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A Verification of the Need for Fire Dampers in Ventilation Channels Passing through Fire Partitions in 17 Rooms on the Troll C Platform

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Norwegian Fire Research Laboratory

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ABSTRACT

This report includes a verification of the need for fire dampers in ventilation channels passing through fire partitions in 17 rooms on the Troll C Platform. The actual rooms are areas which in general are expected to have a rather low fire load density, due to a comparatively small amounts of combustible materials, and due to the fact that these materials are fire retarded.

The main objective of this study is to determine whether fire dampers in the ventilation penetrations in the 17 rooms on the Troll C platform are required or not. That is, whether the pressure build-up within the rooms, due to a fire and extremely tight all-welded compartments, will cause smoke and fire spread via the ventilation system, when neglecting fire dampers in the ventilation channels passing through fire partitions.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Fire	Brann
GROUP 2	Smoke	Røyk
SELECTED BY AUTHOR	Spread	Spredning
	Ventilation dampers	Ventilasjonsspjeld

TABLE OF CONTENTS

CONCLUSIONS AND RECOMMENDATIONS

Generally

The prediction of the maximum pressure build-up due to restricted thermal expansion in this report is rather conservative. This is due to the fact that the fire models used in these calculations do not take into account the effects of the pressure build-up on the air supply rate and the fire development in general.

It has to be pointed out that in the evaluations of the possibility for smoke spread to other rooms via the air supplies, it has been presupposed that the air supply pressure at the air supply channels is in general 100 Pa.

The ratio of room volume to pressure relief area, i.e. area of exhaust and air supply vent openings, is the most important parameter affecting the pressure build-up due to restricted thermal expansion in a all-welded fire compartments. Especially, high values of this ratio will cause high pressure build-ups in the fire room. A high value of the "ratio" implies that a large volume of smoke gases has to be relieved through a small pressure relief area.

The pressure build-up is generally inversely proportional to the square of the pressure relief area. Consequently, when the pressure relief area is doubled, as in case of pressure relief also through the air supplies, the pressure increase is reduced to one-fourth of the pressure increase in case of one opening (i.e. pressure relief only through the exhaust system).

Smoke Spread

Due to the possibly high pressure build-up in the rooms, which strongly restricts the air supply to the room, and thus also the heat release rate of the fire, the smoke spread to other rooms will be generally intermittent.

Table I on the next page shows the results of the calculations with respect to maximum temperatures as well as maximum pressures in the 17 rooms on the Troll C Platform. The table contains also ratings of the degree of smoke spread from each of these 17 rooms to other rooms, via the ventilation system in case of a fire in the rooms.

It appears from the table that there will be smoke spread to a high degree to rooms downstream in the air supply system, and most likely also via the exhaust system, in case of a fire in Water Inj. H.V. Trafo Room. The pressure build-up in this room will in case of pressure relief through the exhaust opening only, as shown in the table, be as high as 2082.5 Pa, while the maximum smoke gas temperature in the room is only 53.4 °C.

There will probably also be smoke spread to a certain degree via the air supplies to rooms downstream in the air supply system from HVAC (port mid.) and HVAC (starb. mid.). The pressure build-ups and temperature loads of these rooms will correspondingly be 675.5 Pa and 54.8 °C, respectively. For the other 14 rooms on the Troll C platform there will be no or insignificant smoke spread to other rooms.

This spread of toxic smoke will most likely lead to severe conditions for the platform personnel staying in room connected to the same ventilation system. This smoke exposure may probably, within some time, lead to incapacitation of the platform personnel if evacuation is hindered.

Table I: An evaluation of the possibilities of smoke spread to other rooms, via the air supply system. The assumed effects of the flow resistance at the inlet, as well as in the exhaust and air supply channels to the fire room, are also taken into consideration.

Fire room	Degree of smoke dispersion to other rooms via the ventilation system: To a high degree	To a Certain degree	Insignificant	No smoke spread	Max. gas temp-rature (°C)	Max. pressure increase in case of One open-ing (Pa)	Two open-ings (Pa)
L.I.R. 1				x	69.7	204.9	52.2
HVAC (port aft)				x	65.8	223.4	57.1
HVAC (starb aft)				x	74.8	302.9	77.6
L.I.R. 2				x	69.7	204.9	52.2
Generator control room				x	200.8	100.7	25.2
HVAC (port outer fwd col)				x	68.5	290.4	74.6
HVAC (port inner fwd col)				x	50.6	131.6	33.5
HVAC (starb outer fwd col)				x	71.6	199.8	50.8
HVAC (starb inner fwd col)				x	68.5	290.4	74.6
Water Inj. H.V. Trafo Room	x				53.4	2082.5	679.1
Process Utilities				x	73.5	149.8	37.9
HVAC (port mid)		x			54.8	675.5	183.5
H.V. Switch Room			x		85.6	433.1	111.7
HVAC (starb. mid.)		x			54.8	675.5	183.5
Electrical Room				x	207.3	118.2	29.7
HVAC (port outer fwd. col. low.d.)				x	68.5	290.4	74.6
HVAC (port outer fwd. col. low.d.)				x	68.5	290.4	74.6

Fire Spread

It can be concluded that the smoke spread to other rooms may occur in case of a fire in three of the 17 rooms on the Troll C platform. This smoke spread will, however, not result in fire spread to the other rooms, because of a too low smoke gas temperature.

Recommendations

Due to the low <u>maximum</u> fire gas temperatures in the three rooms mentioned above, i.e. slightly above 50 °C, which is lower than the actuation temperature of the fire dampers, a shut-down of the ventilation system in case of a fire in these room will not take place. This because fire a damper usually is actuated when the gas temperature exceeds 67-70 °C.

An alternative to installing fire dampers in the actual channels is to increase the pressure relief area, i.e. by increasing the ventilation channel diameter. If the of the exhaust and air supply channel diameters are increased from 200 mm to 315 mm for the Water Inj. H.V. Trafo Room, the maximum pressure in the room will decrease to 459.0 Pa and to 121.7 for pressure relief through one and two openings, respectively. This will cause no or insignificant smoke spread to other rooms via the air supply system.

If the diameters of the ventilation channels of the rooms HVAC (port mid.) and HVAC (starb. mid.) are increased from 200 mm to 250 mm, the corresponding pressures will decrease to 295.1 and 47.4 Pa, and, thus, no smoke spread will take place via the ventilation system.

1. INTRODUCTION

1.1 Generally

SINTEF Civil and Environmental Engineering, Norwegian Fire Research Laboratory (SINTEF NBL) has by a request from Norsk Hydro been asked to carry out a verification of the need for fire dampers in ventilation channels passing through fire partitions in 17 rooms on the Troll C platform /1/.

SINTEF NBL has carried out a similar verification for Norsk Hydro in 21 rooms or areas on the Visund Platform /2/ in the time period from October 1996 to January 1997. The calculation method developed during this study will also be used in the evaluation of the 17 rooms on the Troll C Platform.

1.2 Background

There are mainly the following two severe and unwanted situations that decide whether fire dampers are required in the ventilation channels passing through fire partitions or not:

- *Smoke spread*
- *Fire spread*

In case of a fire in a room the resulting pressure build-up due to the heat generation and a rather tight compartment may cause smoke spread via the ventilation system. This occurs only if the overpressure thus created in case of pressure relief through both the exhausts and the air supplies is above a certain lower limit (e.g. 100 Pa). If the temperature of the fire is sufficiently high, the smoke spread may even lead to fire spread to other rooms. A fire damper, which closes when a fire is detected, prevents effectively both smoke and fire spread to other rooms for a certain time, usually for least an hour.

All bulkheads and decks of the actual rooms on the Troll C Platform are all-welded. Thus, these rooms constitute extremely tight compartments. It is expected that there may be great pressure build-up in case of a fire in the room. The pressure build-up is due to the restricted thermal expansion of the hot smoke gases in case of a fire in a room. A large volume of smoke gases has to be relieved through a small area. The only openings providing for pressure relief, are the ventilation openings or valves. That is, primarily the exhaust valves, but also the air supply valves, when pressure build-up due to thermal expansion exceeds the counterpressure in the air supply channel.

The exhaust system will hardly result in any smoke spread to other rooms, apart in case of extremely high pressure build-ups. However, there may be a significant smoke spread to other rooms downstream in the air supply system, provided that pressure build-up in the fire room exceeds the counterpressure in the air supply channel to the room.

1.3 Objective

The main objective of this study is to determine whether fire dampers in the ventilation penetrations in 17 rooms of the Troll C platform are required or not. That is, to decide whether fire spread and a critical smoke spread will take place when neglecting fire dampers in the ventilation channels passing through these firewalls.

On the basis of the given type and amount (i.e. weight) of combustible materials in the actual rooms (data submitted from Norsk Hydro /1/), the *fire load density* (in MJ per m^2 surface area of the room) and the temperature load (in °C) will be predicted for each room. When the temperature development as function of time from the start of the fire is known, as well as the pressure areas of the exhaust and the air supplies and the room volume, the *pressure build-up* within the rooms (in Pa) can be predicted as a function of time.

The calculated temperature load and pressure *build-up* in each room will determine whether fire spread to other rooms is possible or not. In order to determine whether smoke spread via the ventilation system may take place, the pressure increase due to thermal expansion have to be calculated in all the 17 rooms of the Troll C Platform. The calculated fire or smoke gas temperature, pressure relief area and the volume of the room represent the main input data to these calculations.

2. CALCULATIONS

2.1 Calculation Methods

The following calculation methods will be used in this evaluation:

- Fire load density: NS 3478 /3/.
- Temperature loads: The "Swede Method" /4/.
- Pressure build-up: A method developed by SINTEF NBL /2/ (see section 2.1.3).

2.1.1 Fire Load Density

The calculation procedure for the prediction of the fire load density for each room is according to NS 3478 /3/. The fire load density is, according to this standard, determined by multiplying the weight of each type of material by its heat of combustion (in MJ/kg). This product is calculated for each combustible material in the room, and the products are summed up. This sum is representing the *total fire load* (in MJ) of the room.

The *fire load density* (in MJ/m^2) is predicted by dividing this sum, i.e. the total fire load of the room, by the internal surface area of the room (in m^2). That is the surface area of the all decks (including the "ceiling") and bulkheads. The resulting number is the *fire load density* of the room.

2.1.2 Temperature Loads

When the *fire load density* and the ventilation conditions of the room are known, calculations of the resulting *temperature loads* will be predicted by means of a well known calculation method, i.e. the "Swede Method[1]" /4/. This method will result in a more realistic fire exposure than for example using the ISO 834 time-/temperature curve (NS 3904).

The ISO 834-curve, which represents a predetermined cellulosic fire in an ordinary living room filled with easily combustible materials (e.g. textiles, plastic, wood, paper etc.), will in most cases represent a highly overestimated fire in the actual rooms. The method does not take into account the existing fire load density and ventilation conditions of the rooms, i.e. the two most important parameters for the resulting temperature load. These rooms consist, as already mentioned, of combustible materials, which are fire retarded. Thus, the fire load of the rooms is rather restricted. Further, this curve does not take into account the actual ventilation and the thermal properties of the boundaries of the room, e.g. the thermal conductivity, specific heat density, thickness etc.

"The Swede Method", which actually also is based on a cellulosic fire, the predicted temperature load is predicted depended on the actual *ventilation conditions* and the *fire load density* of the fire room, as well as the actual thermal properties of the boundaries of the room. This is, as opposed to the ISO curve, not representing the *worst case* of an enclosed cellulosic fire, but it is predicting the worst temperature load based on the actual fire conditions of the room. That is, the fire conditions with respect to the actual ventilation and the fire load of the room, as well as the actual thermal properties of the boundaries of the room.

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1 This method is in detail described by Peterson and Öden /4/. We refer to this reference for further information concerning this method. This method represents a fire development that may be expected in an ordinary living room filled with easily combustible materials.

The ISO curve may represent a far more severe fire behaviour and exposure, in which all fire protection measures have to be dimensioned against. On the other hand, the "Swede Method" can be considered as a "realistic fire development" based on the actual fire conditions of the fire room. In Appendix B there is a detailed description of the calculation method used in this study for prediction of the pressure build-ups due to thermal expansion. This method was developed during the Visund Platform evaluation /2/.

2.2 Input Data

Table 2.2 and 2.3 show the input data received from Norsk Hydro a.s /1/. Table 2.2 shows room number and total inner surface area, as well as the area of inner surfaces with insulation and the fraction of the inner surface area with insulation. The not insulated boundaries of the room consist of 10 mm steel plates, while the insulated boundaries consist of 100 mm Rockwool mats on the 10 mm steel plates. The details with respect to the insulation are generally identical to the insulation details of the Visund Platform /2/. When assuming a conductivity of insulated and not insulated boundaries of 0.04 and 50 W/mK, respectively, the effective or resultant conductivity of the boundaries of each room is calculated on the basis of the fraction insulated. The effective or resultant density and specific heat of each room, which are calculated in the same way as the effective conductivity, are shown in Table 2.2.

Table 2.2: Varying parameters of the enclosing boundaries of the fire room. That is, the total inner surface area, the area of inner surfaces with insulation and the fraction of boundaries of the room which is insulated, as well as calculated effective wall thickness, density, specific heat and conductivity of the boundaries[1] (i.e. weighted on the basis of the fractions insulated and not insulated boundaries).

Room no.	Inner room surface area	Insulated surface area	Insulated area fraction	Effective wall thickness	Effective density	Effective specific heat	Effective conductivity	Inner heat transfer coefficient α_i
	m^2	m^2	%	m	kg/m^3	J/kgK	W/mK	W/m^2K
L.I.R. 1	207	53	0.256	0.033	5883.9	591.7	37.2	30
HVAC (port aft)	341	126	0.370	0.043	5017.0	623.5	31.5	30
HVAC (starb aft)	341	126	0.370	0.043	5017.0	623.5	31.5	30
L.I.R. 2	207	53	0.256	0.033	5883.9	591.7	37.2	30
Generator Control Room	295	183	0.620	0.066	3100.6	693.7	19.0	40
HVAC (port outer fwd col)	239	0	0.000	0.010	7840.0	520.0	50.0	30
HVAC (port inner fwd col)	186	89	0.478	0.053	4184.3	654.0	26.1	30
HVAC (starb outer fwd col)	195	44	0.226	0.030	6116.1	583.2	38.7	30
HVAC (starb inner fwd col)	239	0	0.000	0.010	7840.0	520.0	50.0	30
Water Inj. H.V. Trafo Room	928	240	0.259	0.033	5864.1	592.4	37.1	30
Process Utilities	187	0	0.000	0.010	7840.0	520.0	50.0	30
HVAC (port mid)	544	272	0.500	0.055	4020.0	660.0	25.0	30
H.V. Switch room	813	496	0.610	0.065	3178.9	690.8	19.5	35
HVAC (starb. mid.)	544	272	0.500	0.055	4020.0	660.0	25.0	30
Electrical Room	195	52	0.267	0.034	5802.7	594.7	36.7	40
HVAC (port outer fwd col low.d)	239	0	0.000	0.010	7840.0	520.0	50.0	30
HVAC (port outer fwd. col. low.d.)	239	0	0.000	0.010	7840.0	520.0	50.0	30

[1] Calculated on the basis of the fraction insulated and not insulated boundary. The conductivity, density and specific heat of Rockwool mats are presupposed to be 0.04 W/mK, 200 kg/m^3, and 800 J/kgK, respectively.

