MODELAGEM COMPUTACIONAL DE DINÂMICA DE INCÊNDIOS

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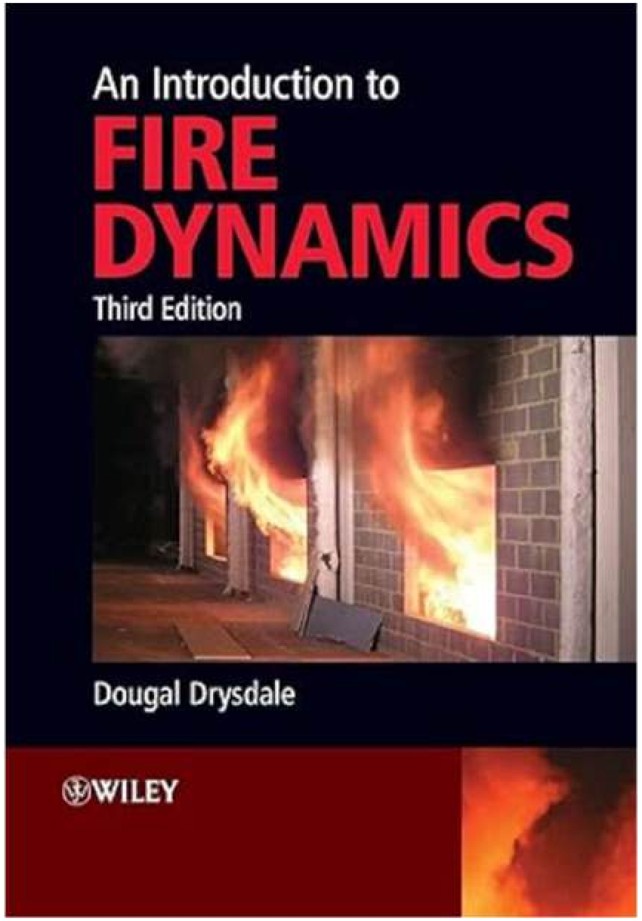
MCSUL/SEMENGO – Rio Grande/RS – 04/12/2024

Agenda

- *O que é dinâmica de incêndios?*
- *Software FDS*
- *Exemplos de estudos realizados*
  - *Fundamentos*
  - *Fenomenologia*
  - *Ferramentas de engenharia*
- *Pesquisas em andamento*

O QUE É DINÂMICA DE INCÊNDIOS?

https://www.youtube.com/watch?v=BtMmymOxdjc


An Introduction to
FIRE DYNAMICS
Third Edition
Dougal Drysdale
WILEY

CONTENTS

Transferência de calor

Mecânica dos fluidos

Termodinâmica

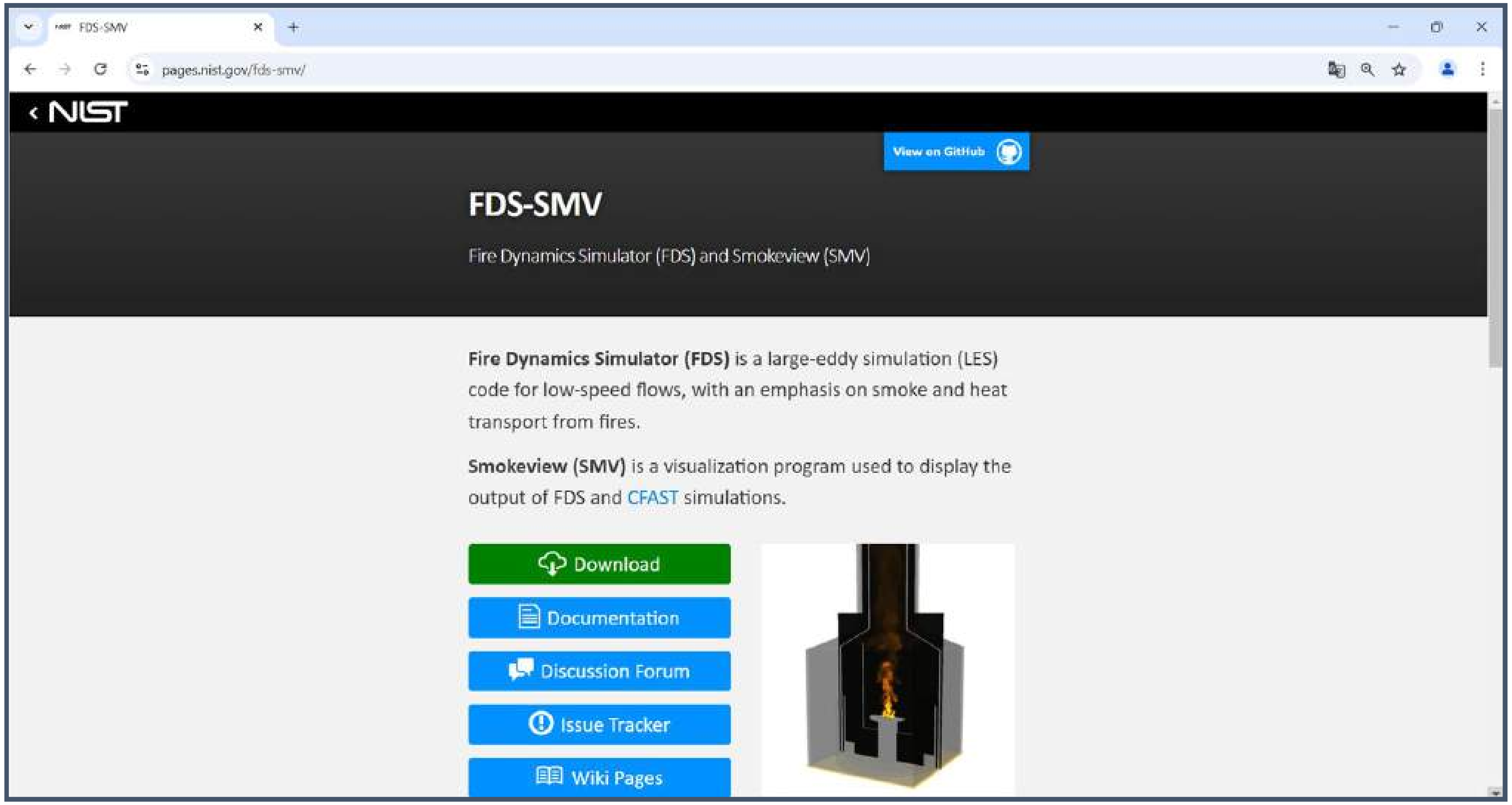
Materiais

SOFTWARE FDS

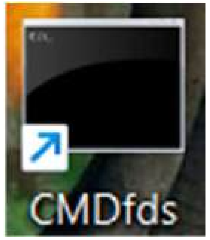
Fire Dynamics Simulator (FDS)

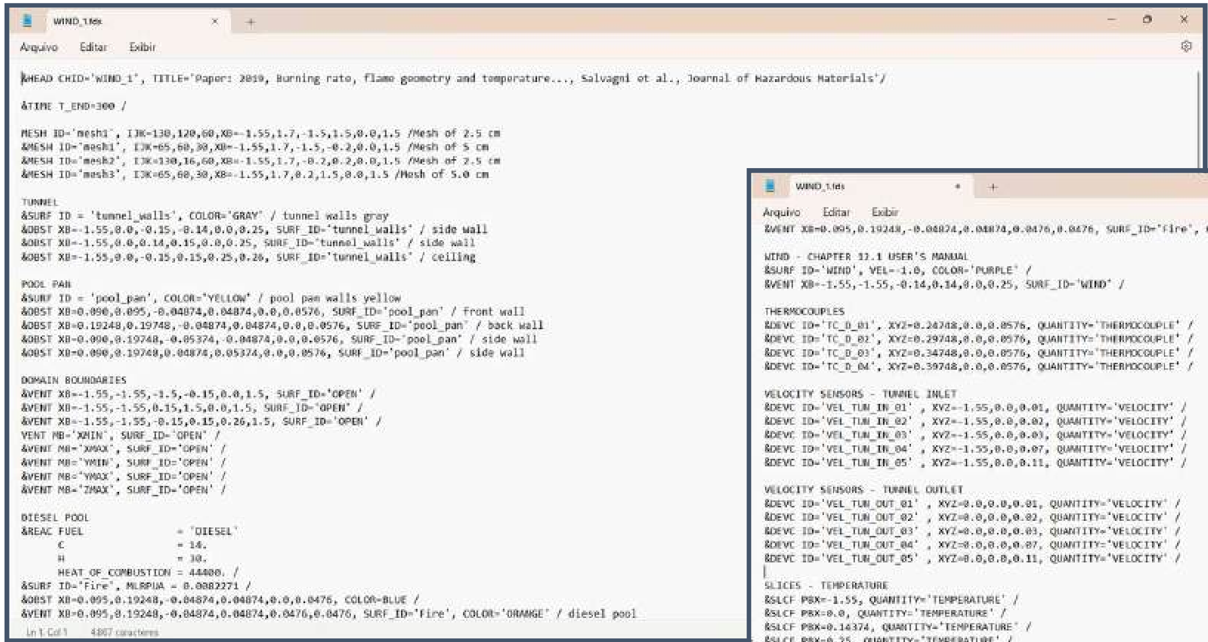
- *Desenvolvido pelo NIST e VTT Technical Research Center*
- *Simulações de escoamentos conduzidos pelo empuxo, em particular, incêndios*
- *Turbulência: metodologia LES, baixo Mach, malha estruturada cartesiana*
- *Combustão: Espécies aglomeradas + EDC; Radiação: FVM + GC ou WBM*
- *Condições de contorno, instrumentos e sensores apropriados para estudos sobre incêndios*
- *Programação escrita em linguagem Fortran, com interface de usuário via arquivo de texto (arquivo de entrada .fds), resultados gravados conforme solicitado pelo usuário em arquivos .csv e .smv (Smokeview: visualização de resultados).*
- *Download (gratuito):* https://pages.nist.gov/fds-smv/

Fire Dynamics Simulator (FDS)



Fire Dynamics Simulator (FDS)





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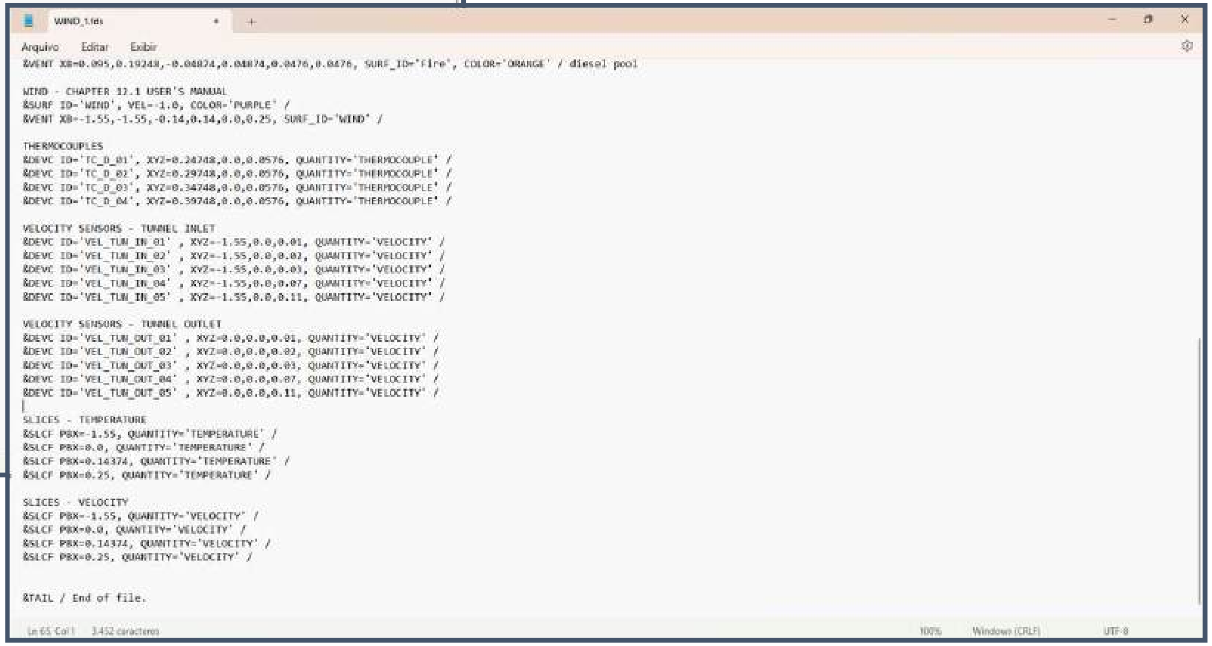

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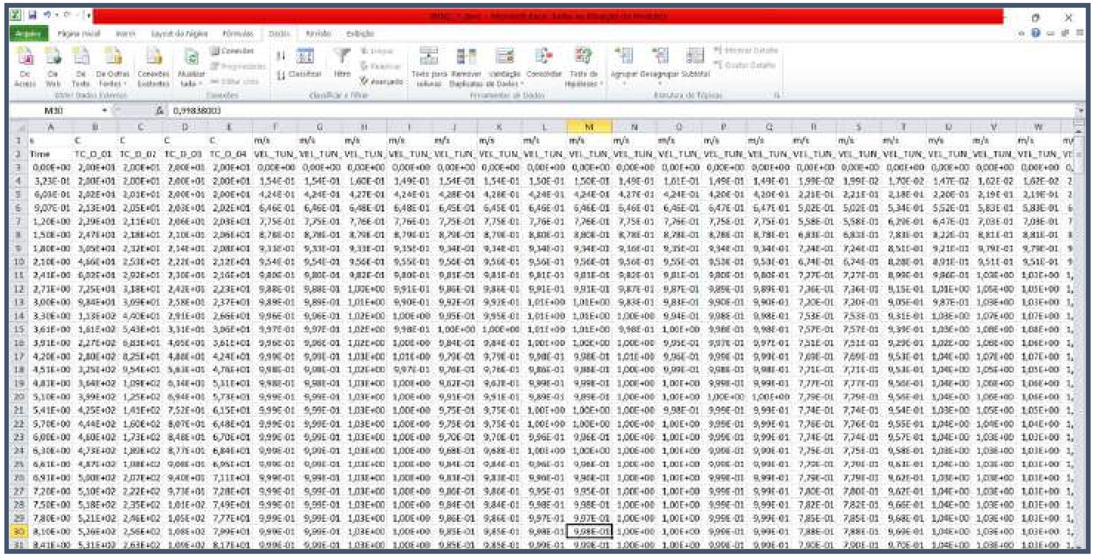
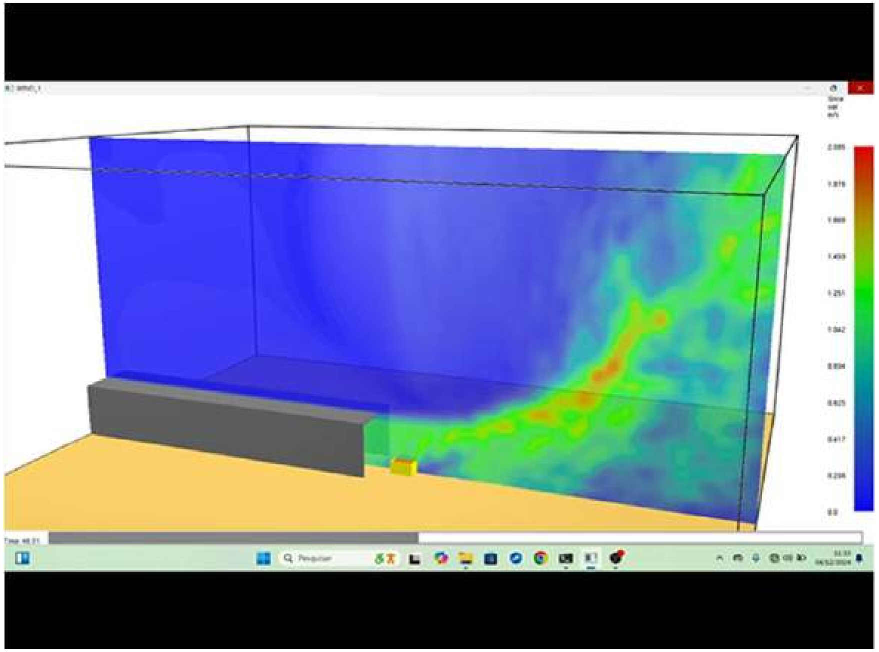
Fire Dynamics Simulator (FDS)





EXEMPLOS DE ESTUDOS

- ***FUNDAMENTOS***
- ***FENOMENOLOGIA***
- ***FERRAMENTAS DE ENGENHARIA***

EXEMPLO DE ESTUDO FUNDAMENTAL

- ***FUNDAMENTOS***

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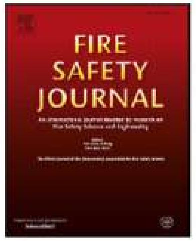

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Radiative transfer calculations in fire simulations: An assessment of different gray gas models using the software FDS

C.S. Fernandes, G.C. Fraga, F.H.R. França, F.R. Centeno *

Universidade Federal Do Rio Grande Do Sul, 425 Sarmento Leite St, Porto Alegre, Brazil

- *Objetivos*

Verificar o desempenho de diferentes modelos de gás cinza (GG) no cálculo da transferência de calor radiativa em simulações de incêndios:

Três diferentes formulações de modelos GG foram implementadas no solver de radiação do software FDS, e seus resultados foram comparados a experimentos.

