Danish Institute of Fire and Security Technology

Argos Validation Report

Comparison of ARGOS Simulations with Full Scale Multi-Room Fire Tests

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1. Introduction

ARGOS is a computer program based on the zone model which describes fire growth and development in multi-compartment buildings. ARGOS is developed by the Danish Institute of Fire Technology. The purpose of this report is to compare ARGOS simulations with full scale fire tests in order to verify the basic principles and implementation of ARGOS. In this report ARGOS simulation results are compared with 3 different test series.

A considerable number of full scale fire tests have been made in recent years, but for many of them one or more of the parameters necessary for simulation or comparison are omitted in the test reports.

Three well documented full scale test series have been selected for verification.

- The two rooms tests series reported by Cooper et al. (1982). These tests are often referred to for model verification, though the rooms and fires studied are relatively small.

- The two rooms test series including fire ventilation in the roof reported by Hägglund (1992). In these tests the rooms and fires are relatively large.

- The three rooms test series reported by Meland and Lønvik (1989). These tests also include various fire detectors.

2. The model

The model used in the simulation is a 2 zone model, based on:

- Rate of heat release from DIFT fire models.
- Smoke filling model from McCaffrey (1983).
- Flow through wall openings from the Bernouilli equation.
- Flow through ceiling openings etc. from Cooper (1989).
- Pressure determination from volume balances by Newton-Raphson iteration with analytical differentiation and the Generalized Dominant Eigenvalue Method for supervision.
- Radiative heat transfer to and from building components.
- Convective heat transfer to and from building components.
- Energy equations for conductive heat transfer in building components.
- The simulation of fire detectors is based on Alpert (1972).
- Numerical integration of the differential equations in the model by a 2nd order Runge-Kutta method with automatic step length control.

For detailed theoretical description of simulation model, please refer to the ARGOS Theory Manual (Baden, 1992).

3. Fire test reported by Cooper et al. 1982

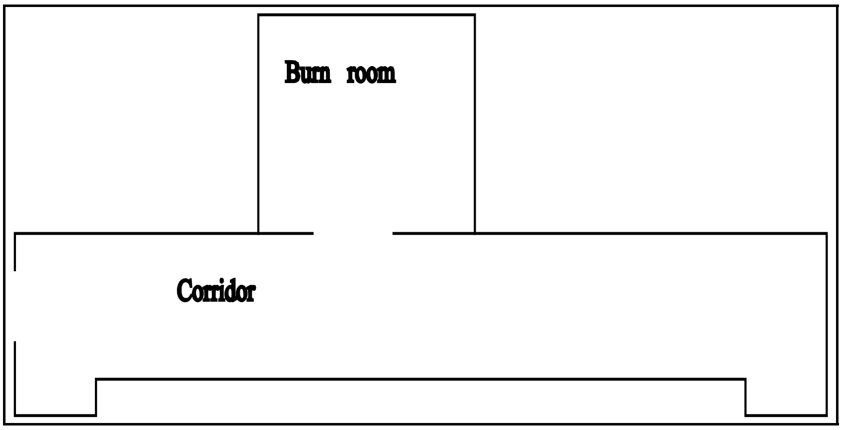


Figure 1 *Sketch of test configuration*

The test program consisted of a series of separate tests involving either two or three rooms. The ceiling height was 2.36 m in all rooms. The rooms were connected by open doorways. All tests used the same burn room of 14 m² area. In the center of the room there was a 0.3 m x 0.3 m methane diffusion burner. The burner was controlled to give a constant rate of heat release of 25-225 kW.

All rooms were lined with 13 mm gypsum board. The doorway between the burn room and the corridor was 2.0 m high and 1.07 m wide. A 0.15 m high, 0.94 m wide hole next to the floor was provided from the corridor to the outside.

Two tests were selected for comparison in this report, both with a two room configuration, and a corridor size of 62.4 m².

The rate of heat release in the two tests was 100 kW and 225 kW respectively.

A full description of the test program is given by Cooper et al. (1982).

3.1 Input data to ARGOS

The input data for the ARGOS simulations are listed in table 3.1

TABLE 3.1

Room dimensions			
	Length	Width	Height
Burn room	4.22 m	3.35 m	2.44 m
Corridor	18.97 m	2.41 m	2.44 m

Wall vent geometry			
	Length	Height	Lower edge
Burn room-corridor	1.07 m	2.03 m	0
Corridor-outside	0.94 m	0.15 m	0

Thermal properties of walls and ceilings (gypsum).						
Temperature	°C	20	93	106	224	1093
Density	kg/m^3	790	790	790	790	790
Heat cap.	kJ/kg/°C	1.272	1.418	12.208	0.951	1.805
Therm. cond.	W/m/°C	0.192	0.214	0.113	0.154	0.292

Rate of heat release is 100 kW for the first test and 225 kW for the second

3.2 Test results

The temperature in each room was measured from floor to ceiling at vertical distances of 0.3 m. However, only the average room temperature rises are reported.

The interface layer height was determined in three different ways:

- The height at which the gas temperature rise above ambient is 10% of the maximum temperature rise.
- Photometer data results measured during the test.
- Visual observations from video tapes.

Simulation results are compared with the layer heights obtained by all three methods.

3.3 Results of comparison

For both the tests there is excellent agreement between ARGOS simulations and test results, as shown in figures 2 to 7.

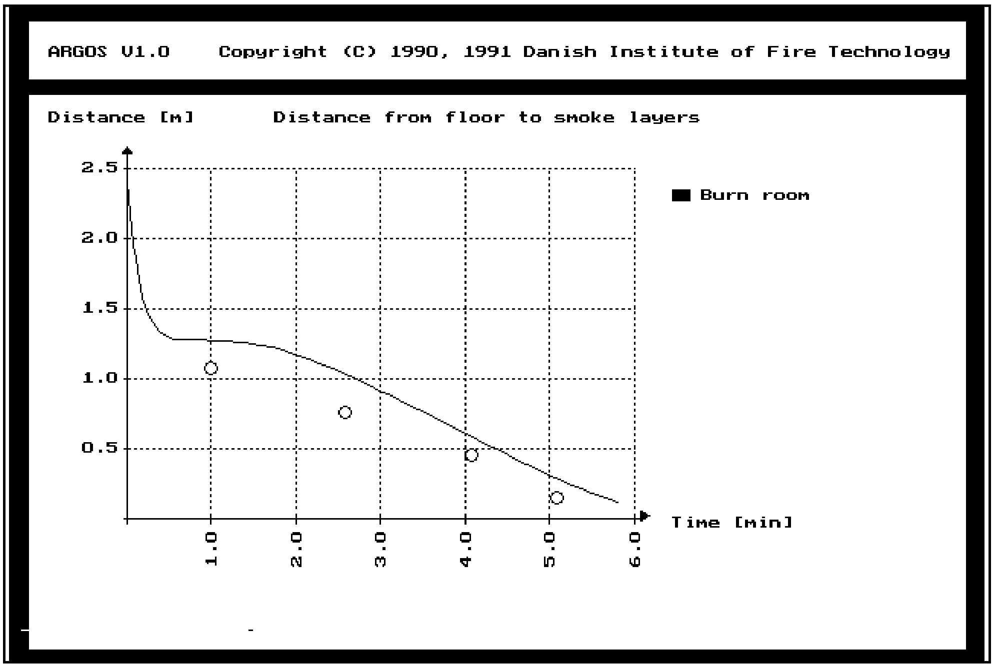


Figure 2 *100 kW fire: Distance from floor to smoke layer versus time. Circles = measured data points; Solid lines = ARGOS simulation.*

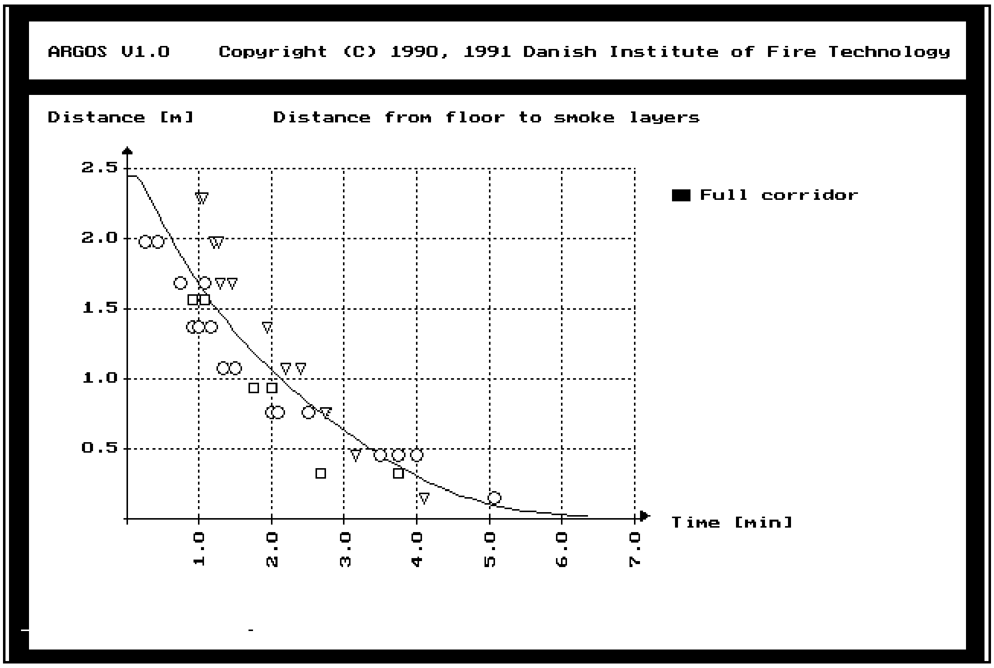


Figure 3 *100 kW fire: Distance from floor to smoke layer versus time. Triangles = photometer data; Circles = thermocouples; Square = visual observation; Solid lines = ARGOS simulation.*

