

Fire risk of Cross Laminated Timber (CLT)

Consequences for prevention and suppression

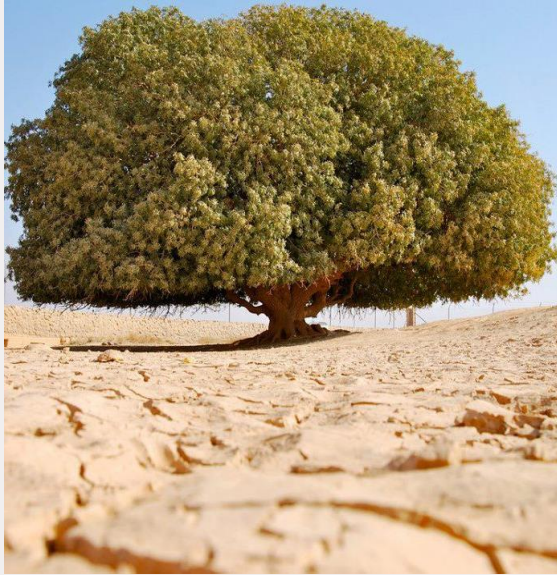
Ruud van Herpen, 2022

Department Built Environment



Popularity of wooden buildings

Living wood



CO_2 : -

Dead wood



CO_2 : 0

Burnt wood



CO_2 : +

What was the problem with wooden buildings?

**London
City fire 1666**

13,200 houses
89 churches



Can we handle this problem?

**Blaze on Sherbrooke Way, Worcester Park, Sutton
(Sept. 2019, 4 stories residential building)**



Timber structure

Performance based: objectives

Risk subsystems:

- Safety of third party properties (neighbouring plots)
- Safety of building occupants and fire service (escape routes and attack routes)
- Safety of the building (load bearing structure) → LOD
- Limiting spread of fire (compartmentation) → LOD
- Limiting smoke propagation (sub compartmentation) → LOD
- Limiting fire development → LOD

LOD:

- Line of Defence



Performance based: assessment criteria

For each risk subsystem, project specific assessment:

$$AST > RST \times \gamma$$

γ = safety factor

AST = available safe time [min] / [min SFC]

RST = required safe time [min] / [min SFC]

LOD's with a large safety factor ensure a fire resilient building

CLT in residential buildings

Walls and floors are the load bearing structure

Walls and floors are the separation constructions of (sub)compartments

Fire resistance criteria (EN 13501-2):

- Load bearing function: R [min SFC]
- Separation function: EI [min SFC]

Rule based:

- CLT exposed to fire can be sufficiently fire resistant

Performance based:

- Does the fire stop after the standard fire duration?
(self extinguishing effect)