Simulações acopladas: transferência de calor radiativa foi resolvida simultaneamente à modelagem de escoamento e combustão.

Três experimentos foram utilizados para comparação de resultados:
- Um incêndio em compartimento fechado, queimando etanol
- Um incêndio em poça em ambiente aberto, queimando heptano
- Um compartimento com uma abertura, queimando metanol

- ***Transferência de calor por radiação térmica e o modelo GG***

Equação da transferência radiativa (RTE) para meio que não espalha radiação térmica:

Forma espectral: $$\frac{dI_\eta}{ds} = -\kappa_\eta I_\eta + \kappa_\eta I_{b\eta}$$

Forma cinza: $$\frac{dI}{ds} = -\kappa I + \kappa I_b$$

Três aproximações foram consideradas para calcular κ:

(1) Modelo padrão do FDS

(2) Modelo com coeficiente de absorção com média de Planck

(3) Modelo com coeficiente de absorção baseado na emitância

- ***Transferência de calor por radiação térmica e o modelo GG***

Fire Safety Journal 108 (2019) 102843

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FIRE SAFETY JOURNAL

Evaluation of different gray gas formulations against line-by-line calculations in two- and three-dimensional configurations for participating media composed by CO_2, H_2O and soot

G.C. Fraga*, L. Zannoni, F.R. Centeno, F.H.R. França
Mechanical Engineering Department, Federal University Rio Grande Do Sul, Porto Alegre, RS, Brazil

Três aproximações foram consideradas para calcular κ:

(1) Modelo padrão do FDS

(2) **Modelo com coeficiente de absorção com média de Planck**

(3) **Modelo com coeficiente de absorção baseado na emitância**

- ***Modelo com coeficiente de absorção com média de Planck (κ_P-based):***

Expressões polinomiais para o coeficiente de absorção em média de Planck para os principais produtos da combustão de hidrocarbonetos: dióxido de carbono, vapor d'água e fuligem.

$$\kappa_P = \frac{\int_\eta \kappa_\eta I_{b\eta} d\eta}{\int_\eta I_{b\eta} d\eta}$$

$$\kappa_\chi = \begin{cases} p_\chi \sum_{i=0}^{5} C_{\chi,i} T^i & \text{for } \chi = c \text{ and } \chi = w \\ b f_v \sum_{i=0}^{3} C_{\chi,i} T^i & \text{for } \chi = s \end{cases} \qquad \kappa_m = \kappa_c + \kappa_w + \kappa_s$$

F. Cassol, R. Brittes, F.R. Centeno, C.V. da Silva, F.H. França, Evaluation of the gray gas model to compute radiative transfer in non-isothermal, non-homogeneous participating medium containing CO2, H2O and soot, J. Braz. Soc. Mech. Sci. Eng. 37 (1) (2015) 163–172, https://doi.org/10.1007/s40430-014-0168-5.

- ***Modelo com coeficiente de absorção baseado na emitância (cb-WSGG):***

A emitância foi calculada conforme a metodologia apresentada em Cassol et al. para superposição de efeitos individuais de CO2, H2O e fuligem, obtidos com o modelo WSGG:

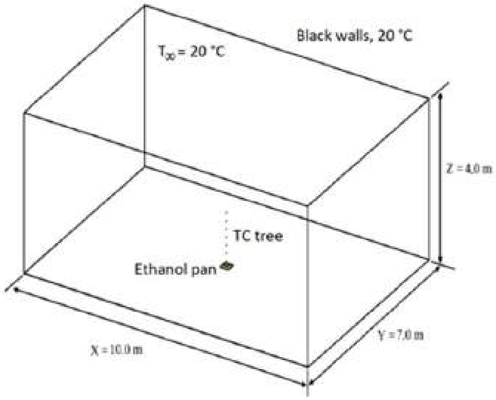
$$\varepsilon = \sum_{i=0}^{4} \sum_{j=0}^{4} \sum_{k=1}^{4} a_{c,i_c} a_{w,i_w} a_{s,i_s} \left\{1 - \exp[(\kappa_{c,i_c} + \kappa_{w,i_w} + \kappa_{s,i_s})S] \right\}$$

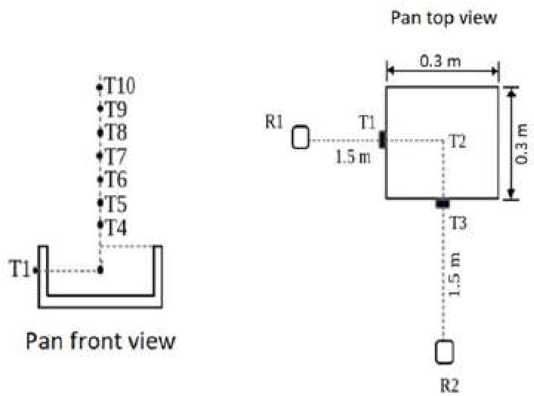
$$\kappa = -\frac{\ln(1 - \varepsilon)}{S}$$

F. Cassol, R. Brittes, F.H. França, O.A. Ezekoye, Application of the weighted-sum-of-gray-gases model for media composed of arbitrary concentrations of H2O, CO2 and soot, Int. J. Heat Mass Tran. 79 (2014) 796–806, https://doi.org/10.1016/j.ijheatmasstransfer.2014.08.032

- ***Experimentos empregados para testes dos modelos***

Test case 1 – Tu et al.





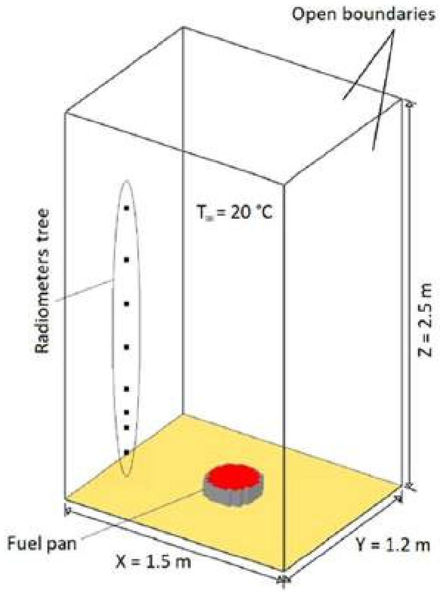
- Closed compartment, 10 m x 7 m x 4 m
- Ethanol square pan, 0.3 m, 14 mm deep
- Measurements: TCs and radiometers

- Radiative fraction = 0.2
- Soot yield = 0.0012 g_{soot}/kg_{fuel}
- Data processing: steady state, average between 200 s and 530 s after ignition

R. Tu, J. Fang, Y.-M. Zhang, J. Zhang, Y. Zeng, Effects of low air pressure on radiation-controlled rectangular ethanol and n-heptane pool fires, Proc. Combust. Inst. 34 (2) (2013) 2591–2598, https://doi.org/10.1016/j.proci.2012.06.036

- ***Experimentos empregados para testes dos modelos***

Test case 2 – Lin et al.

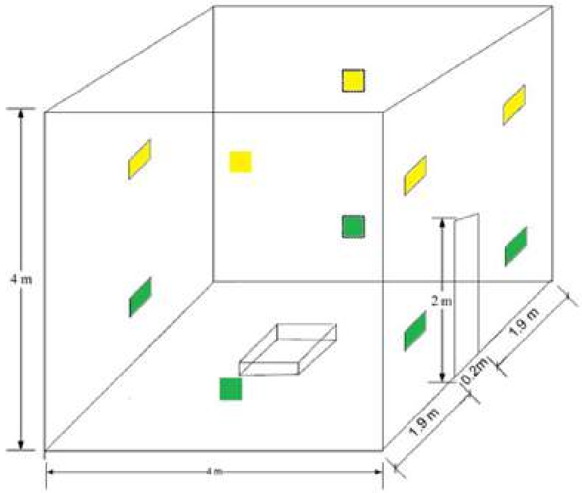


- Open pool fire (domain 1.5 m x 1.2 m x 2.5 m)
- Heptane circular pan, 0.3 m dia, 2 mm deep
- Measurements: tree of radiometers located 0.75 m from pan center
- Radiative fraction = 0.305
- Soot yield = 0.0085 g_{soot}/kg_{fuel}
- Data processing: steady state, average between 100 s and 300 s after ignition

C.-H. Lin, Y.-M. Ferng, W.-S. Hsu, B.-S. Pei, Investigations on the characteristics of radiative heat transfer in liquid pool fires, Fire Technol. 46 (2) (2010) 321–345, https://doi.org/10.1007/s10694-008-0071-7

- ***Experimentos empregados para testes dos modelos***

Test case 3 – Sahu et al.



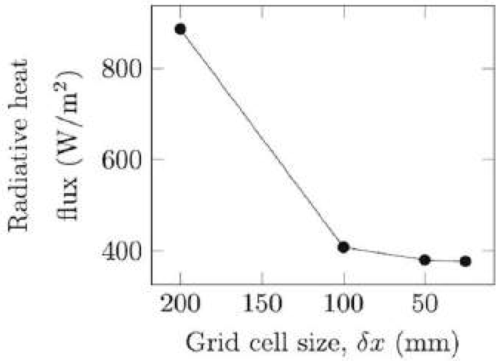
- Compartment (cube, 4 m x 4 m x 4 m) with an opening (2 m x 0.2 m)
- Methanol circular pan, 0.6 m dia, 120 mm deep
- Measurements: net heat flux at walls
- Radiative fraction = 0.2
- Soot yield = 0.006 g_{soot}/kg_{fuel}
- Data processing: transient, averaged around ± 10 s of the desired instant of time

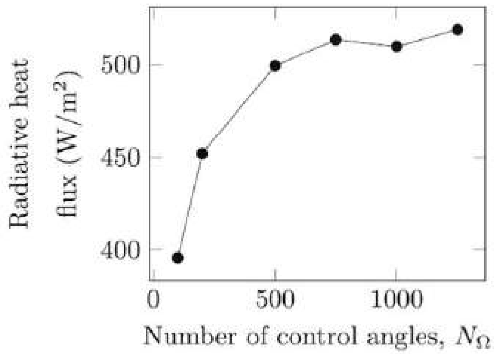
D. Sahu, S. Jain, Shashi, A. Gupta, Experimental study on methanol pool fires under low ventilated compartment, Procedia Earth Planet. Sci. 11 (2015) 507–515, https://doi.org/10.1016/j.proeps.2015.06.051

- ***Modelagem numérica***

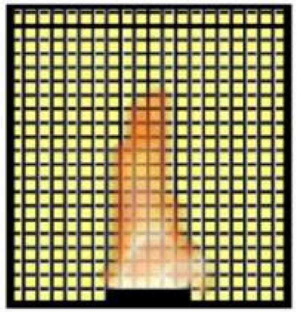
<u>Discretização espacial:</u> malha mais refinada no entorno das chamas e onde os radiômetros estavam posicionados. Estudo de malha baseado no critério $4 \leq D^*/\delta x \leq 16$ e no critério M de Pope.

<u>Discretização angular:</u> $N_\Omega = 500$ para integração direcional da RTE.






Δx = 2,5 cm


Δx = 5 cm

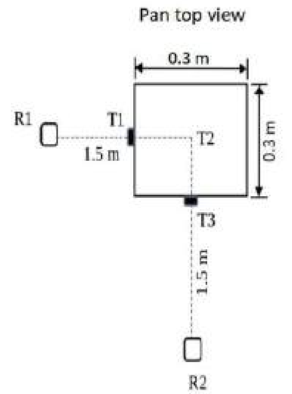
- ***Resultados***

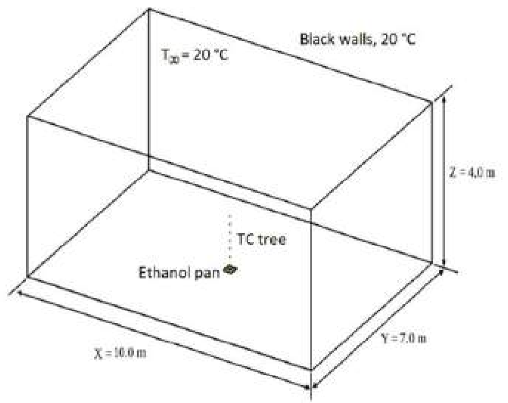
Test case 1 – Closed compartment, ethanol pool

Comparison of results for the simulations with different GG models and the experimental data of [25] for test case 1. The deviations relative to the measurements (in %) are shown in the parenthesis.

