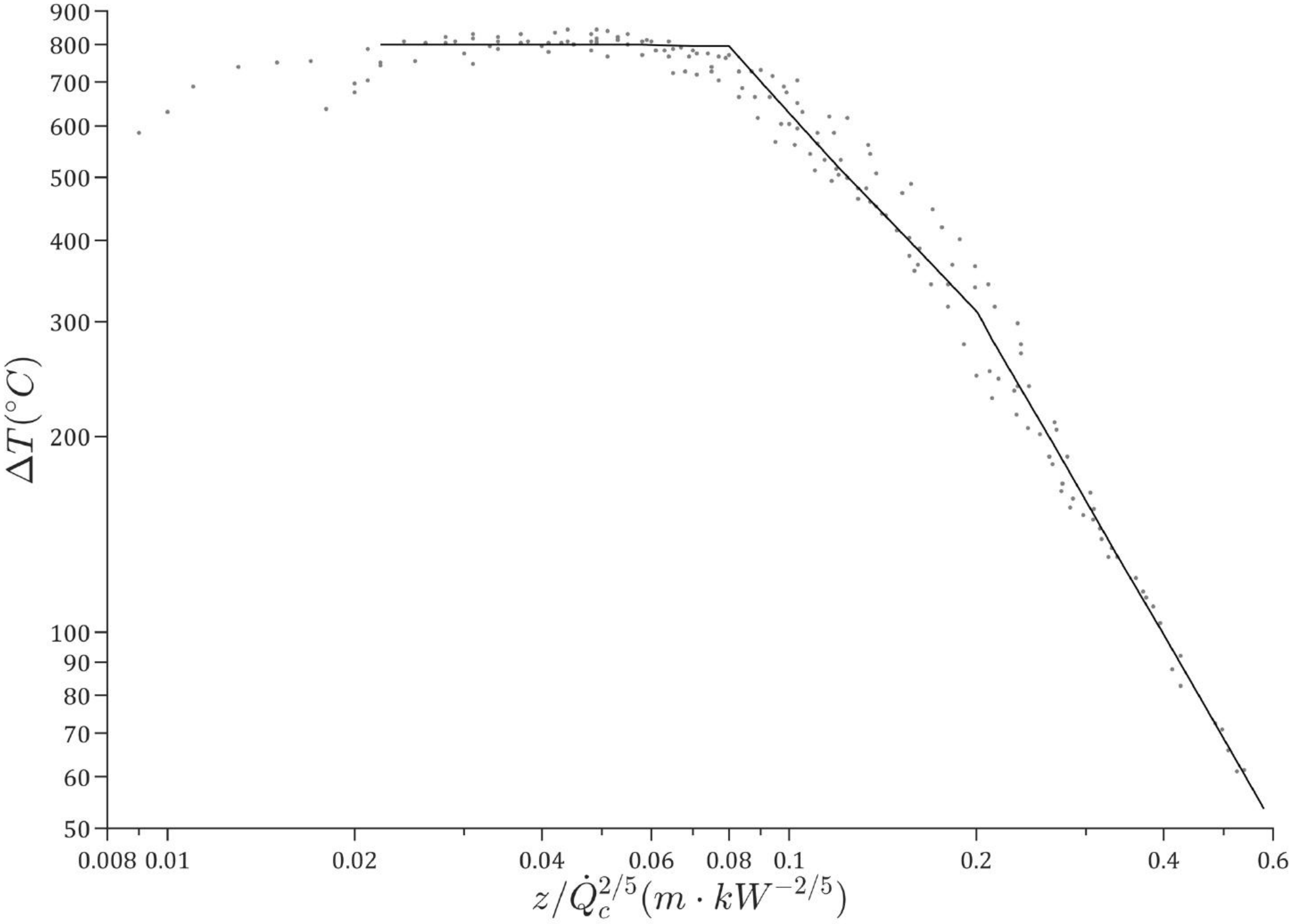

Timber ceiling
Inert walls
Inert walls
Inert walls
Timber floor

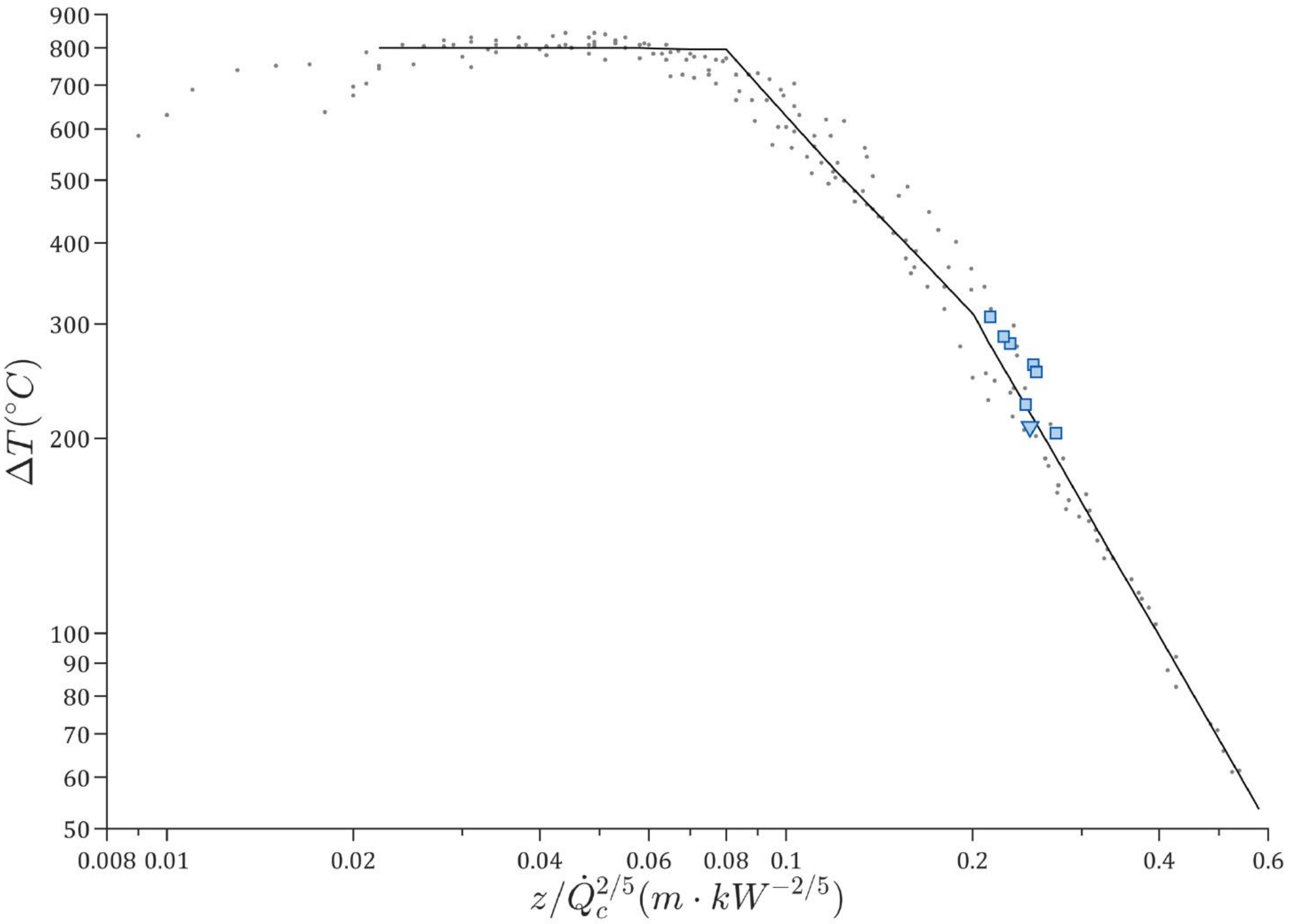

t = 60 s
t = 120 s
t = 360 s
Exp. 2
NI
A = 56.3 cm^3
$\dot{Q}$ = 1.9 kW
Exp. 7
FS
Slow Ign.
A = 100 cm^3
$\dot{Q}$ = 3.0 kW
Exp. 12
FS
Rapid Ign.
A = 154 cm^3
$\dot{Q}$ = 4.7 kW


900
800
700
600
500
400
300
200
100
0
Temperature (°C)
0
60
120
180
240
300
360
420
Time (s)



0 mm
150 mm
300 mm
445 mm
Temperature (°C)
Time (s)
0
100
200
300
400
500
600
700
800
900
60
120
180
240
300
360
420


900
800
700
600
500
400
300
200
100
90
80
70
60
50
$\Delta T(^{\circ}C)$
0.008
0.01
0.02
0.04
0.06
0.08
0.1
0.2
0.4
0.6
$z/\dot{Q}_c^{2/5}(m \cdot kW^{-2/5})$



900
800
700
600
500
400
300
200
100
90
80
70
60
50
$\Delta T(^{\circ}C)$
0.008
0.01
0.02
0.04
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0.4
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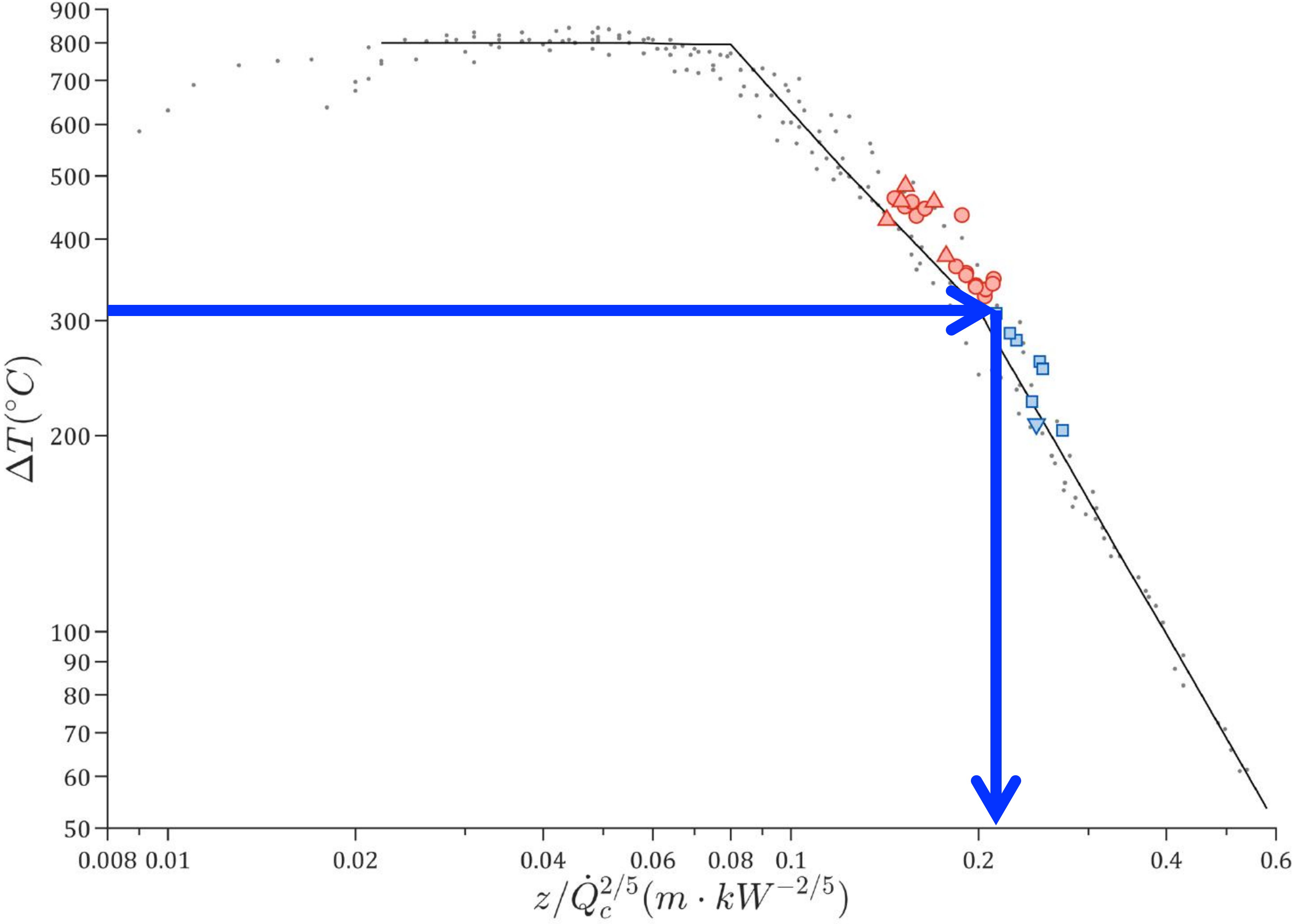

900
800
700
600
500
400
300
200
100
90
80
70
60
50
$\Delta T(^{\circ}C)$
0.008 0.01
0.02
0.04
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0.4
0.6
$z/\dot{Q}_c^{2/5}(m \cdot kW^{-2/5})$

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 ϕ. 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

$$z_f = 0.2 Q_t^{2/5} \tag{6.55}$$

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).

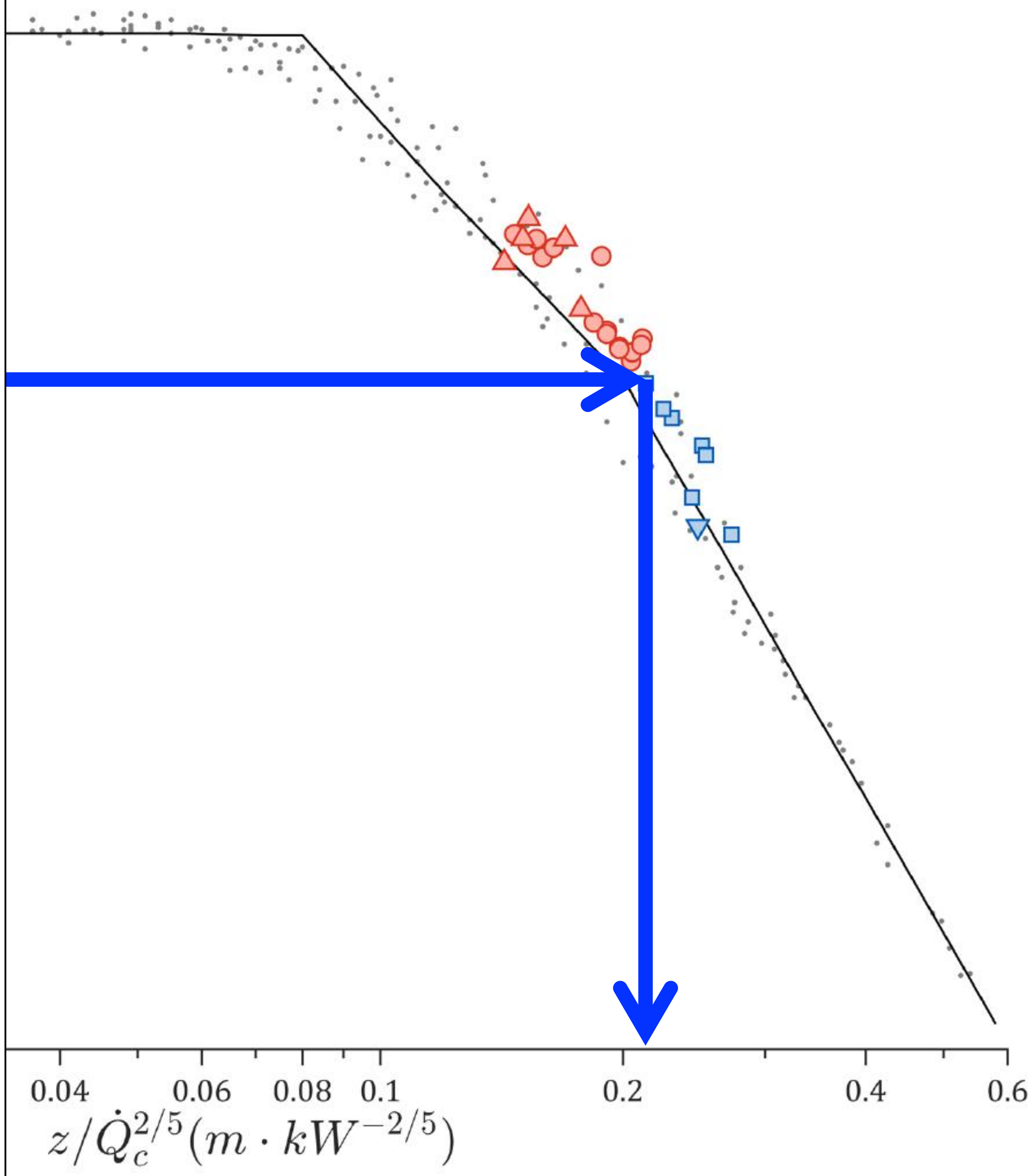
As an alternative to equation 6.55, the mean flame height is also given by

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

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



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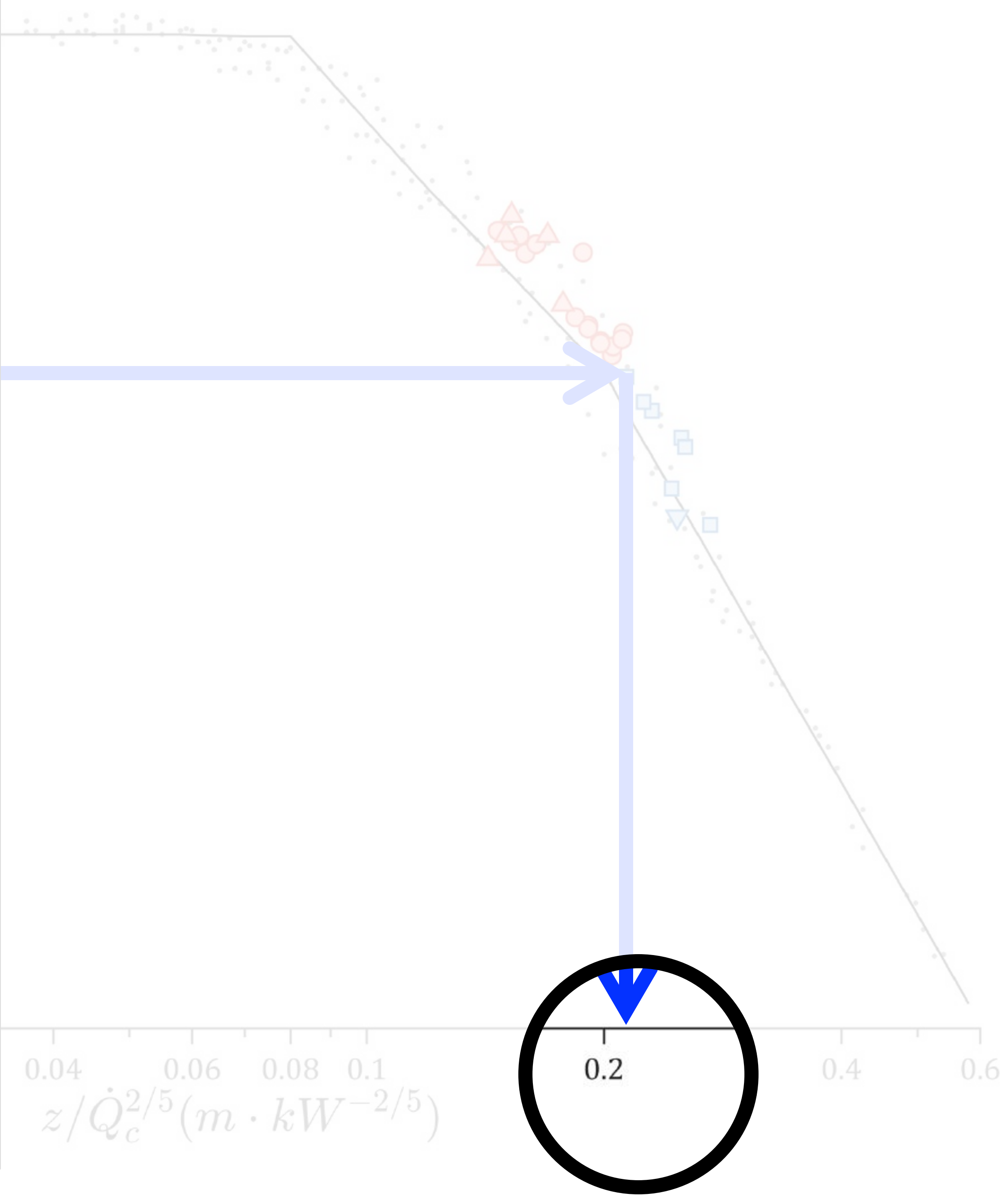
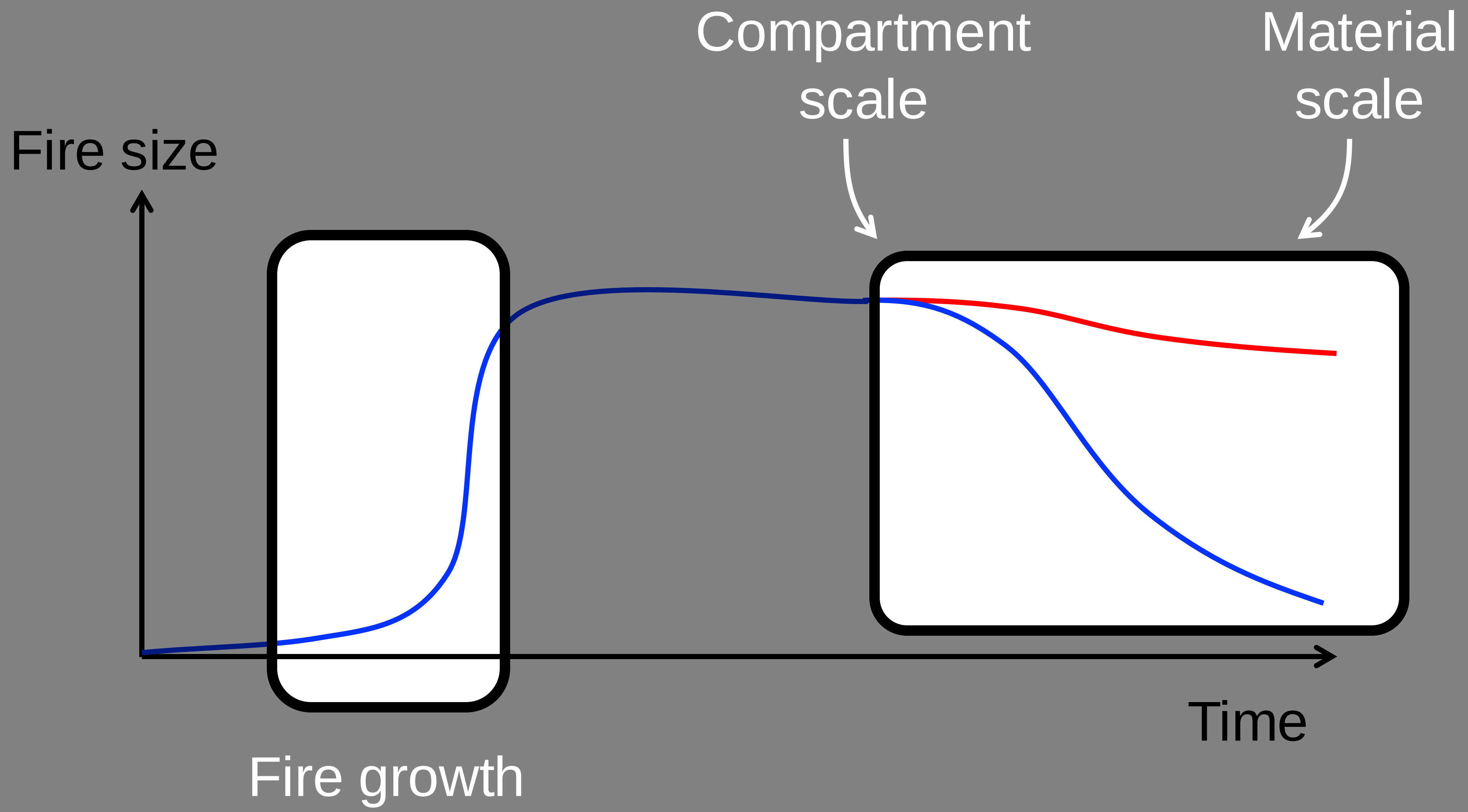




