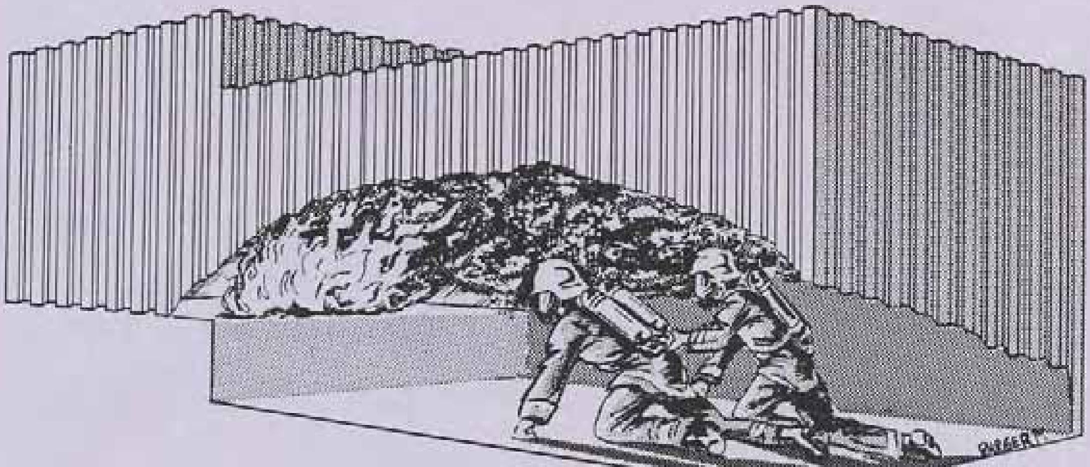
FLASH OVER SIMULATOR

FUNCTION AND SAFE USE

FOU REPORT P 21-069/91



RÄDDNINGS VERKET

FLASH OVER SIMULATOR, FUNCTION AND SAFE USE.

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Object: Investigation on the operation and safe use of a flash over simulator for the training of fire brigades. The properties and operating conditions have been measured in this investigation through practical tests. The safe operating range of the simulator has been determined from the results and based on this, a proposal for a suitable instructor's guide has been drawn up. A miniature mode1 of the flash over simulator has also been built, which has been used for producing a demonstration video tape on the gas fire and flash over phenomena.

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TECHNICAL RESEARCH CENTRE OF FINLAND
Fire Technology Laboratory

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1. Background

During the last years several flash over simulators have been built in Finland and Sweden for the use of fire brigades. The simulators are intended for training the extinguishing personnel. The simulator imitates the conditions in a typical room fire and it can be used, for instance to:

- give the trainees a practical experience of the flash over phase in a room fire and the endurance in such a room,

- teach extinguishing personnel to make observations about the development of the fire and to predict possible dangerous situations,

- teach the importance of appropriate and sufficient protective equipment,

- teach the extinguishing personnel correct and effective methods for confining and extinguishing room fires.

A typical flash over simulator consists of two steel transportation containers, one of which is the actual fire compartment and the other an observation room for the trainees and the instructors. The walls and the ceiling of the fire compartment are lined with combustible materials, that during combustion will cause a burning gas layer in the ceiling of the simulator. From the observation room one can observe the development of the fire and practice extinguishing.

Flash over simulators have until recently been designed and developed mainly by the fire brigades based on their own experiences and practical knowledge. Phenomena influencing its operation have not been systematically investigated, neither have physical parameters in this context been measured so the total understanding of the simulator has thus been very insufficient.

The properties and operating conditions have been measured in this investigation through practical tests. The safe operating range of the simulator has been determined from the results and based on this, a proposal for a suitable instructor's guide has been drawn up. A miniature model of the flash over simulator has also been built, which has been used for producing a demonstration video tape on the gas fire and flash over phenomena

2. Test equipment and instrumentation

In June 1990 a ready made simulator was acquired by the Fire Technology Laboratory of the Technical Research Centre of Finland. The simulator was placed in the so called extinguishing hall for the tests (Fig. 1). The fire compartment of the simulator was 400 mm above the observation room. The observation room had a side door, an end door and a roof hatch. The size of the doors was 1900 mm x 920 mm and of the roof hatch 500 mm x 500 mm. In the ceiling of the observation room there was a 1 m high hinged protective shield at the door post of the side door next to the fire compartment. On the floor of the observation room was a 20 mm thick layer of water proof film plywood.

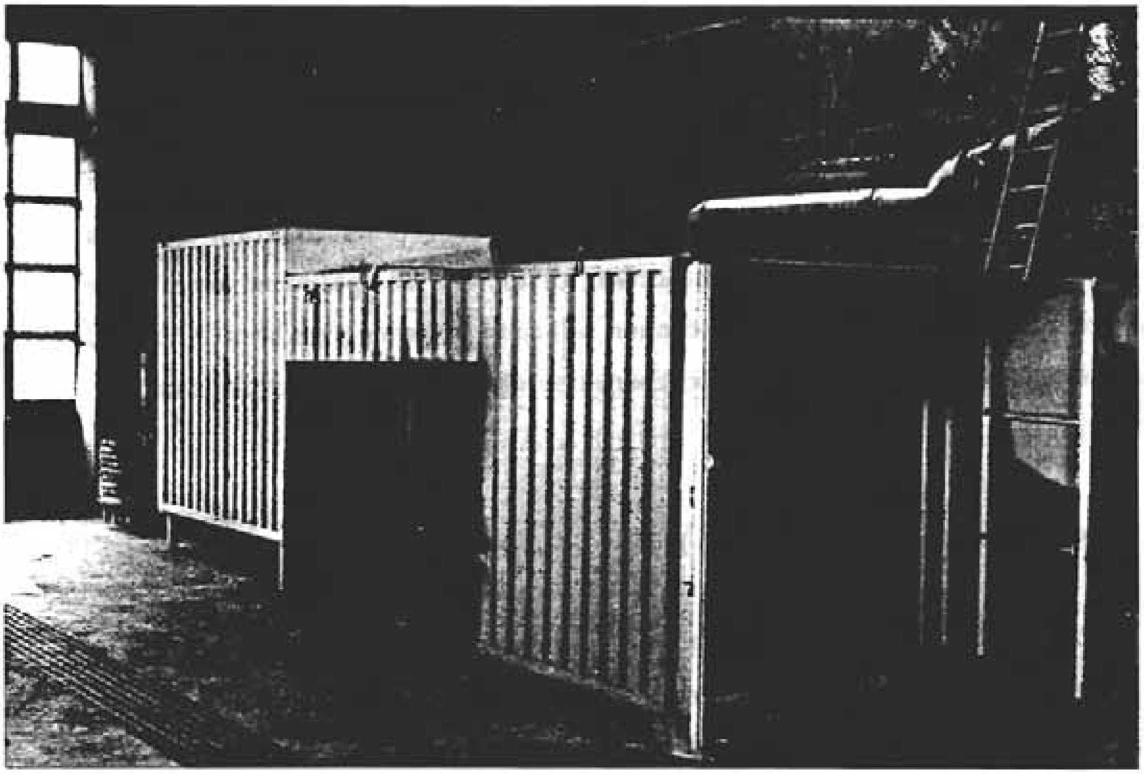

Fig. 1. The simulator without transduers in the extinguishing hall of the Fire Technology Laboratory. The doors and the roof hatch of the observation room are open.

The fire compartment of the simulator was insulated on the inside with 10 mm thick calcium silicate boards lined with a 0,6 mm thick corrugated steel sheet. The density of the calcium silicate boards was about 870 kg/m3 and the heat conductivity 0,173 W/Km. Fig. 2 shows a cross section of the wall of the fire compartment. The ceiling of the observation room was insulated with 10 mm thick calcium silicate boards up to the side door, as also the walis from a leve1 of 127 cm up to the ceiling. The construction of the simulator was almost gas-tight, and in practice the fire gases escaped only through the door openings or the roof hatch.

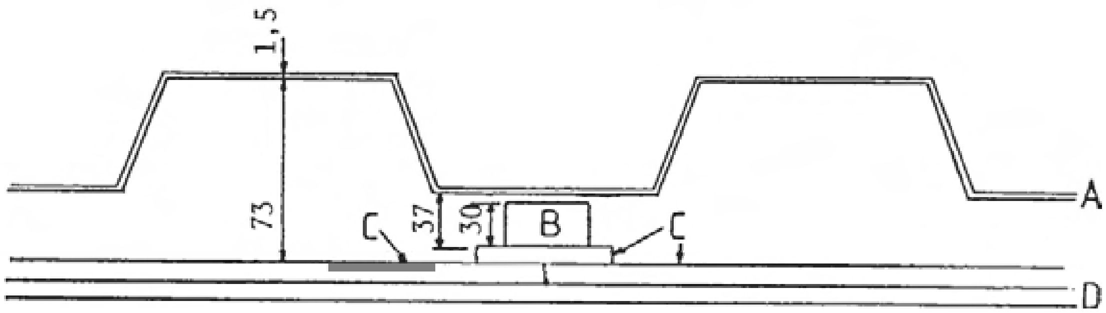

Fig. 2. Cross section of the wall of the fire compartment of the simulator. A external wall of the fire compartment, 1,5 mm corrugated steel sheet, B hollow section beam to which 10 mm thick calcium silicate boards C were mounted, D 0,6 mm corrugated steel sheet, the height of the corrugation is 10 mm. The calcium silicate boards were attached to the hollow section beams every 1200 mm.

In order to measure the vertical distribution of the gas temperatures in the simulator, 12 thermocouples were mounted vertically 20 cm apart both in the fire compartment and the observation room. The gas temperatures were also measured with six suction pyrometers and three sheathed thermocouples belonging to the standard equipment of the simulator. Moreover, the temperatures in the ceilings of the fire compartment and the observation room were measured and also the temperatures at two levels on the interna1 walis of the fire compartment and the observation room. The thermocouples in the fire compartment were soldered to the steel sheets and those in the observation room were attached to the calcium silicate boards by gluing.

The heat flux in the observation room was measured with two transducers, which viewed into the hemisphere extending from the front wall of the transducer. One of the transducers was installed in the horizontal position and it measured the radiation transmitted directly from the fire compartment. The other transducer was kept in the vertical position and it measured the radiation transmitted by the hot gas layer in the ceiling of the observation room. The carbon monoxide (CO) and carbon dioxide (CO) concentrations of the fire gases as well as the oxygen (O_2) depletion were measured with gas analyzers. Oxygen depletion or the amount of oxygen consumed is the difference between the oxygen concentration of the investigated gas and that of the surroundings. The pressure difference between the simulator and the surrounding was measured either in the ceiling or near the floor. In some tests the hydrocarbon concentration was also measured. Table 1 presents the used measuring equipment.

Table 1. Measured properties and corresponding measuring equipment.

Property	Measuring equipment
Temperature	Thermocouple, Type K, diameter 0,25 mm
Heat flux	Medtherm 64-10-18
CO, CO_2	Infrared Industries IR 702 infrared analyzer
Oxygen depletion	Hartmann & Braun Magnos 4 G magneto-pneumatic analyzer
Hydrocarbon	Signal 3000 hydrocarbon analyzer

Appendix 1 presents the construction of the simulator and the location of the installed transducers.

The signals produced by the measuring equipment were collected every 6 seconds with a HP 3497A data aquisition unit controlled by a Hewlett-Packard measuring computer. The measured results were stored on diskettes and transformed into a format used by MS-DOS equipment.

3. Test programme

The purpose of the tests with the simulator was to determine the temperature distribution and the thermal radiation inside the simulator under different operating conditions. The ambition was particularly to find the limits of the fire load and ventilation, under which the equipment still can be safely used and its operation controlled.

The fuel used in the tests was either propane gas, a wood crib in the middle of the floor of the fire compartment, or 3...6 particle boards in the ceiling and on the walls of the fire compartment. The table given in Appendix 2 presents for each test the fire load, the location of the measuring points for the heat flux, gas and pressure and the ventilation conditions. The ventilation was controlled with the doors and the roof hatch. In total 23 tests were conducted. AU tests were made indoors where weather conditions do not affect the measured results.

In the tests with propane gas and wood cribs, the temperatures and the influence of the ventilation were examined in a general sense. In these tests there were no persons inside the simulator.

In the tests with particle board, with the exception of one test, there were 1-2 firemen furnished with appropriate equipment in the simulator. In these tests the influence of the ventilation conditions was examined and two realistic training series were conducted in which the particle boards were ignited in one of the corners of the fire compartment where there were 10 pcs 40 mm x 40 mm x 500 mm wood sticks. The pyrolysis products from the particle boards formed a burning gas layer in the ceiling of the fire compartment and the observation room. The burning gas layer was extinguished with short water mist jets. The ignition source (the wood sticks) and the particle boards continued to burn, and the burning gas layer in the ceiling was allowed to redevelop. This was repeated 2...5 times. In one of the test series the side door was open throughout the exercise and the end door was closed (the 'Swedish' exercise) and in the other series the side door was closed and the end door sometimes open, sometimes closed (the 'Finnish' exercise). The roof hatch was used for controlling the progress of the fire in the initial stages of the exercise and for removing water vapour and combustion gases from the simulator after the fires were extinguished.

In the test series the fire was extinguhhed from below the smoke layer by directing the jet at an angle of 45 degrees into the combustion gases near the ceiling in the back part of the fire compartment. The extinguishing point was at the radiation transducers, 1,7 m from the edge of the observation room. The extinguishing was conducted with Fogfighter branchpipes only.

4. Simulator tests

4.1 Propane gas

4.1.1 100 kW, tests 1 - 3 and 5 - 7

In these tests the influence of the different openings in the simulator was investigated. When the end door was fully open, the temperatures near the ceiling of the fire compartment were about 250 °C. The same results was achieved when the end door was ajar. When both doors were closed and the ventilation was controlled through the roof hatch only, a distinct 'pumping' effect could be noticed, as both the entering air and the leaving combustion gases flowed through the same opening. When all openings were closed, the fire extinguished after a few minutes.

4.1.2 300 kW, test 4

In this test, temperatures of about 500 °C were measured near the ceiling of the fire compartment. No flash over was observed.

4.2 Wood cribs, tests 10 and 11

The wood cribs were ignited with a small heptane tray under the crib. The bigger crib (80 cm x 80 cm x 40 cm, 55 kg) was allowed to burn freely for 18 min before it was extinguished. The gas temperature reached a maximum value of 700 °C. In the test with the smaller crib (80 cm x 80 cm x 20 cm, 25 kg) the end door was closed and the gas concentrations were allowed to grow after which the end door was opened again. In this case the fire grew again rapidly, but the pyrolyzed gases did not cause a flash over.

Appendix 3 presents the temperatures T1...T8 of the gases in the combustion compartment and also the gas concentrations as a function of time in test 11.

4.3 Particle boards

4.3.1 Three particle boards, tests 13 and 14

Two particle boards (1200 mm x 2600 mm x 11 mm) were mounted in one of the corners of the fire compartment and one board in the ceiling. The particle boards were ignited with a small heptane tray placed in the corner. A flash over occurred 5-10 min after the ignition depending on the amount of heptane. The gas temperatures in the fire compartment increased to 900 °C when the fire was allowed to develop freely for 30 min with the end door open.

4.3.2 Six particle boards, tests 15 and 16

Four particle boards were mounted on the walls of the fire compartment and two in the ceiling of the fire compartment. The particle boards were ignited in one of the corners with 10 wood sticks with a size of 40 mm x 40 mm x 500 mm (Fig. 3). The wood sticks had been soaked before ignition with 0,5 litres of paraffine. Two firemen using appropriate protective clothing and self contained breathing apparatuses were in the observation room during the test.

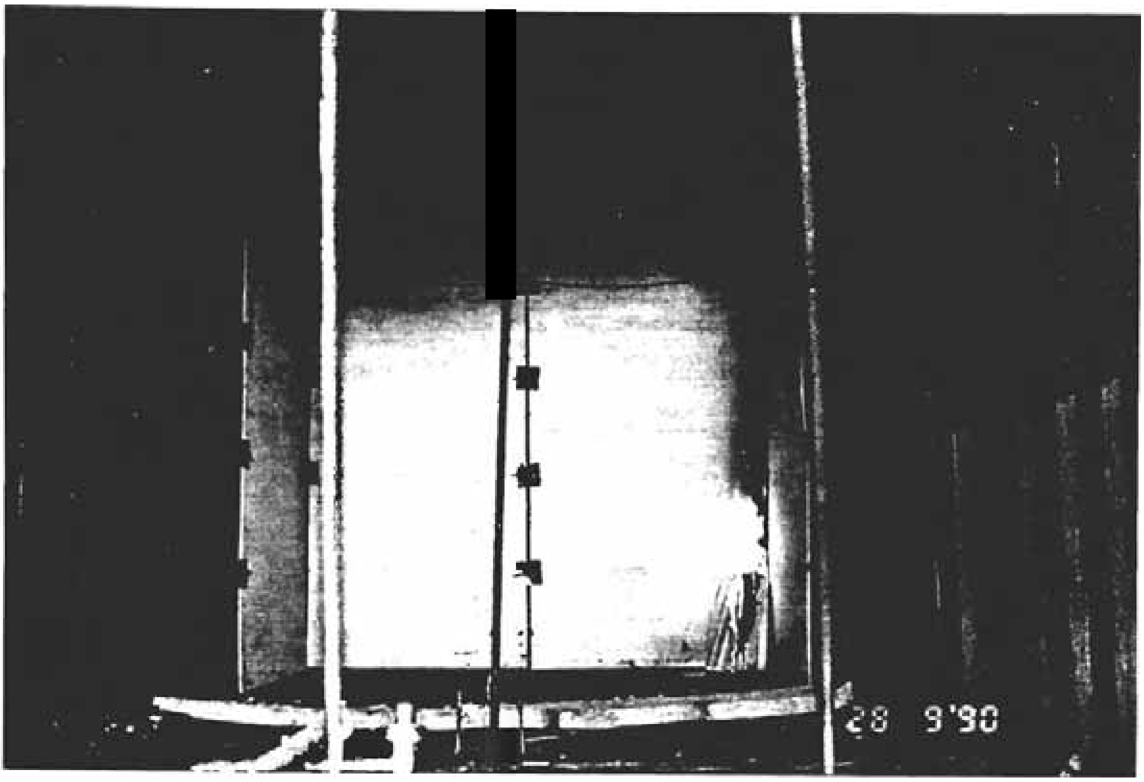

Fig. 3. A few seconds after ignition. The six particle boards in the fire compartment of the simulator have been ignited in one of the corners with 10 wood sticks. In the middle of the fire compartment is a rig with 12 thermocouples 20 cm apart. To the right in the foreground is a similar thermocouple rig in the observation room, to the left is a rig for the heat flux transducers.

The burning gas layer was allowed to develop so far, that the flames reached the ceiling of the fire compartment, and then the end door was closed 8 min after ignition. The gas temperature near the ceiling of the fire compartment dropped from 700 "C to below 400 °C and the flames disappeared. Simultaneously the CO_2 concentration in the ceiling increased to about 20 volume percent and the O_2 concentration decreased with almost the same amount. The end door was opened at 9 min and flames emerged through the door opening. The door was closed immediately and the fire was extinguished with short water mist jets. According to the measured vertical temperature profile in the observation room, the border between the hot and the cool zones was about 1,2 m above the floor of the observation room. Below this border, the temperature was less than 100 "C.

4.3.3 Six particle boards, test 17

In the fire compartment there were four particle boards on the walls and two in the ceiling, which were ignited in the same way as in tests 15 and 16. The roof hatch was closed throughout the test and the protective shield was lifted up. The test simulated a condition where flash over has occurred in the room and the extinguishing of the fire starts from outside the room. The fire was allowed to develop until the flames reached the end door at 8 min. The door was partly closed and the fire decreased. At 10 min the door was opened again and at 11,5 min a fast flame front emerged through the doorway. The plywood floor in the observation room was ignited at this time by the radiation from the flames. The door was left open and the firemen extinguished the fire from the outside with water mist jets. The gas temperature 0,2 m above the floor of the observation room was about 200 °C at 11 min.