CLT in residential buildings

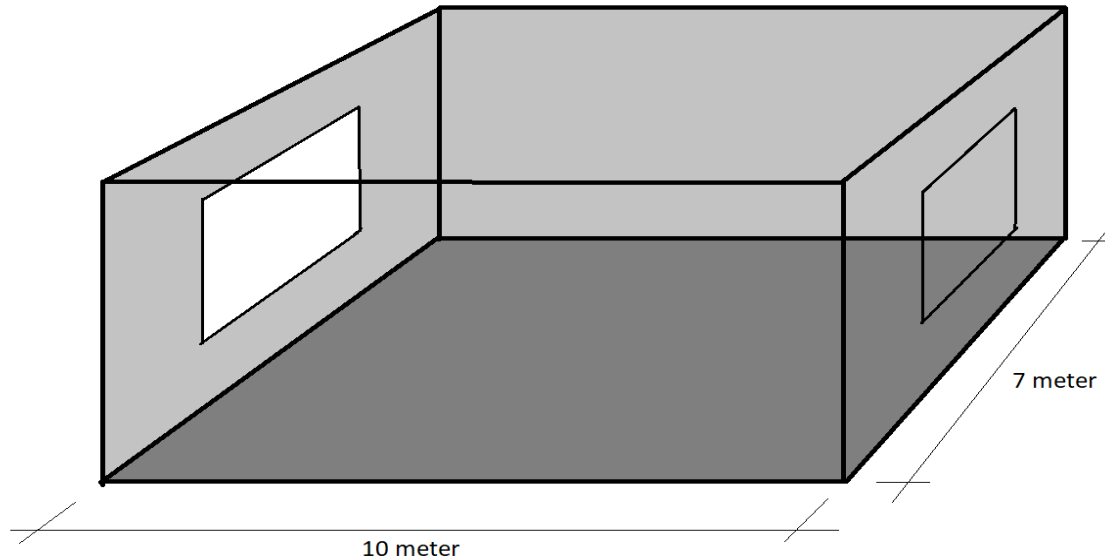


CLT Fire Resistance Test

Performed by
Estonian Academy of
Security Sciences

CLT in residential buildings

Simulation natural fire: Traditional vs. exposed CLT



CLT in residential buildings

Simulation natural fire: Traditional vs. exposed CLT

Boundary condition		Traditional	CLT
Permanent fire load (average)	[MJ/m ²]	-	400 ⁽²⁾
Variable fire load (average)	[MJ/m ²]	780 ⁽¹⁾	780 ⁽¹⁾
Rate of Heat Release density	[kW/m ²]	250 ⁽¹⁾	250 ⁽¹⁾
Time constant fire development	[s]	300 ⁽¹⁾	300 ⁽¹⁾
Combustion value	[MJ/kg]	17,5 ⁽³⁾	17,5 ⁽³⁾
Stoichiometric constant	[kg/kg]	1,27 ⁽³⁾	1,27 ⁽³⁾
Combustion efficiency	[-]	0,8 ⁽³⁾	0,8 ⁽³⁾
Collapsed daylight openings h x b	[m]	1,5 x 8,2 (total)	1,5 x 8,4 (total)

⁽¹⁾ According to NEN-EN 1991-1-2/NB

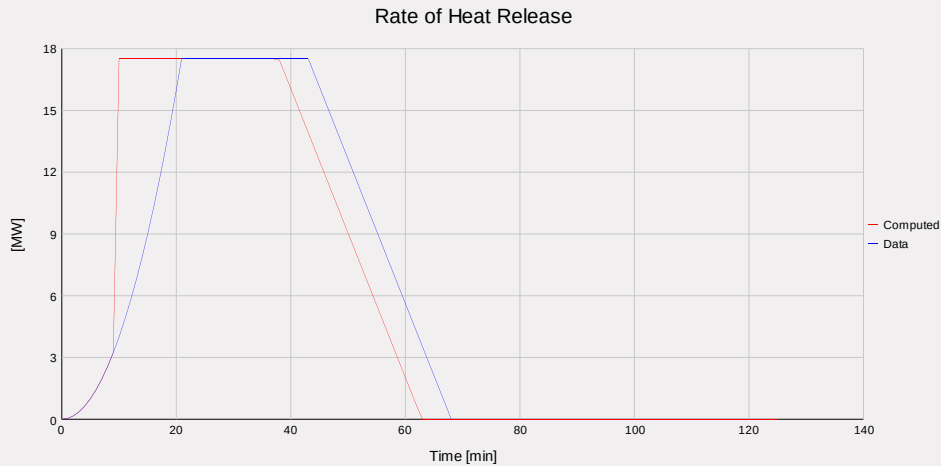
⁽²⁾ Assuming a characteristic permanent fire load of 500 MJ/m²