		Non-sooting calculation		
	Tu et al. [25]	default-FDS	κ_P -based	cb-WSGG
Radiometer 1 (W/ m^2)	473.1 ± 1.5	498.7 (5.4)	372.3 (21)	500.4 (5.8)
Radiometer 2 (W/ m^2)	473.8±1.5	515.0 (8.7)	375.7 (20)	510.2 (7.7)
Maximum temperature (k)	1102±35	1159 (5.0)	1150 (4.2)	1159 (4.9)

		Sooting calculation (max soot: 0.12 ppm)		
	Tu et al. [25]	default-FDS	κ_P -based	cb-WSGG
Radiometer 1 (W/ m^2)	473.1 ± 1.5	505.8 (6.9)	400.1 (15)	510.3 (7.4)
Radiometer 2 (W/ m^2)	473.8±1.5	510.2 (7.7)	405.8 (14)	525.1 (10)
Maximum temperature (k)	1102±35	1129 (2.4)	1148 (4.0)	1160 (5.0)

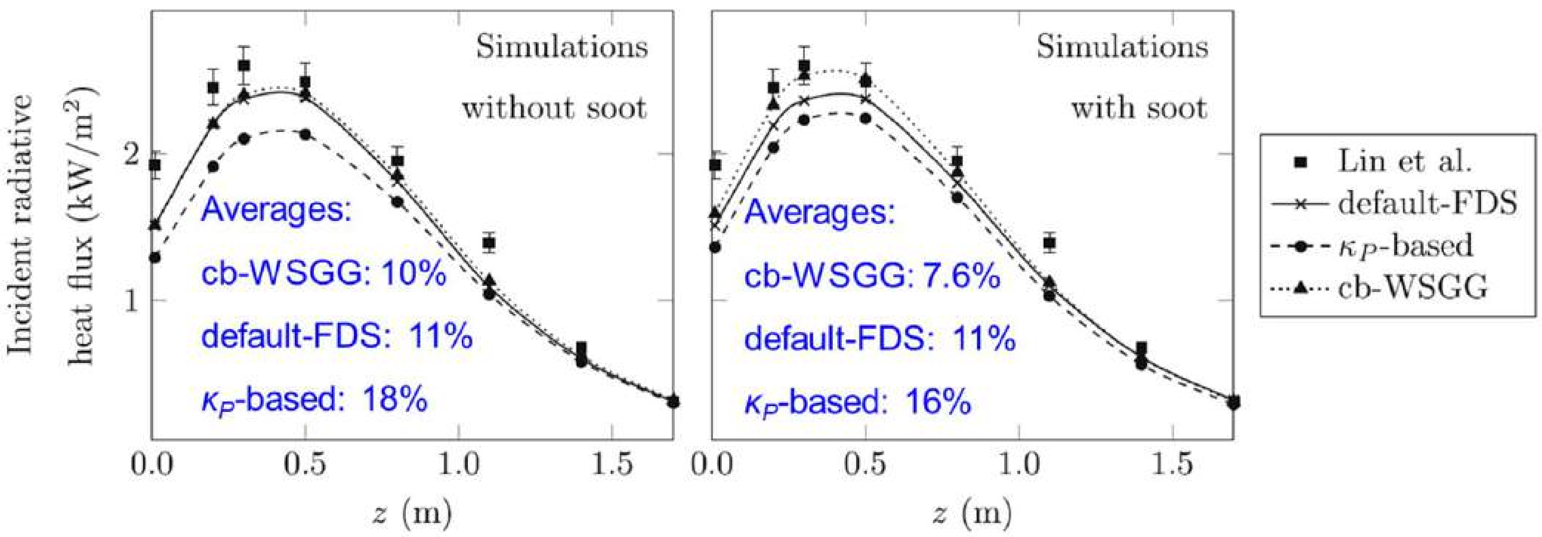


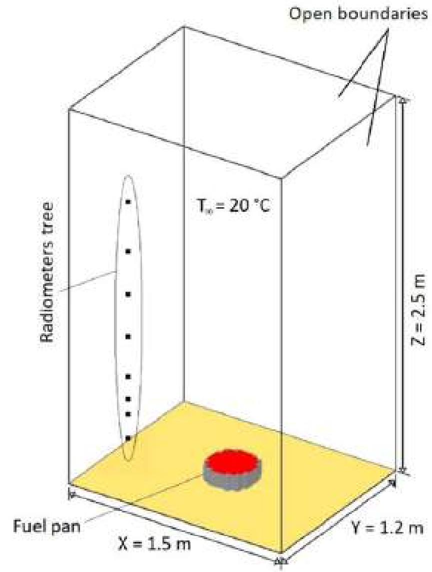


- ***Resultados***

Test case 2 – Open heptane pool fire

Vertical distribution of the radiative heat flux 0.75 m away from the pool center for test case 2. Comparisons between the simulation results and the experimental data of Lin et al. [27].

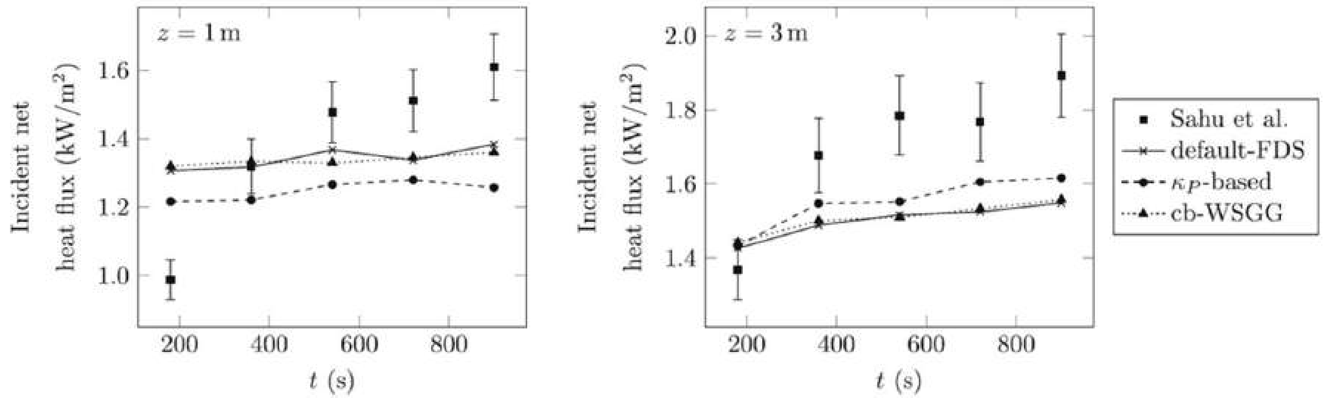


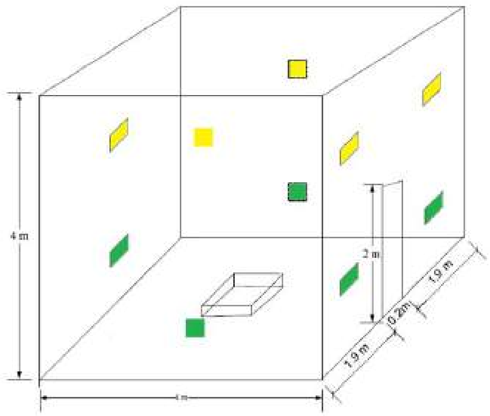


- ***Resultados***

Test case 3 – Compartment with opening, methanol pool

Incident net heat flux on the walls of the containment structure for test case 3 at two vertical positions.





EXEMPLO DE ESTUDO FENOMENOLÓGICO

- ***FENOMENOLOGIA***

https://bahia.ba/brasil/incendio-em-favela-destroi-pelo-menos-20-casas-em-sao-paulo/
https://www.iris-fire.com/
https://jovempan.com.br/noticias/tempo-seco-causa-100-incendios-este-ano-em-favelas-de-sao-paulo.html

https://doi.org/10.1007/s10694-023-01374-y

PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA MECÂNICA

LABORATÓRIO DE DINÂMICA DE INCÊNDIOS

• FENOMENOLOGIA

Fire Safety Journal 120 (2021) 103124

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Semi-empirical model for estimating the heat release rate required for flashover in compartments with thermally-thin boundaries and ultra-fast fires

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Fire Safety Journal 117 (2020) 103211

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Influence of wind on the onset of flashover within small-scale compartments with thermally-thin and thermally-thick boundaries

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[b] School of Engineering, Federal University of Rio Grande do Sul, Brazil

Fire Technology
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Manufactured in The United States
https://doi.org/10.1007/s10694-023-01374-y

Investigating Numerically the Effect of Wind on Fire Spread Between Two Informal Settlements Dwellings

*M. Beshir**, *School of Engineering, University of Edinburgh, Edinburgh, UK and OFR Consult... UK*
M. Mohamed, School ... Melbourne, 4 Wa...
S. A. Kouritem, Mec... Alexandria Unive...
C. K. Lemmertz and ... of Rio Grande do ...
D. Rush, School of ...*

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Numerical Study on the Effect of Atmospheric Wind on the Fire Severity in Informal Settlements with Different Dwellings' Wall Thermal Characteristics

Calisa Katiuscia Lemmertz, Department of Mechanical Engineering, Federal University of Rio Grande do Sul, Sarmento Leite Street, 425, Porto Alegre, RS 90050-170, Brazil
Mohamed Beshir and David Rush, School of Engineering, University of Edinburgh, Edinburgh, UK*
Felipe Roman Centeno, Department of Mechanical Engineering, Federal University of Rio Grande do Sul, Sarmento Leite Street, 425, Porto Alegre, RS 90050-170, Brazil

- ***FENOMENOLOGIA***

Fire Safety Journal 120 (2021) 103124
Contents lists available at ScienceDirect
Fire Safety Journal
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Semi-e…
flashov…
ultra-fa…

M. Beshi…

Fire Technology
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https://doi.org/10.1007/s10694-023-01374-y

Investigating Numerically the Effect of Wind on Fire Spread Between Two Informal Settlements Dwellings

…ersity of Edinburgh, Edinburgh, UK

Fire Safety Journal 117 (2020) 103211
Contents lists available at ScienceDirect
Fire Safety Journal
journal homepage: http://www.elsevier.com/locate/firesaf

Influence of wind on the onset of flashover within small-scale compartments with thermally-thin and thermally-thick boundaries

Felipe R. Centeno [a,b,*], Mohamed Beshir [a], David Rush [a]
[a] School of Engineering, University of Edinburgh, UK
[b] School of Engineering, Federal University of Rio Grande do Sul, Brazil

… Study on the Effect … pheric Wind on the Fire Severity … al Settlements with Different … Wall Thermal Characteristics

…a Lemmertz, Department of Mechanical Engineering, Federal … of Rio Grande do Sul, Sarmento Leite Street, 425, Porto Alegre, …170, Brazil
…ir and David Rush*, School of Engineering, University of … Edinburgh, UK
…Centeno, Department of Mechanical Engineering, Federal … of Rio Grande do Sul, Sarmento Leite Street, 425, Porto Alegre, RS 90050-170, Brazil

- ***Objetivo***

- Influência do vento (velocidade e direção) sobre a taxa de liberação de calor necessária para atingir o flashover em incêndios em compartimentos com paredes termicamente finas ou termicamente espessas.

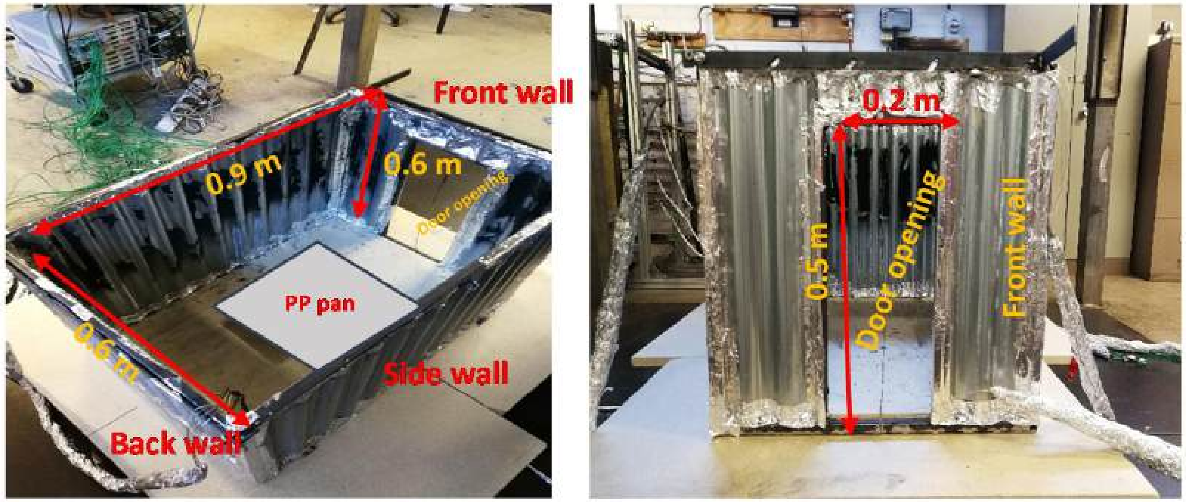

Figure 1. Small-scale compartment experiment (open ceiling for internal visualization). Source: adapted from Beshir *et al.* [9].


Fire Safety Journal 120 (2021) 103124

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journal homepage: http://www.elsevier.com/locate/firesaf

ELSEVIER

Semi-empirical model for estimating the heat release rate required for flashover in compartments with thermally-thin boundaries and ultra-fast fires

M. Beshir[a,*], Y. Wang[a], F. Centeno[a,b], R. Hadden[a], S. Welch[a], D. Rush[a,**]

[a] School of Engineering, University of Edinburgh, UK
[b] School of Engineering, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil

Thin: t_p = 4x10^{-3} s, Bi = 1x10^{-4}
Thick: t_p = 200 s, Bi =1

- *Validação*

Fire Safety Journal 91 (2017) 414–421

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

IAFSS 12th Symposium 2017

Wind effects on flame projection probability from a compartment with opposing openings

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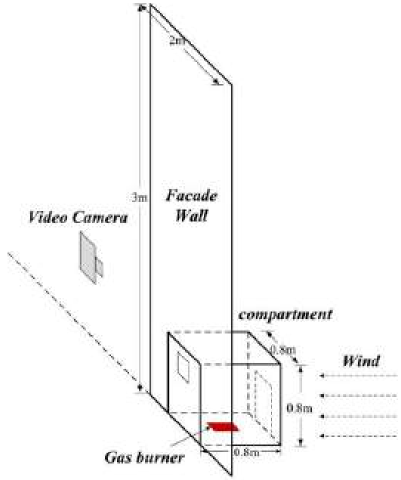
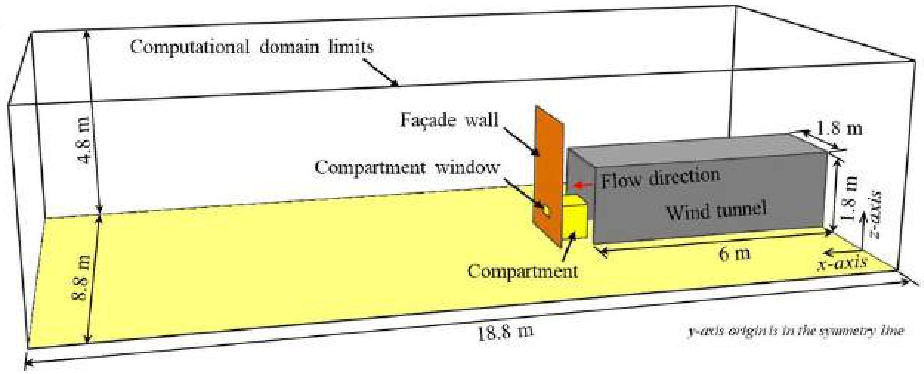
[b] Institute of Advanced Technology, University of Science and Technology of China, Hefei, Anhui 230088, PR China
[c] Department of Civil and Structural Engineering, School of Engineering, Aalto University, 02150 Espoo, Finland