Appendix 4 presents the observations made during test 17, the gas temperatures in the fire compartment and the observation room, the heat fluxes and gas concentrations as well as the wall temperatures in the fire compartment as a function of time.

4.3.4 The 'Swedish' exercise, six particle boards, tests 20 - 23

The fire load and the ignition technique were the same as in tests 15 and 16. The side door was fully open at a 90 degree angle while the end door was closed during the test. Two appropriately furnished firemen were in the simulator during the tests. The fire was allowed to develop to various phases in the fire compartment and the observation room, after which the burning gas layer was extinguished by cooling the combustion gases with short water mist jets. It was the intention to avoid extinguish the burning wood sticks. Because wood may smoulder, it is possible that an explosible gas mixture may form inside the simulator from the air and the pyrolysis gases if the ignition source was allowed to extinguish. If there is such a mixture in the simulator and the particle boards are re-ignited, the mixture may explode. If the ignition source bums all the time, this will assure, that such a mixture does not form, as the pyrolysis products are consumed when they are formed.

Appendix 5 presents the observations made during test 21, the gas temperatures in the fire compartment and the observation room, the heat fluxes, the pressure difference between the fire compartment and the outside and the gas concentrations as a function of time as well as the vertical temperature distribution in the fire compartment and observation room at various times.

Appendix 6 presents the observations made during test 22, the gas temperatures in the fire compartment and the observation room, the heat fluxes, the pressure difference between the fire compartment and the outside and the gas concentrations as well as the wall and ceiling temperatures in the fire compartment and the observation room as a function of time.

4.3.5 The 'Finnish' exercise, six particle boards, tests 24 - 26 and four particle boards, test 27

The ignition technique was the same as in tests 15 and 16. The side door was closed during the tests and the end door was open throughout the test in some of the tests, while in other tests it was sometimes open, sometimes closed. The burning gas layer was also in this test series allowed to develop in the fire compartment and the observation room, then the burning gas layer was extinguished after which the fire development and extinguishment were repeated.

Appendix 7 presents the observations made during test 24, the gas temperatures in the fire compartment and the observation room, the heat fluxes, the pressure difference between the fire compartment and the outside and the gas concentrations as a function of time as well as the vertical temperature distribution in the fire compartment and observation room just before extinguishing of the burning gas layer.

Appendix 8 presents the observations made during test 26, the gas temperatures in the fire compartment and the observation room, the heat fluxes, the pressure difference between the fire compartment and the outside as well as the wall and ceiling temperatures in the fire compartment and the observation room as a function of time and the vertical temperature distribution in the fire compartment and observation room just before extinguishing of the buming gas layer. Appendix 8 also contains a comparison between temperatures measured with sheathed and bare thermocouples as well as between suction pyrometers and bare thermocouples.

Appendix 9 presents the observations made during test 27, the gas temperatures in the fire compartment and the observation room, the heat fluxes and the pressure differences next to the end door as a function of time as we11 as the vertical temperature distniution in the fire compartment and observation room just before extinguishing of the burning gas layer.

5. Mininture model tests

A miniature mode1 in scale 1:9 was built of the fiash over simulator, with one of the side walls made of glass. The purpose of the miniature mode1 was to demonstrate the development of a burning gas layer and the flash over phenomenon.

The length of the fire compartment of the miniature mode1 was 350 mm, the width 240 mm and the height *280* mm while the corresponding dimensions of the observation room were 590 mm **x** 240 mm **x** 280 mm. The floor of the fire compartment was 50 mm above the floor of the observation room. In the roofs of both the fire compartment and the observation room, there were a hatch with a size of 160 mm **x** 160 mm, through which the pressure of a sudden gas explosion could be relieved. There was a door in the front of the observation compartment. The miniature mode1 was insulated on the outside with a 40 mm thick layer of glass wool, except for the front end of the observation room and the glass walls. There were six thermocouples in the fire compartment and three in the observation room at different levels.

A test series comprising of eight tests was conducted with the miniature model, in which a suitable fire load for the demonstrations was searched. For this purpose, tests were made in the fire compartment by burning methane gas with a small burner and also pieces of particle board. The best results were obtained with a burner effect of 8 kW and three *280* mm **x** 210 mm **x** 10 mm particle boards, one of which was mounted in the ceiling. Figure 4 presents the miniature mode1 at the start of a test.

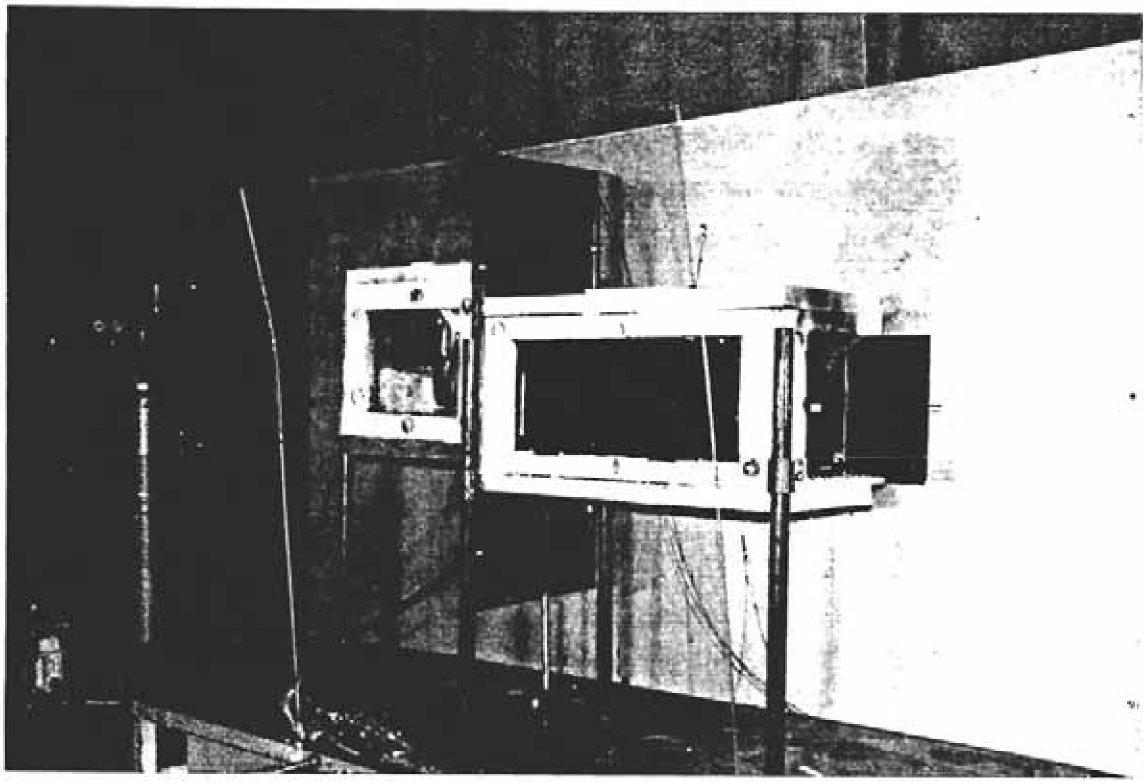

Fig. 4. The miniature mode1 at the start of a test. In the fire compartment the methane flame can be seen, the particle boards have not yet ignited. In front of the miniature model is a protective shield in case of a sudden explosion.

In the tests the burning gas layer was allowed to develop from the fire compartment to the observation compartment, after which the end door was closed. The fire consumed the oxygen quickly and decreased. The methane gas flow was turned on throughout the test, so there was enough combustible material present. Just before the fire was quenched the end door was opened, which caused a flash over. This was repeated 5...10 times. No gas explosions occurred in this test series. The only restricting factor was the rapid smearing of the windows, which set the upper limit for the duration of a test to about 15 min.

The temperatures as a function of time in the fire compartment and the observation room and the vertical temperature distribution in the fire compartment at the times of closing and opening (flash over) of the door are presented in Appendix 10.

The tests made with the miniature model were recorded with a video camera. A demonstration video on the simulator and the flash over phenomenon has been edited from the video tape.

6. Discussion

6.1 Gas temperatures

The gas temperatures were measured with 12 bare thermocouples in the fire compartment as well as in the observation room. For clarity and readability four temperature curves as a function of time have been plotted in one figure. In these figures the elevations are reported relative to the floor of the observation room. The chosen levels are 0,2 m (near the floor), 1,0 m (the level of the face of a kneeling person), 1,6 m (the level of the face of a standing person) and 2,4 m (near the ceiling).

in the figures which present the vertical temperature distribution i.e. the gas temperature as a function of the elevation, the level is always relative to the floor in the respective compartment or room.

The temperature curves plotted as a function of time give a good general view of the progress of the test, while the vertical temperature distributions give the border between the hot and cool gas layers and the average temperatures of the layers.

In test 17 the temperatures in the upper part of both the fire compartment and the observation room increased to 600...800 °C while the temperature near the floor increased to 150...200 °C (Appendix 4, Figs. 1 and 2). It is obvious that under these circumstances where hot gases fill the entire space, staying inside the simulator is not possible. This test shows, however, what temperatures and irradiance levels can be reached in the simulator if the fire is allowed to proceed long enough.

In test 21 the burning gas layer was restricted to the fire compartment for the first extinguishing. In the second extinguishing the gas layer reached the protective shield in the observation room. From Figs. 1 and 2 in Appendix 5, it can be seen that the temperature increases slowly during the initial phase of the fire. The walis of the fire compartment are cold at this stage, which somewhat slows down the fire growth. From the vertical temperature distribution presented in Fig. 3 in Appendix 5, it can be seen that when the burning gas layer is restricted to the fire compartment, the hot layer in the observation room is narrow, or there is no distinct border, but the temperatures increase from about 70 °C at a levei of 1,4 m to about 350 °C near the ceiling. In the first extinguishing the fire and aiso the ignition source were totally extinguished. After the second ignition the burning gas layer was allowed to spread up to the protective shield in the observation room before extinguishing. From the temperature distribution in Fig 4b in Appendix 5 it can clearly be seen that there are two gas layers in the observation room and that their border is at a levei of about 1 m. The fire is at this stage in rapid growth and the thickness of the hot layer in the observation room increases quickly. The temperature in the hot layer reaches 600 °C just before extinguishing and the hot layer approaches the Floor. The temperature at a levei of 0,8 m is, however, 90...100 °C still 20 s before the extinguishing. After the extinguishing the temperature of the hot layer decreases quickly (Appendix 5, Figs. 4c and d), and conditions are reached where a fireman is able to advance in practical extinguishing work.

Test 22 was conducted in the same way as test 21, except that when the burning gas layer reached the observation room, several extinguishings of the burning gas layers were conducted (time interval 600...900 s, Appendix 6, Figs. 1 and 2). The gas temperatures and distributions are almost identical with those of test 21.

In tests 24, 26 and 27 (Appendices 7, 8 and 9) the side door was closed and the end door open, in test 24 the end door was both closed and open during the test. The temperatures and the distributions are at the same levei as in the tests where the side door was open and the end door closed. The difference in the location of the ventilation opening is noticed so, that the start of the fire at the beginning of the exercise was slower when the ventilation opening was farther away from the fire compartment (the end door open and the side door closed).

6.2 Surface temperatures in the walls and ceiling

The temperatures on the walls in the fire compartment increased in the exercise tests to 600 °C 55 cm below the ceiling and to 200...300 °C 60 cm above the floor. The insulation in the fire compartment is necessary to protect the walls of the simulator. The insulation causes the fire to develop more rapidiy, which from a training point of view is undesirable. The insulation technique of the fire compartment should still be developed.

The temperatures on the insulation bards in the ceiling of the observation room increased to 400...600 °C and the surface temperature of the walls to 400...600 °C 55 cm below the ceiling of the observation room and to 200...300 °C 60 cm above the floor of the observation room.

The corresponding temperatures in test 17 were 150...250 °C higher than the temperatures in the exercise test.

6.3 Comparison between different temperature transducers

The sheathed thermocouples, the bare thermocouples and the suction pyrometers were not exactly at the same level or the same location, which makes the comparison somewhat difficult. A comparison between the sheathed thennocouples and the bare thermocouples (Appendix 8, Figs. 6a, b and c) shows, however, that the time delay in rapid temperature changes is 2...4 s faster in favour of the bare thermocouples. When the fire is growing and the temperatures are increasing rapidly, the slow sheathed thermocouples do not register the change quickly enough, but report vaiues that are 50...80 % of the vaiues given by the bare thermocouples, depending on the current temperatures of the sheathed thermocouples.

There is roughly an identical time lag between the suction pyrometers and the bare thermocouples as there is between the sheathed thennocouples and the bare thermocouples (Appendix 8, Figs. 7a, b and c). This follows from the fact that a suction pyrometer measures the gas temperature in the vicinity, but a bare thermocouple reacts also to the radiation from the flames. The time delay for the suction pyrometers is almost zero, a bare thermocouple reports on the other hand too high temperatures too early when the fire is growing, due to the radiation. In Fig 7a the surrounding of suction pyrometer I1 is hotter than that of T10 in the beginning of the fire, because I1 is 0,l m above T10.

6.4 Heat flux

In the exercise tests (tests 20...27) the heat fluxes were less than 5 kW/m^2 except for sharp transient peaks occurring before the extinguishing of a burning gas layer. The maximum irradiances were 10...35 kW/m^2 and the heat flux was more than 20 kW/m^2 for less than 10 s.

In test 17 there were three peaks where the heat flux was more than 20 kW/m^2 for 50...75 s. The heat flux was continuously more than 5 kW/m^2 for 12 min. The maximum irradiance peak value was about 75 kW/m^2.

A textile sample was taken from the protective clothing (6 layers: 3-layer ararnide + 2 cotton college knit + aramide terry knit) of one of the firemen participating in the exercises. The behaviour of this sample subjected to thermal radiation was tested according to the method **ISO/DIS** 6942. In the tests it was shown that at an irradiance of 20 kW/m^2, the time for feeling pain was 57 s and the time to bums of second degree 101 s.

The time for feeling pain of bare skin is 1...2 s at an irradiance of 20 kW/m^2 and the time to bums of second degree about 5 s. The corresponding values of bare skin at an irradiance of 5 kW/m^2 are about 15 s and 30 s.

The simulator is safe to use with the above mentioned clothing, provided that the fire is extinguished in time. The importance of appropriate clothing must, however, be emphasized. Particularly there must not be any unprotected or weakly insulated gaps between the separate pieces of clothing.

6.5 Pressure

In a room fire, the hot combustion gases below the ceiling expand, a slight over-pressure with respect to the surrounding is developing in the upper part of the room and the hot gases tend to escape through all possible openings. Due to this buoyancy flow a slight under-pressure with respect to the surrounding is developing in the lower parts of the room and cold air flows from the outside into the lower parts of the room.

In tests 20...26 the measured under-pressure (P2) was 1...2 Pa at the border between the fire compartment and the observation room. The value 1 Pa = 1 N/m^2 corresponds to a weight of 100 g spread evenly over one square meter. The atmospheric pressure is about 100 000 Pa (100 000 Pa = 1 bar), for example using discontinued units, the normal atmosphere is 760 mmHg = 101 325 Pa. During the extinguishings the under-pressure increases to a vaiue of 2...4 Pa when the hot gases contract while cooling. The signal from the pressure difference transducer was rather noisy. The use of the roof hatch can sometimes also be noticed in the pressure difference.

In test 24 the end door was totally closed at time 5 min 50 s. The simulator was at that time a closed room in which the developed over-pressure reached a maximum value of 190 Pa which corresponds to 19 kg spread evenly over one square meter. The pressure levelled when the end door was opened.

In test 27 the pressure difference between the lower parts of the observation room and the surrounding was 1...2 Pa during the fire and the difference between the upper and lower parts of the observation room 4...6 Pa.

The pressure measurements (P1) conducted in the upper part of the fire compartment failed because the used instrument was too sensitive to temperature changes. The over-pressure developed here is probably of the order of 10 Pa.

6.6 Gas analysis

In examining the diagrams of gas concentrations, it is to be noticed that for oxygen they report oxygen depletion i.e the difference between the oxygen concentration of the gas and the oxygen concentration of ambient air. Air contains normally 20,95 volume percent oxygen. By subtracting the value given by the figures from the value 20,95 one obtains the oxygen concentration of the respective sample (the gas in the simulator).

When an organic compound bums, carbon dioxide, for instance, is released. The oxygen concentrations should thus increase simultaneously as oxygen is consumed (the oxygen depletion is increasing). The diagrams show, however, a time lag of about 45 s between these two, which is caused by different time delays in the gas analyzers.

From Fig. 2 in Appendix 3 it can be seen that when the door has been closed, the gas concentrations are almost the same near the ceiling and the floor, as the combustion gases quickly fill the entire available space. When the door is opened, two layers are formed in the room, a hot layer consisting of combustion gases and below this a cool layer into which fresh air from the outside is mixing. When the door is closed, the carbon dioxide and the carbon monoxide concentrations increase rapidly while the oxygen concentration decreases correspondingly. The development of the two layers, a hot and a cool one, is also clearly observed from the vertical temperature distributions.

Carbon monoxide (CO) is a toxic substance, which is dangerous even at low concentrations. If a person at light work breaths air with a CO concentration of O,6...O,8 volume percent, unconsciousness follows in 5 minutes. If the CO concentration in air is 1,2...1,6 volume percent unconsciousness follows after a few breaths and death in 5 minutes. In heavy work the times are correspondingly shorter.

in tests 20...23 where the side door was open, the CO concentrations were 0,2...1 % near the floor of the observation room (measuring point G2). In tests 24...27 where the end door was open, the concentrations were O,5...1 %. In some of the tests short transient peaks occurred during extinguishing where the CO concentration was 2...5 %. In test 24 the CO concentration was 2...3 % when the doors and the roof hatch were closed.

During the exercises the CO concentration is thus lethally dangerous and the use of self-contained breathing apparatuses is necessary.

The highest measured carbon monoxide concentration near the ceiling of the observation room (measuring point G1) was 6,4 volume percent (test 15) when the doors were closed. There were also other pyrolysis products in the simulator. The carbon dioxide concentration at that instance was 19,6 % and the oxygen concentration had decreased by the same mount. The temperature near the gas collecting tube was about 400 °C. At this instance when the doors were closed, the oxygen had been almost totally consumed and the fire had almost been quenched. The pyrolysis process in the particle boards continued, however, and there were ignitable gases in the simulator. When the door was opened, the oxygen concentration increased and the fire began grow again.

If a sufficient amount of ignitable gases are formed inside the simulator under these circumstances and the door is opened, it is possible that after mixing the gas mixture may explode. In these tests no explosions occurred, but the danger exists and therefore at least one door shall be fully open during simulator exercises.

The upper limit of the measuring range of the hydrocarbon analyzer was 1 volume percent, which was exceeded near the ceiling in the fire compartment (measuring point G1). No clear results were obtained from the measurements about the development of hydrocarbons.

7 Observations on the construction and use of the investigated simulator

7.1 The construction of the simulator

The extemai dimensions of the investigated simulator proved to be practicai. The distance from the protective shield in the observation room to the front of the fire compartment is 2.4 m. The width of the simulator is 2,5 m, so the area between the front of the fire compartment and the protective shield is 6 m^2. A suitable nurnber of persons in this space is 4 students and a trainer.

The technique of mounting the particle boards to the ceiling must be improved. In the simulator the boards fell down on the floor during the exercises. The gases mix effectively in the closed space and the hot gases approach the floor causing a dangerous situation. A grid that prevents the boards from falling down should be mounted in the ceiling.

The ceiling and the upper parts of the observation room are insulated with calcium silicate boards. One of the ceiling boards fell down during the tests. The falling of the insulation boards in the observation room must be prevented by a grid or similar construction.

If a buming gas layer reaches the observation room, a protective shield, behind which people can hide, is necessary.

The size of the doors shall be the same as in ordinary buildings. The door and the door opening shall be dimensioned so that the door cannot stick due to therrnal expansion. The same is true for the lock (clasp) of the door.

There could also be a door on the other side of the simulator. This would be convenient if the simulator is used outdoors, as the wind direction then would be irrelevant.

