5th International Seminar on Underground Space
Health & Safety in Underground Space
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Tunnels in operation: design provisions for air quality control in tunnels in operation

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Summary

- > Introduction
- > Methods
- > Analysis of the results
- > Conclusions

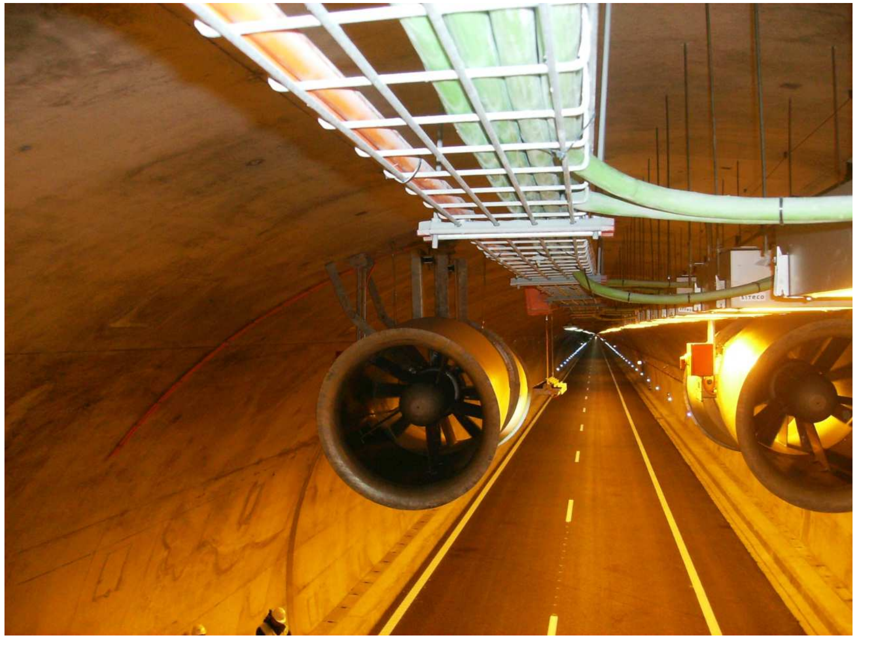
Supported on the previous work

> Viegas, João; Oliveira Costa, Carlos; Monteiro, Bernardo E Pereira, Paulo - Impact of the pressure differences generated by the smoke control system in tunnels (in Portuguese). 6ªs Jornadas de Segurança aos Incêndios Urbanos, 29 de novembro, 2018, Coimbra.

> Viegas, João; Oliveira Costa, C.; Sousa, L.; Correia, A. – Estimate of the heat release rate of the fire in Marão Tunnel in 2017-06-11 (in Portuguese). CILASCI 5 - 5th Iberian-Latin-American Congress on Fire Safety, 15-16 de julho de 2019, Porto

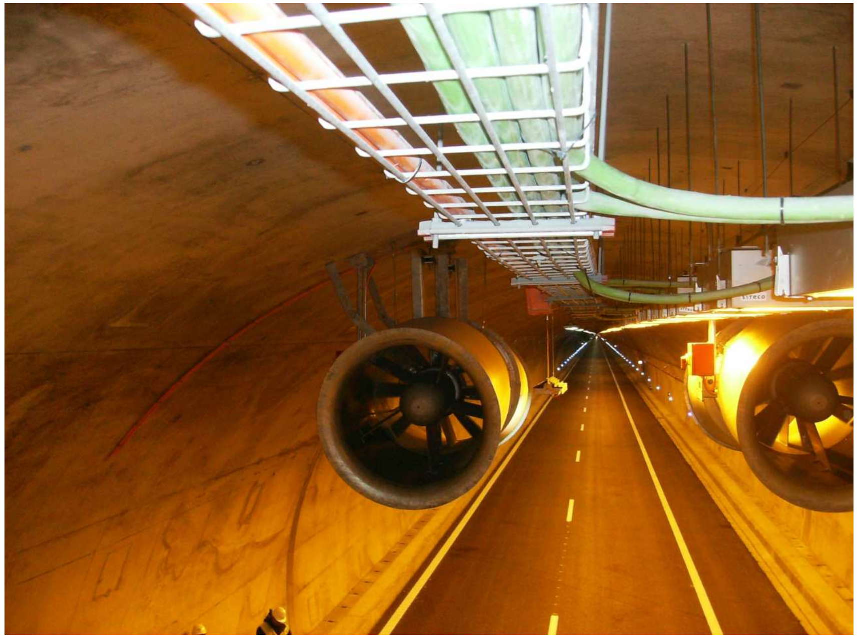
Introduction

- Ventilation of road tunnels is a major engineering issue, in special in case of fire.
- Ventilation provides the adequate environment:
  - for the users egress and
  - for the firemen tasks.
- Motorway tunnels with two independent unidirectional galleries are usually provided with longitudinal ventilation.



Introduction

> In this presentation:
  - a real fire scenario is showed, where the smoke control technique adopted was very successful;
  - the impact of the pressures generated by the longitudinal smoke control on the emergency exits is showed.



Introduction

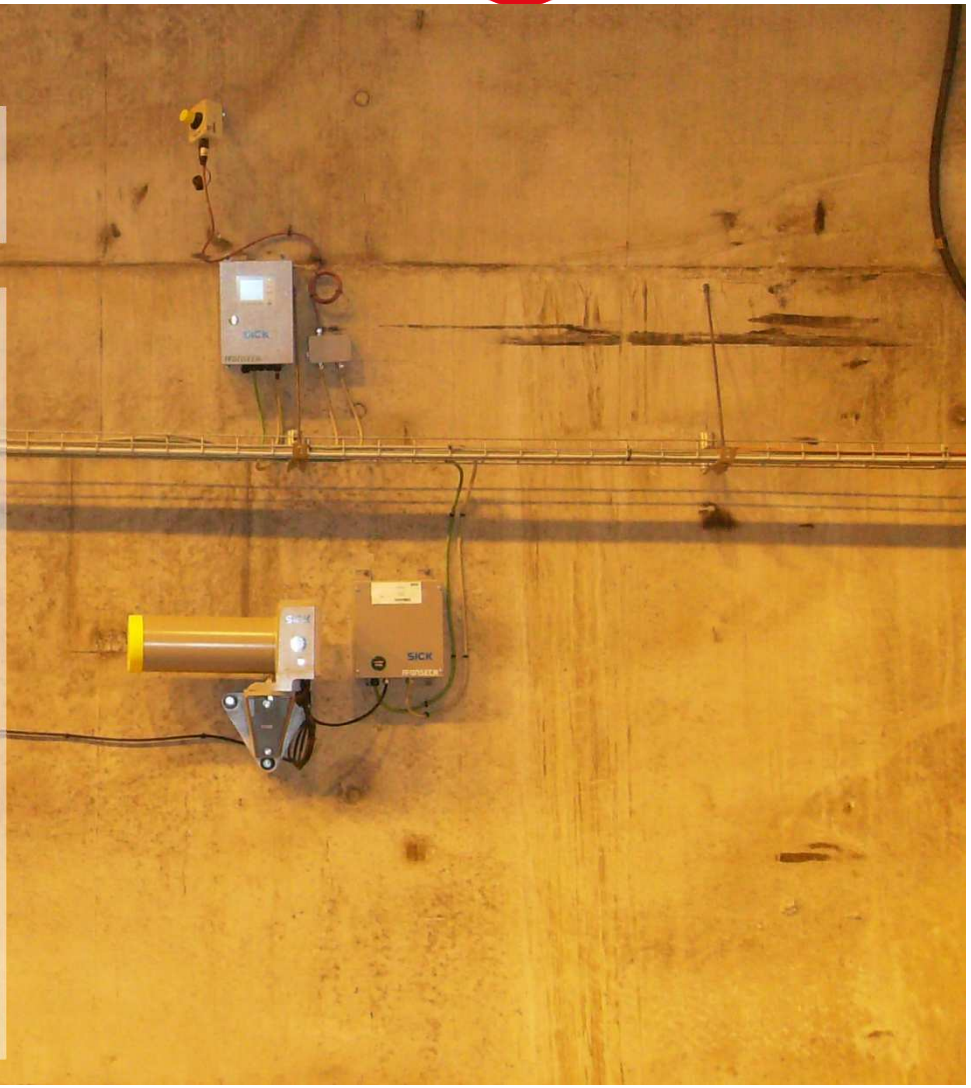
- Marão Tunnel is the longest one in Portugal (5600 m).
- At 20:29 a bus fire occurred, about 1800 m after the entrance portal.
- There was no victims but the bus was fully bunt out.
- References indicate that bus fires have a HRR of about 25 MW to 36 MW and a released energy of about 28 GJ to 41 GJ.
- The research question is:
  - **What was the HRR of this bus fire?**

