PREDICTING TOXIC SPECIES GENERATION RESULTING FROM EXTERNAL CLADDING FIRES

Prof Ed Galea
Director

Fire Safety Engineering Group
Centre for Safety, Resilience and Protective Security
University of Greenwich, UK

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e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

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  - Dr Zhaozhi Wang,
  - Dr John Ewer,
  - Dr Fuchen Jia

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Wang Z., Jia F., Galea E.R., Ewer J., CFD simulation of the BS 8414 test for cladding applications, 2025

https://doi.org/10.1016/j.firesaf.2025.104366.

Wang Z., Jia F., Galea E.R., Ewer J., Predicting toxic species generation resulting from external cladding fires, 2026

https://doi.org/10.1016/j.firesaf.2026.104693

- Special thanks to Prof Richard Hull and his colleagues from University of Central Lancashire and FPA for providing access to BS8414 test data involving toxic gas generation.

(i) Jones N., Peck G., McKenna S., Glockling J.L.D., Harbottle J., Stec A.A., Hull Richard., Burning behaviour of rainscreen façades, Journal of Hazardous Materials, 2021(403).

(ii) Peck G., Jones N., McKenna S., Glockling J.L.D., Harbottle J., Stec A.A., Hull Richard, Smoke toxicity of rainscreen façades, Journal of Hazardous Materials, 2021(403).

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

Cladding fires; Causes of deaths

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

Highrise Building Cladding Fires

https://en.wikipedia.org/wiki/File:Shanghai_jiaozhou_road_fire.jpg

2010: Shanghai; 28 floor building; fire occurred during external insulation installation; **58 fatalities and 71 injuries**.

https://media.cnn.com/api/v1/images/stellar/prod/151231144636-15-dubai-fire-1231.jpg?q=w_4173,h_2347,x_0,y_0,c_fill/h_447

2016: Dubai, 63 floor Address Downtown hotel; ACM cladding fire; **16 injuries**.

https://metro.co.uk/wp-content/uploads/2018/06/sei_15352990-e1528117132927.jpg?quality=90&strip=all&w=494

2017: London, 23 floor Grenfell Tower; ACM cladding fire; **72 fatalities**.

https://media.rnztools.nz/rnz/image/upload/s--3-tRvqV3--/ar_16:10,c_fill,f_auto,g_auto,q_auto,w_1050/v1764157554/4JXB8NJ_AFP___20251126___868J9G3___v2___HighRes___TopshotHongKongChinaFire_jpg?_a=BACCd2AD

2025: Hong Kong, 7 buildings in a resident estate; Bamboo scaffolding and flammable materials; **159 fatalities and 79 injuries**.

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

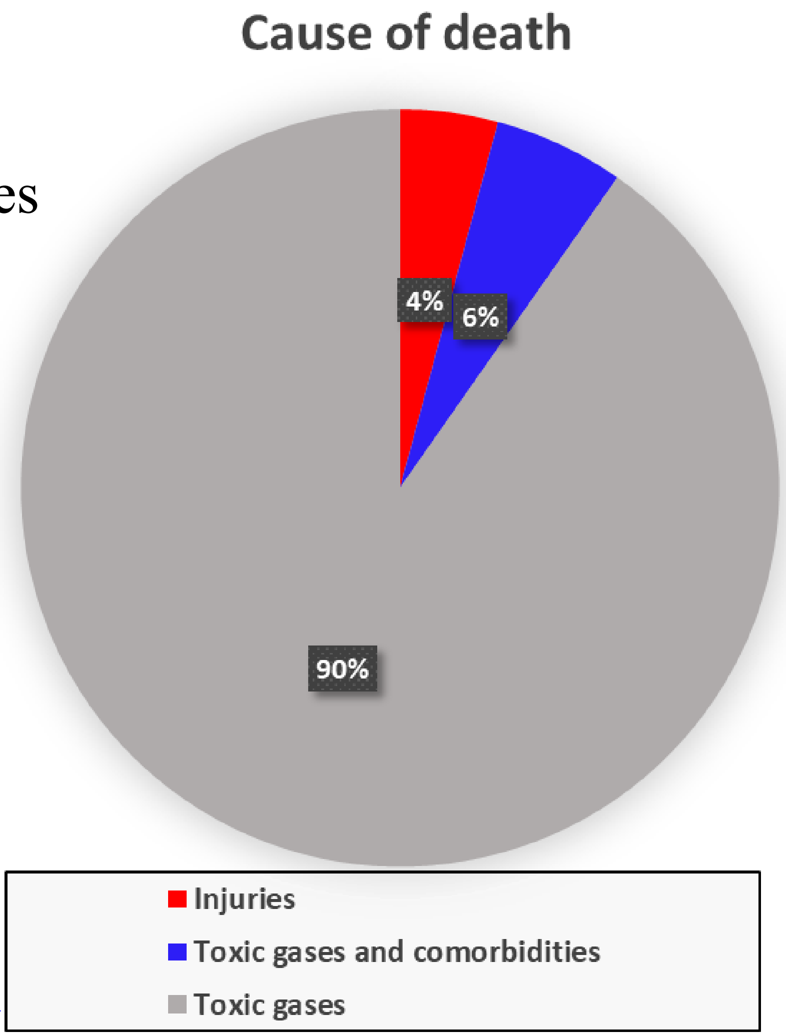
Cause of Fatalities in Grenfell Tower Fire

- **Cause of Grenfell Tower fatalities**
  - 72 fatalities
  - 3 (or 4.2%) caused by multiple injuries (fall from height)
  - 4 (5.6%) by inhalation of asphyxiant gases and other comorbidities
  - 65 (**90.3%**) by inhalation of asphyxiant gases from fire effluent

(based on medical cause of death reported in Vol 6, Grenfell Tower Inquiry: Phase 2 report, 2024)

- **Key factor impacting evacuation**
  - Heavy smoke in lobbies and stairwell
- **Contributions to the toxic gases** (Purser, 2024)
  - **The external cladding and insulation in the early fire stages**
  - The window infill panel and surroundings in the early fire stages
  - The contents of flats

It is important to explore the impact on evacuation of the toxic smoke produced by burning cladding/insulation materials entrained into the building.

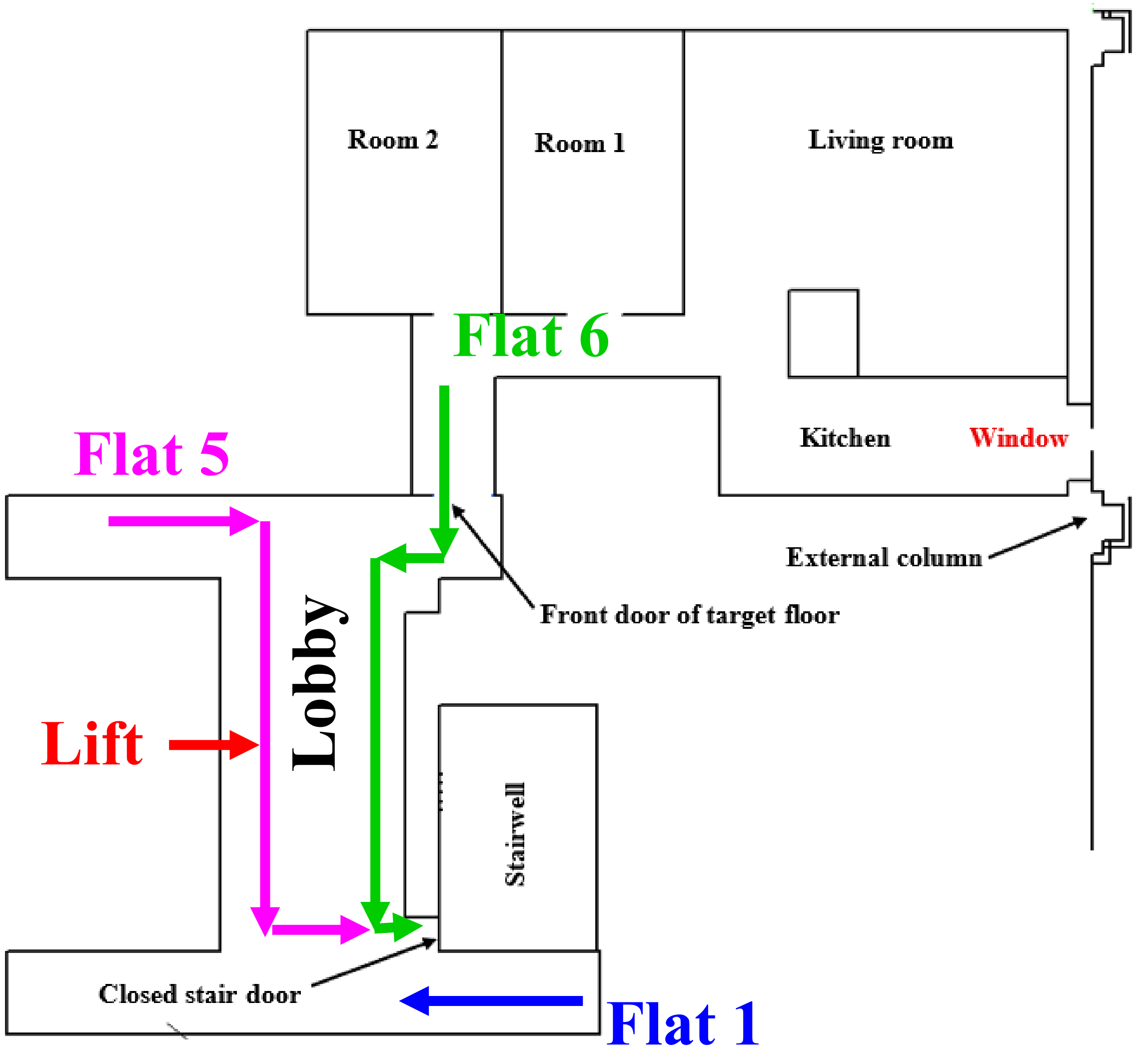


Events on a Typical Floor in GT Fire

GT fire Floor 10 (timings based on Purser, 2025)

- No internal fire in Flat 6. Some occupants on this floor failed to evacuate early and became trapped by dense smoke in the lobby.
- **Flat 6:** occupants left their flat at **01:23** as it filled with smoke, leaving the Flat6 door open (F6DO).
- **Lift:** 3 people enter lobby from lift around **1.5-2min** after F6DO (~ **01:24:30)**. They all died in the lobby due to inhalation of toxic gases.
- **Flat1:** occupant evacuated with difficulty **8min** after F6DO (~ **01:31)**.
- **Flat 5:** occupant evacuated **23min** after F6DO (~ **01:46).** They collapsed at stair door and was assisted by others.
- Occupants in other flats on this floor were trapped in their flats for hours.