During the exercises it was noticed that a larger roof hatch would speed up the ventilation of smoke and water vapour. The size of the roof hatch of the simulator was 0,5 m x 0,5 m = 0,25 m^2. If the side of the hatch would be 5 cm longer, the area of the hatch would be 0,55 m x 0,55 m = 0,3 m^2 or 20 % bigger. The roof hatch must be operable both from inside and outside the simulator.

In the tests it was noticed that during the initial phases of the fire, smoke and water vapour emerged from under the boards of the fire compartment, which decreased visibility. Because the simulator was gas proof, the smoke that had entered behind the boards and the water vapour coming from the moist insulation boards cooled from the cold external walls and flowed downwards. A few holes in the upper part of the external wall of the simulator would remove this smoke and water vapour. These ventilation holes do not affect the development of the burning gas layer.

7.2 Use of the simulator

A suitable number of persons in the investigated simulator is 4 students and their trainer. With this number, all have the time to practice extinguishing and to observe the development of the fire without to much crowdiny.

For simulator exercises protective clothing with a sufficient number of layers must be used, cf. clause 6.4. The functioning and leakproofness of the self contained breathing apparatuses must be verified.

In the exercise tests of this investigation the fire load comprised four or six particle boards. Other wall materials were not investigated. The particle boards proved to be suitable, they are cheap and readily available. No real difference between the exercises with four or six particle boards could be observed. Particle boards with a fire retardant treatment should not be used as the fire would develop much slower. Dangerous substances could also be formed from these fire retardants.

The ignition source consisting of a crib of wood sticks proved to be useful. The ignition can be made easier by using petroleum or some other flammable liquid (formerly flammable liquid of Class II). The amount of liquid must not exceed 1 litre. Highly flammable liquids (formerly flammable liquids of Class I), for instance petrol, must not be used.

During the exercises at least one door must be kept open throughout the test. If the door is closed, the fire is quenched, but the pyrolysis process continues in the particle boards. It is possible, that an over-rich mixture is formed, that is not combustible. When the door is opened fresh air flows into the simulator and mixing occurs and the mixture becomes combustible and an uncontrollable flash over may occur. Such conditions did not take place during the simulator tests of this project, but due to occupational safety the door should not be closed. A flash over can, on the other hand, be easily demonstrated in the miniature model of the simulator.

The extinguishing of the burning gas layer can be carried out either before it spreads into the observation room or when the burning gas layer reaches the protective shield in the observation room. If the burning gas layer is restricted to the fire compartment, the temperatures in the observation room do not increase very much and the conditions are safe. If the burning gas layer is in the observation room, the conditions are more realistic. The extinguishing must be timed correctly, because the burning gas layer flows quickly down towards the floor in a few ten seconds. The proper time to start the extinguishing is when the flames are reaching the protective shield in the observation room i.e. before the thickness of the burning gas layer begins to grow. The reporting of a certain limit temperature is not practical and safe, because sheathed thermocouples are rather slow. A thermocouple may get broken during a test and the temperature report comes anyway from outside the simulator and may be delayed.

For the extinguishings not too much water should be used. If the fire has proceeded far enough and too much water has been used, the forming water vapour fills the simulator causing bums.

The temperatures measured during the exercises must be recorded on, for instance, a plotter. Such a log can be useful in two ways: from the instructional point of view it is important that the trainees can see by themselves in what temperatures they have been; the knowledge of the recording has probably an impeding effect, preventing possible exaggerations.

During the exercises there shall be at least one person outside the simulator wearing a self contained breathing apparatus and an extra hose. Before the exercise one must agree upon the signalling of emergencies and the order of escape.

8 Conclusions

As a conclusion of what has been presented before, it can be stated that the simulator, correctly used is we11 suitable for use as a training too1 for studying the development and extinguishing of a burning gas layer. The equipment is, however, a small one and it does not reflect the conditions in a real room fire, where there are several rooms bigger than the simulator. The events occurring during a fire and the sensation of staying in a room where there is a burning gas layer are, however, obvious. An actual flash over must be avoided in this apparatus. The fire shall develop so slowly that the situation is always under control. A more appropriate name for the equipment would thus be roam fire simulator.

In the simulator exercises the role of the trainer is emphasized. The tirning of the extinguishing, the amount of water and the ventilation through the roof hatch are all conducted according to the subjective feeling of the trainer. The timings mentioned in clause 7.2, the time when the burning gases reach the observation room or when it reaches the protective shield in the observation room must be determined subjectively. Which condition is chosen depends on how realistic conditions are anticipated

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APPENDIX 10 **Miniature model test, 8 kW methane burner and 3 particle boards**

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The flash over simulator and the location of the measuring transducers

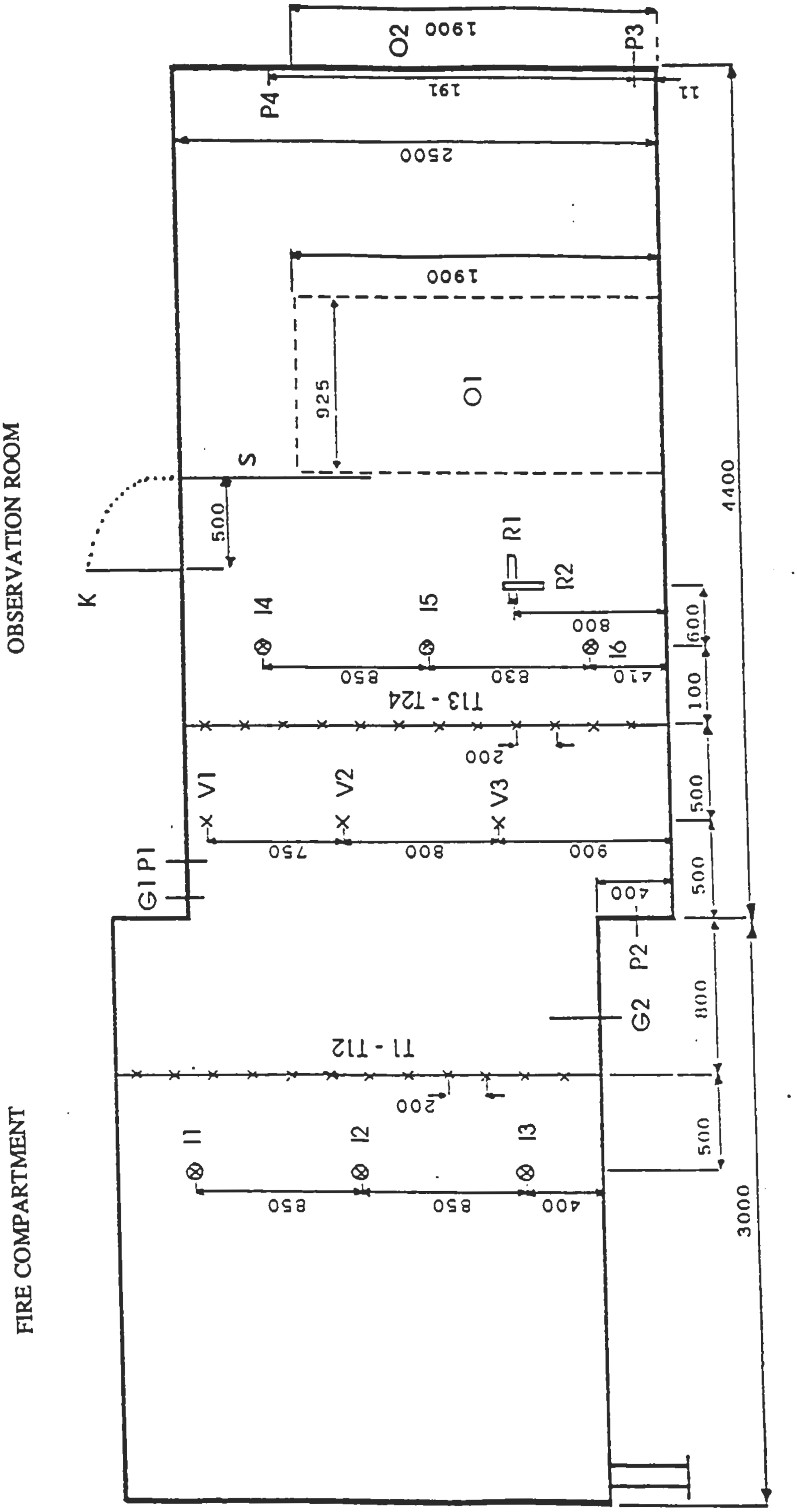


Fig 1. Side view of the flash over simulator and the location of the measuring transducers. **I1...I6** suction pyrometers, **T1...T24** bare thermocouples in air, **V1...V3** sheathed thermocouples, **G1, G2** sampling tubes of the gas analyzers, pressure difference transducers **P1** and **P2** between the fire compartment and the surrounding, **P3** between the observation room and the surrounding and **P4** between the upper and lower parts of the observation room (at the level of P3), **R1, R2** heat flux transducers, **S** protective shield, **K** roof hatch, **O1** side door, **O2** end door.

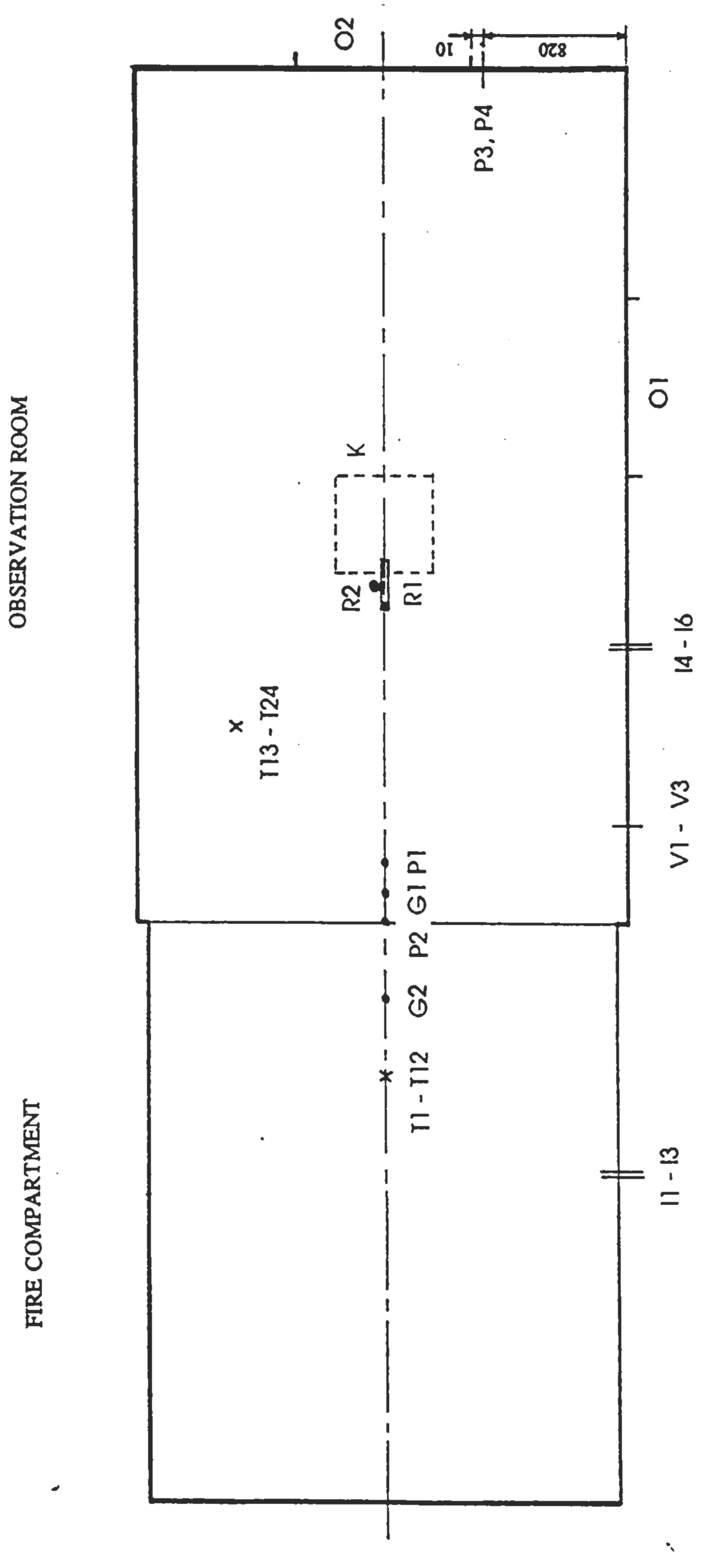
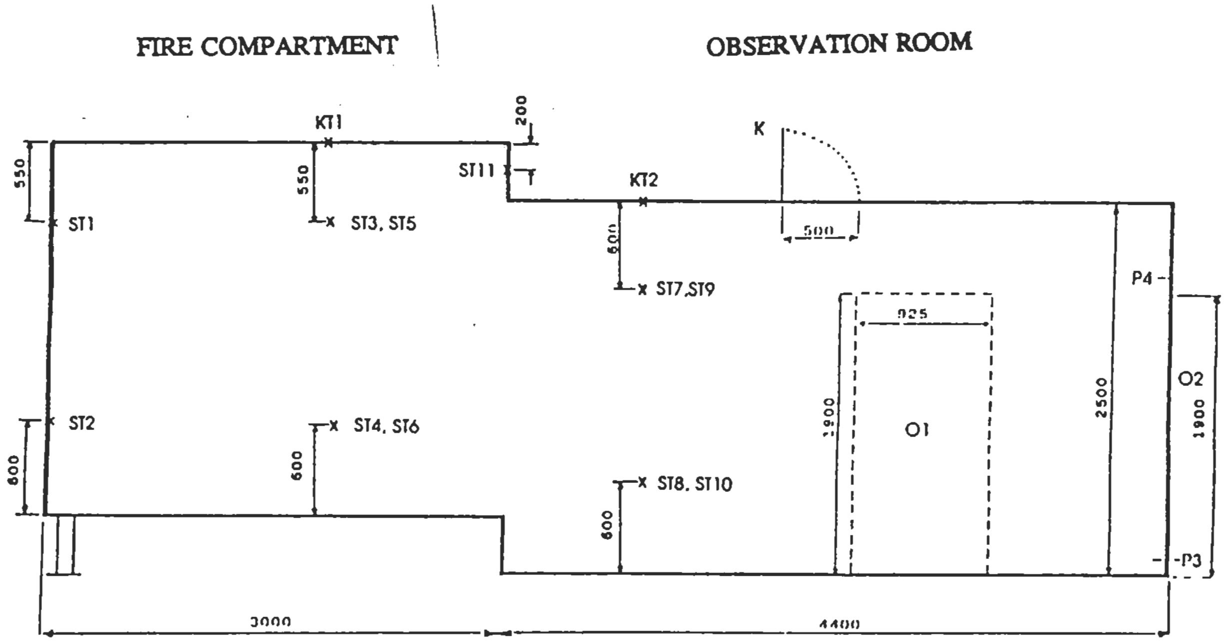


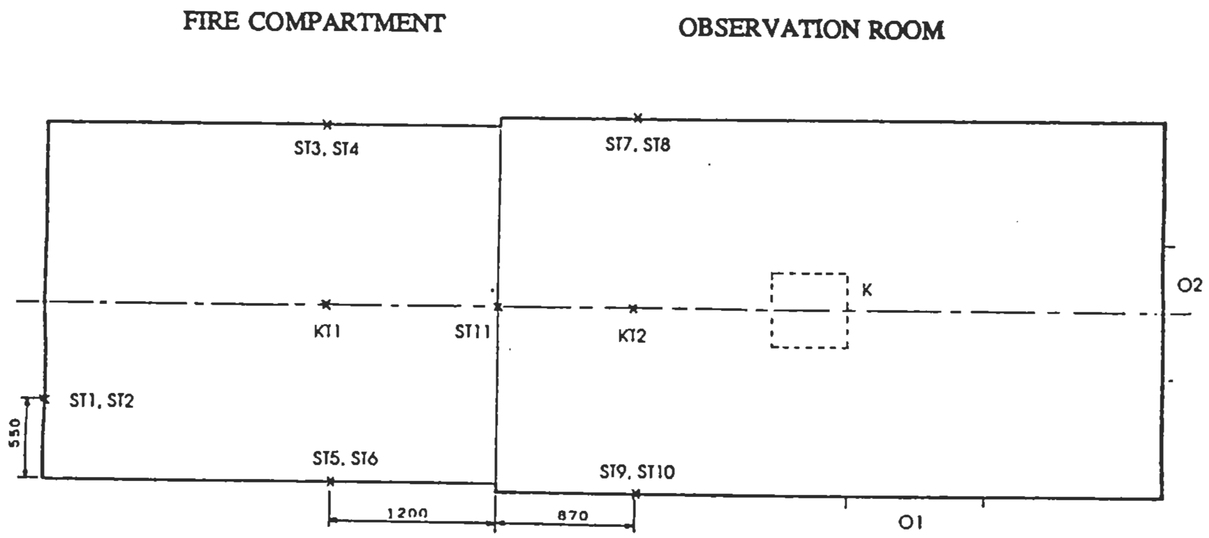
Fig. 2. View from above of the flash over simulator and the location of the measuring transducers. **I1...I6** suction pyrometers, **T1...T24** bare thermocouples in air, **V1...V3** sheathed thermocouples, **G1, G2** sampling tubes of the gas analyzers, **P1...P4** pressure difference transducers, **R1, R2** heat flux transducers, **S** protective shield, **K** roof hatch, **O1** side door, **O2** end door.

Fig. 3. Location of thermocouples mounted to the ceiling (**KT1, KT2**) and the walls (**ST1... ST10**) of the flash over simulator. a) side view, b) from above.

a)



b)



The tests conducted in the flash over simulator

Table 1. The tests conducted with the flash over simulator, location of the heat flux, gas and pressure transducers and a short notice of each test. The locations of the gas and pressure transducers is presented in Appendix 1, the location of the heat flux transducers is reported using two distances, the first one is the distance from the front of the fire compartment (m) and the second one the level measured from the floor (m).