(a) Experimental model



- ***Validação***

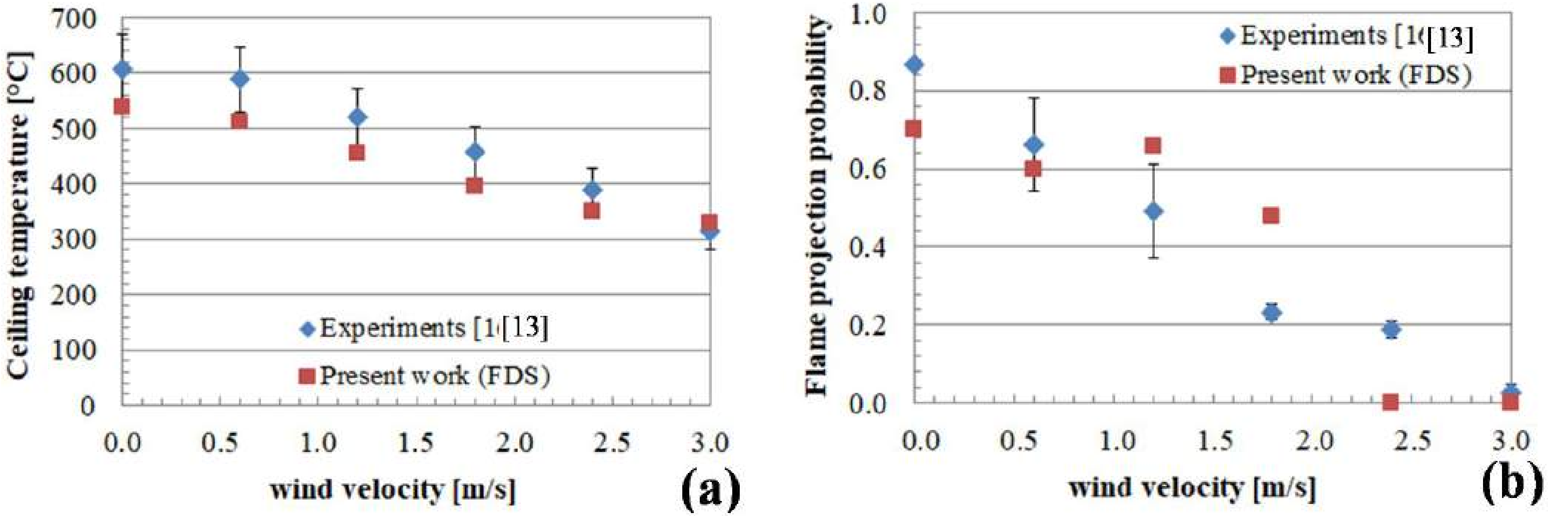
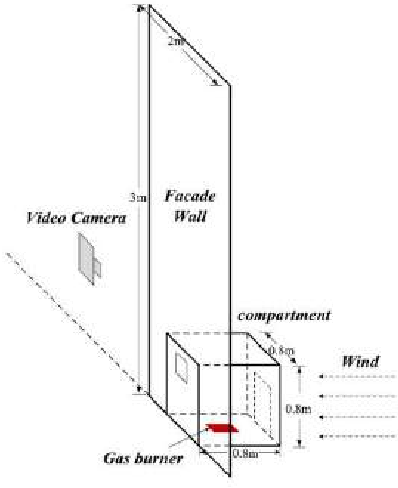
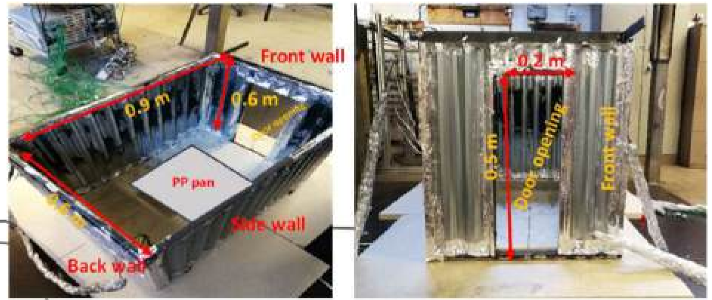


Figure 3. Comparison between experiments (Li *et al.* [13]) and FDS (present work) for several wind velocities for a heat release rate of 87.84 kW: (a) Temperatures beneath the ceiling, (b) Flame projection probability.



(a) Experimental model

- ***Casos estudados***



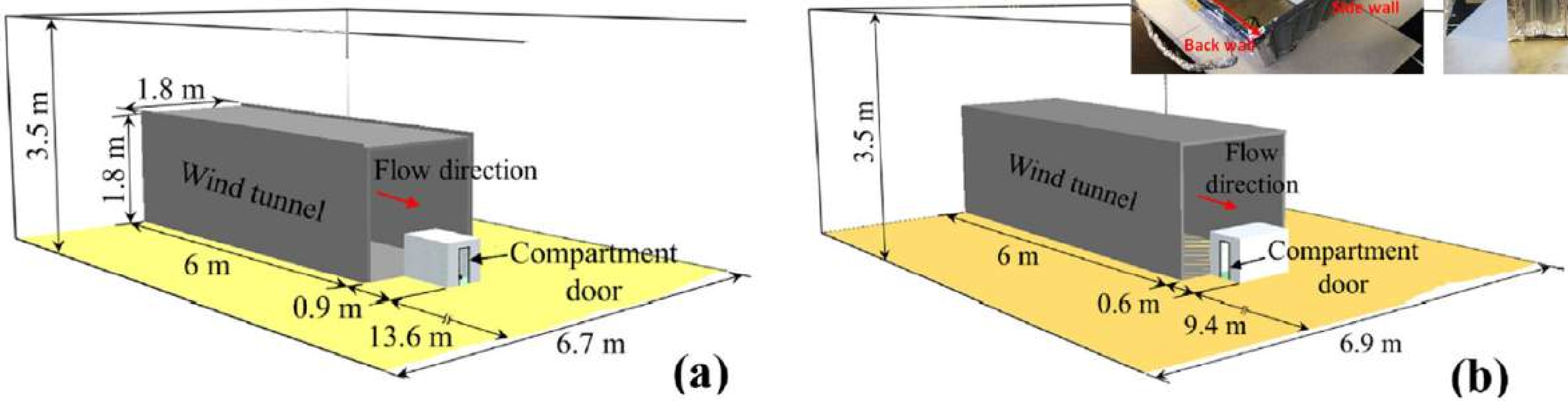


Fig. 5. Domain dimensions and main dimensions of the wind tunnel and the compartment: (a) Compartment positioned with its back wall windward (*BWW*), (b) Compartment positioned with its side wall windward (*SWW*).

- Malha: BWW 1.485.225 volumes e SWW 1.209.600 volumes
- Tempo computacional: 70 horas (thin) até 160 horas (thick)

- ***Estudo de malha***

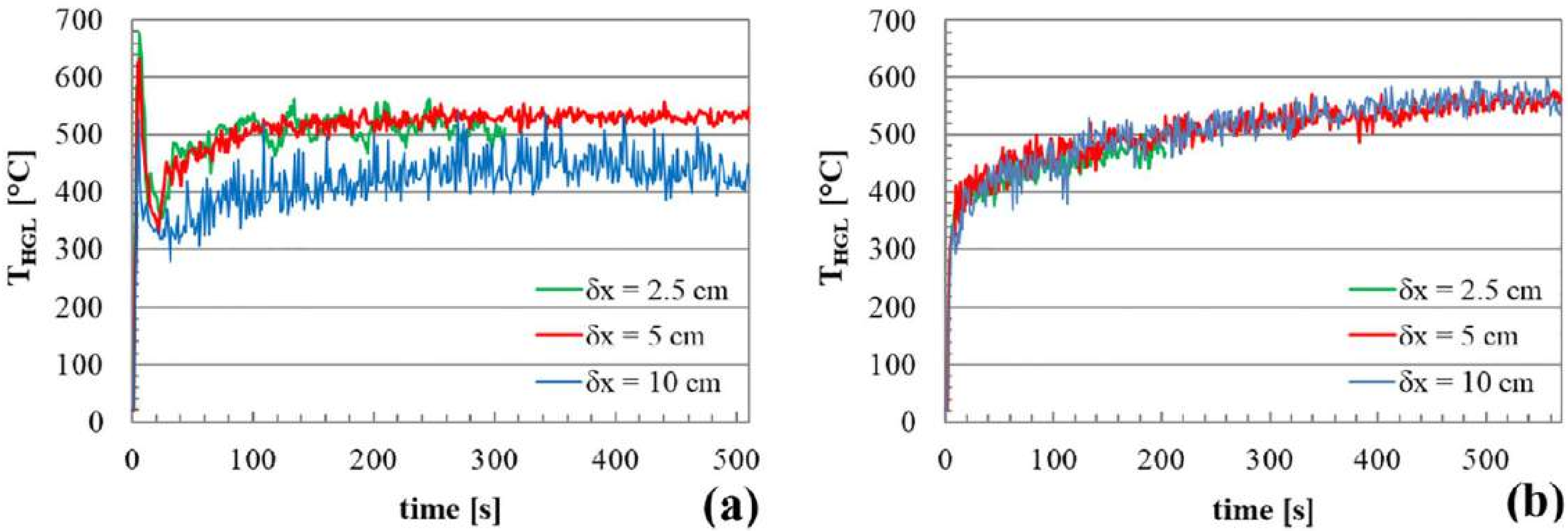
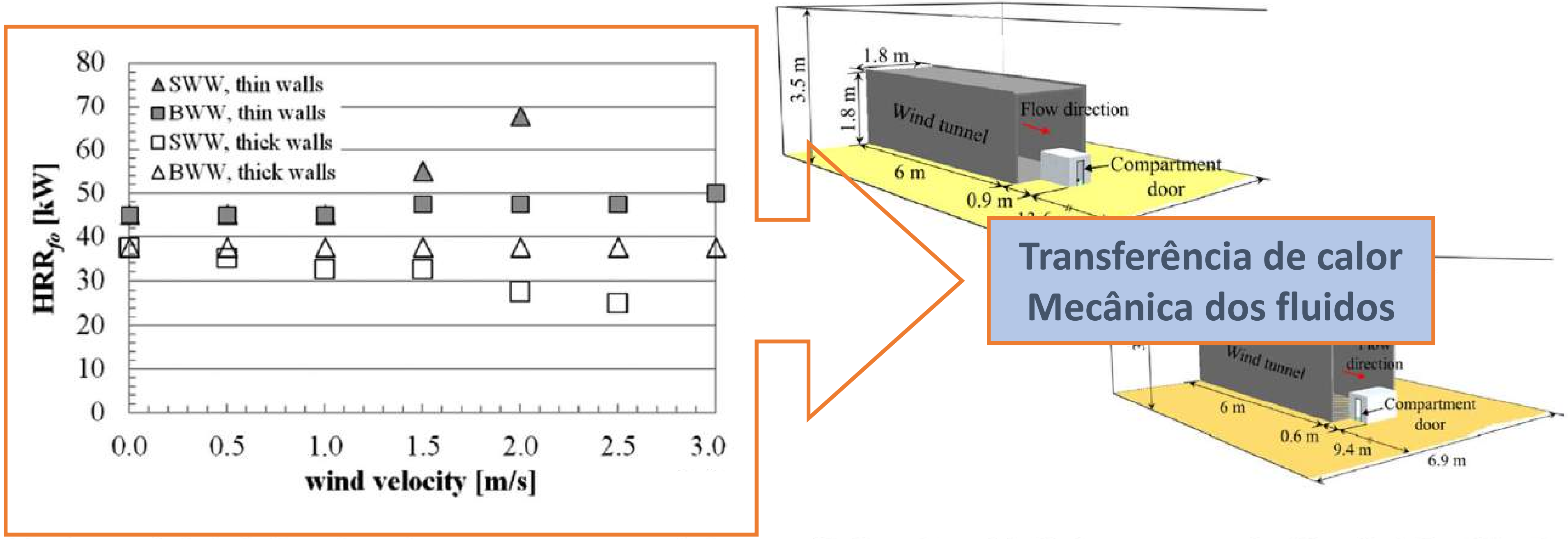


Fig. 6. Mesh sensitivity analysis: influence of the domain discretization size ($\delta x = 2.5$ cm, $\delta x = 5$ cm, $\delta x = 10$ cm) on the hot gas layer temperature. Results obtained for: (a) Side wall windward (*SWW*), thermally-thin boundaries, wind velocity = 2 m/s, HRR = 67.5 kW, (b) Back wall windward (*BWW*), thermally-thick boundaries, wind velocity = 3 m/s, HRR = 37.5 kW.

- ***Taxa de liberação de calor necessária para atingir flashover***



Transferência de calor
Mecânica dos fluidos

Fig. 7. (a) Influence of wind velocity on heat release rate necessary to reach the onset of flashover (HRR_{fo}) inside the compartment for side wall windward (*SWW*) and back wall windward (*BWW*) and for thermally-thin and thermally-thick boundaries;

- ***Análise de transferência de calor***

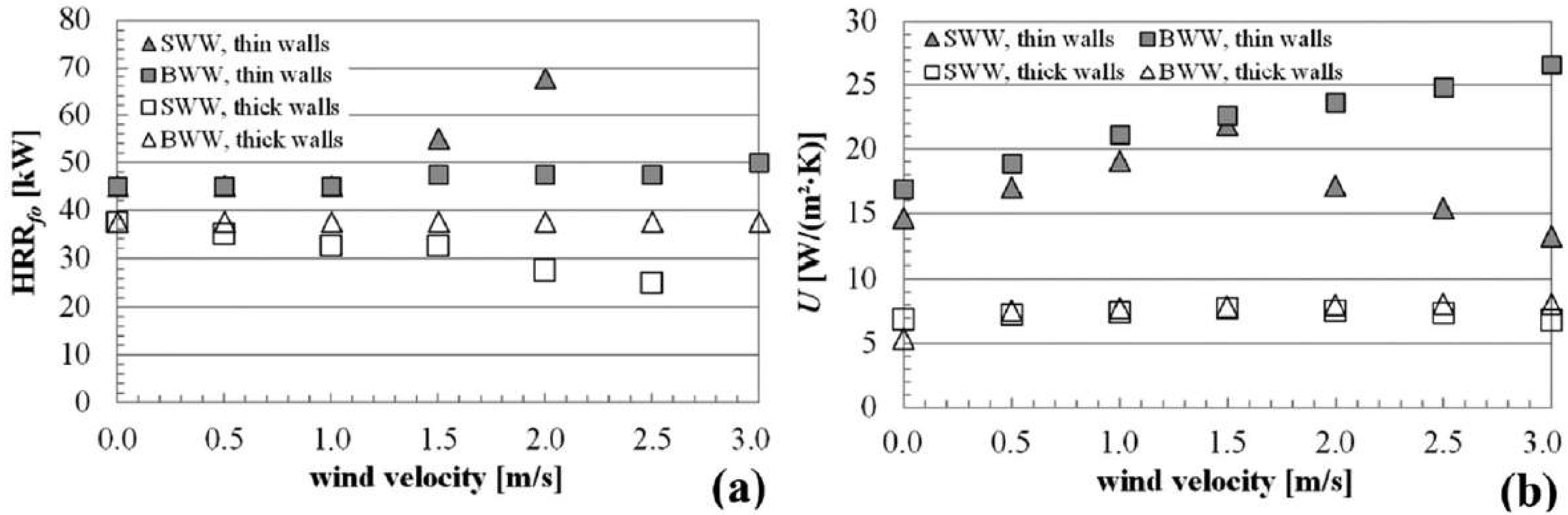
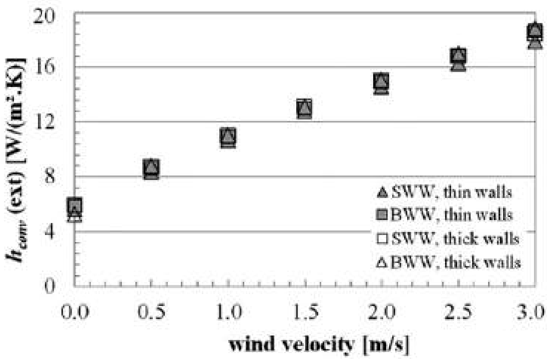
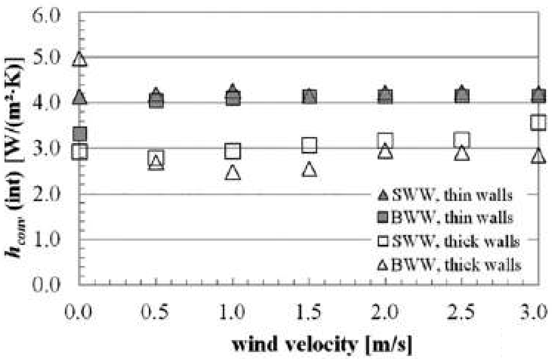


Fig. 7. (a) Influence of wind velocity on heat release rate necessary to reach the onset of flashover (HRR$_{fo}$) inside the compartment for side wall windward (*SWW*) and back wall windward (*BWW*) and for thermally-thin and thermally-thick boundaries; (b) Influence of wind velocity on the overall heat transfer coefficient (*U*).