Compartment scale
Material scale
Fire size
Time
Fire growth

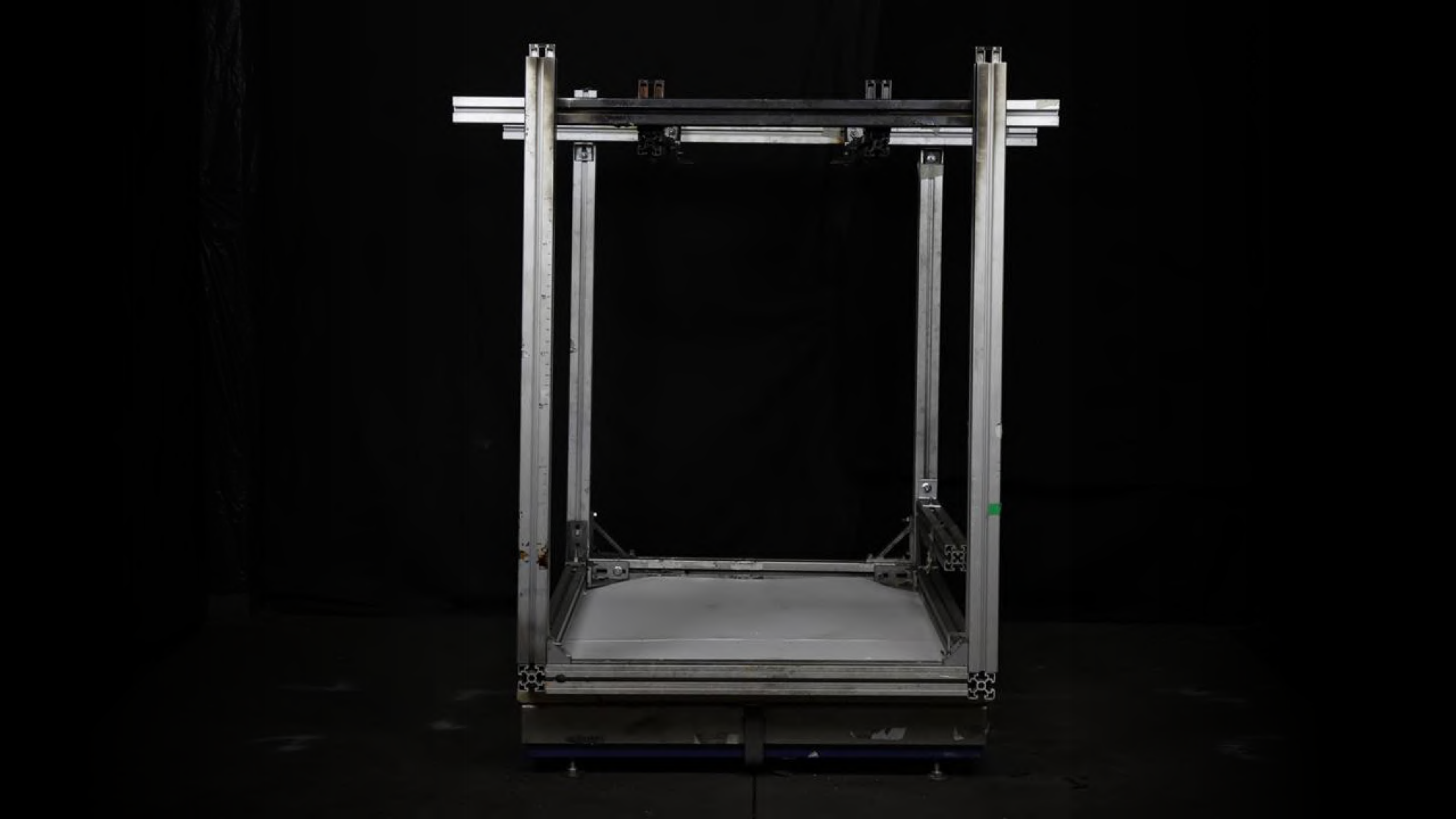
Problems with studying the decay phase:

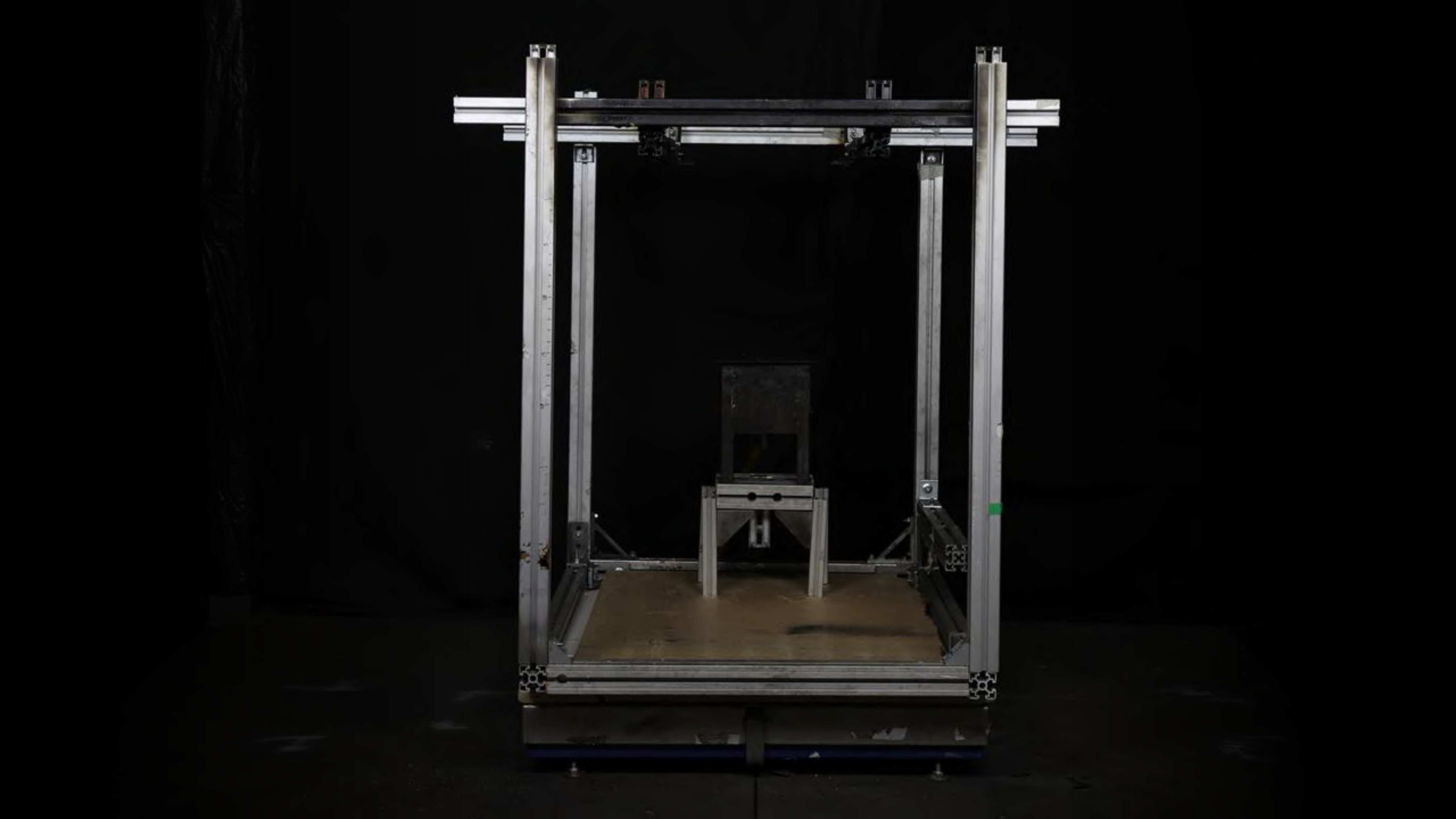
Fuel takes a while to "burn out"

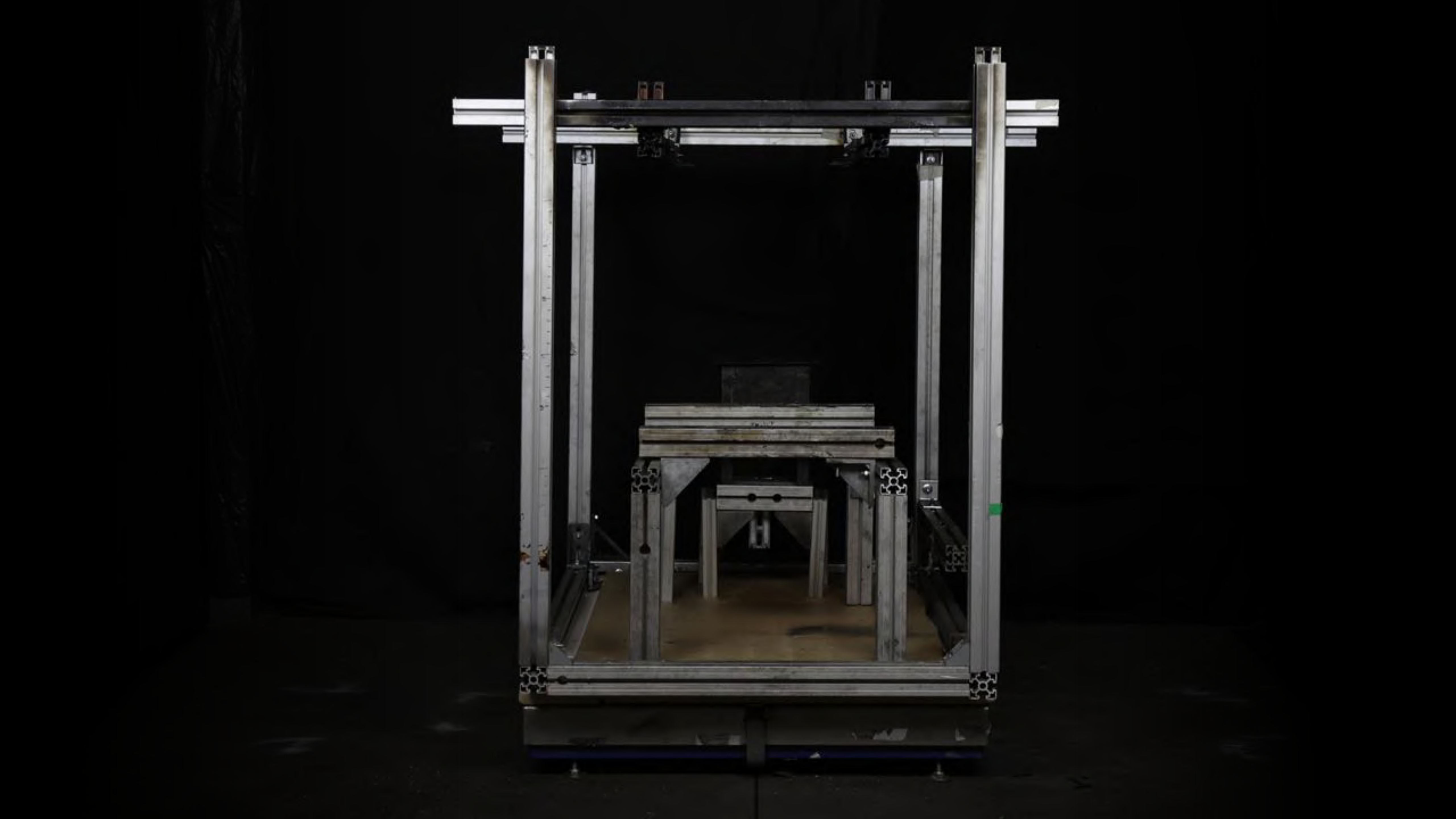
Delamination makes it stochastic.

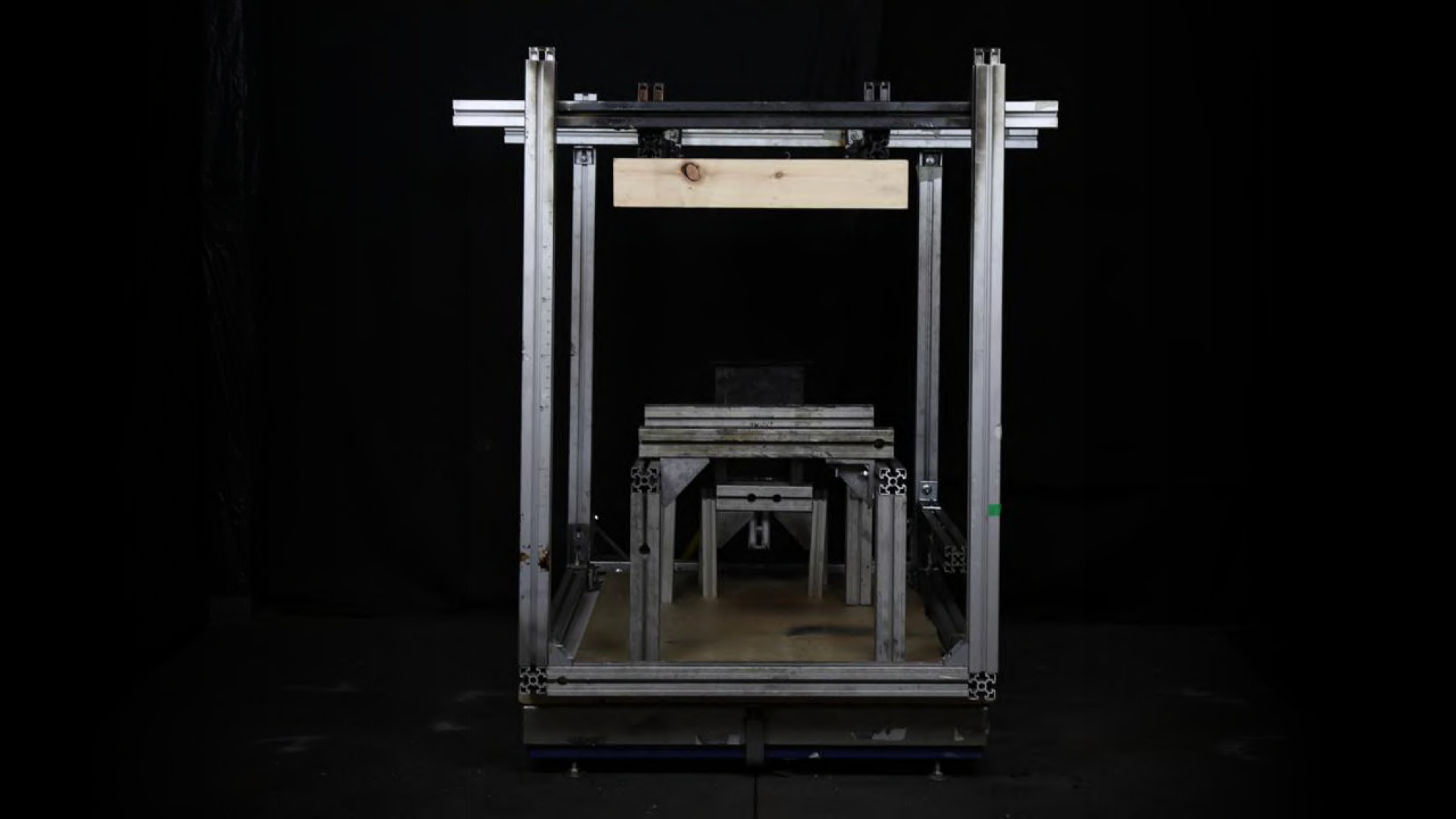
Local failures of fire protection systems.