Test no.	Fire load	CO, CO_2, O2,	Heat flux	Pressure	Notice
1 - 3	Propane gas 100 kW	G1 at the beginning G2 at the end	1,7;1,5	P1	end door open, side door and roof hatch closed
4	Propane gas 300 kW	-"-	-"-	-"-	-"-
5	Propane gas 100 kW	-"-	-"-	-"-	end door 15 cm ajar, side door and roof hatch closed
6	Propane gas 100 kW	-"-	-"-	-"-	roof hatch open, side and end doors closed
7	Propane gas 100 kW	-"-	-"-	-"-	doors and roof hatch closed
10	Wood cribs 80 cm x 80 cm x 40 cm	-"-	1,0;1,5	-"-	end door 15 cm ajar, side door and roof hatch closed
11	Wood cribs 80 cm x 80 cm x 20 cm	G1 0...6 min G2 6...33 min	-"-	-"-	end door open/closed, side door and roof hatch closed
12	-"-	G1 at the beginning, later G2	-"-	-"-	-"-
13	3 particle boards, ignition: 1 l of heptane in a 30 cm x 30 cm tray	G1	-"-	-"-	end door open, side door and roof hatch closed
14	3 particle boards, ignition: 2 l of heptane in a ϕ 45 cm tray	G1 at the beginning	2,0;1,5	-"-	-"-
15	6 particle boards, ignition: 10 pcs 50 cm wood cribs and 0,5 l of paraffin	G1	1,7;1,5	-"-	roof hatch and end door open/closed, side door closed, 2 fire men in the simulator, extinguishing with water jets at the end

Table 1, continued

Test no.	Fire load	CO, CO_2, O2,	Heat flux	Pressure	Notice
16	6 particle boards, ignition: 10 pcs 50 cm wood cribs and 0,5 l of paraffin	G2	1,7;1,5	P1	roof hatch and end door open/closed, side door closed, 2 fire men in the simulator, extinguishing with water jets at the end
17	-"-	G2	1,7;0,8	-"-	side door and roof hatch closed, end door open/closed until a fast flame front emerged through the end doorway after which the fire was extinguished from outside with water jets
20	-"-	G1	-"-	P2	side door open, end door and roof hatch closed
21	-"-	G2	-"-	-"-	side door open, roof hatch closed/open, end door closed. 2 fire men in the simulator, extinguishing of the burning gas layer with water jets
22	-"-	-"-	-"-	-"-	-"-
23	-"-	-"-	-"-	-"-	-"-
24	-"-	-"-	-"-	-"-	end door and roof hatch open/closed, side door closed, one fire man in the simulator, extinguishing of the burning gas layer with water jets
25	-"-	-"-	-"-	-"-	end door and roof hatch open/closed, side door closed, one fire man in the simulator, extinguishing of the burning gas layer with water jets
26	-"-	-"-	-"-	-"-	end door open, roof hatch open/closed, side door closed, one fire man in the simulator, extinguishing of the burning gas layer with water jets
27	4 particle boards, ignition: 10 pcs 50 cm wood cribs and 0,5 l of paraffin	-"-	-"-	P3, P4	end door open, roof hatch open/closed, side door closed, one fire man in the simulator, extinguishing of the burning gas layer with water jets

Test 11, wood crib 80 cm x *80* cm x 20 cm

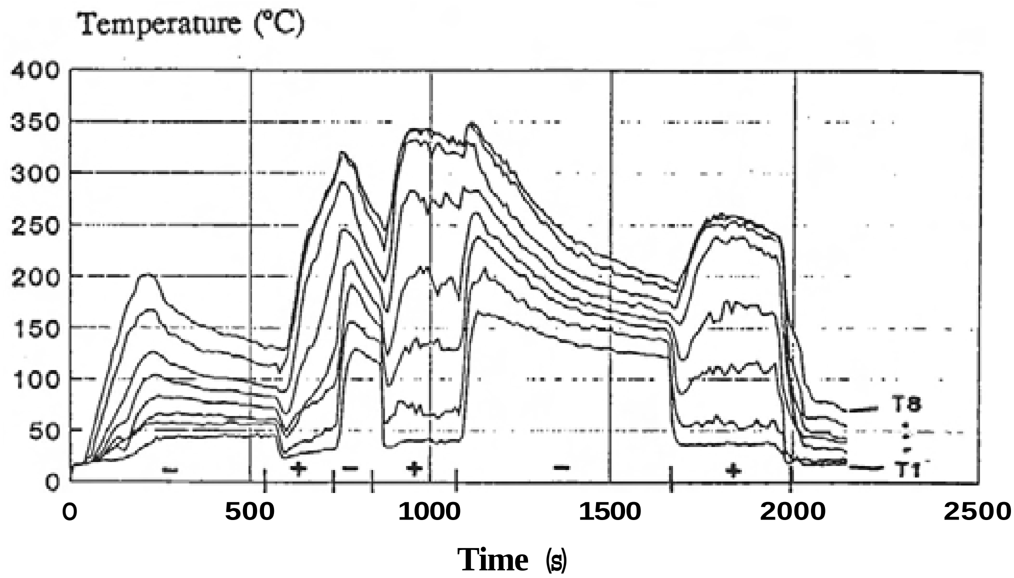


Fig. 1. The temperatures T1...T8 in the fire compartment as a function of time, the curve on the top is T8. the one at the bottom is T1 and the others are in their numerical sequence between these. + the end door has been open, - the end door has been closed.

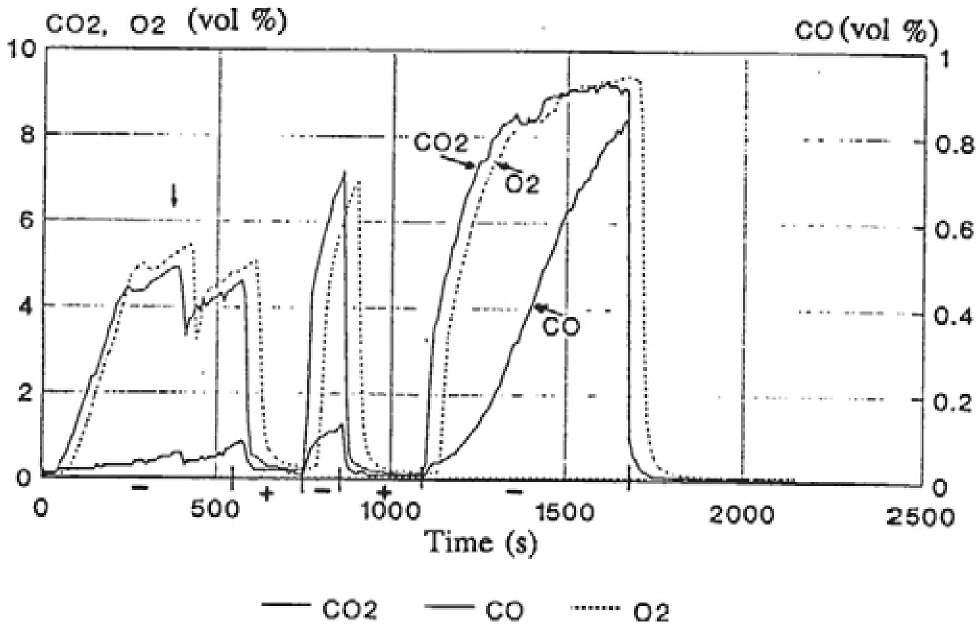


Fig 2. CO_2, CO concentrations and oxygen depletion O_2 as a function of time. + the end door has been open, - the end door has been closed, at the arrow the sampling location has been changed from G1 to G2.

Test 17,-6 particle boards

Table 1. Observations made during test 17. The numbered events are recorded in the measured results plotted as a function of time.

No.	Time (s)	Time (min:s)	Event
	0		Data acquisition is started, the end door is open, the time is 2 min 30 s from ignition
1	440	7:20	The end door is closed
2	450	7:30	The end door is opened
3	485	8:05	Flames emerge from the end door. the door is closed
4	515	8:35	The end door is opened
5	615	10:15	The end door is closed
6	620	10:20	The end door is opened
7	680	11:20	A rapid flame front emerges from the end door, extinguishing is commenced, the door is still open

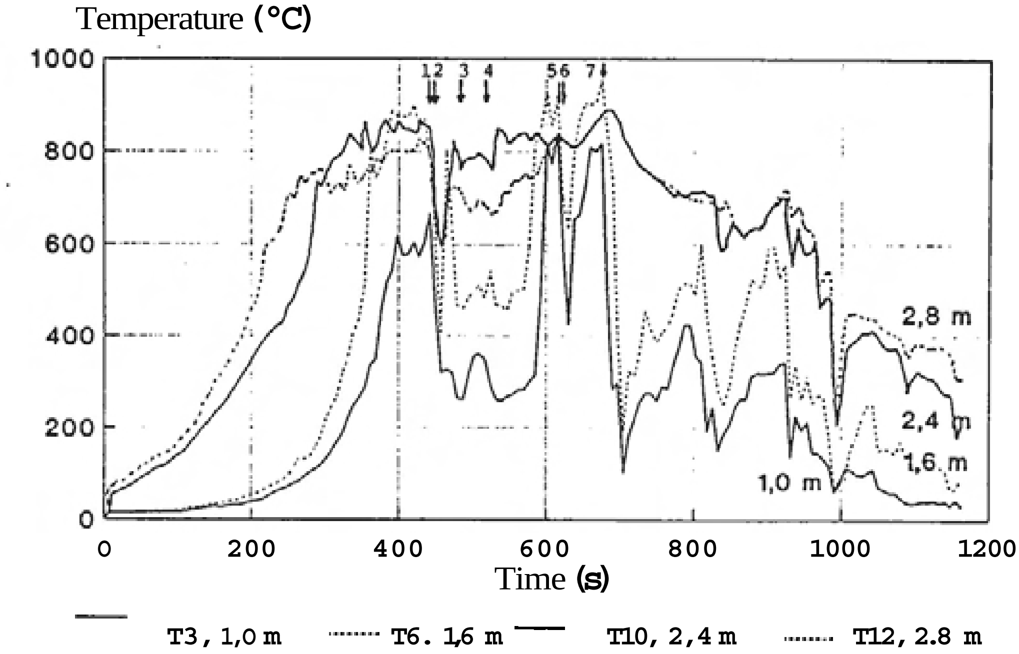


Fig. 1. The temperatures T3, T6, T10 and T12 in the fire compartment as a function of time in test 17. The numbers indicate the elevation of the thermocouples from the floor of the observation room

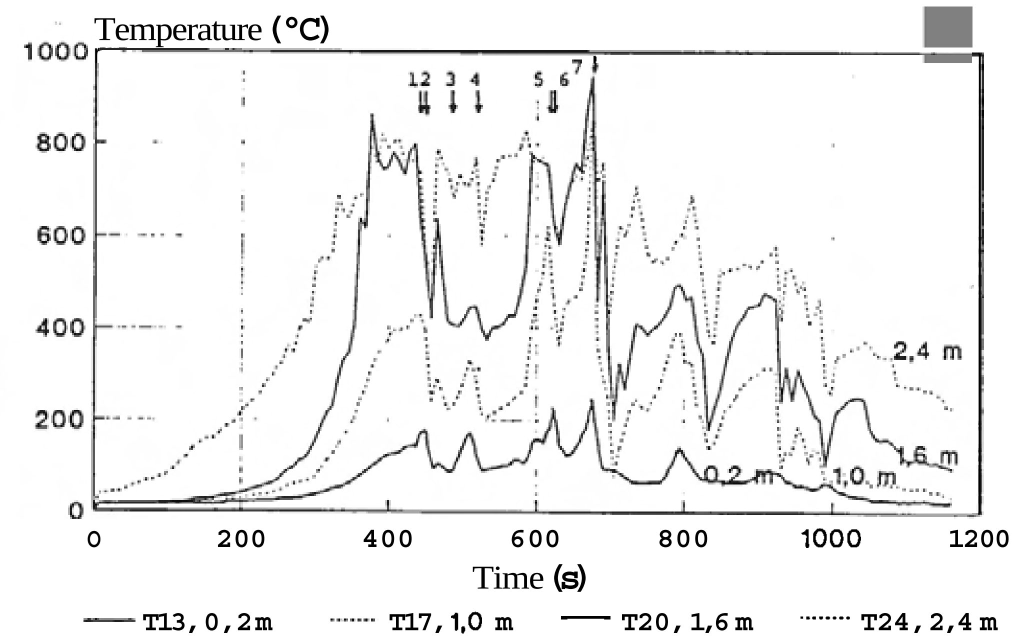


Fig. 2 The temperatures T13, T17, T20 and T24 in the observation room as a function of time in test 17. .The numbers indicate the elevation of the thermocouples from the floor of the observation room.

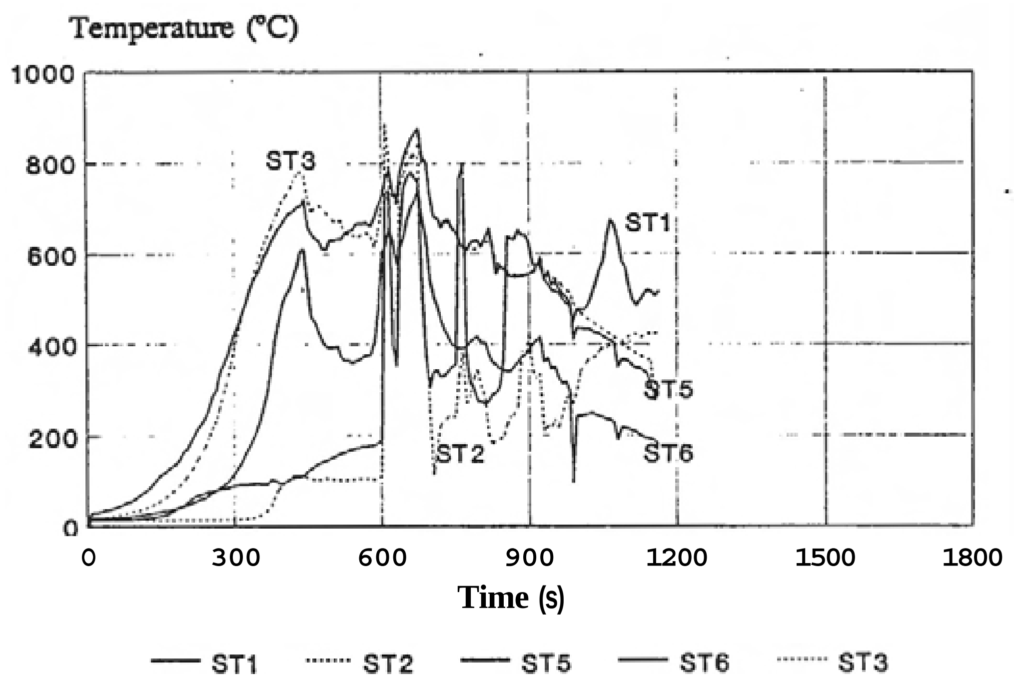


Fig. 3. The wall temperatures in the fire compartment as a function of time in test 17.

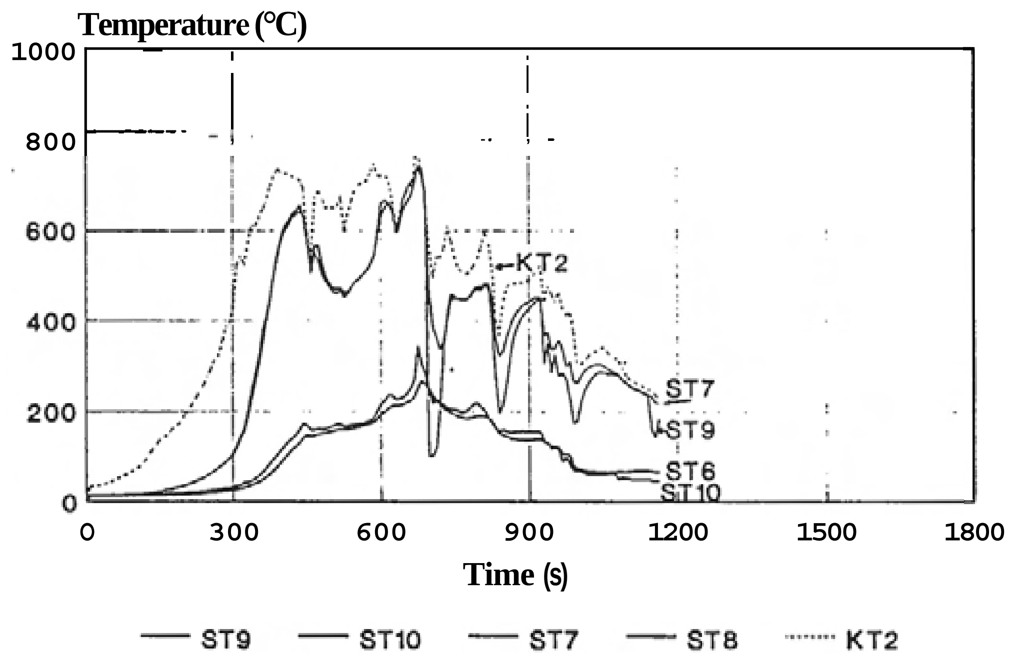


Fig. 4. The ceiling and wall temperatures in the observation room as a function of time in test 17.

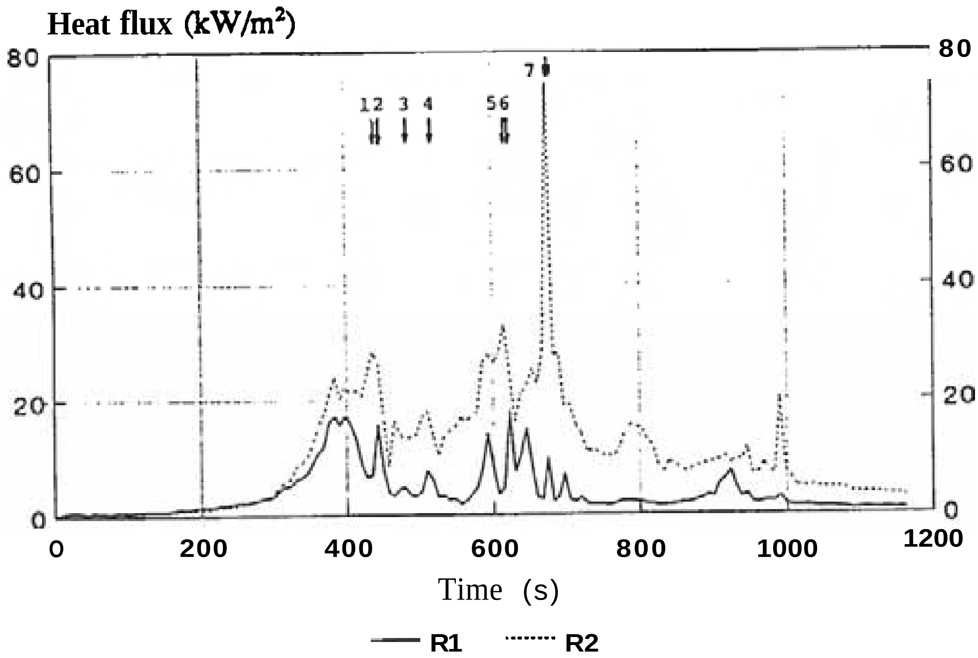


Fig. 5. The heat flux as a function of time in test 17.

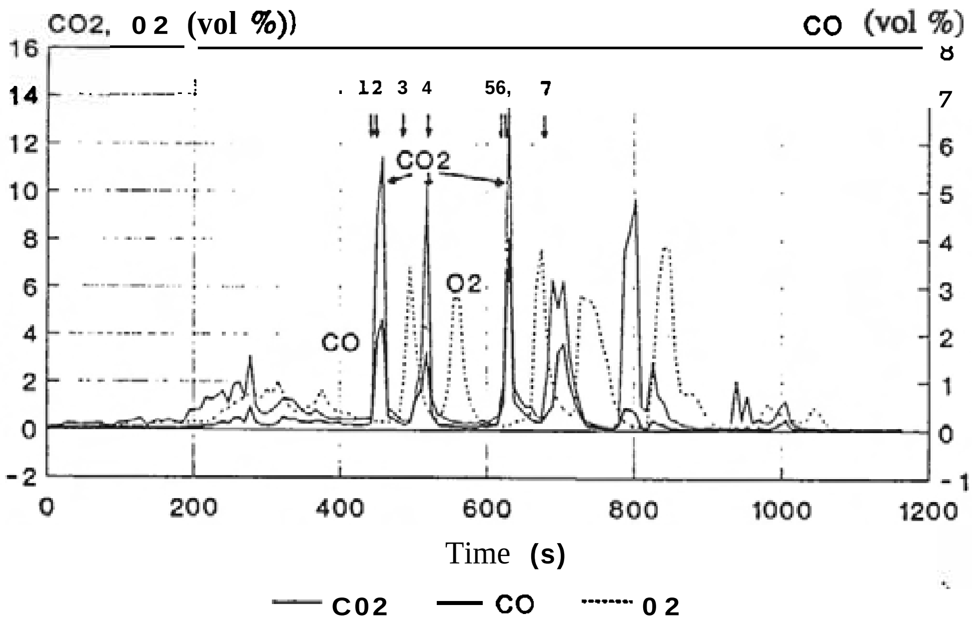


Fig. 6. CO_2, CO concentrations and oxygen depletion O_2 as a function of time in test 17.

Test 21, 6 particle boards

Table 1. Observations made during test 21. The numbered events are recorded in the measured results plotted as a function of time.