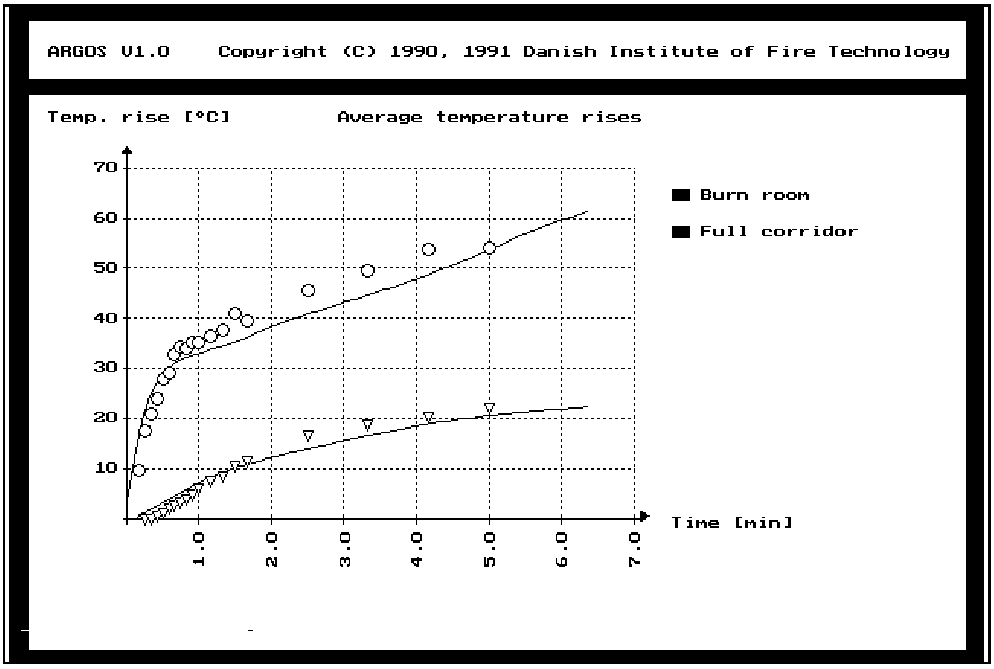


Figure 4 *100 kW fire: Average temperature rises versus time fire. Circles = measured data points; Triangles = measured data points; Solid lines = ARGOS simulation.*

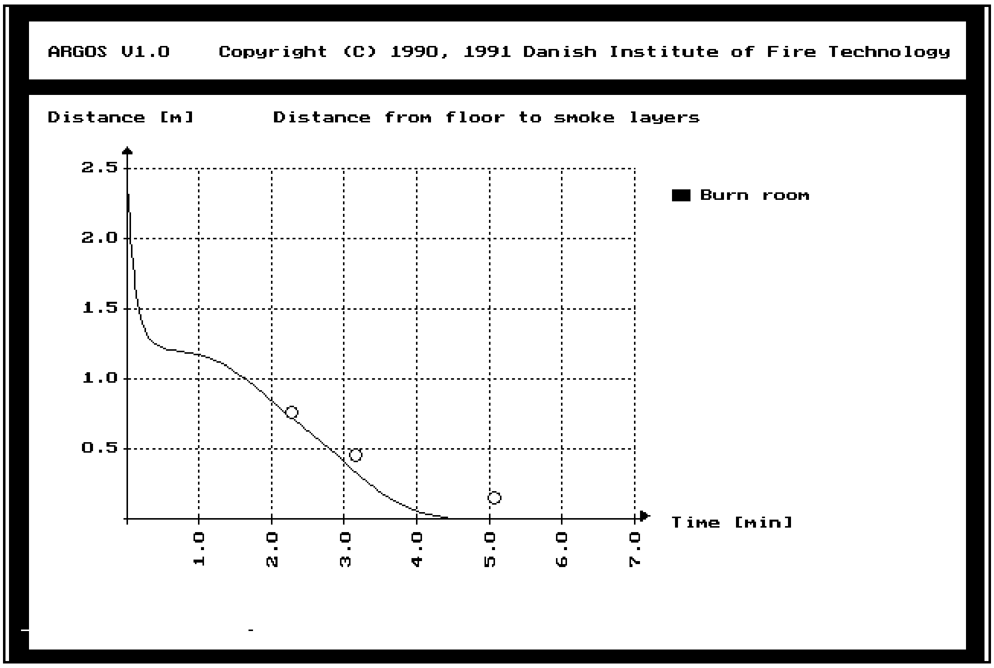


Figure 5 *225 kW fire Distance from floor to smoke layer versus time. Circles = measured data points; Solid lines = ARGOS simulation.*

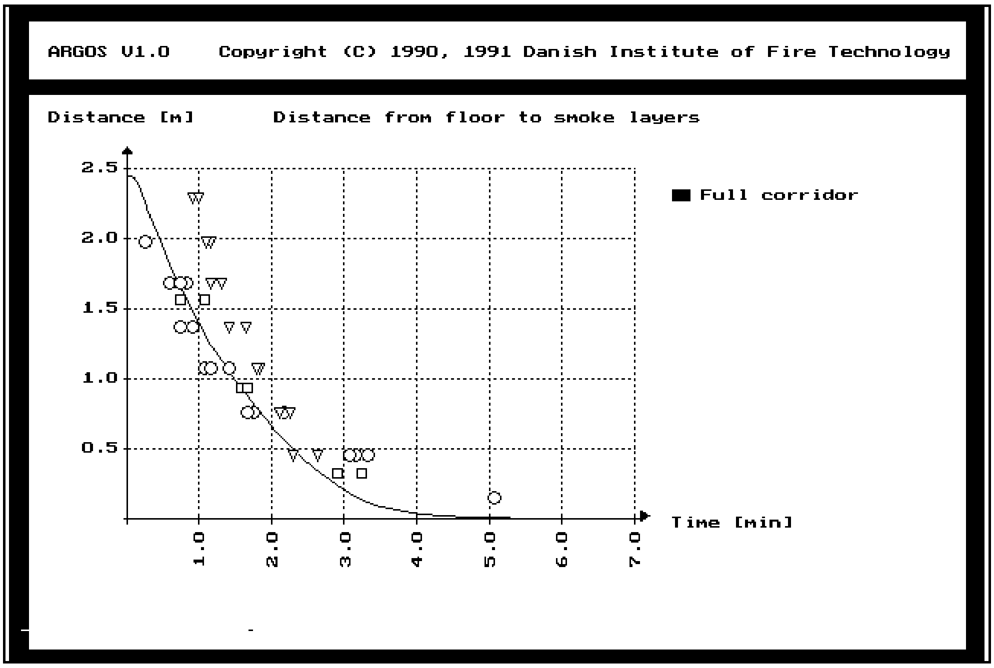
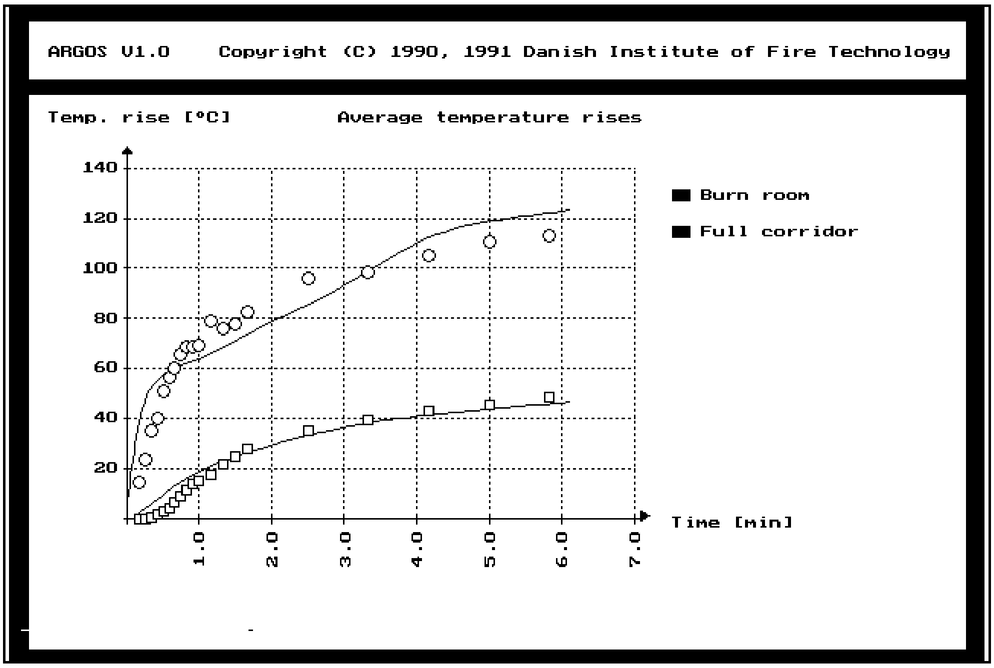