2.3 Results

2.3.1 Fire Load Density and Temperature Loads

Table 2.4 shows the calculated results with respect to the fire load density (in MJ/m^2) and the resulting possible maximum temperature loads (in °C) of each room. In Appendix A there are curves showing the temperature development as a function of time during the first hour from the start of the fire, when assuming neither manual nor automatic fire suppression.

2.3.2 Pressure Build-up due to Thermal Expansion

Table 2.5 shows the calculated results with respect to the resulting maximum pressure build-up in the same rooms. In Appendix A there are curves showing the pressure development as a function of time during the first hour from the start of the fire, when assuming neither manual nor automatic fire suppression are actuated. The left Y-axis of the curves in Appendix A shows the temperature scale (in °C), while the right Y-axis shows the pressure scale (in Pa = N/m^2).

There are two curves showing the pressure development, i.e. an upper and a lower curve, along with the temperature development of the hot fire gases in the room. The upper curve (termed "1 opening") applies to the case where only the exhaust vent provides for pressure relief, while the lower curve (termed "2 openings") represent the case where both the exhaust and the air supply vent provides for pressure relief.

The latter case (i.e. "2 openings") is only valid if pressure build-up in the room exceeds the counterpressure and the flow resistance in the air supplies, and, thus, both vent openings provide for pressure relief. In the evaluation of possible smoke spread the counterpressure is presupposed to be 100 Pa. If the pressure increase exceeds 100 Pa only in the case of "1 opening" (not on case of “2 opening”), and there will be no smoke spread via the air supply channel to other rooms. If there shall be any severe smoke spread via the ventilation plant to other rooms, the pressure increase in the room in case of 2 openings has to exceed 100 Pa.

Table 2.3: The input data for the calculation of fire load densities, temperature loads and pressure build-up in case of fire in 17 rooms on the Troll C Platform. All data are received from Norsk Hydro /5/.

Area (room no. and description)	Length x Width x Height (m)	Inner sur-face area of the room (m^2)	Ventil-ation rate. (m^3/s)	Effective diameter of the ventil-ation openings (mm)	Weight of combustible materials: Light fixtures (kg)	Cables (kg)	Panels (kg)	Other combustibles (kg or liter)
L.I.R. 1	7.9 x 7.2 x 3.5	207	0.097	160	6	792	3325	
HVAC (port aft)	10.4 x 9.6 x 3.5	341	0.139	200	9	353	0	
HVAC (starb aft)	10.4 x 9.6 x 3.5	341	0.167	200	11	183	0	
L.I.R. 2	7.9 x 7.2 x 3.5	207	0.097	160	6	792	2100	
Generator control room	10.4 x 8 x 3.5	295	0.861	400	15	1680	5800	100 kg paper
HVAC (port outer fwd col)	8.7 x 8 x 3.5	239	0.097	160	6	218	0	
HVAC (port inner fwd col)	8.7 x 8 x 3.5	186	0.069	160	8	367	50	
HVAC (starb outer fwd col)	6.8 x 8 x 3.5	195	0.097	160	9	332	50	
HVAC (starb inner fwd col)	8.7 x 8 x 3.5	239	0.097	160	8	400	0	
Water inj. h.v. trafo room	12 x 20 x 7	928	0.278	200	10	840	0	500 liter lube oil and 10 liter solvents[1]
Process utilities	7.9 x 7.2 x 2.8	187	0.083	160	6	218	0	
HVAC (port mid)	8 x 14.4 x 7	544	0.167	200	10	783	0	100 paper
H.V. Switch room	12.8 x 16 x 7	813	0.639	400	10	3360	860	
HVAC (starb. mid.)	8 x 14.4 x 7	544	0.167	200	10	664	0	100 paper
Electrical room	6.8 x 8 x 3.5	195	0.583	315	11	658	5920	
HVAC (port outer fwd. col. low.d.)	8.7 x 8 x 3.5	239	0.097	160	6	291	0	
HVAC (port outer fwd. col. low.d.)	8.7 x 8 x 3.5	239	0.097	160	6	291	0	

1 *500 l lube oil corresponds approximately to 1000 kg of paper due to the fact that paper has a heat of combustion (in kJ/kg) which is roughly half the value of lube oil. However, 10 l of solvents corresponds roughly to 10 kg of paper, since the heat of combustion of solvents and paper is approximately equal. Consequently, 500 l of lube oil and 10 l of solvents corresponds to 1010 kg of paper. This value is used as the fire load of the Water inj. h.v. trafo room for the calculation of the fire load density of the room..*

Table 2.4: The main input data for calculation of fire and temperature loads of the 17 rooms on the Troll C Platform and the results with respect to max. temperature loads as well as the time of max. temperature load of the actual areas

Fire Room (room no. and description)	Length x Width x Height (m)	Ventilation rate (m^3/s)	Equivalent opening area[1] (m^2)	Equivalent opening height = width[2] (m)	Total fire load of the area (MJ)	Total fire load density of the area (MJ/m^2)	Max. temperature load (°C)	Time of max. temperature load (min.)
L.I.R. 1	7.9 x 7.2 x 3.5	0.097	0.31	0.56	94829	458.11	69.7	10.5
HVAC (port aft)	10.4 x 9.6 x 3.5	0.139	0.42	0.65	8326	24.42	65.8	11
HVAC (starb aft)	10.4 x 9.6 x 3.5	0.167	0.49	0.70	4462	13.09	74.8	10
L.I.R. 2	7.9 x 7.2 x 3.5	0.097	0.31	0.56	66654	322.00	69.7	10.5
Generator control room	10.4 x 8 x 3.5	0.861	1.80	1.34	174685	592.15	200.8	15
HVAC (port outer fwd col)	8.7 x 8 x 3.5	0.097	0.31	0.56	5152	21.56	68.5	11
HVAC (port inner fwd col)	8.7 x 8 x 3.5	0.069	0.24	0.49	9775	52.55	50.6	10.5
HVAC (starb outer fwd col)	6.8 x 8 x 3.5	0.097	0.31	0.56	8993	46.12	71.6	10
HVAC (starb inner fwd col)	8.7 x 8 x 3.5	0.097	0.31	0.56	9384	39.26	68.5	10.5
Water inj. h.v. trafo room	12 x 20 x 7	0.278	0.73	0.85	42780	46.10	53.4	10.5
Process utilities	7.9 x 7.2 x 2.8	0.083	0.28	0.53	5152	27.55	73.5	10.5
HVAC (port mid)	8 x 14.4 x 7	0.167	0.49	0.70	20539	37.76	54.8	10.5
H.V. Switch room	12.8 x 16 x 7	0.639	1.42	1.19	97290	119.67	85.6	13.5
HVAC (starb. mid.)	8 x 14.4 x 7	0.167	0.49	0.70	17802	32.72	54.8	9.5
Electrical room	6.8 x 8 x 3.5	0.583	1.32	1.15	151547	777.16	207.3	13.5
HVAC (port outer fwd. col. low.d.)	8.7 x 8 x 3.5	0.097	0.31	0.56	6831	28.58	68.5	10.5
HVAC (port outer fwd. col. low.d.)	8.7 x 8 x 3.5	0.097	0.31	0.56	6831	28.58	74.7	10.5

1 That is, the opening area which give the same ventilation rate in case of natural, fire induced ventilation through this opening, in case of a ventilation controlled fire in the room.

2 That is, the width and height of the equivalent opening area assuming a quadratic ventilation opening area through which natural ventilation takes place.

Table 2.5: The main input data to the calculations of pressure build-up, the maximum temperature and maximum pressure increase due to thermal expansion as a result of fire in 17 rooms on the Troll C Platform. The latter characteristic is calculated in case of the exhaust opening and in case of both the exhaust opening and the air supply opening are representing the total the leakage area for pressure relief. It has to be pointed out that the effects of ventilation is neglected in these calculations, due to the fact that the pressures of the ventilation channels to the rooms are not known.

Fire Room (room no. and description)	Length x Width x Height (m)	Volume of the Room (m^3)	Effective supply/ exhaust opening diameter (mm)	Pressure relief opening area (1 open.) (m^2)	Ratio of room volume to pressure relief area (m)	Fire load density (see Table 2.4) (MJ/m^2)	Max. smoke gas temperature in the room (°C)	Max. pressure increase in case of one (1) and two (2) openings (Pa) (1)	(2)	Time to max. value of temperature and pressure (min.)
L.I.R. 1	7.9 x 7.2 x 3.5	199.1	160	0.0201	9901	458.11	69.7	204.9	52.2	10.5
HVAC (port aft)	10.4 x 9.6 x 3.5	349.4	200	0.0314	11123	24.42	65.8	223.4	57.1	11
HVAC (starb aft)	10.4 x 9.6 x 3.5	349.4	200	0.0314	11123	13.09	74.8	302.9	77.6	10
L.I.R. 2	7.9 x 7.2 x 3.5	199.1	160	0.0201	9901	322.00	69.7	204.9	52.2	10.5
Generator control room	10.4 x 8 x 3.5	291.2	400	0.1257	2317	592.15	200.8	100.7	25.2	15
HVAC (port outer fwd col)	8.7 x 8 x 3.5	243.6	160	0.0201	12116	21.56	68.5	290.4	74.6	11
HVAC (port inner fwd col)	8.7 x 8 x 3.5	243.6	160	0.0201	12116	52.55	50.6	131.6	33.5	10.5
HVAC (starb outer fwd col)	6.8 x 8 x 3.5	190.4	160	0.0201	9470	46.12	71.6	199.8	50.8	10
HVAC (starb inner fwd col)	8.7 x 8 x 3.5	243.6	160	0.0201	12116	39.26	68.5	290.4	74.6	10.5
Water inj. h.v. trafo room	12 x 20 x 7	1680.0	200	0.0314	53476	46.10	53.4	2082.5	679.1	10.5
Process utilities	7.9 x 7.2 x 2.8	159.3	160	0.0201	7921	27.55	73.5	149.8	37.9	10.5
HVAC (port mid)	8 x 14.4 x 7	806.4	200	0.0314	25669	37.76	54.8	675.5	183.5	10.5
H.V. Switch room	12.8 x 16 x 7	1433.6	400	0.1257	11408	119.67	85.6	433.1	111.7	13.5
HVAC (starb. mid.)	8 x 14.4 x 7	806.4	200	0.0314	25669	32.72	54.8	675.5	183.5	9.5
Electrical room	6.8 x 8 x 3.5	190.4	315	0.0779	2443	777.16	207.3	118.2	29.7	13.5
HVAC (port outer fwd. col. low.d.)	8.7 x 8 x 3.5	243.6	160	0.0201	12116	28.58	68.5	290.4	74.6	10.5
HVAC (port outer fwd. col. low.d.)	8.7 x 8 x 3.5	243.6	160	0.0201	12116	28.58	68.5	290.4	74.6	10.5

3. EVALUATIONS

3.1 The Resulting Temperature Load and Pressure Build-up

3.1.1 Temperature Load

From Table 2.4 it appears that the parameters affecting the temperature loads are primarily the fire load density and the air supply to the room. Generally, high fire load densities and a high air supply rates will result in high temperatures in the rooms (e.g. in Generator Control Room and in Electrical Room). This because a high air supply rate is capable of sustaining a larger fire in the room.

However, if the fire load is high and the air supply rate is low, which is the case for L.I.R. 1, the temperature load will be low. This because the low air supply rate will restrict the rate of heat release within the room. Generally, a high air supply rate is usually more important, for attaining a high temperature load, than a high fire load. The fuel load will usually be abundant anyway, even in these rooms with rather restricted fuel load. This is, however, not at all the case for the air supply, which is rather restricted for all the 17 rooms of this study.

The time for the occurrence of the maximum temperature loads is for all room approximately 10 minutes after the start of the fire. This applies generally, apart from two rooms, i.e. HVAC (starb. mid.) and Electrical room, in which this occurs somewhat later, i.e. at 13.5 minutes after the start of the fire.

3.1.2 Pressure Build-up

It appears from the curves in Appendix A that there is a very close relationship between the temperature and pressure build-up. As shown in the curves in Appendix A, the pressure build-up follows the temperature development rather closely. The time for the occurrence of the maximum pressure loads coincides with the occurrence of the maximum temperature load. That is, the times for the maximum pressure loads are for all room approximately 10 minutes after the start of the fire. This applies generally, apart form two rooms. That is, HVAC (starb. mid.) and Electrical room, in which this occurs somewhat later, i.e. at 13.5 minutes after the start of the fire.

It is, however, not only the temperature of the room that determines the pressure build-up in a room. The pressure relief area of the room is certainly also a very important parameter for the pressure build-up, in addition to the volume of the room. The pressure relief area is either equal to the effective exhaust area (i.e. the upper curve in the curves in Appendix A), or it is equal to the opening area of the exhaust and air supply vent. The latter area is valid, as already mentioned, only if the pressure build-up exceeds the counterpressure in the air supply channel.

In fact, the main parameters affecting the pressure build-up due to restricted thermal expansion are the *temperature load* and the *ratio of room volume to the pressure relief area*. This ratio will from now on only be termed as the *"ratio"*. A high value of the *ratio* implies that a large volume of smoke gases at a certain temperature has to be relieved through a small pressure relief area. Consequently, the pressure build-up will be rather high in case of high values of the *ratio*. From the results of this study it seems as if a high value of the ratio is definitely more important, for achieving a high pressure build-up, than a high temperature load.

It appears from Table 2.5 and the figures in Appendix A, that the pressure build-up is very dependent on whether one or two openings serve as the pressure relief area. The pressure build-up due to thermal expansion is in fact inversely proportional to the square of the pressure relief area. Consequently, when the pressure relief area is doubled, as in case of "2 openings", the pressure build-up is reduced to one-fourth of the pressure build-up in case of "1 opening" (see figures in Appendix A). From table 2.5 and the curves in Appendix A, one may see that this is true.

