Horizon 2020

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Project full title: **Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**

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Coordinator: **RISE Research Institutes of Sweden**

Internal Report IR11.16

Hull Exposure Levels Above Openings and Limits for Unprotected Areas

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Abstract

There are current and proposed requirements in the SOLAS regulations regarding the safe distances from ro-ro openings to life safety appliances. There are however no requirements placed on the performance requirements for hull construction to accommodation (where people may be evacuating and assembly stations may be located) and control spaces (from where emergency response may be being coordinated) above a ro-ro opening. It is clear therefore that there is a missing element to the current regulations which will establish appropriate performance requirements for the hull construction above and adjacent to ro-ro openings and a safety distance for unprotected hulls.

The protection provided to these spaces by unprotected hulls has been assessed by way of a heat transfer analysis to establish a limit of exposure they can reasonably withstand without allowing fire spread or endangering occupants within the accommodation space. This limit was calculated tp ne a heat exposure (incident heat flux) of 5 kW/m^2.

This limit was then compared with data from calculations carried out in LASH FIRE and previous projects, as well as experimental data to estimate the exposure to hulls from fire plumes exiting ro-ro space openings. On the basis of this comparison, it is proposed that a zone extending 7 m above and 6 m horizontally from the top of ro-ro space openings is provided with protected hull construction. It should be noted that a number of assumptions have been made in the calculation and assessments within this report and no dedicated verification or validation testing has been undertaken. The results and recommendations contained within this report should therefore be used with caution and only where confidence that the assumptions are valid is high.

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No.	Short name	Full name of Partner	Name and contact info of persons involved
01	RISE	RISE Research Institutes of Sweden AB	Alastair Temple – alastair.temple@ri.se

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01	2023-02-23	Alastair Temple	Draft of report
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Contents

1 Executive summary

1.1 Problem definition

In addition to the safety requirements for the risks of smoke and fire spread from a ro-ro space opening preventing access to, or damaging life safety equipment as explored elsewhere in Action 11-C, there are areas of a ship such as that may be required to be continued to be used in a fire scenario. Currently there is no performance requirements for the hull of these areas and so if LSA is positioned above a ro-ro space opening, they may be exposed to high levels of heat and this could in turn hinder the response to the fire. The study documented in this report aims to assist in establishing an appropriate extent of protected area that should be designed in ship hulls above openings in ro-ro spaces to prevent this occurrence.

1.2 Technical Approach

This assessment uses a combination of heat transfer simulations conducted in the SAFIR (The University of Liege, 2011) finite element package with a review of data from the literature. The former to establish an exposure limit for unprotected hulls and the later to determine the exposure that can be expected above a ro-ro space opening, and therefore the extent to which protected hulls should be provided.

1.3 Results and achievements

Based on the heat transfer calculation an exposure limit of 5 kW/m^2 is concluded for unprotected hulls. Comparing this is limit to the exposure above openings in previous simulations and experiments from the literature a zone, where protected hull is required, of 7 m above and 6 m horizontally from any ro-ro deck opening is proposed.

1.4 Contribution to LASH FIRE objectives

This internal report contributes both to the objectives of the action 11-C and the objectives of the LASH FIRE project. The results can be used to support decision making and revision of internal IMO regulations. The results can also be directly used by end users and shipyards to guide design of ships and operations.

1.5 Exploitation and implementation

The results can be used to support decision making by regulatory and standardisation bodies and classification societies. End users and shipyards can also use the results to support design of ships and operations. In addition, the risk control measures identified in this work can be used to improve the fire safety of both new builds and existing ships.

2 List of symbols and abbreviations

1D	One dimensional
CFD	Computational Fluid Dynamics
CLT	Cross-laminated timber. An engineered timber product made from layers of timber with each layer at 90° to each other providing strength in two directions. Used to construct walls and slabs.
FDS	Fire Dynamics Simulator (a CFD package specifically designed for simulating fire and smoke).
FEM	Finite Element Modelling
HT	Heat transfer analysis
IMO	The International Maritime Organization
K	Degrees kelvin
LSA	Life safety appliances e.g. lifeboats, escape chutes, lifejackets etc.
Ro-ro space	Ro-ro spaces are spaces not normally subdivided in any way and normally extending to either a substantial length or the entire length of the ship in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or other receptacles) can be loaded and unloaded normally in a horizontal direction.
SOLAS	Safety of life at sea
VTT	Teknologian tutkimuskeskus VTT Oy

3 Introduction and Aims

Main author of the chapter: Alastair Temple, RISE

The analysis carried out within this report, IR11.16, is an expansion of the terms of WP11. There are current and proposed requirements in the SOLAS, discussed further in IR 11.7 and D11.4, regulations regarding the safe distances from ro-ro space openings to life-saving appliances (LSA).

There are however no requirements placed on the performance requirements for hull construction to accommodation (where people may be evacuating) and to control spaces (from where emergency response may be being coordinated) above a ro-ro space opening. It is clear therefore that there is a missing element to the current regulations which will establish appropriate performance requirements for the hull construction above and adjacent to ro-ro space openings and a safety distance for unprotected hulls. The aim of this report is to provide a reasonable estimation of the exposure to the hull construction from a fire plume ejected out of ro-ro space opening, and thereby establish a zone around these openings where some level of fire resistance should be provided to the hull to protect occupants within.

4 Methodology

There were two parts to this study which required distinct methodologies. The first part was to establish the critical heat flux at which unprotected (i.e. with no fire resistance rating) hulls can be considered to not provide sufficient protection to accommodation spaces. To achieve this a one dimensional (1D) heat transfer analysis of a steel hull build up exposed to varying heat fluxes was undertaken. It established the level of exposure that unprotected hulls can be expected to withstand without allowing fire spread to internal materials, see section 4.1 for details. Once this exposure level had been established, it could then be contrasted against exposure levels from experimental data and simulations in the literature, see section 4.2.

4.1 Heat Transfer Analysis

To provide results that can be applicable across a wide range of vessels and situations, either a representative, or a conservative, scenario must be established for modelling. Due to the limited performance requirements (with respect to fire) the overall hull bulkhead construction of vessels can vary considerably beyond the external steel surface. Inside the hull there may have an air gap before an internal lining or may be insulated with a mineral wool or polymer-based insulation (before or after an air gap) and may run services within this space. Due to this variation, and the fact that the overall hull construction can therefore not be considered to meet any specific performance levels it is not possible to develop a “representative construction” model which matches all hulls. Instead, a small number of variations, as discussed later in this section, with 2 thicknesses of steel (6 mm and 12 mm) with different backings have been modelled.

The heat transfer modelling shall therefore be of a conservative nature and aim to produce results assuming a construction build up that is representative of a construction that would fair worst when exposed to heating. A representation of a steel hull backed by a combustible insulation product is used for this basis, and the pass-fail criteria utilised shall be that used typically for fire resisting construction including SOLAS requirements for fire resisting construction (SOLAS II-2 Part A Regulation 3 (International Maritime Organisation, 2023)) , e.g. a temperature rise of 140 K on the unexposed side of the hull steel as highlighted in Figure 1.

The model itself was a one dimensional (1D) heat transfer through solid steel, the boundary condition on one side was an imposed heat flux, while three different conditions were considered for the rear boundary; adiabatic (i.e. no heat lost), a 6 mm thick portion of generic insulation (with material properties representative of sufficient insulation to represent an A-30 insulation class), and direct to ambient (20°C) air. Hull thicknesses of 6 mm and 12 mm were considered and for each combination of steel thicknesses and rear boundary case the hull was heated by the radiant heat fluxes in Table 2 for a duration of 1 hour. A case matrix can be seen in Table 1.