Figure 6 *225 kW fire: Distance from floor to smoke layer versus time. Triangles = photometer data; Circles = thermocouples; Square = visual observation; Solid lines = ARGOS simulation.*



Figur 7 *225 kW fire: Average temperature rise versus time. Circles = measured data points; Squares = measured data points; Solid lines = ARGOS simulation.*

4. Fire tests reported by Hägglund 1992

The test program consisted of 3 series of separate tests, all involving a two room configuration. All the tests used the same burn room of 3 m x 4 m and height of 2.6 m. The burn room was connected to the adjacent room by a 2 m high and 1 m wide opening. The adjacent room was 5.6 m x 5.6 m area and 6.1 m high.

The burn room was closed except for the above mentioned open doorway between the two rooms. The fuel used in all tests was kerosene with a lower heat of combustion of 43 mJ/kg. The fuel was burned in open pans with sizes of 0.5 m x 0.5 m and 0.75 m x 0.75 m respectively.

A full description of this test program is given by Hägglund (1992).

Test series 1

In this series only two tests are reported by Hägglund, namely test 1 and test 5. The tests are identical except for the fire size. In the first test the 0.5 m x 0.5 m fire area was used, and in the second test the 0.75 m x 0.75 m fire area was used. The secondary room was connected to the outside by a 0.25 m high and 0.8 m wide vertical opening at floor level.

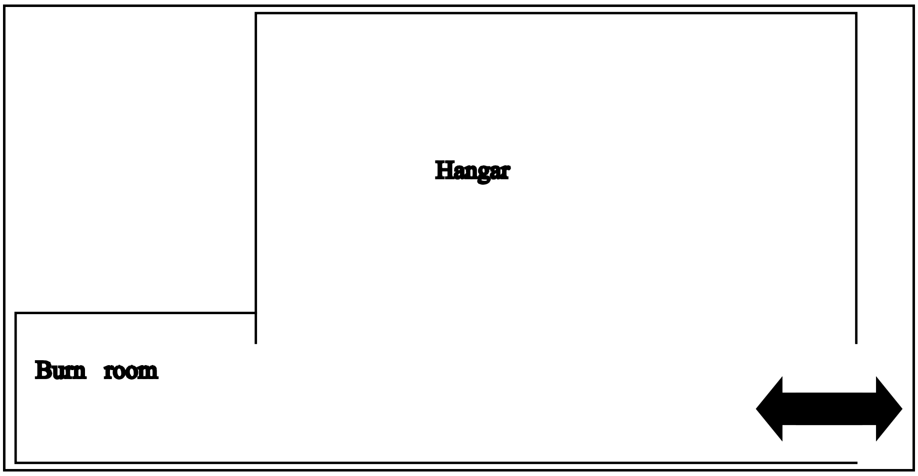


Figure 8 *Sketch of test configuration for test series 1*

Test series 2

In this series 6 tests are reported by Hägglund. In test 9, 10 and 14 the 0.5 x 0.5 m² fire area was used, and in tests 11, 12 and 13 the 0.75 m x 0.75 m fire size.

In all the tests there were two openings from the hangar to the outside.

- one vertical opening at floor level
- one horizontal opening in the roof.

The geometry of the two openings are listed in table 4.1.

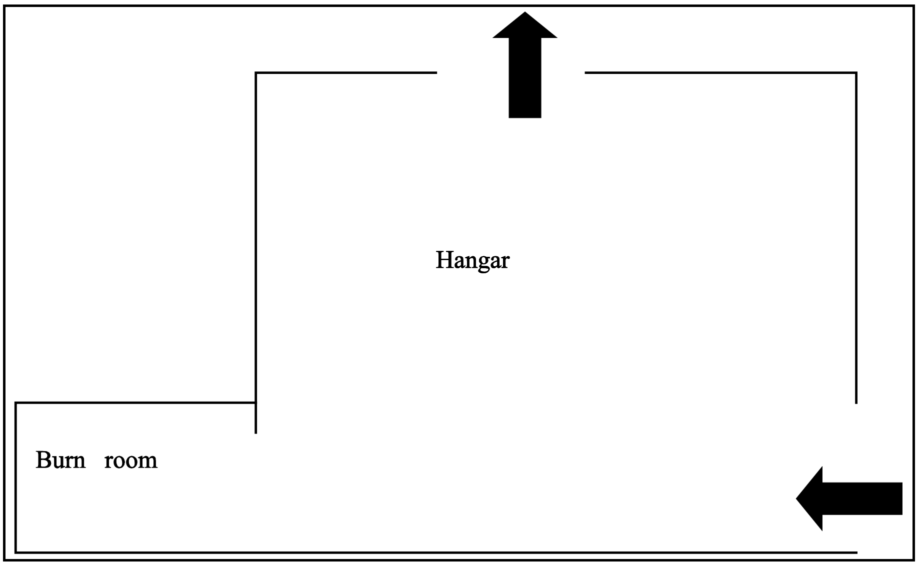


Figure 9 *Sketch of test configuration for test series 2*

Test series 3

In this series 2 tests are reported, one with each of the two fire sizes.

The openings to the outside are identical to test series 2. However the floor level of the fire room is located 2.8 m higher than the secondary room.

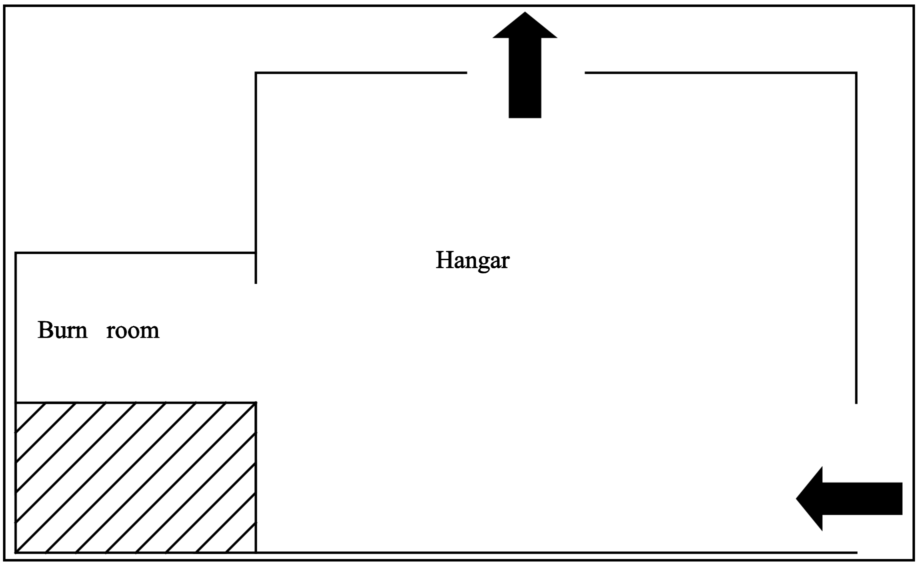


Figure 10 *Sketch of test configuration for test series 3*

4.1 Input data to ARGOS

The input data for the ARGOS simulations are listed in table 4.1. The fire is specified using the standard data given in ARGOS, except for the parabolic fire growth parameter α, which was estimated from the data reported by Hägglund.