What smoke and toxic gas conditions did these people experience when evacuating?



Layout of Floor 10 and evacuation paths

Cladding fire modelling and model validation

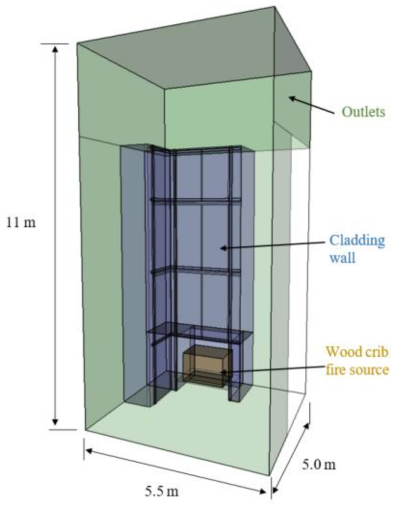
e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

BS8414 SMARTFIRE CFD Fire Model

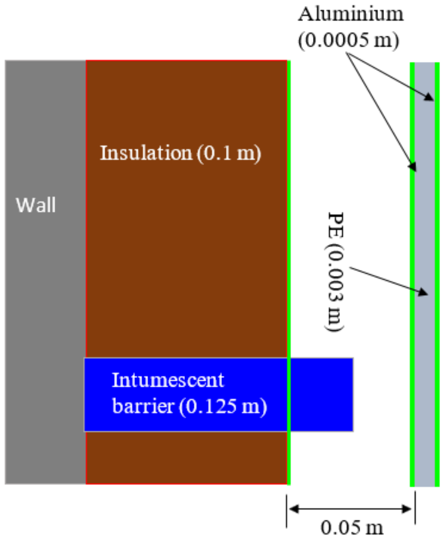
The fire model is developed by FSEG using SMARTFIRE [Wang et al., 2025; 2026]

- Computational domain 5.5 m × 5.5 m and 11 m high (adjustable). Ignition criteria include:
    - For ACM surface, ignition temp set to 550 ^{O}C for all core materials with ignition temperature below this value (e.g.. PE, FR PE). Temp corresponds to value at which aluminium loses its strength.
    - For ACM exposed edge, ignition temp set to maximum of 480 ^{O}C and core material ignition temp.
        - Value determined by calibration from CFD simulation.
    - Flame spread rate (from experiments) (this criterion has negligible impact for the DCLG test simulations)
- Burning rate: once a cell is ignited, it releases gaseous fuel based on cone calorimeter data

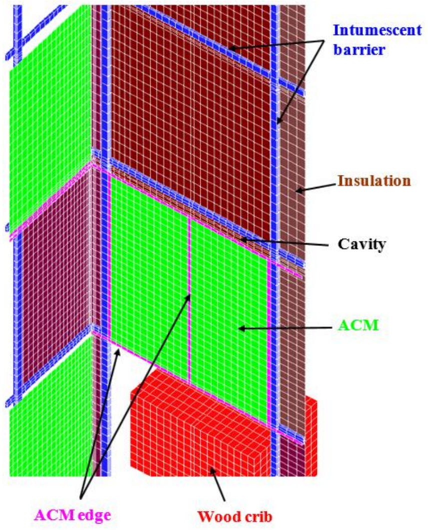
BS8414 CFD simulation domain



Side view of the cladding system (element size adjustable)



Details of ACM panel, insulation and barriers



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http://fseg.gre.ac.uk
University of Greenwich

Validation Using FPA BS 8414 Test Data

Assumption

As the toxic gases in the FPA tests are extracted via a vent within the cladding system (see the right figure), it is assumed the combustion of the wood crib is at well-ventilated conditions, while the combustion of the ACM panel and the insulation material are at under-ventilated conditions.

Governing Equations

$$\frac{\partial \rho Y_i}{\partial t} + \nabla \cdot (\rho \vec{U} Y_i) = \nabla \cdot (\rho \Gamma \nabla Y_i) + S_{Y_i} \qquad (1)$$

- i stands for burnable materials including wood, ACM core and insulation.
- Y_i is the fraction of mass i which is generated from material i.

Gas mass fraction contributed from combustion of individual materials

$$Y^{CO} = \sum_i Y_i y_i^{CO} \qquad (2)$$

$$Y^{CO2} = \sum_i Y_i y_i^{CO2} \qquad (3)$$

$$Y^{HCN} = \sum_i Y_i y_i^{HCN} \qquad (4)$$

$$Y^{H2O} = \sum_i Y_i y_i^{H2O} \qquad (5)$$

$$Y_{O2} = A(1 - \sum_i Y_i) - \sum_i Y_i Y_i^{O2} \qquad (6)$$

- y_i^j is the yield of species j (CO, CO_2, HCN, etc.) under the combustion assumptions described above (consumption for O_2) derived from tube furnace data.
- A is the ambient mass fraction of O_2.

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

Fire Model Summary

The SMARTFIRE CFD fire BS8414 model produces:

- **Key test data and fire behaviour consistent with the current requirements of the BS 8414 protocol including:**
  - the temperature profiles, as a function of time, at individual locations
  - the developing fire plume as a function of time
  - the final state of damage of the cladding system including the burn through regions etc.
  - a pass/fail result for the cladding system with the cause identified
- **Additional quantification of relevant fire behaviour including:**
  - the HRRs for each material component of the cladding system such as the ACM panel
  - the lateral and vertical flame spread rates of the cladding system
  - the burning/burnt-off locations of the ACM panel and insulation, as a function of time
  - the activation state of barrier intumescent strips, as a function of time
  - the toxic gas generation resulting from burning of cladding/insulation materials

- Model validated using 7 DSLG BS8414 fire tests (for a variety of ACM/insulation materials)
- Toxic gas generation validated using 2 FPA BS8414 fire tests (ACM-A2/PIR and ACM-PE/PIR)
  - One 30 min simulation requires an average of 95 hrs for a mesh consisting of 642,600 cells.

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

Validation Using DCLG BS 8414 Test Data

Pass/fail results and fail causes [Wang et al., 2025]

- The BS 8414 model correctly reproduced both the pass/fail results for all seven DCLG BS 8414 tests;
- The model correctly identified the failure causes (i.e. **Criterion 3**: flame spread extending above the test apparatus at any time during the test duration) and approx failure time.

DCLG test	Cladding materials	Experiment	Simulation
1	PE; PIR	Fail due to Criterion 3 at approx 360s	Fail due to Criterion 3 at approx 360s
2	PE; Stone wool	Fail due to Criterion 3 at 275s	Fail due to Criterion 3 at approx 360s
3	FR PE; PIR	Fail due to Criterion 3 at approx 1390s	Fail due to Criterion 3 at approx 1310s
4	FR PE; Stone wool	Pass	Pass
5	Limited combustibility mineral core; PIR	Pass	Pass
6	Limited combustibility mineral core; Stone wool	Pass	Pass
7	FR PE; Phenolic insulation	Fail due to Criterion 3 at approx 1525s	Fail due to Criterion 3 at approx 1360s

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
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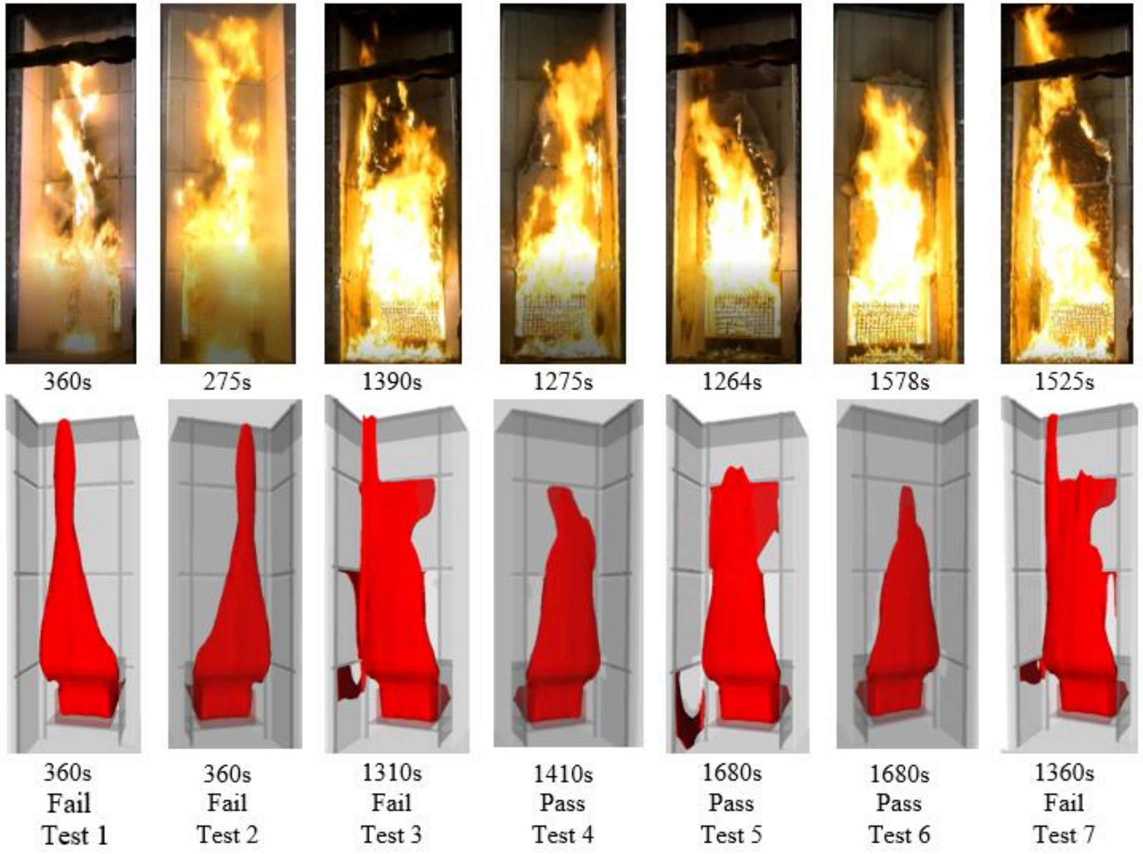
Validation Using DCLG BS 8414 Test Data



- Observed and simulated flames (simulated visible flame envelopes are defined using a 525 ^{O}C temp iso-surface), at the time to fail or the maximum height (if cladding system passes the test)

- Burnt off ACM panel in the experiments and the predictions (white area) (red dots represent actively burning locations)