⁽³⁾ According to NEN 6055

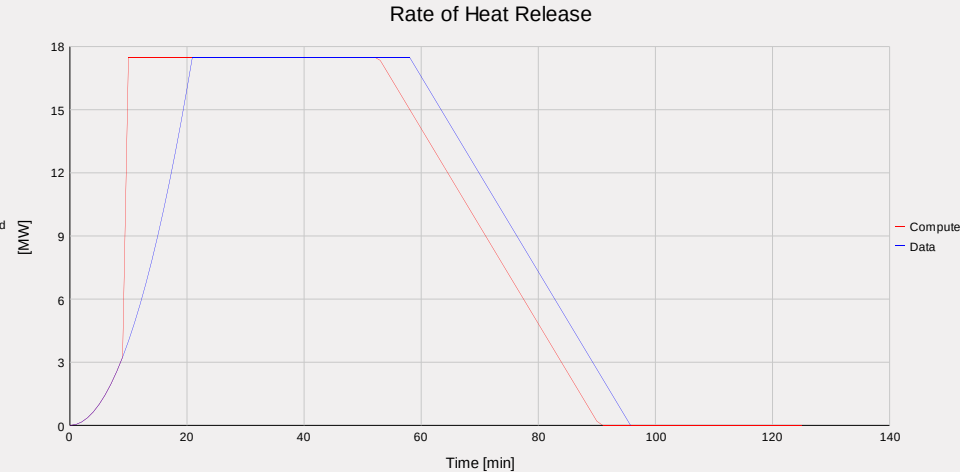
CLT in residential buildings

Thermal action by fire

Thermal action by fire (traditional)



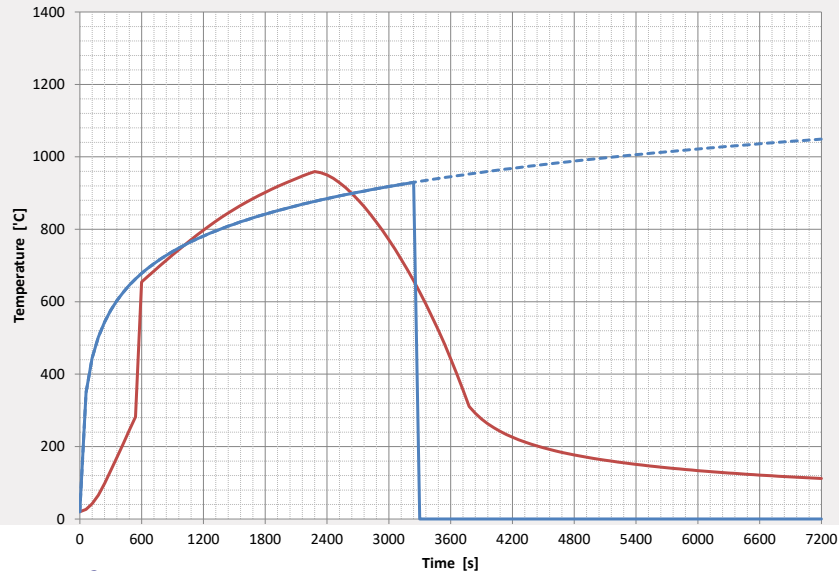
Thermal action by fire (CLT)



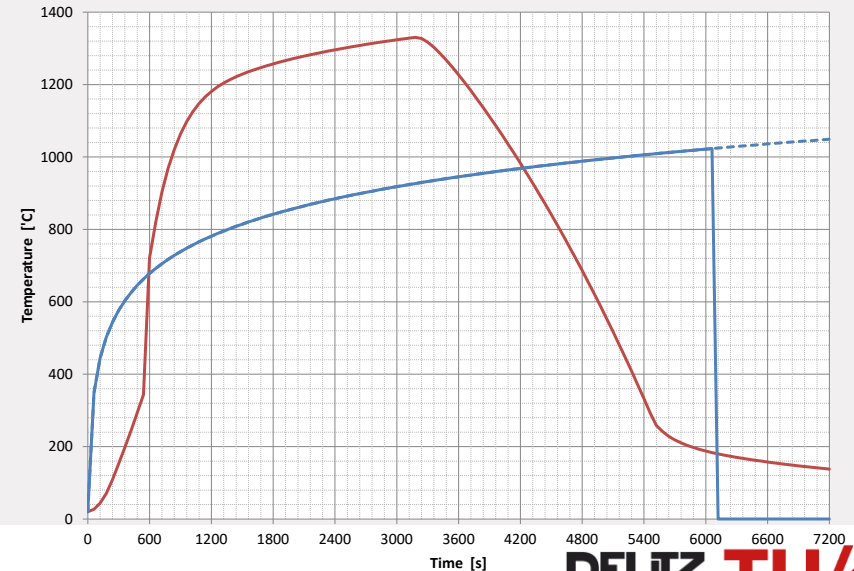
CLT in residential buildings

Thermal action by fire

Thermal action by fire (traditional) 55 min SFC



Thermal action by fire (CLT) 101 min SFC



CLT in residential buildings – sensitivity analysis

Each boundary condition (x_i):