TABLE 4.1

Room dimensions			
	Length	Width	Height
Burn room	3.0 m	4.0 m	2.6 m
Hangar	5.6 m	5.6 m	6.1 m

Vent geometry			
	Length	Height	Lower edge
Burn room - Hangar	1.0 m	2.0 m	0.0 m
Hangar - outside	See below		

Thermal properties of walls and ceilings (concrete).						
Temperature	°C	0	20	200	375	2000
Density	kg/m^3	2300	2300	2300	2300	2300
Heat cap.	kJ/kg/°C	1.000	1.000	1.000	1.000	1.000
Therm. cond.	W/m/°C	1.400	1.400	1.000	0.800	0.800

Ventilation between Hangar and outside		
	Wall vent geometry width x height, m x m	Roof vent geometry width x length, m x m
Series 1		
Test 1	0.8 x 0.25	1.0 x 1.0
Test 5	0.8 x 0.25	1.0 x 1.0
Series 2		
Test 9	1.0 x 1.0	1.0 x 1.0
Test 10	1.0 x 1.0	1.0 x 2.0
Test 14	2.0 x 1.0	1.0 x 2.0
Test 11	1.0 x 1.0	1.0 x 2.0
Test 12	2.0 x 1.0	1.0 x 2.0
Test 13	2.0 x 1.0	1.0 x 4.0
Series 3		
Test 17	1.0 x 1.0	1.0 x 1.0
Test 20	1.0 x 1.0	1.0 x 1.0

Fire sizes are shown in figures 11 and 15

4.2 Test results

In series 1 interface heights and temperatures in the two rooms were measured. The interface was determined both from visual estimation and from measured smoke densities. The layer height was only measured in the secondary room. In both rooms the temperature is measured from floor to ceiling at vertical intervals of 0.5 m .

4.3 Results of comparison

For test series 1 the simulated and measured results are compared in figure 11 to 18.

From figures 13 and 17, it appears that the temperature measurements are delayed during the initial temperature rise. Actually the measured temperatures nearest to the ceiling correspond to the simulated temperature of a ceiling mounted heat detector with a response time index, RTI = 20 $\sqrt{m \cdot s}$, which is a rather fast commercial heat detector. The actual thermocouples were placed below the ceiling jet where the gas velocity is smaller, so the time delay in the temperature measurements might have been considerable, even with much lower RTI values.

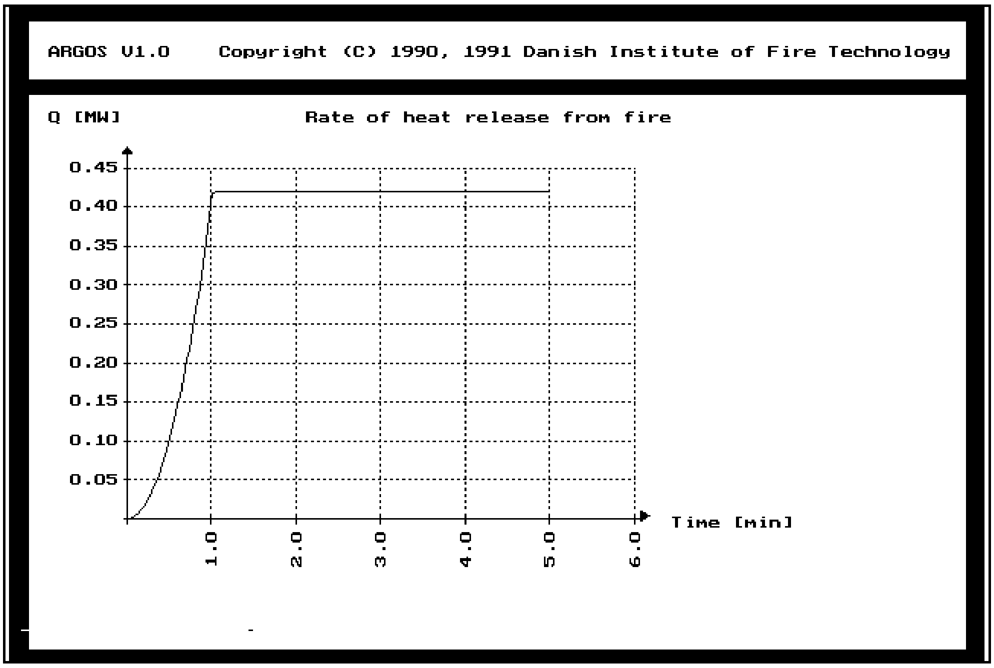


Figure 11 *Test 1: Combustion rate in MW*

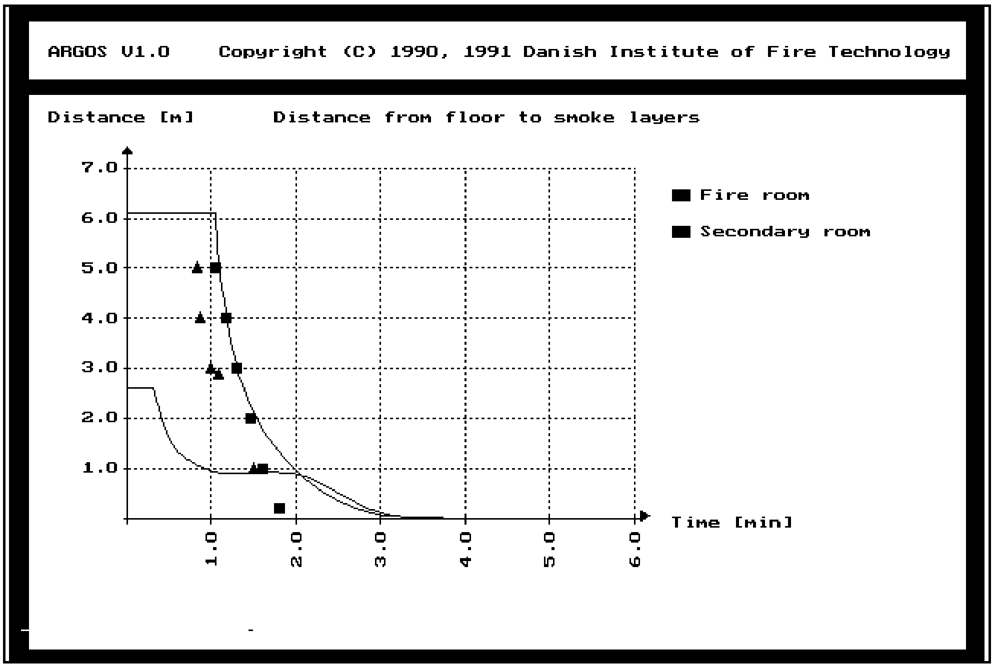


Figure 12 *Test 1: Measured and simulated smoke layer heights. Triangles = smoke meter, Square = visual estimation, Solid line = ARGOS simulation*

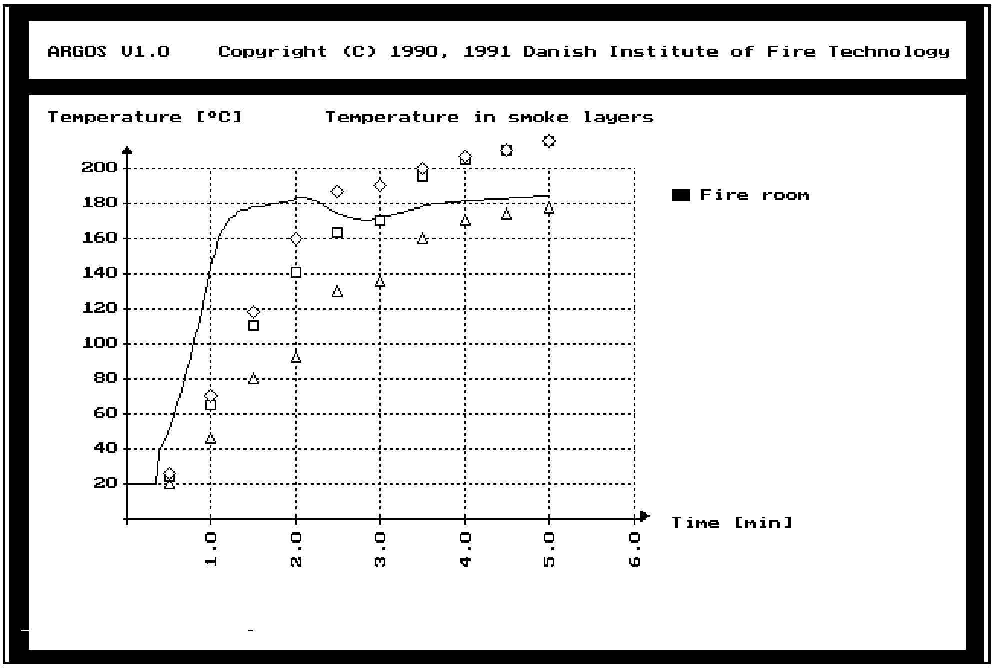


Figure 13 *TEST 1: Temperature in smoke layer versus time. Points = measurement in 2.2, 1.7, and 1.2 m height; Solid line = ARGOS simulation*