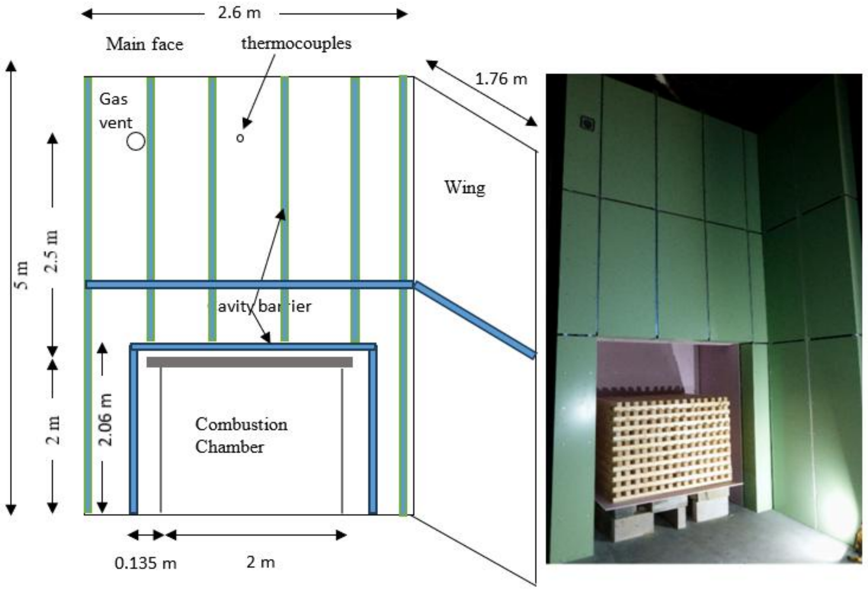
Validation Using FPA BS 8414 Test Data

Key Assumption [Wang et al., 2026]

- As the toxic gases in the FPA tests are extracted via a vent within the cladding system (see the right figure), it is assumed **the combustion of the wood crib is at well-ventilated conditions**, while the **combustion of the ACM panel and the insulation material are at under-ventilated conditions**.

Vent Extraction

- Measured extraction rate applied as inlet condition
- Monitored gases from outside and inside the cavity – limited by cavity barriers



Schematic of test facility and the finished cladding panels

Yields of toxic gases (based on the above assumptions)

		Wood (Hansen-Bruhn et al. 2023)	PE (McKenna S.T., 2019)	Stone wool (A2) (McKenna S.T., 2019)	PIR (McKenna S.T., 2019)
Yield (kg/kg)	CO	0.007	0.14	0.005	0.316
	CO_2	1.64	1.594	0.031	0.549
	HCN	0	0	0	0.0142

Computational cost

- One simulation requires an average of 95 hrs, for a mesh consisting of 642,600 (100×63×102) cells;
- PC: 4.5 GHz 10-core processor and 128 GB of memory

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e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

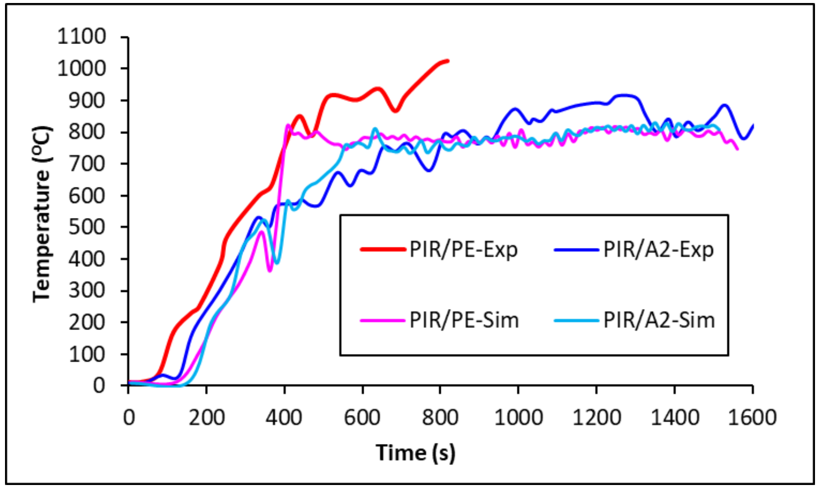
Validation Using FPA BS 8414 Test Data

Temperature profiles

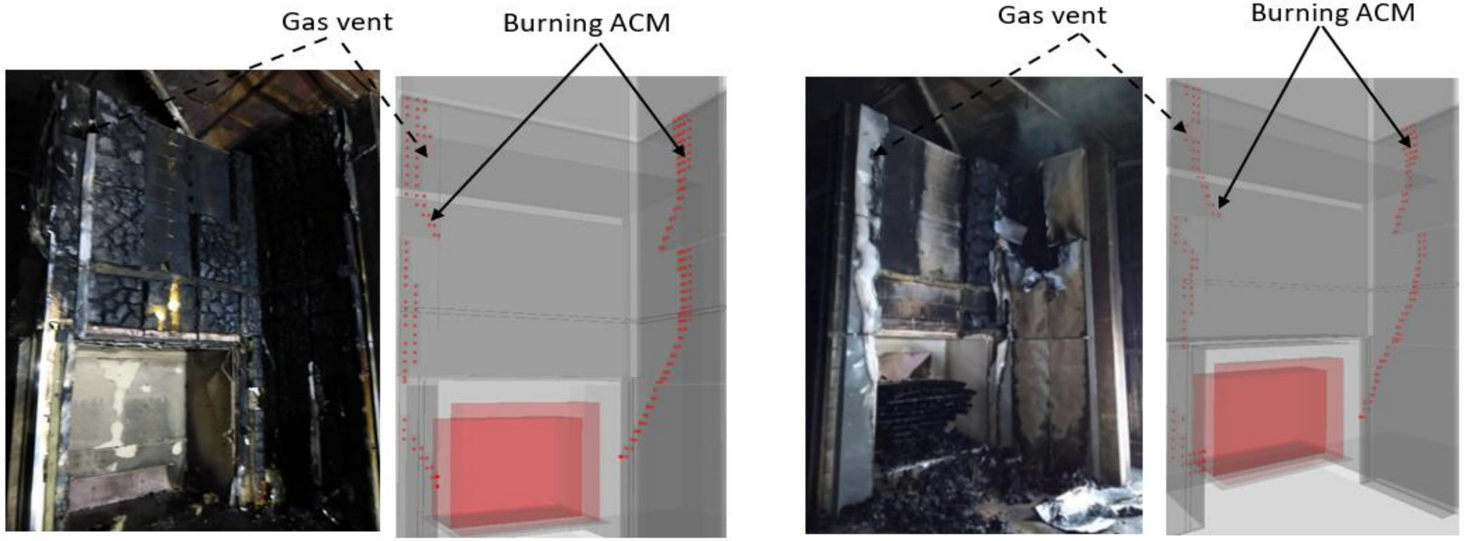
- The PIR/PE test was extinguished at 810 s for safety reasons;
- The predictions of temperature generally in good agreement with the measured data for the two tests.

Burnt off ACM panels

- For the PIR/PE test, while the ACM on virtually all of the wing wall was consumed in the fire experiment, only approximate half of the wing wall is burnt off at the time when the fire was extinguished in the simulation.
- The predicted burnt off locations on both the main wall and the wing wall for the FPA PIR/A2 test are comparable with that observed in experiment



Measured and predicted temp at thermocouple location 0.05 m in front of the cladding



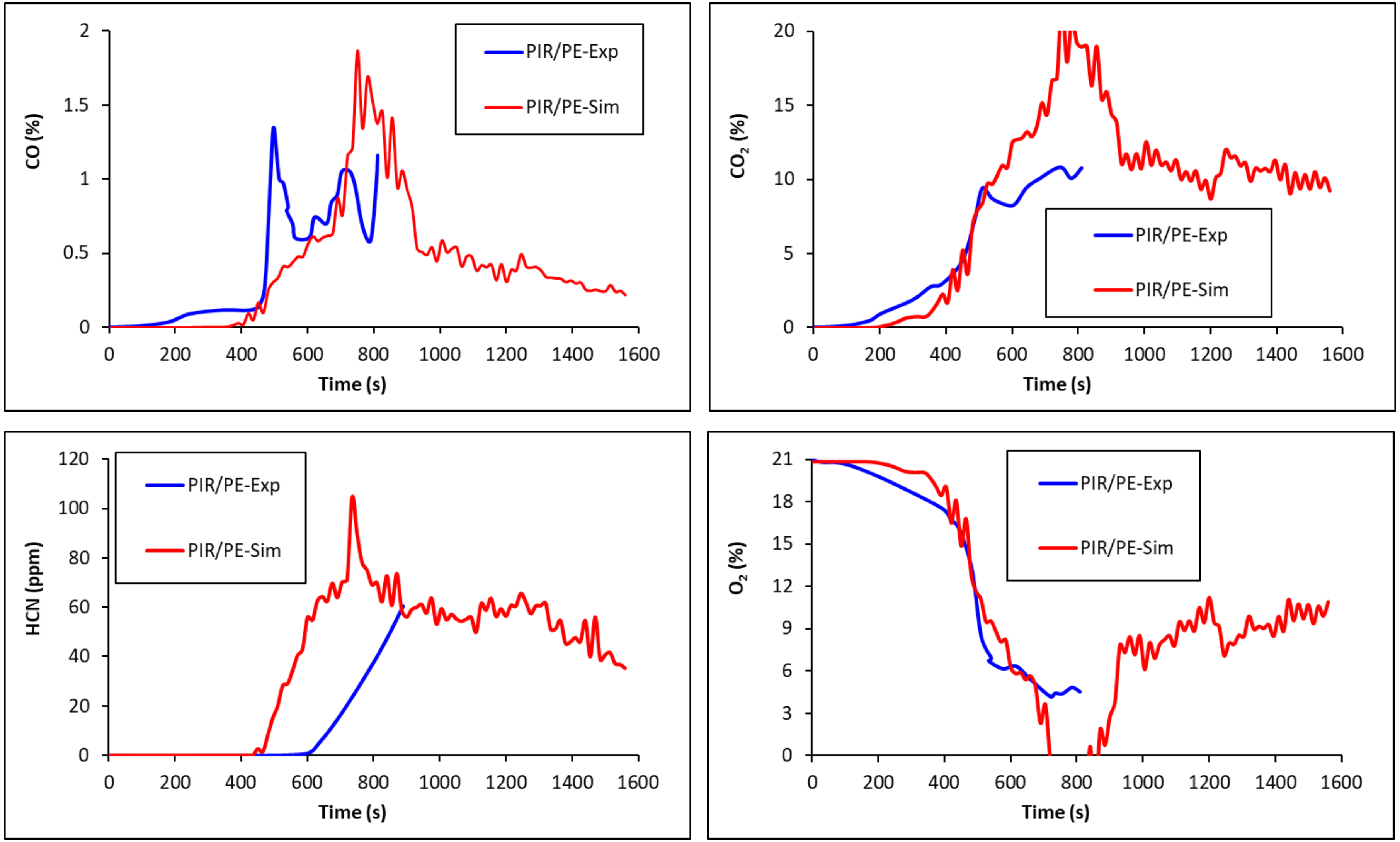
Observed damage of the PIR/PE (left) and PIR/A2 (right) cladding system and the predicted burning ACM (red dots) at the end of simulation.