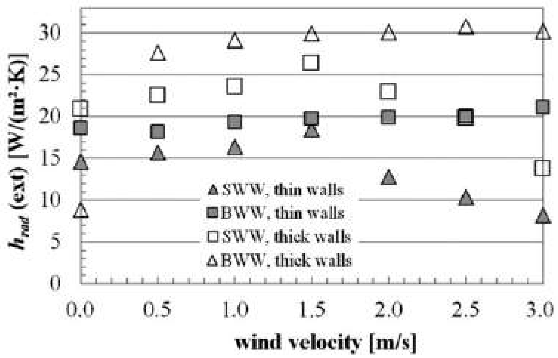
$$U=\left(R_{cond}+R_{EQ,\mathrm{int}}+R_{EQ,ext}\right)^{-1}=\left(\frac{\delta}{k}+\left(\frac{1}{h_{conv}+h_{rad}}\right)_{\mathrm{int}}+\left(\frac{1}{h_{conv}+h_{rad}}\right)_{ext}\right)^{-1}$$

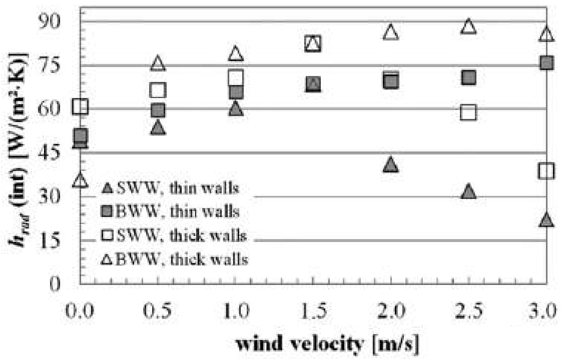
- ***Análise de transferência de calor***



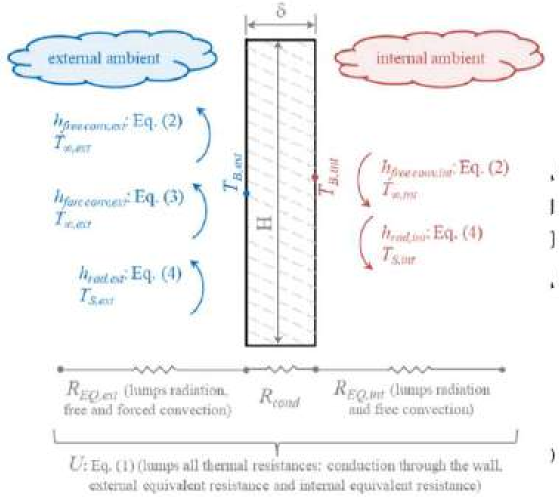


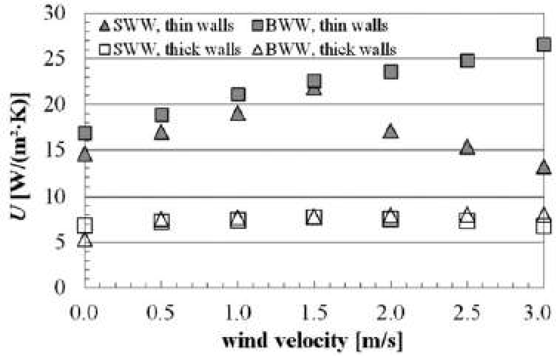
Coeficiente convectivo





Coeficiente radiativo





Coeficiente global

- ***Análise de mecânica dos fluidos***

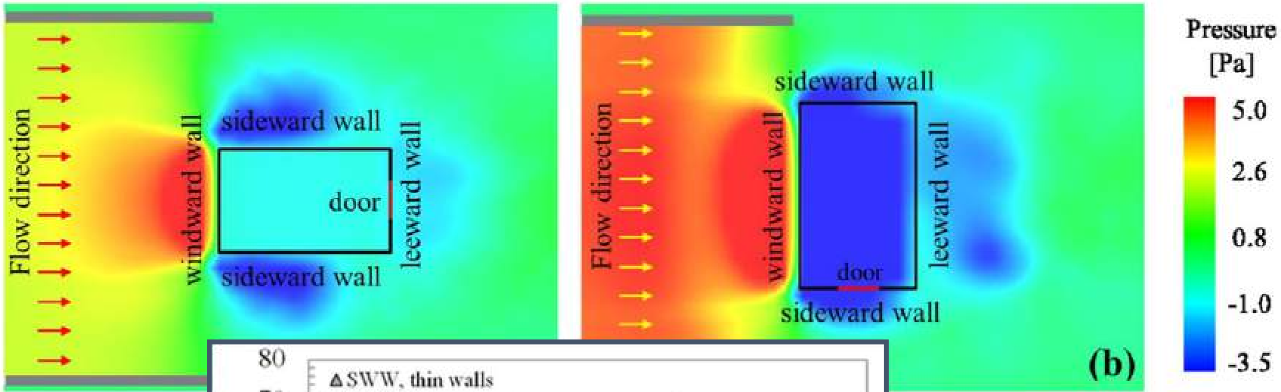
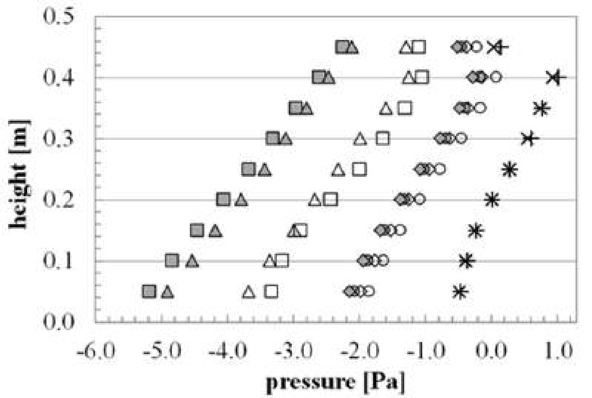
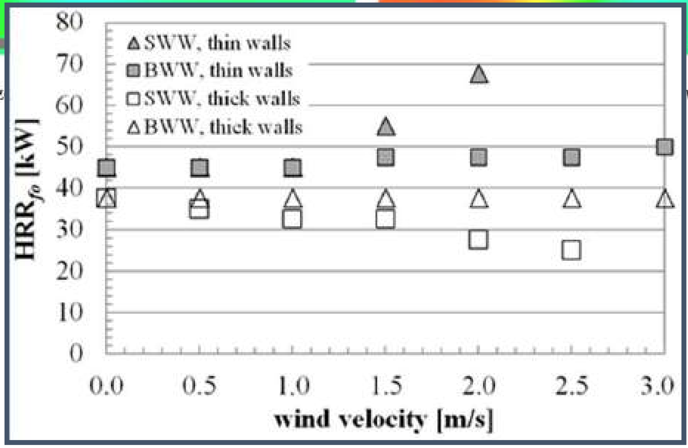
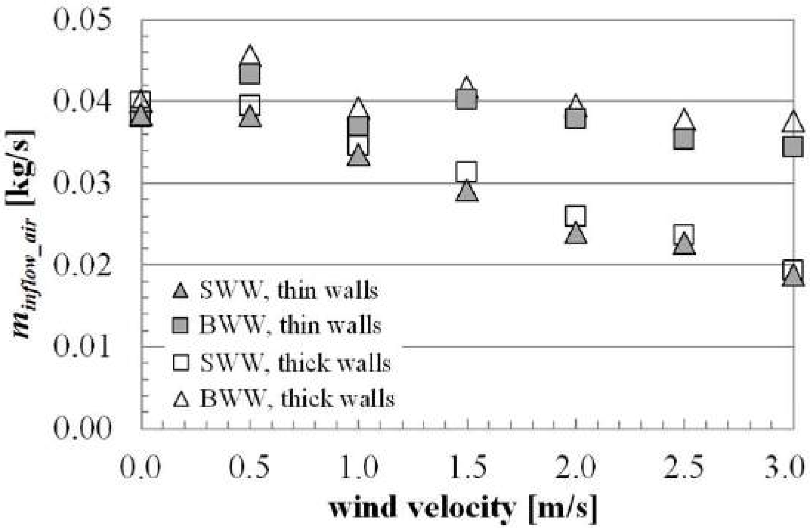


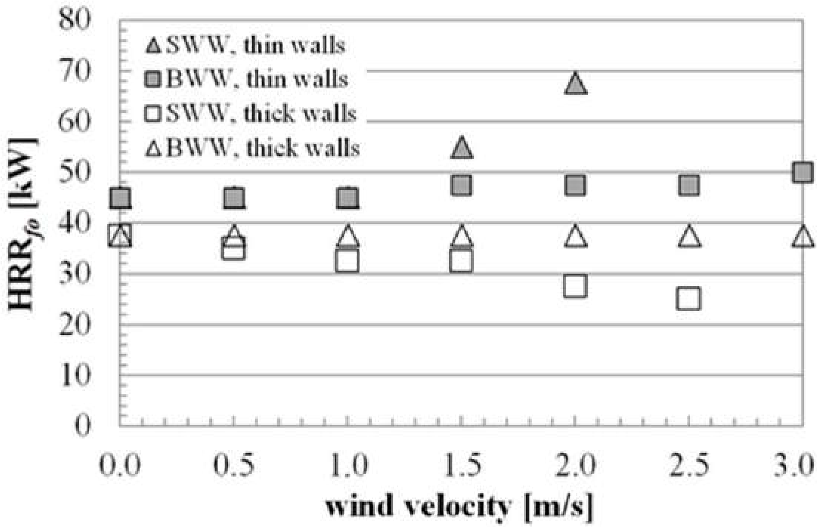
Fig. 11. Pressure slices at a horiz… walls: (a) *BWW*, HRR_{fo} = 37.5 kW; (b) *SWW*, HRR = 37.5 kW.



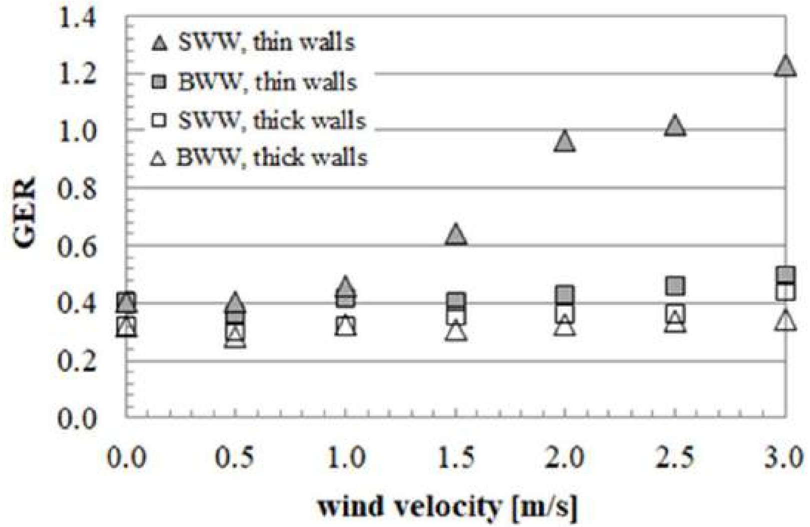


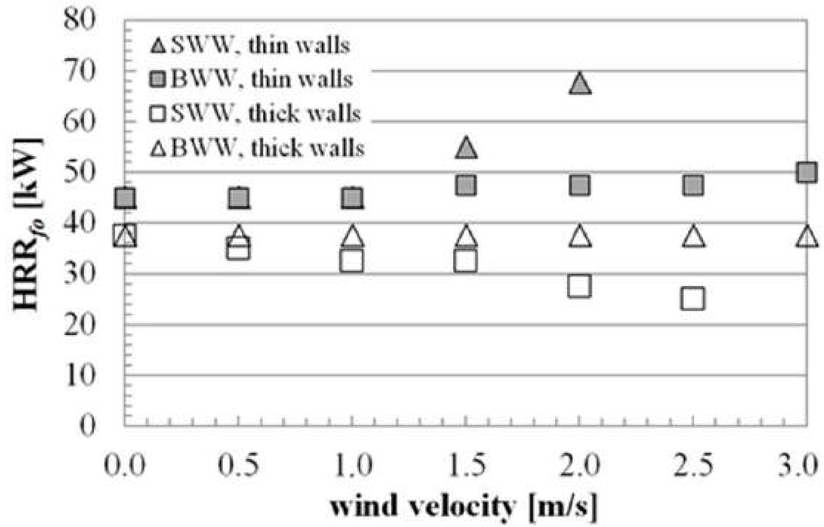
- ***Análise de mecânica dos fluidos***





- ***Análise de mecânica dos fluidos***





$$GER = \left(\dot{m}_{fuel} / \dot{m}_{inflow\_air}\right) / \left(\dot{m}_{fuel} / \dot{m}_{inflow\_air}\right)_{stoich}$$

EXEMPLO DE DESENVOLVIMENTO DE FERRAMENTA DE ENGENHARIA

- *FERRAMENTAS DE ENGENHARIA*

Journal of the Brazilian Society of Mechanical Sciences and Engineering (2022) 44:195
https://doi.org/10.1007/s40430-022-03431-z

TECHNICAL PAPER

Semi-empirical correlations for predicting hot gas layer temperature in pre-flashover compartment fires considering fire source location

Calisa Katiuscia Lemmertz[1] · Rodolfo Prediger Helfenstein[1] · Mohamed Beshir[2] · David Rush[2] · Wolfram Jahn Von Arnswaldt[3] · Felipe Roman Centeno[1]

International Journal of Thermal Sciences 208 (2025) 109464

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

ELSEVIER

journal homepage: www.elsevier.com/locate/ijts

The impact of fire source location on hot gas layer temperature in multi-compartment pre-flashover fires: Analysis and semi-empirical model development

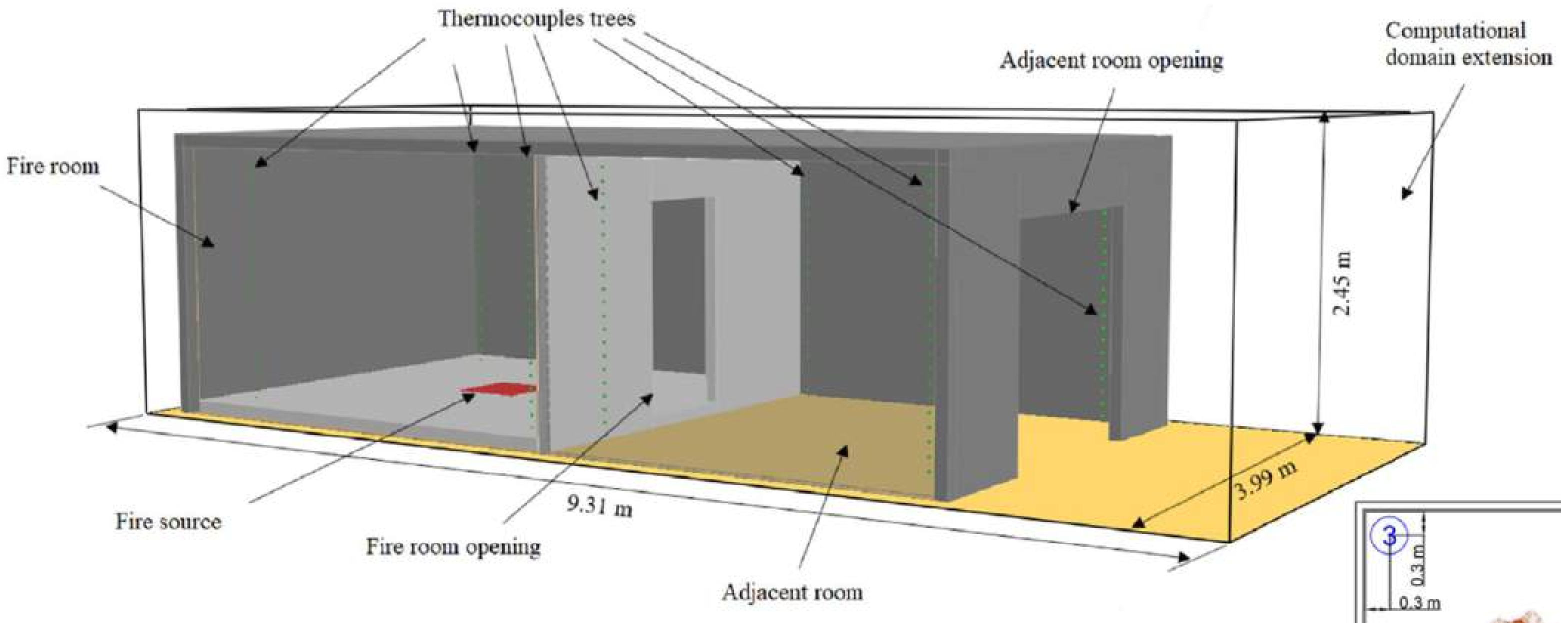
Rodolfo Prediger Helfenstein, Calisa Katiuscia Lemmertz, Felipe Roman Centeno *