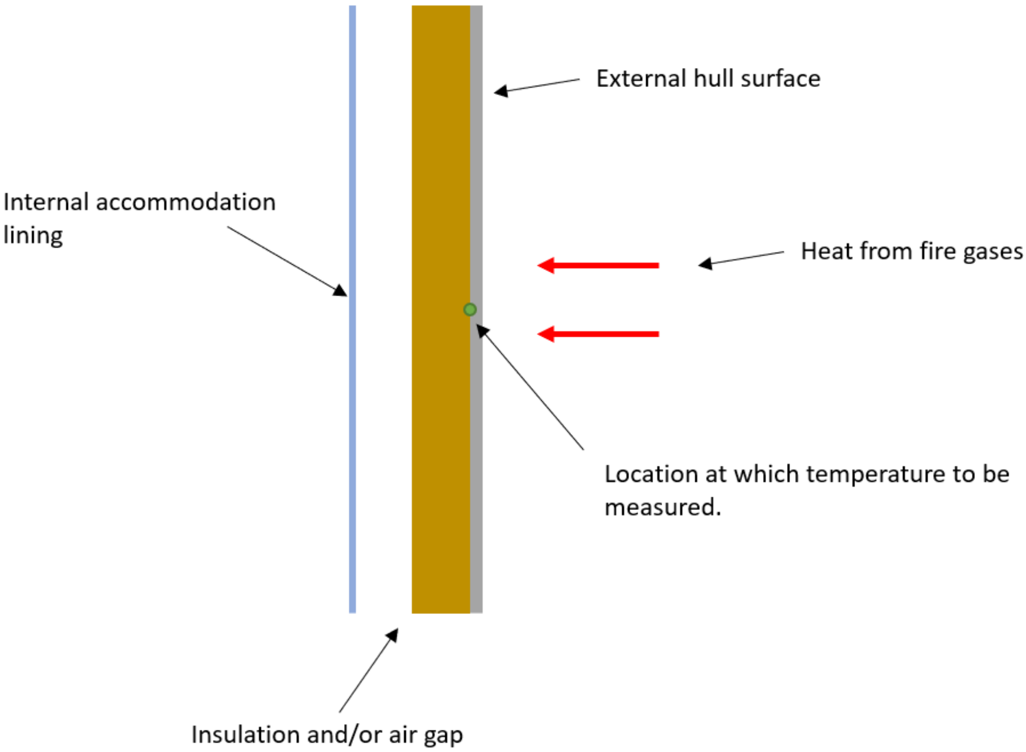

Figure 1. Sketch of hull construction considered for the 1D heat transfer analysis

Table 1. Simulation geometry cases

Case	Backside Boundary Condition	Steel Thickness
1	Adiabatic	6 mm
2	Insulated	6 mm
3	Ambient	6 mm
4	Adiabatic	12 mm
5	Insulated	12 mm
6	Ambient	12 mm

Table 2. List of radiant heat fluxes modelled

List of Radiant Heat Fluxes Modelled (kW/m^2)
4.5
5
5.5
6

7
8
9
10

The material properties from Eurocode 3 Part 1-2 (EN 1993-1-2) for the design of steel structures in fire were used for the steel while those for the insulation in the cases with the insulation are shown in Table 3. The simulations were carried out using the SAFIR software package (The University of Liege, 2011) and a sample of the FEM layout for the models can be seen in Figure 2.

Table 3. Insulation Material Properties

Temperature (°C)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m^3)
0	0.032	840	24
10	0.032	840	24
100	0.041	840	24
200	0.057	944.7	24
400	0.127	1154	24
550	0.18	1197.5	24
600	0.2	1212	24
650	0.22	1399.0	24
700	0.23	1586	24
1200	0.23	1586	24

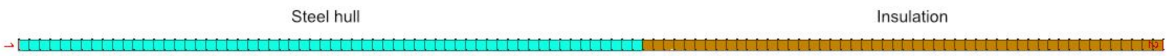

Figure 2. Image showing the FEM layout of the heat transfer model for a case with 6 mm thick steel hull (blue) and 5 mm of insulation (brown). The heated boundary is on the left of the image while the right hand boundary is to ambient (20°C) air.

4.2 Exposure Comparison

Once the limit of acceptable exposure to unprotected areas has been established the next stage is to determine the area at which the heat fluxes that the hull will be exposed to can be expected to exceed this limit. This can be done by two means, experimental data, or simulations, in this project literature data of both types has been utilised. The sources from which the data has been extracted are:

- SP Fire 105 Façade tests – The SP Fire 105 standard is a façade fire standard with an opening of 3 m wide and 0.71 m high, see Figure 3. The fuel source is 60 litres of heptane, and the fire lasts for approximately 17 minutes. Data used for comparison is from a test on a non-combustible façade and two timber facades as reported in IR11.12.
- Mass timber compartment fires – An experimental series of fires in compartments constructed from cross-laminated timber (CLT), with exposed surfaces and a false façade above the opening. Undertaken as the *Fire Safe Implementation of Mass Timber In Tall Buildings* (Sjöström, Brandon, Temple, Hallberg, & Kahl, 2021) by RISE the data used comes from compartments with a total opening width of 4.5 m and a height of 1.78 m, see Figure 4. The data used in this review (from tests ca2, 3 and 5 of the series) peaked at approximately 30 MW and lasted for roughly half an hour.

- Modelling undertaken by Teknologian tutkimuskeskus VTT Oy (VTT) as part of the LASH FIRE project (IR11.7) – CFD modelling of an 85 MW lorry fire in a ro-ro deck was undertaken as part of the LASH FIRE project using the FDS software package. Data from above opening 2 and a fire in location 2 of this modelling has been used for comparisons. Comparisons are shown with and without a safety factor of 1.5 that was applied by VTT during their work. While there are a lot of openings to the fire compartment in this model, they are in groups which can be each treated as a single opening. The data used here has been taken from the set of openings closest to the fire which have a total width of approximately 5.6 m (made up of 3 adjacent windows of 2 m, 1.8 m and 1.8 m each).
- Data from modelling work undertaken in work package 2 of the FIRESAFE II project (Leroux, Mindykowski, Evegren, & Gusin, 2018) for heat fluxes at distances from the corner of an opening was also used.

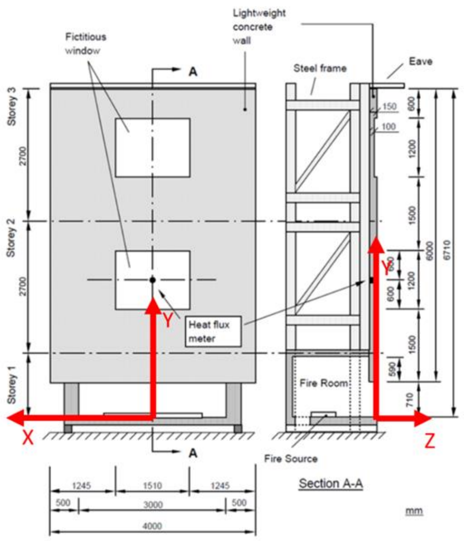

Figure 3. Drawings showing the size of the openings for a SP Fire 105 test and a photo of a test underway (note this is an indicative photo from ri.se and not of the particular tests utilised in this note).