Average value: $\bar{x}_i$

Variation: dx_i

Standard Deviation: s_i

Impact on outcome AST-RST (t):

Variation: dt

Specific Variation: dt/dx_i

Specific Variancy: $(s_i dt/dx_i)^2$

Probability AST-RST :

Total Variancy: $var = \sum_i (s_i dt/dx_i)^2$

Standard Deviation: $s = \sqrt{var}$

CLT in residential buildings – sensitivity analysis

Stochast	AVG	SD
Permanent fire load density [MJ/m ²]	0 (traditional) 400 (CLT)	0 (traditional) -300 ⁽¹⁾ / +120 (CLT)
Variable fire load density [MJ/m ²]	780	-120 / +120 ⁽²⁾
Rate of Heat Release density [kW/m ²]	250	-100 / +100 ⁽³⁾
Time constant fire development [s]	300	-100 / +100 ⁽³⁾

(1) Based on fire extinguishment in CLT construction when the variable fire load is combusted

(2) Based on NEN-EN 1991-1-2/NB

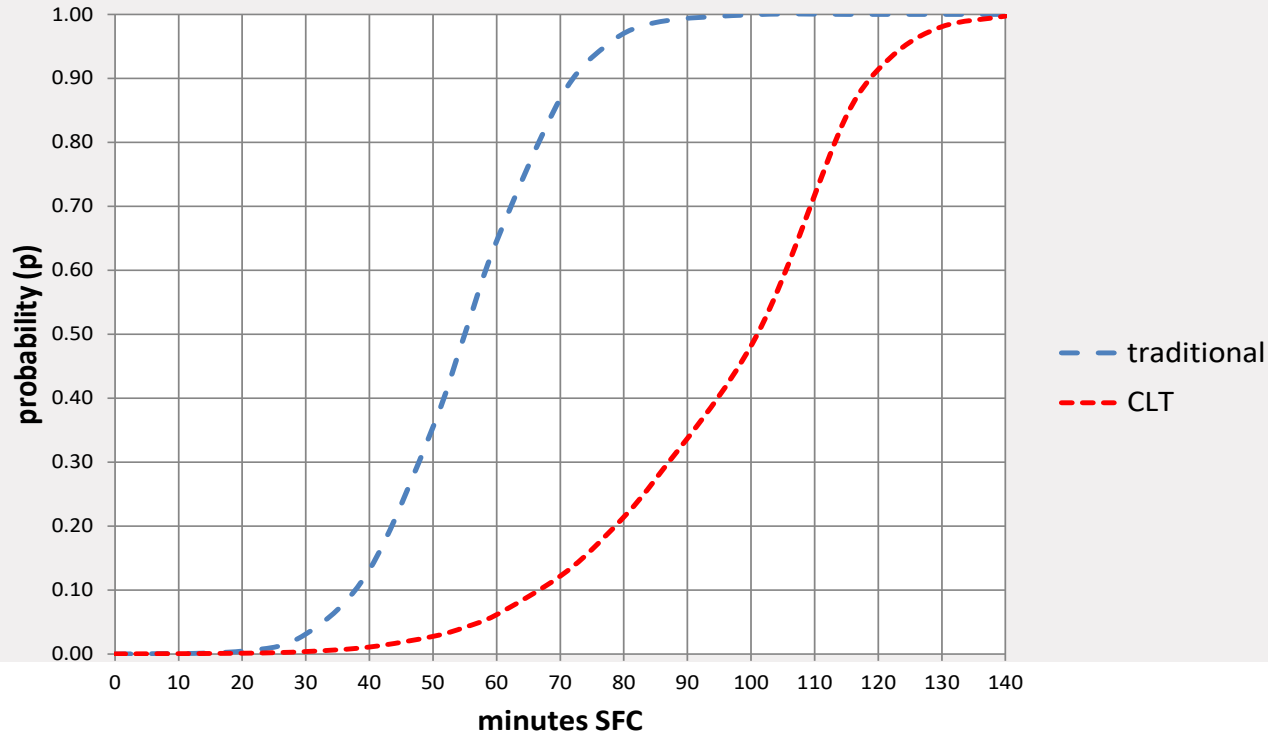
(3) Based on bandwidth of the classification