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

Validation Using FPA BS 8414 Test Data

Gas concentrations in PIR/PE test

- The PIR/PE test was extinguished at 810 s for safety reasons;
- The predictions of gas concentrations generally follow the measured trends.
- Predicted HCN occurs earlier than measured, possibly due to the measuring process.



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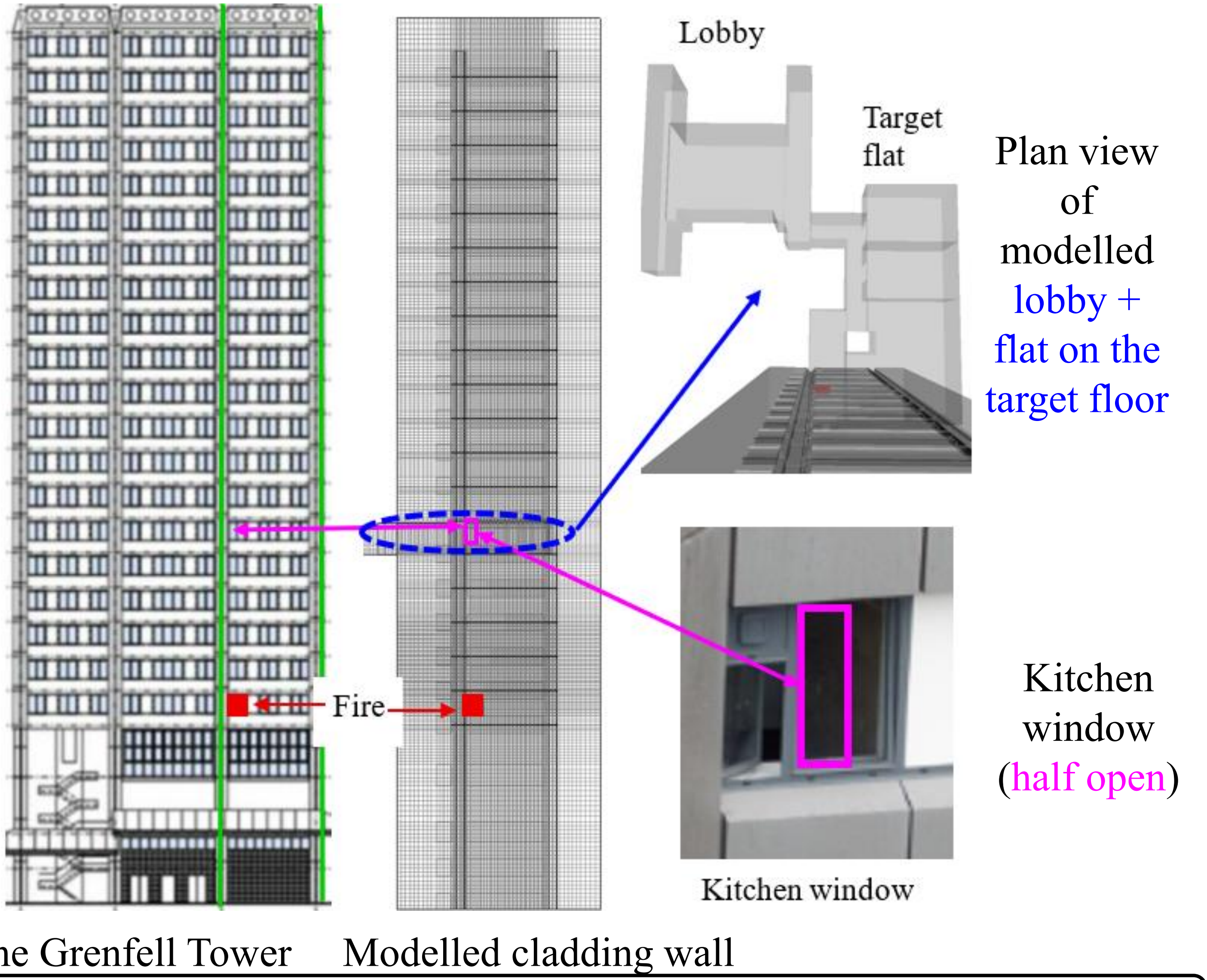
Model application to tenability analysis for a high-rise building subjected to an external cladding fire

Simulating toxic gas concentration within a High-Rise building due to external cladding fire

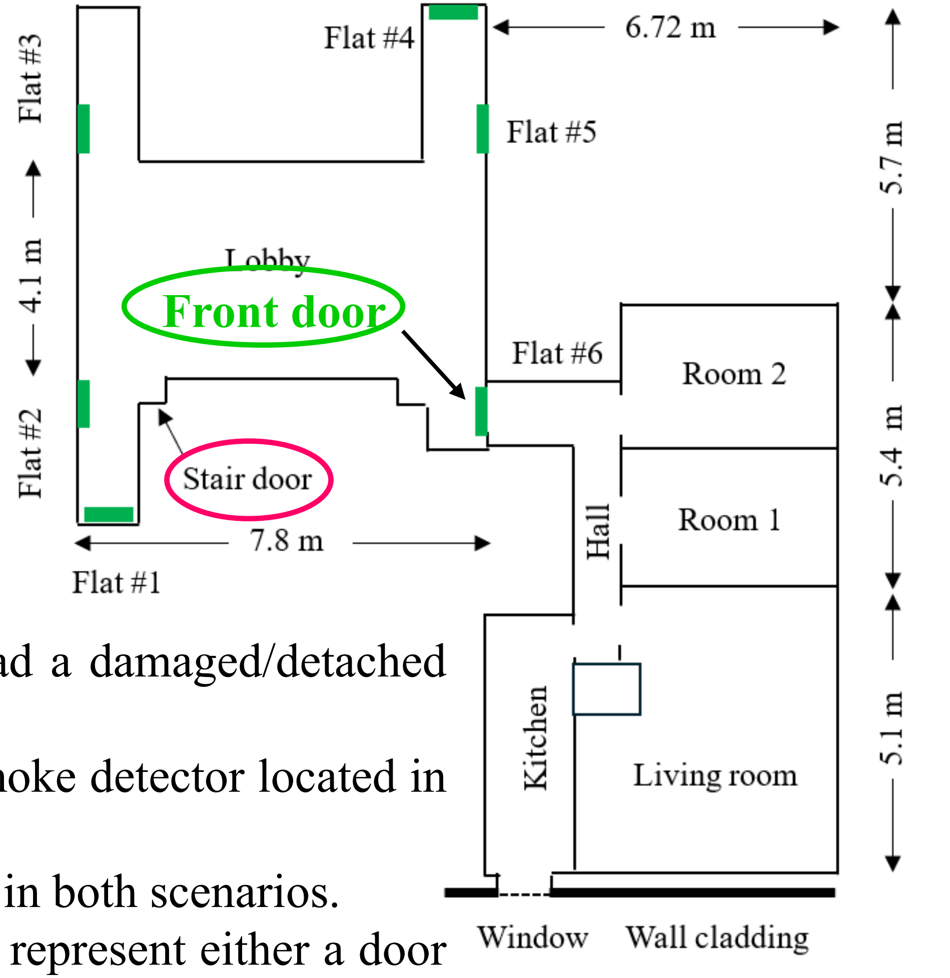
- High-rise building demonstration using a section of a building similar to Grenfell tower (PE ACM, with PIR insulation).
- A fire source of 1 MW located at a kitchen window of a lower corner flat is applied for 240 s.
- An external wind with components of 1.0 m/s normal to the window and 0.5 m/s from left to right is adopted.
- Species concentrations in a target flat and associated communal lobby **5 floors** above the fire floor (i.e. floor 9) are monitored.
- The large kitchen window of the target flat is assumed to be half open (**worse case scenario**).



e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

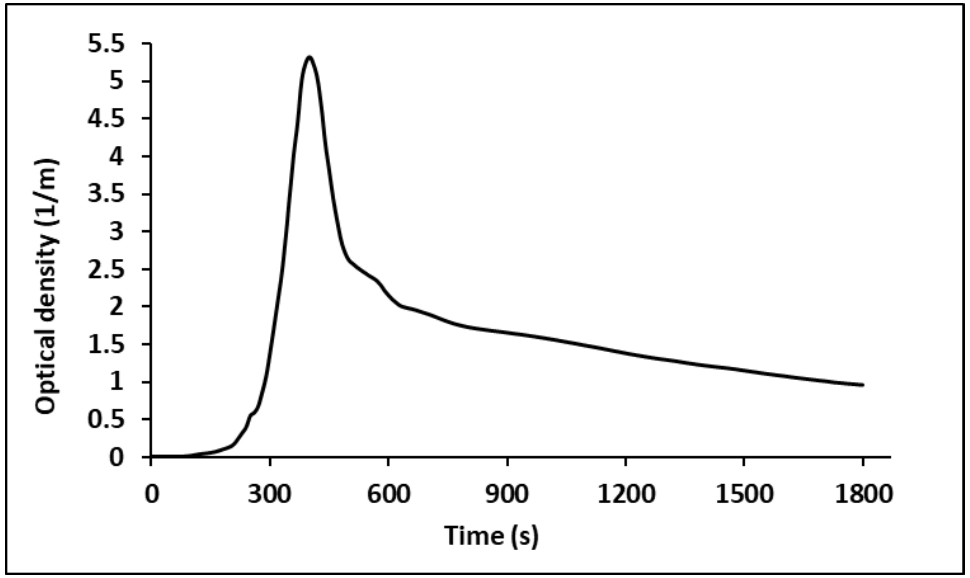
High-Rise Building Cladding Fires - Scenarios

- **Target floor:** the target flat is similar to Flat 6 of GT including room dimensions. However, communal lobby is wider i.e., 4.1 m c/w approximately 2.6 m in GT.
- **Flat door opening scenarios:**
  - **Scenario D1:** the front door of the target flat is assumed closed throughout the simulation, with door leakage via 0.003 m gaps along the four edges of a 0.8 m × 2.0 m door (0.02 m^2).
  - **Scenario D2:** the front door is initially closed (with leakage as defined in Scenario 1) but is opened at 200 s (for evacuation) and remains open for the remainder of the simulation.
- **Assumptions:**
  - In D2 the flat door is either wedged open during the evacuation or had a damaged/detached automatic door closer, known to be an issue in the Grenfell Tower fire.
  - Time to open flat door in D2 is based on the likely time to activate a smoke detector located in the flat hall derived from the D1.
  - All the flat internal doors, including the kitchen door, are assumed open in both scenarios.
  - The stair door is partially open with area of 0.1 m^2 in both scenarios to represent either a door wedged open by fire hose or the open/close effect due to evacuation.
- **Computational cost:** Simulation domain 1 million cells; PC: 4.5 GHz 10-core processor and 128 GB of memory; A 30 min fire simulation requires 70 hrs using research version of SMARTFIRE.