Marão Tunnel, 2017-06-11


Infraestruturas
de Portugal

Methods

- The assessment of the fire temperature and of the HRR is usually done by damage analysis.
- In this case it was possible to register some data during fire event by the tunnel sensors, before their destruction, or even during whole fire event, when they were located far from the fire:
  - Fibrolaser fire detection system (destroyed by the fire)
  - Weather stations at the portals
  - Three ultrassonic velocity sensors inside the tunnel



Methods

> The HRR convected part in the section of the middle anemometer was estimated by the air expansion due to the temperature.

$$\dot{Q}_{c\_i} = v_1 A \frac{\rho_0 T_0}{T_1}\left(C_{\mathrm{p\_i}} \frac{v_{\mathrm{i}} T_1}{v_1} - C_{\mathrm{p\_1}} T_1\right) \Leftrightarrow \dot{Q}_c$$
$$= A \rho_0 T_0 \left(C_{\mathrm{p\_i}} v_{\mathrm{i}} - C_{\mathrm{p\_1}} v_1\right)$$

> Fully turbulent flow and continuity are considered.

> Correction factors were used to obtain the average velocity in the tunnel section.

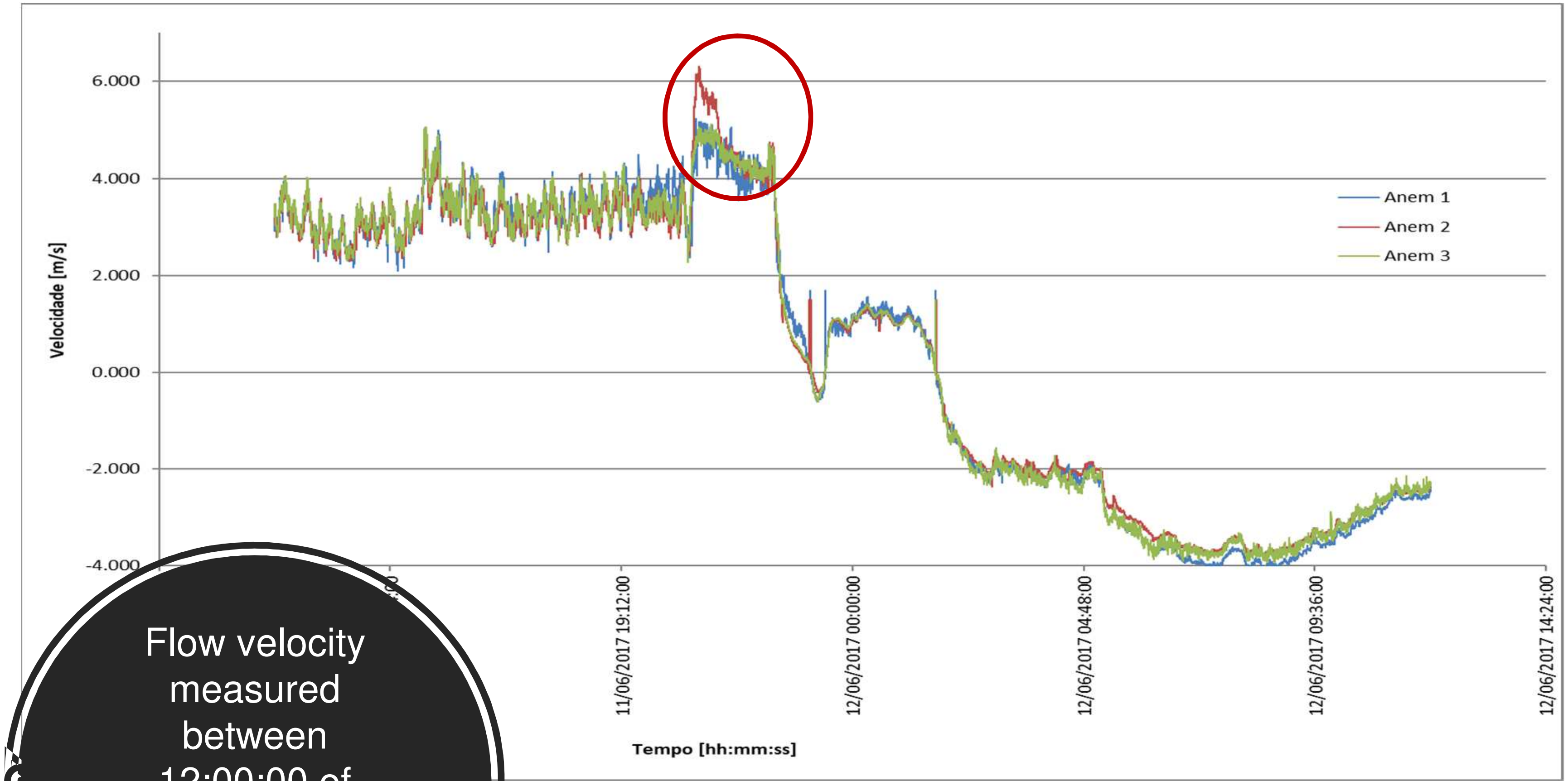
Anemomether	Correction factor	Standard uncertainty [m/s]
S-ANE-1	0,743	0,41
S-ANE-2	0,665	0,39
S-ANE-3	0,657	0,39

Methods

- The HRR standard uncertainty in the measurement section is 14.1 MW.
- The estimation of the average temperature in the fire section was made by:

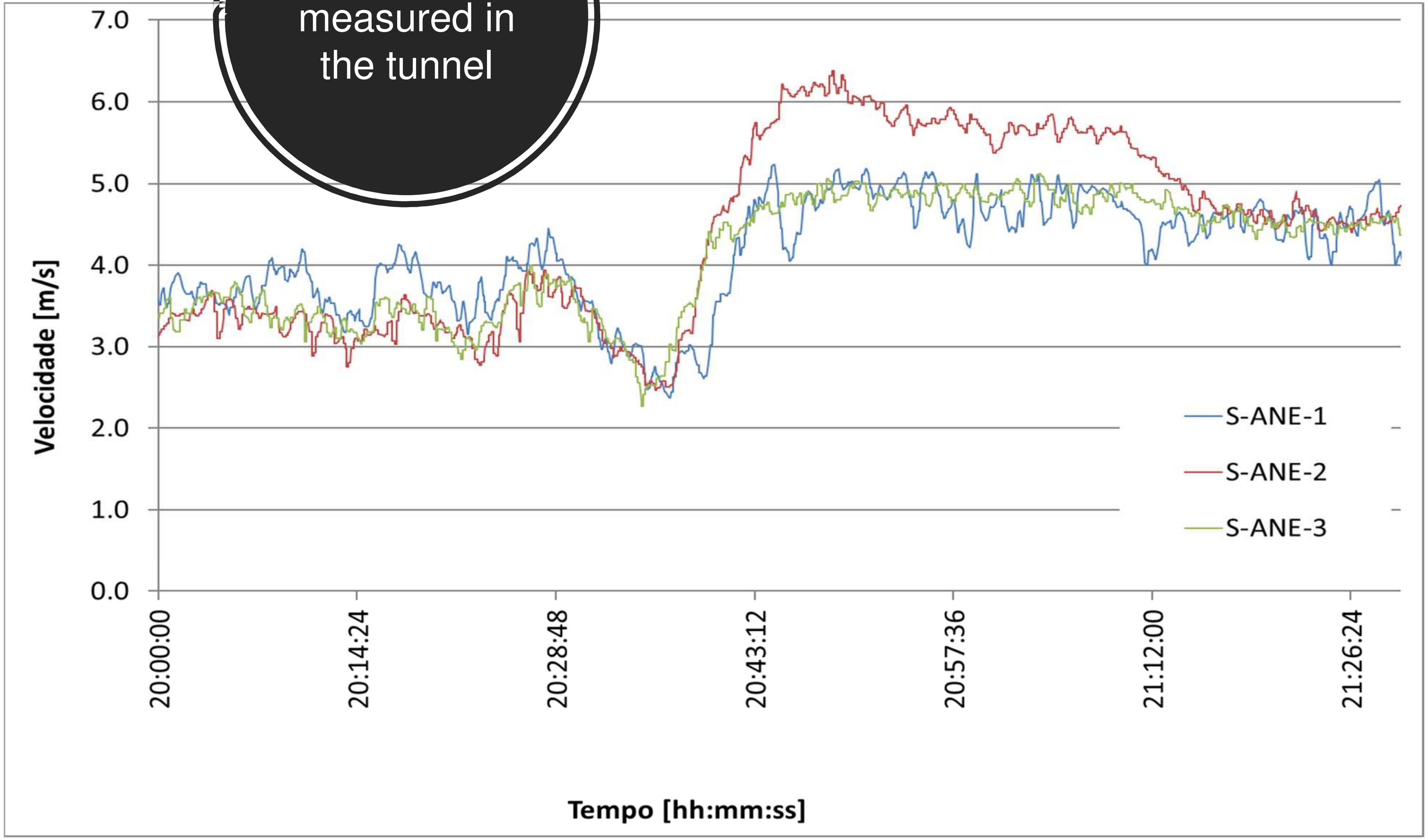
$$T_{max} = (T - T_0)e^{\frac{x}{x_e}} + T_0 \qquad x_e = \frac{C_p \rho_0 W_0 D_H}{4h_{app}} \qquad h_{app} \approx 10\ W/(m^2 K)$$