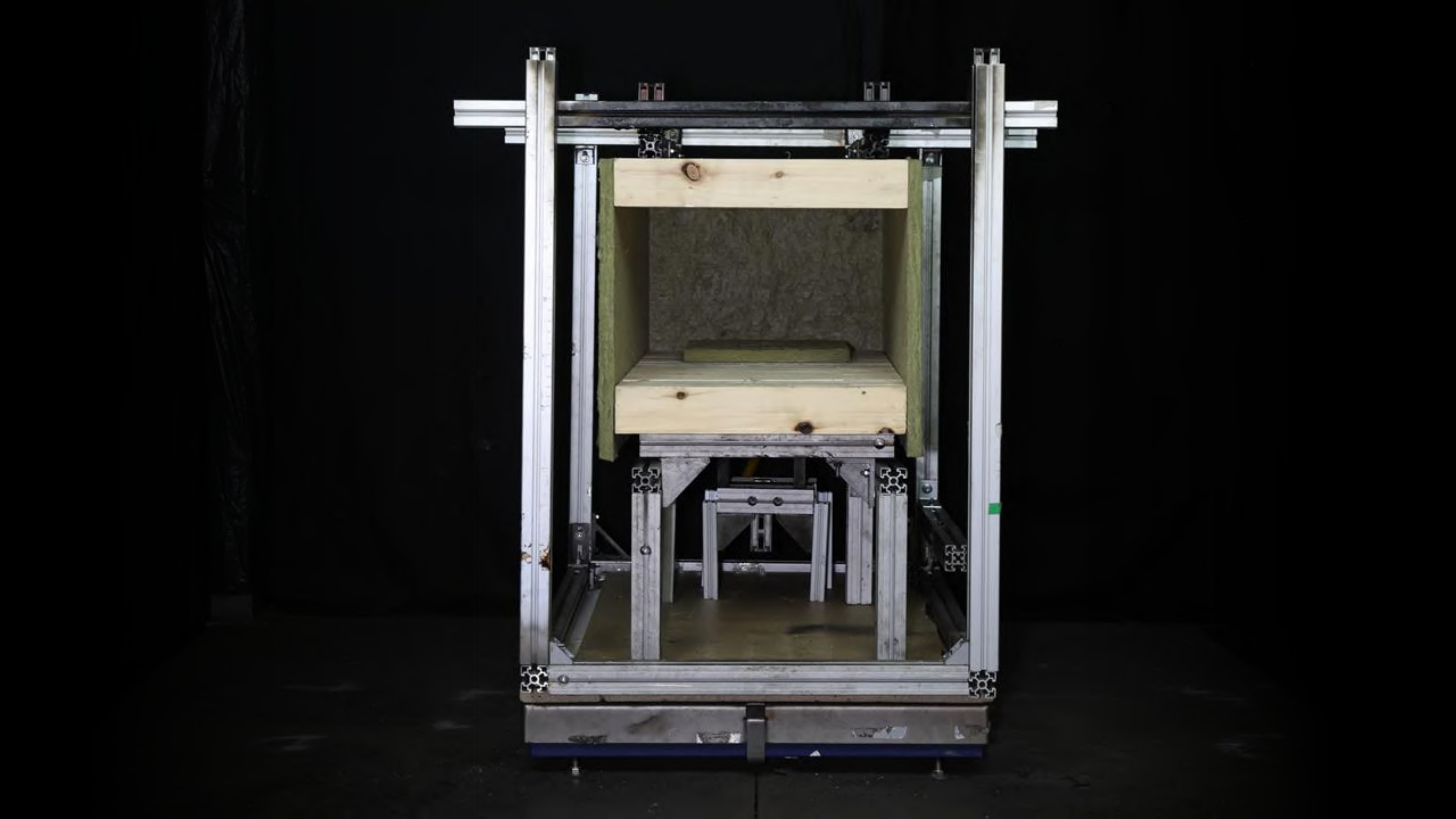

4210

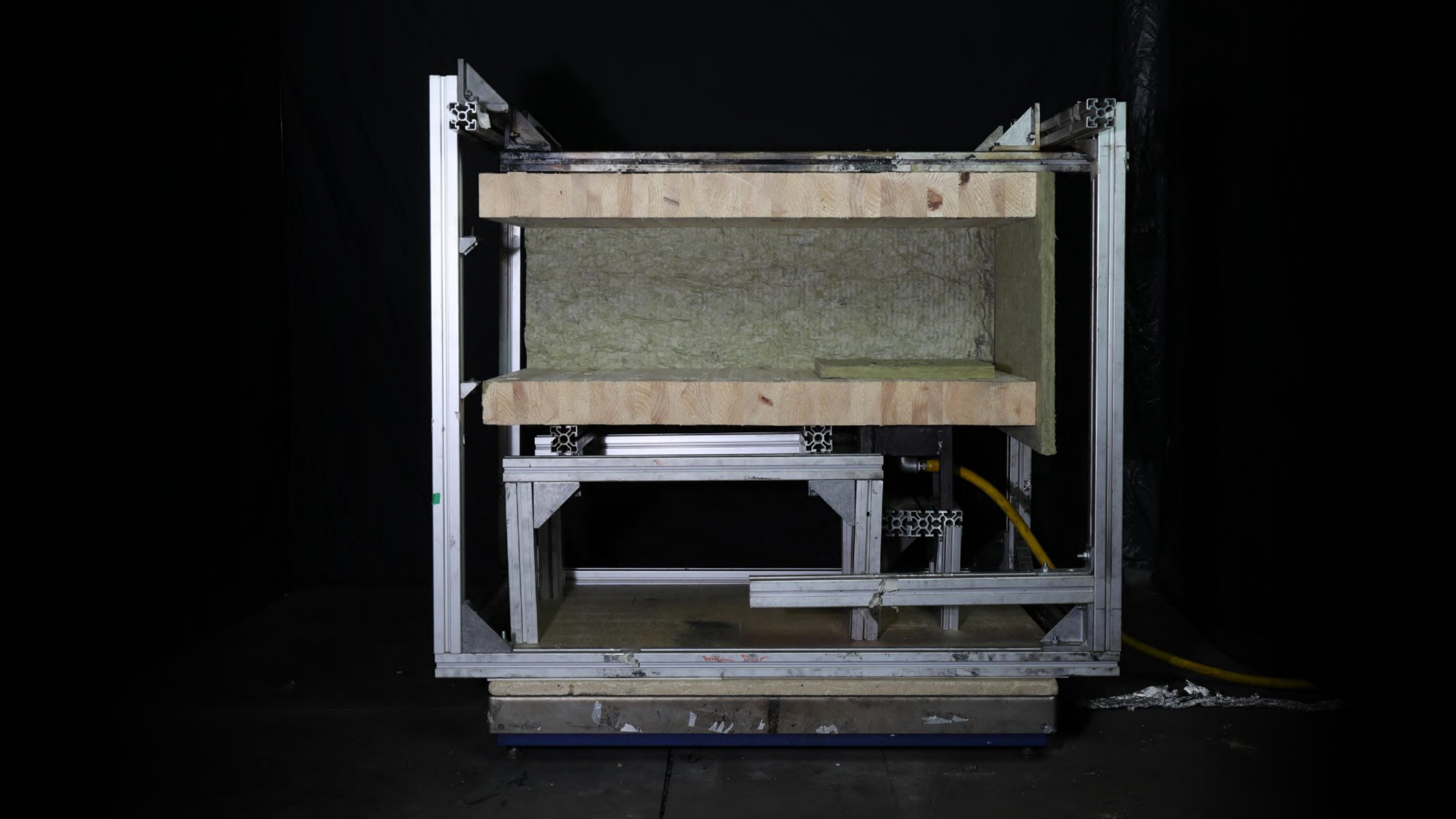


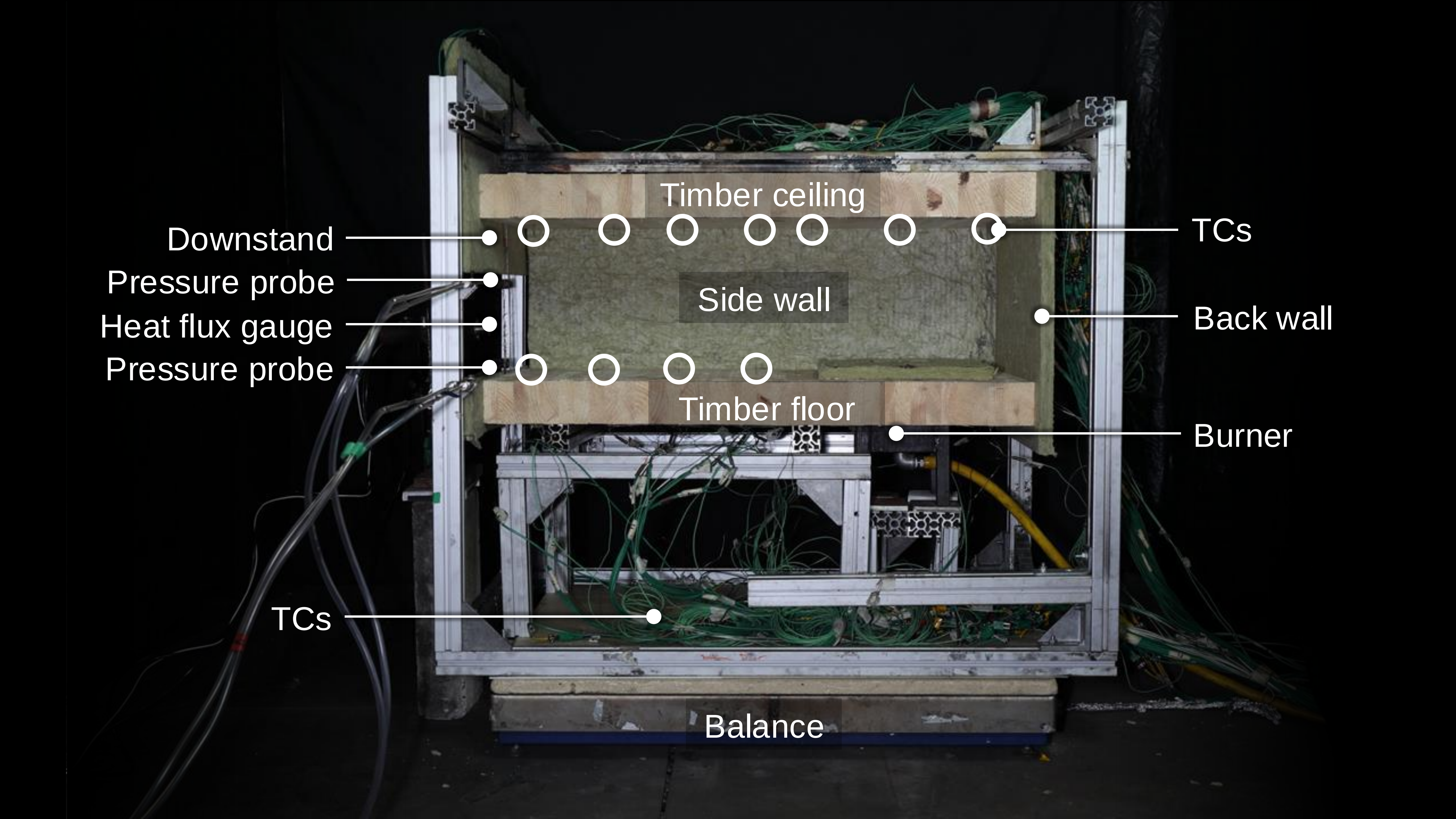




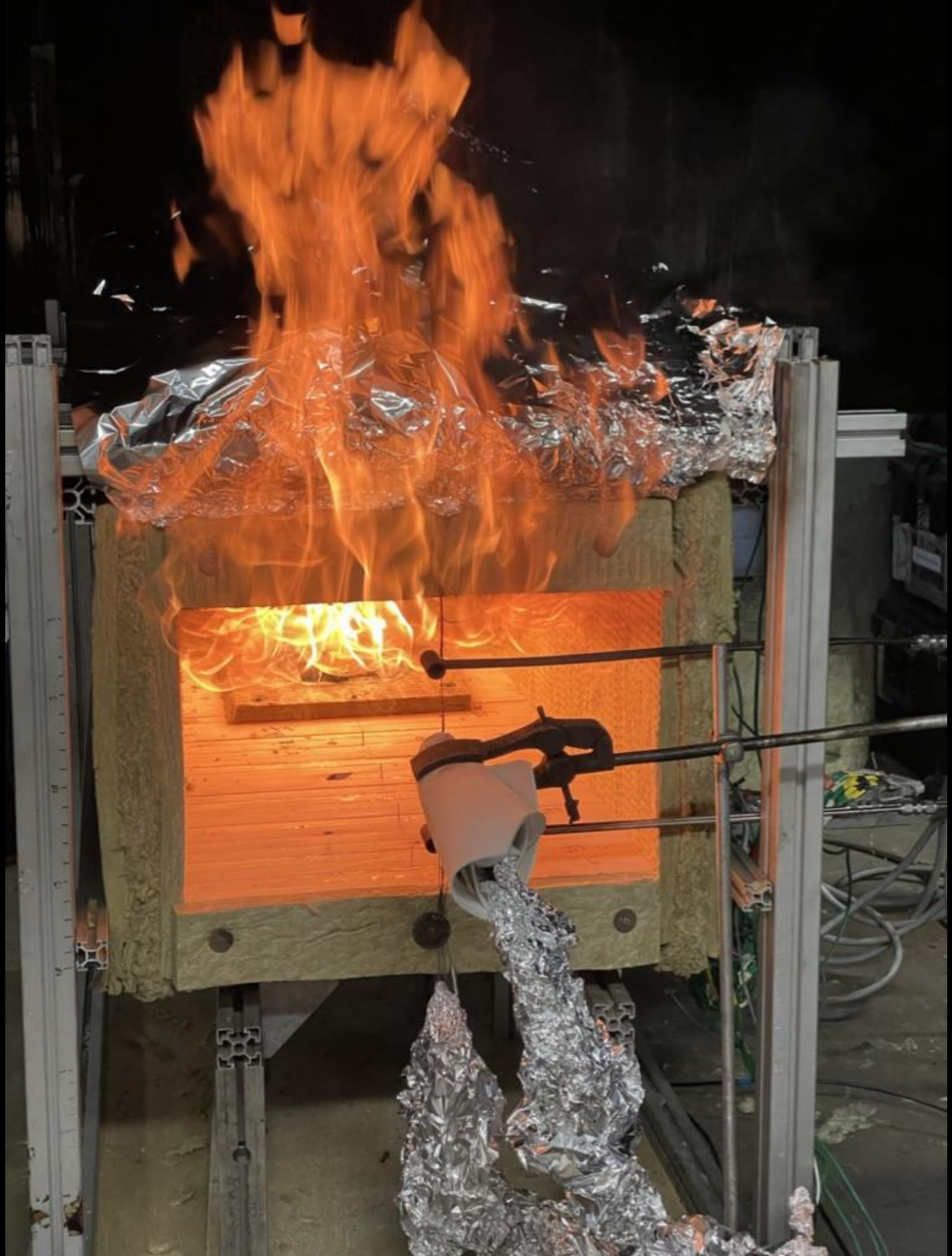


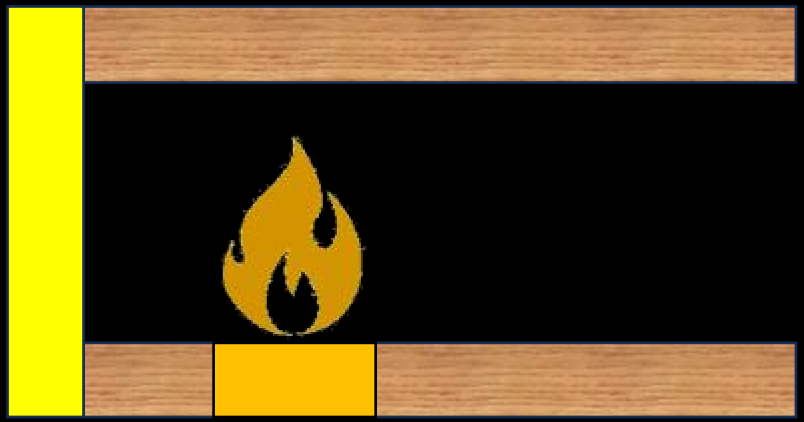


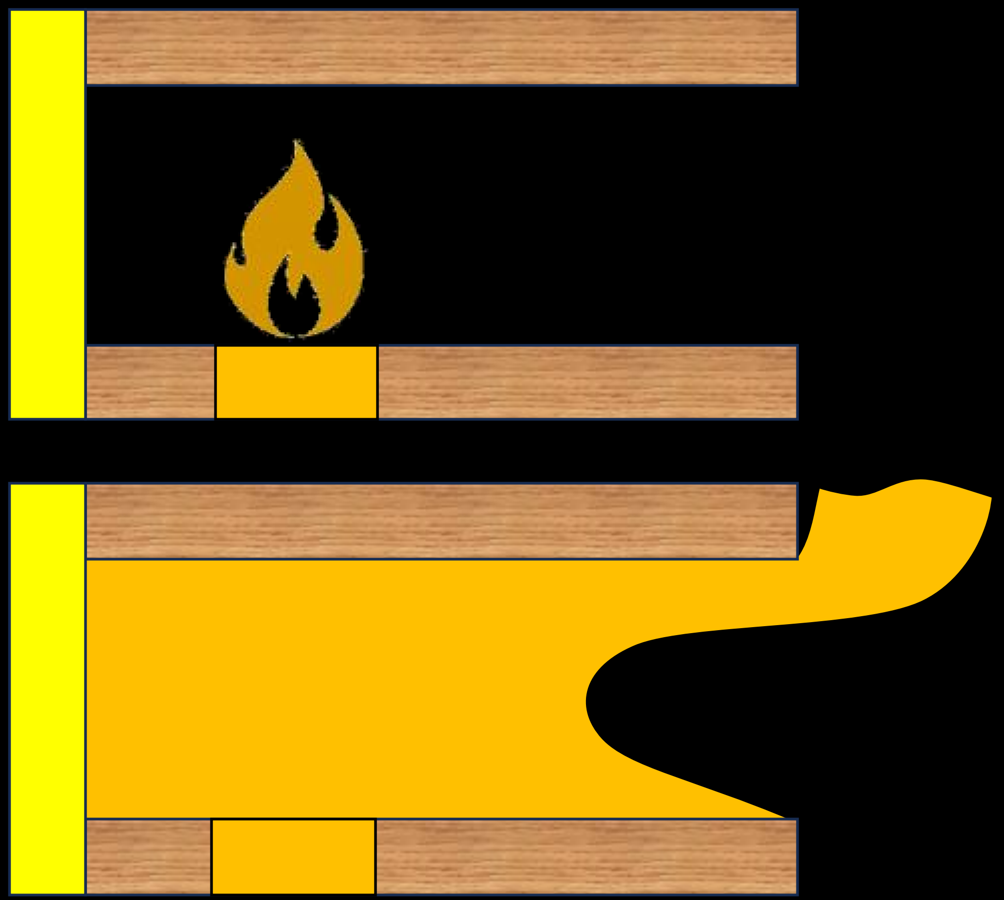


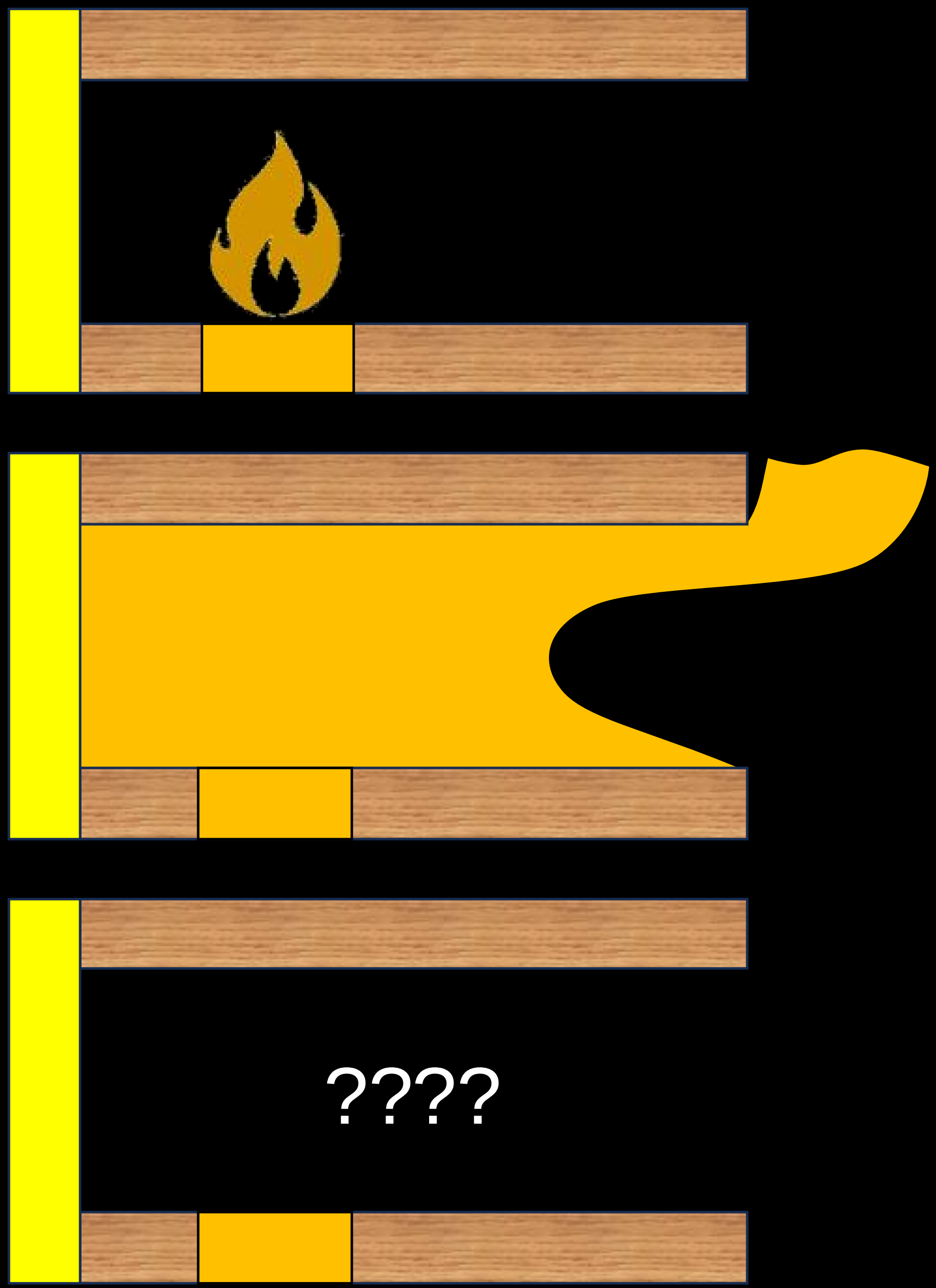


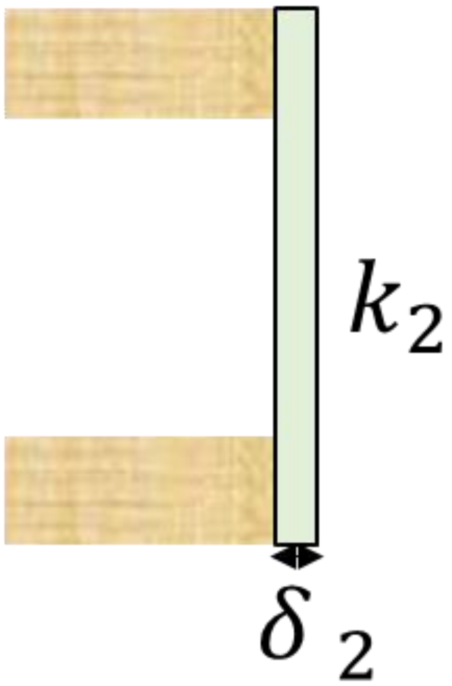
Timber ceiling
Downstand
Pressure probe
Heat flux gauge
Pressure probe
Side wall
TCs
Back wall
Timber floor
Burner
TCs
Balance