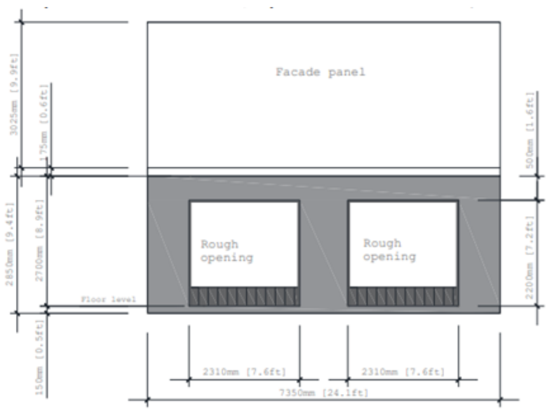

Figure 4. Drawing showing the size of the openings for the mass timber compartment fire experiments and a photo of one of the tests near the fire's peak.

The data collected from these sources has been split into two zones, that directly above the window, which can be utilised to establish the overall height of any protected area for which centreline exposure can be used as a proxy see Figure 5. The second zone extends above and away from the top corners of the opening as illustrated in Figure 6.

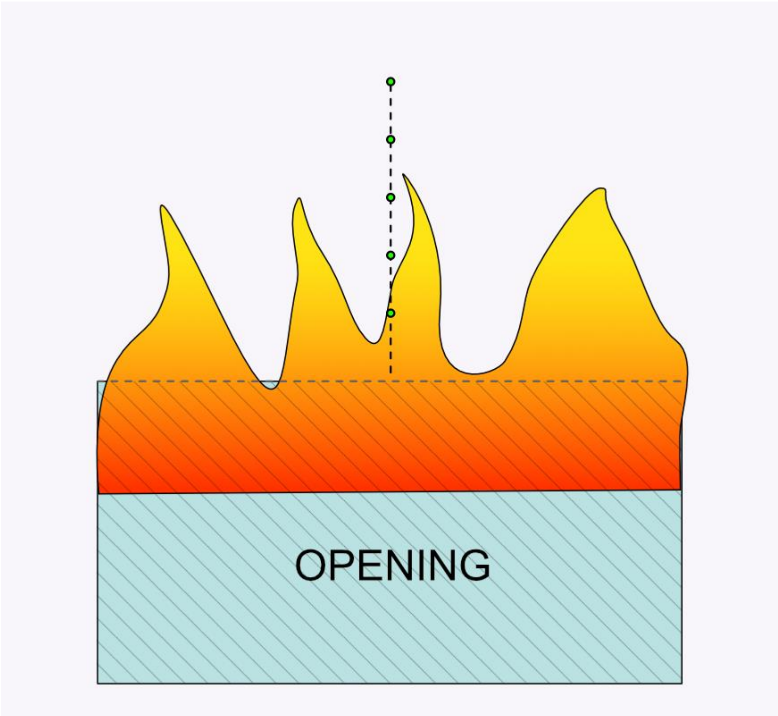

Figure 5. Sketch showing where exposure is reviewed along the centreline above window openings.

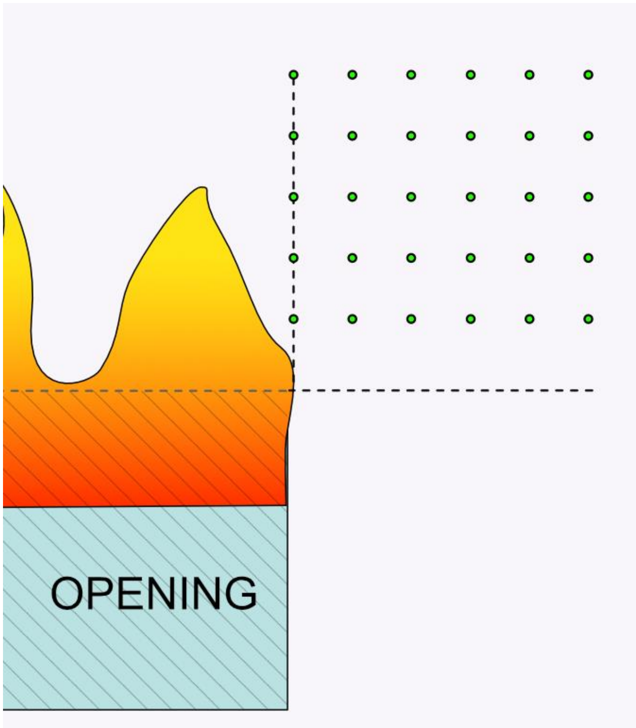

Figure 6. Sketch showing how the extent of the exposure above the corner of the opening is reviewed.

5 Results

Main author of the chapter: Alastair Temple, RISE

5.1 Heat Transfer Analysis

The full results of the heat transfer analysis can be seen in the Annex to this report (section 9.1). As discussed in section 4.1 the failure criteria was been defined as a rise of 140 K over ambient. In the modelling undertaken an ambient temperature of 20°C was used and the time to reach the critical temperature of 160°C in each of the cases has been plotted in Figure 7.