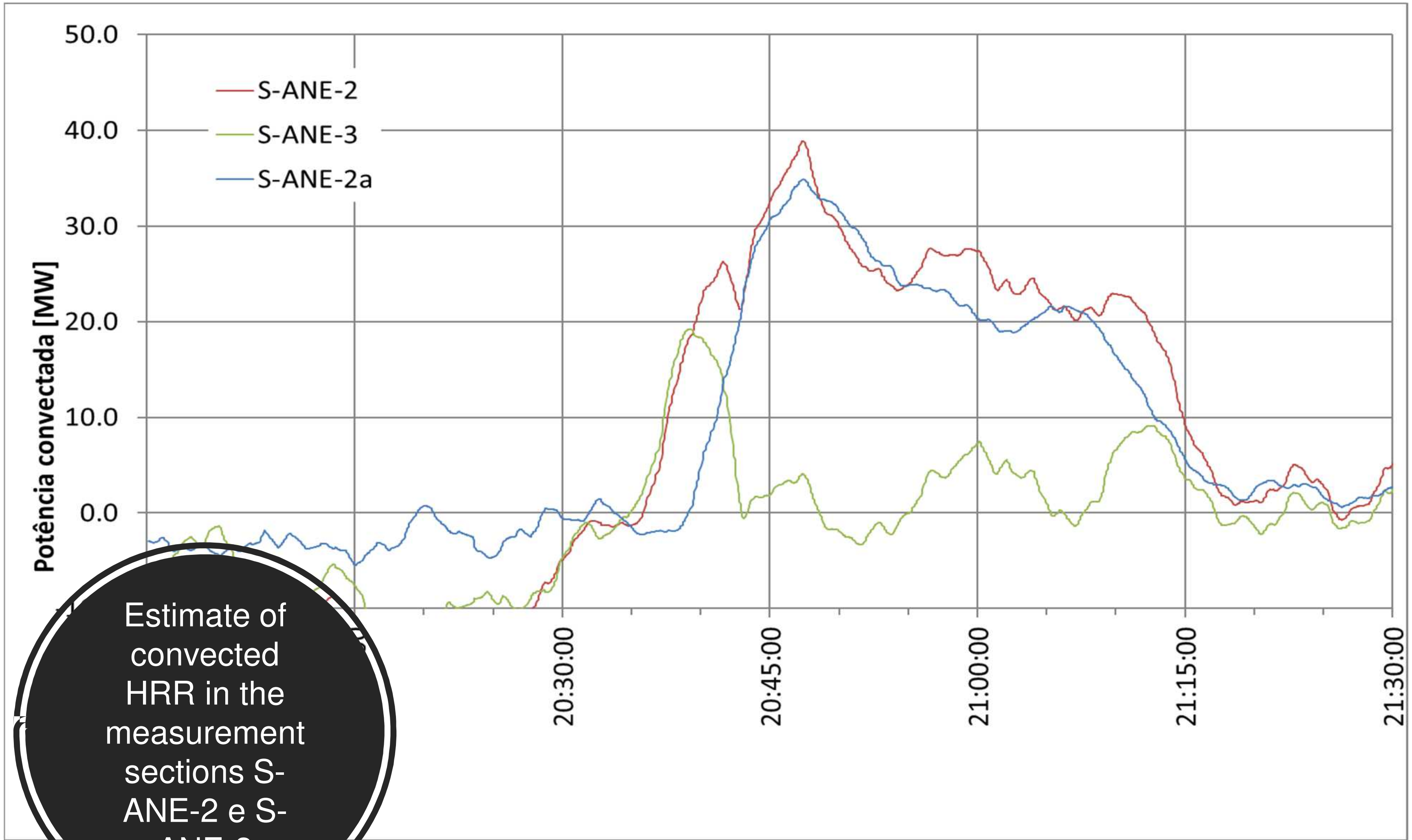
- The average temperature standard uncertainty in the fire section is 40 K.



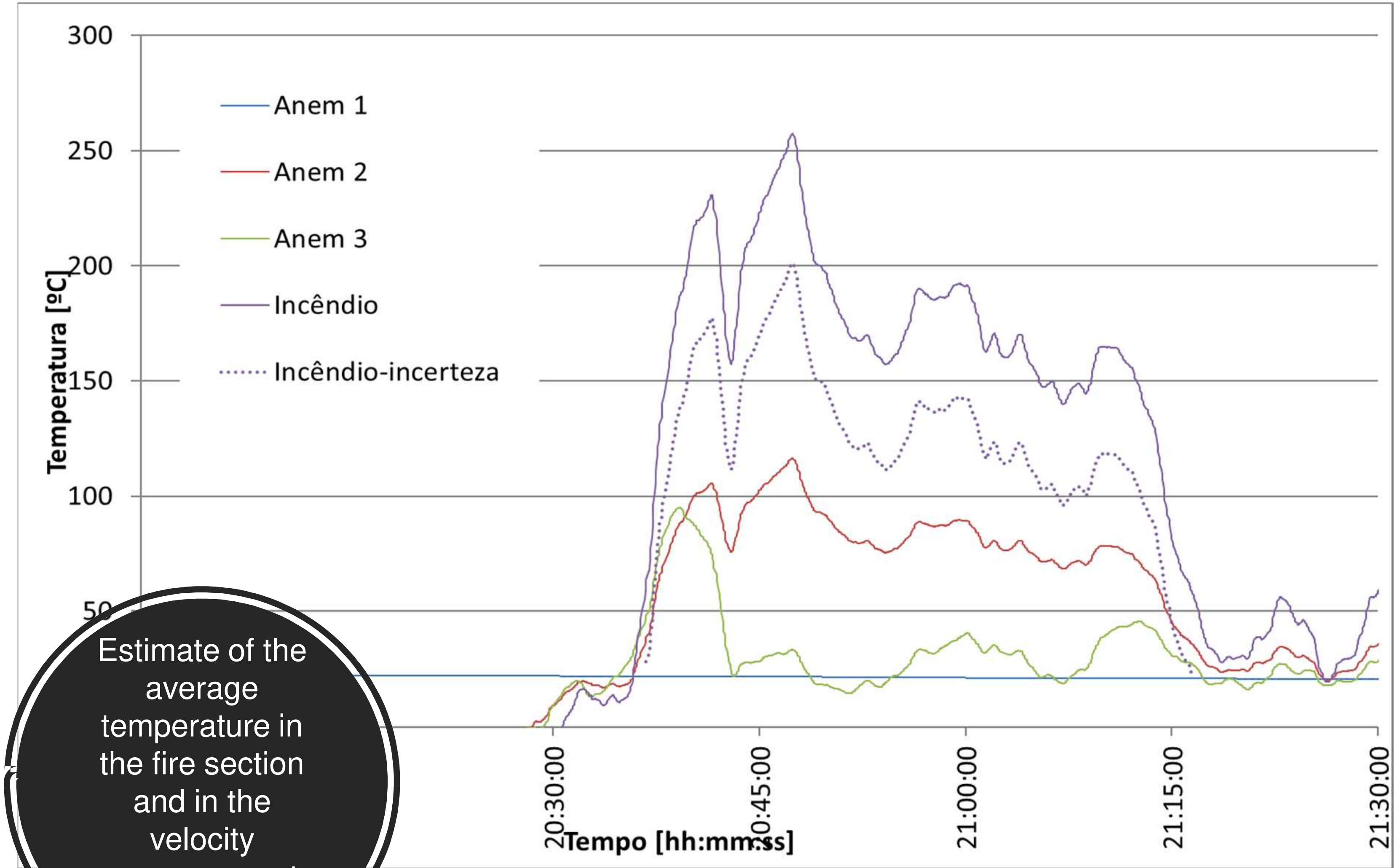
Flow velocity measured between 12:00:00 of 2017-06-11 and 12:00:00 of 2017-06-12.