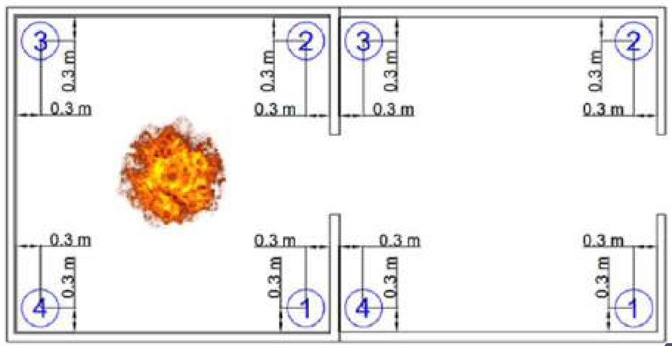
Department of Mechanical Engineering, Federal University of Rio Grande do Sul, Sarmento Leite Street, 425, Porto Alegre, RS, 90050-170, Brazil

- ***Objetivos***

- Analisar a influência da posição do fogo na sala sobre a temperatura da camada de gases quentes e seu comportamento em um incêndio em compartimento com duas salas.
- Desenvolver um modelo de engenharia semi-empírico para calcular a temperatura da camada de gases quentes na sala adjacente à sala onde está o fogo.

- ***Domínio computacional***

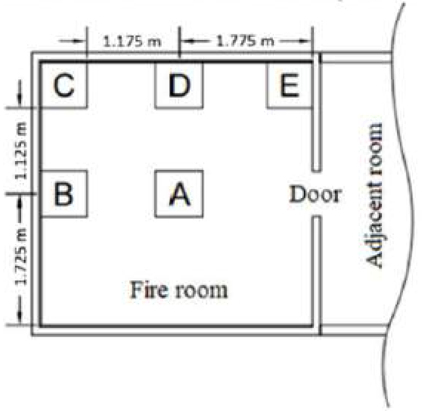


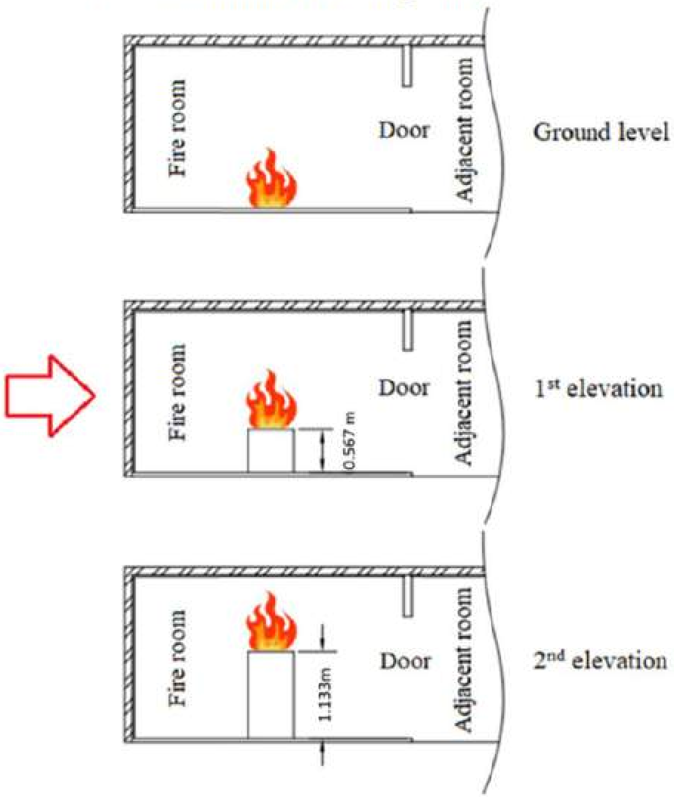


- ***Posições do fogo***

Vertical variation of the fire position

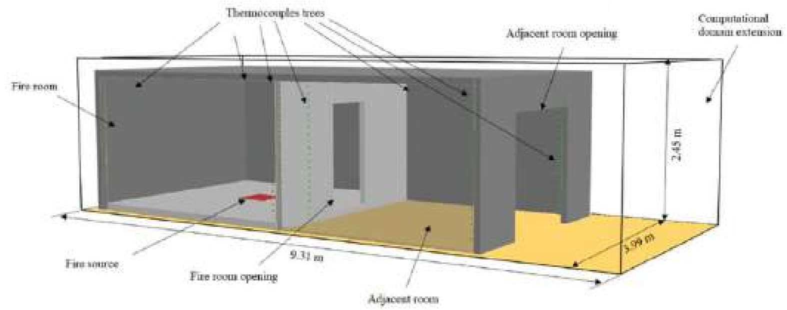
Horizontal variation of the fire position





List of the openings and HRRs employed in the simulations.

#	Fire room opening (m^2)	HRR (kW)	Adjacent room opening (m^2)
1	0.59 × 1.7	86	1.8 × 1.8
2	0.89 × 1.7	86	1.8 × 1.8
3	0.59 × 1.7	171	1.8 × 1.8
4	0.89 × 1.7	171	1.8 × 1.8
5	0.59 × 1.7	342	1.8 × 1.8
6	0.89 × 1.7	342	1.8 × 1.8
7	1.19 × 1.7	86	1.8 × 1.8
8	1.19 × 1.7	342	1.8 × 1.8
9	1.19 × 1.7	86	1.19 × 1.8
10	1.19 × 1.7	342	1.19 × 1.8
11	1.19 × 1.7	86	0.89 × 1.8
12	1.19 × 1.7	342	0.89 × 1.8
13	0.89 × 1.7	86	1.19 × 1.8
14	0.59 × 1.7	86	0.89 × 1.8
15	0.89 × 1.7	342	1.19 × 1.8
16	0.59 × 1.7	342	0.89 × 1.8
17	0.59 × 1.7	86	1.19 × 1.8



- ***Estudo de malha***

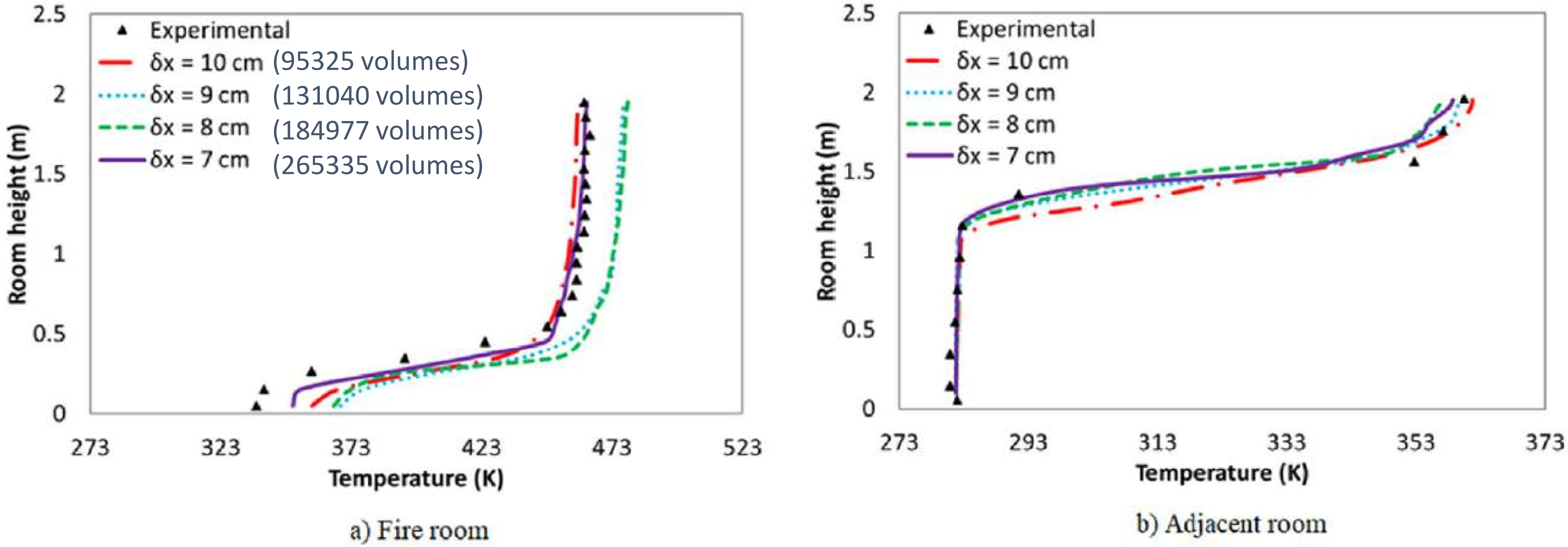


Fig. 4. Mesh sensitivity analysis of the temperature profiles for Scenario 1: (a) fire room and (b) adjacent room.

PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA MECÂNICA

LABORATÓRIO DE DINÂMICA DE INCÊNDIOS

- ***Estudo de malha***

Values of D^* and $D^*/\delta x$ for the evaluated meshes for each fire scenario.

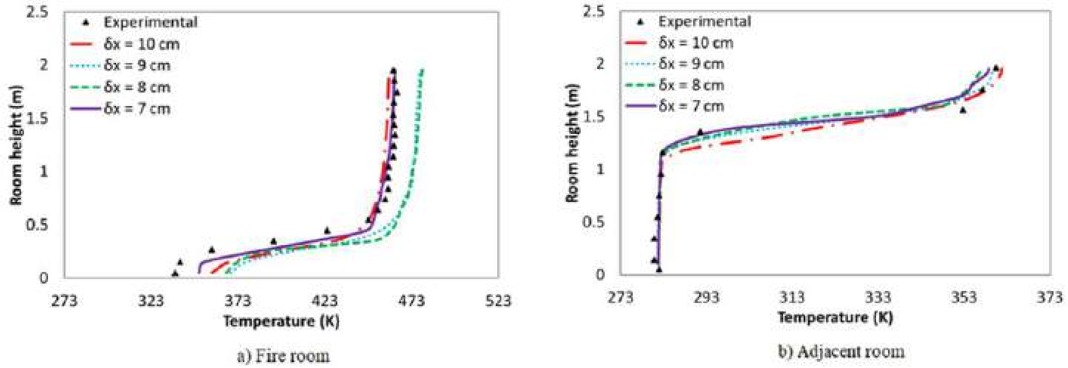
Scenario	D^*	$D^*/\delta x$			
		$\delta x = 10$ cm	$\delta x = 9$ cm	$\delta x = 8$ cm	$\delta x = 7$ cm
1	0.360	3.60	4.00	4.50	5.14
2	0.361	3.61	4.01	4.51	5.15
3	0.474	4.74	5.27	5.92	6.77
4	0.625	6.25	6.95	7.82	8.93
5	0.625	6.25	6.94	7.81	8.93
6	0.606	6.06	6.73	7.57	8.65
7	0.796	7.96	8.84	9.95	11.37

Mesh quality analysis for Scenario 1.

δx	Fire room		Adjacent room		Computational time (h)	
	z_{int} (m)	T_u (K)	z_{int} (m)	T_u (K)		
10 cm	0.22	455.7	1.15	359.7	≈12	(95325 volumes)
9 cm	0.24 (9.1 %)	473.4 (3.9 %)	1.24 (7.8 %)	357.8 (0.5 %)	≈17	(131040 volumes)
8 cm	0.25 (4.2 %)	473.5 (0.0 %)	1.26 (1.6 %)	355.2 (0.7 %)	≈26	(184977 volumes)
7 cm	0.23 (8 %)	458.3 (3.2 %)	1.29 (2.4 %)	356.1 (0.3 %)	≈42	(265335 volumes)

* Values inside the brackets are relative deviations associated with the immediately coarser mesh result.

- ***Validação***



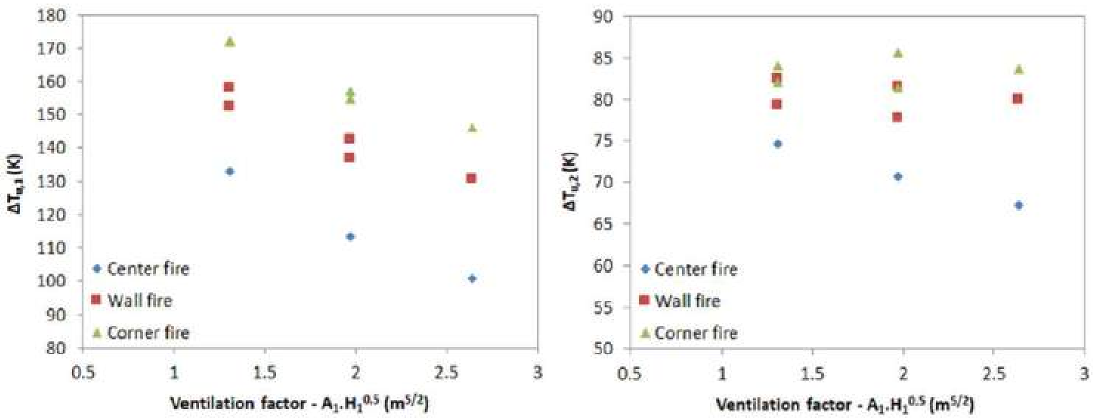
$$I_1 = \int_0^{H_s} T(z)dz \qquad I_2 = \int_0^{H_s} \frac{1}{T(z)}dz$$

$$z_{int} = \frac{T_L\left(I_1 I_2 - H_s^2\right)}{I_1 + I_2 T_L^2 - 2T_L H_s}$$

Comparison between experimental data (Nakaya et al. [28]) and numerical results (present study).