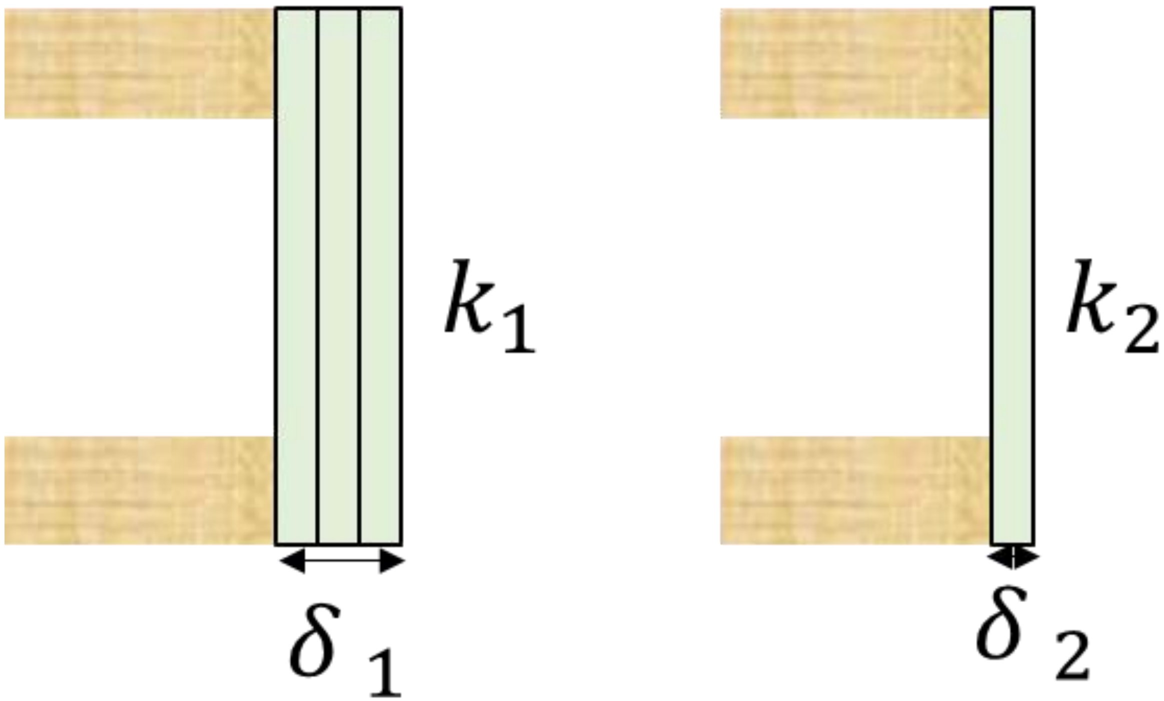


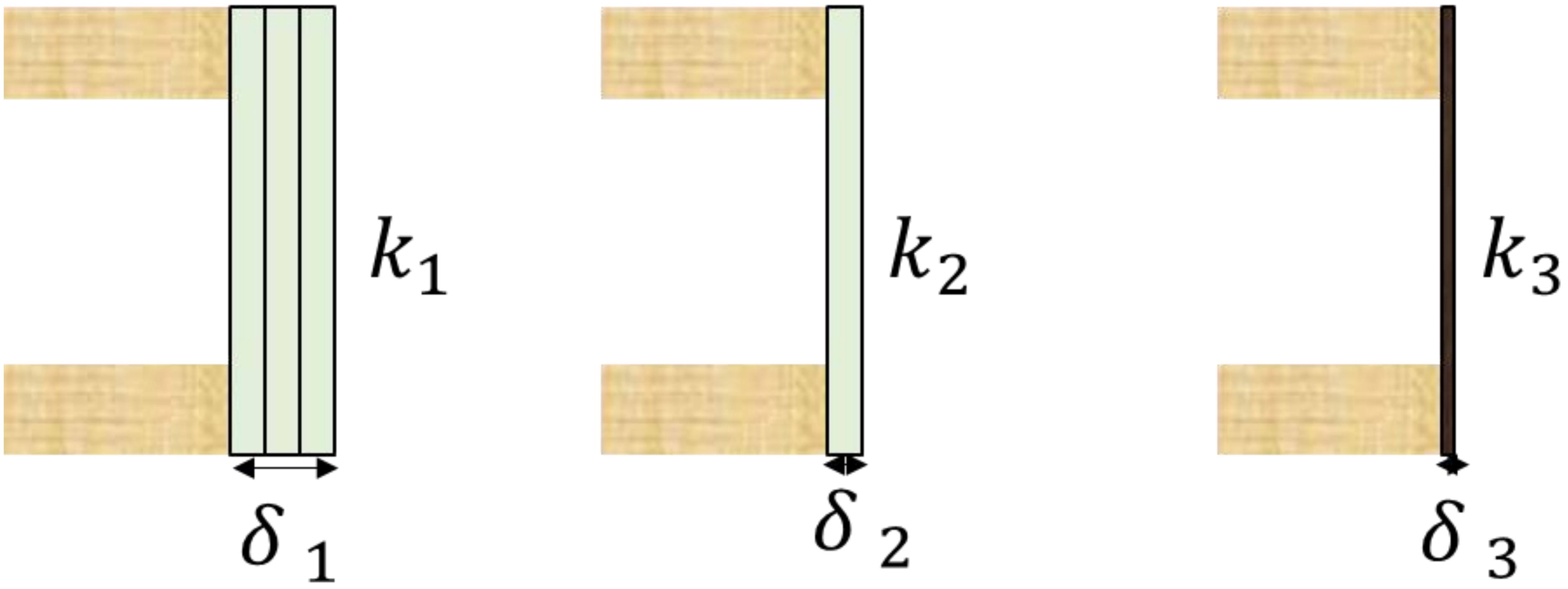


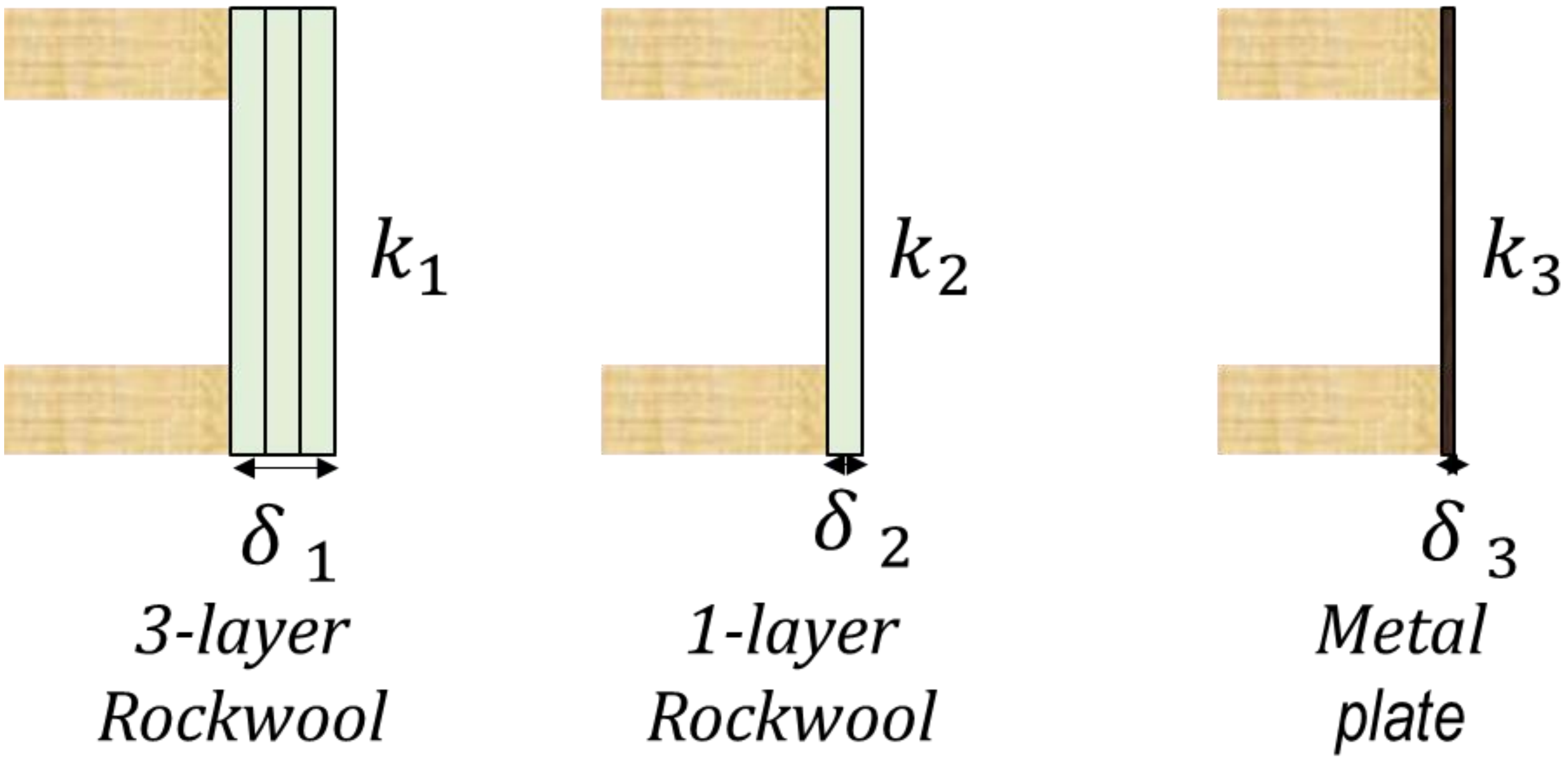


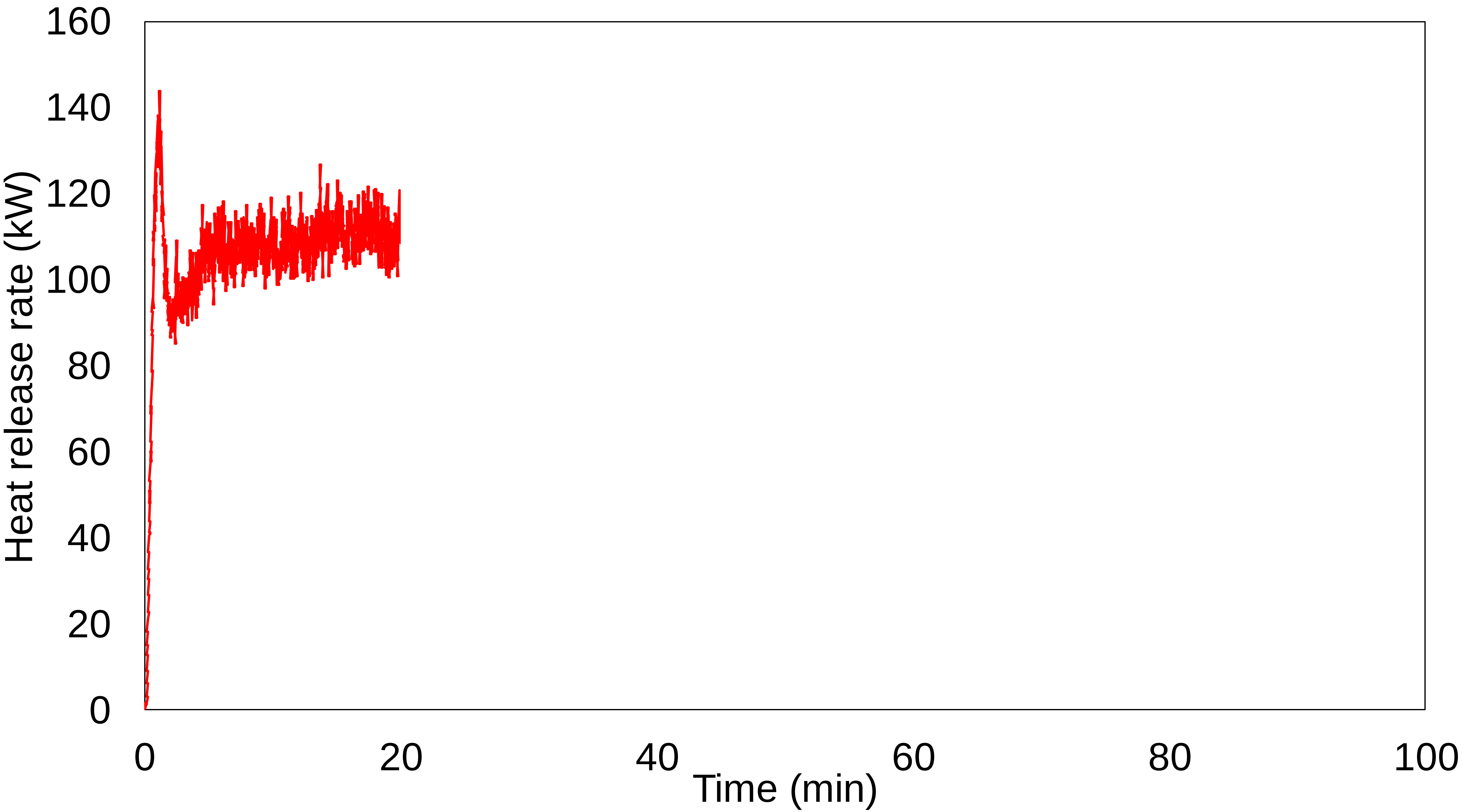

k_2
δ_2


k_1
δ_1
k_2
δ_2

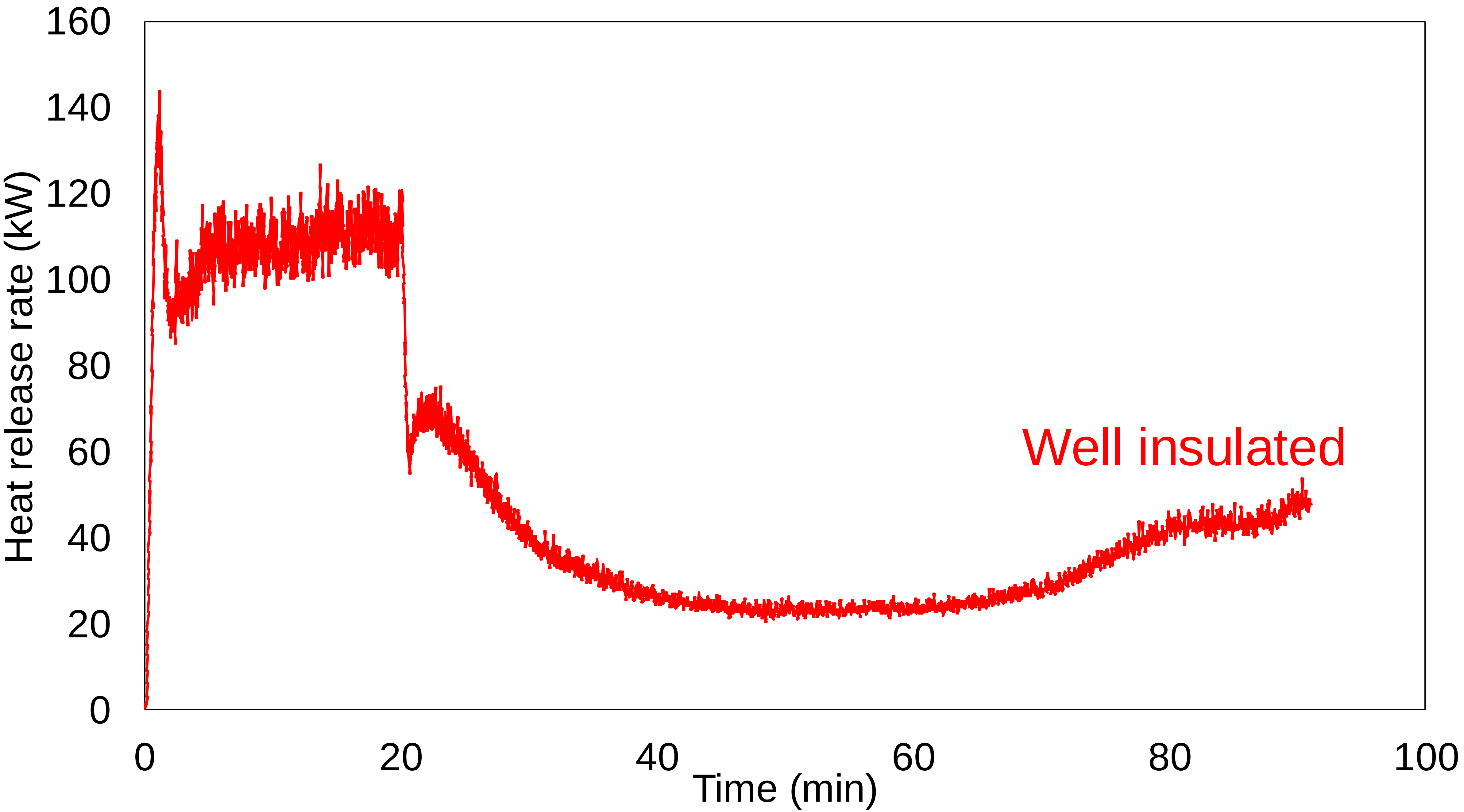


k_1
k_2
k_3
δ_1
δ_2
δ_3


k_1
δ_1
3-layer
Rockwool
k_2
δ_2
1-layer
Rockwool
k_3
δ_3
Metal
plate



Data: Ali Ahmed Awadallah (UoE PhD student)



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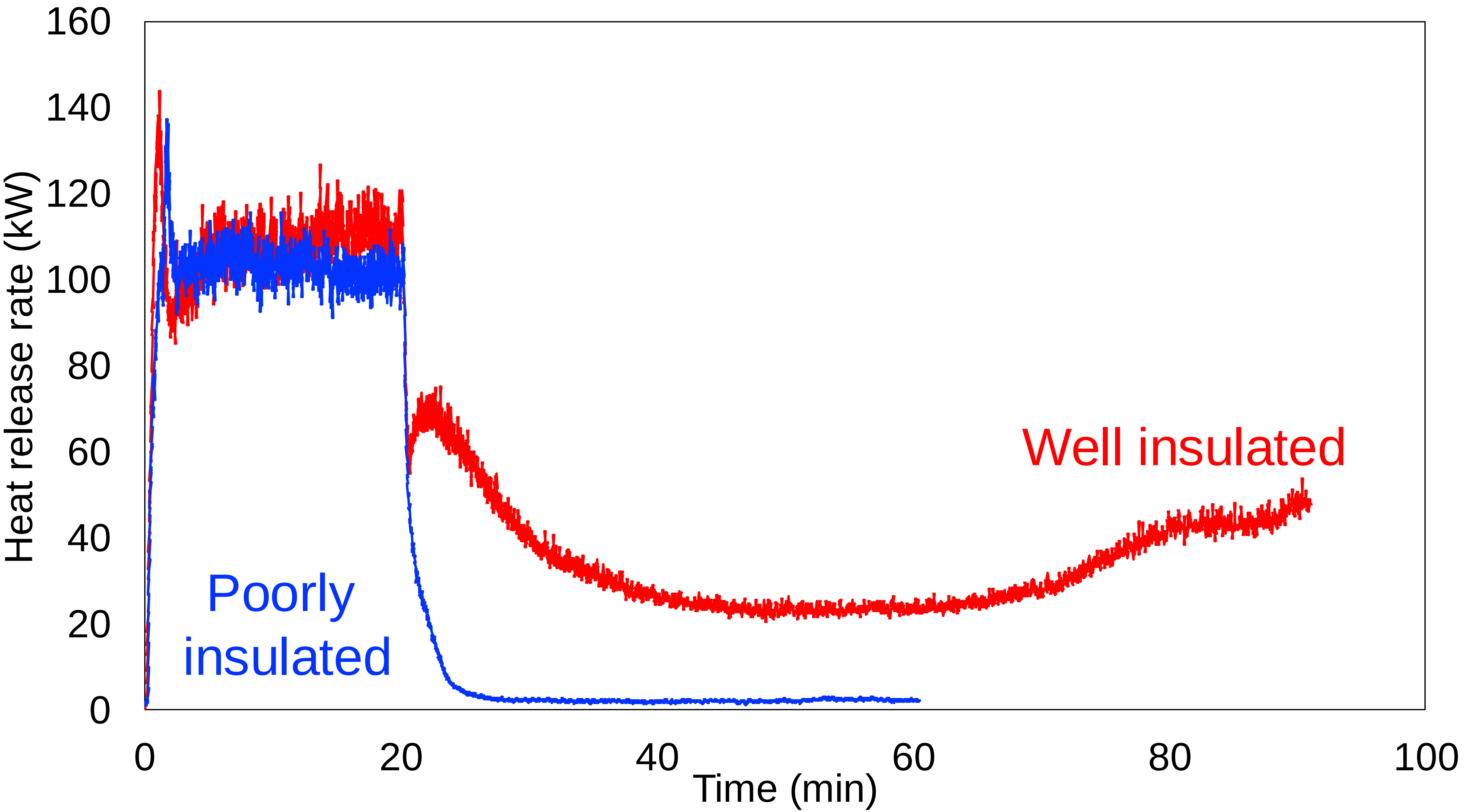