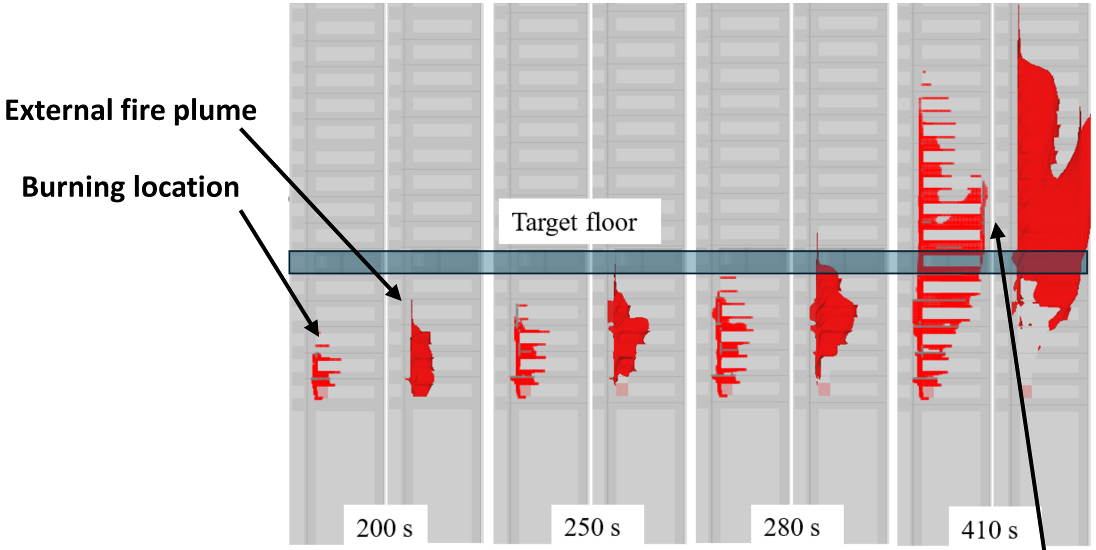


Layout of the lobby and flat rooms

External Cladding Fire Spread and Optical Density within Target Flat



Flat hall optical density in Scenario D1



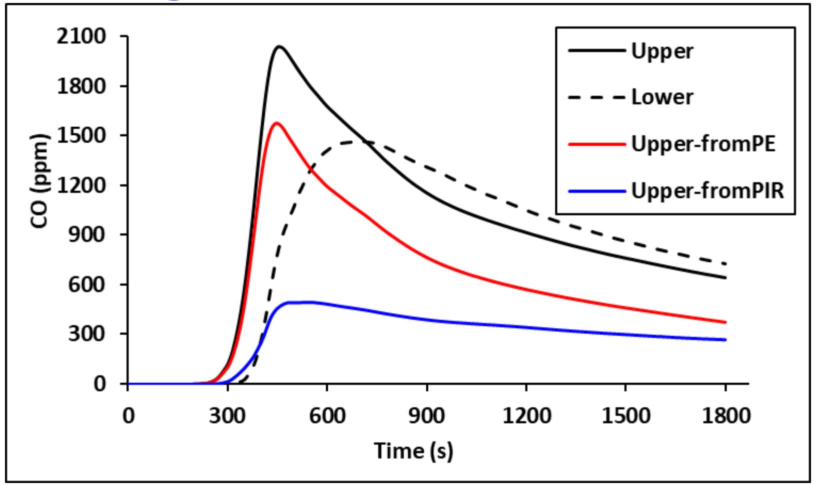
Scenario D1: Left Images: burning location and Right Images: fire plume (represented by 798K temp iso-surface) at key times

- The **optical density (OD)** in the UL of flat hall reaches 0.135/m (visibility distance of approx. 6m) at **200 s**.
  - Given this OD, most domestic smoke detectors are likely to activate, and if not, occupants confronted with this reduction in visibility are likely to decide to evacuate.
  - The door opening time for D2 (i.e., 200 s) is based on time to reach this OD.
- At **200 s**, the fire plume is two floors below the target flat.
  - This suggests the smoke concentration in flats above the fire floor, assuming a kitchen window is open (and a gentle wind), will be sufficiently high to alert flat occupants to evacuate **80 s** before the external fire arrives at approx. **280 s**
- The peak OD of 5.3/m (0.2m min visibility) occurs at **410 s**, with external fire extending many floors above target floor

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

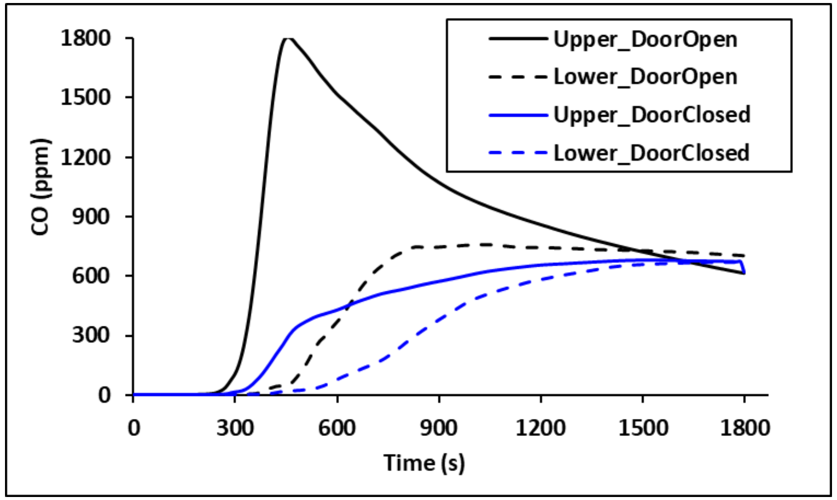
Predicted Toxic Species on the Target Floor

- **Target Flat**
  - **Temperature Peak Room1**: UL 68 ^{O}C (440s); LL 35 ^{O}C (520s); the max radiative flux is 0.7 kW/m^2.
  - **CO Peak Room1:** UL 2037 ppm (450s); LL 1464 ppm (190s).
  - The majority of the CO in Room1 is generated by the burning PE (approximately 77%), not PIR.



Room 1 CO concentrations in D1

- **Lobby CO Peak Concentration**
  - **(D1) When flat door is closed:** UL 683 ppm; LL 671 ppm.
  - **(D2) When flat door is open:** UL 1800 ppm (460s); LL, 758 ppm (1030s).



Lobby CO concentrations in D1/D2

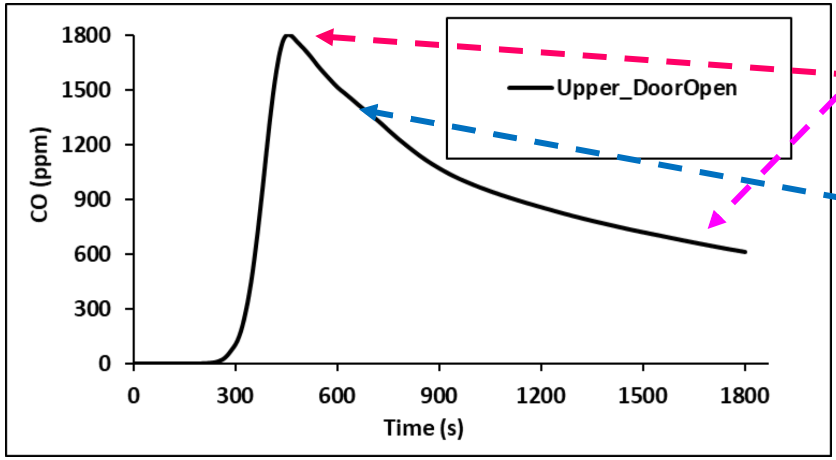
- **Upper Layer (UL):** defined as 1.5m – 2.0 m
- **Lower Layer (LL):** defined as 0.5m – 0.8 m