From Table 2.5 it appears that fortunately the areas with high values of the "ratio" and temperature load do not coincide. For example, one may see that the Water Injection H.V. Trafo Room has the highest ratio, but only one room has a lower maximum temperature load than this room. In spite of this, this room attains an extremely high-pressure build-up of 2082.5 Pa in case of only one opening, and 679.1 Pa in case of two openings. Likewise, the two rooms with the second highest ratio, i.e. the HVAC (port mid.) and HVAC (starb. mid.), have the third lowest temperature load. However, these two rooms attain a pressure as high as 675.5 Pa in case of one opening, and a pressure of 183.5 Pa in case of two openings.

Provided that the ratio is high enough, there will be a high-pressure build-up for even small temperature increases in the rooms. In the three above-mentioned examples, the temperature loads are only slightly above 50 °C, while the ratios of these rooms are as high as 53476 and 25669.

On the other hand, a high temperature load needs necessarily not to give a high-pressure build-up in the room due to thermal expansion, if the "ratio" is low. The rooms with the highest temperature loads, i.e. HVAC (port outer fwd. col.) and Electrical room, have a temperature load of only slightly above 200 °C. However, since the "ratio" is less than 2500, i.e. less than one-tenth of the ratios of three above mentioned rooms, pressure build-up of these rooms are only 100.7 and 118.2 Pa (one opening), respectively.

3.1.3 The Effects of Pressure Build-up on the Air Supply Rate and the Fire

As shown in the diagrams in Appendix A, the temperature, as well as the pressure, increase rapidly after the start of the fire. This rapidly increasing counterpressure in the air supplies, will also result in a decreased rate of air supply to the room. Due to the already mentioned high sensitivity of the heat release to the rate of air supply, this will result in a decreased rate of heat release in the fire room, which again will lead to a decreased temperature load. This is however, not taken into account in the calculations the resulting temperature development.

For the calculation method used in here, the fire development is calculated independently of the pressure build-up in the room. However, in a real fire situation, the pressure build-up will affect the air supply rate to the fire, and, thus, the resulting temperature load of the room. The fire will probably suffer from oxygen starvation before the pressure reaches its maximum value. Thus, the maximum calculated values of the pressure build-up will in a real fire situation probably be lower than estimated here, due to the effects of pressure build-up on the air supply rate. However, the calculated results are an indication of the maximum pressure build-up in all-welded and forced ventilated compartments, even though this pressure probably is somewhat overestimated.

When the fire begins to suffer from oxygen starvation, the rate of heat release will decrease. Thus temperature and pressure gradients will decrease correspondingly. This will continue until the pressure has decreased so much that the air supply rate again is capable of sustaining a more severe fire. Thus, the temperature and pressure will increase once more, until the fire again will suffer from oxygen starvation.

In this way the temperature and pressure will oscillate between a maximum and a minimum value. The time period between the maximum and the minimum value will depend on the insulated fraction of the boundaries of the fire room. If this insulation fraction is 0 %, this time period will be short. On the other hand, if the insulation fraction is 100 %, this time period will be significantly longer. The latter is due to the fact that the heat loss of the fire room is low, and the temperature and pressure build-up in the room will decrease slowly.

Due to the rather severe effects of the pressure build-up on the air supply rate and pressure build-up, as previously discussed, it can be concluded that the real values of the maximum fire temperature and pressure build-up in table 2.5 are conservative estimates compared to real case.

3.1.4 The Effect of a Ventilation System in Operation on the Pressure Build-Up

As already mentioned pressure build-up in the room are calculated on the basis of a ventilation system not in operation. A question in this connection may be: To what extents will a ventilation system in operation affect the pressure build-up in a fire room, and in what direction? - positive or negative, i.e. a larger or a smaller pressure build-up?.

In this connection we have consulted ventilation expertise within SINTEF Energy (i.e. section for HVAC) /6/. Our own assumptions have by this contact to a large extent been confirmed. *That is, a ventilation system in operation will most likely have an insignificant or no effect on pressure build-up due to restricted thermal expansion within the room.*

3.1.5 The Effect of Balancing Dampers on the Calculated Pressure Build-Ups

The balancing dampers in ventilation channels will reduce the sectional area of the given effective supply/exhaust opening diameter of the ventilation channels too a certain degree. This will have an effect on the calculated pressure build-up by increasing the pressure build-up compared to the calculated pressure build-ups, where this reduction of the sectional area is neglected. However, it has already been pointed out that the calculated results are rather conservative, due to the fact that the effect of the pressure build-up on the air supply rate and the fire is not taken into account in these calculations. Consequently, it is expected that the results are still rather conservative, even though the effect of the narrowing of the sectional area of the ventilation channels (due to the balancing dampers) is taken into consideration.

3.2 Smoke Spread

3.2.1 Exhaust System

The exhaust system will, according to Jensen /5/, hardly cause smoke spread to other rooms via the ventilation system. All the smoke gases will effectively and safely be evacuated via the exhaust system. However, this applies primarily to moderate pressure build-ups, i.e. below 500-800 Pa according to the calculations in this report. The highest-pressure build-up calculated in this study is in the Water Inj. H.V. Trafo Room. Since, the maximum pressure increase in case of two openings is of 679.1 Pa, there may be smoke spread through both the exhaust and air supply channel from this room. However, for all the other 16 rooms the pressure is too low to cause smoke spread via the exhaust system. *Consequently, it can be concluded that there will be smoke spread via the exhaust system only in case of fires in the Water Inj. H.V. Trafo Room.*

3.2.2 The Air Supply System

Smoke spread via the air supply system will occur, as already stated when pressure build-up due to thermal expansion in the room exceeds the counterpressure in the air supply channel. If this is the case, there will be smoke spread through the air supply channel primarily to rooms, which are located *downstream* (with respect to the air supply system) of the room. Consequently, there will be pressure relief through both the exhaust and the air supply channel, and the pressure relief area is doubled.

As it appears from Table 2.5 and the figures in Appendix A, pressure build-up in the room will fall dramatically (i.e. by one-fourth), when there is pressure relief through two openings instead of only one opening. In this evaluation we will presuppose that the pressure in the air supply channels is approximately 100 Pa, and that only rooms with pressure build-up exceeding this value, will attain smoke spread via the air supply system.

Table 2.6 shows the evaluated degree of smoke spread from the different rooms on the Troll C platform in case of a fire in the rooms. That is, *no* and *insignificant* smoke spread, as well as smoke spread *to a certain degree* and *to high degree* to other rooms. The conservative estimates of pressure build-up in Table 2.6 are also taken into account in these evaluations (refer section 3.1.3). The smoke spread will in any case not be continuos, but rather intermittent.

Table 2.6: An evaluation of the possibilities of smoke spread to other rooms, via the air supply system. The assumed effects of the flow resistance at the inlet to as well as in the exhaust and air supply channels to the fire room are also taken into consideration.

Fire room	Degree of smoke dispersion to other rooms via the ventilation system:				Max. gas temp-rature	Max. pressure increase in case of	
	To a high degree	To a Certain degree	Insigni-ficant	No smoke spread	(°C)	One open-ing (Pa)	Two open-ings (Pa)
L.I.R. 1				x	69.7	204.9	52.2
HVAC (port aft)				x	65.8	223.4	57.1
HVAC (starb aft)				x	74.8	302.9	77.6
L.I.R. 2				x	69.7	204.9	52.2
Generator control room				x	200.8	100.7	25.2
HVAC (port outer fwd col)				x	68.5	290.4	74.6
HVAC (port inner fwd col)				x	50.6	131.6	33.5
HVAC (starb outer fwd col)				x	71.6	199.8	50.8
HVAC (starb inner fwd col)				x	68.5	290.4	74.6
Water Inj. H.V. Trafo Room	x				53.4	2082.5	679.1
Process Utilities				x	73.5	149.8	37.9
HVAC (port mid)		x			54.8	675.5	183.5
H.V. Switch Room			x		85.6	433.1	111.7
HVAC (starb. mid.)		x			54.8	675.5	183.5
Electrical Room				x	207.3	118.2	29.7
HVAC (port outer fwd. col. low.d.)				x	68.5	290.4	74.6
HVAC (port outer fwd. col. low.d.)				x	68.5	290.4	74.6

From table 2.6 it appears that there will be smoke spread to a high degree to other rooms both via the exhaust system and the air supply system for the Water Inj. H.V. Trafo Room. There will be smoke spread to a certain extent via the air supply system of the rooms HVAC (port mid.) and HVAC (starb. mid.). The pressure build-ups of the latter two rooms are 675.5 and 183.5 Pa in case of pressure relief through one and two openings, respectively.

The three rooms mentioned above will be supplied with more or less large amounts of highly toxic smoke gases of temperature only slightly above 50 °C. Thus, the smoke spread to these three rooms may presumably cause incapacitation of platform personnel after some time, if evacuation of the this room is hindered.

3.3 Fire Spread

Fire spread may take place either by *loss of integrity* (penetration of smoke gases) or by *loss of heat insulation*. In the latter case fire spread may occur, either by radiation from the heated surfaces of the channel (i.e. the unexposed side of the heated ventilation channel due to the flow of hot smoke). If this shall be prevented, the maximum and average temperature increase on the exterior side of the heated ventilation channel shall not be higher than 180 and 140 °C, respectively. Thus, in rooms in which the calculated smoke gas temperature exceeds 140 °C, the ventilation channels have to be insulated correspondingly in order to prevent fire spread.

Loss of integrity (penetration of smoke gases) may occur if the fire gases spread to other rooms via the ventilation system. As already stated, smoke spread may occur if the overpressure due to thermal expansion in the fire room exceeds the counterpressure in the ventilation channels. If, at the same time, the temperature of the smoke gases is high enough to ignite easily ignitable materials in the room, the fire may spread to this room. The minimum smoke gas temperature, which is capable of igniting a material, is very dependent on the type of the material. For most combustible materials this minimum temperature is between 300-400 °C /7/. In case of prolonged exposure, this temperature limit may be even lower than this.

However, the gases may be cooled significantly in the ventilation channels before they enter the room, and after being discharged into the room and mixed with the air in the room. A critical value of at least of 400 °C will be chosen as the maximum smoke gas temperature that can be tolerated in the room if loss of integrity by smoke spread via the ventilation system. For fire spread due to loss of insulation (for non-insulated channels) a corresponding critical value of at least 200 °C may be chosen. For insulated channels the smoke gas temperature must be significantly larger than 200 °C if a loss of insulation of the channels shall take place.

Since the maximum temperature of the actual rooms of this study is slightly above 50 °C, it may be concluded that these temperatures are far too low to cause fire spread via the ventilation system. However, there may be a severe smoke spread of highly toxic fire gases to other rooms in case of fire in the Water Inj. H.V. Trafo Room, and smoke spread to a certain degree in case of fire in the HVAC (port mid.) and HVAC (starb. mid.).

3.4 Measures to prevent smoke spread

3.4.1 Generally

There are in principle the following two ways of preventing smoke spread via the ventilation system if the pressure build-up is too high:

1. Increasing the diameter of the ventilation channels and the area of the vents
2. Installing fire dampers

3.4.2 Increasing the diameter of the ventilation channels

If the of the exhaust and air supply channel diameters are increased from 200 mm to 315 mm for the Water Inj. H.V. Trafo Room, the maximum pressure build-up in the room will decrease to 459.0 Pa and to 121.7 for pressure relief through one and two openings, respectively. These will probably lead to no or insignificant smoke spread to other rooms via the air supply system. If the diameters of these channels are increased to 400 mm, the corresponding pressure build-ups will be 185.1 and 47.4 Pa, and there will definitely not be no smoke spread to other rooms.

If the diameters of the ventilation channels to the rooms HVAC (port mid.) and HVAC (starb. mid.) are increased from 200 mm to 250 mm, the corresponding pressures as mentioned above will decrease to 295.1 and 47.4 Pa, and, thus, no smoke spread will take place via the ventilation system.

3.4.3 Installing Fire Dampers

An alternative to increasing the diameter of the ventilation channels, for preventing smoke spread, is to install fire dampers in the actual channels, primarily when the channel is passing through the fire partitions of the room.

Fire dampers are usually actuated when the gas temperature exceeds 67-70 °C.

In the three rooms, in which smoke spread may take place via the ventilation system, the maximum gas temperatures are only slightly above 50 °C. *The fire dampers will not be actuated, because of the fact that the maximum temperatures never will reach the actuation temperatures of the fire dampers.*

From the gas temperature and pressure development curves in Appendix A applying to Water Inj. H.V. Trafo Room it appears that the pressure build-up is still rather high, even for temperatures in the range 30-40 °C in the room. There will most likely be smoke spread even at this temperature level in the room. *Since this temperature level is rather close to the maximum temperatures in the room without any fire n the room, it will hardly be of any help to have a lower set point for the actuation temperatures of the fire dampers. The fire dampers in the ventilation channels may in such cases be actuated even at normal room conditions.*

Shutdown of the fire dampers must in these cases be actuated by other devices than heat detectors, e.g. smoke of flame detectors.

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APPENDIX A: Curves Showing the Temperature and Pressure Development in the Rooms as a Function of Time

On the subsequent pages in this there are curves showing the temperature and pressure developments as function of time in 21 room on the Troll C platform.

1. L.I.R. 1
2. HVAC (port aft)
3. HVAC (starb aft)
4. L.I.R. 2
5. Generator control room
6. HVAC (port outer fwd col)
7. HVAC (port inner fwd col)
8. HVAC (starb outer fwd col)
9. HVAC (starb inner fwd col)
10. Water inj. h.v. trafo room
11. Process utilities
12. HVAC (port. mid.)
13. H.V. Switch room
14. HVAC (starb. mid.)
15. Electrical room
16. HVAC (port outer fwd. col. low.d.)
17. HVAC (port outer fwd. col. low.d.)