Flow velocity measured in the tunnel

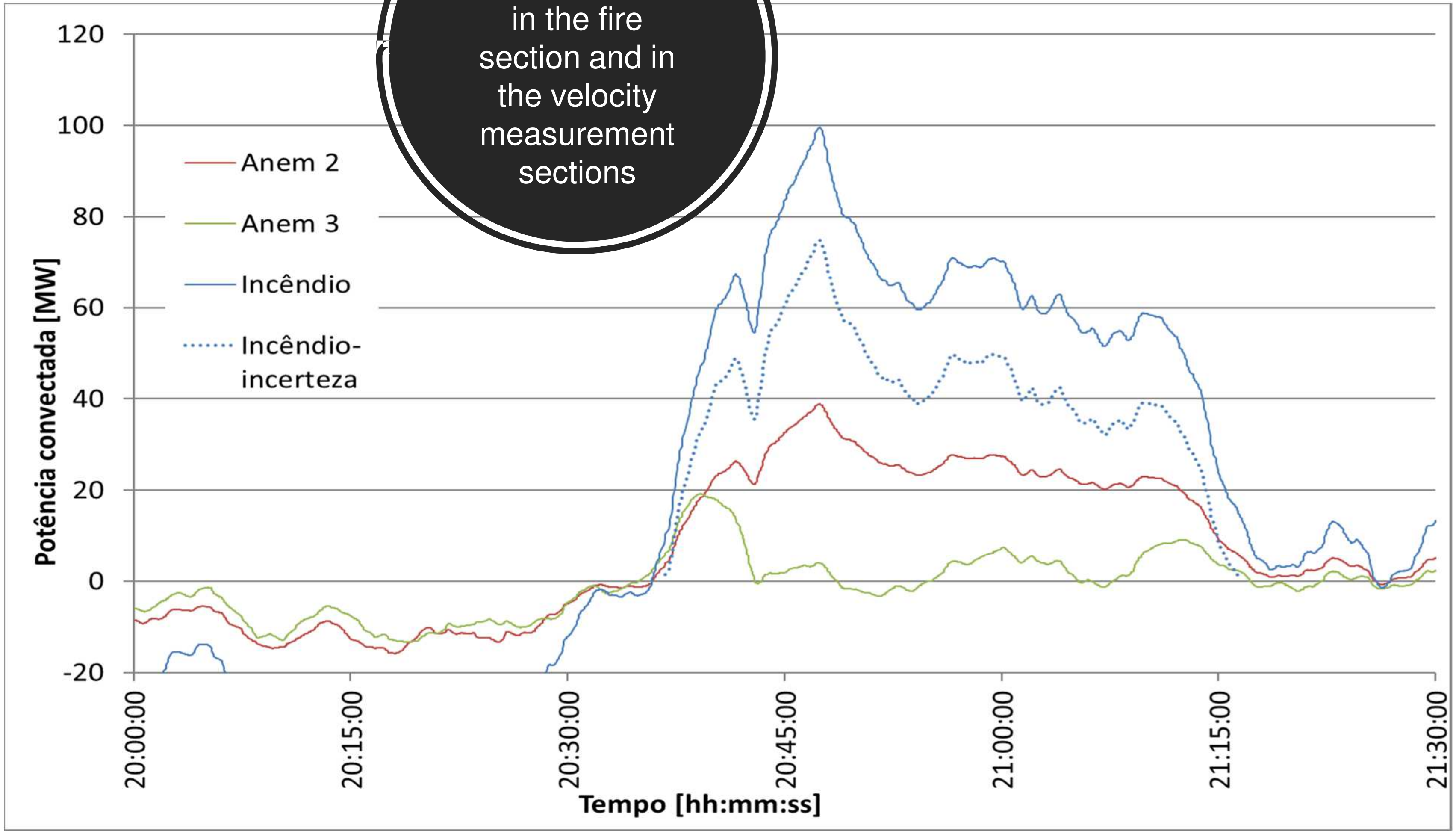




Estimate of convected HRR in the measurement sections S-ANE-2 e S-ANE-3



Estimate of the average temperature in the fire section and in the velocity measurement sections



Estimate of the convected HRR in the fire section and in the velocity measurement sections

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The problem

It is estimated that the convected heat output in the anemometer measuring section may have reached about 35 MW, with a standard uncertainty of 14.3 MW being estimated.

The estimate of the convected heat output in the fire section points to excessively high values when compared to the information known by the literature, even taking into account the uncertainty estimation.

We have the thermal history of the fire, but we miss a good referential to interpret it.

Methods

> The HRR convected part in the section of the middle anemometer was estimated by the air expansion due to the temperature.

$$\dot{Q}_{c\_i} = v_1 A \frac{\rho_0 T_0}{T_{\text{[illegible]}}}\left(C_{p\_i}\frac{v_i T_1}{v_{\text{[illegible]}}} - C_{p\_1} T_1\right) \Leftrightarrow \dot{Q}_c$$
$$= A \rho_0 T_0 \left(C_{p\_\text{[illegible]}} - C_{\text{[illegible]}}\right)$$

Temperature should modify the velocity profile

> Fully turbulent flow and continuity are considered.

> Correction factors were used to obtain the average velocity in the tunnel section.