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

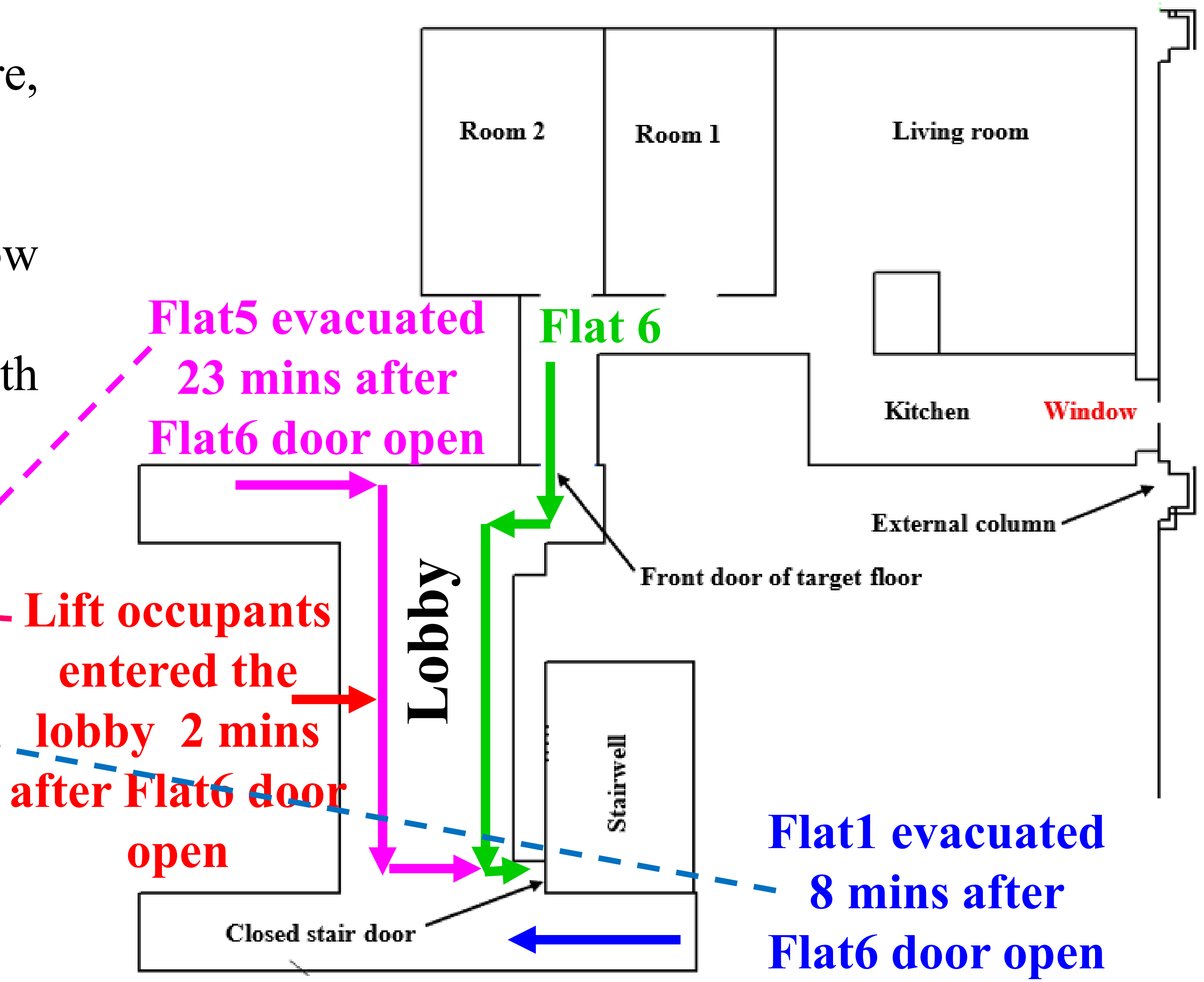
Events on a Typical Floor during GT Fire

GT fire Floor 10 evacuation analysis

- The three people from the **lift** on Floor10 in GT fire, were likely exposed to the peak CO in lobby.
    - 1800 ppm CO → incapacitation in 15 mins
    - However, note that HCL (from burning window surrounds and PIR) not included in analysis.
    - Incapacitation likely occurs sooner with instantaneous exposure to high level of HCl.
- **Flat 5** occupant likely missed the peak CO in lobby.



Predicted lobby CO in Scenario with flat door open



Layout of Floor 10 and evacuation paths

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
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Predicted Tenability on the Target Floor (Floor9)

location	FIN	Duration	FICO (PE+PIR)	FICO(PE)	FICO(PIR)	FIHCN (PIR)	FIN(PIR)/FIN(PE)
Flat6 UL	1	1280 s (21.3 min)	0.84	0.59	0.25	0.02	0.46
Flat6 LL	1	1520 s (25.3 min)	0.86	0.60	0.26	0.02	0.47
Flat6 sleeping	0.36	1600 s (26.7 min)	0.3	0.2	0.10	0.01	0.55
lobby UL	1	1510 s (25.2 min)	0.85	0.64	0.21	0.01	0.34
lobby LL	0.57	1600 s (26.7 min)	0.52	0.36	0.16	0.01	0.47

- **FIN** (the fractional incapacitating dose); **UL** (upper layer); **LL** (lower layer).
- In this analysis, Time 0 = fire alarm activation i.e., 200 s after the start of the external fire.
- **In Flat 6:**
  - A standing/crawling male (RMV 25 l/min) is incapacitated in **21.3 min/25.3 min**.
  - A sleeping male (RMV 8.5 l/min) acquires an FIN of 0.36 after 26.7 min.
- **In Lobby:**
  - A standing person is incapacitated in **25.2 min**, and if crawling, their FIN will reach 0.57 after 26.7 min.
- The contribution to the overall FIN from PIR is between 1/3 and 1/2 that of the ACM/PE
- The fractional incapacitating dose of HCN (FIHCN) contributes less than 5% of the total FIN
- Tenability is limited by the opening size of the kitchen window (and the burning of window surroundings).

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

Potential Impact of a Lobby Smoke Control System (LSCS)

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
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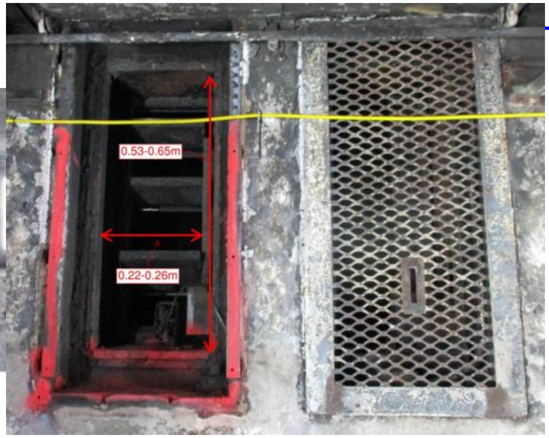
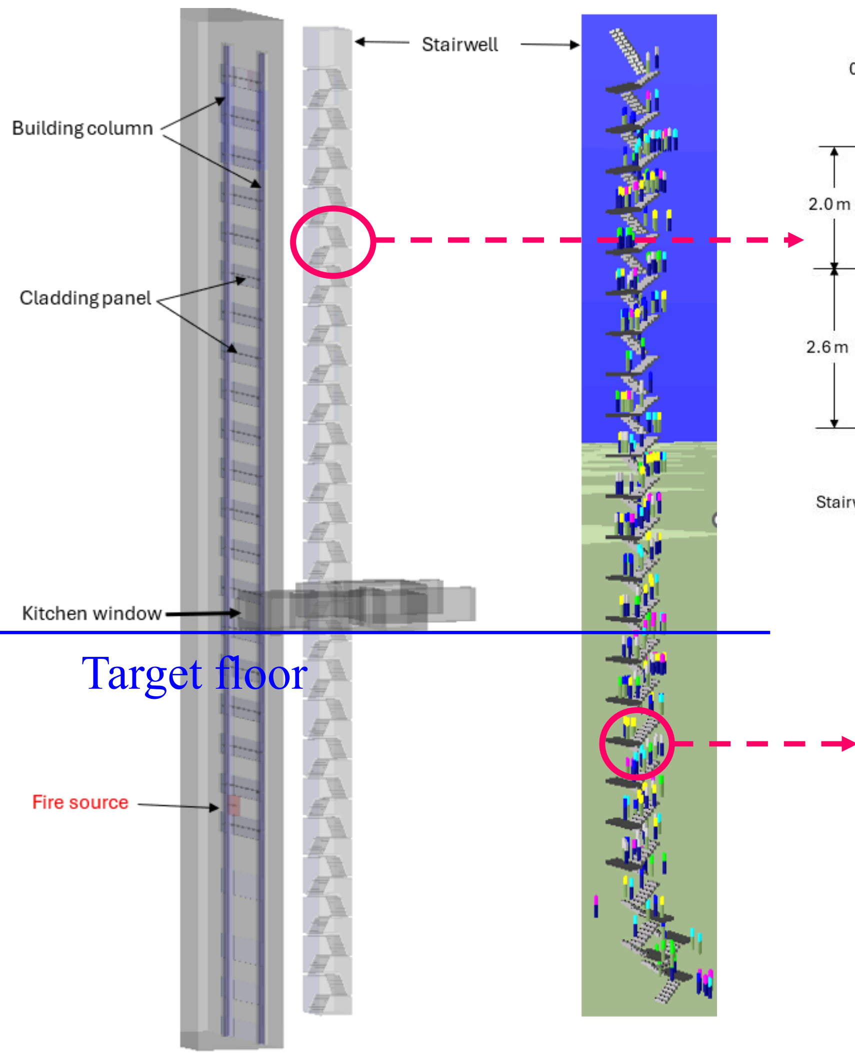
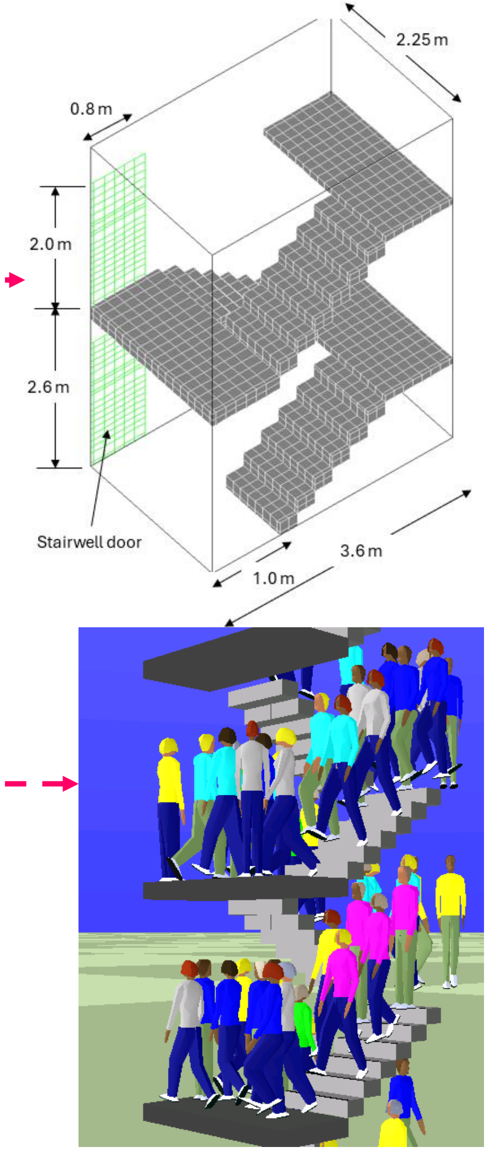
Impact of a Lobby Smoke Control System

- The lobby width in this study is reduced from 4.1 m in previous Scenarios D1 and D2 to 2.6 m to better represent GT.
- The lobby stair leakage is assumed to be 0.1 m^2, representing a partially closed door (e.g. obstructed by fire hose or representative of people occasionally opening/closing door)
- In GT, there are four (inactive) smoke vents with top two for air supply and lower two for air extraction.