No.	Time (s)	Time (min:s)	Event
	0		Data acquisition is started
1	44	0:44	Ignition
2	386	6:26	The ceiling of the fire compartment is burning all over, there are no flames in the observation room, the smoke boundary is in the fire compartment about 1,5m above the floor, extinguishing of the burning gas layer with short water mist jets
3	400	6:40	The wood crib in the corner extinguished, the gas under the ceiling is burning
4	810	13:30	The wood crib is re-ignited with a match
5	900	15:00	The smoke boundary reaches the floor in the fire compartment
6	1000	16:40	The flames reach the protective shield in the observation room
7	1020	17:00	Extinguishing of the burning gas layer with short water mist jets
8	1160	19:20	The roof hatch is opened, extinguishing
	1220	20:20	The fire is extinguished

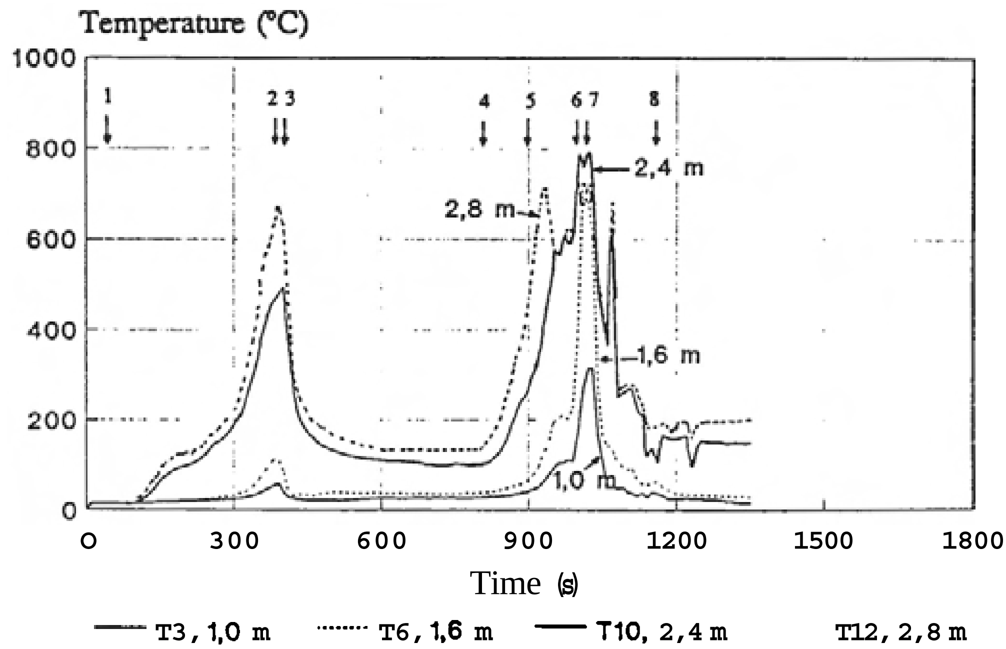


Fig. 1. The temperatures T3, T6, T10 and T12 in the fire compartment as a function of time in test 21. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

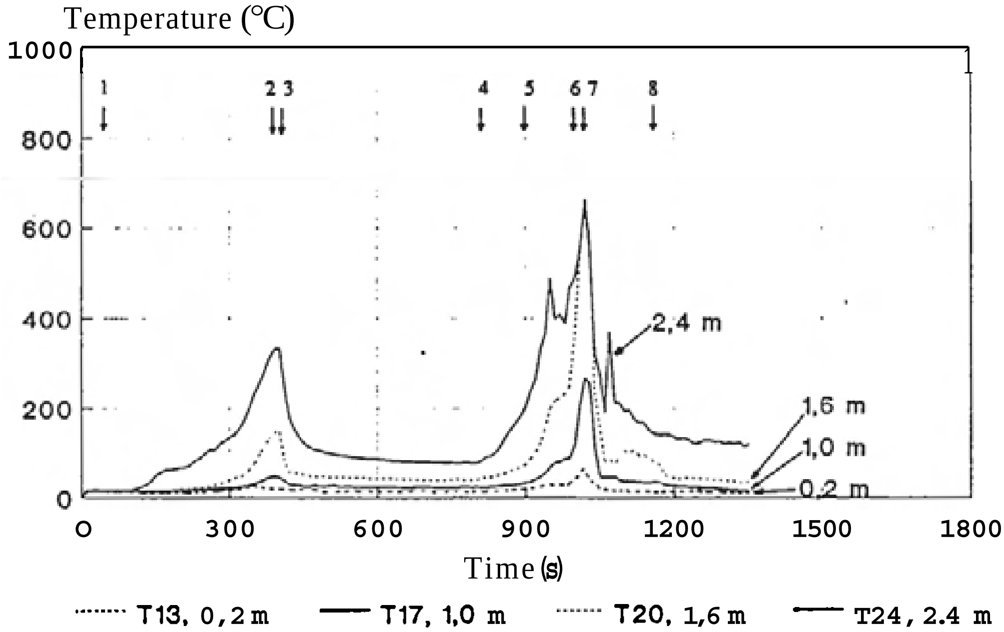
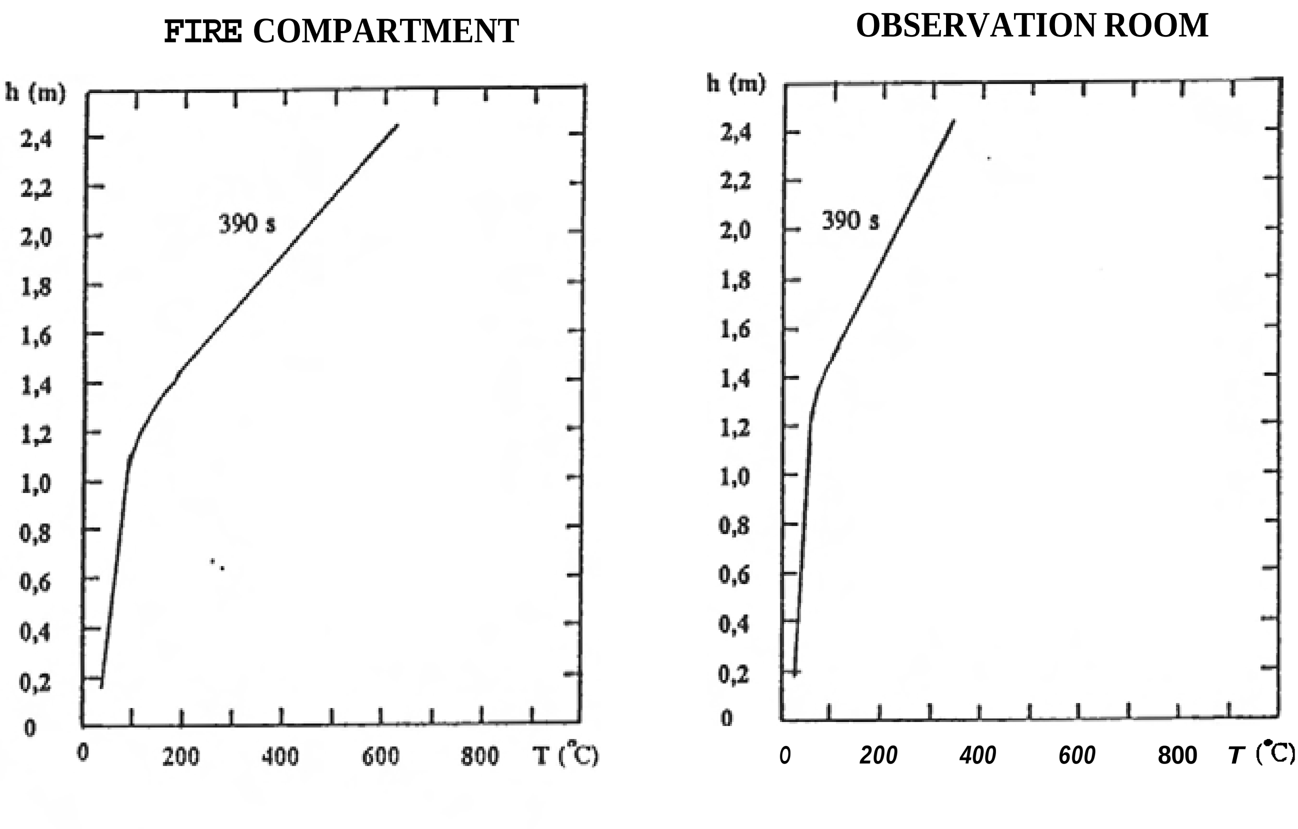


Fig. 2. The temperatures T13, T17, T20 and T24 in the observation room as a function of time in test 21. The numbers mdicate the elevation of the thermocouples from the floor of the observation room.



a) b)

Fig. 3. The vertical temperature distributions in test 21 at test time 390 s. The buming gas layer is confined to the fire compartment and is extinguished at test time 386 s (Observation 2). The elevations h are relative to the floor of the respective room. a) fire compartment, b) observation room.

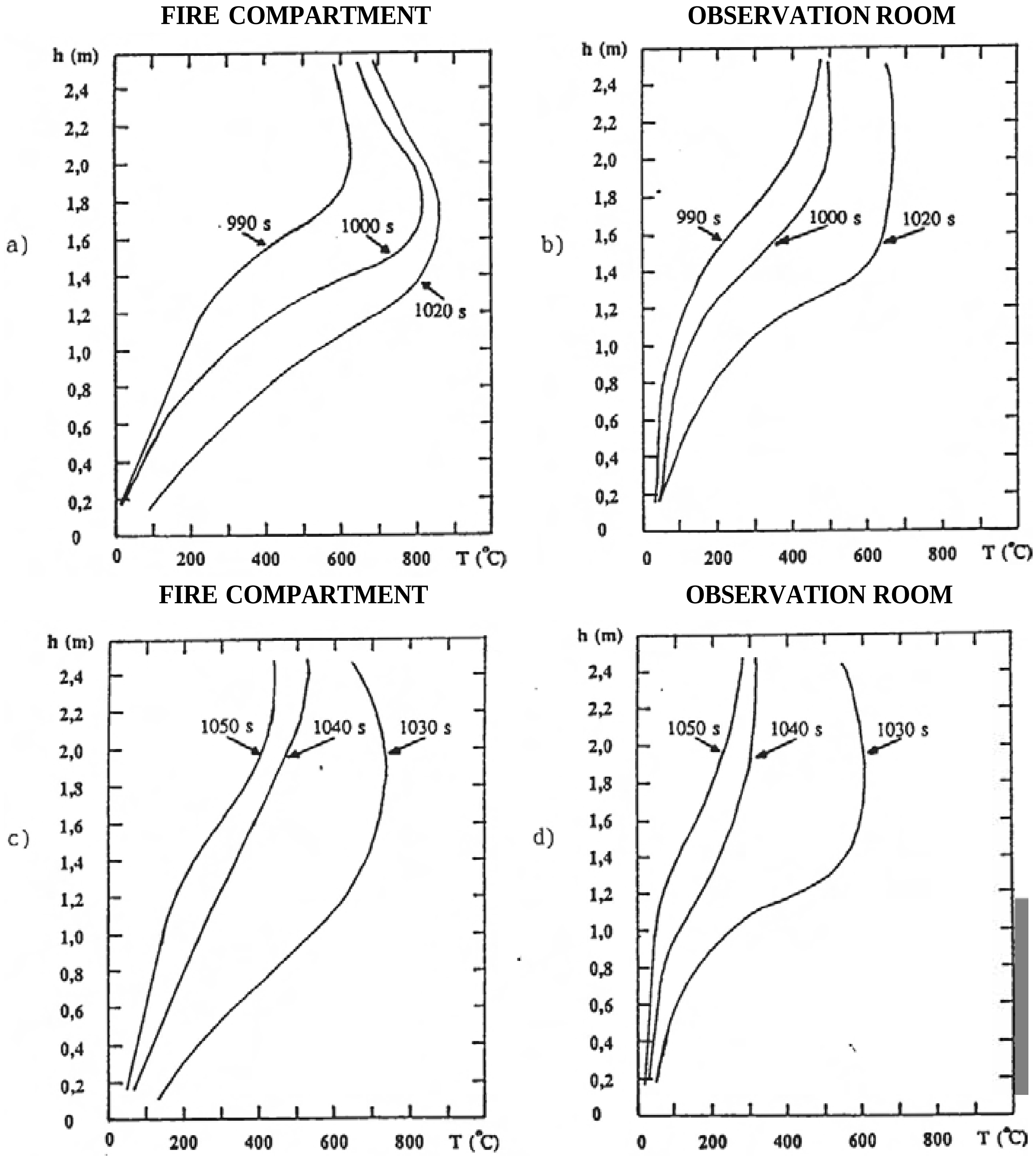


Fig. 4. The vertical temperature distributions in test 21 prior to the extinguishing of the burning gas layer at test time 1020 s (Observation 7) and after it. The burning gas layer reached the protective shield in the observation room. The elevations b are relative to the floor of the respective room. a) fire compartment before extinguishing, b) observation room before extinguishing, c) fire compartment after extinguishing, d) observation room after extinguishing.

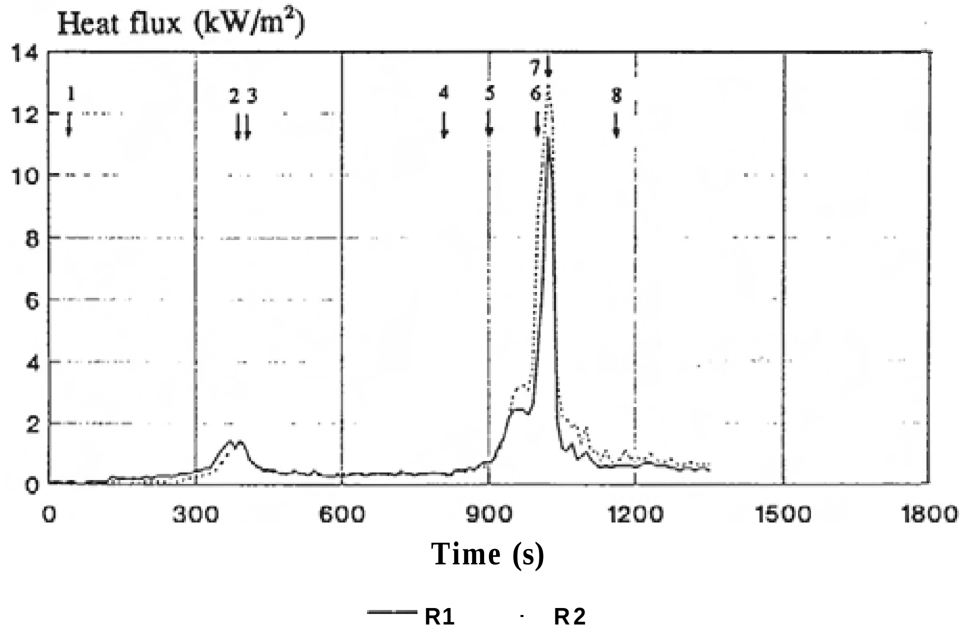


Fig. 5. The heat flux as a function of time in test 21.

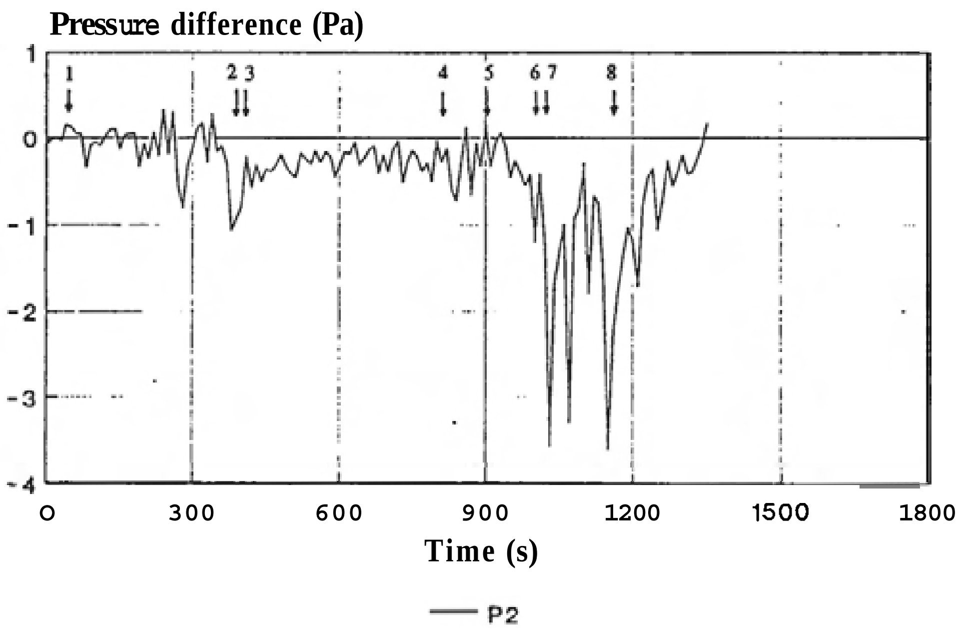


Fig. 6. The pressure difference between the fire compartment and the surrounding as a function of time in test 21.

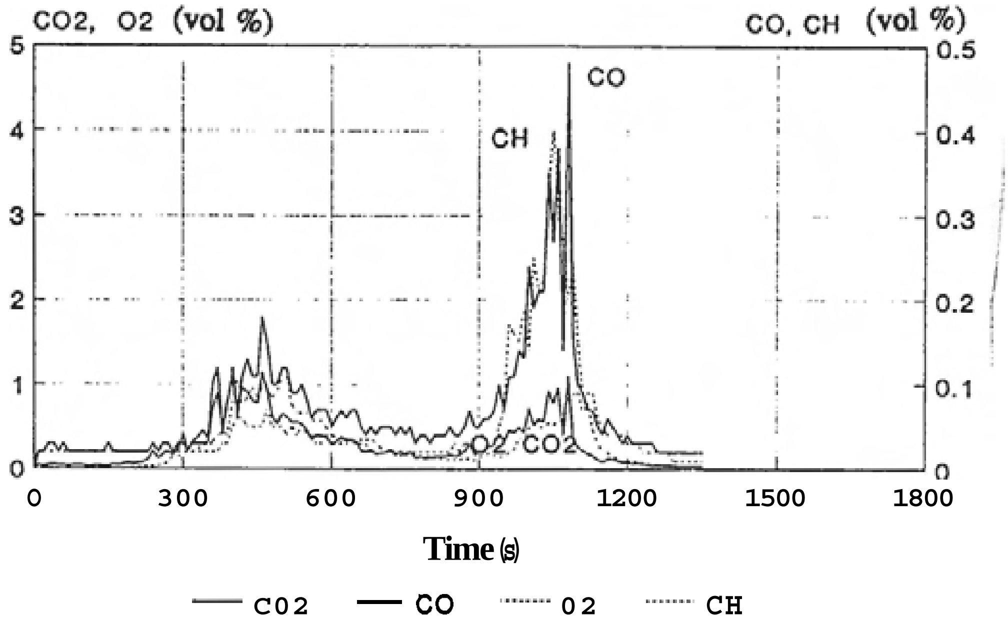


Fig. 7. CO_2, CO, CH concentrations and oxygen depletion O_2 as a function of time in test 21.

Test 22, 6 particle boards

Table 1. Observations made during test 22. The numbered events are recorded in the measured results plotted as a function of time.