Anemomether	Correction factor	Standard uncertainty [m/s]
S-ANE-1	0,743	0,41
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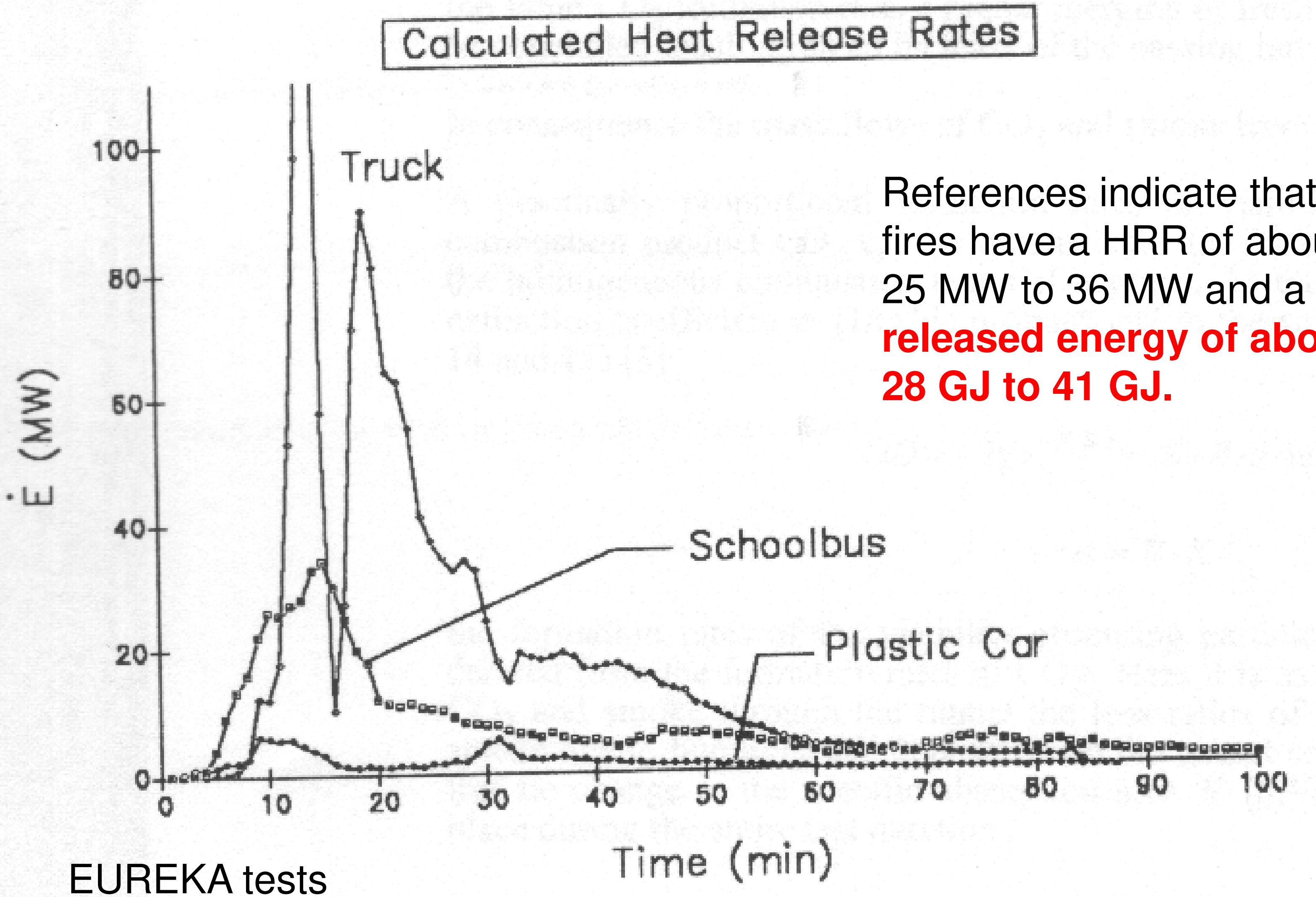
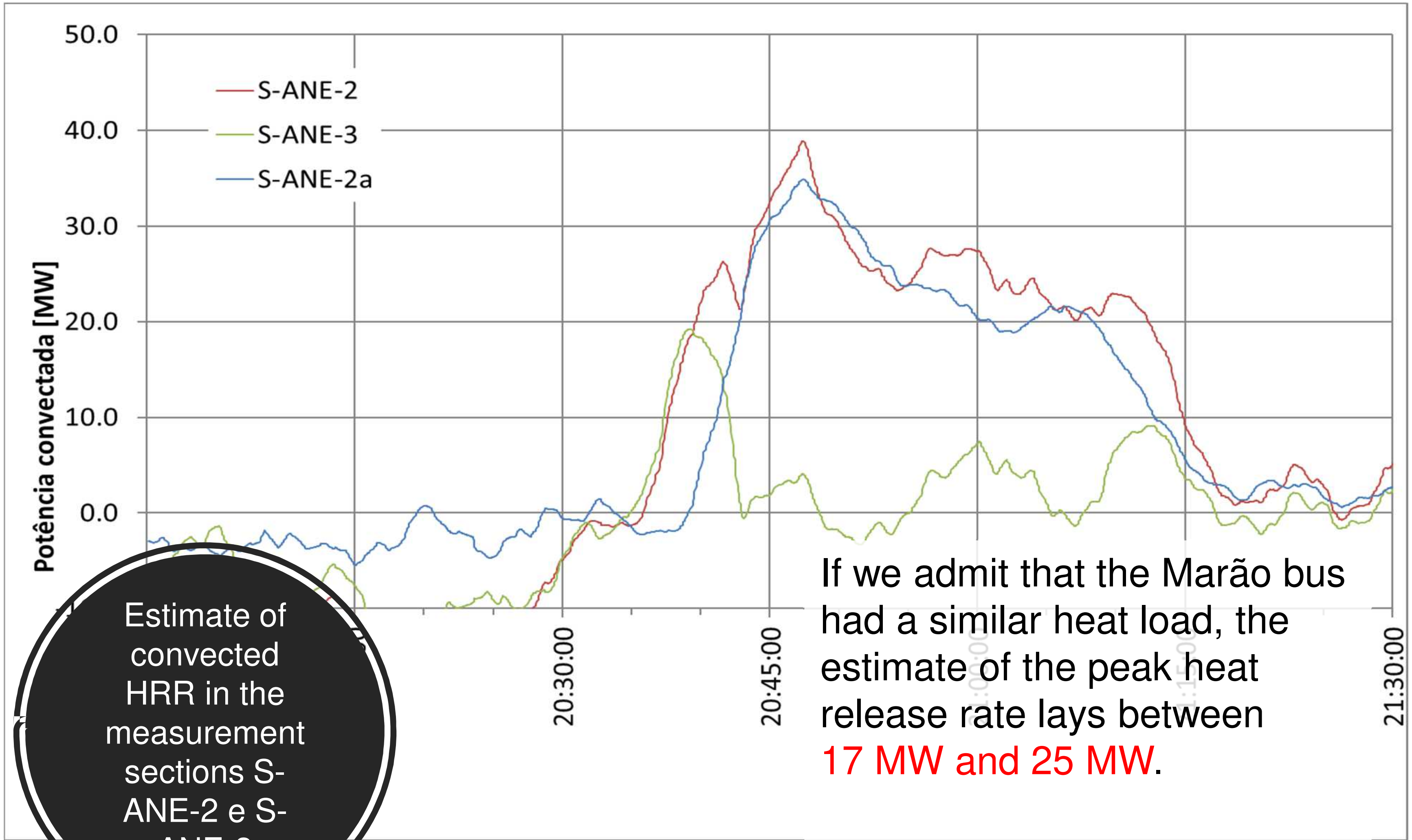
S-ANE-3	0,657	0,39



References indicate that bus fires have a HRR of about 25 MW to 36 MW and a **released energy of about 28 GJ to 41 GJ.**

EUREKA tests



Estimate of convected HRR in the measurement sections S-ANE-2 e S-ANE-3

If we admit that the Marão bus had a similar heat load, the estimate of the peak heat release rate lays between 17 MW and 25 MW.

Emergency exits

> The distance between emergency exits in new tunnels shall not exceed 500 m.

Emergency exits

> Since the long tunnels in mainland Portugal of the Trans-European and national road networks have unidirectional road galleries, the emergency exits are transverse galleries connecting road galleries, protected by a pressure system.

Objetives

> To assess the impact that pressure differences generated by the tunnel smoke control system have on the use of emergency exits.

> To evaluate the impact of emergency exits opening on the performance of the tunnel smoke control system.

Methods

> The flow is currently modeled using a generalization of the Bernoulli equation, which includes tunnel-specific terms.

wind action | stack effect | piston effect | jet fans action

$$\frac{1}{2}(\delta_{p1}-\delta_{p2})\rho_0\bar{V}_v\,|\bar{V}_v| + \gamma(\rho_0-\rho)gL + \frac{1}{2}\frac{C_x\Sigma}{S}\rho(U-\bar{V}_{va})|U-\bar{V}_{va}| + k\frac{F_0}{S}\frac{\rho}{\rho_{Lab}}\left(1-\frac{\bar{V}_{va}}{\bar{V}_{Imp}}\right) = f\frac{\rho\bar{V}_{va}^2 L}{2\,D_H} + \frac{1}{2}\xi\rho\bar{V}_{va}^2 + c\frac{Q_c}{\bar{V}_{va}\,D_H^2} \quad (1)$$

loss of pressure through the gallery | local pressure losses | loss of pressure due to fire

Methods

> Experimentally determine the relevant constants for the flow in real tunnels:

- Marão Tunnel (13 emergency exits)
- Gardunha Tunnel (5 Emergency exits)

$$\frac{1}{2}(\delta_{p1}-\delta_{p2})\rho_0\bar{V}_v\,|\bar{V}_v| + \gamma(\rho_0-\rho)gL + \frac{1}{2}\frac{C_x\Sigma}{S}\rho(U-\bar{V}_{va})|U-\bar{V}_{va}| + k\frac{\Sigma_0}{S}\frac{\rho}{\rho_{Lab}}\left(1-\frac{\bar{V}_{va}}{\bar{V}_{Imp}}\right) = f\frac{\rho\bar{V}_{va}^2 L}{2D_H} + \frac{1}{2}\xi\rho\bar{V}_{va}^2 + c\frac{\dot{Q}_c}{\bar{V}_{va}D_H^2} \qquad (1)$$

tunnel friction factor

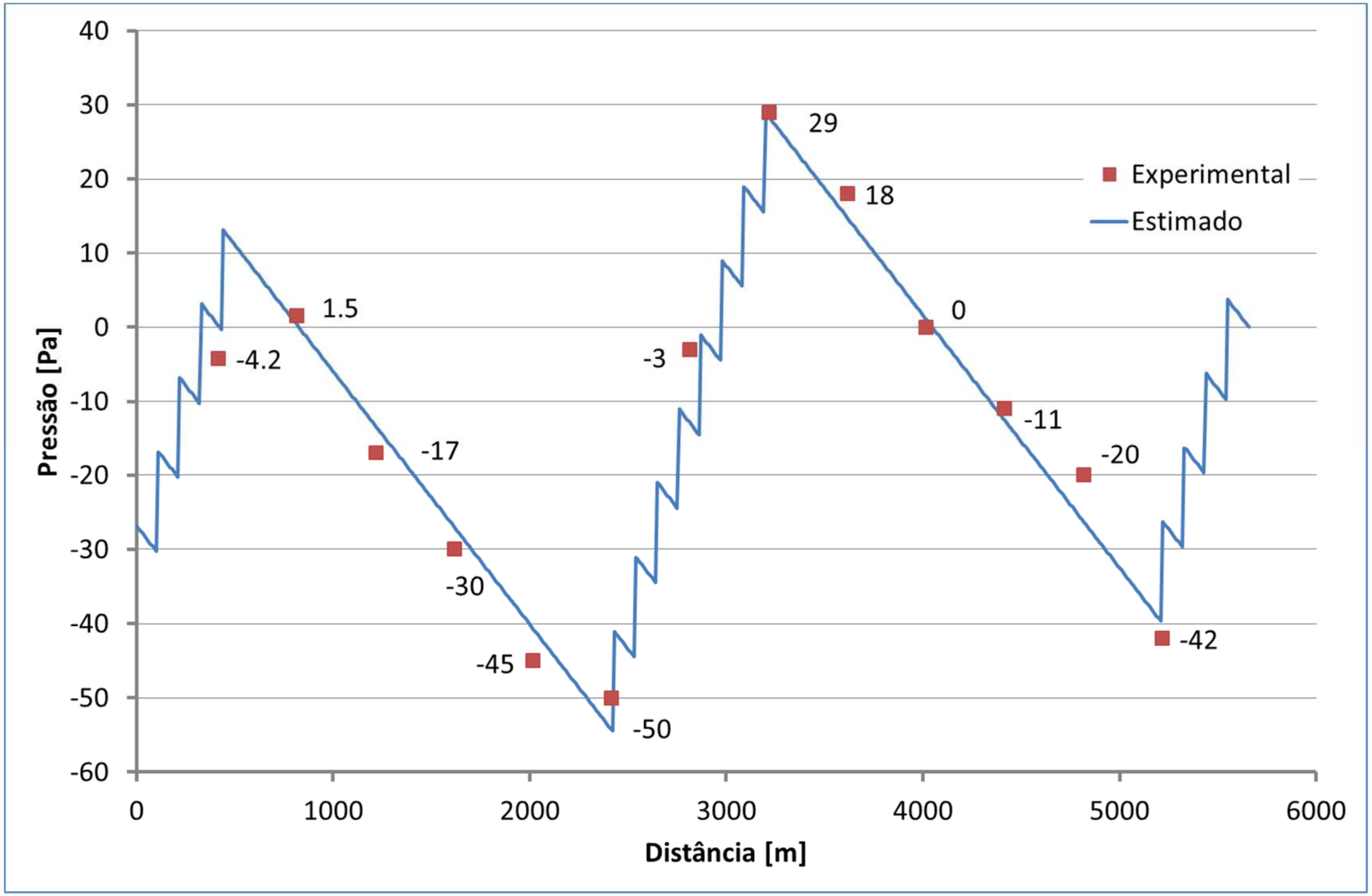
presure loss coefficients

jet fans position coefficient

Methods

- All jet fans in the descending gallery of each tunnel have been activated.
- Pressure difference was measured between the two road galleries through each emergency exit.
- Fit of static pressure curve along tunnel to experimental results by least squares method

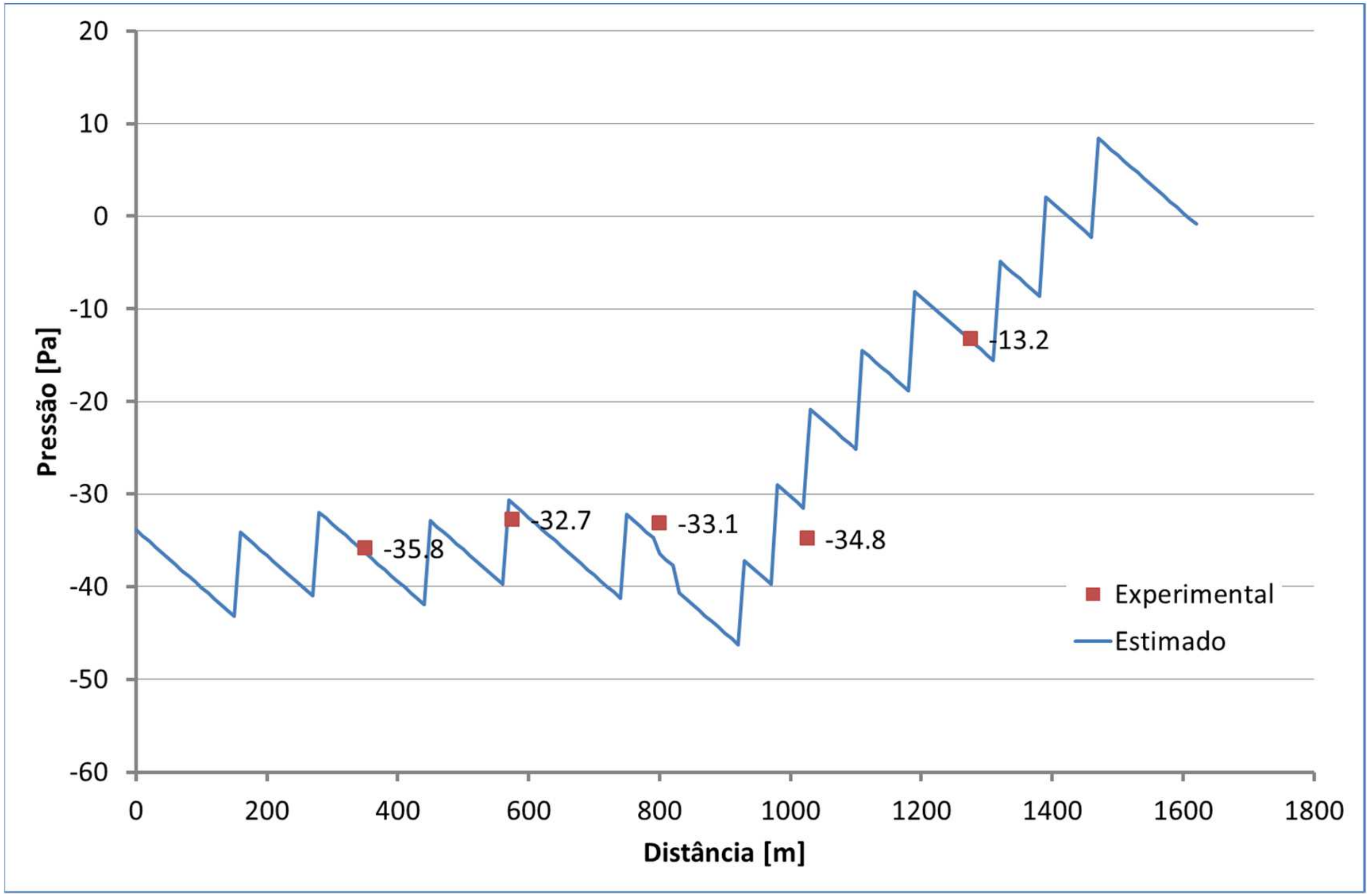
Measured and estimated pressure differences between road galleries in the Marão Tunnel



Estimated aerodynamic characteristics of Marão Tunnel

	$\bar{V}$		
	$6{,}87 - 0{,}54\ m/s$	$6{,}87\ m/s$	$6{,}87 + 0{,}54\ m/s$
Jet fans position coefficient k	0,85	0,92	0,94
Tunnel friction factor f	0,013	0,011	0,010
Pressure loss coefficient for entrance portal ξ_e	0,2	0,0	0,0
Pressure loss coefficient for exit portal ξ_s	1,0	1,0	1,0

Measured and estimated pressure differences between road galleries in the Túnel da Gardunha



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Estimated aerodynamic characteristics of Gardunha Tunnel

	$\bar{V}$		
	$5{,}65 - 0{,}42\ m/s$	$5{,}65\ m/s$	$5{,}65 + 0{,}42\ m/s$
Jet fans position coefficient k	0,84	0,84	0,85
Tunnel friction factor f	0,031	0,026	0,022
Pressure loss coefficient for entrance portal ξ_e	1.12	0,84	0,61
Pressure loss coefficient for exit portal ξ_s	1,0	1,0	1,0

Methods

- Application of one-dimensional model with experimentally determined aerodynamic characteristics.
- Inclusion of the reference fire scenario in the one-dimensional model.