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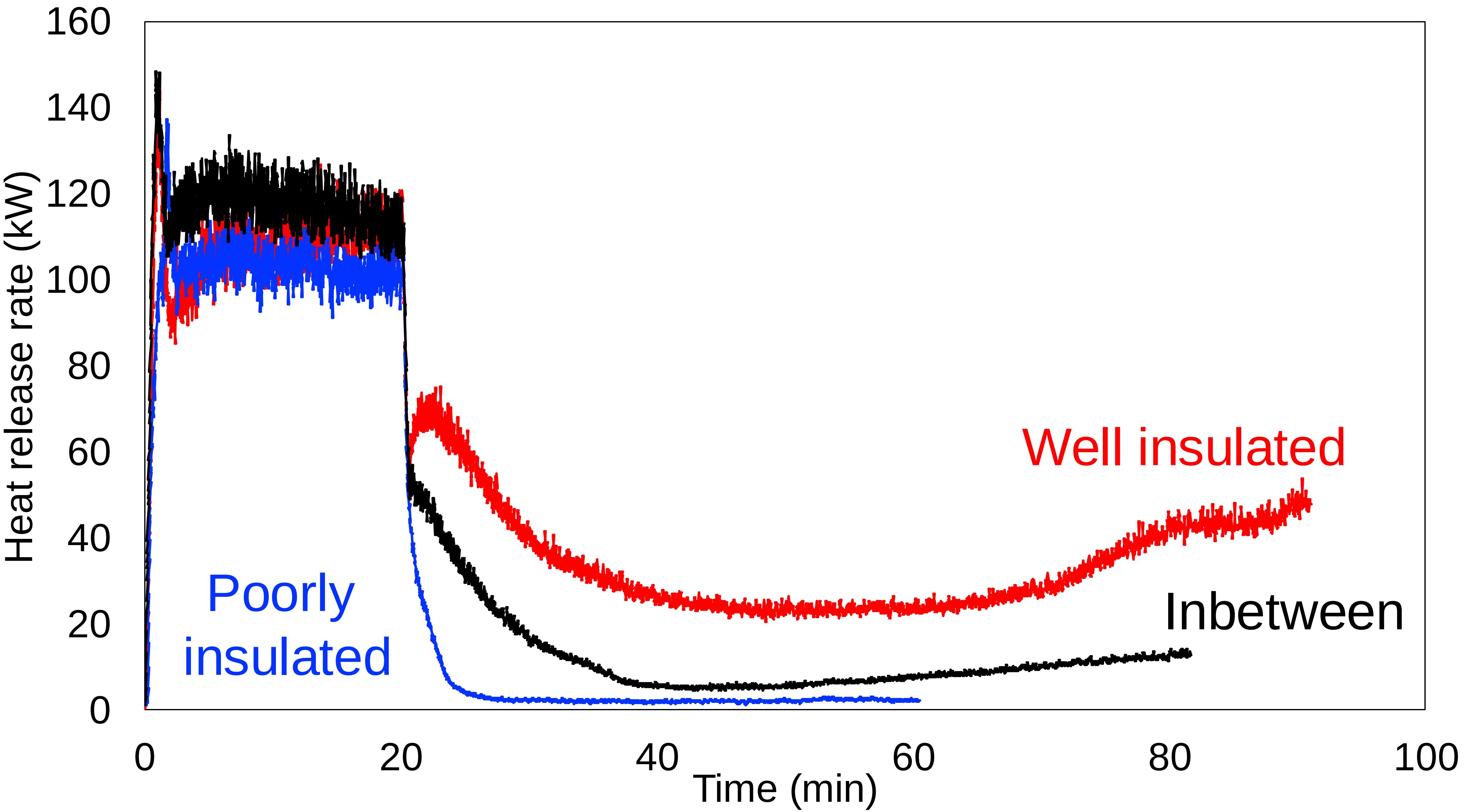

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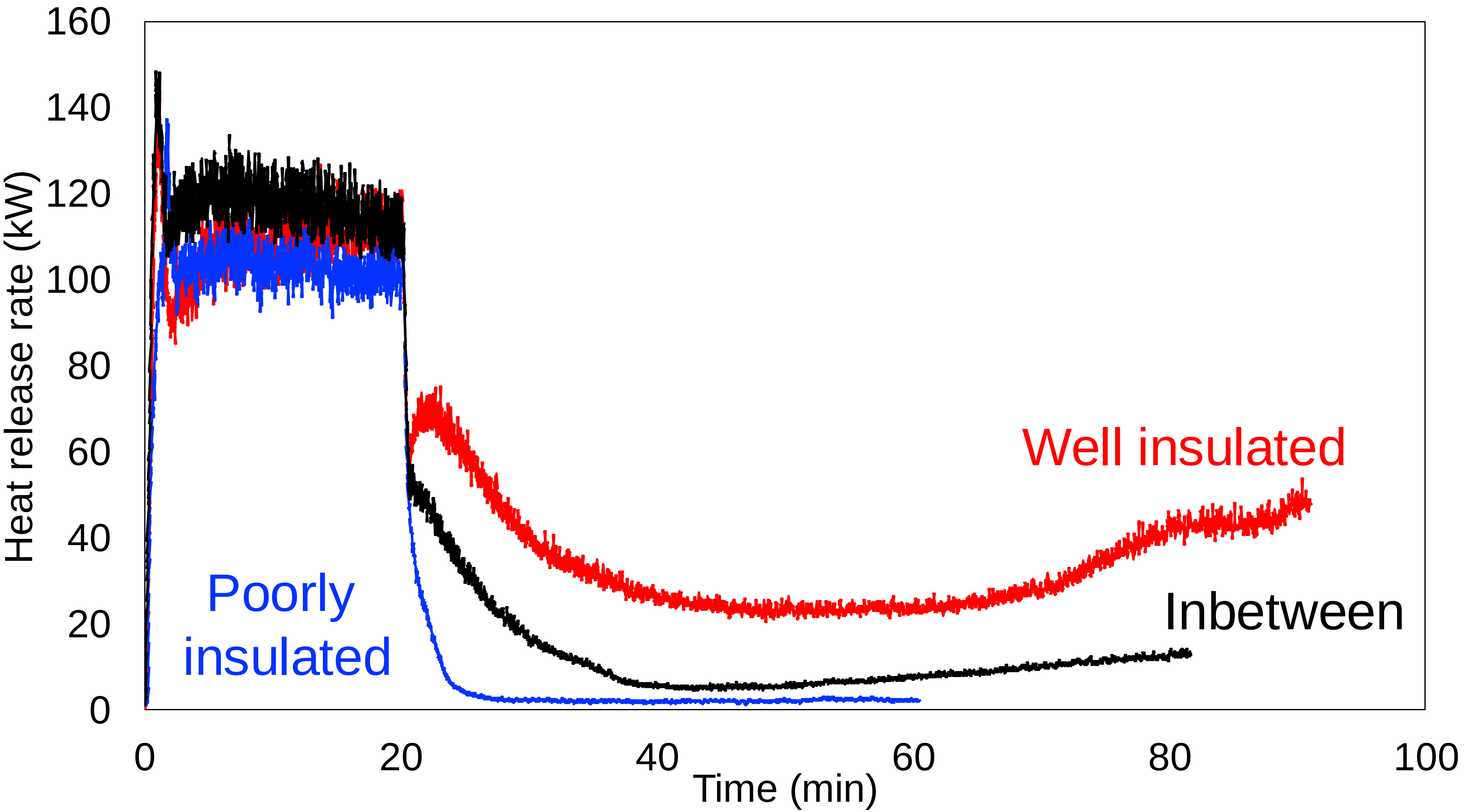


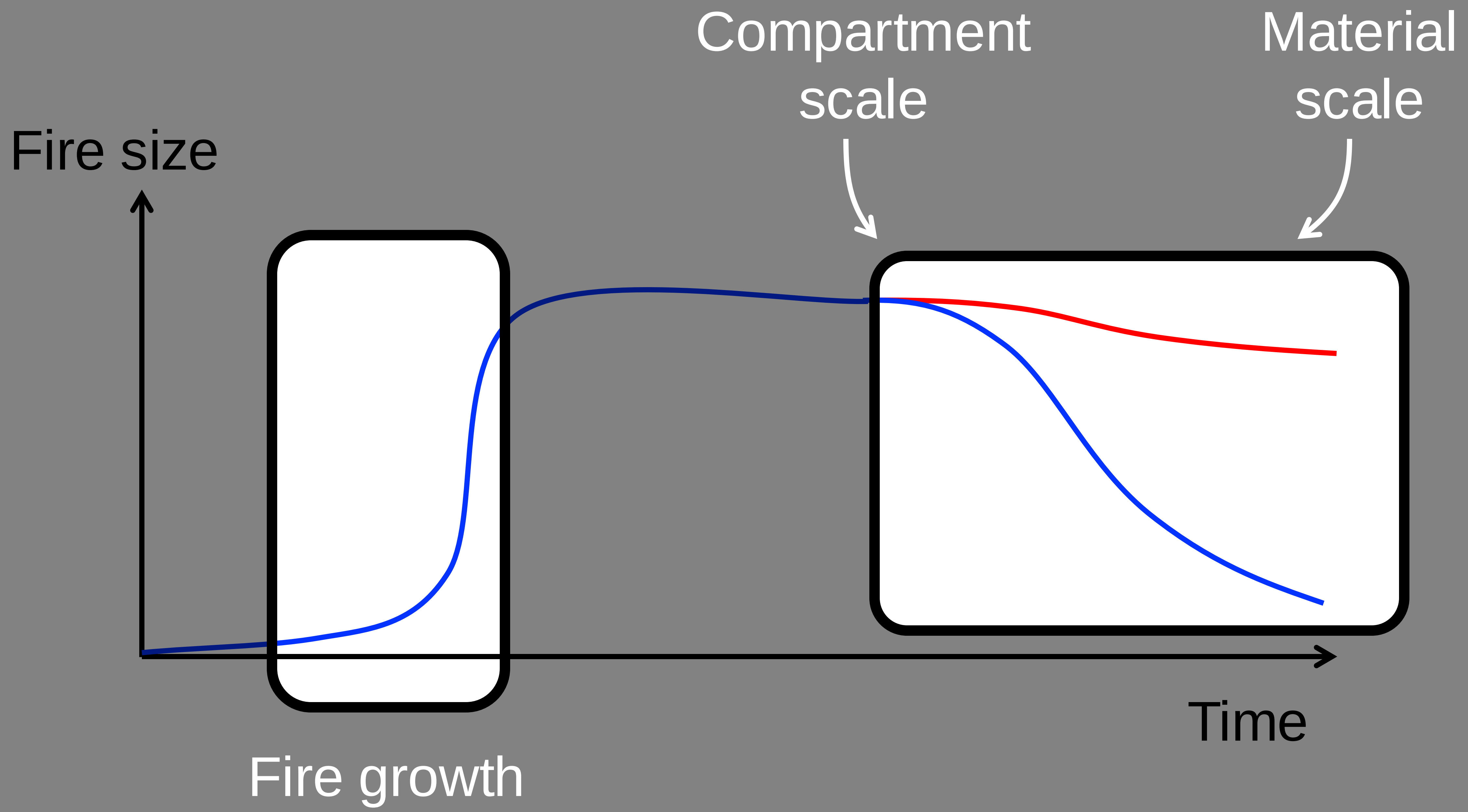
Data: Ali Ahmed Awadallah (UoE PhD student)

How do building geometry and materials influence outcome?

Thermal properties

Openings

Exposed surfaces


Compartment
scale
Material
scale
Fire size
Time
Fire growth

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

External heat flux

Flame heat feedback

Heat released by char oxidation

Losses from the surface

Conductive losses

Energy stored in the char

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

External heat flux

Flame heat feedback

Heat released by char oxidation

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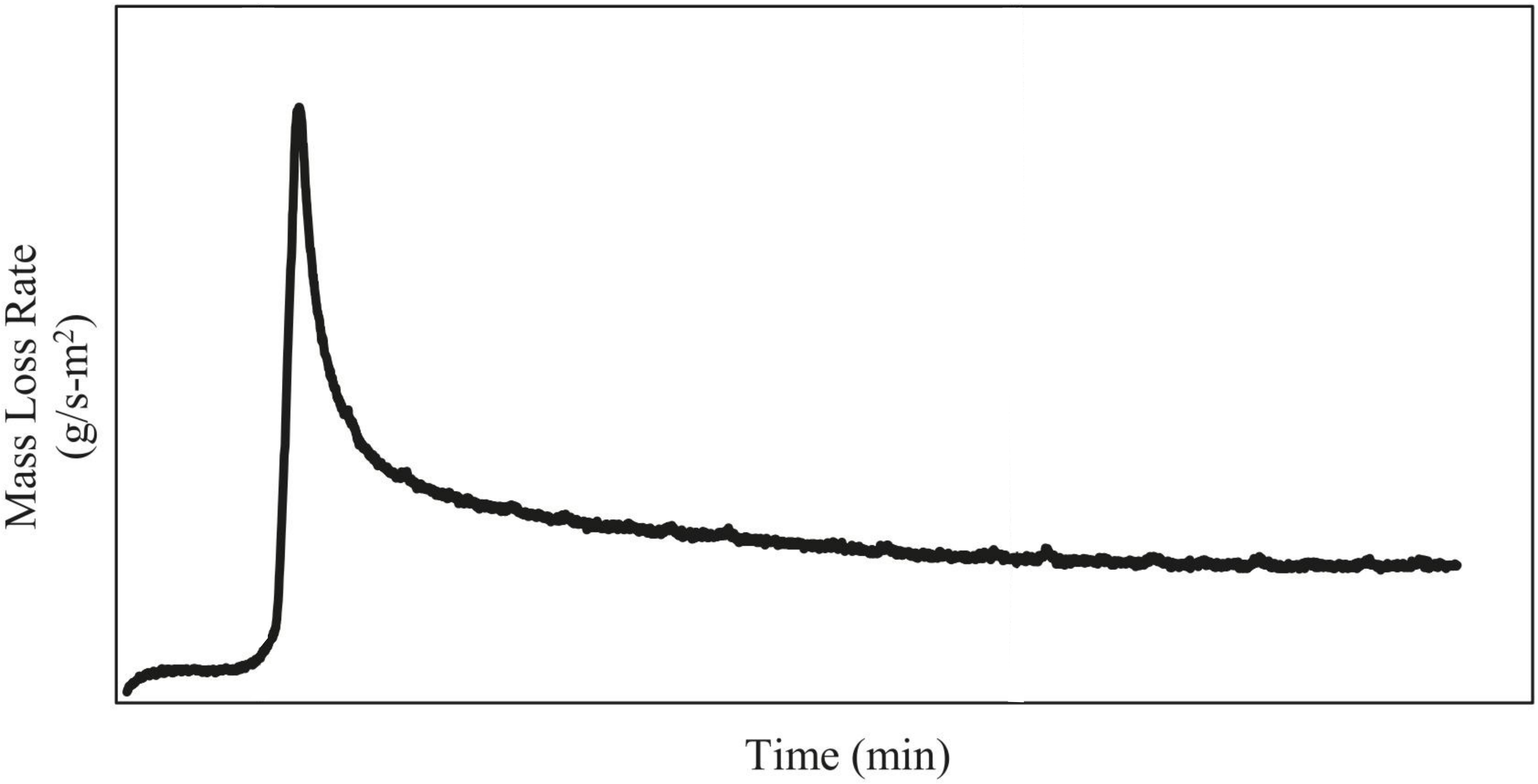
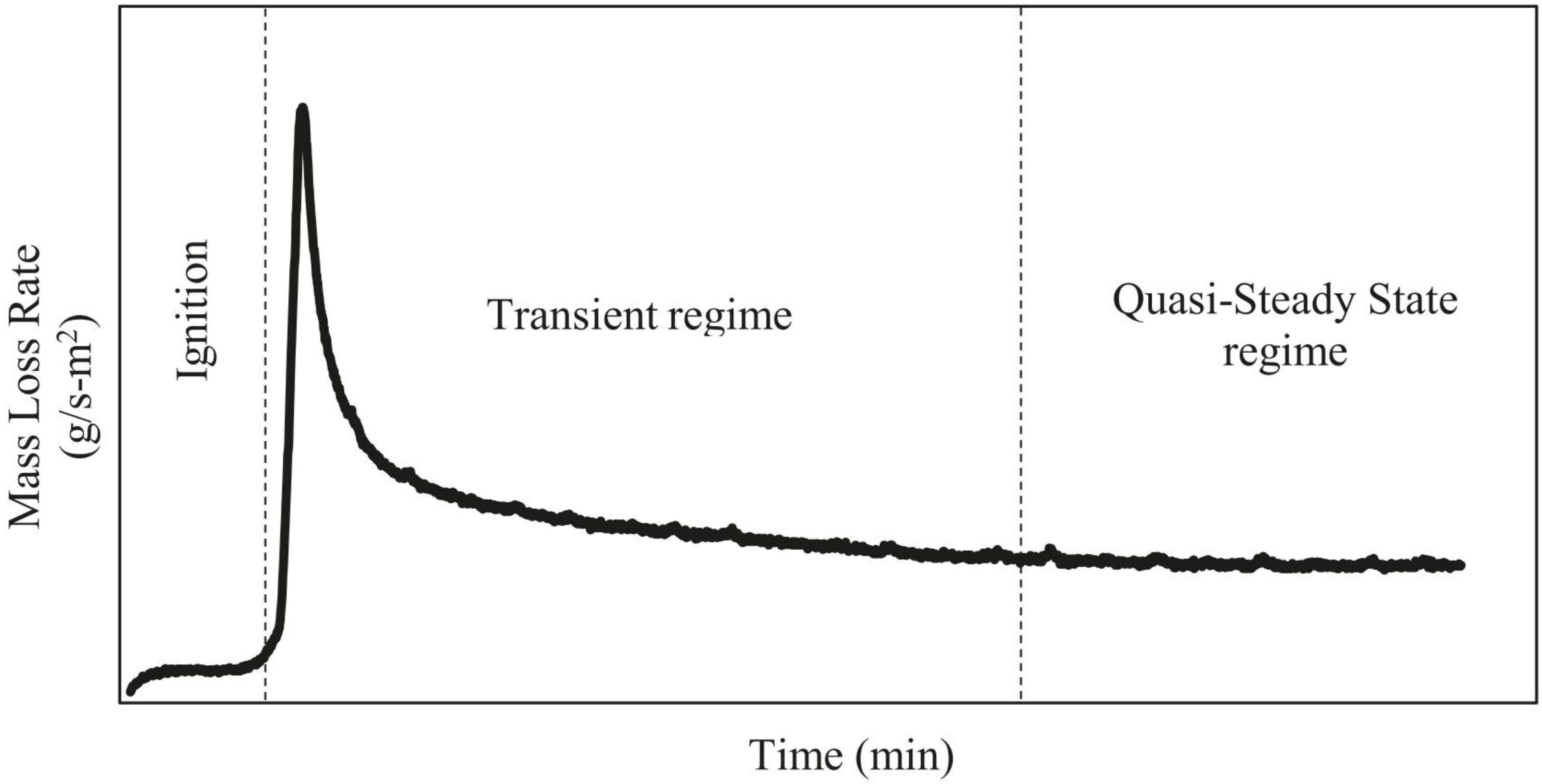
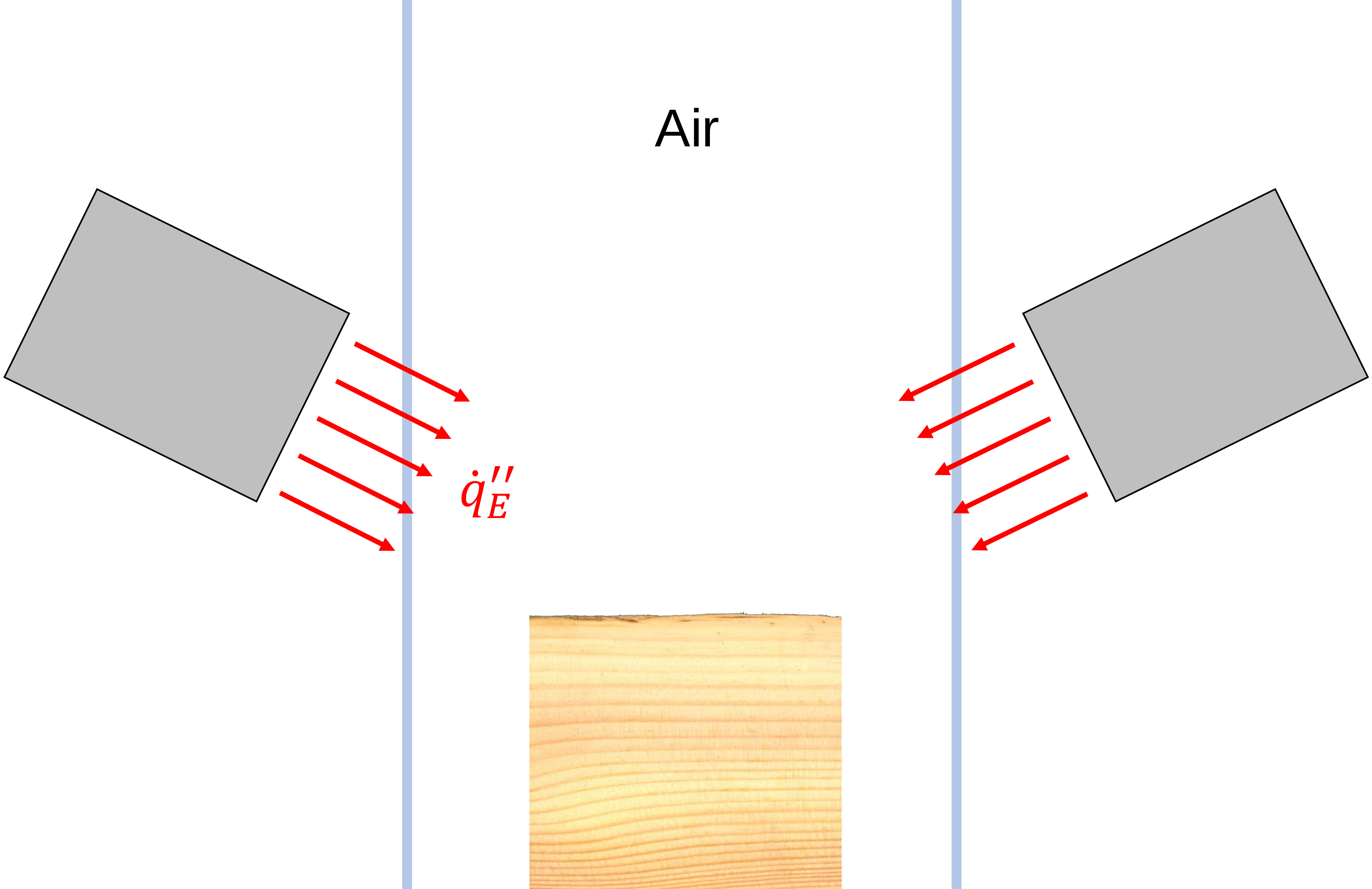
Conductive losses