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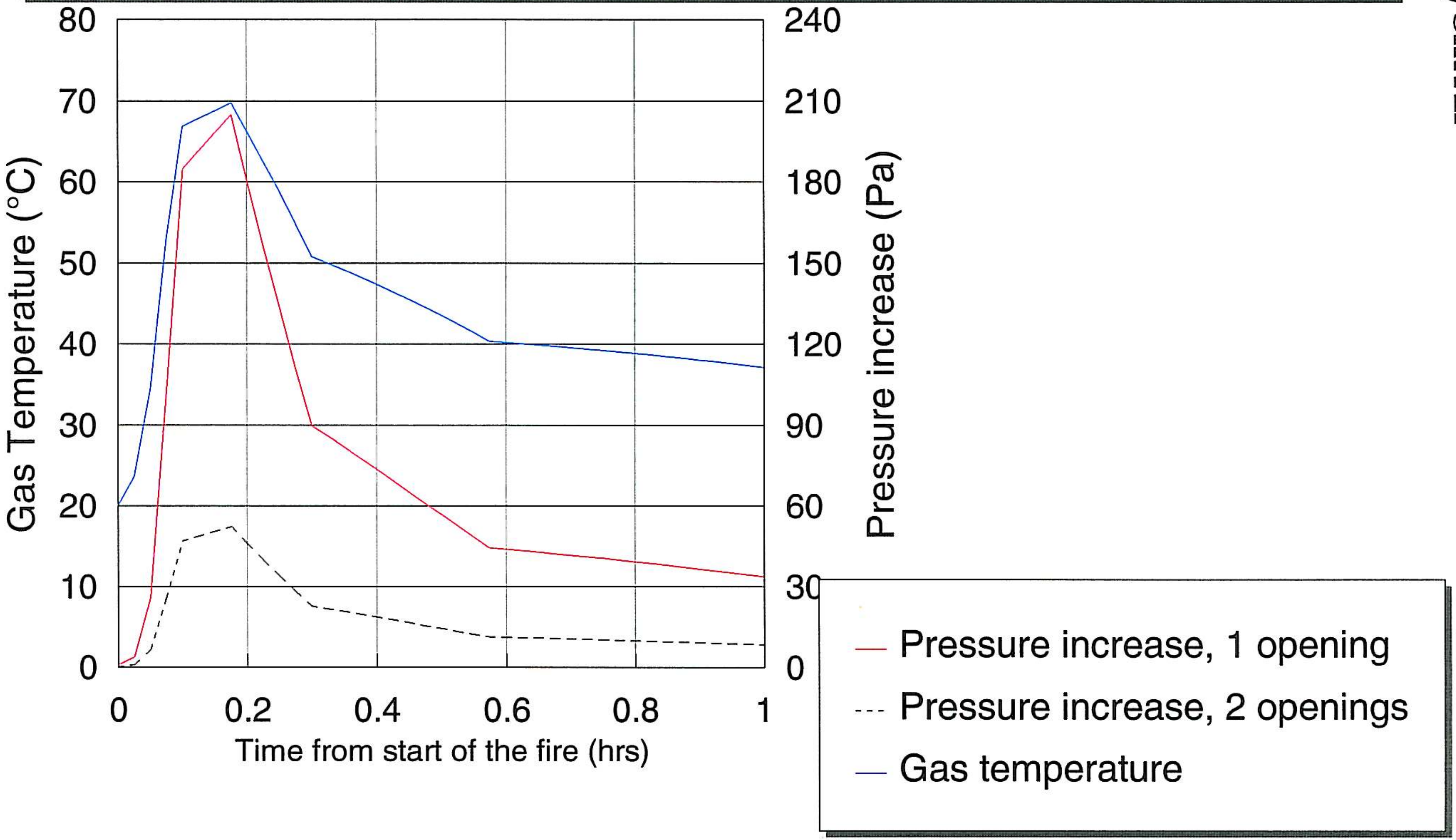
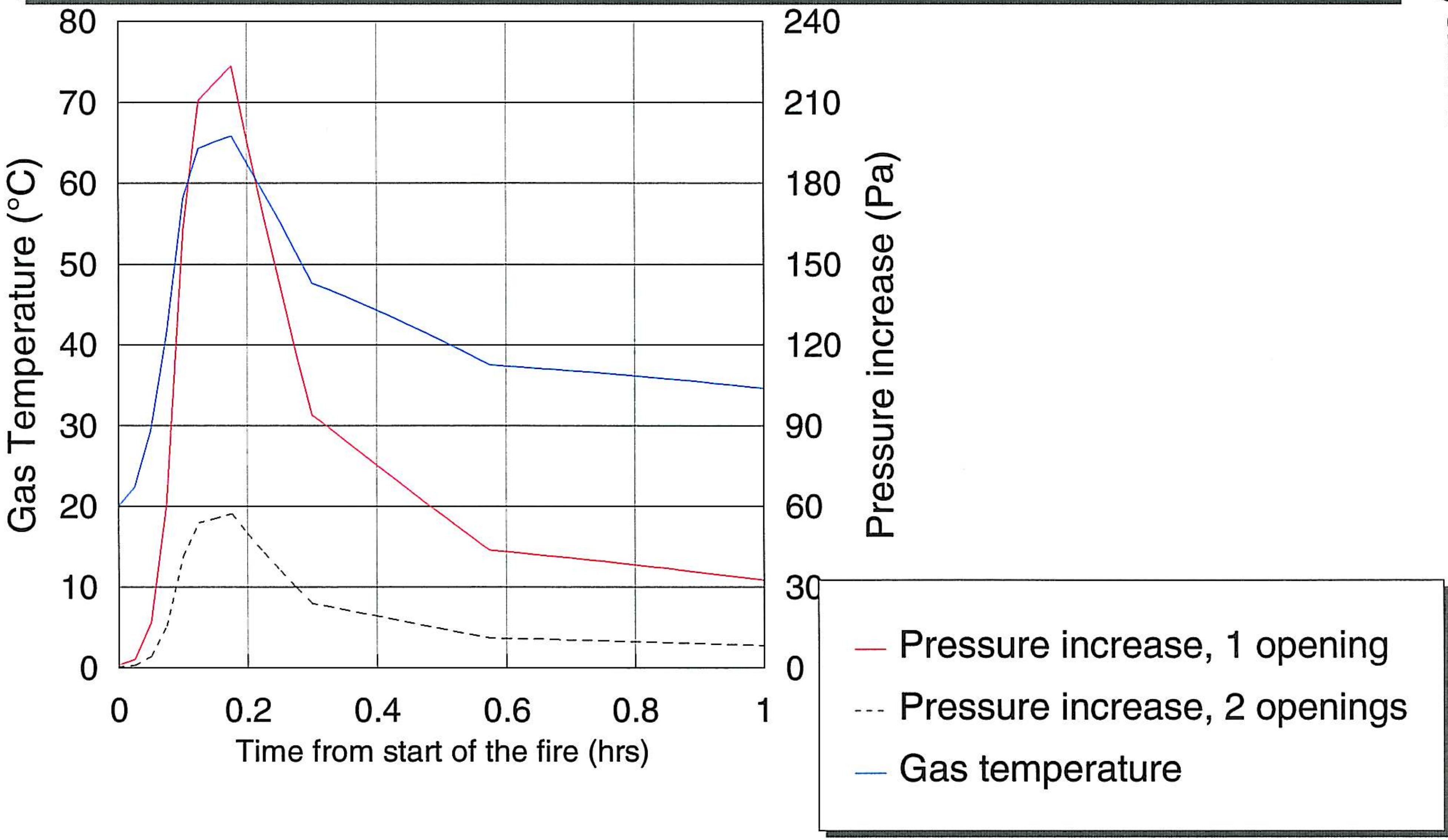
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in L.I.R. 1



Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (port aft)



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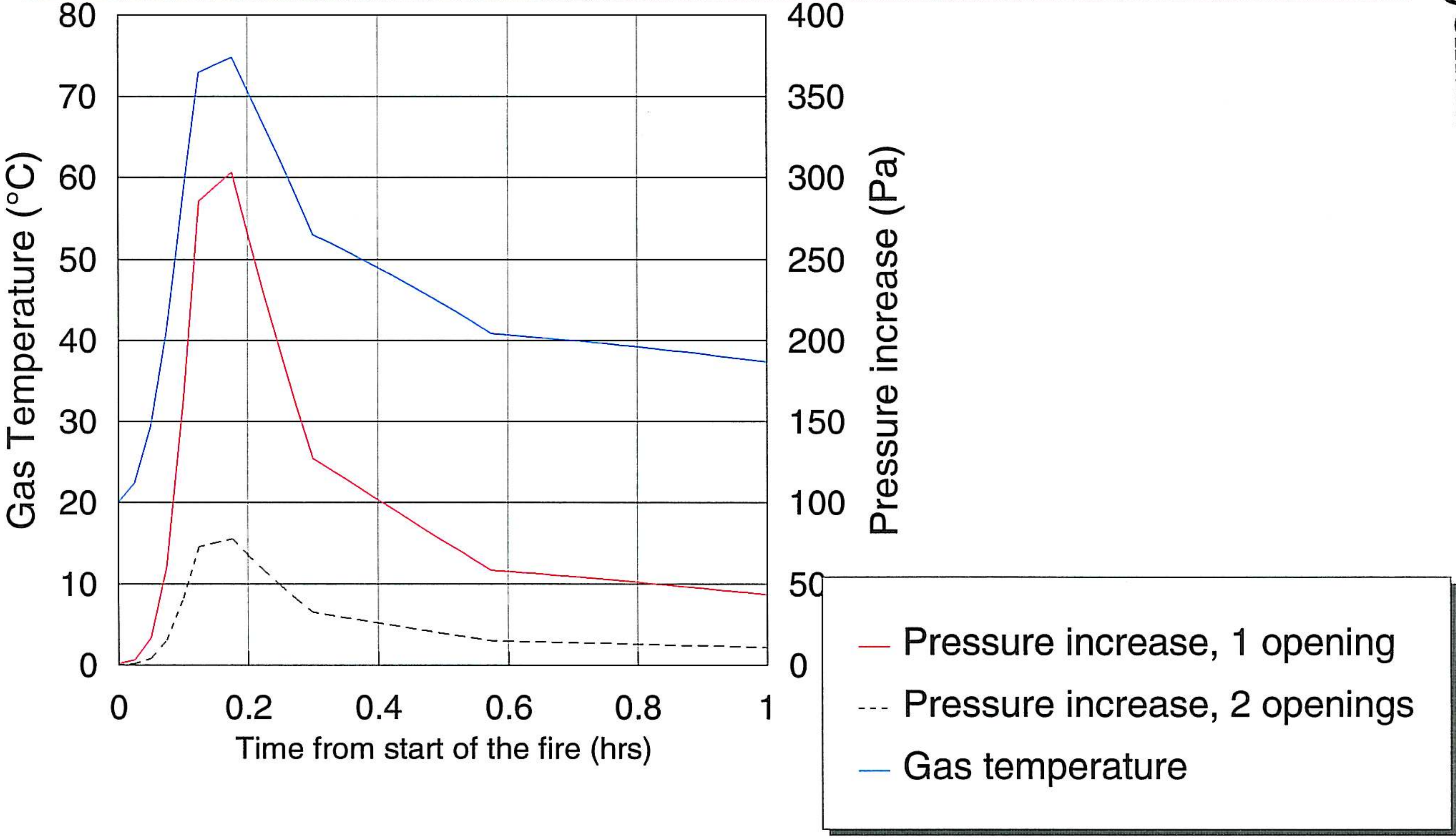
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (starb. aft)



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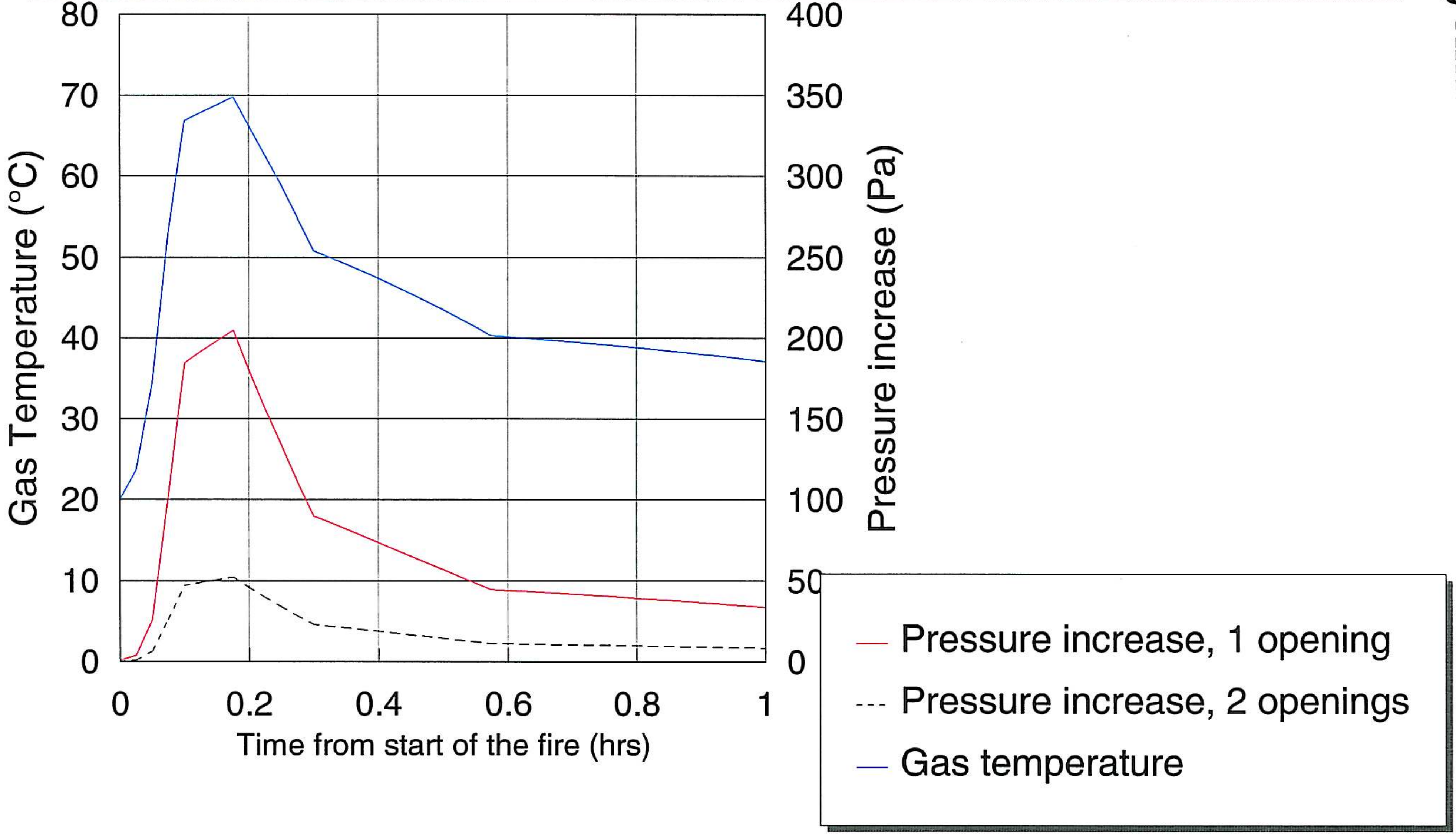
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in L.I.R. 2