No.	Time (s)	Tie (min:s)	Event
	0		Data acquisition was started
1	60	1:00	Ignition
2	310	5:10	About half of the ceiling area in the fire compartment is burning
3	330	5:30	The burning gas layer is extinguished with short water mist jets
4	395	6:35	Ventilation for a few seconds through the roof hatch
	550	9:10	The ceiling of the fire compartment is burning
5	630	10:30	Ventilation for 7 seconds through the roof hatch
6	680	11:20	The burning gas layer is extinguished with short water mist jets
7	725	12:05	Ventilation for 10 seconds through the roof hatch
8	745	12:25	The burning gas layer is extinguished with three short water mist jets, the time between the jets is 5 seconds
9	763	12:43	Ventilation for 13 seconds through the roof hatch
10	790	13:10	Ventilation for 13 seconds through the roof hatch
11	826	13:46	The burning gas layer is extinguished with three short water mist jets, the time between the jets is 3 seconds
12	857	14:17	A ceiling board fell down in the fire compartment, the flames are near the side door, the burning gas layer is extinguished with short water jets
13	880	14:40	The burning gas layer is extinguished with three water mist jets, the time between the jets is 10 seconds, the fire is extinguished
	1000	16:40	The roof hatch is opened

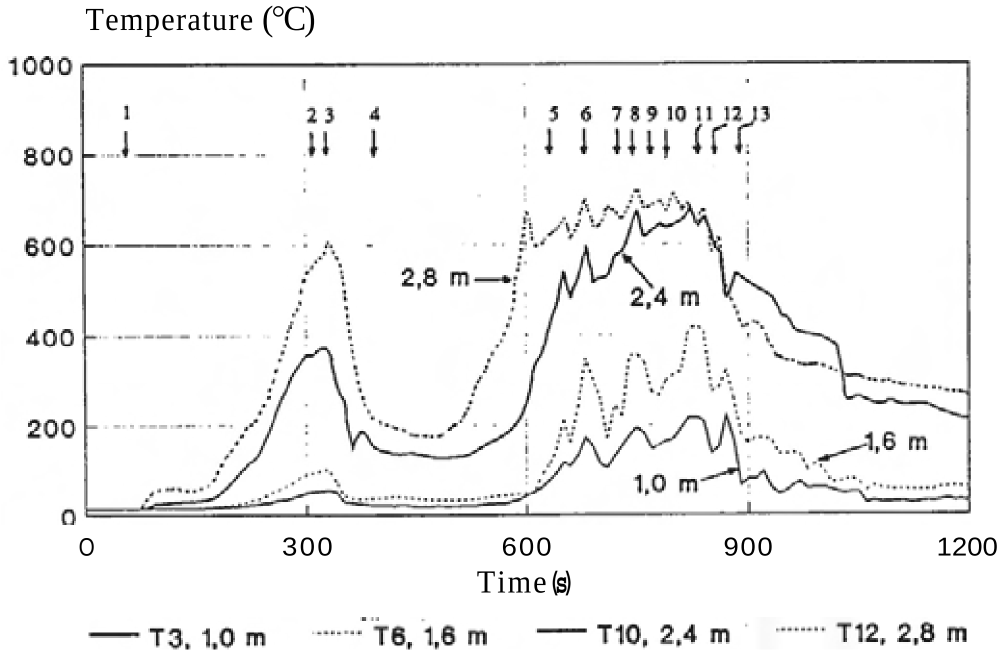


Fig. 1. The temperatures T3, T6, T10 and T12 in the fire compartment as a function of time in test 22 The numbers indicate the elevation of the thermocouples from the floor of the observation room.

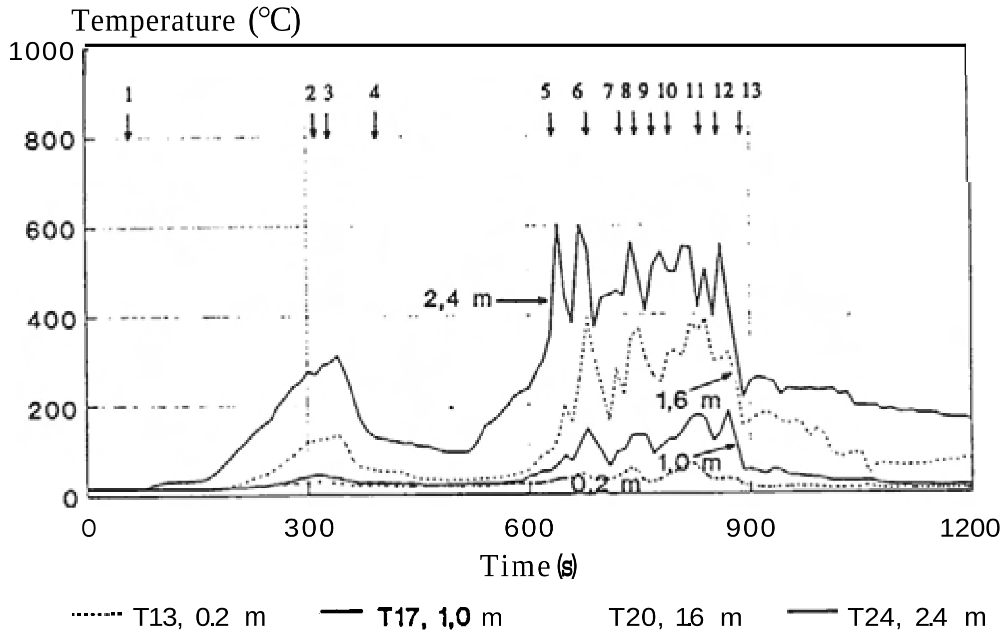
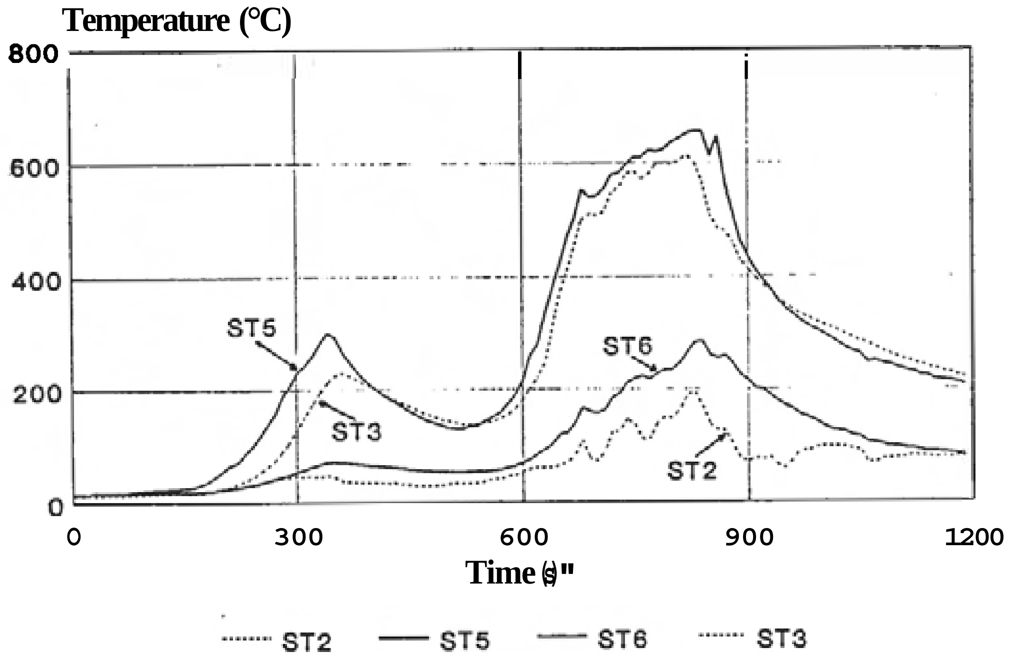


Fig. 2. The temperatures T13, T17, T20 and T24 in the observation room as a function of time in test 22 The numbers indicate the elevation of the thermocouples from the floor of the observation room.

a)



b)

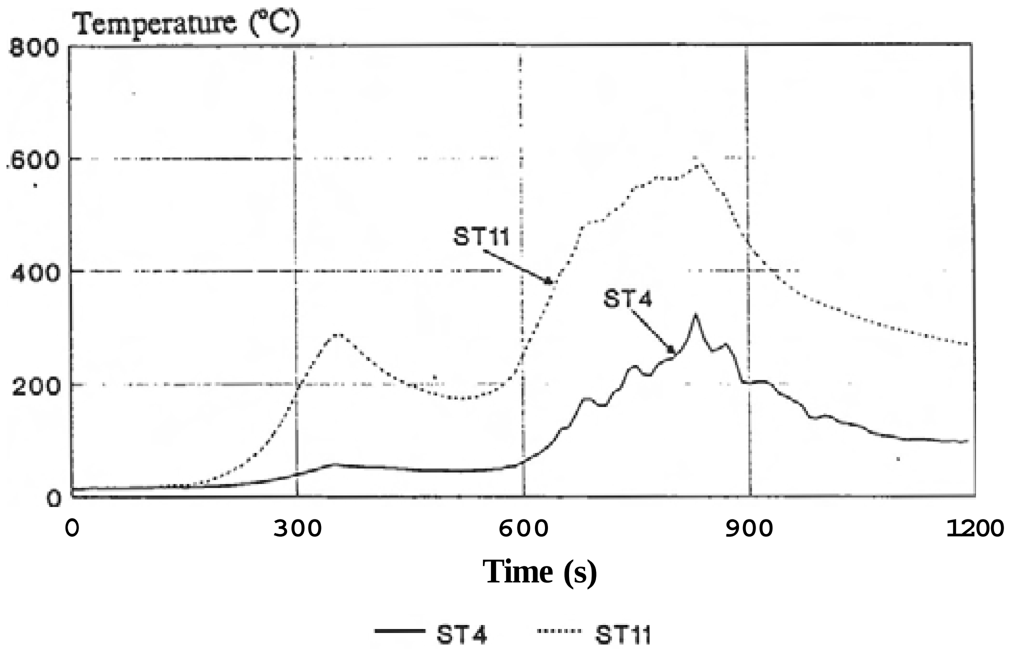


Fig. 3. a) and b) the wall-temperatures in the fire compartment as a function of time in test 22.

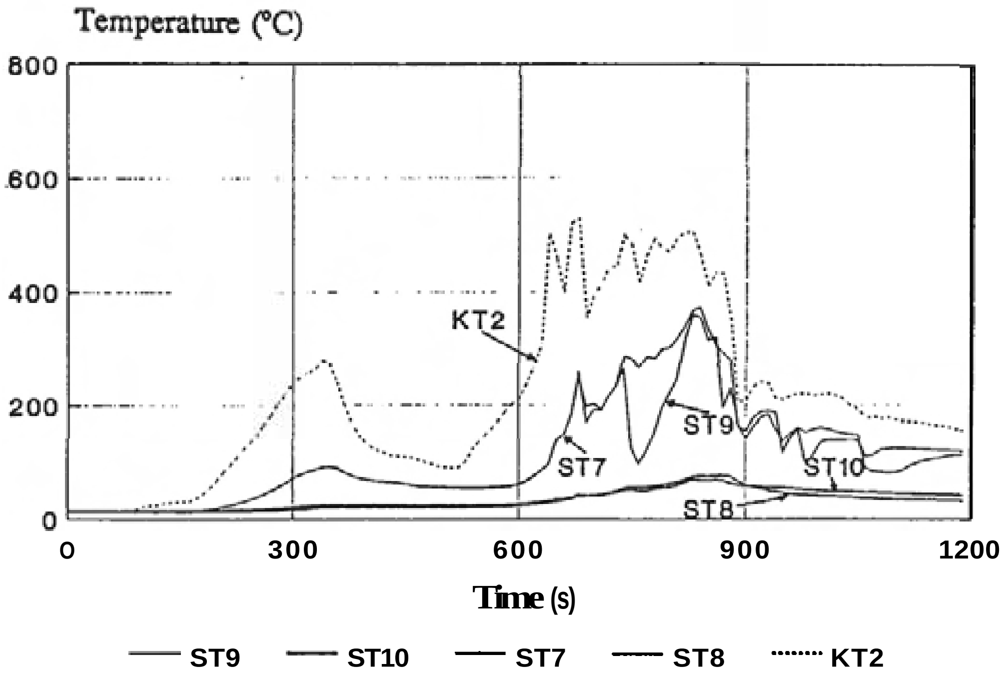


Fig. 4. The wall and ceiling temperatures in the observation room as a function of time in test 22.

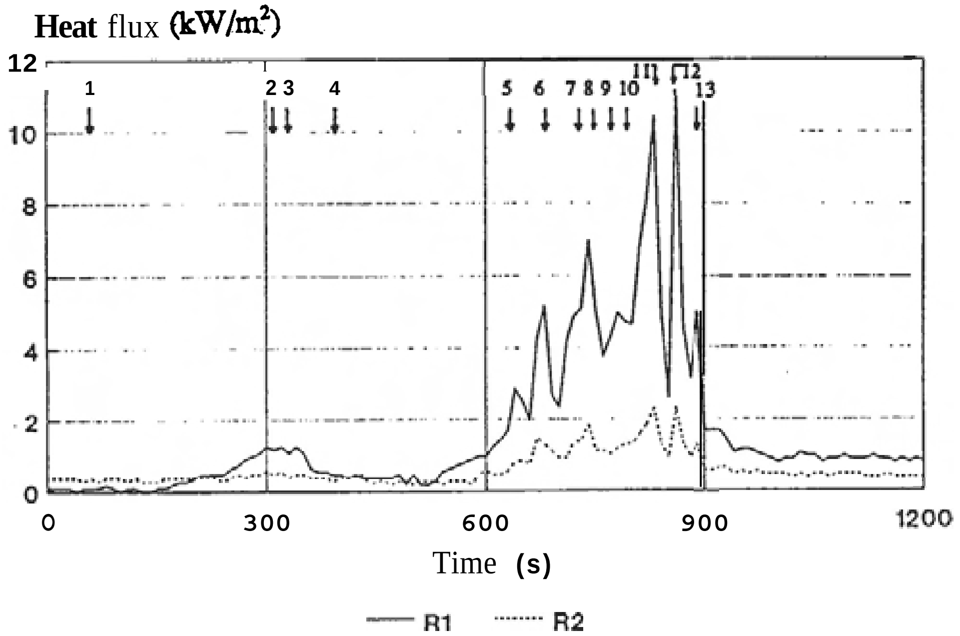


Fig. 5. The heat flux as a function of time in test 22.

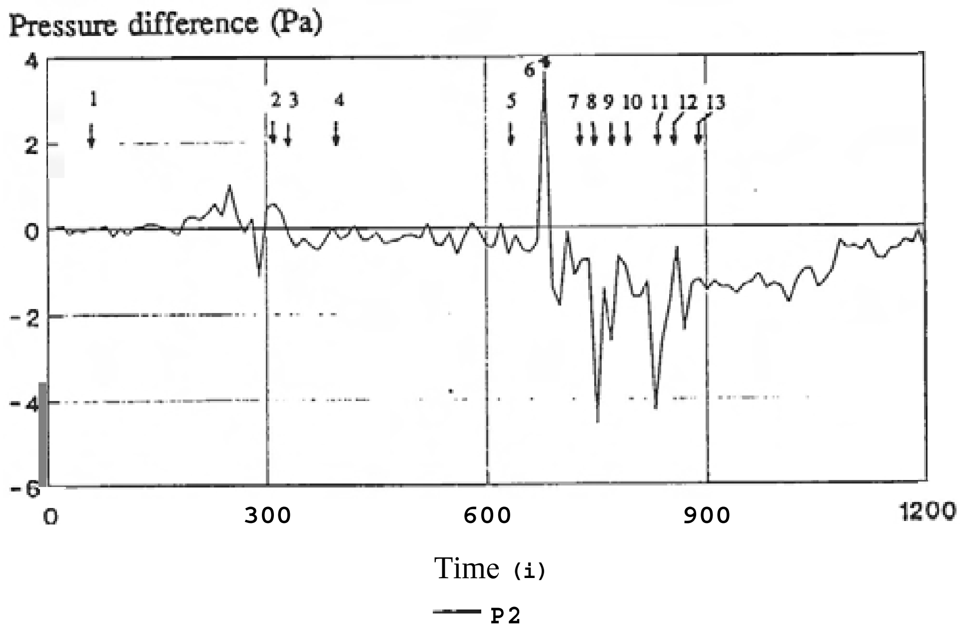


Fig. 6. The pressure difference between the fire compartment and the surrounding as a function of time in test 2 2

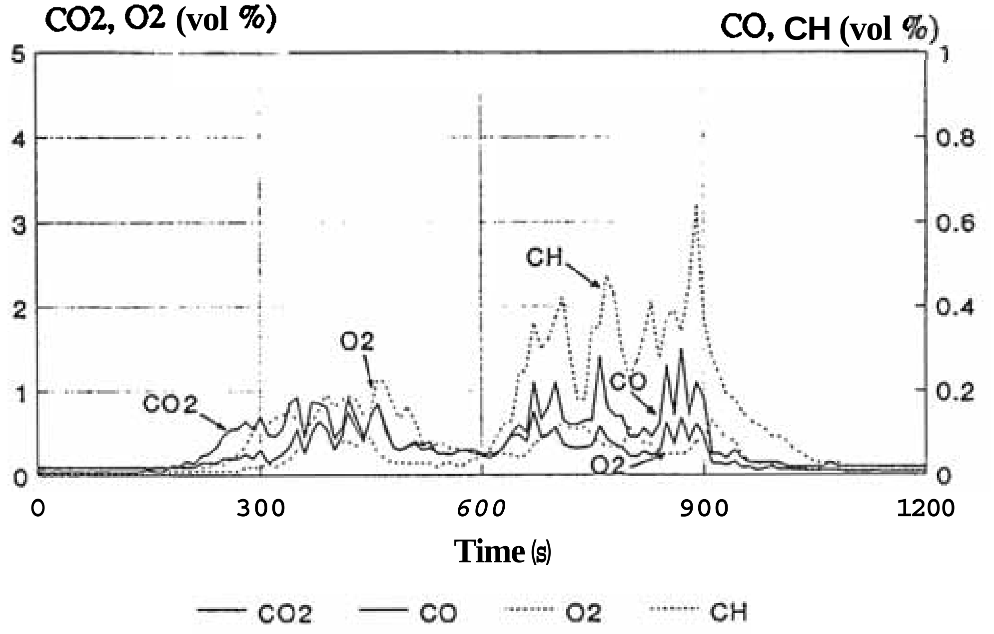


Fig. 7. CO_2, CO, CH concentrations and oxygen depletion O_2 as a function of time in test 22

Test 24, 6 particle boards

Table 1. Observations made during test 24. The numbered events are recorded in the measured results plotted as a function of time.