CLT in residential buildings – sensitivity analysis

	Traditional [min. SFC]	CLT [min. SFC]
AVG	55	101
SD	-13,4 / +13,4	-26,6 / +14,0

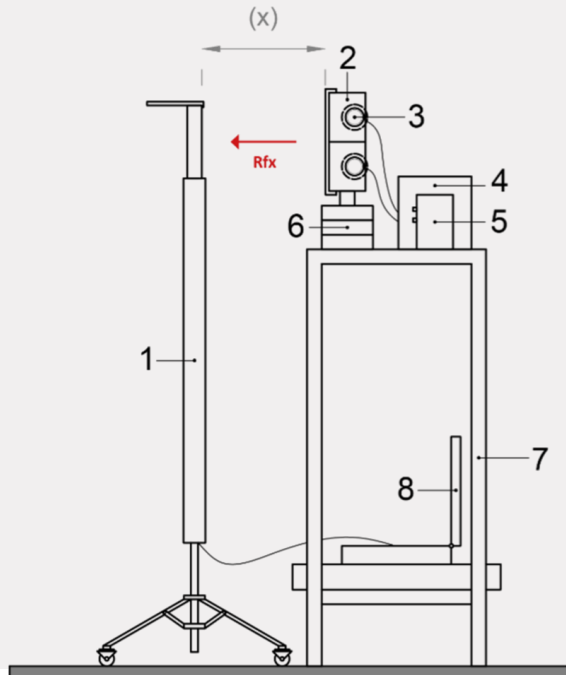
Reliability of fire compartmentation

equivalent fire duration
cumulative distribution probability



Lab research

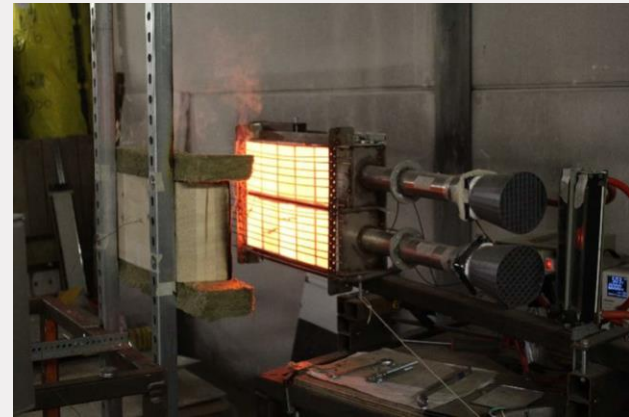
Masterproject *Fire resilience of CLT*



Elevation Key

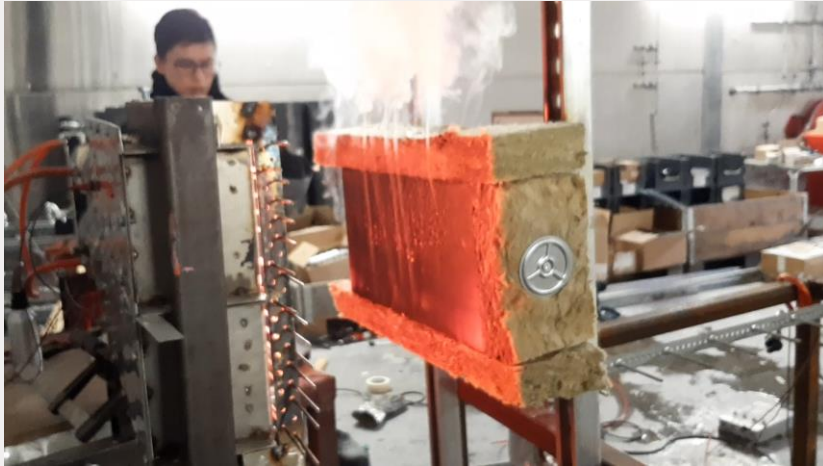
- 1 infrared radiation sensor - 2 radiant panel (480mm x 270mm) - 3 ventilation tubes
- 4 voltage regulator - 5 PID temperature controller - 6 cold-rolled profile (40mm x 40mm)
- 7 cold-rolled table (40mm x 40mm) - 8 Graphtec GL 240 Midi data logger