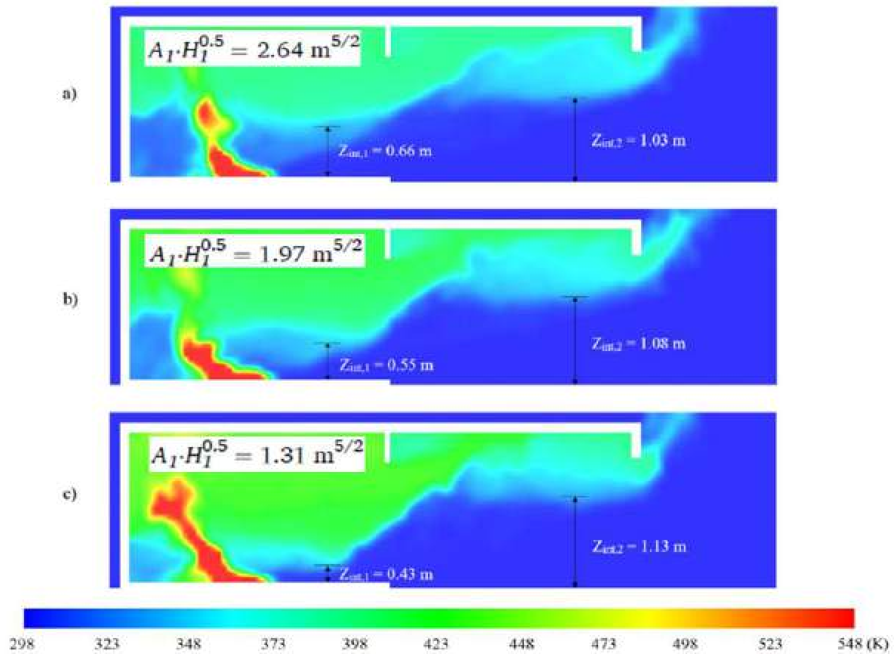
Scenario	Room	z_{int} (m)			T_u (K)		
		Experiment	FDS	Relative Dev. [%]	Experiment	FDS	Relative Dev. [%]
1	Fire	0.26	0.23	−11.5	460.2	458.3	−0.4
2		0.36	0.35	−2.8	411.0	414.8	0.9
3		0.49	0.41	−16.3	492.7	503.4	2.2
4		0.20	0.24	20.0	834.7	847.6	1.5
5		0.33	0.25	−24.2	723.1	749.7	3.7
6		0.38	0.34	−10.5	638.2	675.2	5.8
7		0.32	0.26	−18.8	816.9	865.7	6.0
1	Adjacent	1.40	1.29	−7.9	356.8	356.1	−0.2
2		1.35	1.15	−14.8	349.2	358.5	2.7
3		1.25	1.10	−12.0	425.9	422.1	−0.9
4		1.11	1.19	7.2	465.1	469.1	0.9
5		1.35	1.09	−19.3	513.9	508.4	−1.1
6		1.15	1.05	−8.7	507.8	502.5	−1.0
7		1.15	1.03	−10.4	575.7	569.4	−1.1

- ***Resultados: influência dos fatores de ventilação (*** $A_1.H_1^{0.5}$ ***e*** $A_2.H_2^{0.5}$ ***)***



a) Fire room
b) Adjacent room

Fig. 5. Influence of the fire room ventilation factor on ΔT_u in (a) fire room ($\Delta T_{u,1}$) and (b) adjacent room ($\Delta T_{u,2}$), considering the different fire source positions (center, wall, corner) at ground level.



Fire at the center of the room at ground level
(temperature slice placed at the center of the door width).

- ***Resultados: influência dos fatores de ventilação ($A_1.H_1^{0.5}$ e $A_2.H_2^{0.5}$)***

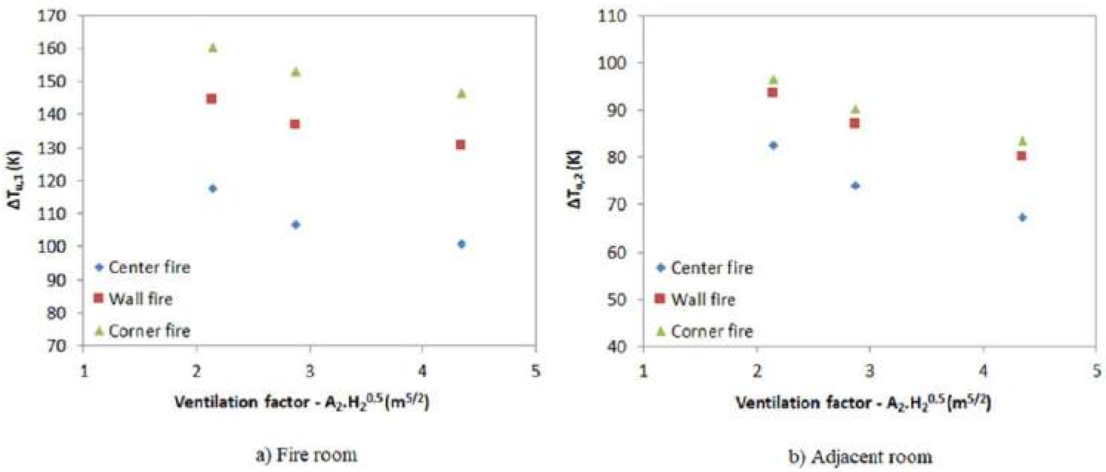
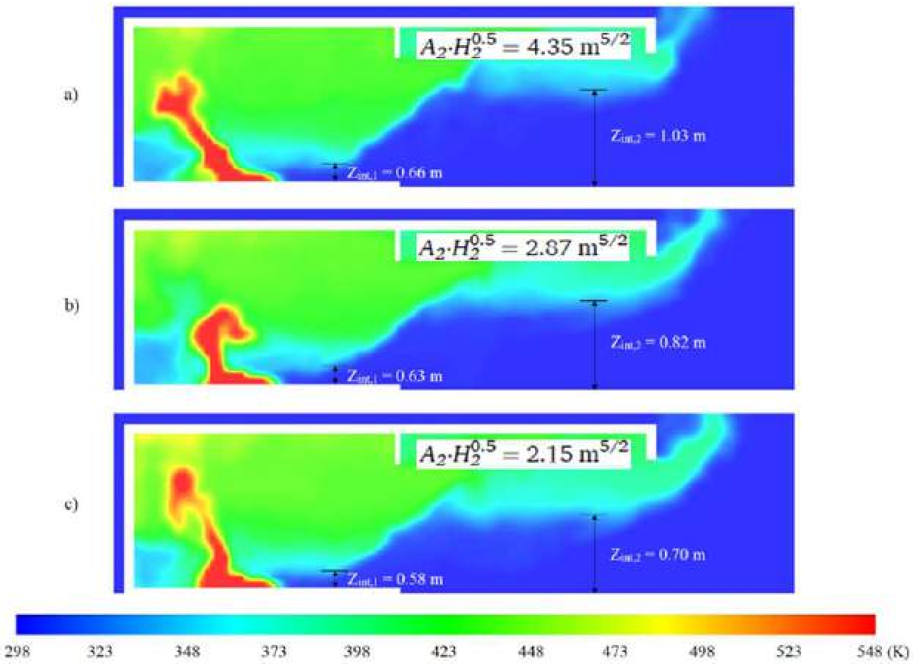
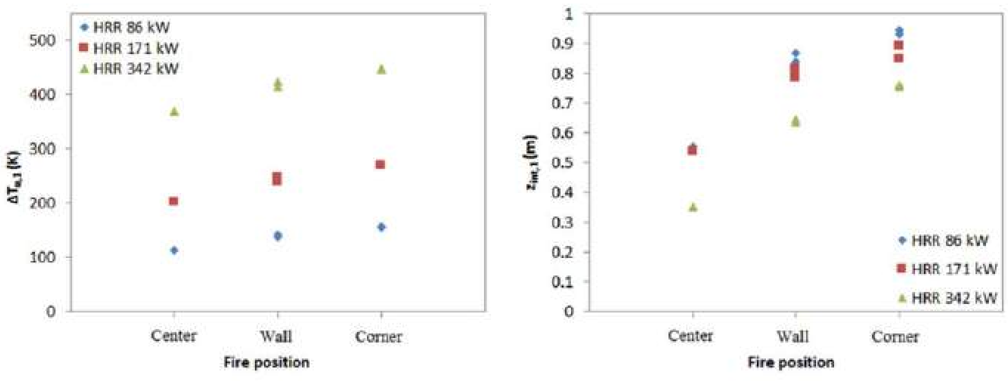


Fig. 7. Influence of the adjacent room ventilation factor on ΔT_u in a) fire room and b) adjacent room, considering the different fire source positions at ground level.



Fire at the center of the room at ground level
(temperature slice placed at the center of the door width).

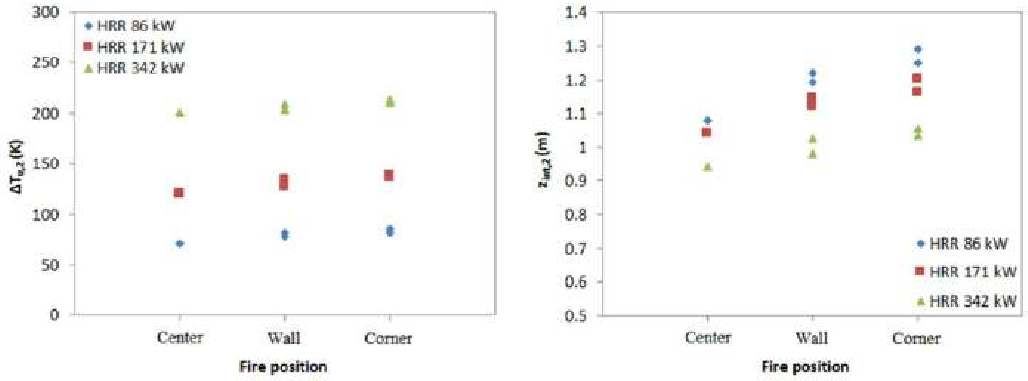
- ***Resultados: influência da posição do fogo (no nível do piso)***



a) Hot gas layer temperature

b) Interface height

Fig. 9. Comparison of (a) $\Delta T_{u,1}$ and (b) $z_{int,1}$ with the variation of the fire position at ground level.

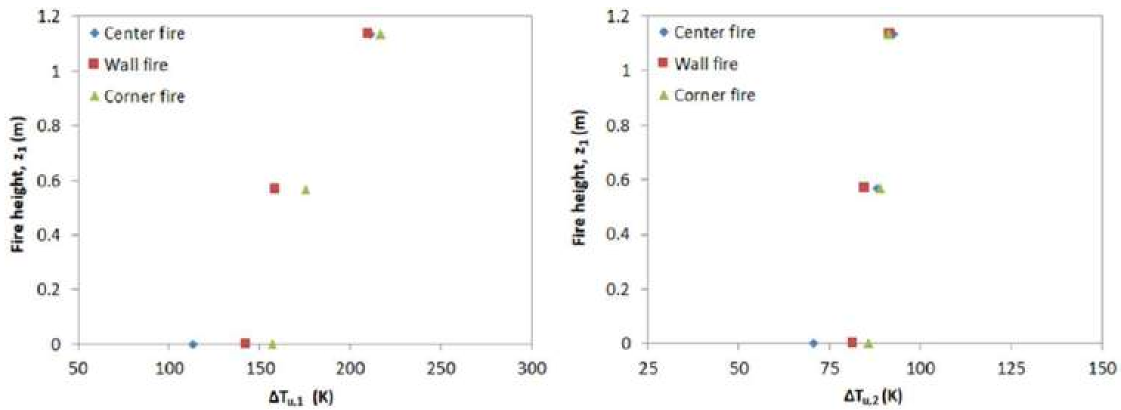


a) Hot gas layer temperature

b) Interface height

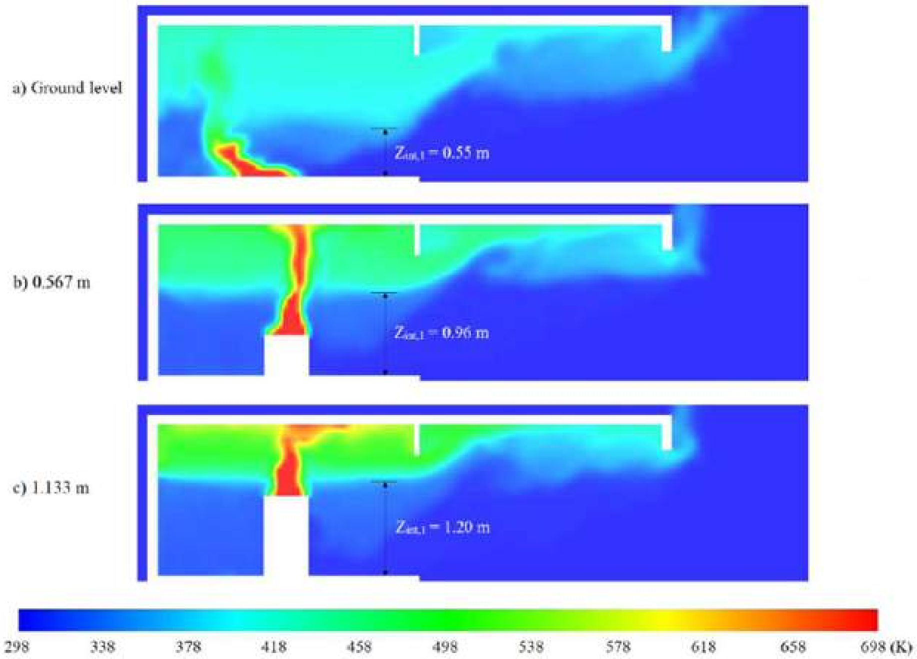
Fig. 10. – Comparison of (a) $\Delta T_{u,2}$ and (b) $z_{int,2}$ with the variation of the fire position at ground level.

- ***Resultados: influência da posição do fogo quando elevado do piso***



a) Fire room b) Adjacent room

Fig. 11. Influence of the fire source elevation on ΔT_u in (a) fire room and (b) adjacent room.



- ***Resultados: modelo de engenharia semi-empírico***

- Balanço de energia para uma sala: $\dot{Q} = \dot{m}_{g,1} c_p (T_{u,1} - T_\infty) + h_{k,1} A_{t,1} (T_{u,1} - T_\infty)$
- Balanço de energia para duas salas: $\dot{Q} = h_{k,1} A_{t,1} \Delta T_{u,1} + h_{k,2} A_{t,2} \Delta T_{u,2} + \dot{m}_{g,2} c_p \Delta T_{u,2}$

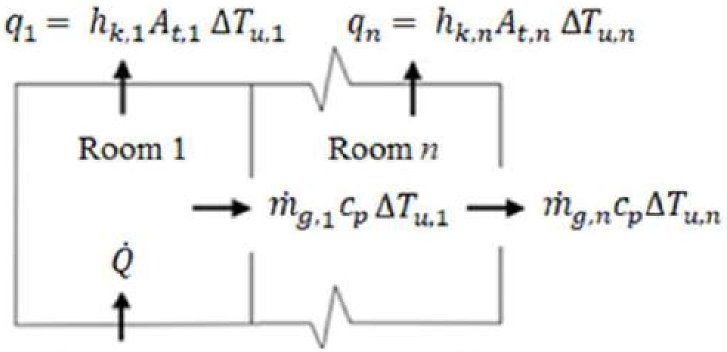


Fig. 14. – Energy balance in a multi-compartment [adapted from Johansson [15]].

$$\Delta T_{u,2} = \frac{\dot{m}_{g,1} c_p \Delta T_{u,1}}{\dot{m}_{g,2} c_p + h_{k,2} A_{t,2}}$$

$\dot{m}_{g,1} \propto A_1 . H_1^{0.5}$ $\quad h_k = \frac{k}{d}$ for $t > t_p$

$\dot{m}_{g,2} \propto A_2 . H_2^{0.5}$ $\quad h_k = \left(\frac{k c_p \rho}{t}\right)^{1/2}$ for $t \leq t_p$

$t_p = \left(\frac{\rho c_p}{k}\right)\left(\frac{d}{2}\right)^2$

$\Delta T_{u,1}$: exemplo MQH $\frac{\Delta T}{T_\infty} = 1.6 \left(\frac{\dot{Q}}{\sqrt{g} C_P \rho_\infty T_\infty A_0 \sqrt{H_0}}\right)^{\frac{2}{3}} \left(\frac{h_k A_T}{\sqrt{g} C_P \rho_\infty A_0 \sqrt{H_0}}\right)^{-\frac{1}{3}}$