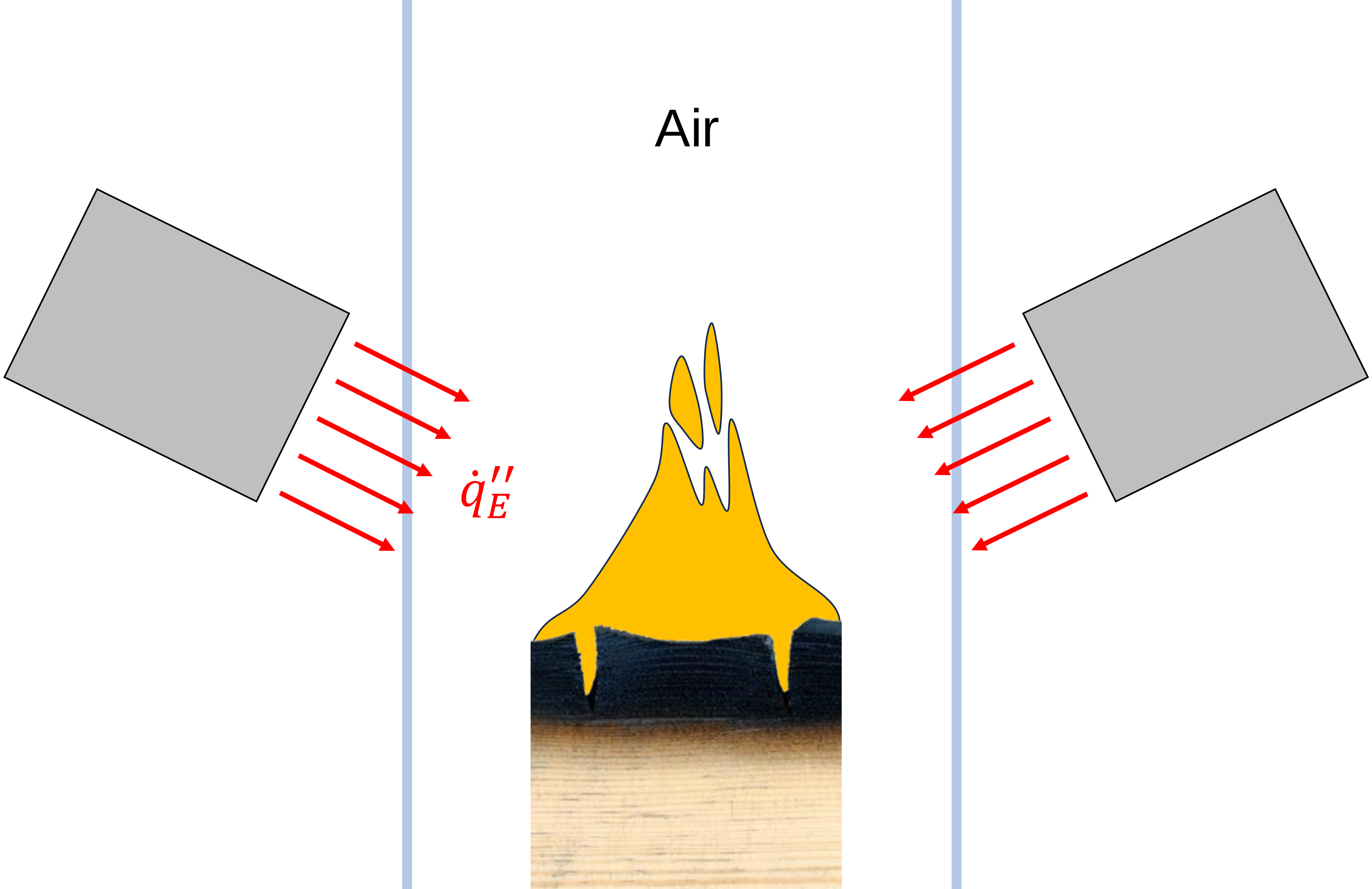
Energy stored in the char


Mass Loss Rate
(g/s-m2)
Time (min)

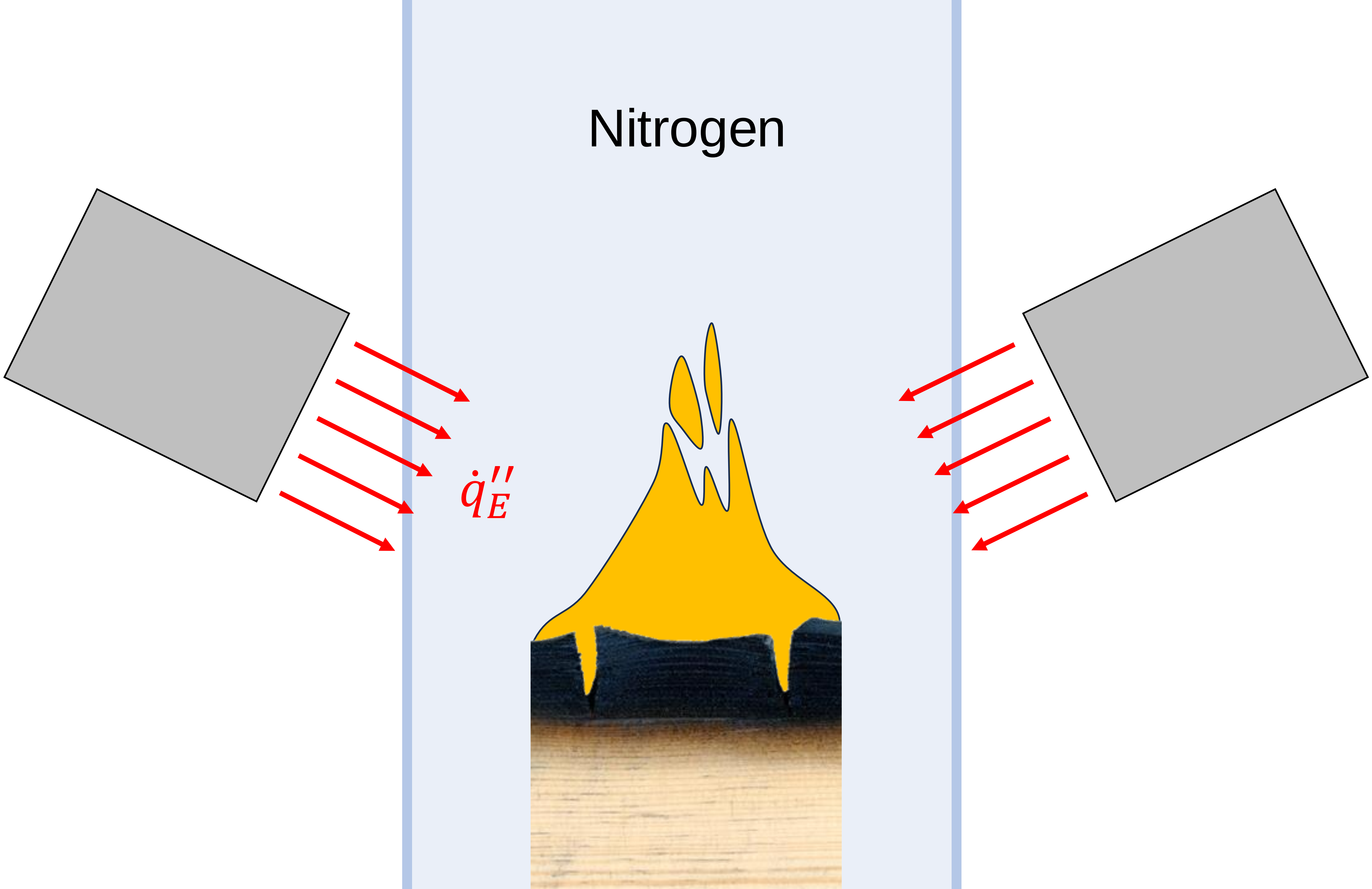

Mass Loss Rate
(g/s-m2)
Ignition
Transient regime
Quasi-Steady State
regime
Time (min)