No.	Time (s)	Time (min:s)	Event
	0		Data acquisition is started, the end door is open
1	40	0:40	Ignition
	180	3:00	About half of the area of the ceiling in the fire compartment is burning
2	247	4:07	The roof hatch is opened
3	309	5:09	The roof hatch is closed
4	350	5:50	The end door is totally closed
5	450	7:30	The end door is opened
6	640	10:40	The fire is extinguished
7	790	13:10	The wood cnb is re-ignited
8	906	15:06	Ventilation for 13 seconds through the roof hatch
9	950	15:50	The end door is about 20 cm ajar
10	982	16:22	The buming gas layer is extinguished with two short water mist jets the time between the jets is 3 seconds
11	1012	16:52	The end door is opened
12	1060	17:40	Ventilation for 13 seconds through the roof hatch
13	1140	19:00	The buming gas layer is extinguished with a water mist jet
14	1150	19:10	Ventilation for 30 seconds through the roof hatch
15	1210	20:10	The burning gas layer is extinguished with two water mist jets, the time between the jets is 11 seconds
	1280	21:20	The fire is extinguished with water

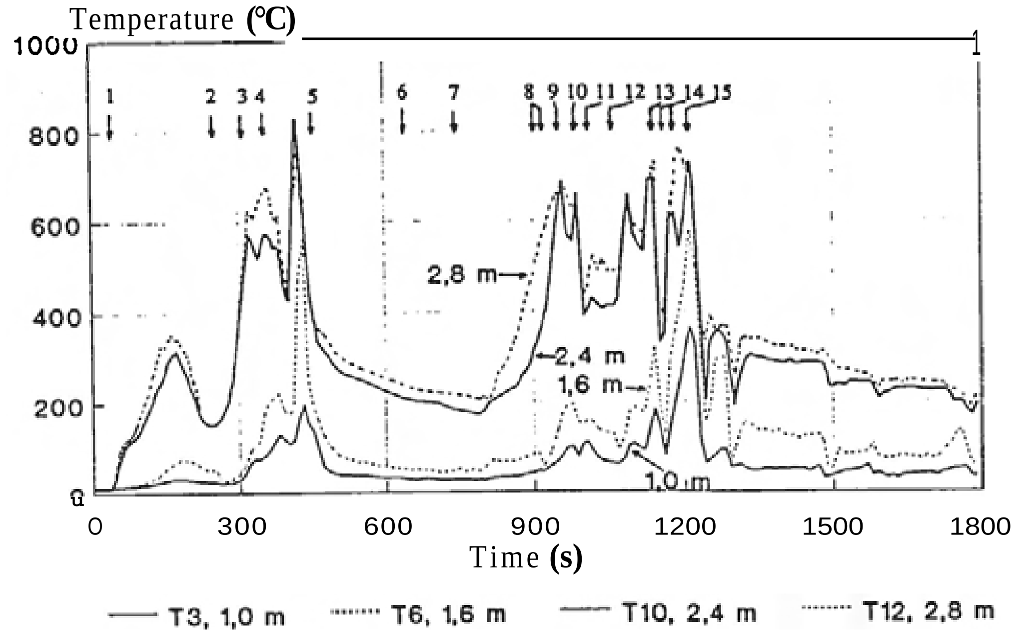


Fig. 1. The temperatures T3, T6, T10 and T12 in the fire compartment as a function of time in test 24. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

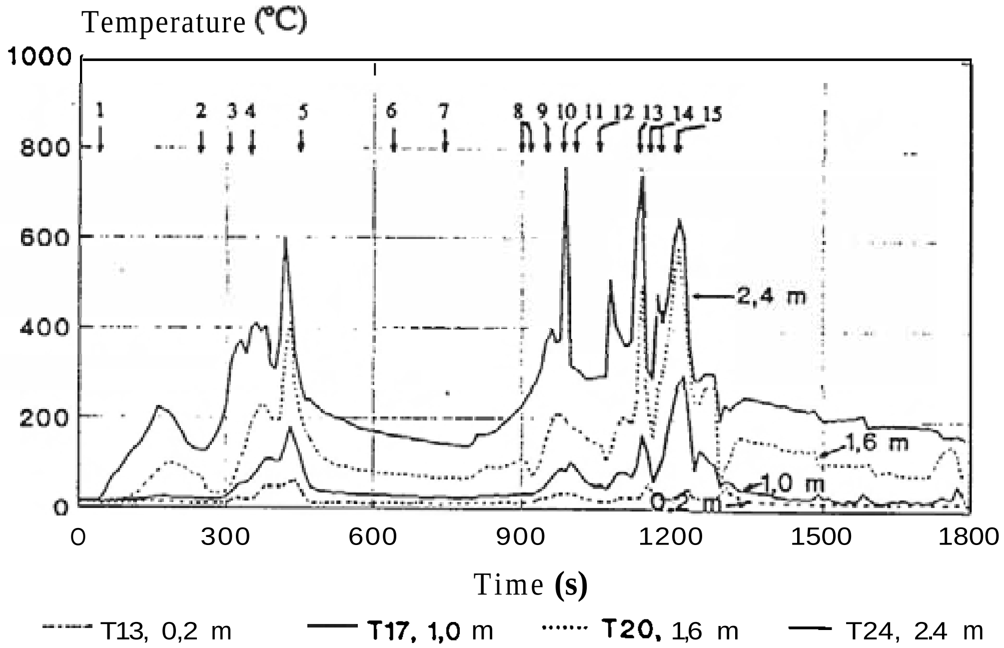


Fig. 2 The temperatures T13, T17, T20 and T24 in the observation room as a function of time in test 24. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

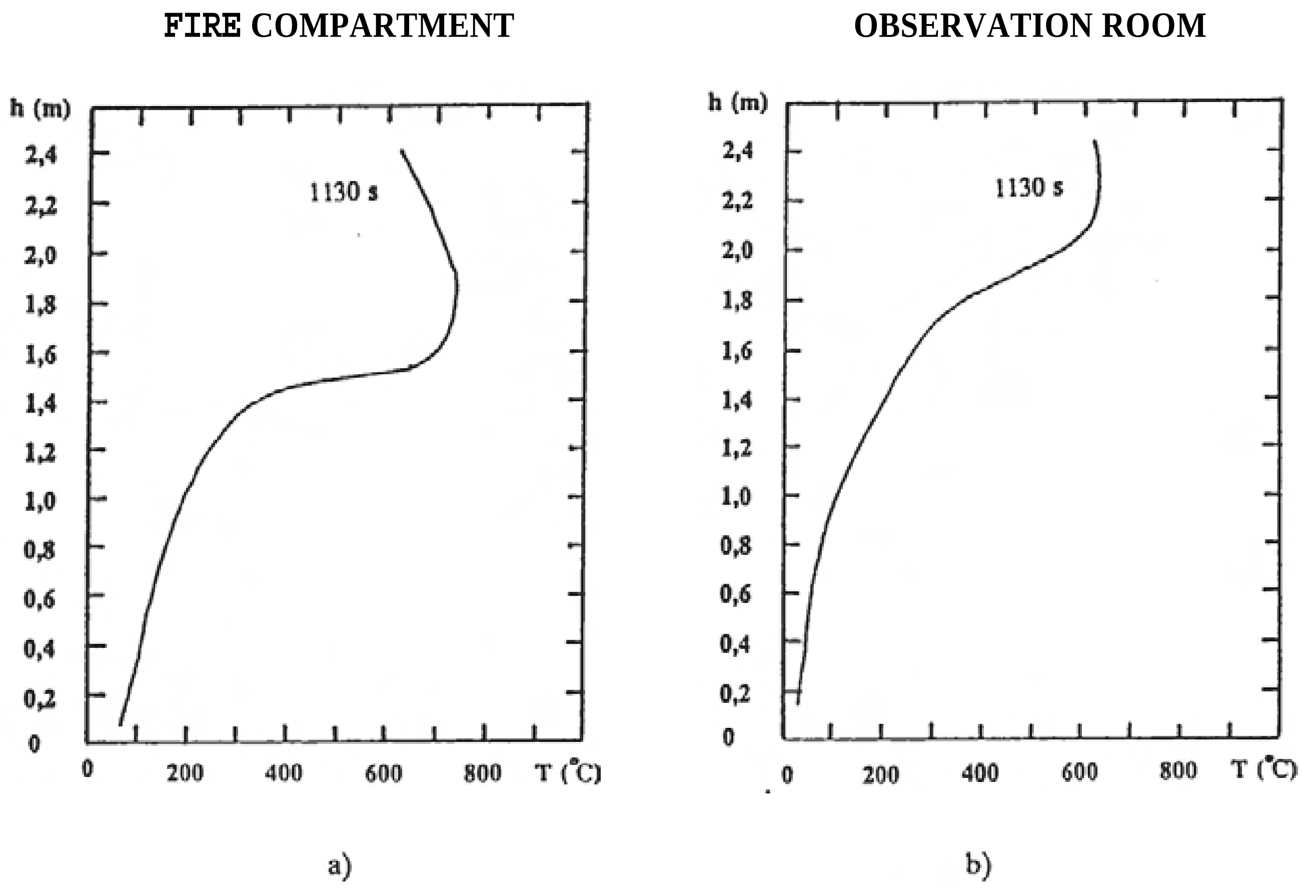


Fig. **3.** The vertical temperature distributions in test 24 at test time 1130 s. The burning gas layer has reached the protective shield in the observation room and is extinguished at test time 1140 s (Observation 13). The elevations **h** are relative to the floor of the respective room. a) fire compartment, b) observation room.

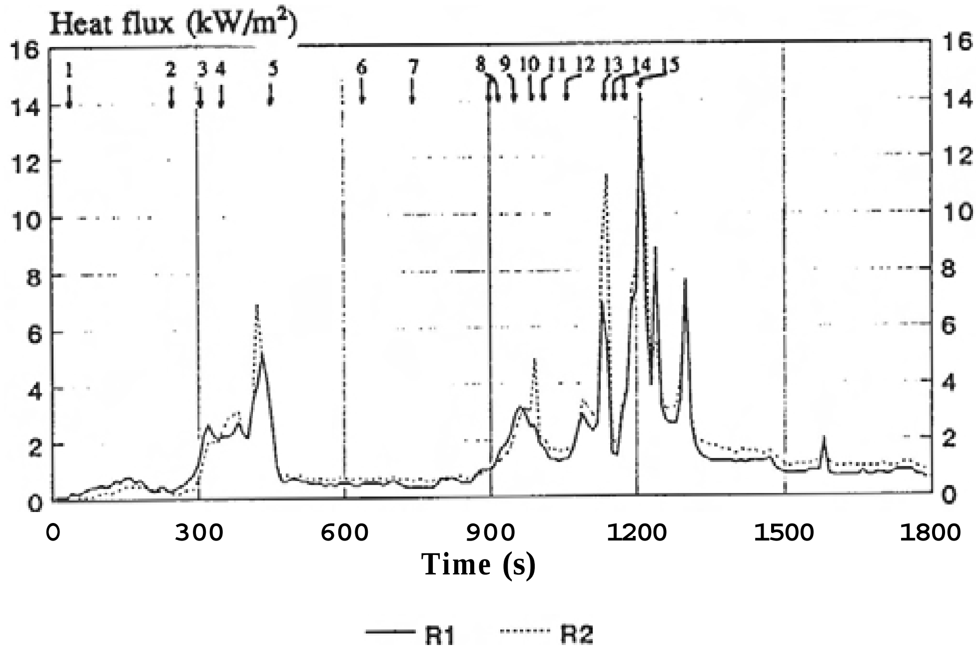


Fig. 4. The heat flux as a function of time in test 24.

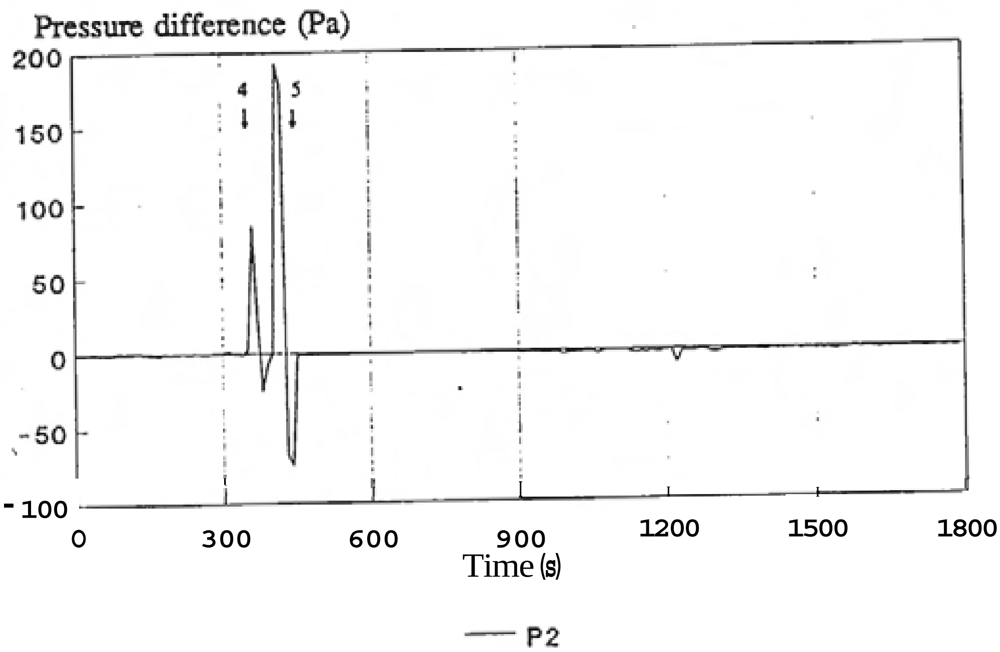


Fig. 5. The pressure difference between the fire wmpartment and the surrounding as a function of time in test 24.

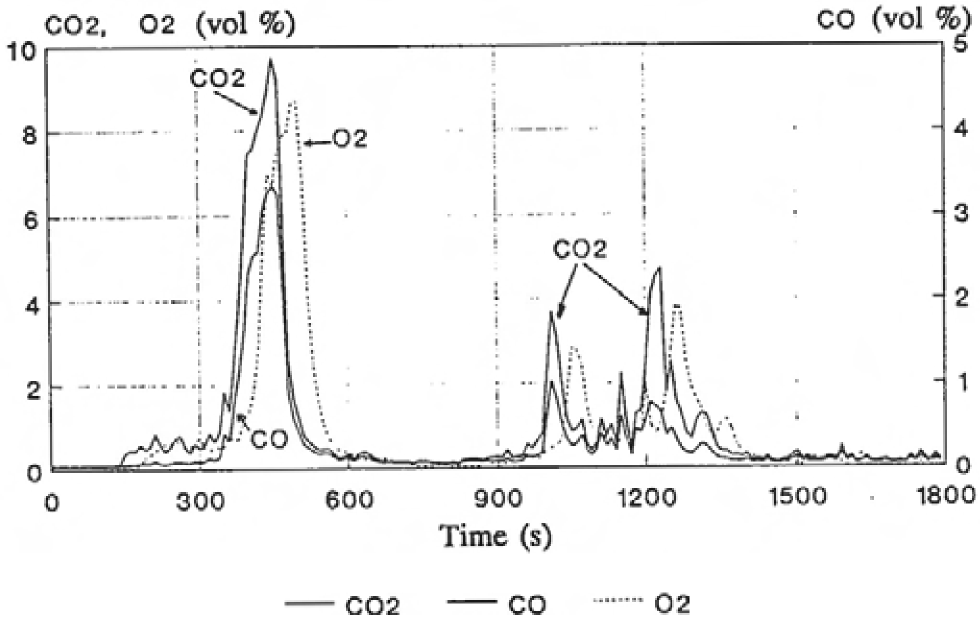


Fig. 6. CO_2, CO concentrations and oxygen depletion O_2 as a function of time in test 24.

Test 26, 6 particle boards

Table 1. Observations made during test 24. The numbered events are recorded in the measured results plotted as a function of time.

No.	Time (s)	Time (min:s)	Event
	0		Data acquisition is started
1	50	0:50	Ignition, the roof hatch is opened
2	211	3:31	The roof hatch is closed
2	246	4:06	The roof hatch is opened
3	440	7:20	The burning gas layer is extinguished with two water mist jets, the time between the jets is 5 seconds
4	466	7:46	The roof hatch is closed
4	482	8:02	The roof hatch is opened
5	560	9:20	The roof hatch is closed
5	570	9:30	The roof hatch is opened
6	637	10:37	The roof hatch is ciosed
6	663	11:03	The burning gas layer is extinguished with a water mist jet
6	680	11:20	The roof hatch is opened
7	740	12:20	The roof hatch is closed
8	780	13:00	The ceiling board to the right fell down, the burning gas layer is extinguished with a water mist jet, the roof hatch is opened
9	890	14:50	The roof hatch is closed
10	960	16:00	The burning gas layer is extinguished with a water mist jet
11	1000	16:40	The roof hatch is opened

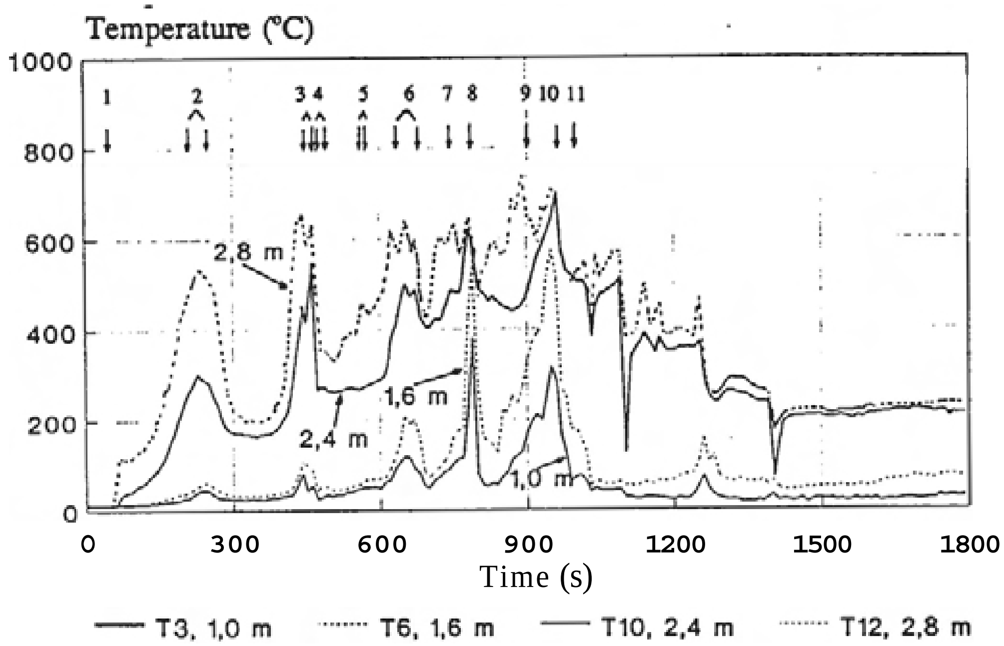


Fig. 1. The temperatures T3, T6, T10 and T12 in the fire compartment as a function of time in test 26. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

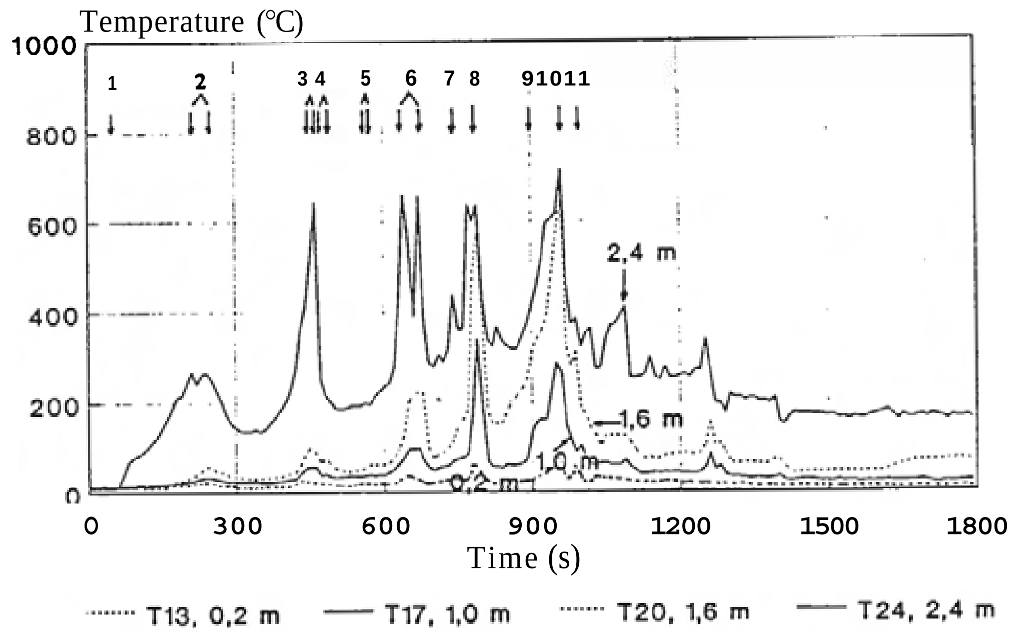


Fig. 2 The temperatures T13, T17, T20 and T24 in the observation room as a function of time in test 26. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