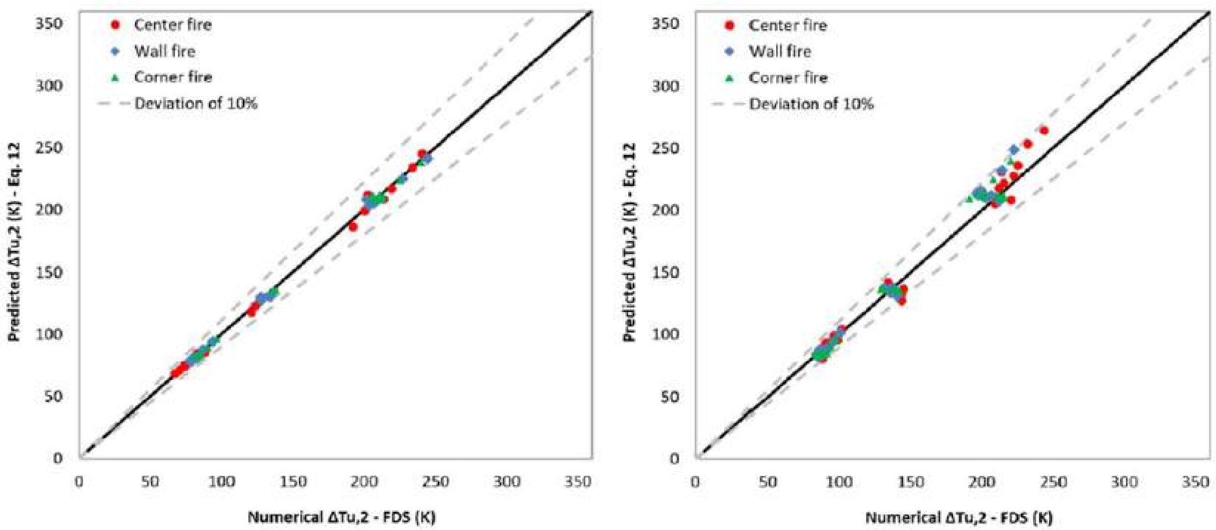
$$\Delta T_{u,2} = \alpha \, \Delta T_{u,1}{}^{\beta} \left(\sqrt{g} \rho_\infty \, c_p A_1 H_1{}^{0.5}\right)^{\gamma} \left(\frac{1}{\sqrt{g} \rho_\infty \, c_p A_2 H_2{}^{0.5} + h_{k,2} A_{T,2}}\right)^{\varphi} + \xi T_\infty \frac{z_1}{H_{s,1}}$$

- ***Resultados: modelo de engenharia semi-empírico***

$$\Delta T_{u,2} = \alpha\, \Delta T_{u,1}{}^{\beta} \left(\sqrt{g}\rho_{\infty}\, c_p A_1 H_1{}^{0.5}\right)^{\gamma} \left(\frac{1}{\sqrt{g}\rho_{\infty}\, c_p A_2 H_2{}^{0.5} + h_{k,2} A_{T,2}}\right)^{\varphi} + \xi T_{\infty} \frac{z_1}{H_{s,1}}$$

Table 7 Coefficients for the correlation (Eq. (12)) for each fire source location.

Fire position	α	β	γ	φ	ξ
Center	$10^{0.034}$	0.869	0.218	0.126	0.12
Parallel to a Wall	$10^{-0.013}$	0.859	0.233	0.104	0.045
Corner	$10^{-0.083}$	0.884	0.211	0.095	0.007



a) Ground positions   b) Elevated positions

Fig. 15. Comparisons between HGL temperature predicted with Eq. (12) and numerical data from FDS for fire source for (a) ground positions and (b) elevated positions

- ***Resultados: validação externa do novo modelo de engenharia***

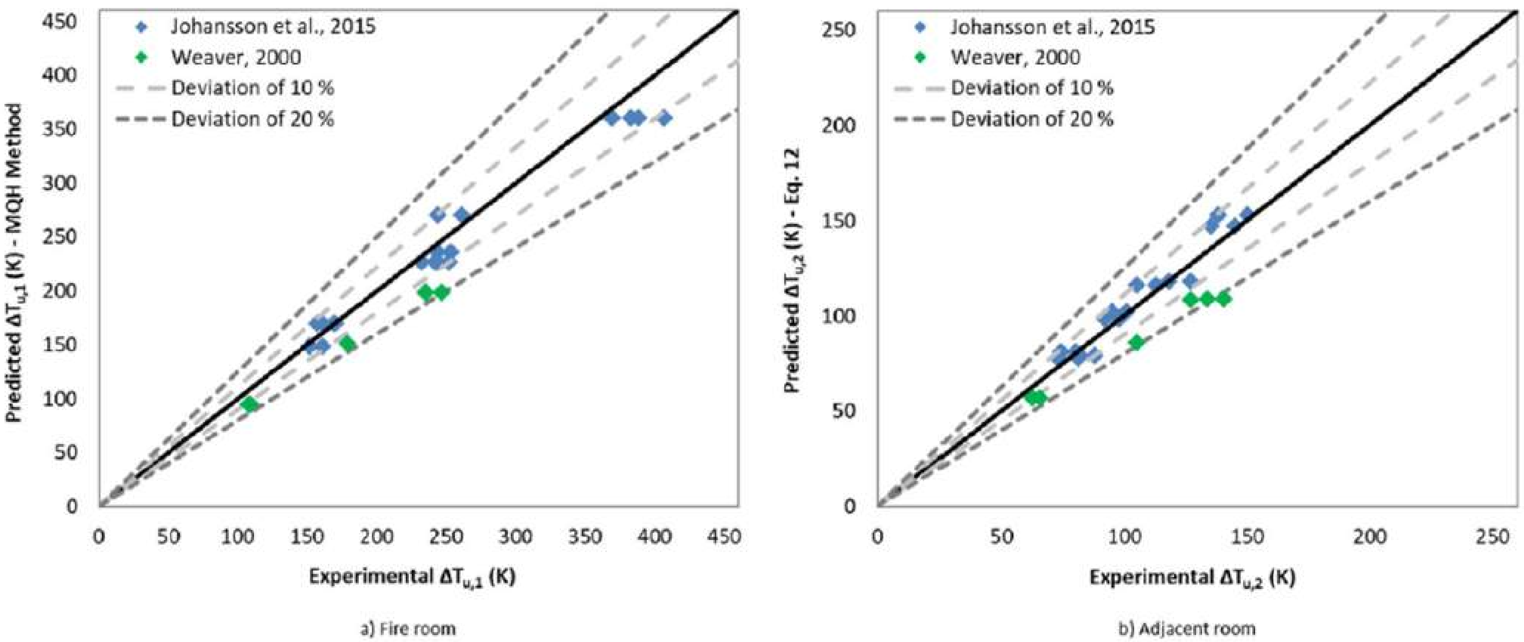


Fig. 16. ΔT_u (a) for the fire room and (b) for the adjacent room for a fire positioned in the center of the room: comparisons between predictions using the new model and experiments. Predictions: (a) $\Delta T_{u,1}$ by the MQH Method and (b) $\Delta T_{u,2}$ by Eq. (12).

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Incêndios em casas de madeira e em terrenos com aclive

https://gauchazh.clicrbs.com.br/porto-alegre/noticia/2021/10/seis-casas-sao-destruidas-por-incendio-no-bairro-rubem-berta-em-porto-alegre-ckv2uoft000bh019m8swh5w6r.html
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https://engeplus.com.br/noticia/seguranca/2014/casa-de-madeira-e-destruida-em-incendio

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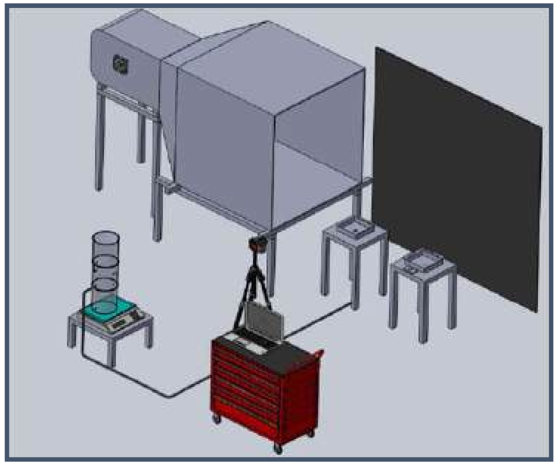
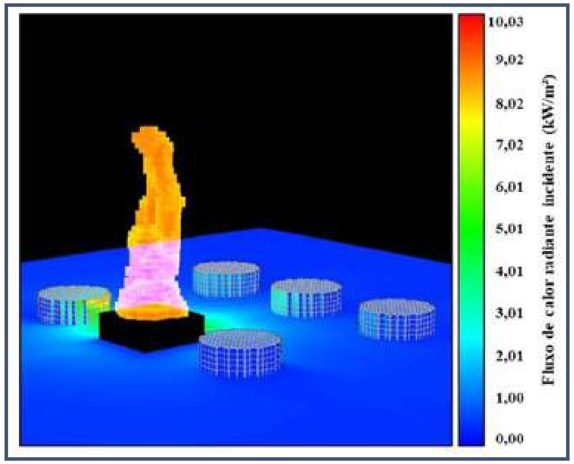
https://www.editoraroncarati.com.br/v2/Artigos-e-Noticias/Artigos-e-Noticias/Incendio-em-areas-de-tancagem-de-produtos-diversos.html





Espalhamento do fogo entre pool fires/tanques

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Numerical simulation and consequence analysis of accidental hydrogen fires in a conceptual offshore hydrogen production platform

Hong Lin [a,b,*], *Haochen Luan* [a], *Lei Yang* [c], *Chang Han* [a], *Shuo Zhang* [a], *Hongwei Zhu* [b], *Guoming Chen* [b]

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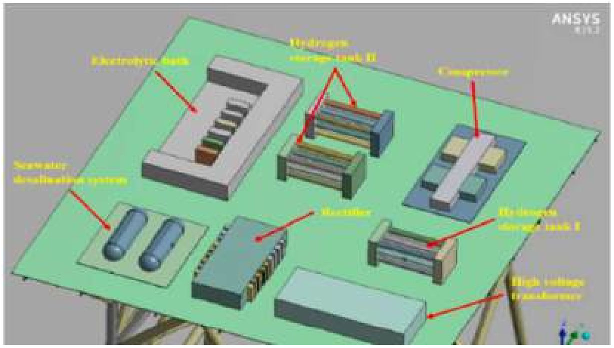

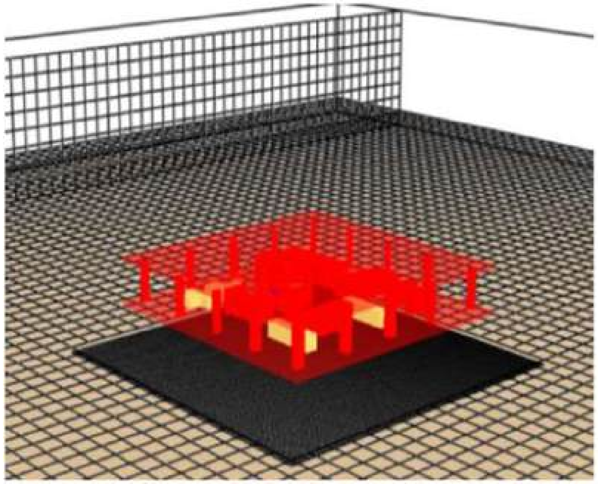

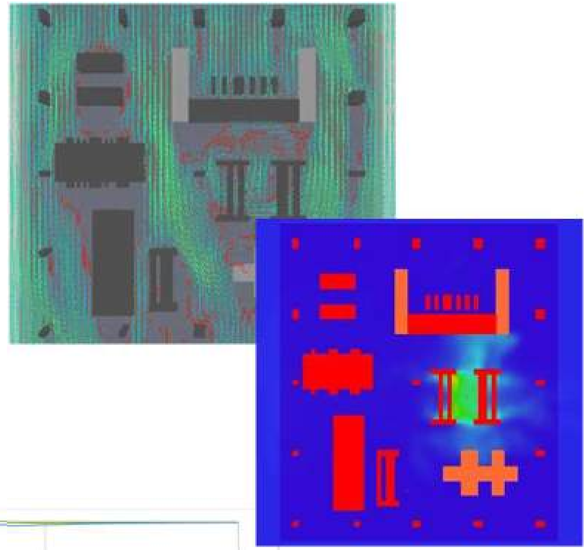

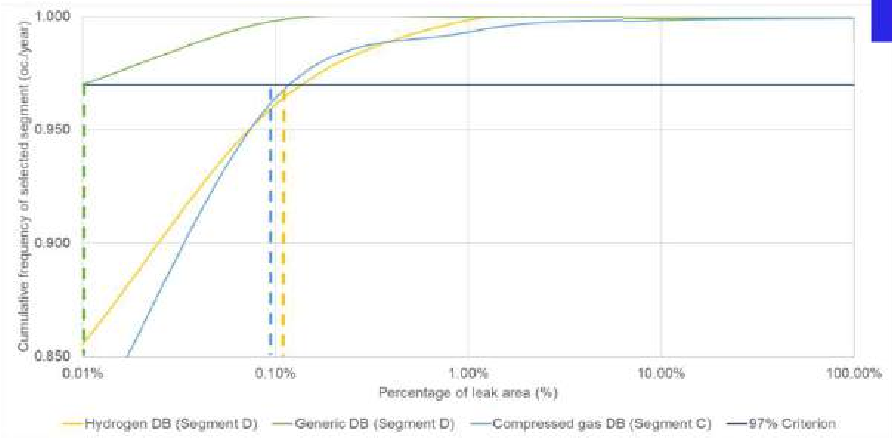

Análise de riscos

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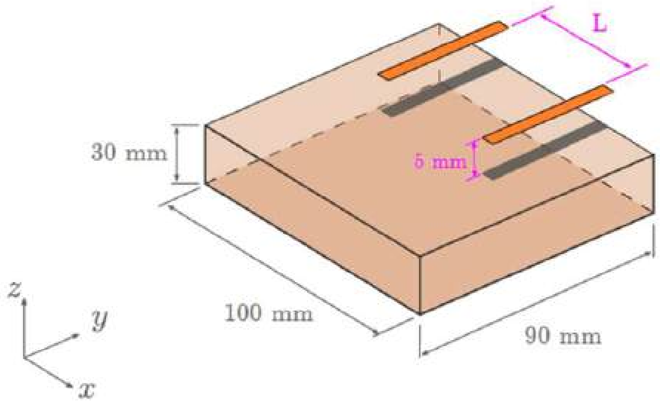

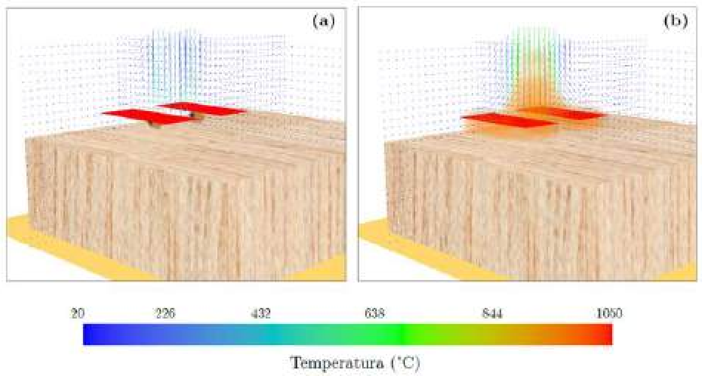

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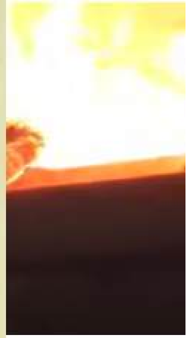

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PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA MECÂNICA

LABORATÓRIO DE DINÂMICA DE INCÊNDIOS

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Obrigado!

Prof. Dr. Felipe Roman Centeno

MCSUL/SEMENGO – Rio Grande/RS – 04/12/2024