DERIX



Lab research

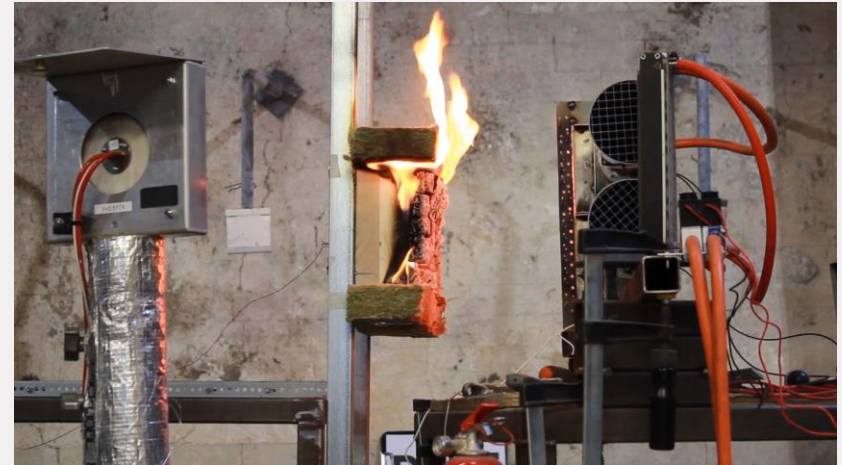
Self extinguishing effect and delamination (ME and PU glue)



Andrés Berdugo Calderon (Politecnico Torino)

Lab research

Self extinguishing effect and delamination (ME and PU glue)



Lab research

Results:

- $Q_{\text{rad}} = 100 \text{ kW/m}^2$ → no measurement possible
- $Q_{\text{rad}} = 25 \text{ kW/m}^2$ → burn in speed: 0,3 mm/min (flaming/smouldering)
- $Q_{\text{rad}} = 15 \text{ kW/m}^2$ → burn in speed: 0,15 mm/min (smouldering)
- $Q_{\text{rad}} = 10 \text{ kW/m}^2$ → burn in speed: 0,15 mm/min (smouldering)
- $Q_{\text{rad}} = 5 \text{ kW/m}^2$ → burn in speed: 0,15 mm/min (smouldering)

Transition from flaming to smouldering combustion (CLT):

- Burn in depth: 3 – 8 mm

All experiments (90 min): continuous smouldering combustion in CLT samples

- No self extinguishing effect was found

Adjusted simulation

Thermal action by fire

Modeled contribution of permanent fire load (CLT):

- Fully developed fire: 0.6 mm/min (assumption)
- Decay phase: 0.3 mm/min (flaming combustion)
- Variable fire load combusted: 0.15 mm/min (smouldering combustion)

After 2 hours natural fire (Ozone simulation):