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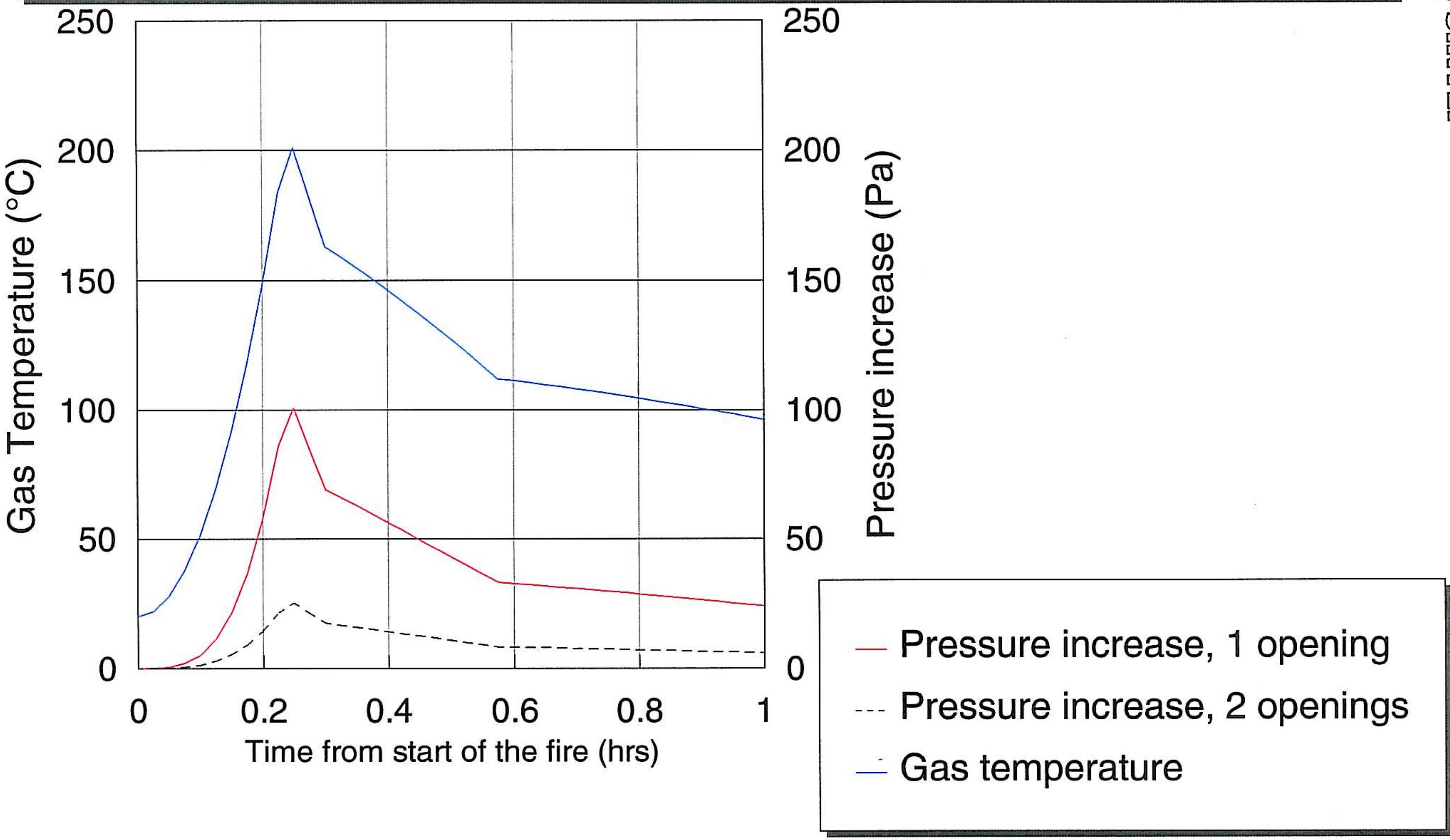
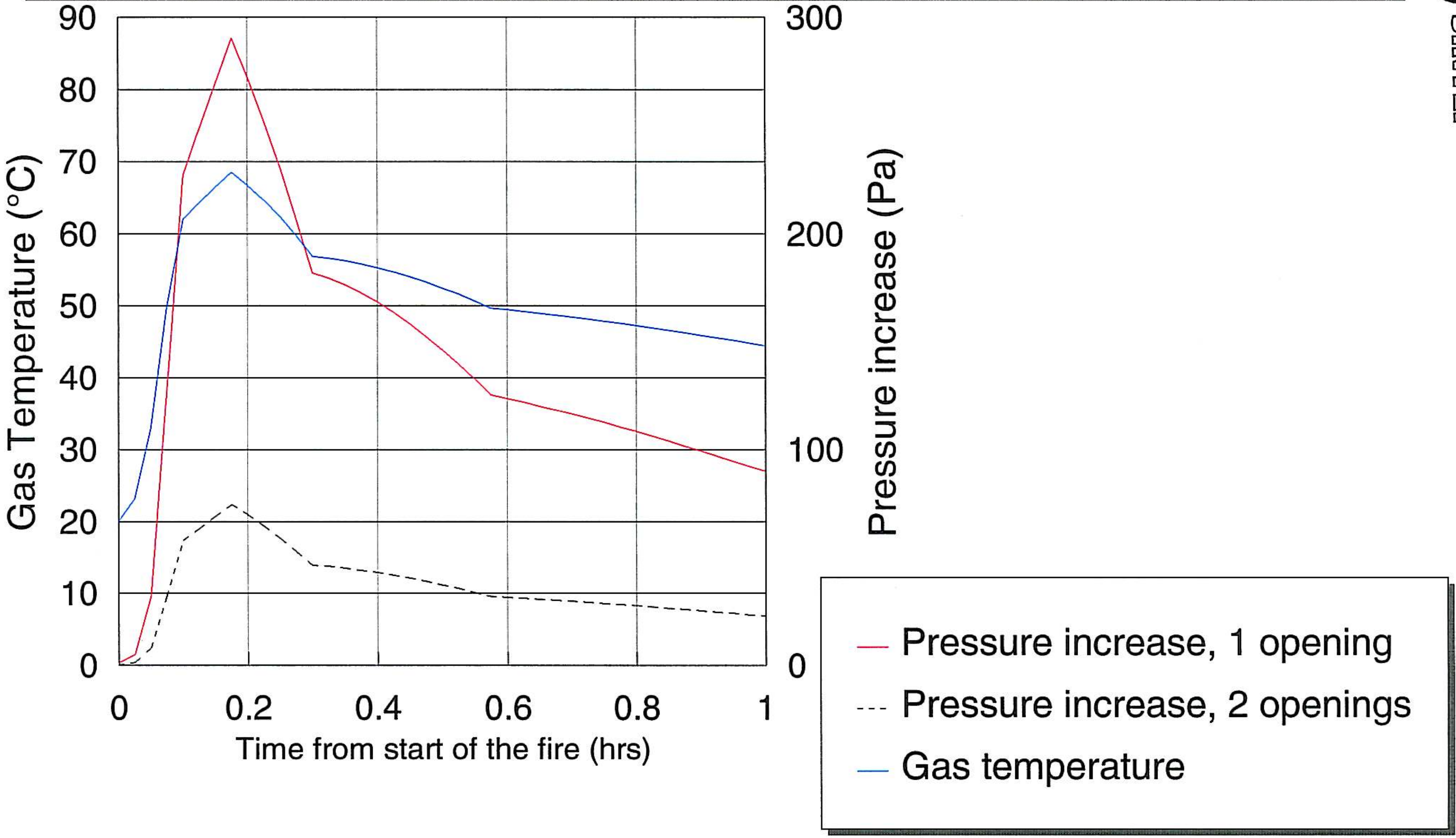
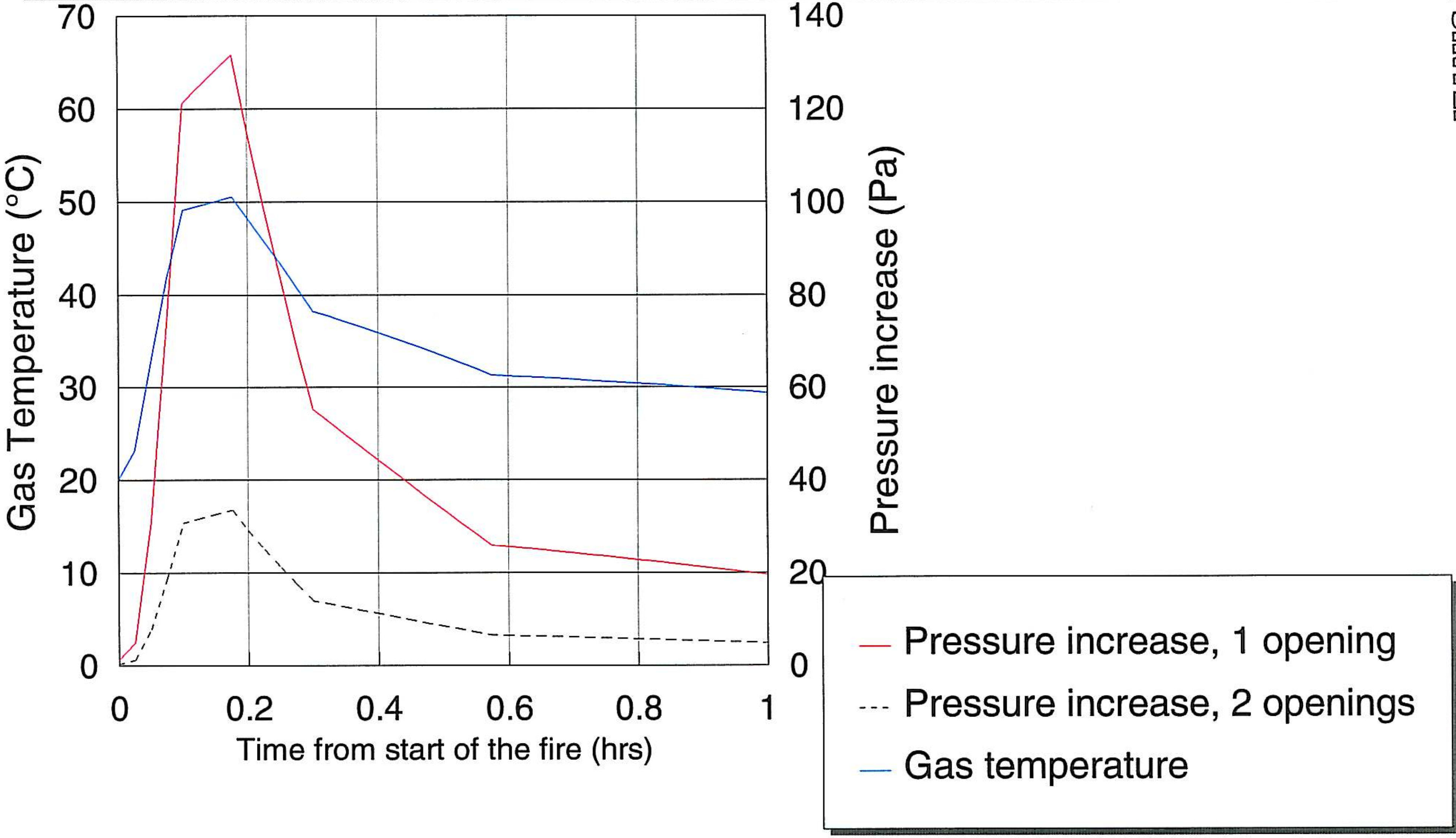
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in GENERATOR CONTROL ROOM



Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (port outer fwd. col.)



Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (port inner fwd. col.)