Lobby vents in GT (were not active during the GT fire, Lane, 2018)





Modelled cladding wall, target floor and stairs (left) and stair for evacuation analysis

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
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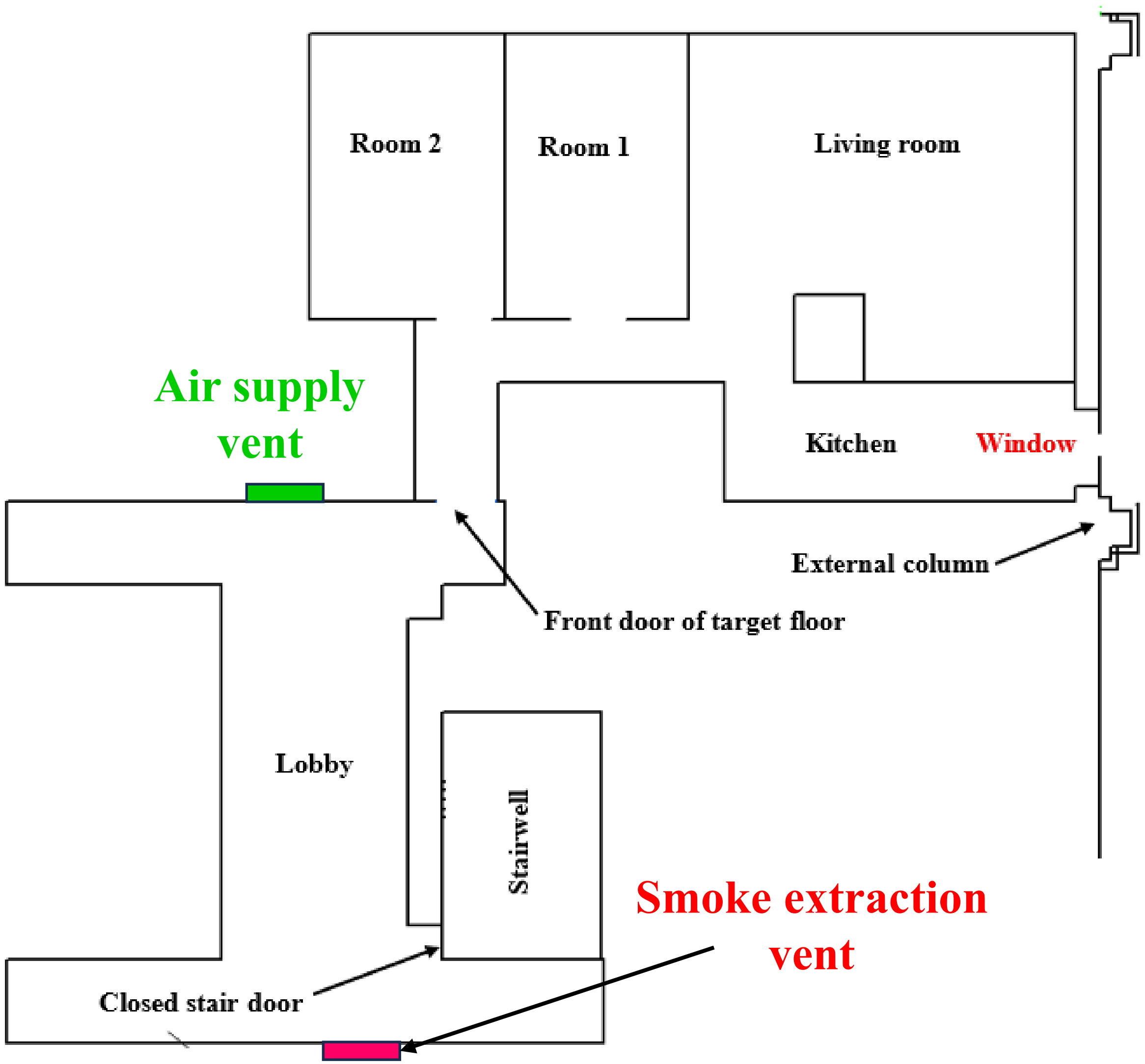
Impact of a Lobby Smoke Control System - Scenarios

Four lobby smoke control system (LSCS) scenarios

- **Scenario S1**: i.e. Scenario D2 with the flat door open at 200 s, with the partially open stairwell door and with a reduced lobby size;
- **Scenario S2**: The same as Scenario S1 but with GT vent locations (effective free area of 0.25 m^2 each, with the overall area of 0.48 m^2) with the bottom vent for smoke extraction) in the Lobby. The air extraction rate is 1.5 m^3/s.
- **Scenario S3:** The same as scenario S2 but with inlet and extract vents located in the upper level.
- **Scenario S4:** The same as scenario S3 but with half the assumed smoke extraction rate, i.e. 0.75 m^3/s.

NOTE1: the effective vent size may not be compliant with this artificial extraction rate in this demonstration.

NOTE2: Assume manual intervention starts smoke extraction at 320 s (5.3 min) after fire starts, i.e. 120 s after the flat 6 door is opened.



Top view of the modelled target flat, lobby and stairwell

Impact of a Lobby Smoke Control System – OD on Target Floor and Stairs

Conditions in Flat6

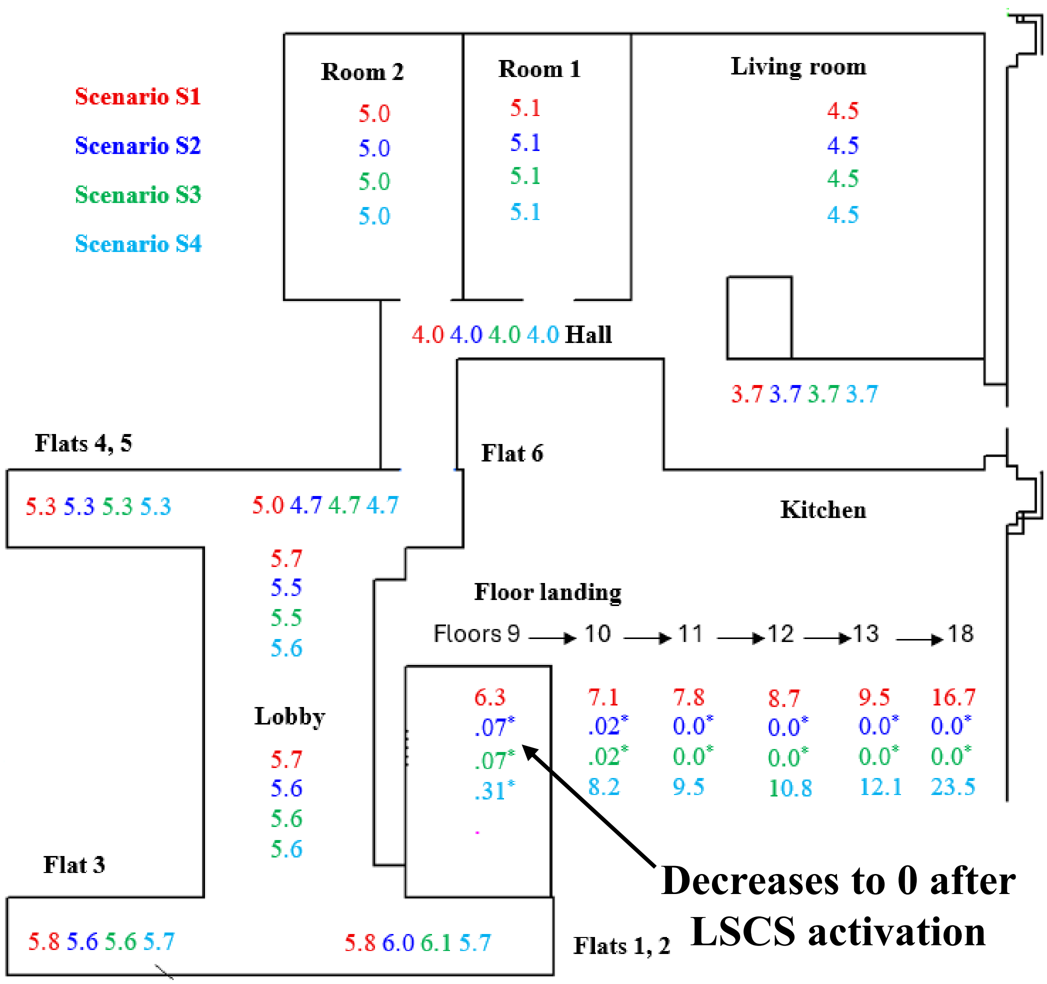
- With the flat door open, LSCS has no impact on the time for Flat6 UL OD to reach 0.5/m - times from 3.7min in kitchen to 5.1min in Room1.

NOTE1: LSCS activated at 5.3 min.

NOTE2: An OD of 0.5/m = 1.7m visibility distance

Conditions in the Lobby and Stairs

- Opposite lifts, LSCS has a minor impact on the OD, with time to reach 0.5/m reduced from 5.7min to 5.5min or 5.6min regardless of scenario.
- In **S1** without LSCS, the OD on Floor9 landing reaches 0.5/m at 6.3 min, and on Floor18 at 16.7 min.
- In **S2** and **S3**, the LSCS effectively prevents the smoke from entering the stairs, resulting in very low OD on the stairs from floor9 to floor18, regardless of location of extraction vent, i.e. bottom (**S2**) or top (**S3**).
- In **S4,** with reduced smoke extraction rate (0.75 m^3/s), although the max OD on the stairs of Floor9 is 0.31/m (the average value of the UL and LL for floor landing), the time to reach 0.5/m on higher floors is 8.2min for floor10 and 23.5min for floor18.
  - LSCS with 0.75 m^3/s extraction rate of cannot prevent smoke from spreading up the stairs beyond one floor, impacting evacuation.
  - Visibility in stairs in **S4** only marginally better than S1



Time (min) for optical density to reach 0.5/m.
Data with * indicates max OD within 30 min