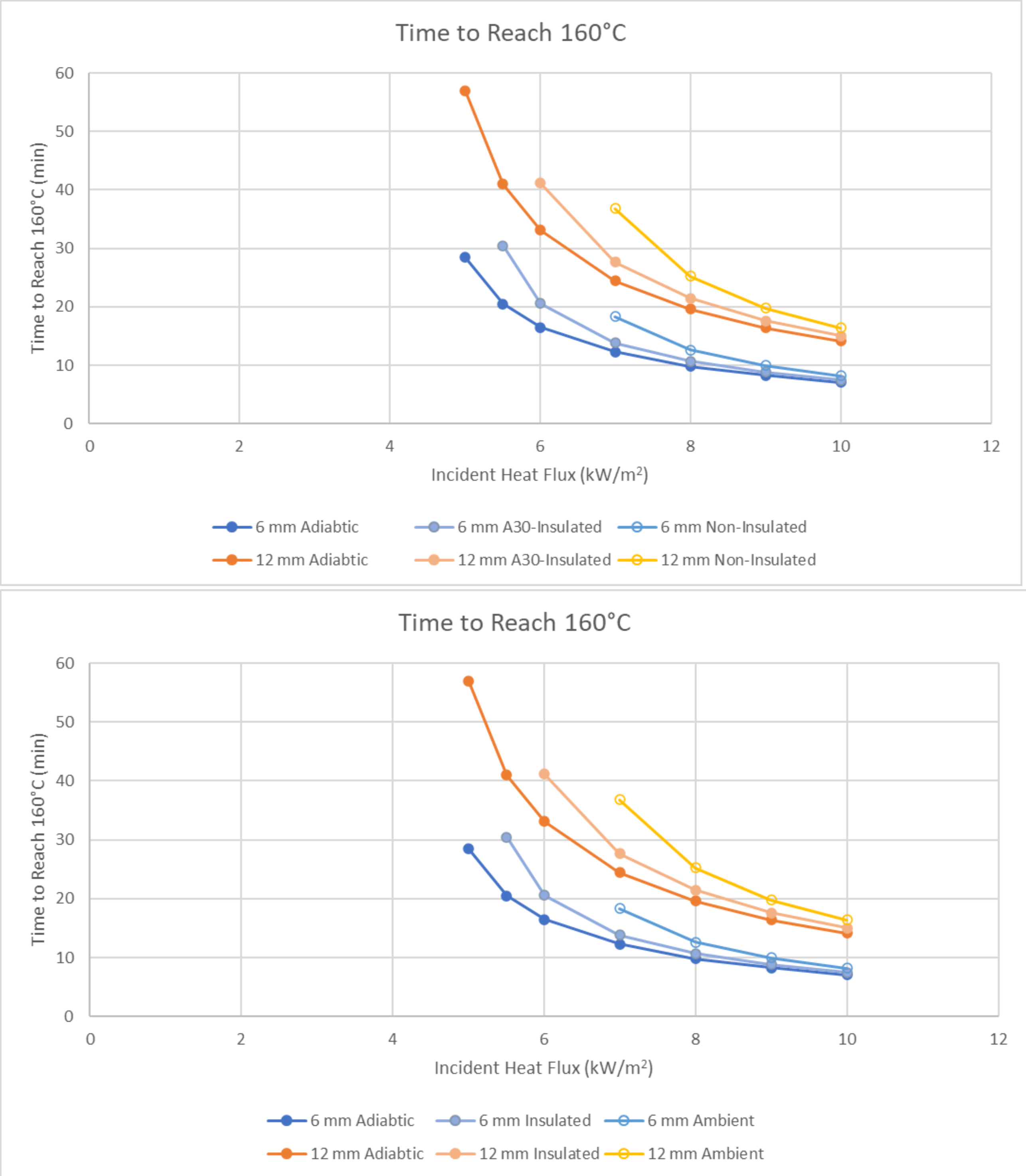

Figure 7. Time for the steel backface to reach the critical failure temperature of 160°C.

From Figure 7 it can be seen that for the insulated and non-insulated cases an exposure of at least 5 kW/m^2 is needed to cause a sufficient temperature rise. For the cases with an adiabatic boundary a time of approximately 30 minutes is required to reach this limit. A reasonably conservative exposure limit for unprotected areas was therefore taken as 5 kW/m^2.

5.2 Exposure Comparisons

5.2.1 Centreline Heat Fluxes

A comparison of the heat fluxes above the centreline of the openings in the various data sources can be seen in Figure 8, with the full results shown in 8 a) and a zoomed in view of the results, with incident heat fluxes up to 200 kW/m^2, shown in 8 b).

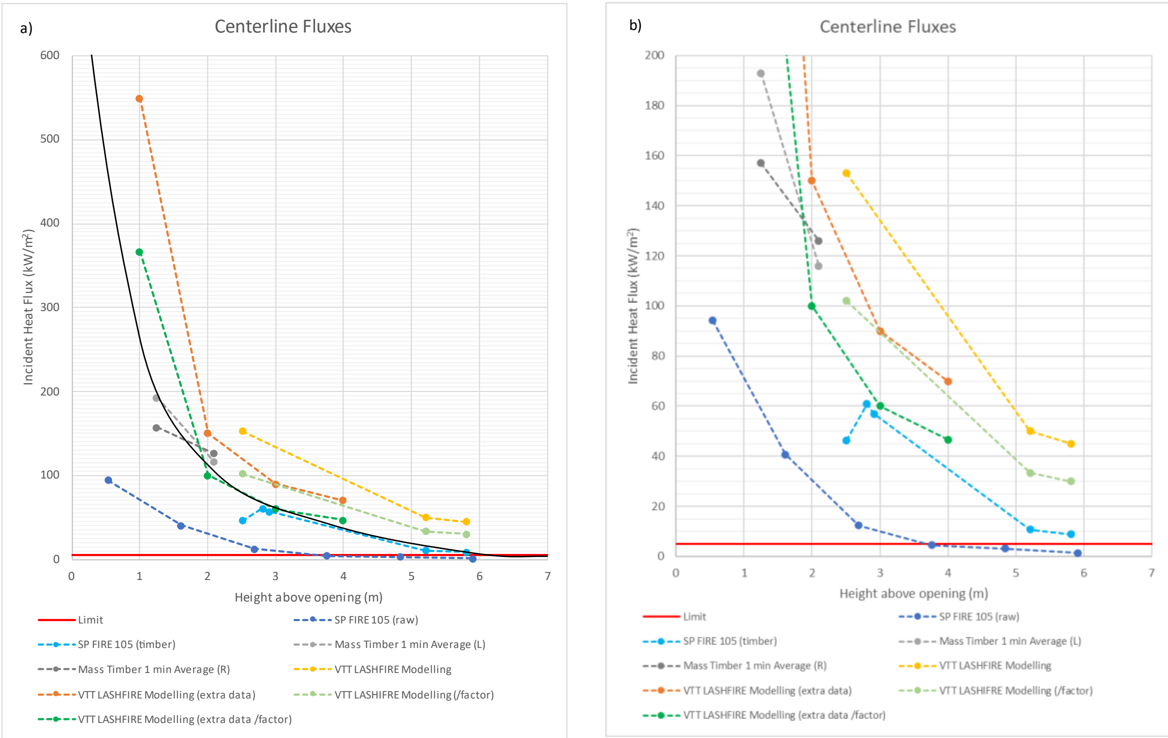

Figure 8. Heatfluxes above the centreline of an opening. a) shows full extent of data and indicative reasonable assumption curve. b) shows a zoomed in view of the same data up to a maximum induced heat flux of 200 kW/m². .

The following observations can be made from this data:

- The modelling results without a safety factor (green curves) cross through the results from the mass timber compartment tests (grey curves). While the fires in the mass timber compartment tests had a lower peak heat release rate than the modelled ro-ro ship fire, the fire compartment was much smaller and only had one set of openings through which all the gas would be released (as opposed to a ro-ro space with a large number of openings, which are themselves often clustered in groups to give equivalent of a single large opening). The similarity in exposure between them therefore indicates that for the purposes of this study the modelling results without the safety factor are reasonable for this study.
- A number of the result curves appear to be approaching a plateau in heat flux values at 6 m. It is likely this is the full extent of the flaming in these scenarios and that the exposure can therefore be expected to drop of quite quickly after. This matches visible observations during the SP 105 fire tests and visual plots of the radiation in the modelling which appears drops of quickly above two decks, see Figure 9.

On the basis of the above observations, Figure 8 a) also includes a sketch of a “reasonable case” exposure curve in solid black, with the limit being reached at approximately 7 m in height.

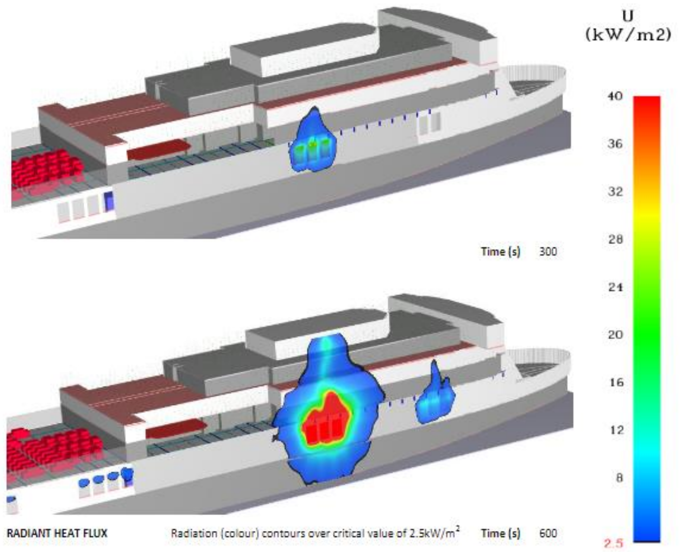

Figure 9. Image from LASH FIRE IR11.7 showing sharp drop off in heat flux above two decks in height, 5 min (early stages) and 10 min (peak fire size) into the fire.