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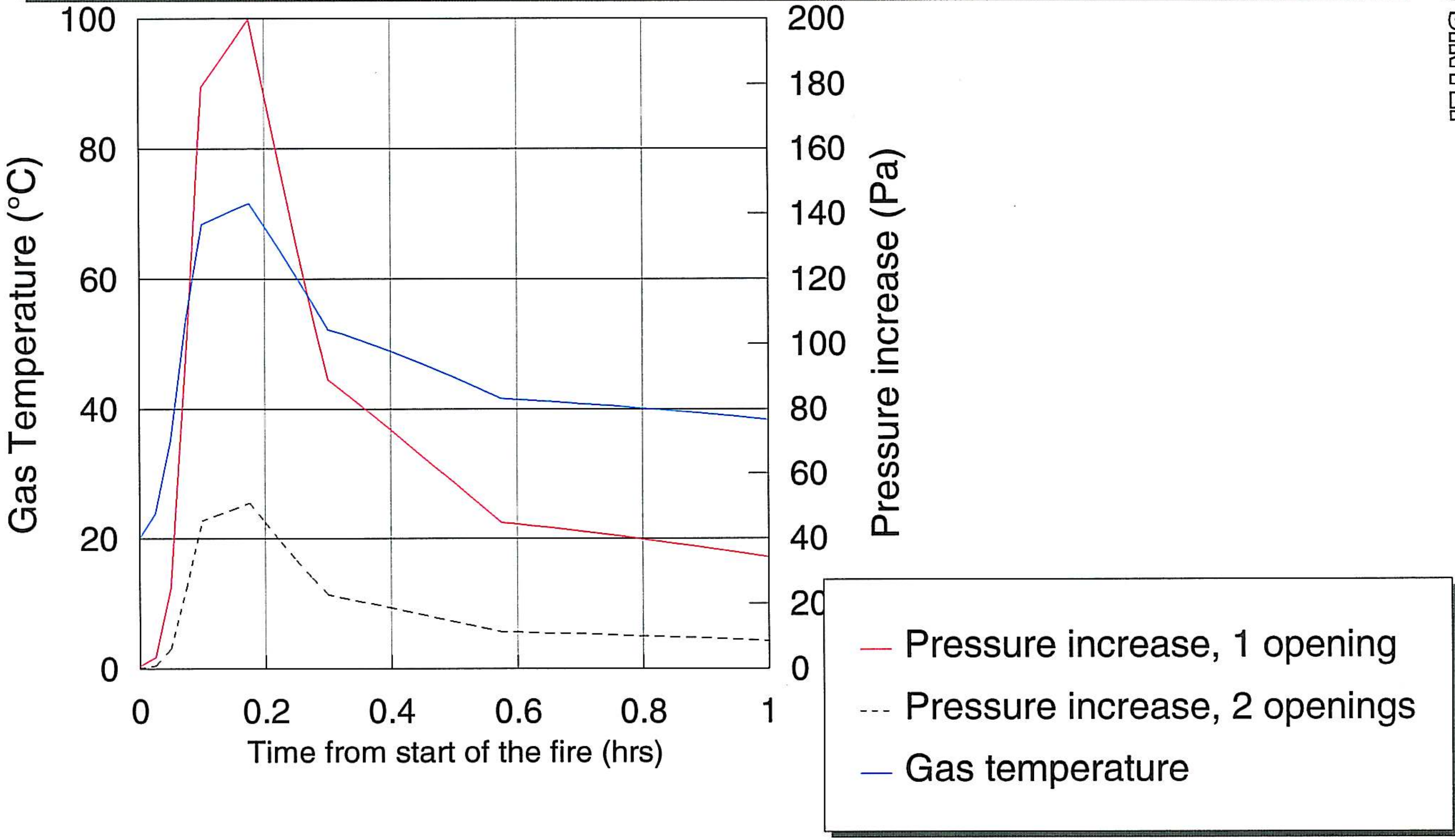
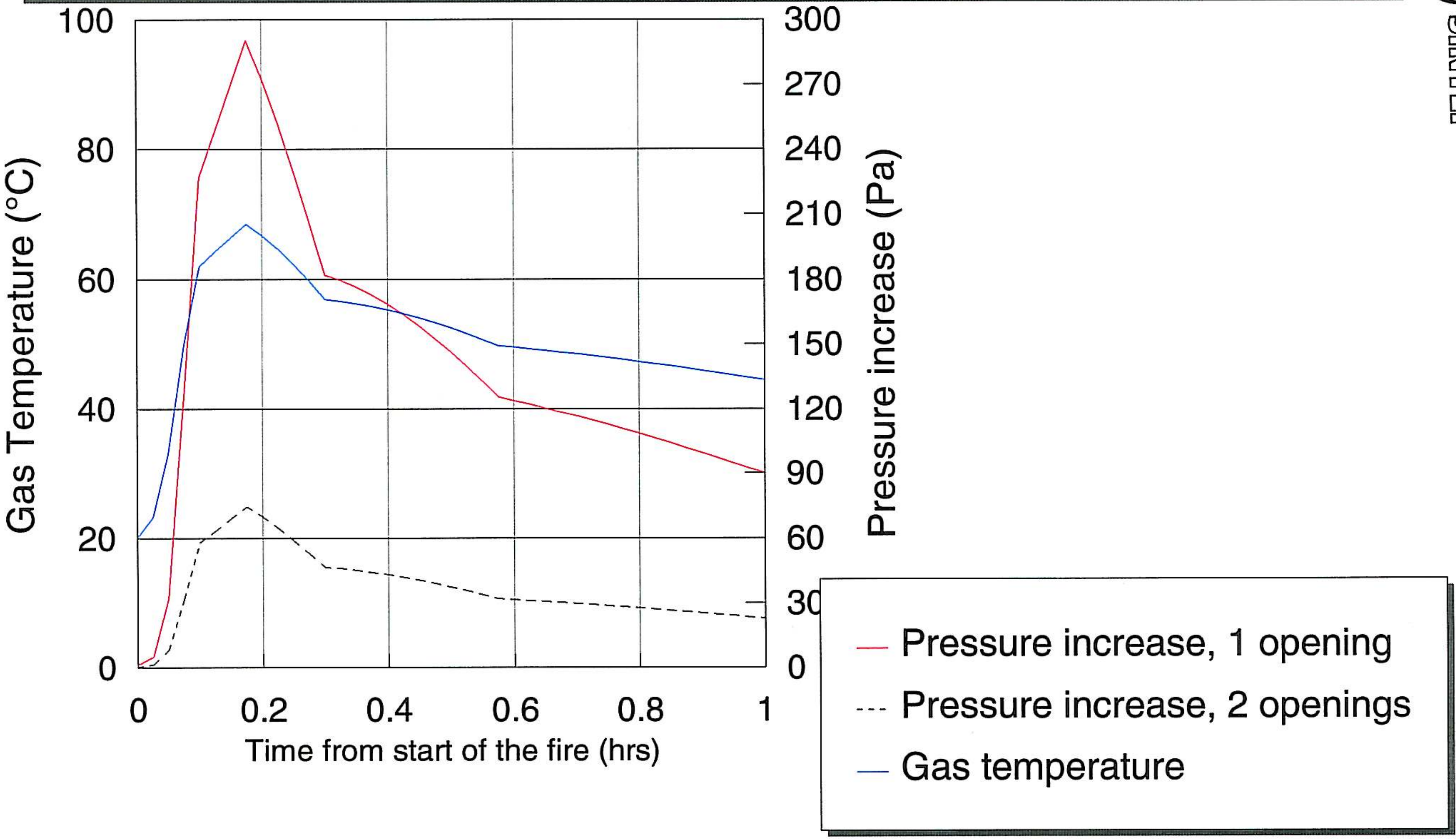
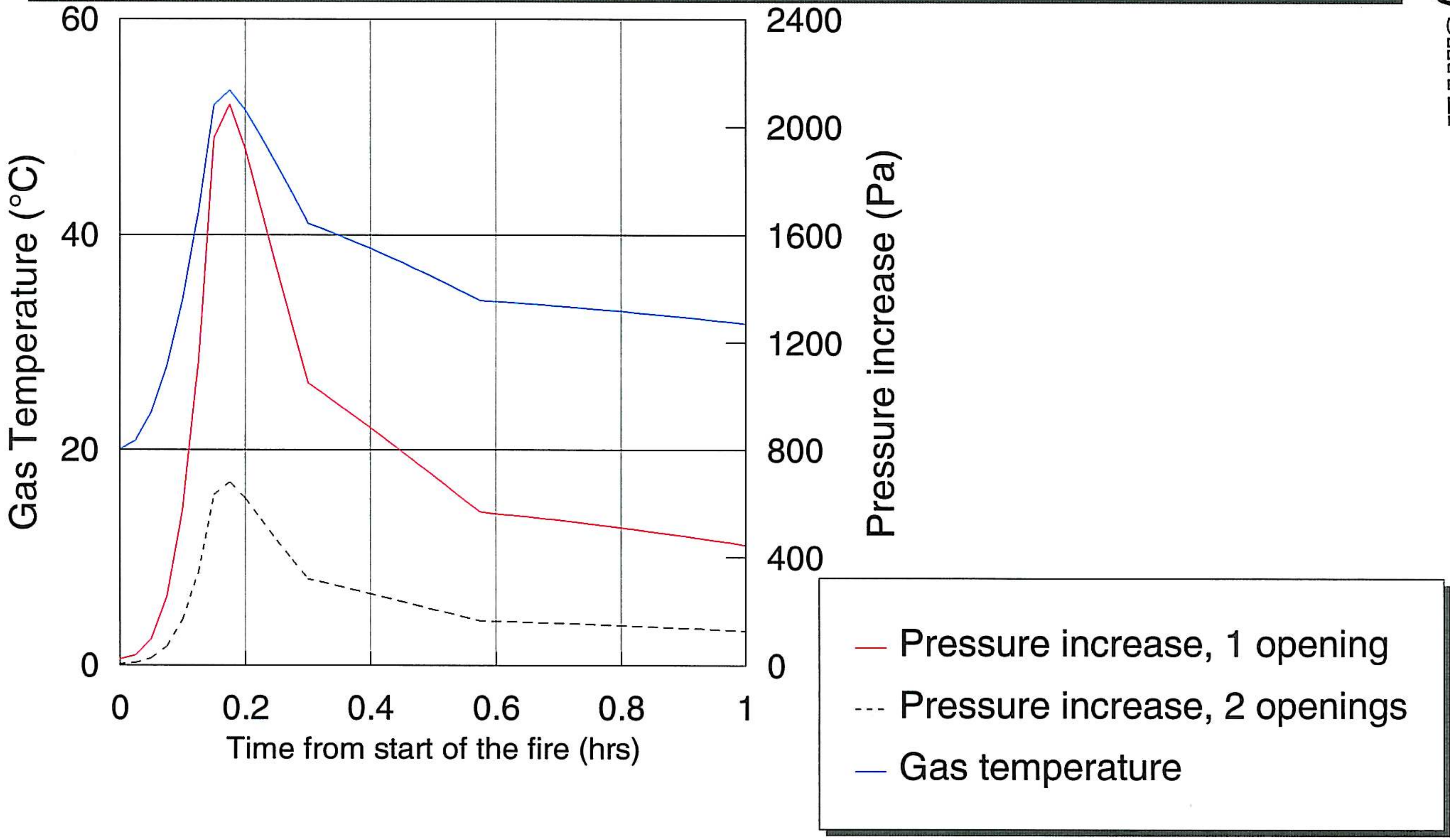
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (starb. inner fwd. col.)



Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (starb. outer fwd. col.)



Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in Water Inj. HV Trafo Room



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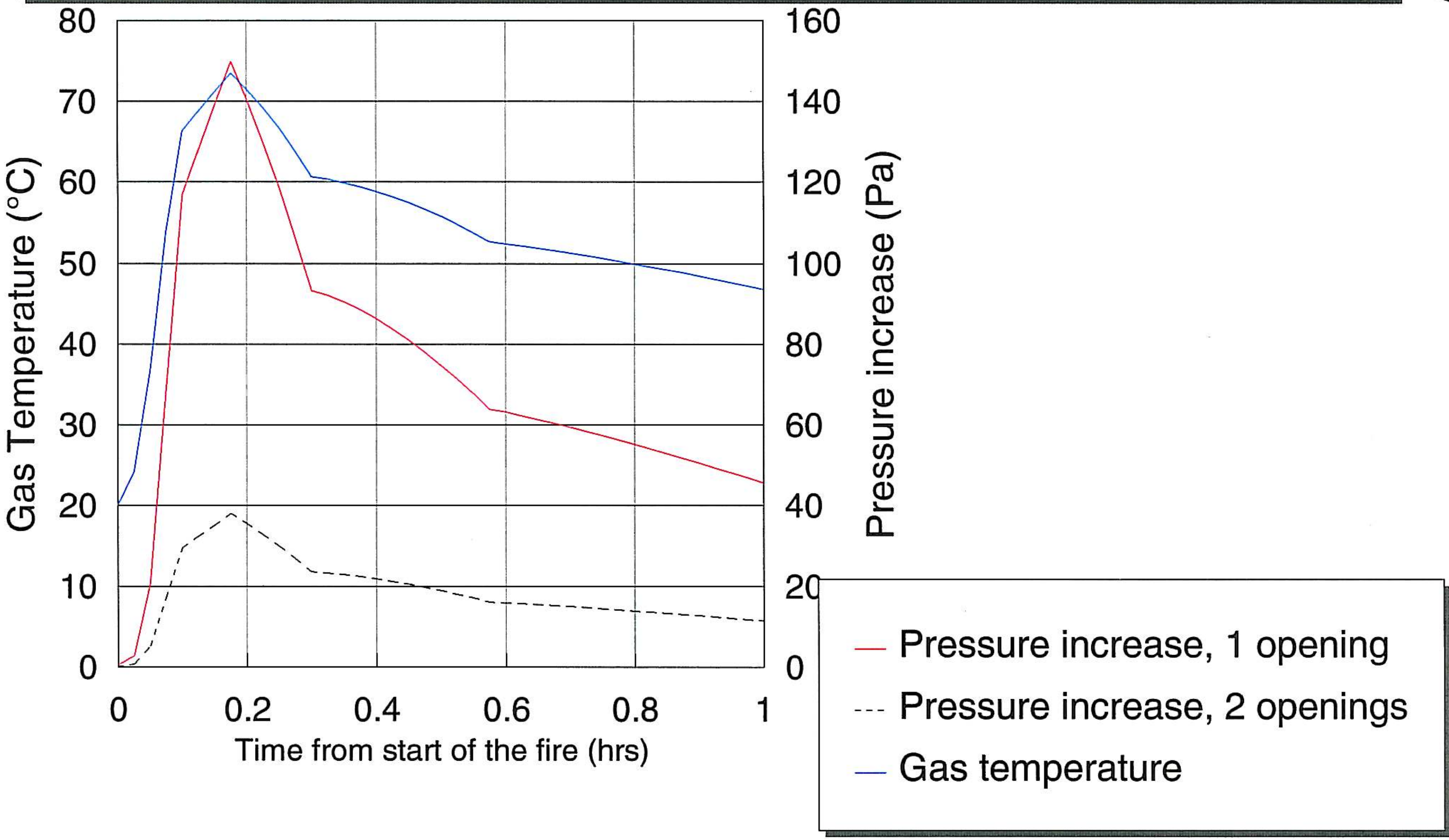
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in Process Utilities