Estimated pressure difference between road galleries in Marão Tunnel with and without fire

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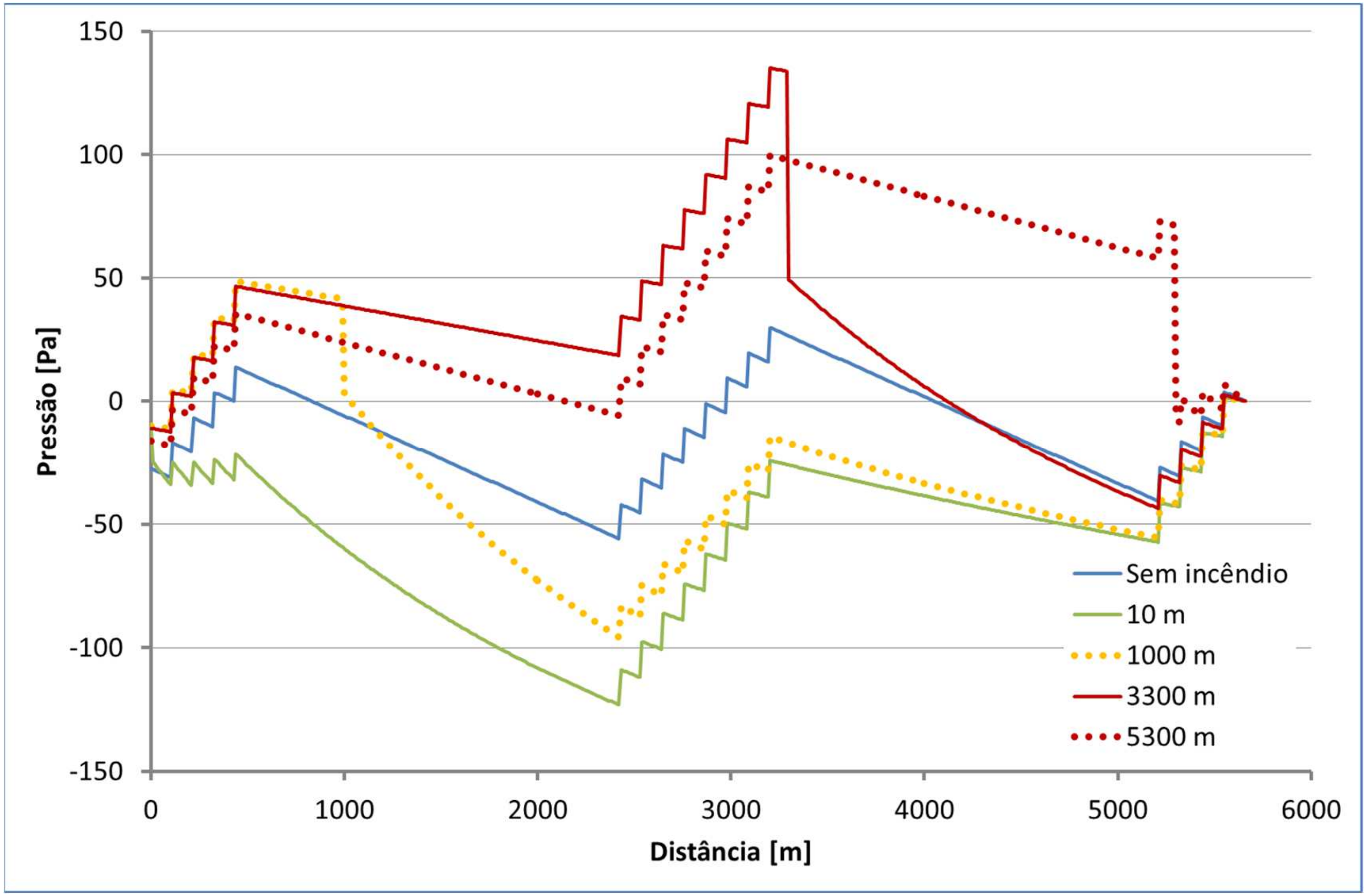
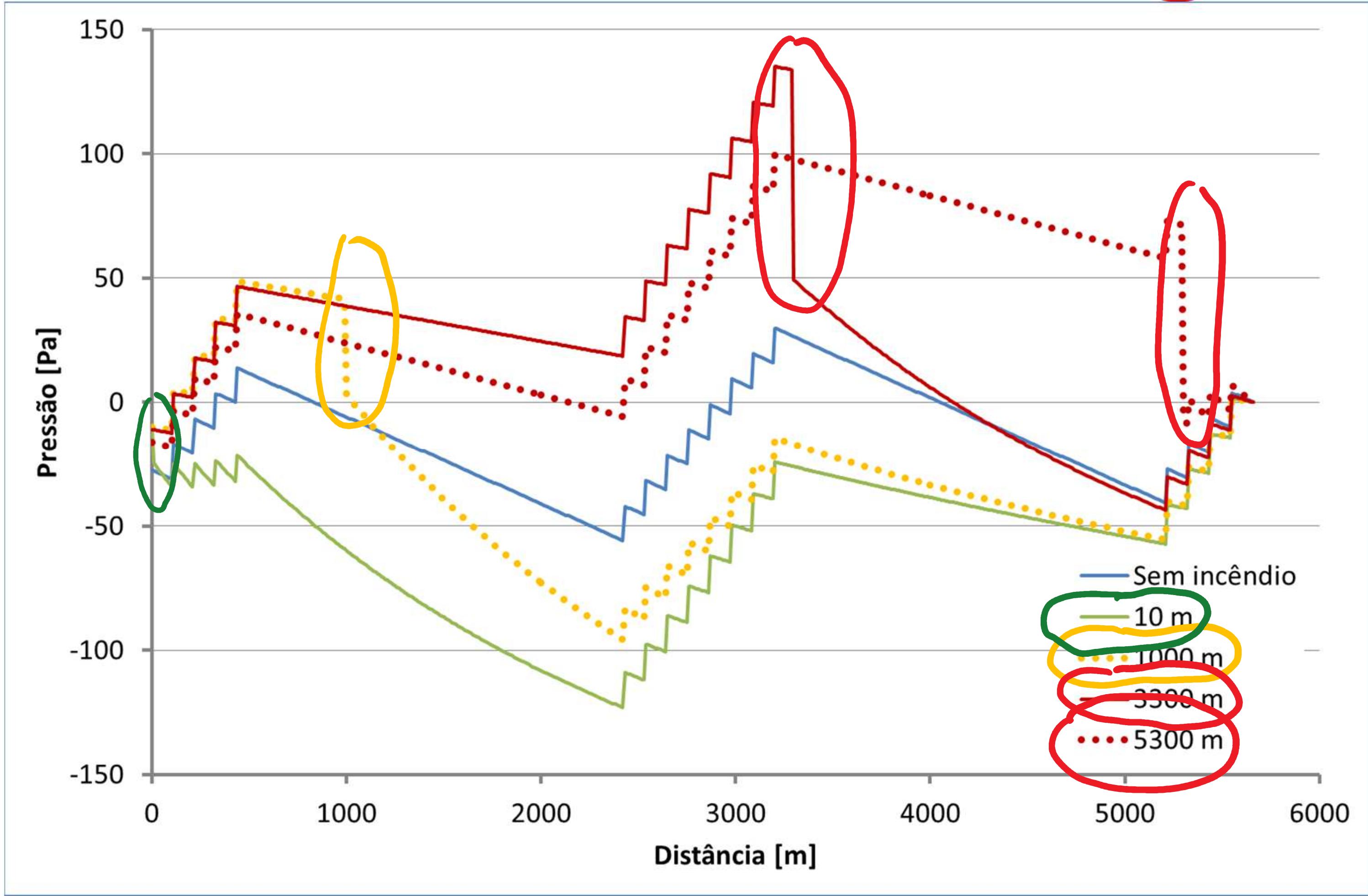
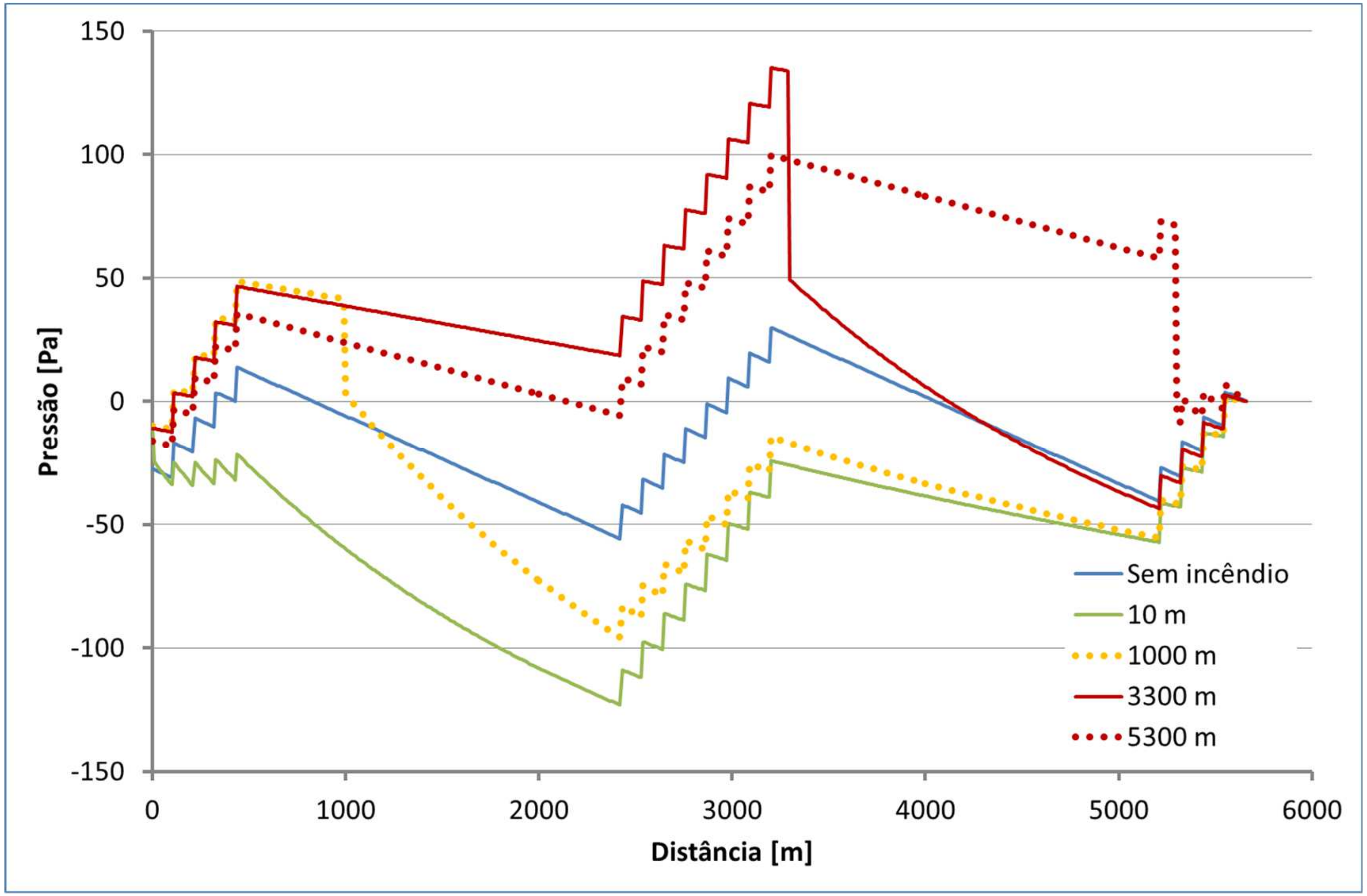