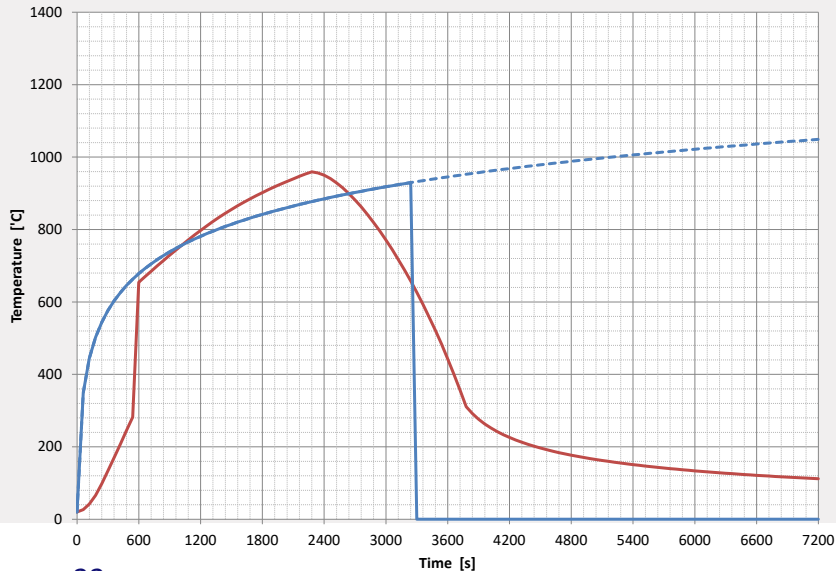
- Burn-in depth: 34 mm
- Corresponding to permanent fire load density 530 MJ/m² floor area

Note: façade openings enlarged to full façade width

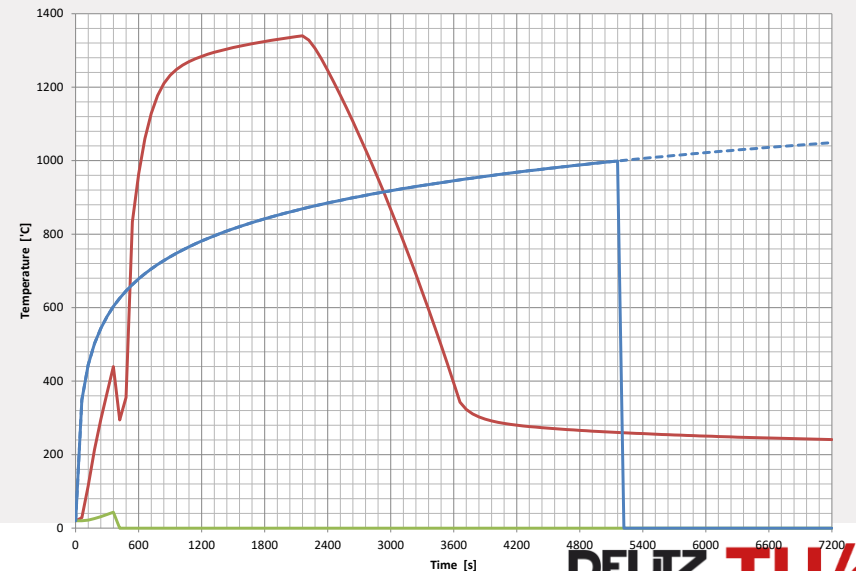
Adjusted simulation

Thermal action by fire

Thermal action by fire (traditional) 55 min SFC



Thermal action by fire (CLT) 86 min SFC



Adjusted sensitivity analysis

	Traditional [min. SFC]	CLT [min. SFC]
AVG	55	86
SD	-13,4 / +13,4	-21,2 / +13,7

Conclusions

CLT exposed to fire

- Burn-in depth of CLT separation constructions, exposed to fire: > 30 ~ 40 mm, depending on self extinguishment
- Exposed CLT can be fire resistant (EN 13501-2, SFC), but:
 - Failure probability of fire compartmentation increases
 - Probability of burn down scenario increases:
CLT building is less fire resilient than a traditional building
 - Stay-in-place concept / partial evacuation: not possible
 - Increasing probability of fire spread to neighbouring plots
 - Increasing water requirement for fire suppression

Robust solutions

Active reduction of thermal action by sprinkler protection

Passive protection of CLT construction by fire resistant cladding

Need for research:

- Self extinguishing effect of CLT by char layer at radiation flux $Q_{\text{rad}} < 5 \text{ kW/m}^2$?

www.fellowfse.nl

r.a.p.v.herpen@tue.nl
r.vanherpen@peutz.nl