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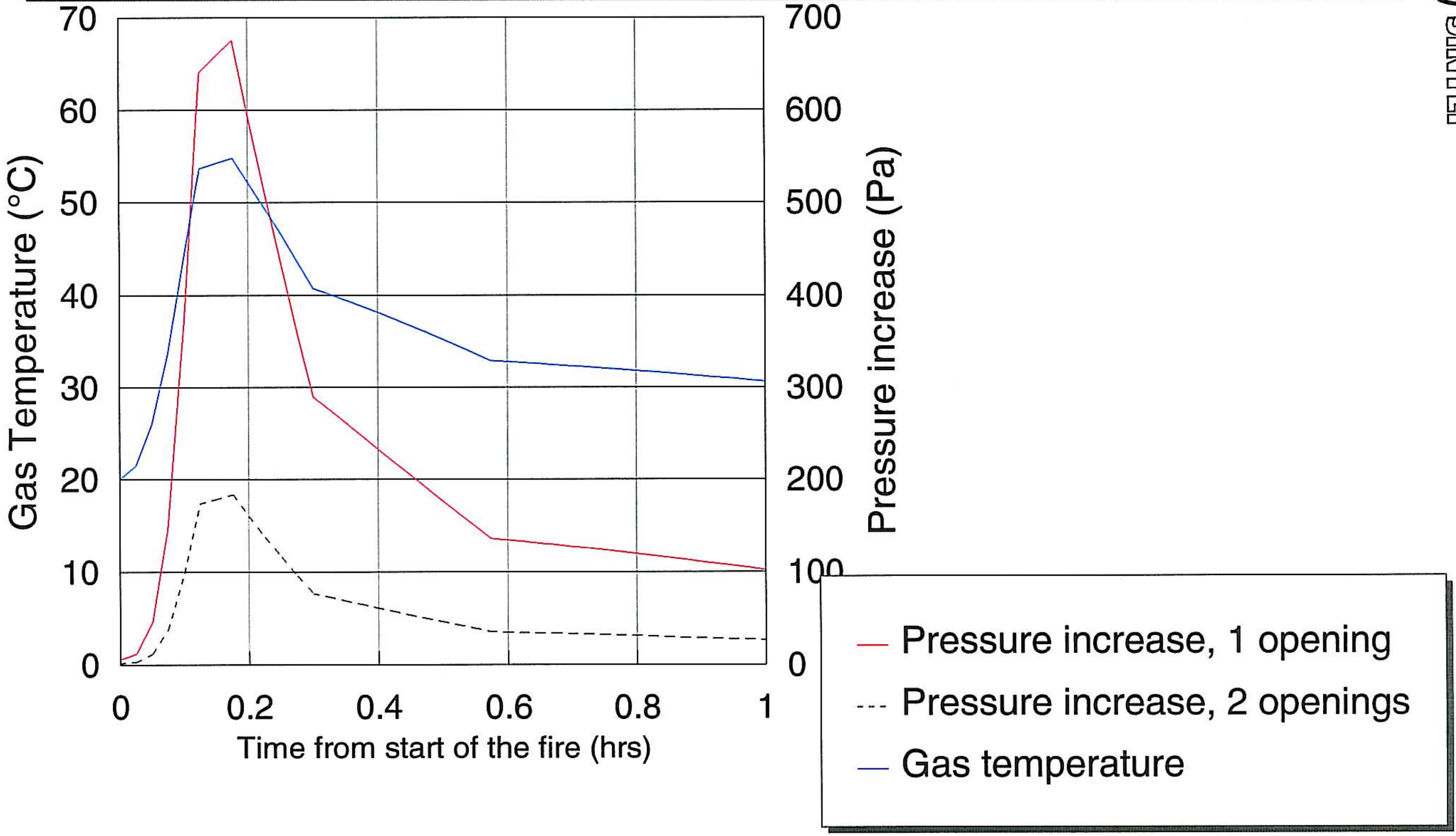
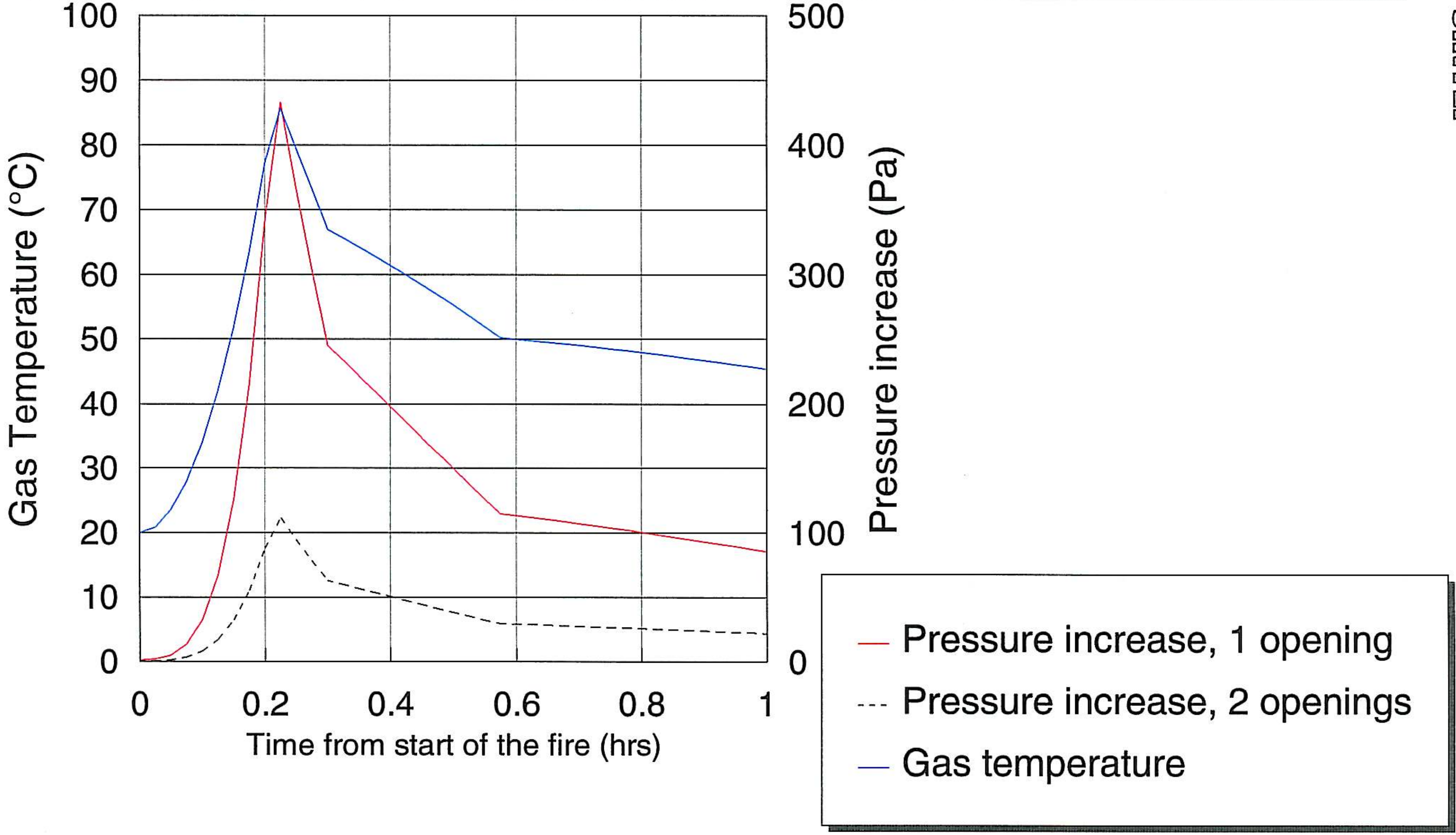
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (port mid.)

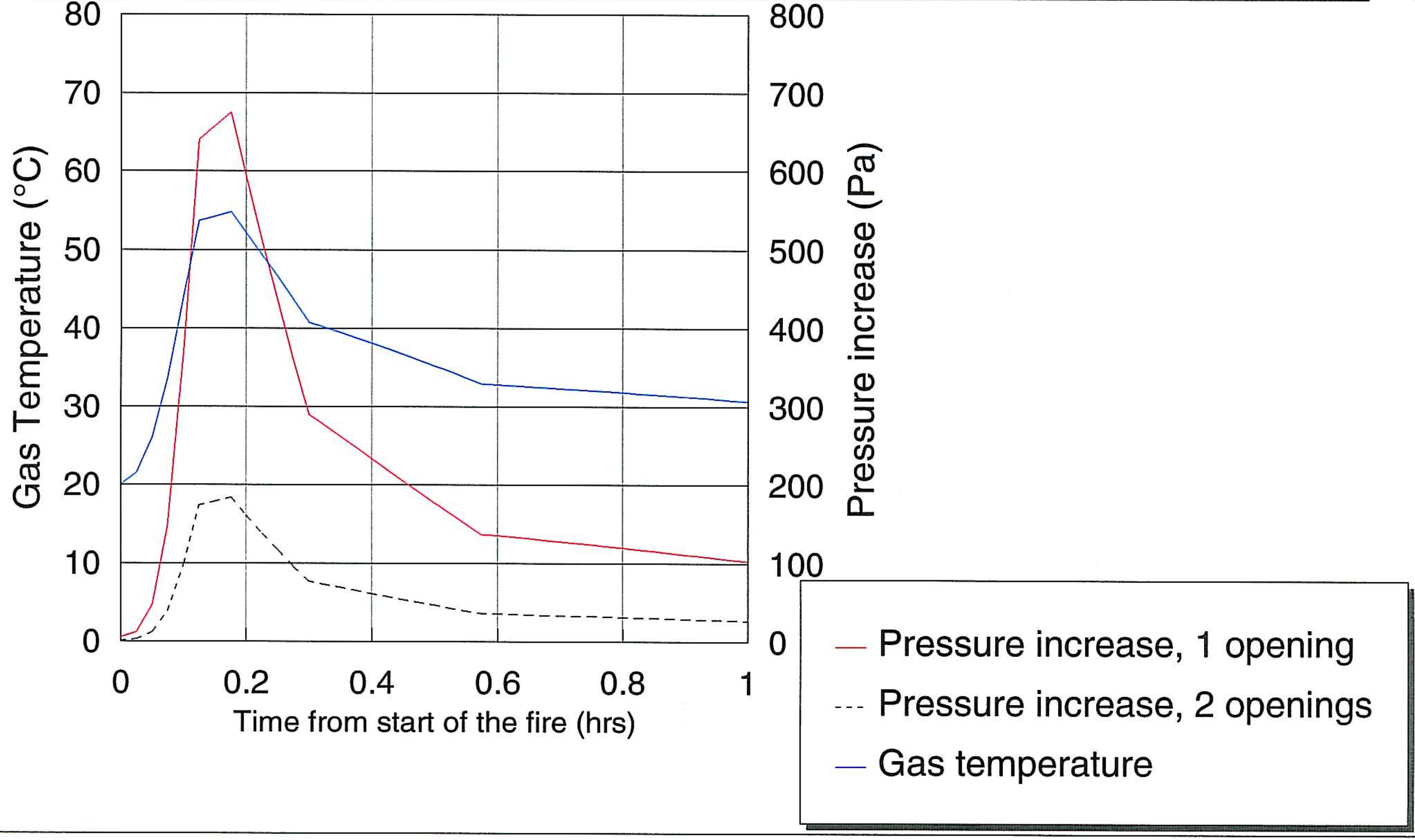


Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in H.V. Switch Room

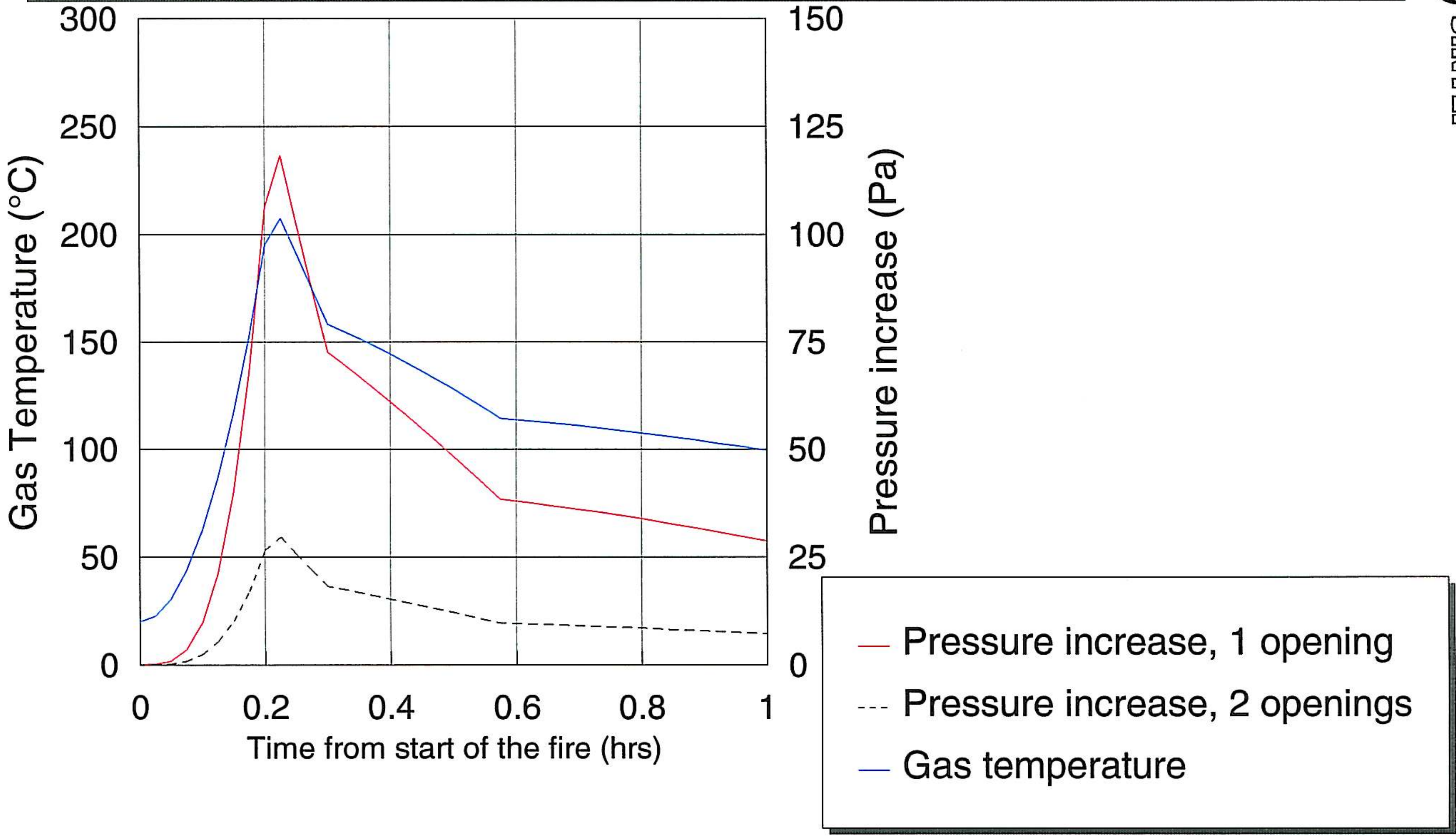


SINTEF

Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (starb. mid.)

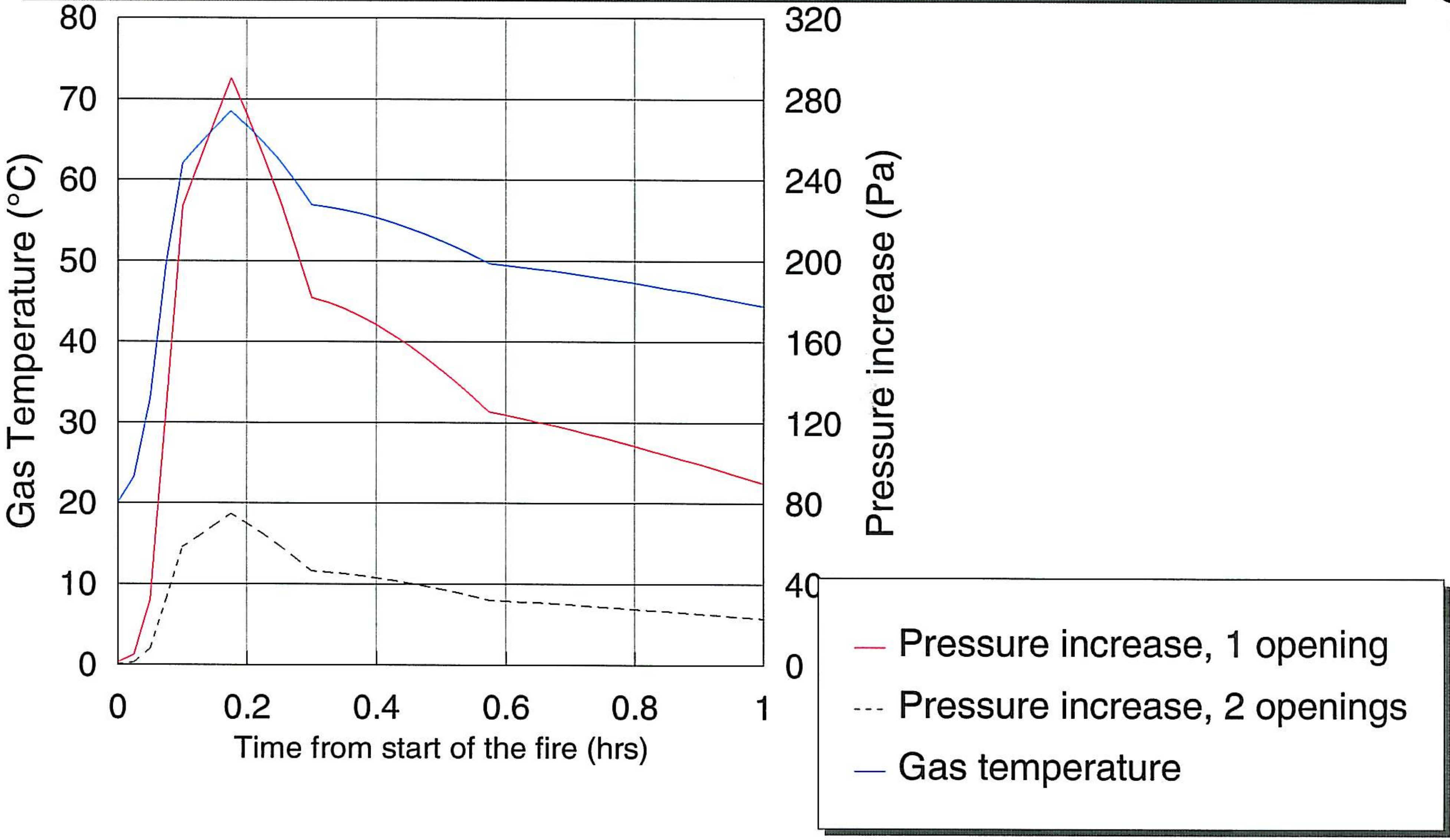


Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in Electrical Room



SINTEF

Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (port outer fwd. col. low. d.)