5.2.2 Corner Heat Fluxes

As noted in section 4.2 the heat flux varies with different distances from the upper corner of an opening and was calculated as part of the FIRESAFE II project (Leroux, Mindykowski, Evegren, & Gusin, 2018). These heat fluxes can be seen in Figure 10 a and b below. Comparison between the FIRESAFE II project and the results from an SP 105 timber test demonstrate that the FIRESAFE II project calculation has produced realistic results. Similar plotting of the results from the LASHFIRE project modelling can be seen in Figure 11a and b.

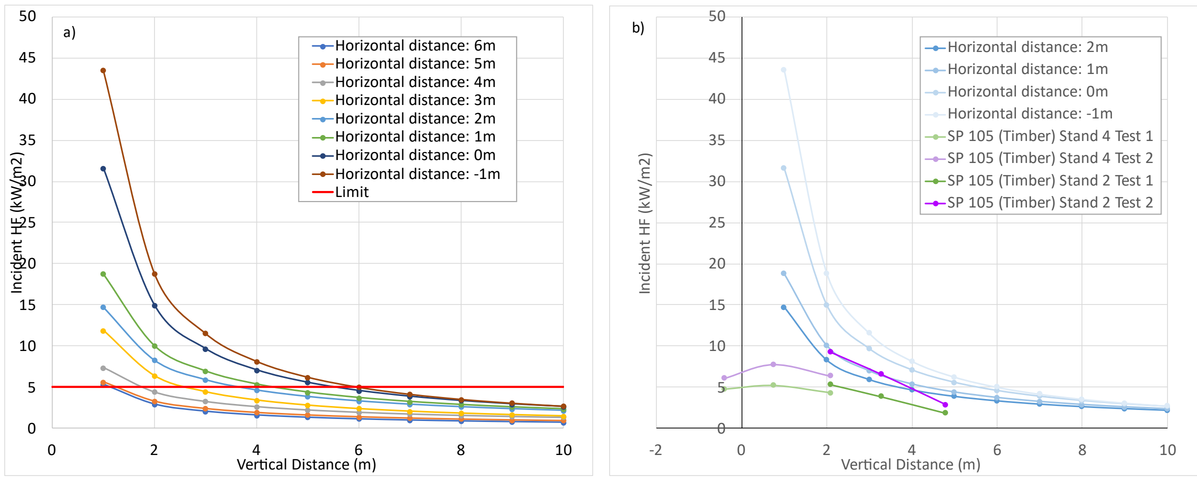

Figure 10. Variation of heat fluxes to the hull at distances from the corner of an opening. Graph a) shows results from FIRESAFE II project while b) includes a selection of these shown against results from 2 SP Fire 105 tests (stand 4 at 0.5 m horizontal distance and stand 2 at 1.5 m).

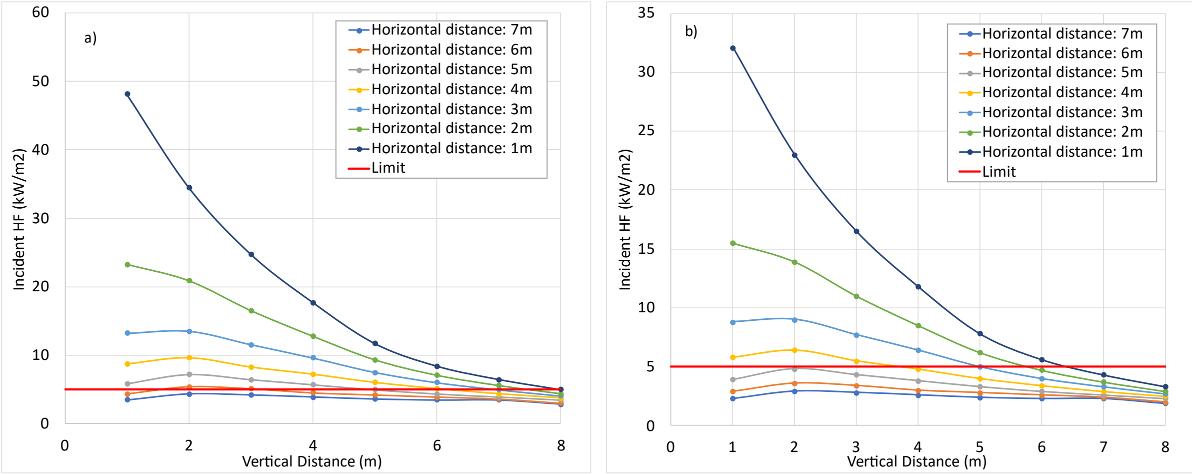

Figure 11. Variation of heat fluxes to the hull at distances from the corner of an opening based on results from LASH FIRE project modelling shown a) with applied factor of 1.5 and b) without the applied factor.

A vertical distance of 6 m is sufficient to keep the exposure below the 5 kW/m^2 limit in the FIRESAFE II and LASH FIRE (without the safety factor) calculations while with only 5 m required based on the SP 105 results. Where the safety factor is applied to the LASH FIRE simulation results, the maximum height required is 8 m. At a height of 3 m above the opening, a horizontal distance of 3 m is required in the FIRESAFE II calculation and SP 105 test results, 3.5 m for the LASH FIRE calculation without the safety factor and 7 m for the LASH FIRE calculation with a safety factor. Given the similarity in results between all the raw results, despite the increased fire size of the LASH FIRE simulation, the application of the safety factor to the LASH FIRE results is overly conservative and not required when considering horizontal distances. Based on the distances here and in section 5.2.1 a zone extending 7 m above a ro-ro space opening and 6 m horizontally was suggested to be constructed from hull structures protecting against the spreading of fire to internal spaces.

6 Conclusion

Main author of the chapter: Alastair Temple, RISE

A two-part study has been conducted investigating the reasonable extent to which unprotected hull should be provided to accommodation spaces above the openings in a ro-ro space. In the first part of the study a heat transfer study was conducted to establish an exposure limit for unprotected areas of hull to prevent ignition of interior materials. Based on a temperature limit of 160°C (i.e. a temperature rise of 140 K over ambient) and the calculations conducted a limit of 5 kW/m^2 was established. The second part of the study then reviewed fire exposure from a series of calculations and tests available within the literature (including other work within LASH FIRE) against this limit. It was found that there is a larger sensitivity to the fire size above an opening than for exposure to the side. Additionally, based on the review undertaken a zone extending 7 m above any opening and up to 6 m horizontally from the opening was suggested to be required to be protected to avoid fire spread to internal spaces. When considering these results, it should be remembered that no experimental work has been undertaken to verify or validate the findings and assumptions in this study. Care must therefore be taken that the recommendations are only used where the reader is confident that the assumptions are valid and/or conservative for their particular case.

7 References

International Maritime Organisation. (2023). International Convention for the Safety of Life at Sea (SOLAS), 1974 as Amended. International Maritime Organisation.

Leroux, J., Mindykowski, P., Evegren, F., & Gusin, L. (2018). *FIRESAFE II Containment and Evacuation.* Lisbon: European Maritime Safety Agency.

Sjöström, J., Brandon, D., Temple, A., Hallberg, E., & Kahl, F. (2021). *Exposure from mass timber compartment fires to facades.* Borås: RISE.

The University of Liege. (2011). SAFIR Technical documentation.