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

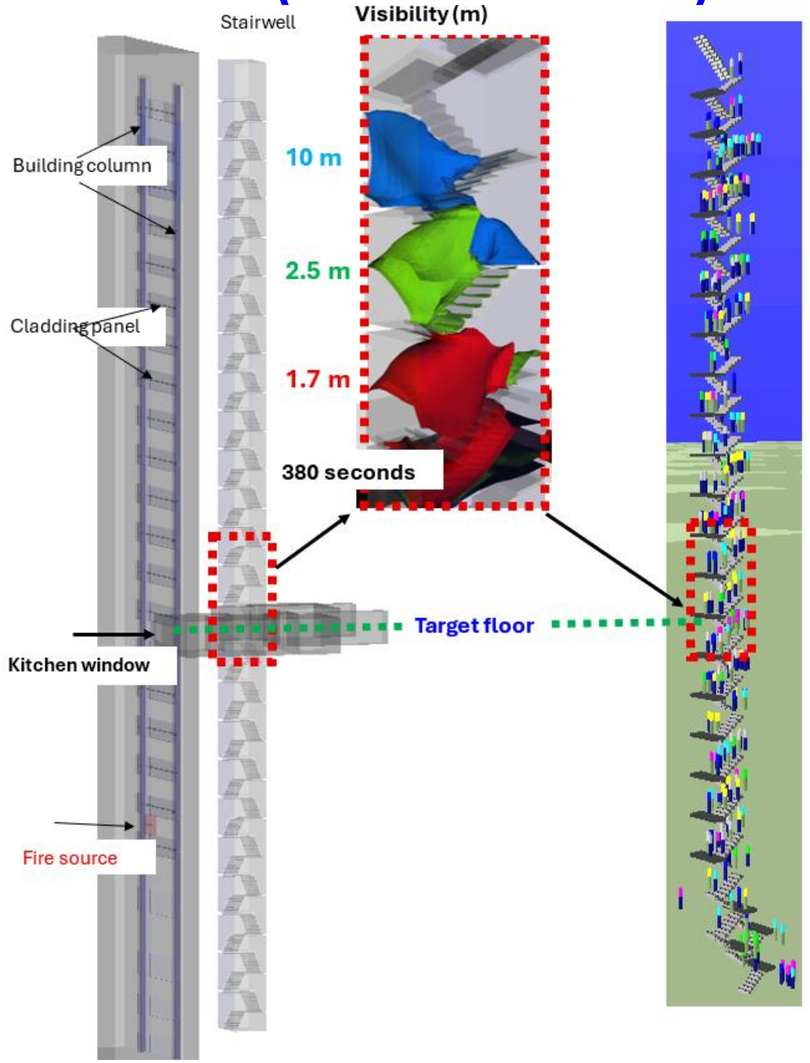
Impact of reduced visibility in stairs and lobby – Scenario S1 (without LSCS)

STAIRS:

- Visibility distance on Floor9 landing < 1.7 m at 378 s (6.3 min), measured from the start of the external fire.
- On the stairs, smoke obscuration (i.e., visibility distance) constrains safe evacuation.
- To safely evacuate, occupants from the 10th floor and above, must descend past Floor9 landing before 378 s.

FLOOR9 LOBBY:

- By around 5.7 min visibility in the lobby < 1.7m, this is 2.4 min after Flat6 door is opened.
  - Potentially explains evacuation difficulties of occupants from Flat1and Flat5
  - Lift occupants enter lobby at time of peak CO concentration and almost zero visibility.
- (UK (Woods 1972, 1990) and USA (Bryan 1977, 1996) studies show - 91% and 76% respectively, of study sample turn back when visibility < 4m)



Visibility (m) on the stairs at Floor9 and the two floors above

Impact of a Lobby Smoke Control System – FIN/FIH on Target Floor and Stairs

Conditions in Flat 6

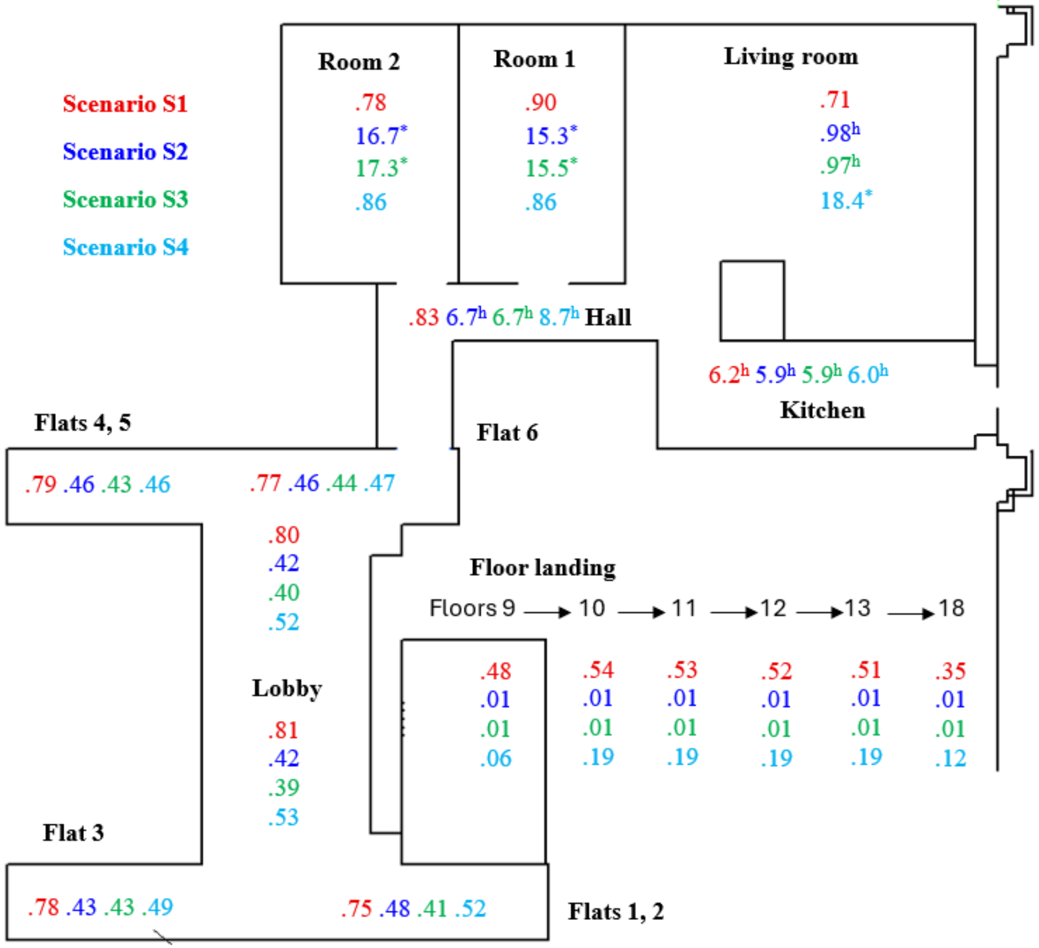
- Incapacitation times and FIN/FIH worse with LSCS due to smoke being drawn into flat by LSCS, but occupants have safely evacuated after 200s (which is why flat6 door is open).
- Incapacitation in kitchen and hall are due to heat exposure, other rooms due to toxic gases.

Conditions in Lobby and Stairs

- No incapacitation in lobby and stairs for 30 min exposure

NOTE: we assume occupants exposed to LL if the UL OD > 0.5/m.

- Toxic gas inhalation main hazard in lobby and stairs
- The LSCS can reduce FIN in the lobby by up to 50% for 30 min exposures, but FIN still very high, suggesting hazardous conditions.
  - **S3** (top) produces marginally better conditions than **S2** (bottom)
- In **S1**, max FIN for 30 min exposure without LSCS on stairs peaks at 0.54 for floor10 decreasing to 0.35 for floor18.
- In **S2** and **S3**, as LSCS prevents smoke from entering stairs, FIN values of only 0.01.
- In **S4**, with an airflow rate of 0.75 m^3/s LSCS cannot completely prevent smoke from spreading up stairs, generating FIN values of 0.19 on floor10 decreasing to 0.12 on floor18.



FIN values for 30 min exposure and incapacitation time* and (FIH values and associated time to incapacitation)^h

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich

Limitations

- The tenability assessment in this study is limited to the fire hazards resulting from **the combustion of the external cladding** and does not include the compartment fire which is likely to occur later. Once a compartment fire is developed, the fire hazards in the lobby are impacted by effluents from both external and internal fires.
- It is assumed that the external fire effluent entrained into the building enters the building via a half-open kitchen window.
- It is assumed that the combustion of the ACM panel and the insulation material are burning in **under-ventilated conditions**. While this assumption is validated using BS 8414 tests data, the model would benefit from experiments including the representation of a second-floor partially open window for the measurement of toxic gas concentrations.
- In the open flat door scenario (D2), the predicted lobby tenability (25 minutes) is longer than that suggested by Professor Purser for the Grenfell fire (2025). This is likely due to **simplifications** in the model including:
    - The penetration of the external fire effluent is only via a partially open kitchen window. Other 'leakage' routes, such as rapid burn-throughs due to poor construction and failed glazing at other windows will impact tenability.
    - Irritant gases such as HCl produced by burning window surrounds are not included in this study.
    - The modelled lobby area is larger than that of the Grenfell Tower.
- Leakage rates from the stair door into the staircase were represented as a small constant opening. This was assumed to represent either a door wedged open by fire hose, or alternatively, to represent the opening/closing of the door during evacuation. This assumption should be explored using a sensitivity study.
- The impact of mechanical smoke extraction rates and activation time should be explored using a sensitivity study.

Concluding Comments

- The SMARTFIRE cladding fire model has been **validated** using data from seven DCLG BS 8414 tests and its capability to predict toxic species has been validated using data from two FPA BS 8414 tests.
- The model was used to **assess tenability** for a hypothetical high-rise clad as in GT. Conditions within Flat6 and the communal lobby located 5 floors above the initial fire are assessed. Smoke from the external fire enters via a half-open kitchen window.
    - o Smoke concentration within Flat6 is sufficiently high to set off a domestic smoke detector after 200 s, alerting Flat6 occupants to evacuate when the external fire is at least two floors below the target floor.
    - o If Flat6 occupants commence their evacuation shortly after hearing alarm, they are likely to be able to safely evacuate through lobby, irrespective of the status of flat door after they exit Flat6. However, if their evacuation is delayed by 21 min, they will be incapacitated due to the inhalation of toxic smoke produced by the external cladding fire alone.
    - o The FIN contribution from PIR to overall FIN within Flat6 is ~ 1/2 that of ACM/PE and from ~ 1/3 to 1/2 in the lobby.
    - o The HCN (from the PIR) contribution to the FIN is minor < 5%.
- Predicted conditions on floor9 provide some insight into conditions faced by GT occupants on a similar floor:
    - Flat5+1 occupants would have difficulties evacuating due to near zero visibility in lobby from 2.4min after F6DO.
    - Lift occupants would have arrived into lobby at around time of peak CO concentration and near zero visibility.
    - Lack of visibility on stairs constrains evacuation for those above floor9, and in lobby
- A mechanical **smoke control system** in the lobby with an air extraction rate of 1.5 m^3/s, if activated sufficiently early:
    - Makes little difference to the visibility in lobby, making evacuation challenging, but reduces FIN by 40%.
    - Does effectively prevent the toxic smoke from entering the stairs from the lobby making evacuation viable.
    - If the extraction rate is halved to 0.75 m^3/s e.g., operating the system over two floors, then it cannot completely prevent smoke spread to the stairs, reducing visibility and increasing toxicity making evacuation more challenging.

e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk
University of Greenwich