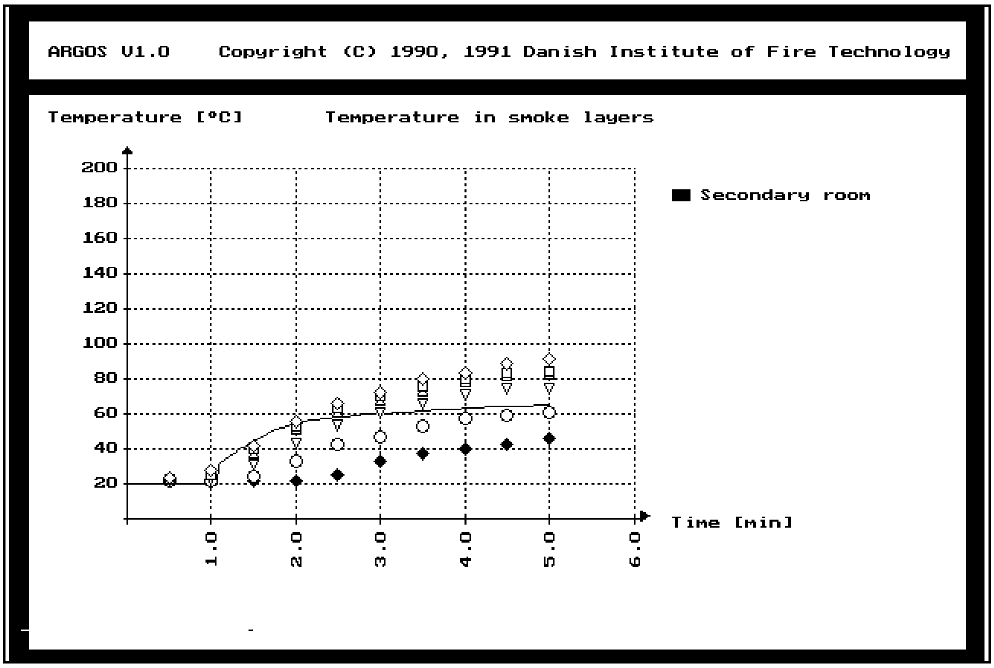


Figure 14 *Test 1. Temperature in smoke layer versus time. Points = measurement in 5.5, 4.5, 3.5, 2.5, 1.5 and 0.5 m height; Solid line = ARGOS simulation*

For test 5 the simulated rate of heat release shown in figure 15 decreases after about 3.5 minutes. Correspondingly the simulated smoke layer temperature decreases slightly after 3.5 minutes, cf. figure 17. The decrease is initiated when the oxygen mole fraction reaches 10.5%. For oxygen mole fractions lower than 10.5% the calculated rate of heat release is reduced by a factor X_{O2}/10.5%, where X_{O2} is the simulated oxygen mole fraction in %.

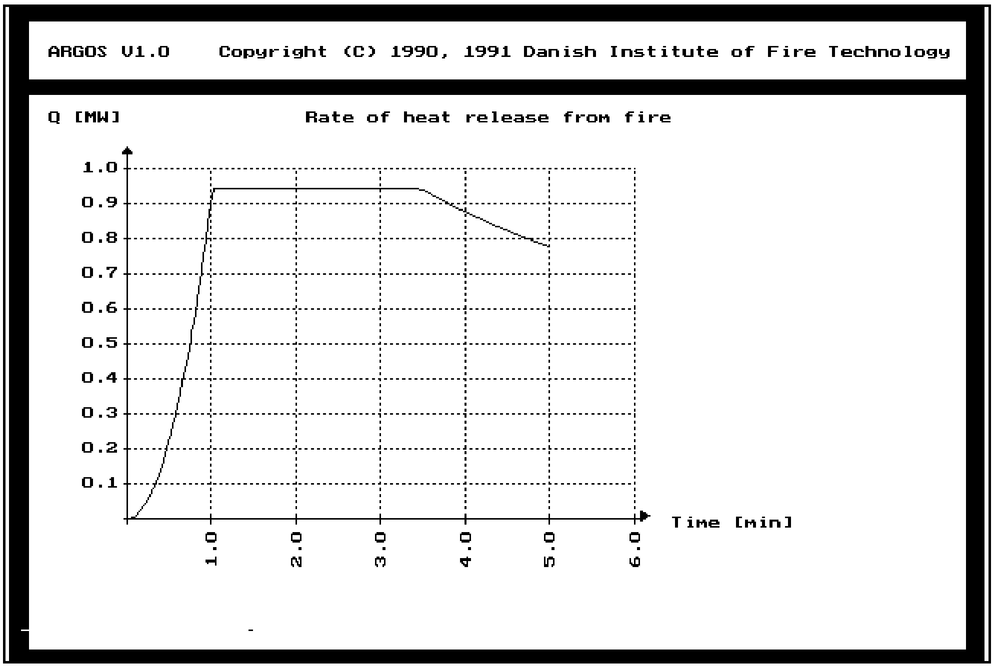


Figure 15 *Test 5: Combustion rate in MW.*

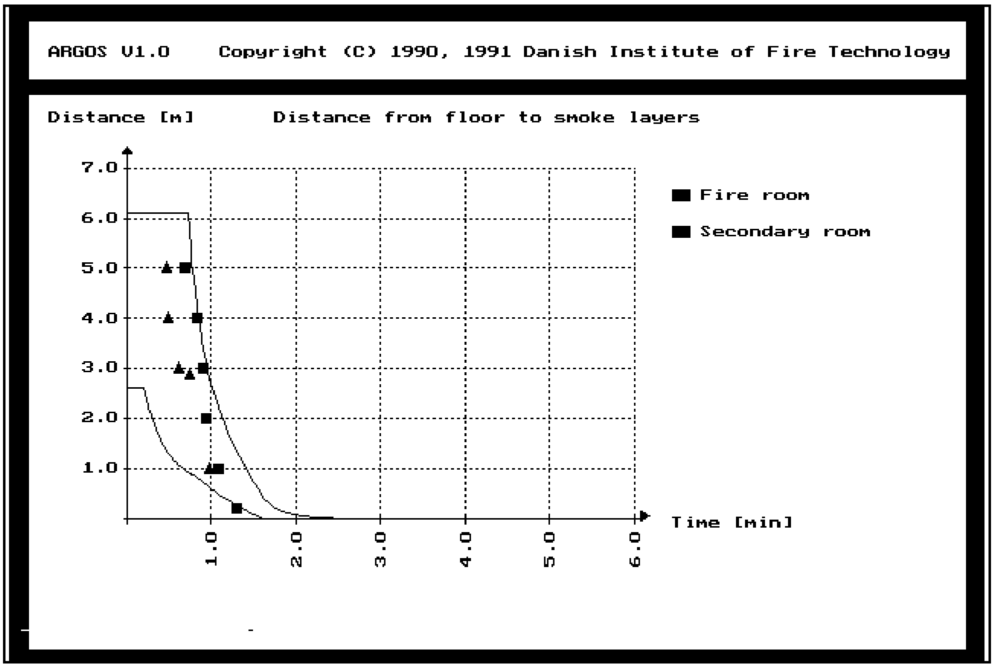


Figure 16 *Test 5: Distance from floor to smoke layer versus time. Triangle = smoke meter, Square = visual estimation, Solid line = ARGOS simulation.*

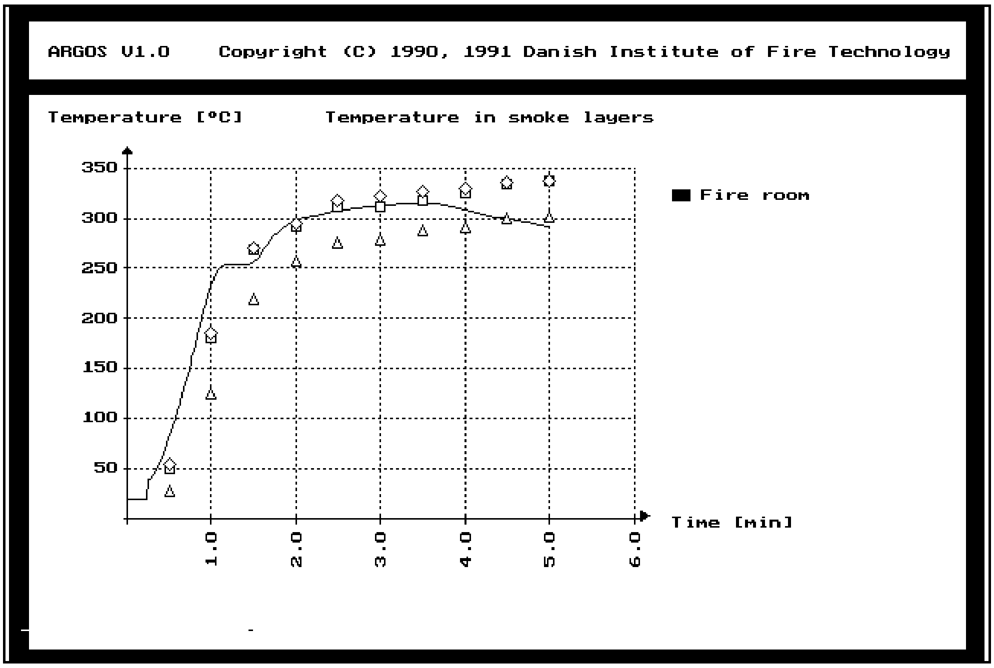


Figure 17 *Test 5: Temperature in smoke layer versus time. Points = measurement in 2.2 m, 1.7 m, and 1.2 m height, Solid line = ARGOS simulation*