8 Indexes

8.1 Index of tables

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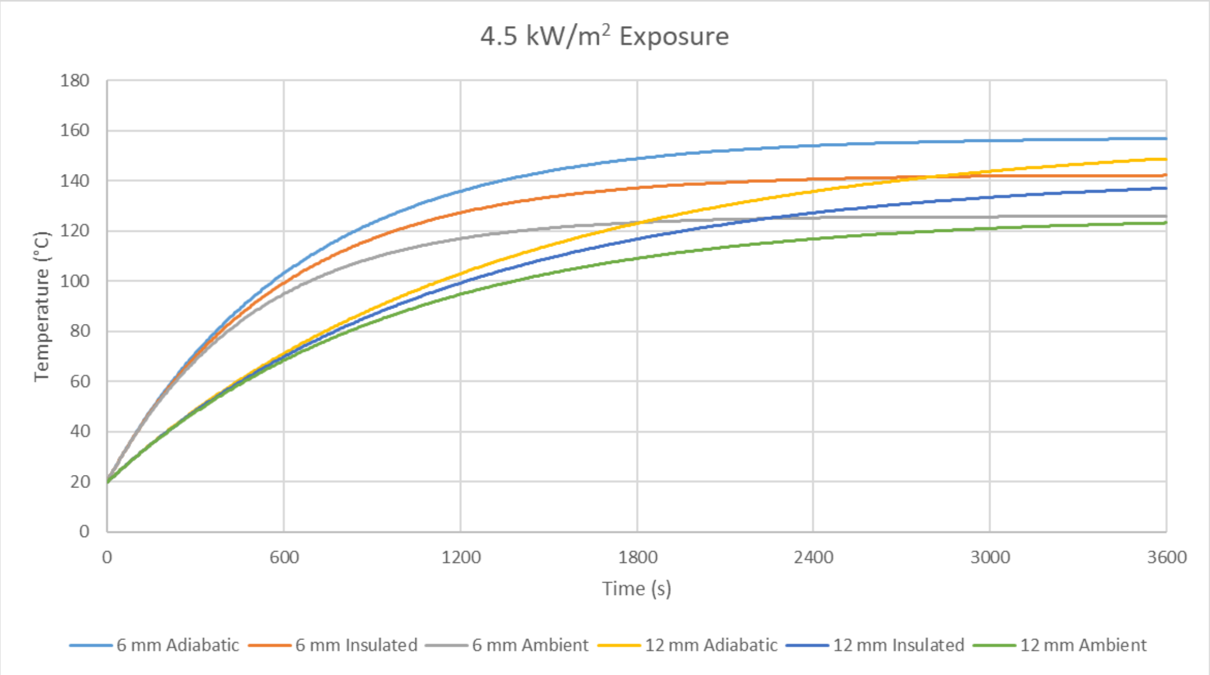
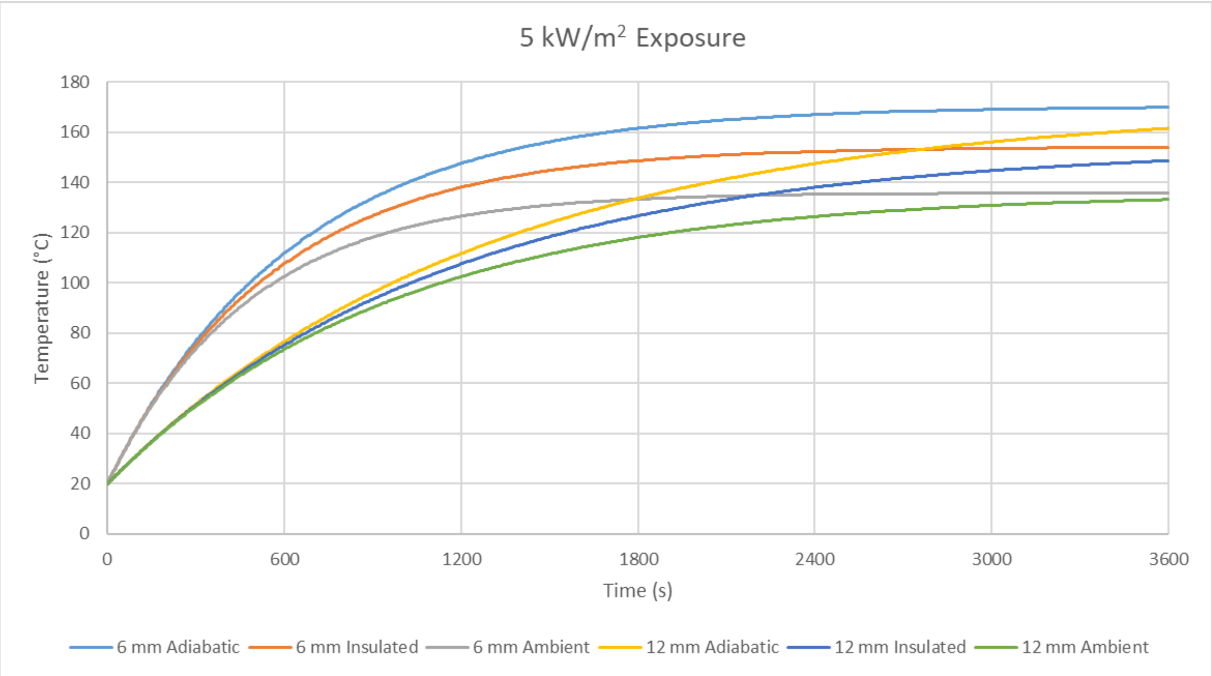
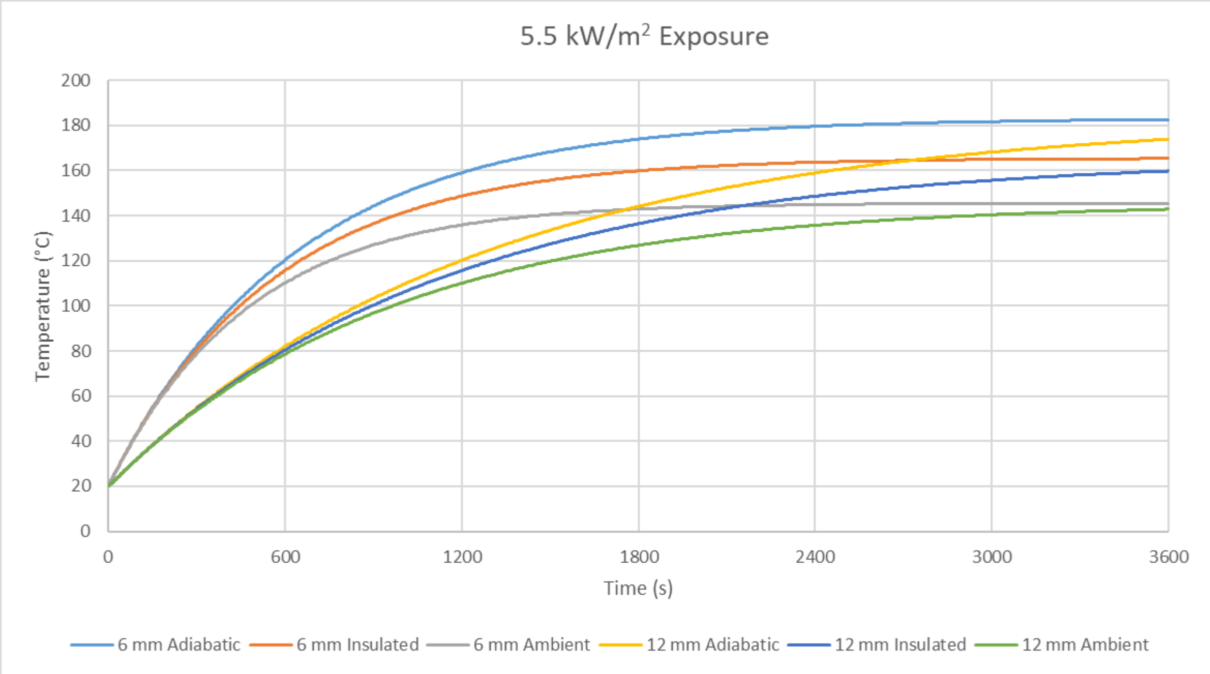
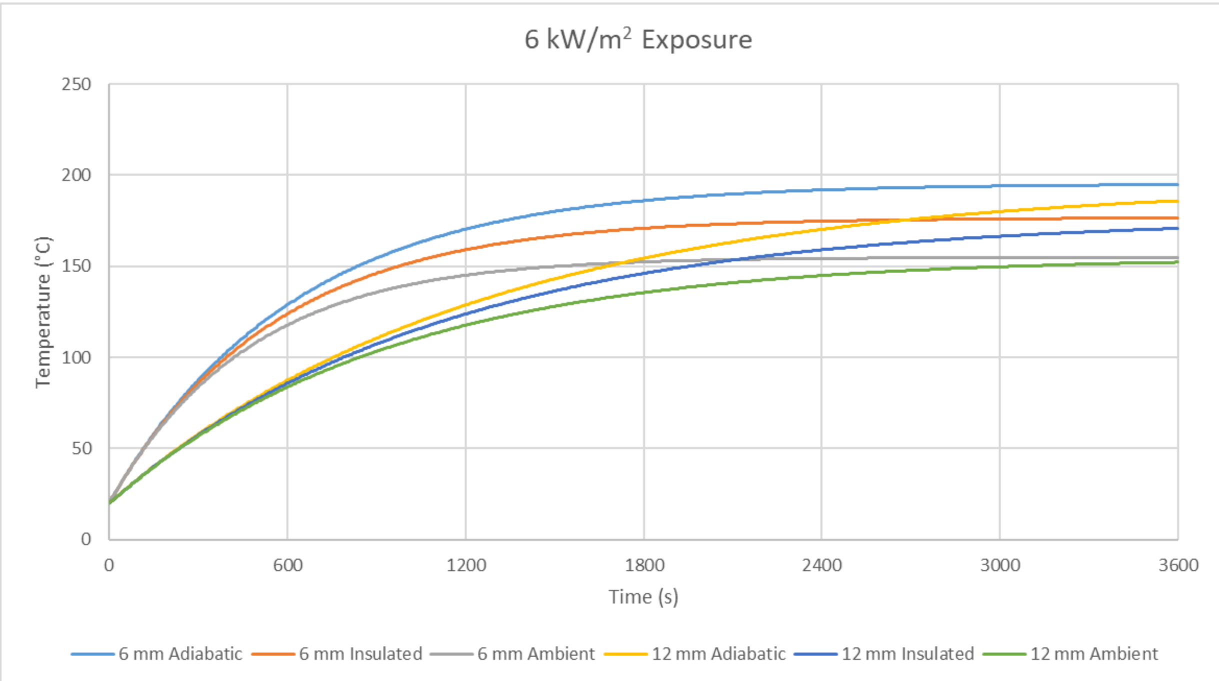
9 ANNEXES