150
100
50
0
-50
-100
-150
Pressão [Pa]
0
1000
2000
3000
4000
5000
6000
Distância [m]
Sem incêndio
10 m
1000 m
3300 m
5300 m

Conclusions



Conclusions

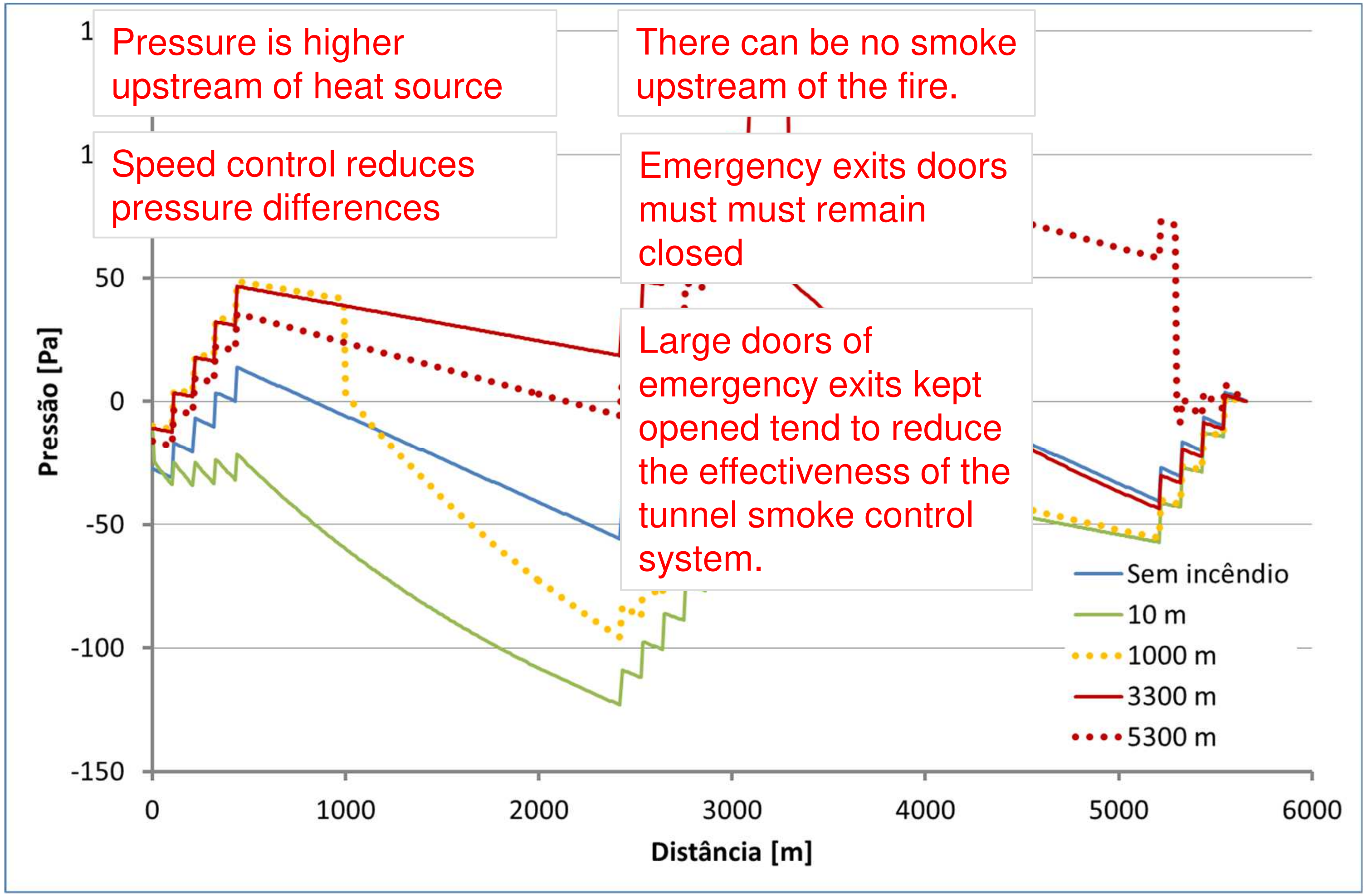
Pressure is higher upstream of heat source

Speed control reduces pressure differences

There can be no smoke upstream of the fire.

Emergency exits doors must must remain closed

Large doors of emergency exits kept opened tend to reduce the effectiveness of the tunnel smoke control system.



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