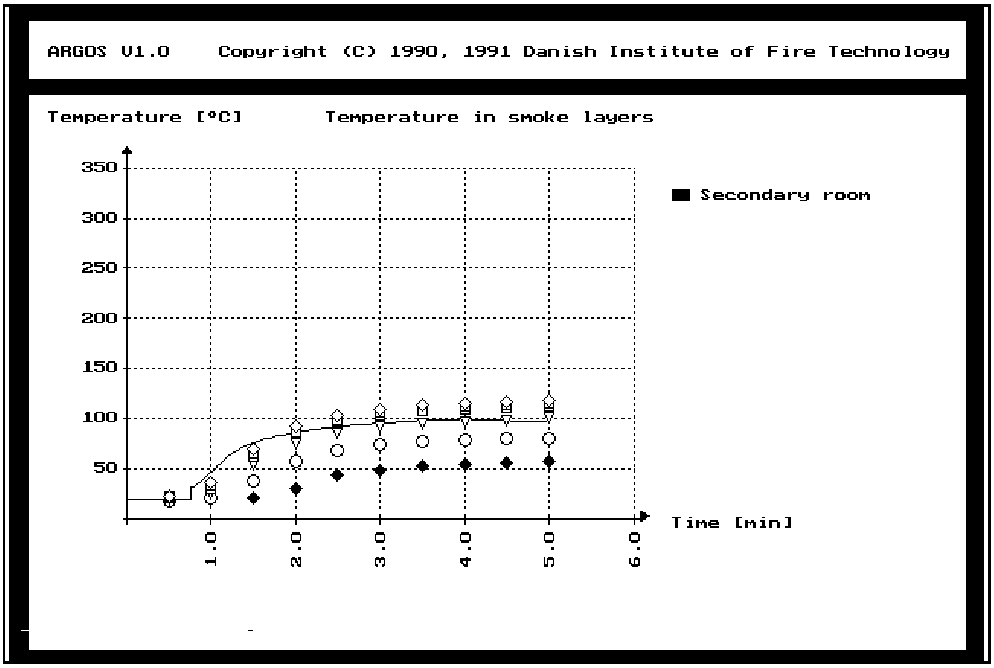


Figure 18 *Test 5: Temperature in smoke layer versus time. Points = measurement in 5.5, 4.5, 3.5, 2.5, 1.5 and 0.5 m height, Solid line = ARGOS simulation*

In series 2 and 3 the test results are reported in tables which give interface heights and layer temperature 4 minutes after ignition. According to the report these values have reached a steady-state condition at this time. The measured and simulated results are compared below. It is seen that ARGOS also performs well in simulating smoke ventilation.

Test Series 2	Layer temperature, °C burn room		Layer temperature, °C hangar		Floor to layer, m hangar	
	ARGOS	Measured	ARGOS	Measured	ARGOS	Measured
Test 9	184	180 - 220	63	55	2.2	1.5
Test 10	184	180 - 220	60	55	2.4	1.5
Test 14	184	180 - 220	55	45	2.8	2.5
Test 11	261	300 - 340	95	90	2.5	1.5
Test 12	261	300 - 340	84	90	3.0	2.0
Test 13	261	300 - 340	75	80	3.2	2.5

Test Series 3	Layer temperature, °C burn room		Layer temperature, °C hangar		Floor to layer, m hangar	
	ARGOS	Measured	ARGOS	Measured	ARGOS	Measured
Test 17	184	180 - 220	88	75	4.6	4.5
Test 20	263	300 - 340	139	115	4.4	4.5

5. Fire tests reported by Meland and Lønvik (1989)

The test facility was a 3 room configuration, with a burn room of 17 m² with height 2.5 m, a corridor and a staircase. The burn room and the corridor were connected with a closed door. The corridor and the staircase were connected with an open door and the staircase was in open connection with the outside.

The fire was in a mattress of polyurethane with blankets of polyester. The sheets were of cotton. It is assumed that the lower heat of combustion on average is 25 MJ/kg, see Tewardson (1988).

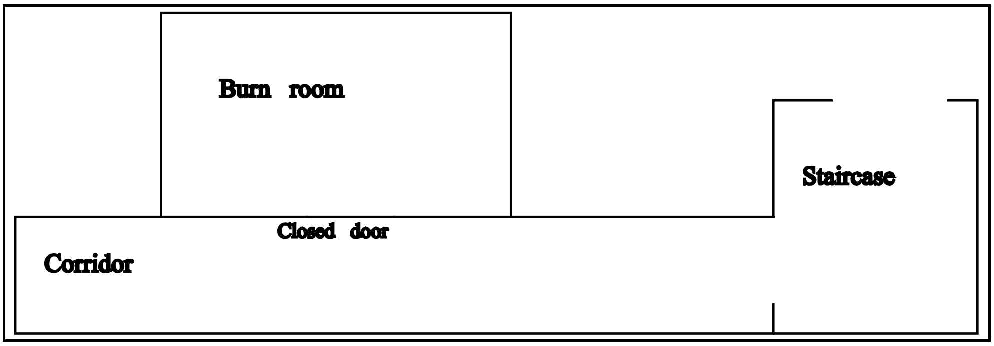


Figure 19 *Sketch of test configuration*

A full description of this test program is given by Meland and Lønvik (1989).

5.1 Input data to ARGOS

The burn room was leak tested before the fire test. Blowing air into the burn room at a constant rate of 500 m^3/h at ambient temperature and pressure resulted in a 50 Pa pressure rise in the burn room.

The ARGOS Theory Manual gives the following correlation (bernouilli) between flow, pressure difference and opening area.

$$v = C_b \cdot w \cdot h \cdot \sqrt{\frac{2 \cdot \Delta P}{\rho_j}}$$

where

v	Volumetric flow rate in m^3/s
w	Width of opening in m
h	Height of opening in m
C_B	= 0.7 is the Bernoulli flow coefficient
ρ_0	= 1.199 kg/m^3 is the density of air at 20°C
ΔP	Pressure difference in Pa

Inserting the measured flow and pressure rise gives an opening area of 0.021 m².

During the fire the mass loss of the burning material was measured. Given that the lower heat of combustion is equal to 25 MJ/kg the rate of heat release can be calculated as from:

$$Q = H_v \frac{dm}{dt}$$

where

m	Weightloss in kg
ΔH_v	lower heat of combustion in MJ/kg
t	Time in seconds
Q	Rate of heat release in MW

The fire is assumed to be located 0.25 m above floor level. In ARGOS it is assumed that the fire is located at floor level. Therefore the room height is reduced by 0.25 m in ARGOS calculations.

The input data for ARGOS is given in table 5.1

TABLE 5.1

Room dimensions			
	Length	Width	Height
Burn room	5.5 m	3.09 m	2.25 m
Corridor	5.5 m	2.55 m	2.5 m
Stair Case	3.0 m	3.0 m	2.5 m

Vent geometry			
	Width	Height	Lower edge
Burn room-corridor (Closed door)	0.009 m	2.1 m	0.0 m
Corridor - outside	0.9 m	2.2 m	0.0 m
Burn room-outside	0.01 m	2.2 m	0.0 m

Thermal properties of walls and ceilings (gypsum).						
Temperature	°C	20	93	106	224	1093
Density	kg/m^3	790	790	790	790	790
Heat cap.	kJ/kg/°C	1.272	1.418	12.208	0.951	1.805
Therm. cond.	W/m/°C	0.192	0.214	0.113	0.154	0.292

SINTEF Fire Start					
Date points	#1	#2	#3	#4	#5
Time in seconds	0	130	200	300	340
Q(t) in MW	0.001	0.001	0.26	0.21	0.11
Smoke Potential in dB/m	400.00				

Automatic fire alarms:

Heat detector

Activation temperature : 58 °C

RTI : 10 $(m*sek)^{1/2}$

Distance between detectors : 1.41 m

Smoke detector

Smoke sensitivity : 0.30 dB/m

Distance between detectors : 1.41 m

5.2 Test results

By integrating the rate of heat release as a function of time from the ARGOS input, the weightloss can be calculated. This is shown in figure 20.