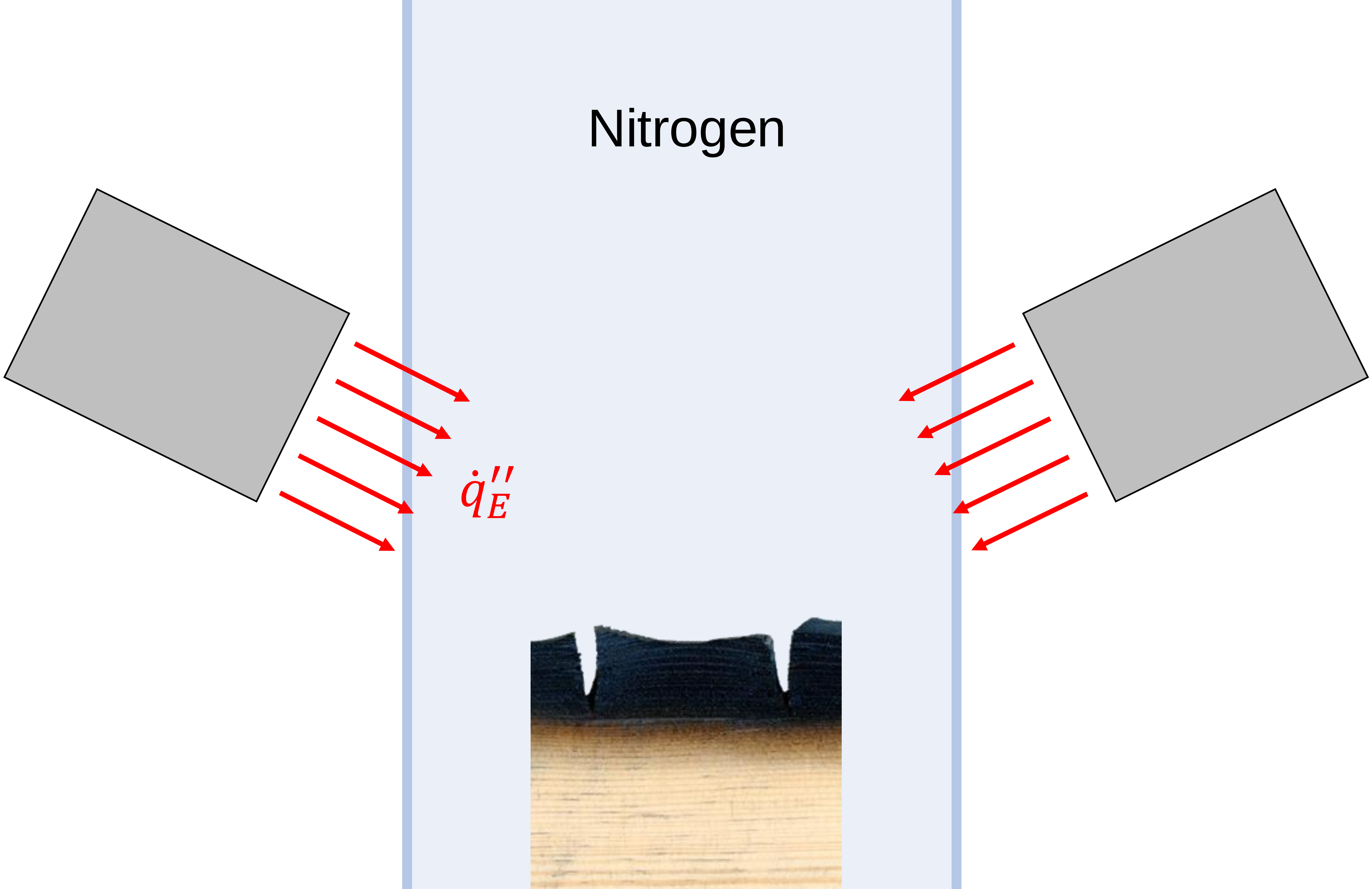
Air
$\dot{q}_E''$

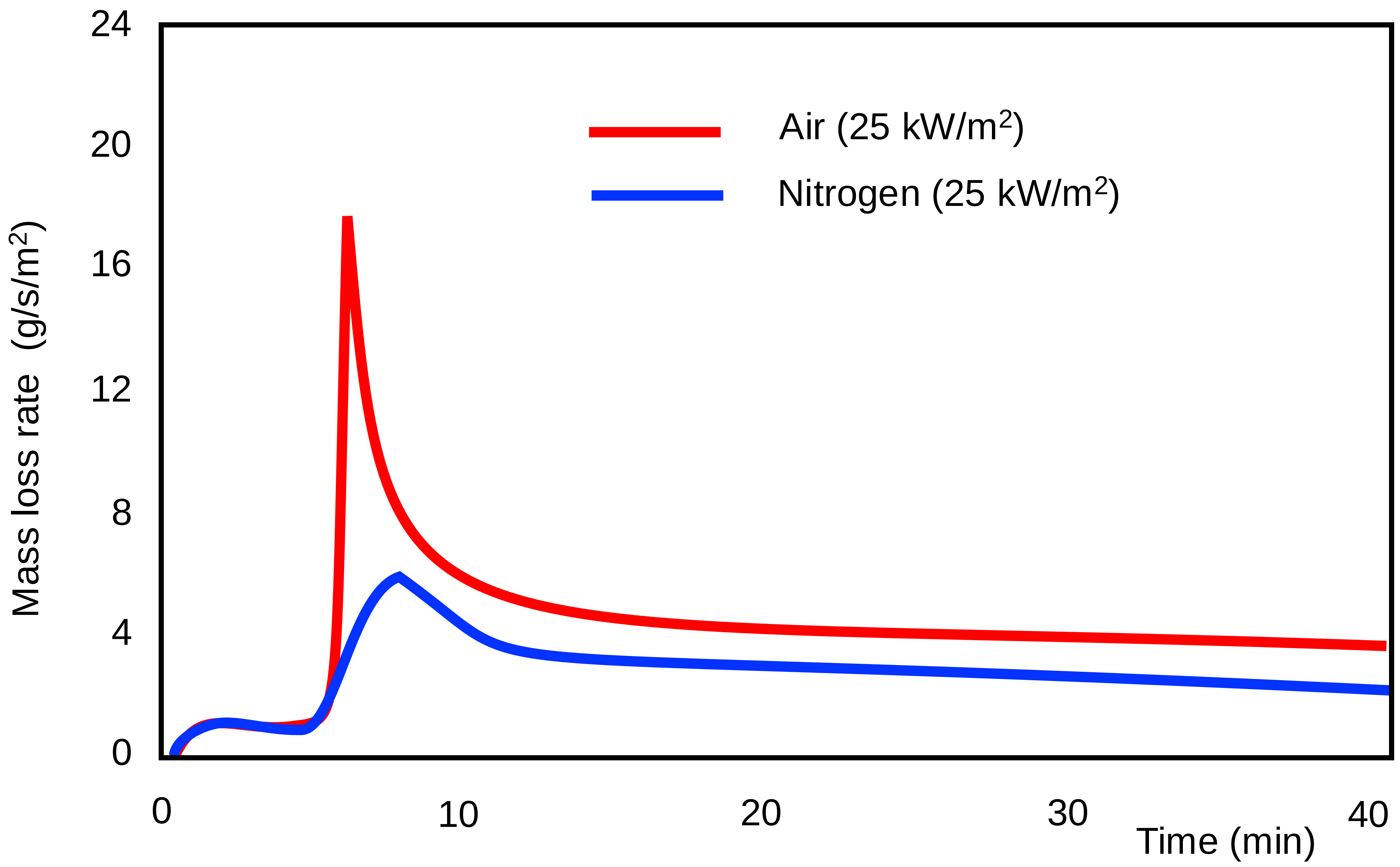


Air
$\dot{q}''_E$

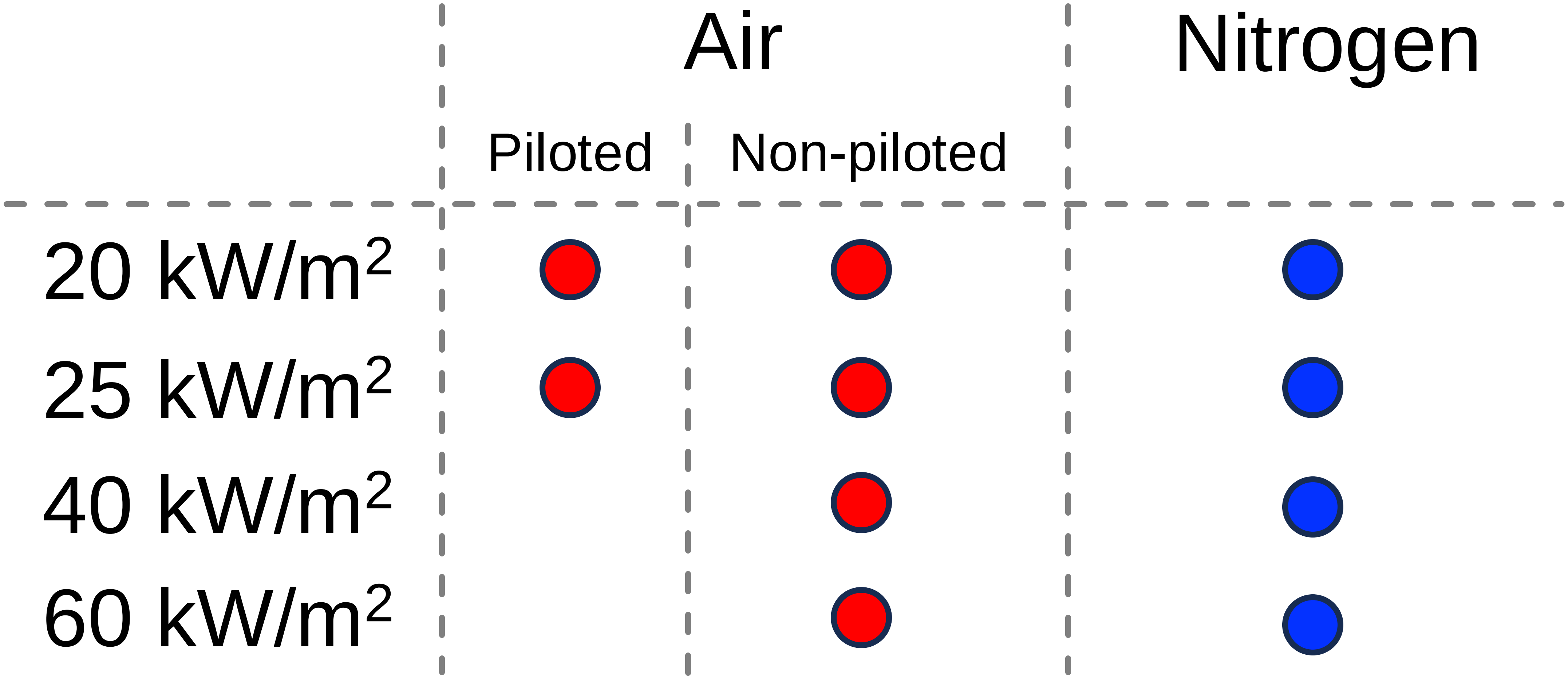


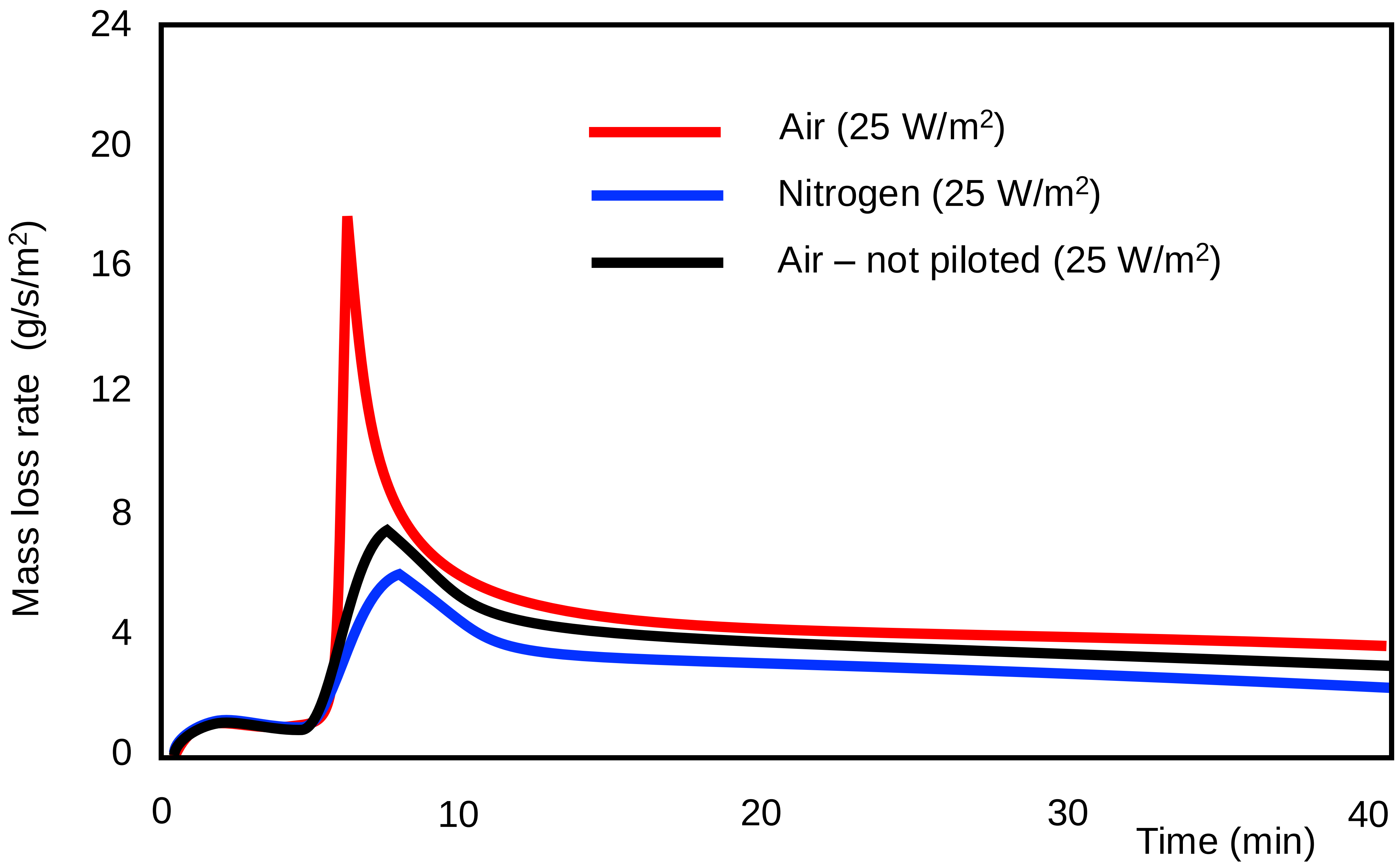
Nitrogen
$\dot{q}''_E$


Nitrogen
$\dot{q}''_E$

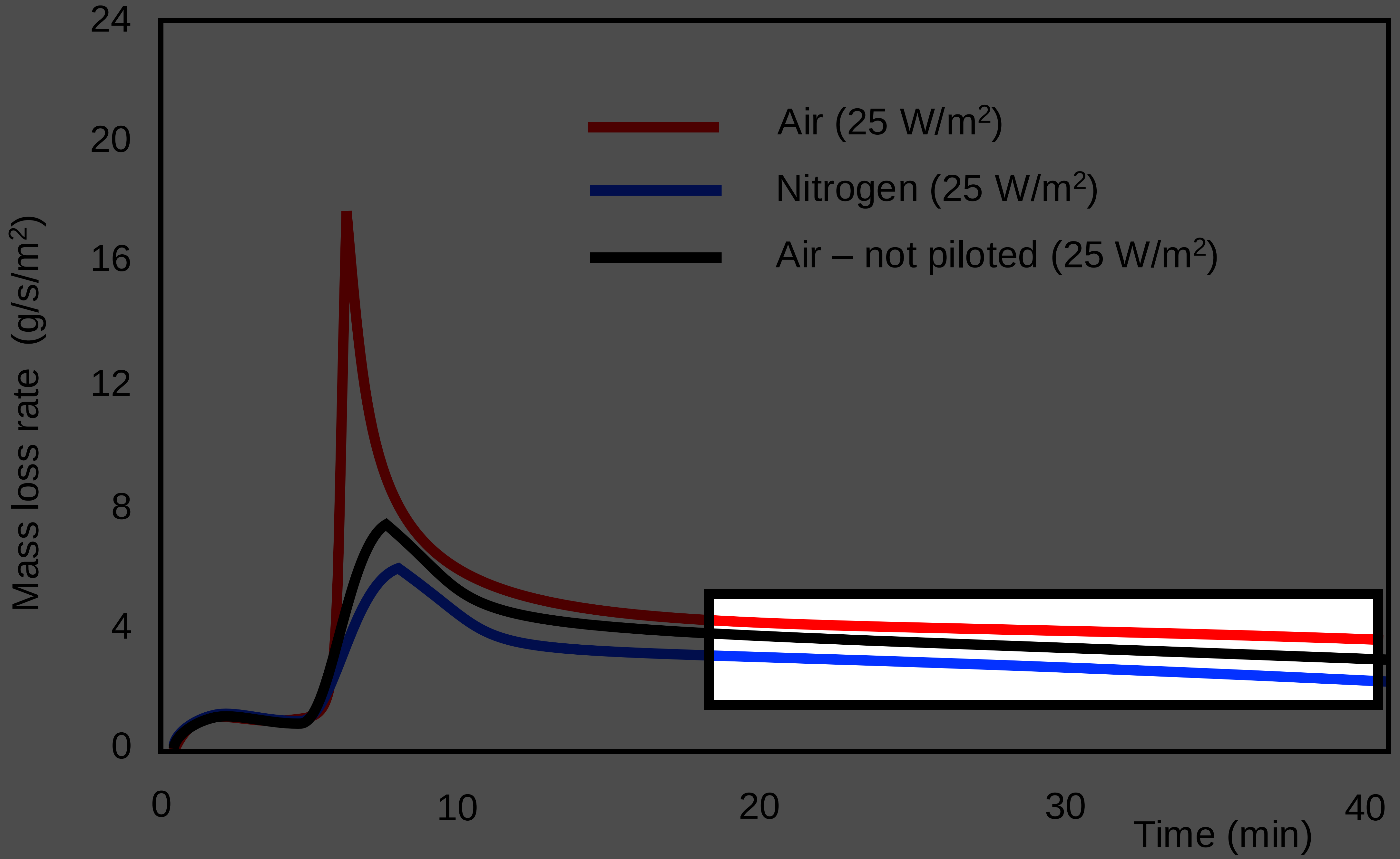


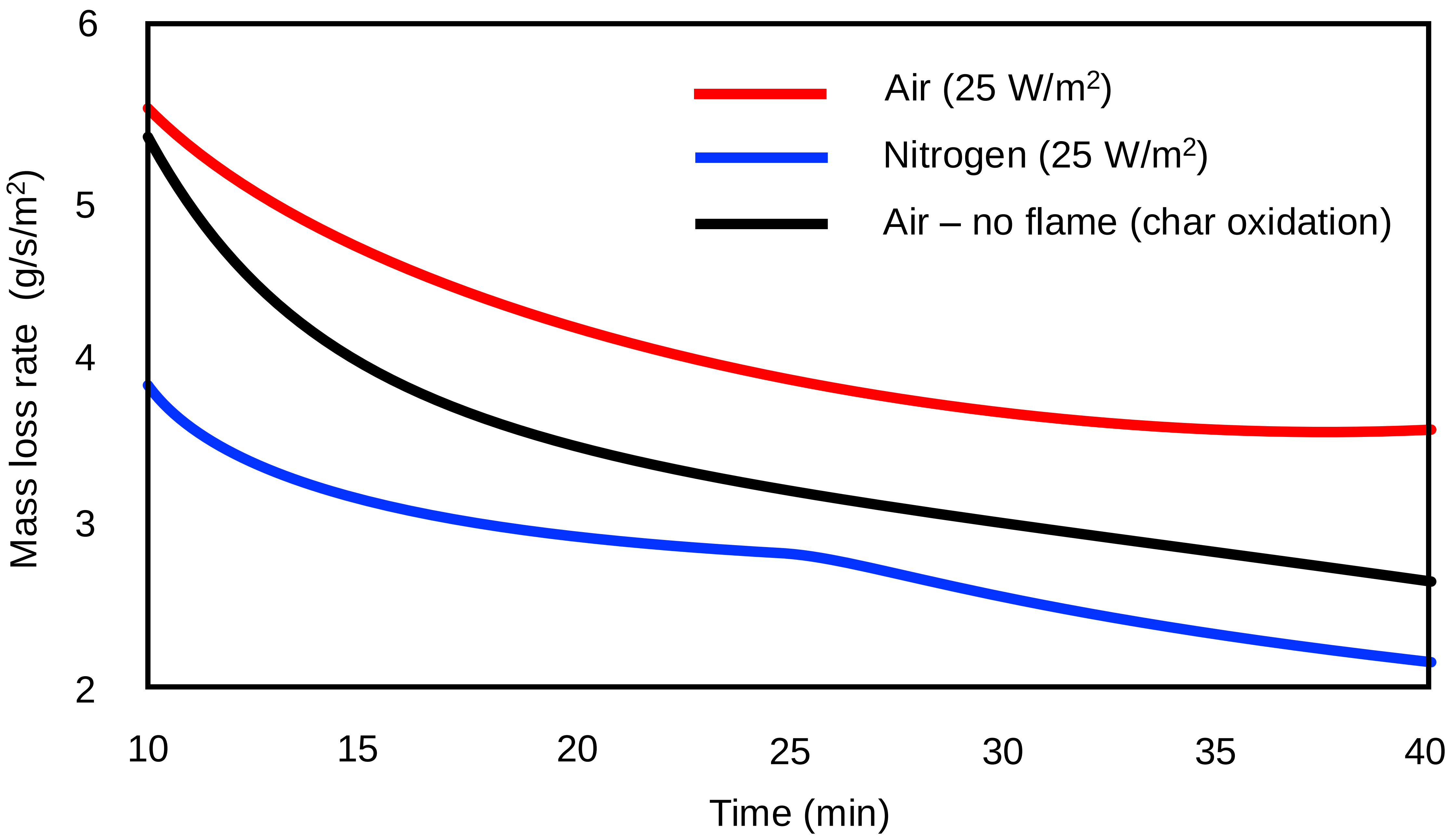
Air (25 kW/m2)
Nitrogen (25 kW/m2)
Mass loss rate (g/s/m2)
Time (min)
0
4
8
12
16
20
24
0
10
20
30
40

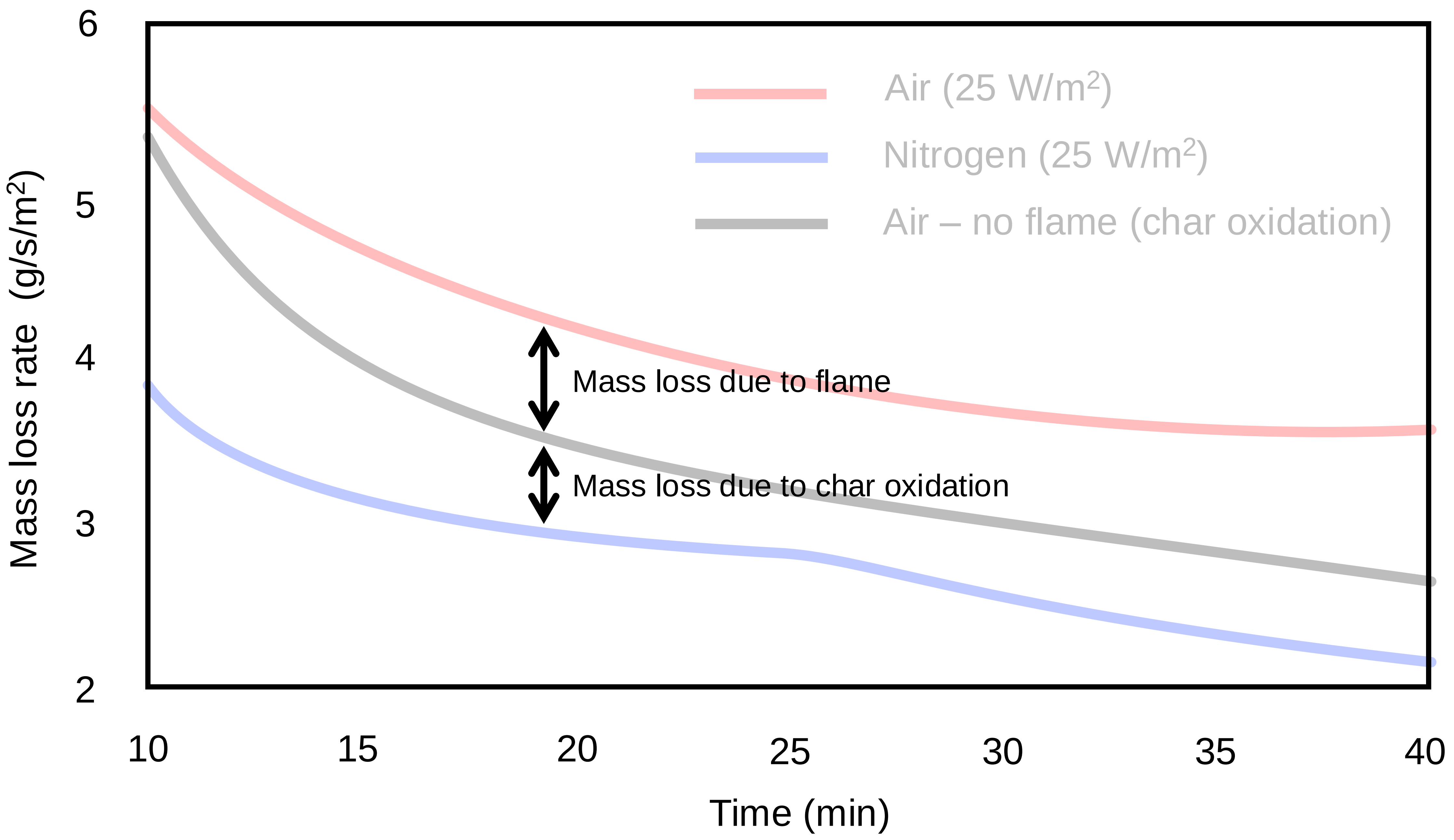

Air
Nitrogen
Piloted
Non-piloted
20 kW/m2
25 kW/m2
40 kW/m2
60 kW/m2



24
20
16
12
8
4
0
Mass loss rate (g/s/m2)
0
10
20
30
40
Time (min)
Air (25 W/m2)
Nitrogen (25 W/m2)
Air – not piloted (25 W/m2)


Air (25 W/m2)
Nitrogen (25 W/m2)
Air – not piloted (25 W/m2)
Mass loss rate (g/s/m2)
Time (min)
0
4
8
12
16
20
24
0
10
20
30
40


Mass loss rate (g/s/m2)
6
5
4
3
2
10
15
20
25
30
35
40
Time (min)
Air (25 W/m2)
Nitrogen (25 W/m2)
Air – no flame (char oxidation)



Air (25 W/m2)
Nitrogen (25 W/m2)
Air – no flame (char oxidation)
Mass loss due to flame
Mass loss due to char oxidation
Mass loss rate (g/s/m2)
Time (min)
6
5
4
3
2
10
15
20
25
30
35
40