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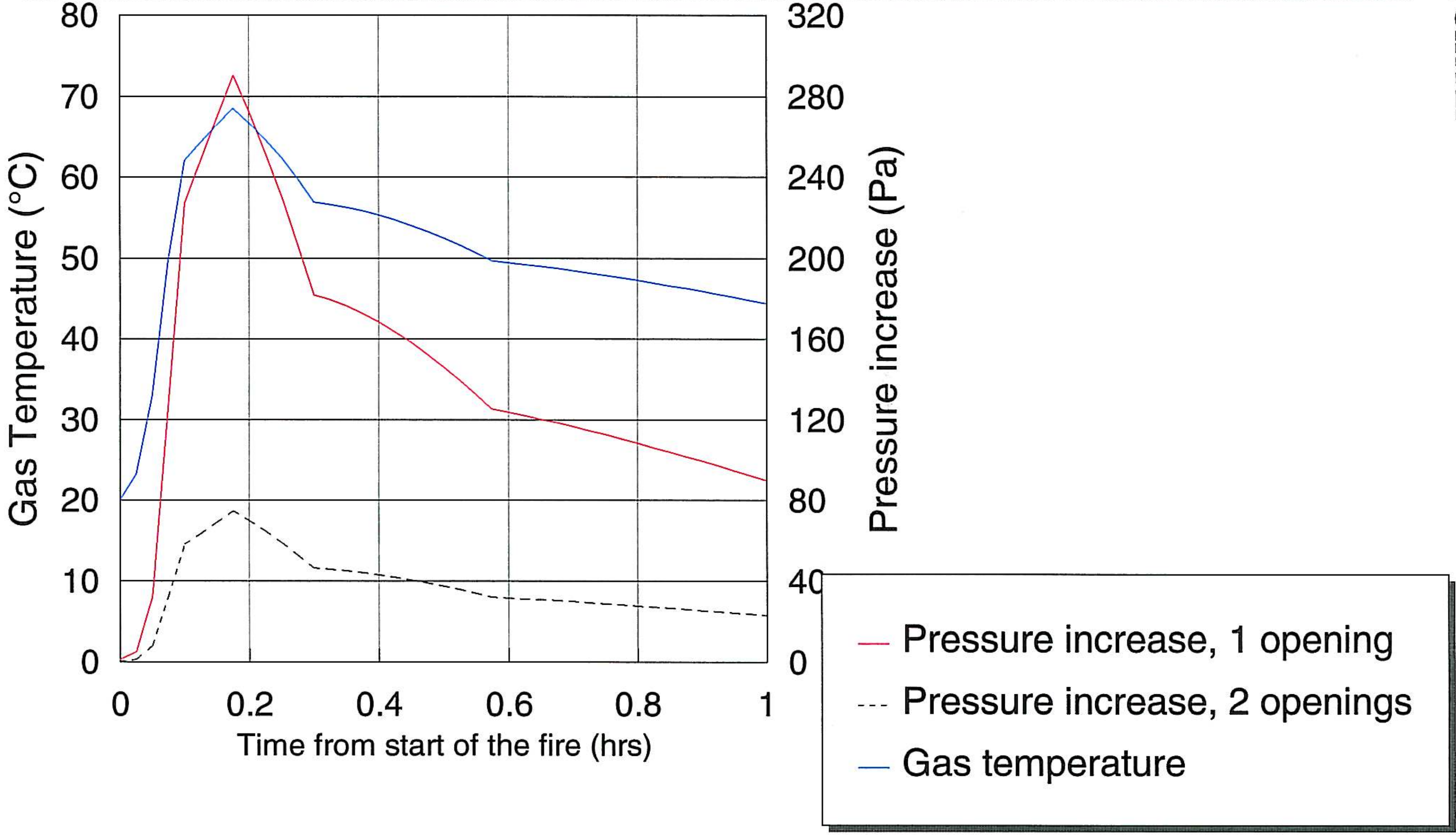
Smoke gas temperatures and resulting pressure increase due to thermal expansion in case of a fire in HVAC (st.b. outer fwd. col. low. d.)



APPENDIX B: Documentation of Calculation method Used for the Prediction of the Pressure Build-Up

General

The following two calculation methods will be used in this evaluation:

- Fire load density: NS 3478 /3/.
- Temperature loads: The "Swede Method" /4/.
- Pressure build-up: A method developed by SINTEF NBL /2/ (see section 2.1.3).

When the fire load density is, the pressure build-up due to thermal expansion may be predicted by the method presented in this appendix. The "Swede Method" uses the fire load density of the actual room, predicted on the basis of NS 3478, as a basic input parameter for the prediction of temperature load of the actual fire room.

In order to take into account that a fire in the actual rooms not will have that rapid fire development as predicted by the "Swede Method" (i.e. due to the extensive use of fire retarded materials), the energy release term of the model is replaced by a "t-squared fire", and by assuming a *slow* fire development. The energy release term Q_c of the fire room is given by the following equation:

$$Q = \propto \cdot t^2 \qquad (2.1)$$

α is a coefficient representing the speed of the fire development. For a "slow fire development", which applies in this case, α is equal to 2.9 W/s^2. On the other hand, for a *medium*, *fast* and *ultrafast* fire development α is equal to 11.3, 46.8 and 187.7 W/s^2, respectively. The reason for using a slow fire development is to predict a more realistic fire development, reflecting the fire development of a fire in electronic equipment, like for example fire retarded cables, panels etc. The introduction of a slower fire development, will, however, not affect the values of the maximum temperature load and pressure increase in the room, only the time when these values occur.

Table 2.1 shows the values of the basic parameters of the "Swede Method" chosen for the calculations. Since these parameters are recommended to be used by the authors of this method (i.e. Peterson and Öden /4/), these parameters are kept unchanged for all the rooms.

Table 2.1: An overview of the basic input parameters for the "Swede Method" and the values of these parameters chosen for the calculation of the temperature load of the rooms on the Troll C platform.

Input parameter (/4/[1])	Input value	Unit
The temperature in the rooms at the start of the fire:	17	°C
The heat transfer coefficient of external surfaces of bulkheads and deck:	10	W/m^{2}K
The coefficient "χ" in the expression of the heat release rate:	330	kg/hm$^{5/2}$
The coefficient "χ" in the expression of the convective heat loss:	1950	kg/hm$^{5/2}$
The coefficient α for the degree of complete combustion of the material:	0.6	-
Specific heat if the fire gases:	1300	J/kgK
Effective heat of combustion of the combustible materials:	20.0	MJ/kg
α in the "t-squared fire" expression of the heat release rate of the model:	2.9	W/s^2

[1] See reference /4/ for a closer description of this method and the input parameters.

The following heat of combustion of the respective materials of the rooms are used /8/:

- Fire resistant cables:	23.3 MJ/kg
- Panels (polyethylene):	20.0 "
- Solvents (glycol/alcohol):	25.0 "
- Hydraulic oil:	43.0 "
- Lubeoil:	42.0 "
- Paper:	17.0 "

The "Swede Method" uses as a basic input parameter the dimensions of one or more ventilation openings of a *naturally ventilated* compartment. In this case, where the rooms are only forced ventilated, the *forced air supply rate* (in m^3/s) is known. However, the forced air supply rate, m_a (in kg/s), can be transferred to the *"equivalent dimensions"* of an opening in a naturally ventilated fire compartment by the following relation:

$$m_a = 0.5 \cdot A_o \sqrt{H_o} \qquad (2.2)$$

A_o is the area (in m^2) of the ventilation opening, and H_o and W_o are the height and the width (in m) of the ventilation opening. By assuming a square opening (i.e. $H_o = W_o$), the *equivalent width* and *height* of the ventilation opening may be predicted by the following relation:

$$H_o = W_o = (2 \cdot m_a)^{2/5} \qquad (2.3)$$

Pressure Build-up due to Thermal Expansion

The following basic equation for the mass balance for a fire compartment may be established when the ventilation of the fire compartment is neglected[1]:

$$m = m_o - \rho \cdot v_e \cdot A_e \cdot dt \qquad (2.4)$$

where: m = the mass content of heated fire gases and air at time t (kg)
m_o = the initial mass content of air at the ignition of the fire (kg)
t = the actual time at which m is mass content of air and fire gases in the room (s)
dt = the time increment (s)
ρ = the density of the heated fire gases leaving the fire compartment through the exit openings of the compartment (kg/m^2)
v_e = the exit velocity of the heated fire gases through the exit openings (m/s)
A_e = the area of the exit openings (m^2)

The following equations apply for the exit velocity v_e (m/s), the mass content m (kg), pressure build-up Δp (Pa) and pressure p (Pa), all at time t (s):

$$v_e = \sqrt{\frac{2\Delta p}{\rho}} \qquad (2.5)$$

$$m = \rho \, V \qquad (2.6)$$

1 The reason for this is partly due to the fact that the counterpressure of the air supply channel is not known and partly for simplicity. As discussed later in Section 3.2.3, it is not expected that the ventilation will affect the overpressure due to restricted thermal expansion very much.

$$\Delta p = p - p_o \tag{2.7}$$

$$p = \rho\, RT \tag{2.8}$$

where: R = the gas constant for air = 286,7 (kJ/kg K)
T = the temperature of the fire gases at time t (K)
V = the volume of the fire compartment (m^3)
p_o = the initial pressure in the room (i.e. the atmospheric pressure = $1\cdot 10^5$ Pa) (Pa)

When combining the equations (2.4) - (2.8), the following relation for the pressure build-up Δp may appear:

$$\Delta p = \frac{-(2k_1\rho_o RT - k_2 p_o) + \sqrt{(2k_1\rho_o RT - k_2 p_o)^2 + 4(-k_1 + k_2)k_1(\rho RT)^2}}{2(-k_1 + k_2)} - p_o \tag{2.9}$$

where:

$$k_1 = \left(\frac{V}{A_e RT\Delta t}\right)^2 \tag{2.10}$$

and:

$$k_2 = \frac{2}{RT} \tag{2.11}$$

Δt (in seconds) in Eq. (2.10) is the time interval between each calculation. A time interval or time step of 90 seconds is used in the calculations of temperature load and pressure build-up .

The expressions (2.9)-(2.11) were used in order to calculate the pressure build-up in the fire room at time t when the temperature load, T (K), the volume, V (m^3), and the exit opening area, A_e (m^2), of the room are known.

In equation (2.4) a drag coefficient due to flow resistance of the air supply inlet and the exhaust vents, as well as the exhaust and air supply channel to and from the room (i.e. flow resistance in channels, bends etc.), should also be included. A high resistance in the channels and valves will increase pressure build-up in the room compared to the situation where an ideal flow nozzle is representing vent of the room. This latter nozzle with a minimum of flow resistance is assumed in these calculations.

However, the drag coefficients of the ventilation system were not available for SINTEF NBL. Thus, the calculations are carried out without including any flow resistance in the ventilation system. The flow resistance in the inlet of the exhaust and air supply channel is, however, not expected to be very high, and it is, thus, neglected in the calculations. The omission of the drag coefficient and by assuming an ideal nozzle is in fact slightly underestimating the pressure build-up in the rooms.

As accounted for in Section 3.1.3 the pressure increase will restrict the air supply to. This is not taken into account in the estimation of the temperature loads, which probably will be lower than estimated by the "Swede method". Since the pressure build-ups are a strong function of the temperature in the room, the pressure build-up will also be overestimated. This overestimation will more than compensate the underestimation of the pressure build-up due to the omission of the drag coefficient and by assuming an ideal nozzle.

The inner heat transfer coefficient

The inner heat transfer coefficient α_i used in the calculations is given by the following expression:

$$\alpha_i = \frac{5.77\,\varepsilon_r}{T_g - T_w}\left[\left(\frac{T_g + 273}{100}\right)^4 - \left(\frac{T_w + 273}{100}\right)^4\right] + 25 \qquad (W/m^2K) \qquad (2..12)$$

where: T_g = the smoke gas temperature calculated by the "Swede Method" (°C)
T_w = the temperature of the enclosing boundaries or "walls" (°C)
ε_r = the resultant emissivity between flames, smoke gases and the boundaries of the fire room (-).

The inner heat transfer coefficient, α_i, consists of the following two terms:

$$\alpha_i = \alpha_r + \alpha_c \qquad (2.13)$$

The first term $\propto_r$ represents the heat transfer due to thermal radiation from the flames and hot gases, while the second term $\propto_c$ represents heat transfer coefficient due to convective heat transfer. This latter number is assumed constant and equal to 25 W/m^2K. The first term is very dependent on the temperature of the fire gases T_g. It is, at least to a certain degree, also dependent on the temperature of the inner boundary surfaces T_w. Calculated values of α_i, based on the calculated values of the temperature loads (based on an iteration process) are shown in Table 2.2.

Table 2.3 shows the rest of the input data for the calculation of the fire load densities. That is, the dimensions, inner surface area, the pressure relief area, i.e. the diameter of exhaust and air supply channels, and the weight of light fixtures, cables, panels and other combustible materials.