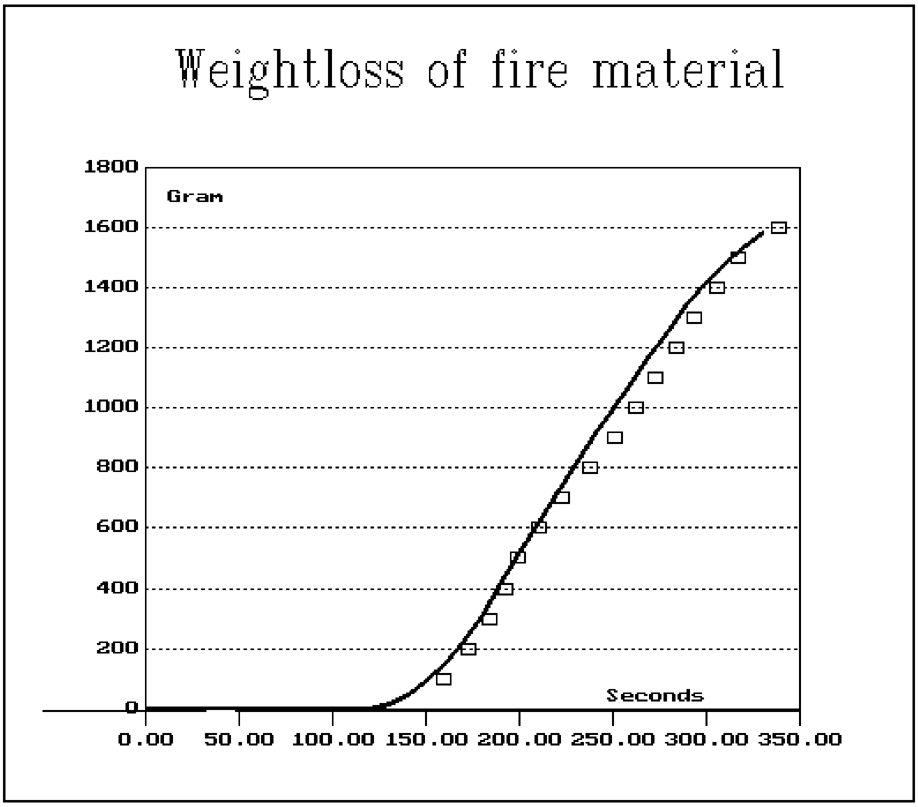


Figure 20 *Weightloss of fire material versus time. Curve = calculated weightloss from argos inddata; Squares = measured testresults*

This shows that the rate of heat release used in the simulation correlates to the weight loss measured in the test.

During the fire the temperature in the burn room was measured at heights of 0.25 m, 0.75 m, 1.25 m, 1.75 m and 2.25 m.

The average temperature rise in the burn room is calculated as follows:

$$\Delta T = \frac{25 \cdot \Delta T_{25} + 50 \cdot \Delta T_{75} + 50 \cdot \Delta T_{125} + 50 \cdot \Delta T_{175} + 50 \cdot \Delta T_{225}}{225cm}$$

where

ΔT_i = measured temperature at height i above the floor.

5.3 Results of comparison

The calculated average temperature rises are compared with ARGOS simulations in figure 21.

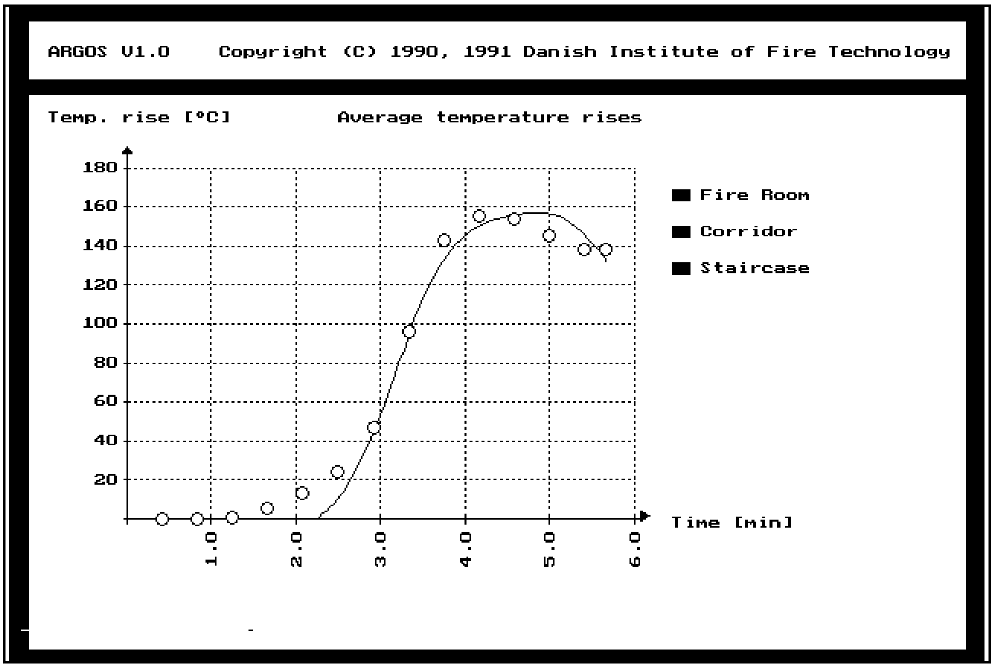


Figure 21 *Average temperature rise versus time. Circles = testresults; Curve = ARGOS simulation*

Defining the smoke layer interface as the height where the temperature rise is more than 20°C, leads to the interface heights shown in figure 22.

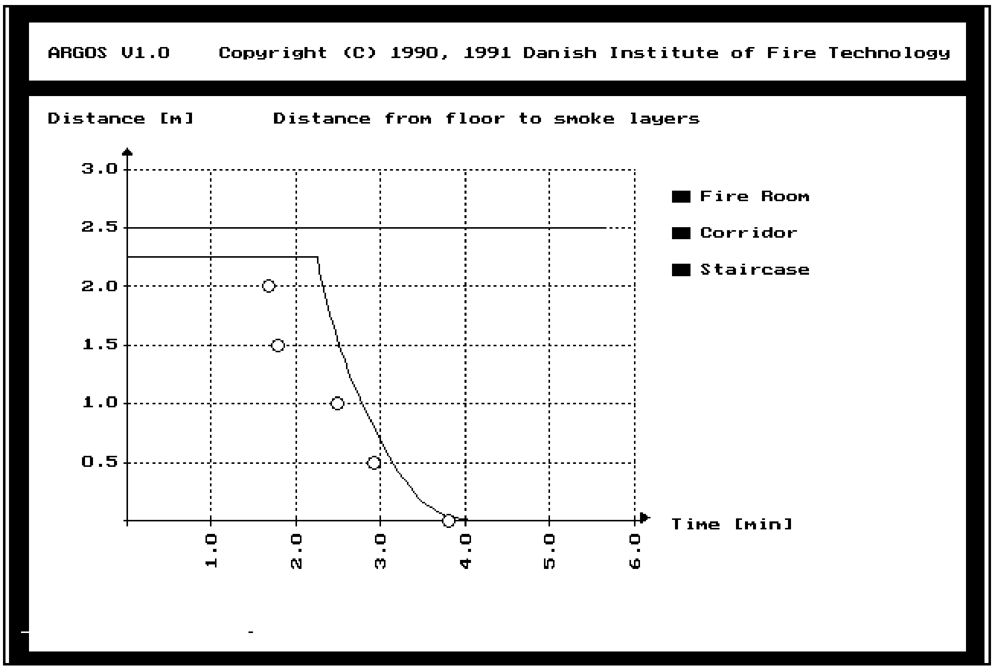


Figure 22 *Distance from floor to smoke layer versus time. Circles = Measured interface height, Curve = ARGOS simulation.*

The average temperature in the smoke layer can be calculated by the same formula as for the average temperature rise in the room, if only temperature measurements in the smoke layer are included. The smoke layer temperature thus calculated is shown in figure 23.

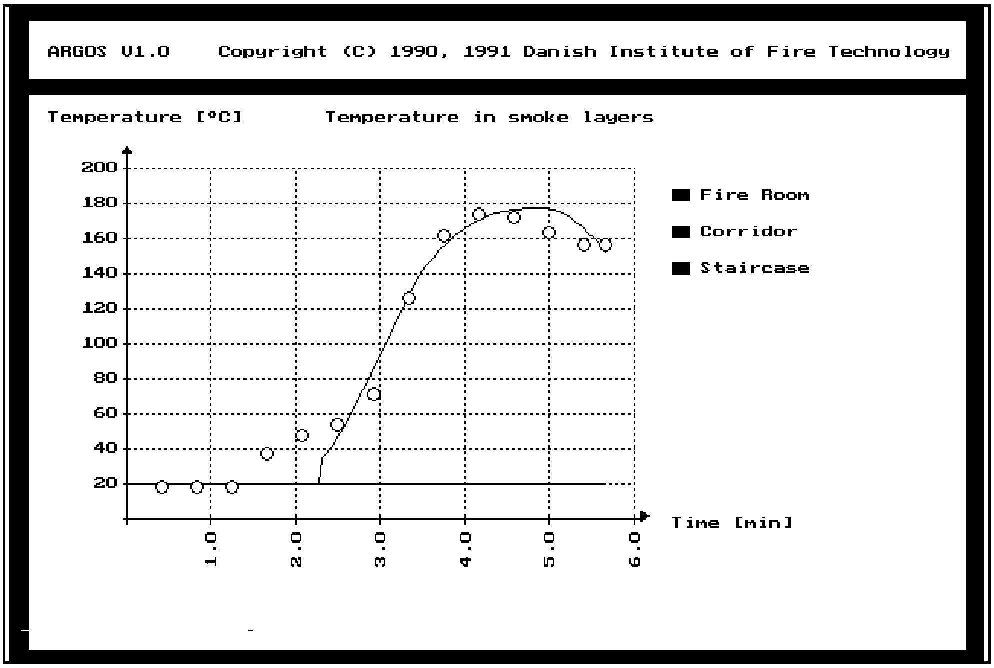


Figure 23 *Temperature in smoke layers versus time. Circles = smoke layer temperature from test results; Curve = ARGOS simulation*

Finally the oxygen depletion just under the ceiling was measured. This is compared with ARGOS simulations in figure 24.