9.1 Heat Transfer Calculation Results






5.5 kW/m2 Exposure
Temperature (°C)
200
180
160
140
120
100
80
60
40
20
0
0
600
1200
1800
2400
3000
3600
Time (s)
6 mm Adiabatic
6 mm Insulated
6 mm Ambient
12 mm Adiabatic
12 mm Insulated
12 mm Ambient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100
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0
0
600
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1800
2400
3000
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Time (s)
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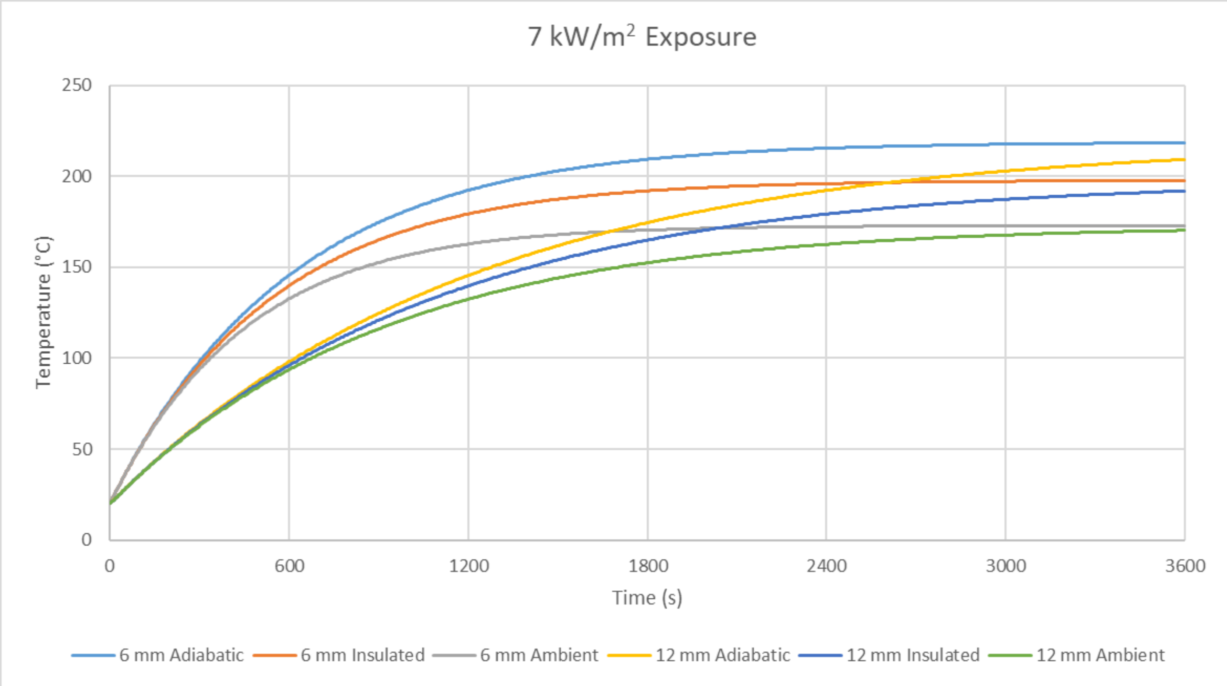
6 mm Insulated
6 mm Ambient
12 mm Adiabatic
12 mm Insulated
12 mm Ambient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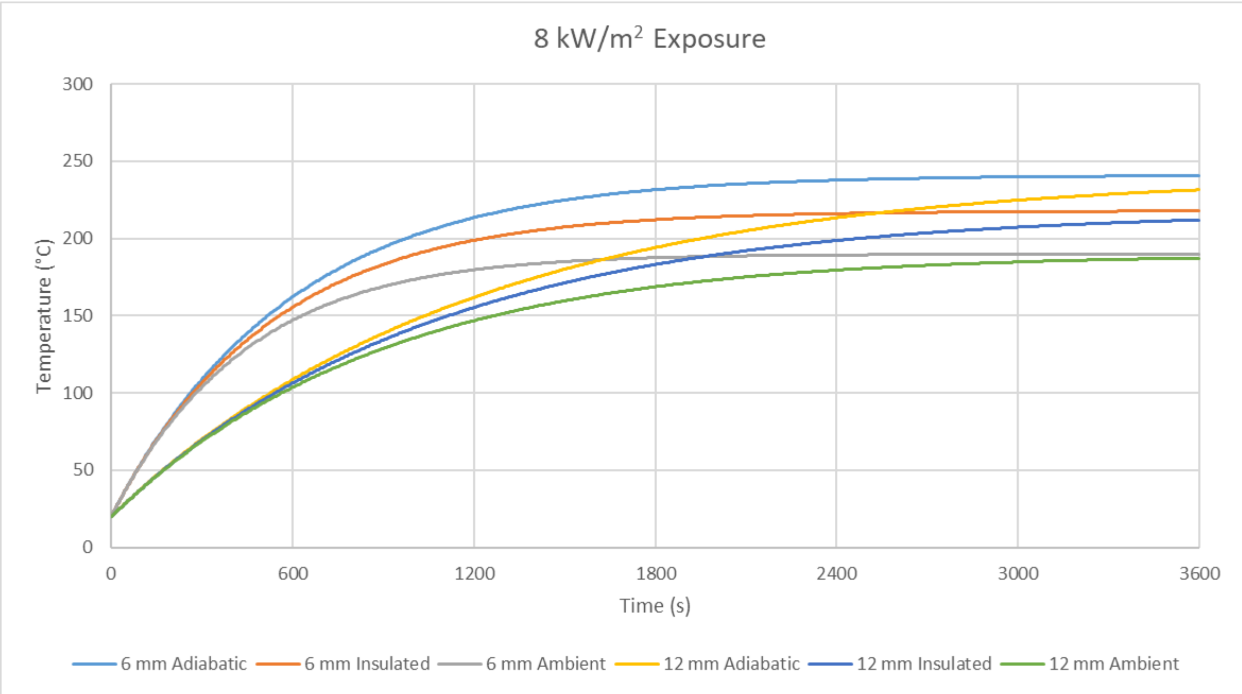
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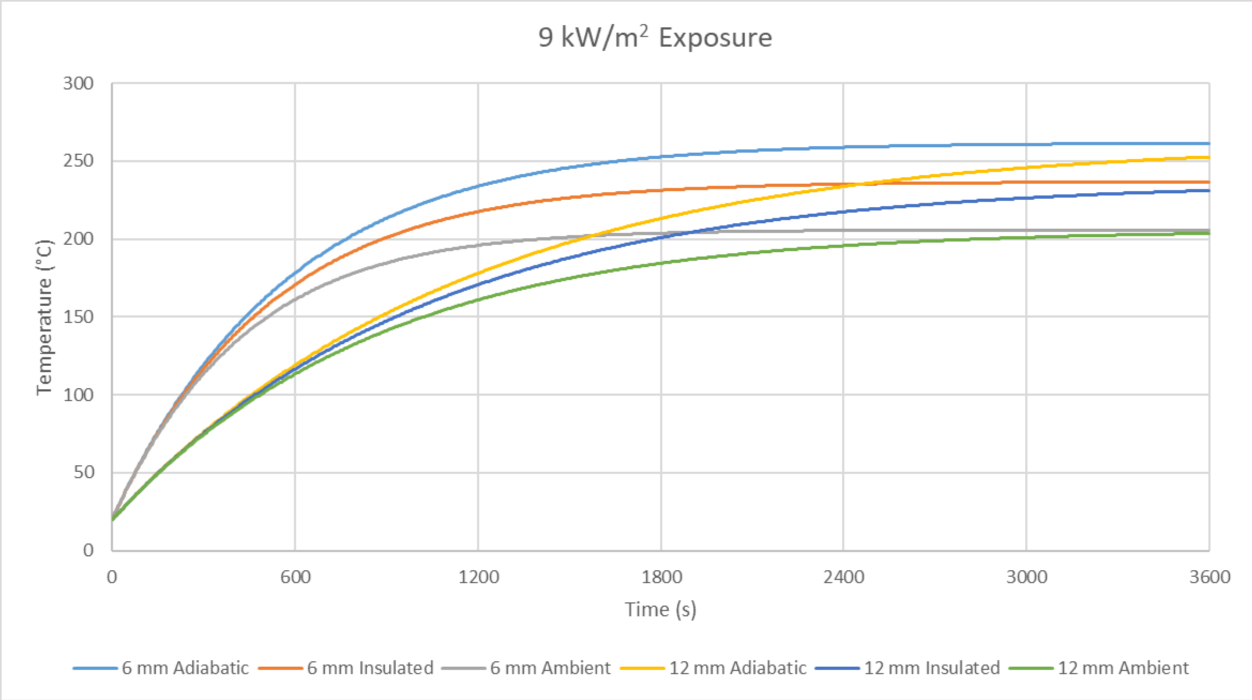
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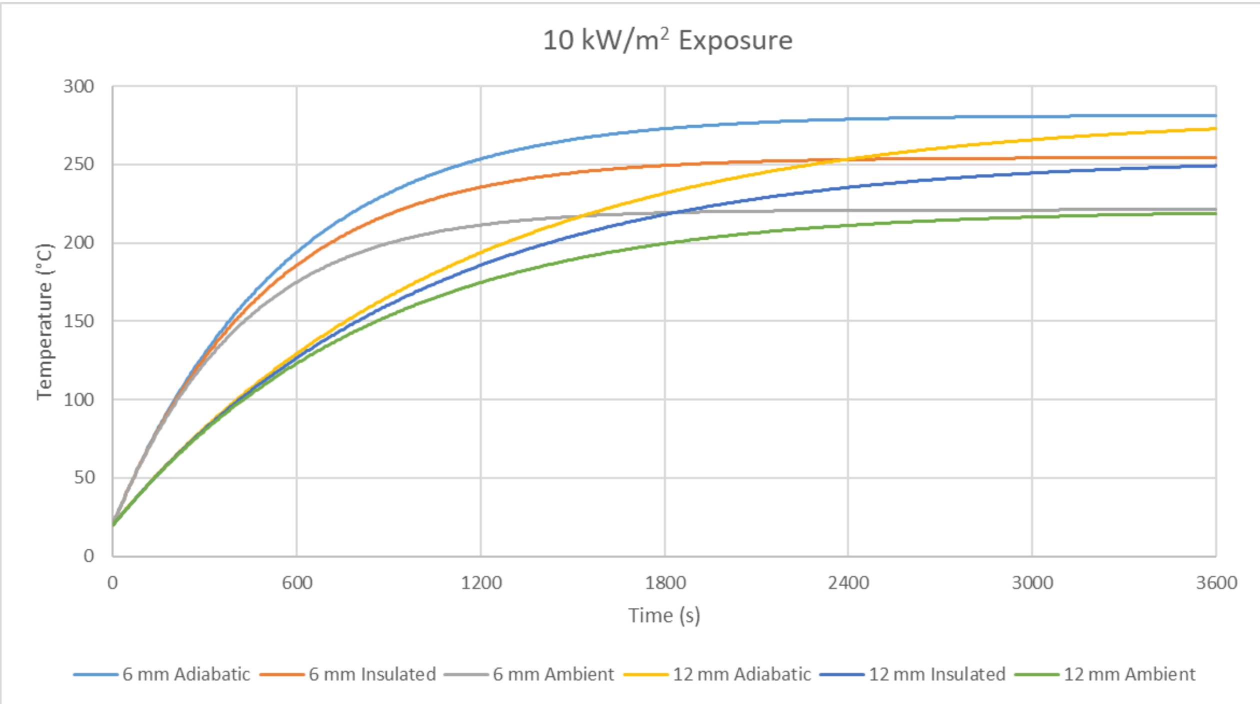
12 mm Ambient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6 mm Ambient
12 mm Adiabatic
12 mm Insulated
12 mm Ambient