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

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

External heat flux

Flame heat feedback

Heat released by char oxidation

Losses

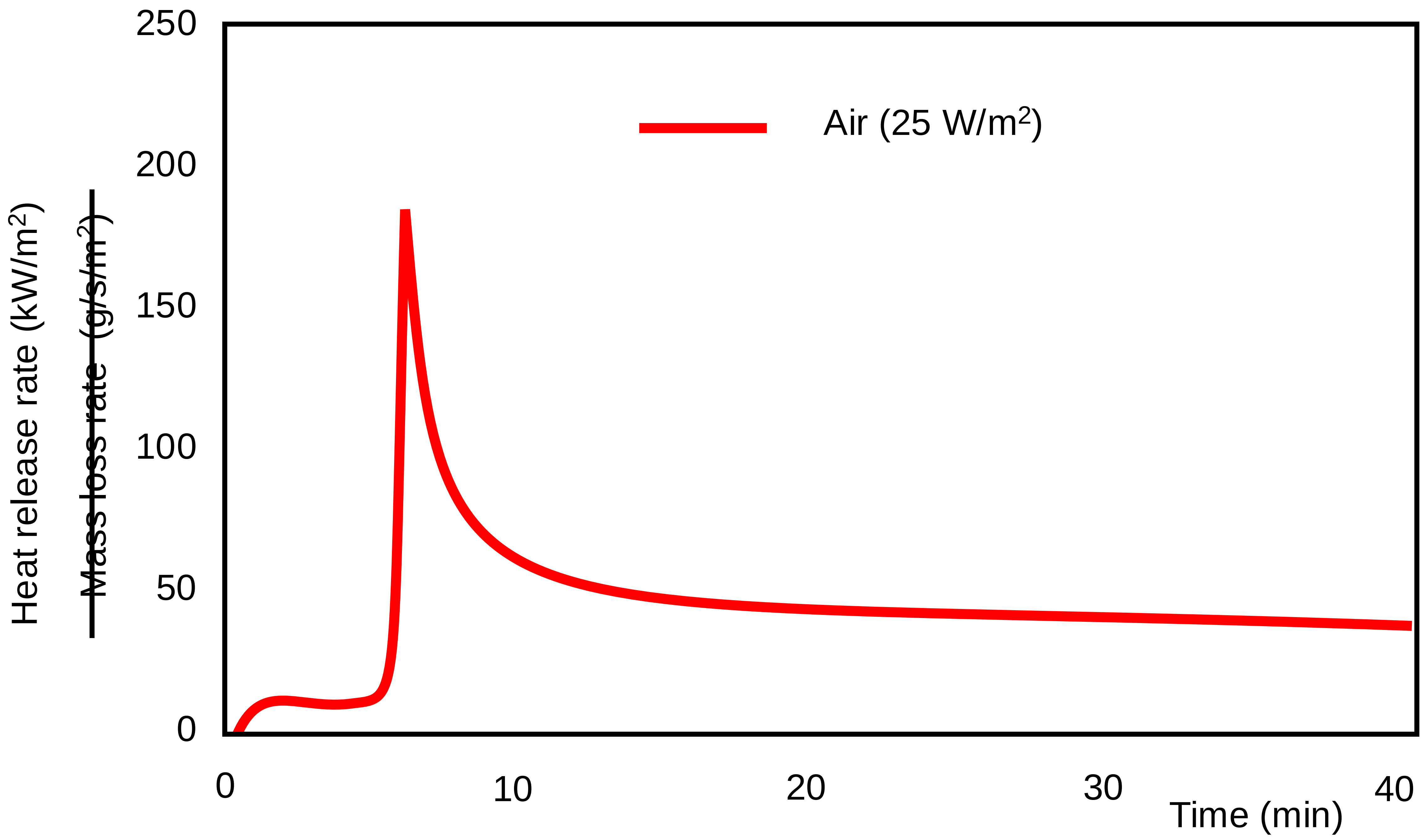
$L_v = 1.82$ MJ/kg

~20 kW/m^2 feedback from the flame

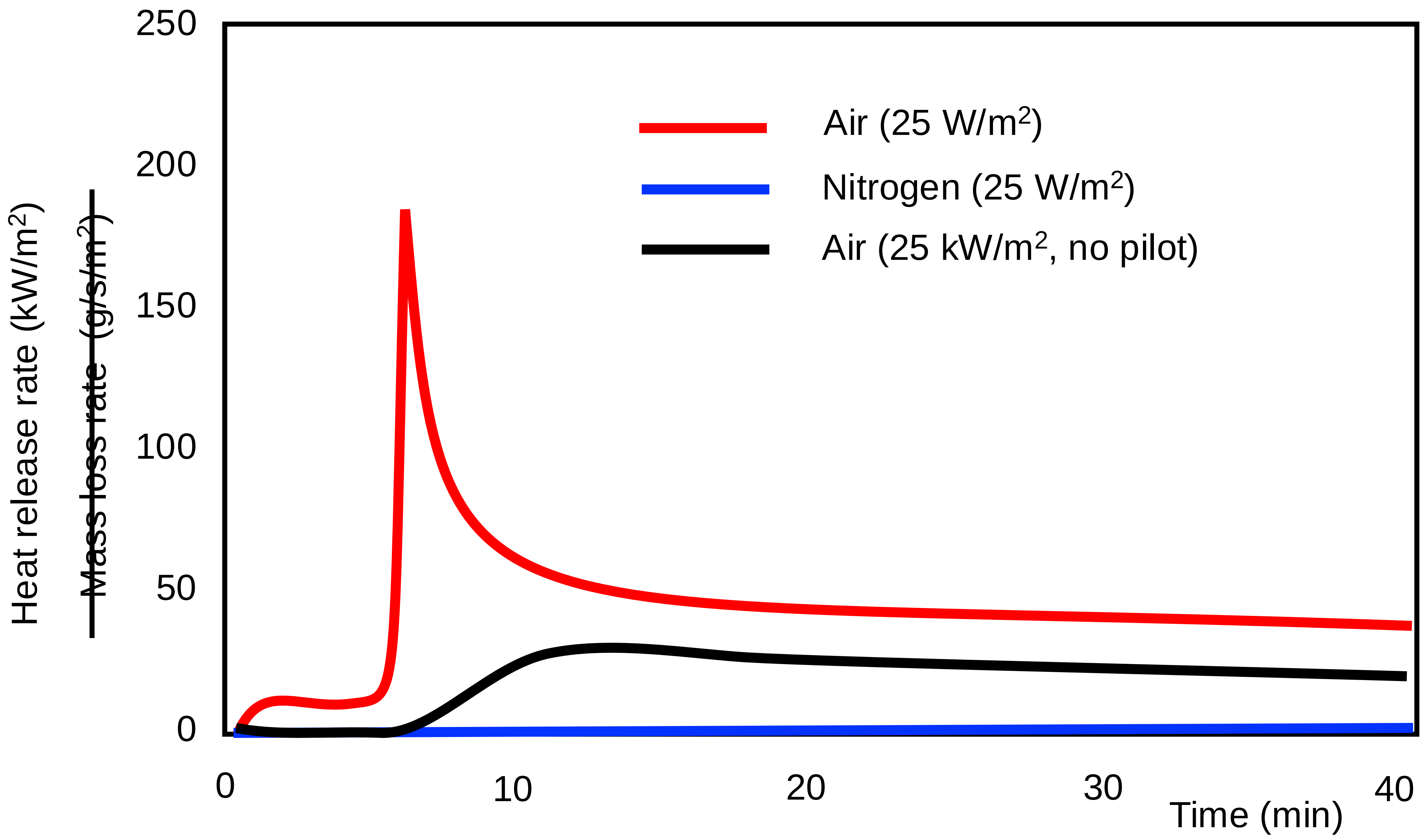
~4 kW/m^2 feedback char oxidation

Total feedback around 3 kW/m^2 during **steady state.**

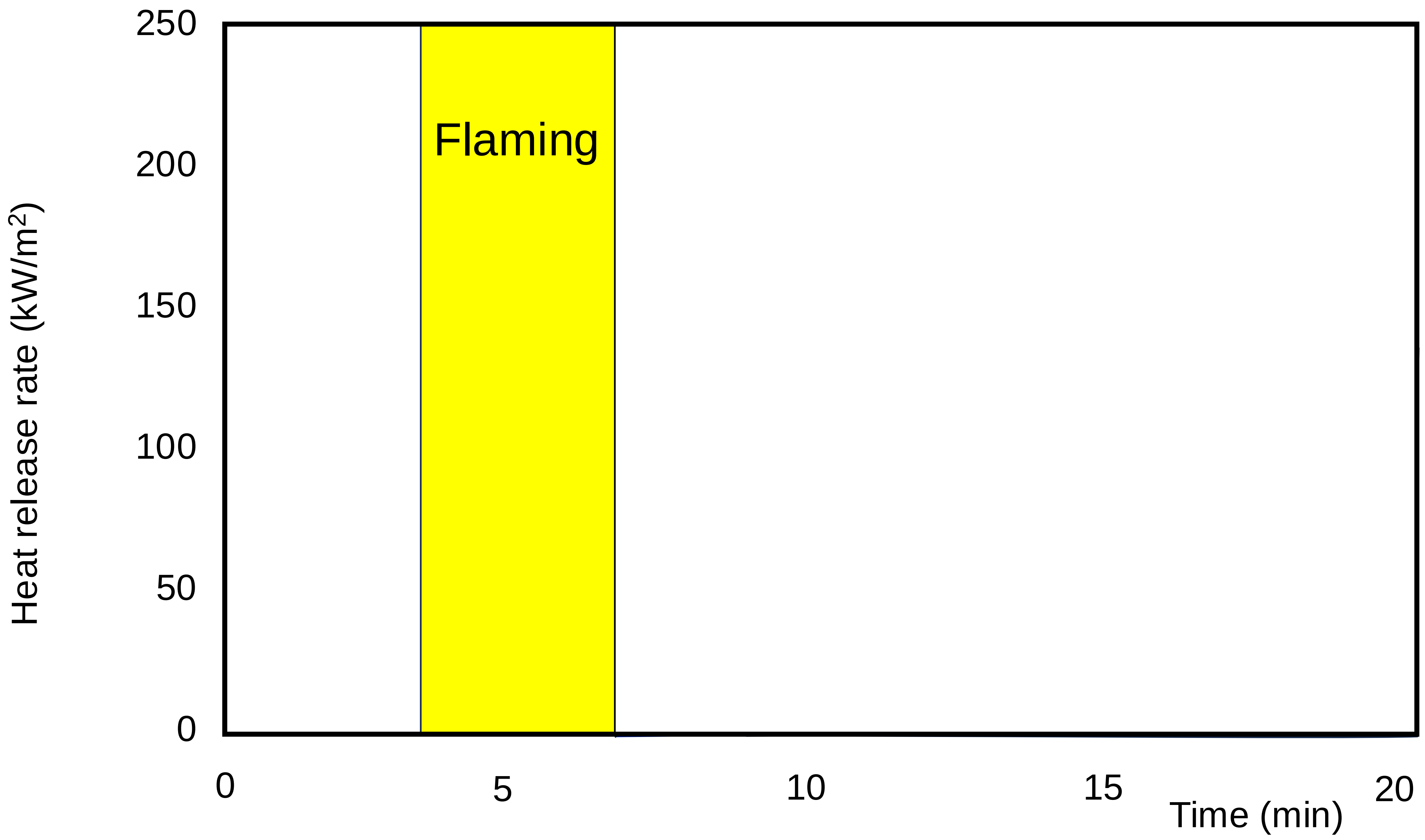
Feedback vs. heat released



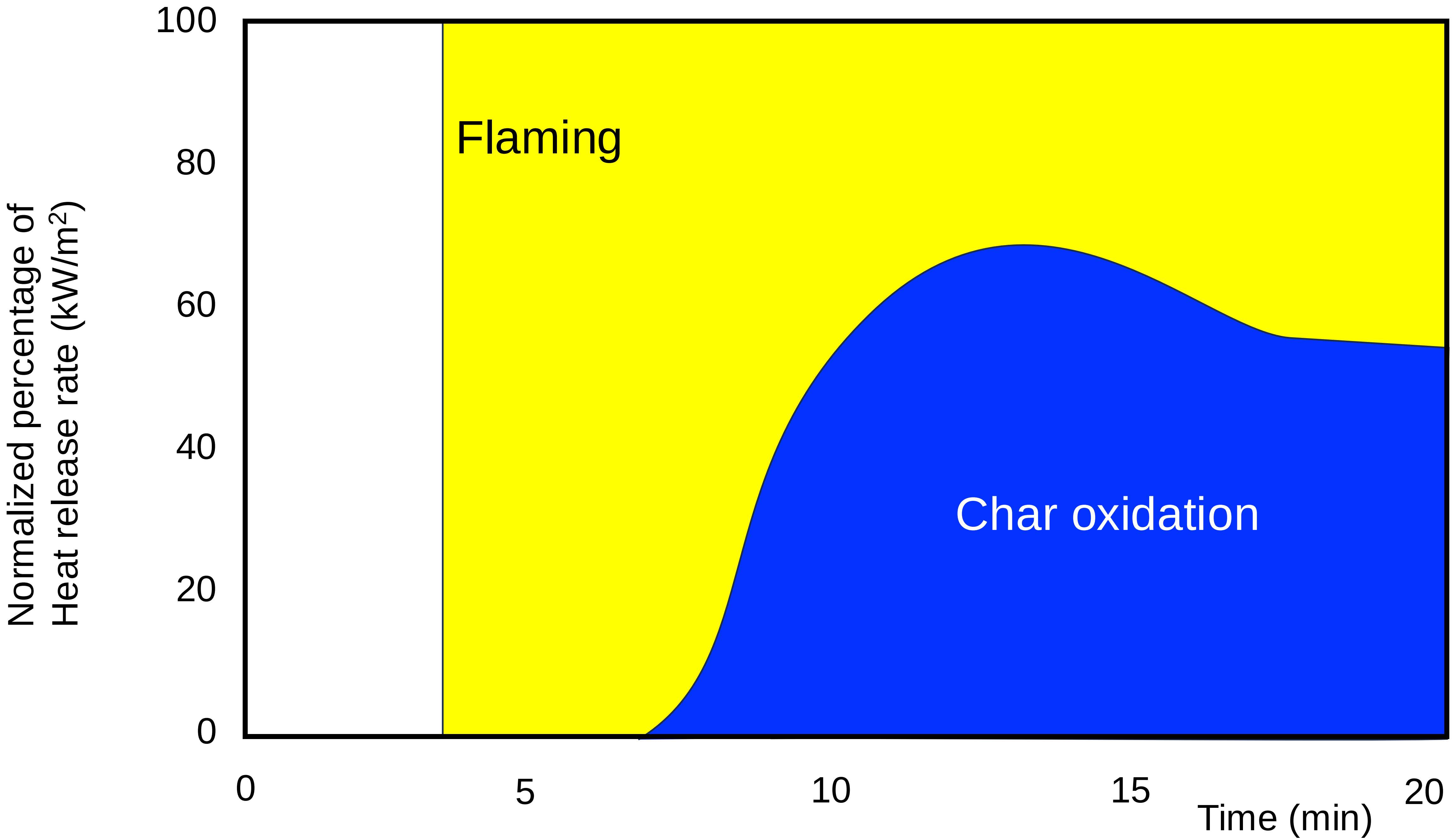
Air (25 W/m2)
250
200
150
100
50
0
0
10
20
30
40
Time (min)
Heat release rate (kW/m2)
Mass loss rate (g/s/m2)



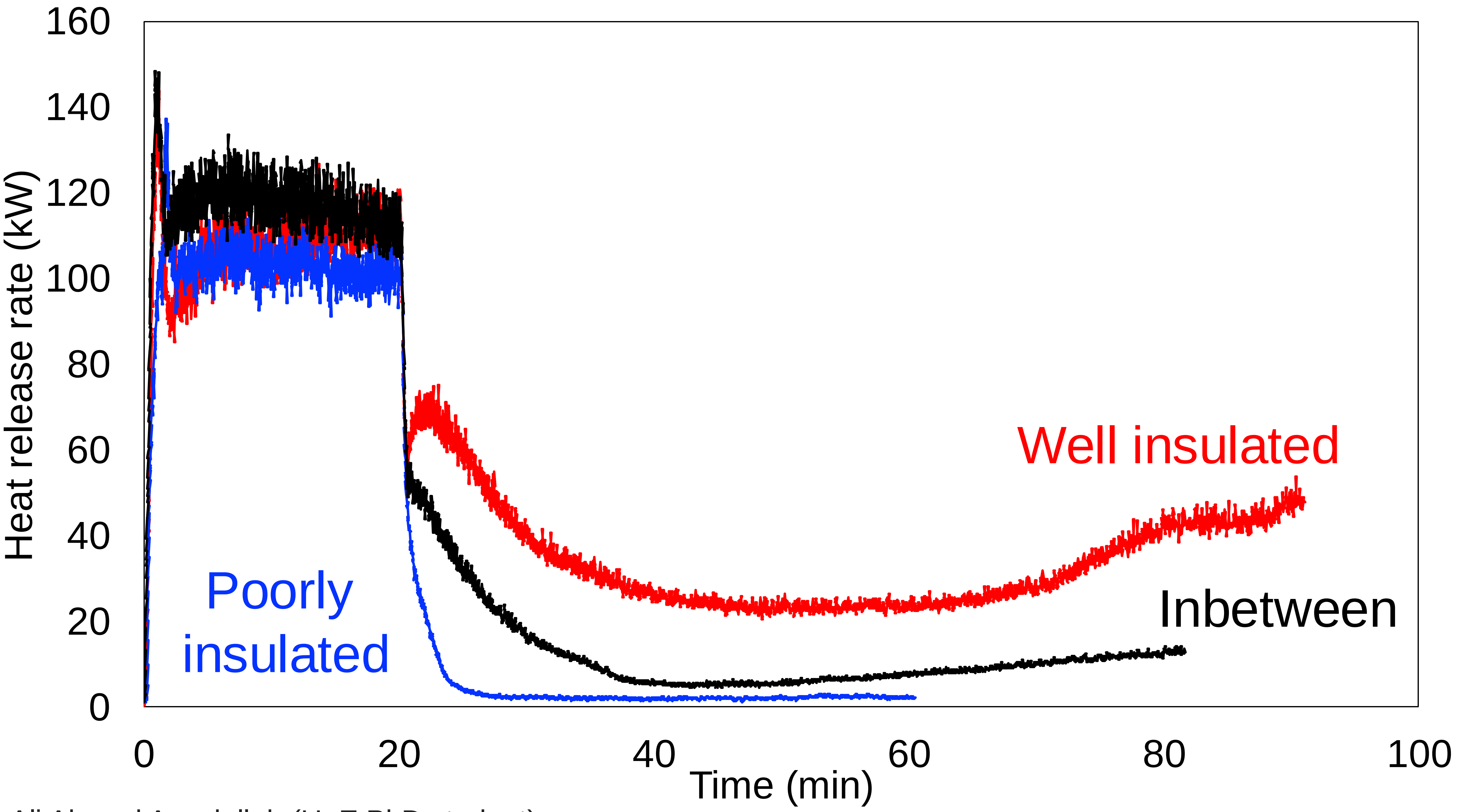
Air (25 W/m2)
Nitrogen (25 W/m2)
Air (25 kW/m2, no pilot)
Heat release rate (kW/m2)
Mass loss rate (g/s/m2)
Time (min)
250
200
150
100
50
0
0
10
20
30
40



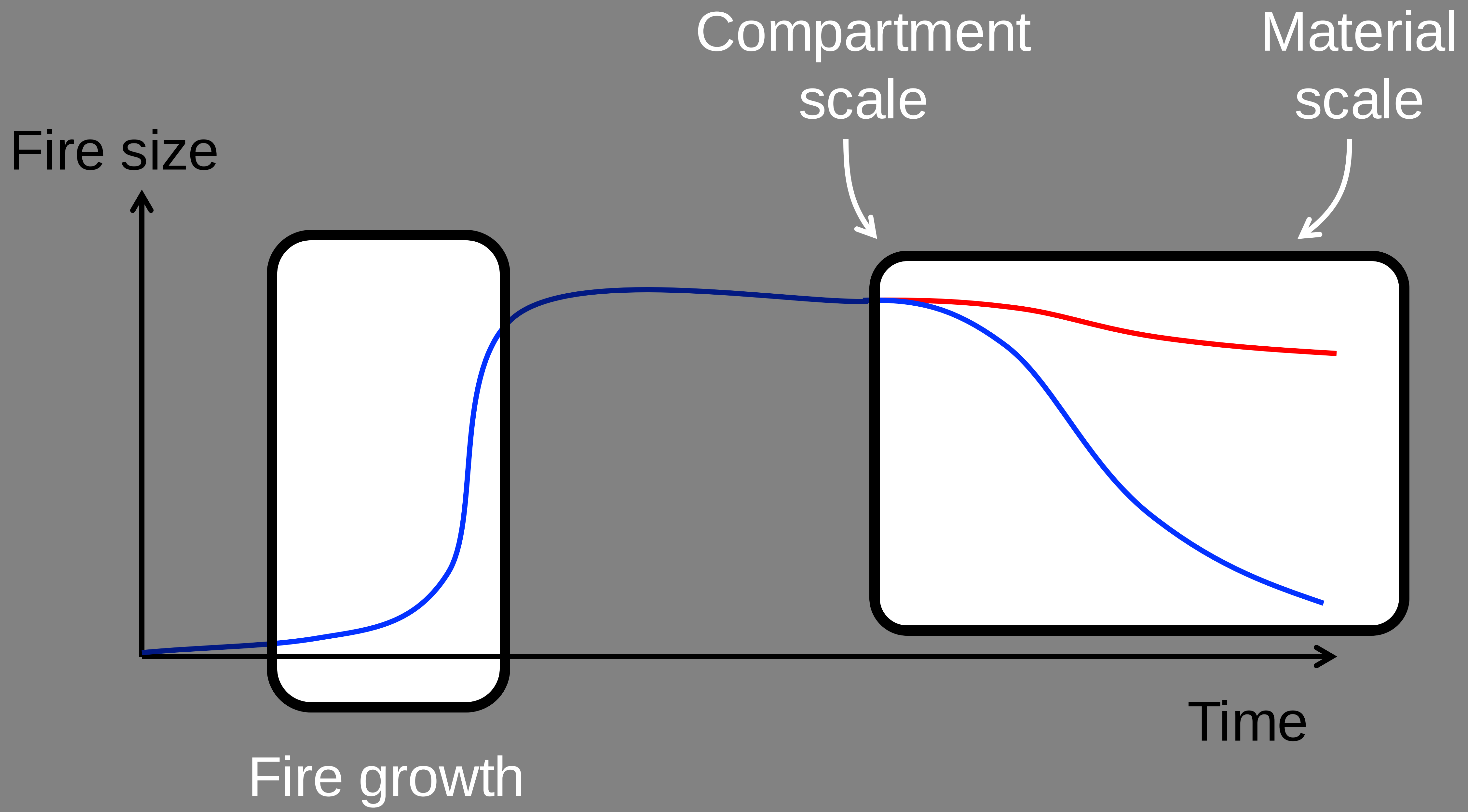
Heat release rate (kW/m2)
250
200
150
100
50
0
Flaming
0
5
10
15
20
Time (min)


Normalized percentage of
Heat release rate (kW/m2)
100
80
60
40
20
0
Flaming
Char oxidation
0
5
10
15
20
Time (min)

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



Data: Ali Ahmed Awadallah (UoE PhD student)


Compartment
scale
Material
scale
Fire size
Time
Fire growth

https://doi.org/10.1016/j.ijadhadh.2024.103834

https://doi.org/10.1016/j.firesaf.2024.104167

https://doi.org/10.1016/j.firesaf.2024.104196

https://doi.org/10.1016/j.firesaf.2020.103058

https://doi.org/10.1016/j.firesaf.2024.104164

https://doi.org/10.1016/j.firesaf.2023.103793

https://doi.org/10.1007/s10694-018-0787-y

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Angus Law


Cameron MacLeod


David Morrisset


Mark Partington


Ian Pope


Laura Schmidt

Questions

Feedback (kW/m^2)

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