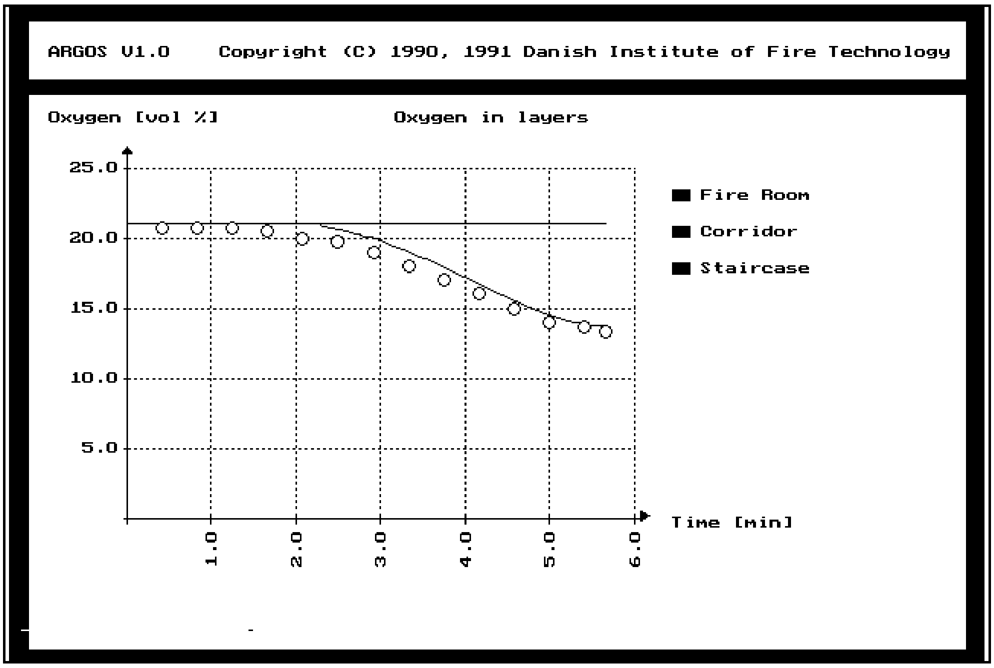


Figure 24 *Oxygen concentration in smoke layer as a function of time. Circles = Oxygen concentration as measured in the test results. Curve = ARGOS simulation.*

In ARGOS optical smoke detectors and heat detectors can be simulated. The detectors used in the test program had sensitivities according to the classification used in EN 54. The heat detectors used were grade 1.

The observed detection times for ceiling mounted detectors are compared with the detection times simulated by ARGOS in figures 25 and 26. For optical detectors the measured detection times vary considerably, even though they had identical specifications and were placed in the same horizontal distance from the burning object.

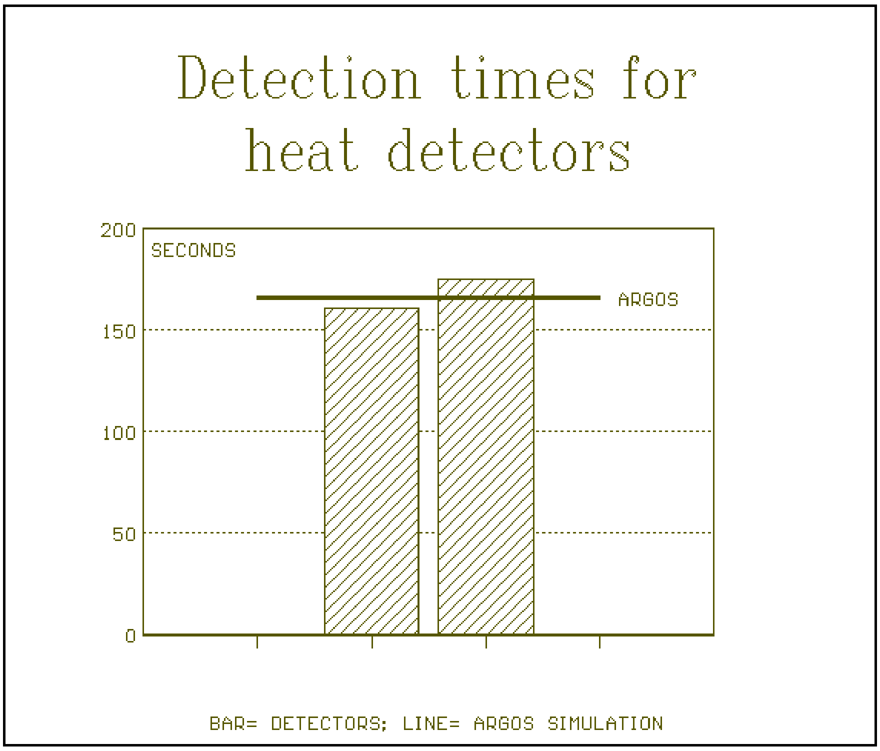


Figure 25 *Detection times in seconds for heat detectors and ARGOS simulation*

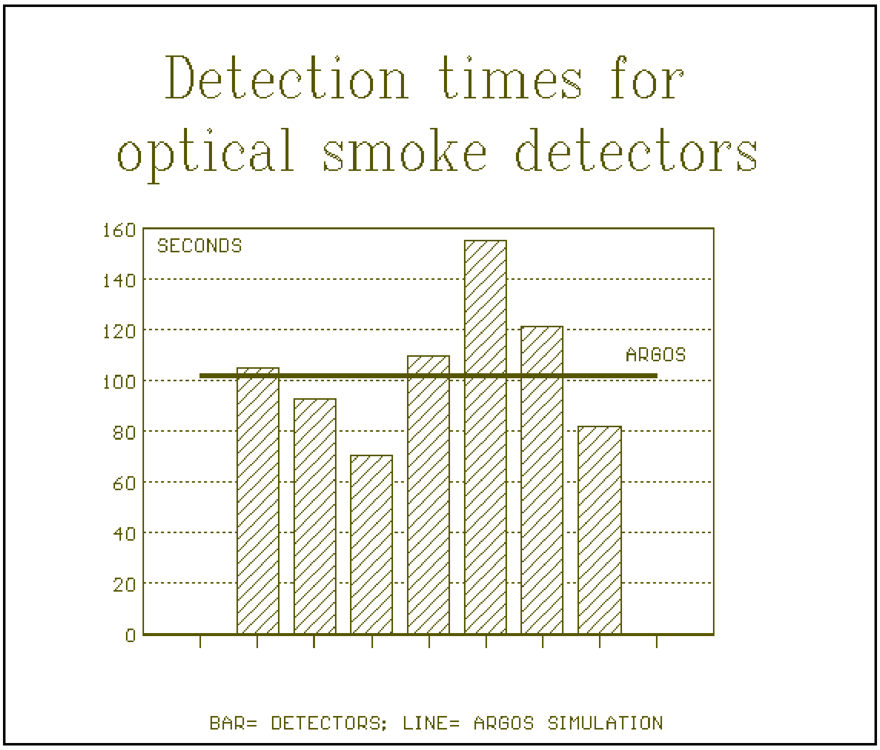


Figure 26 *Detection times in seconds for optical smoke detectors and ARGOS simulation*

6. Conclusions

Comparing ARGOS simulation results with some of the best and most varied full scale fire test results available today shows good or excellent agreement between measured and simulated temperatures, oxygen concentrations and detection times for heat and smoke detectors.

The agreement between measured and simulated distances from floor to smoke layer is good. From the test results refereed to in this report it appears:

- That the distinction between smokelayer and cold air is not always as sharp as assumed in zone modelling.

- That the observed smoke/air interface position do depend very much on the method of observation.

The comparison in this report shows that the basic principles and implementation of ARGOS lead's to satisfactory simulation of a wide variety of fire scenarios.

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