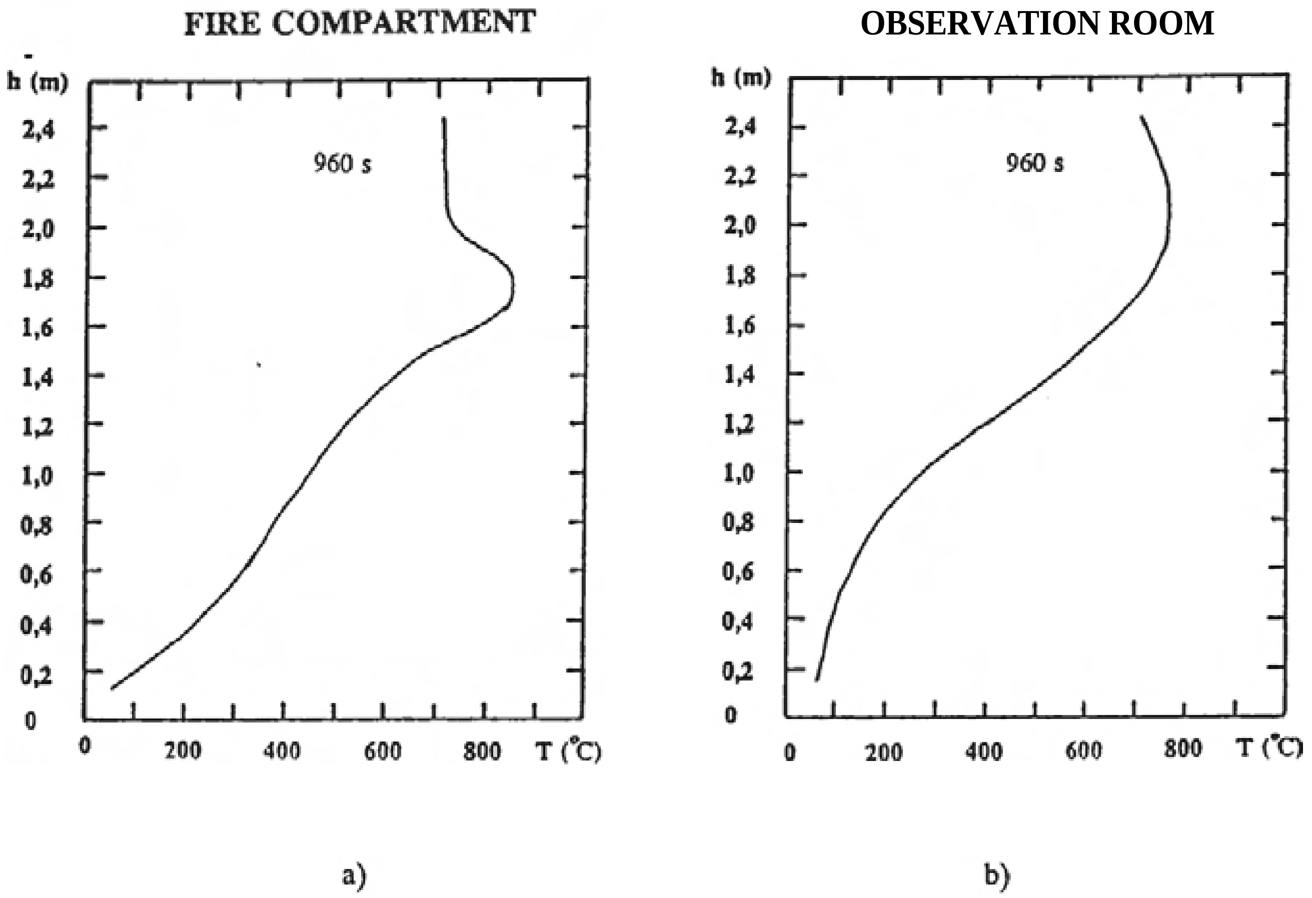
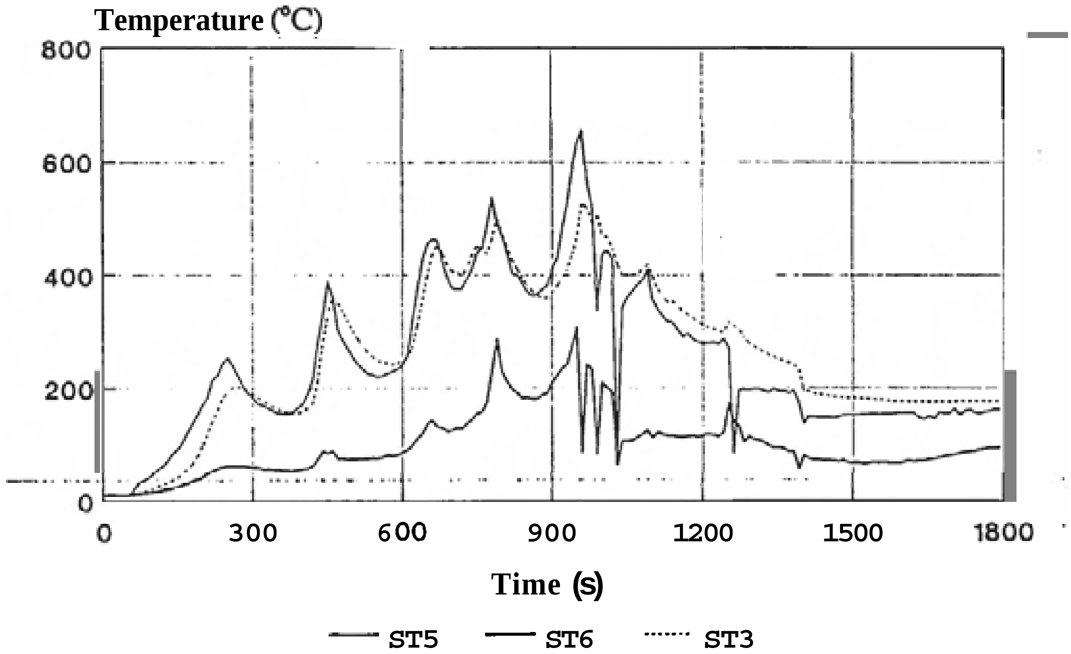


Fig. 3. The vertical temperature distributions in test 26 at test time 960 s. The burning gas layer has reached the protective shield in the observation room and is extinguished at test time 960 s (Observation 10). The elevations h are relative to the floor of the respective room. a) fire compartment, b) observation room.

a)



b)

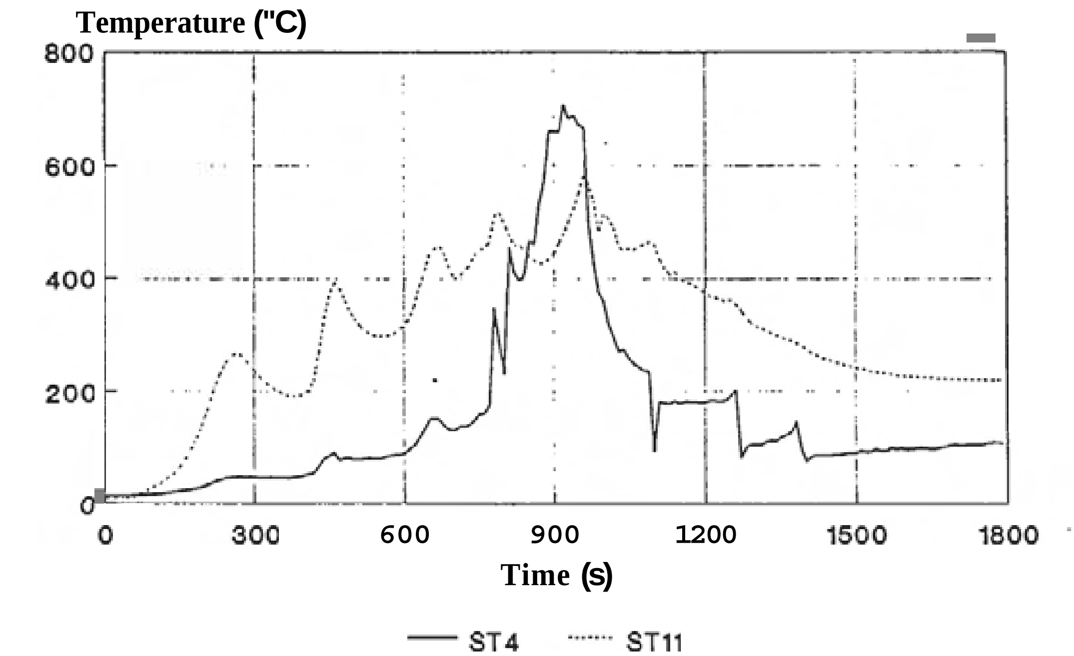


Fig. 4. a) and b) the wall temperatures in the fire compartment as a function of time in test 26.

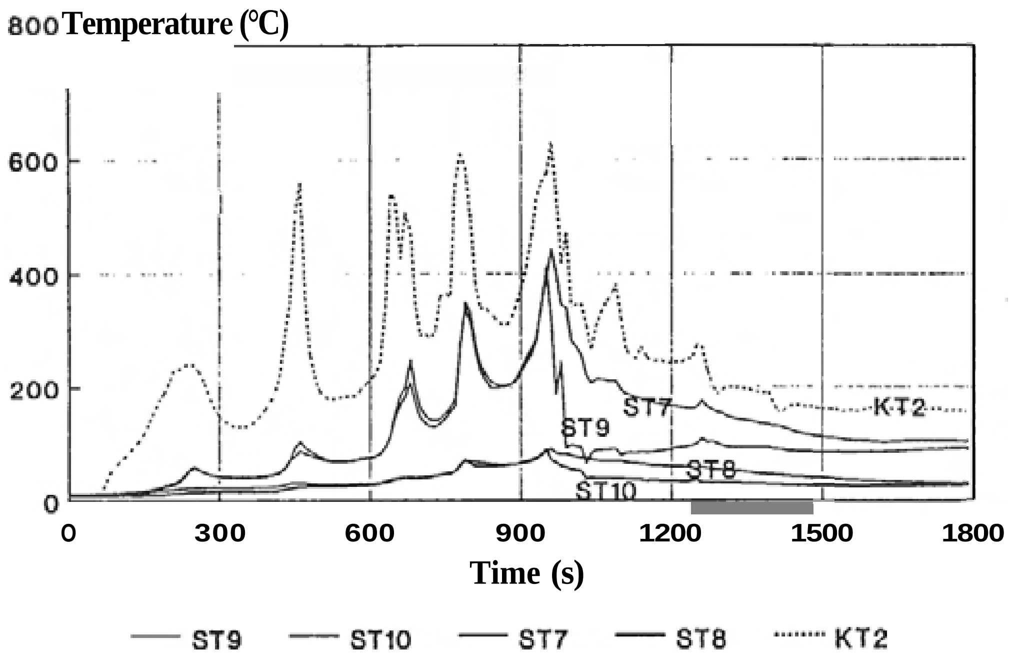
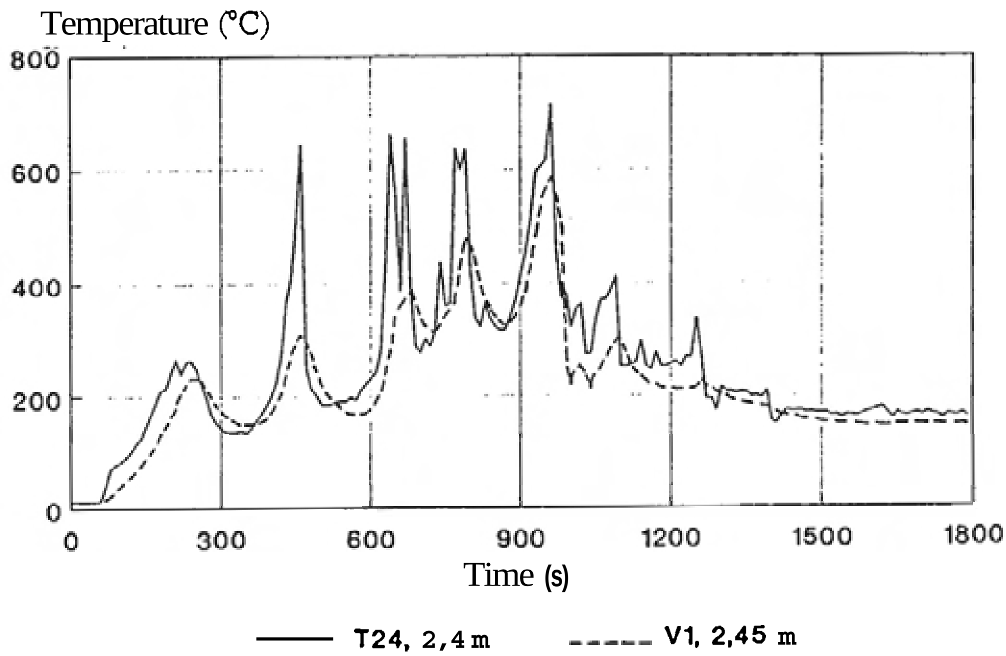


Fig. 5. The wall and ceiling temperatures in the observation room as a function of time in test 26.

a)



b)

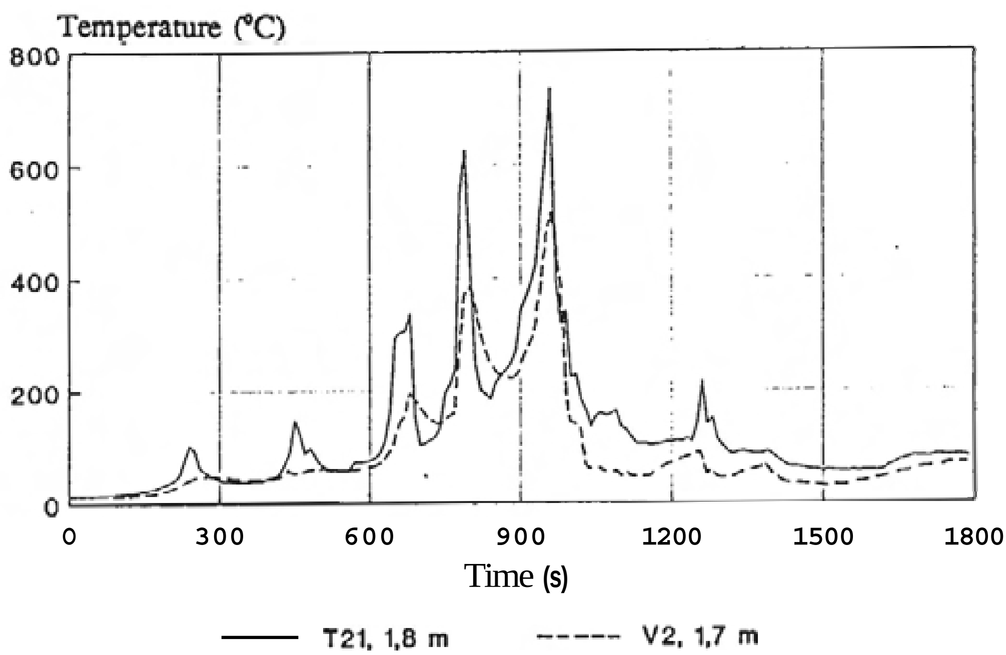
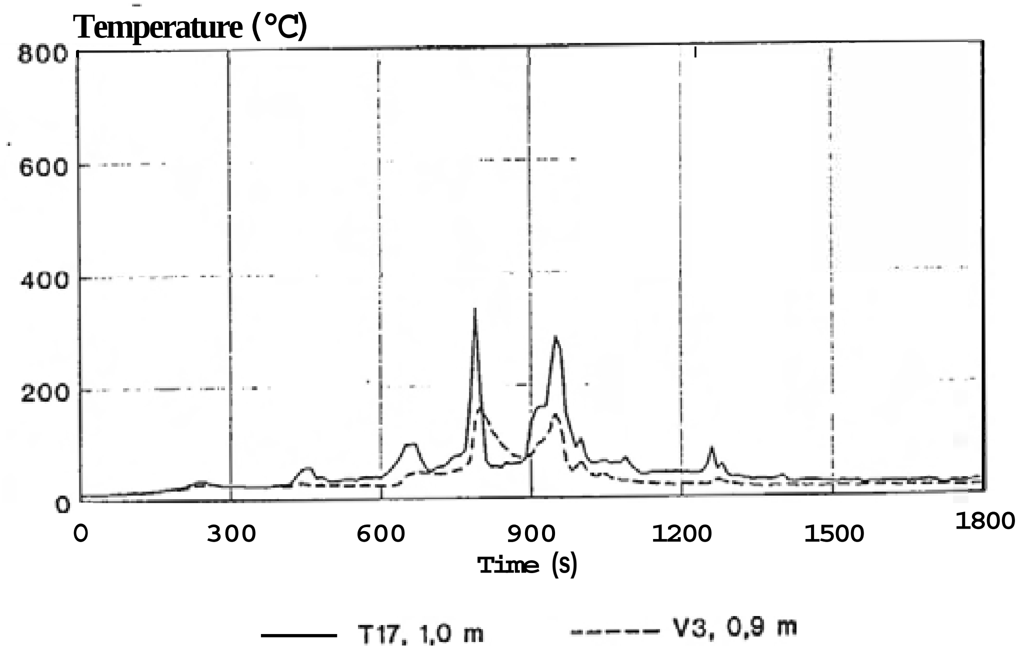
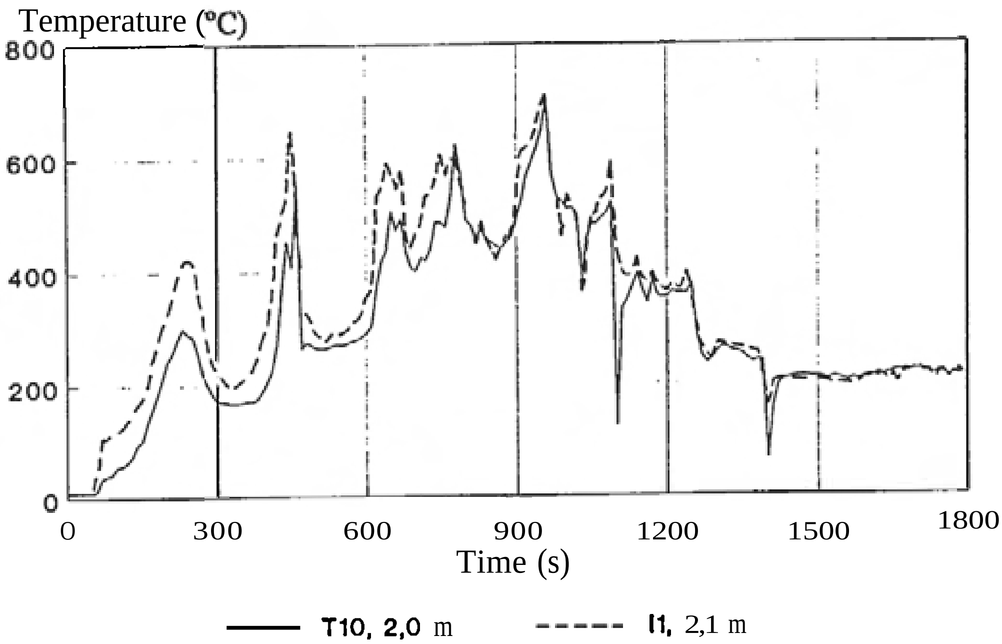


Fig. 6. Temperature of gases in the observation room in test 26 measured with bare and sheathed thermocouples. a) T24 and V1, b) T21 and V2, c) T17 and V3. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

c)


Temperature (°C)
800
600
400
200
0
0
300
600
900
1200
1500
1800
Time (s)
T17, 1,0 m
V3, 0,9 m

a)



b)

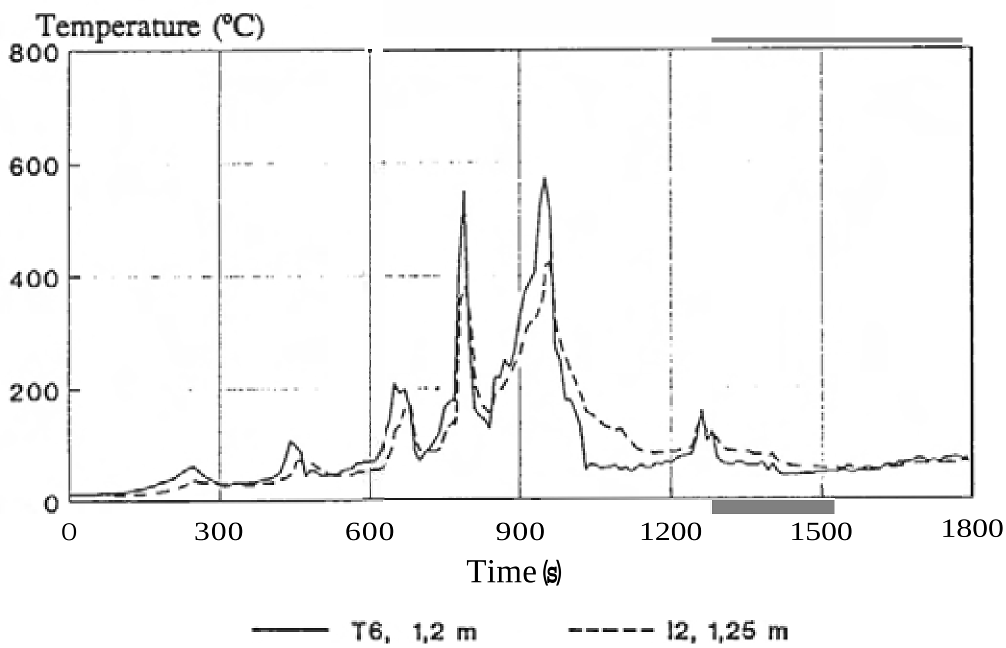
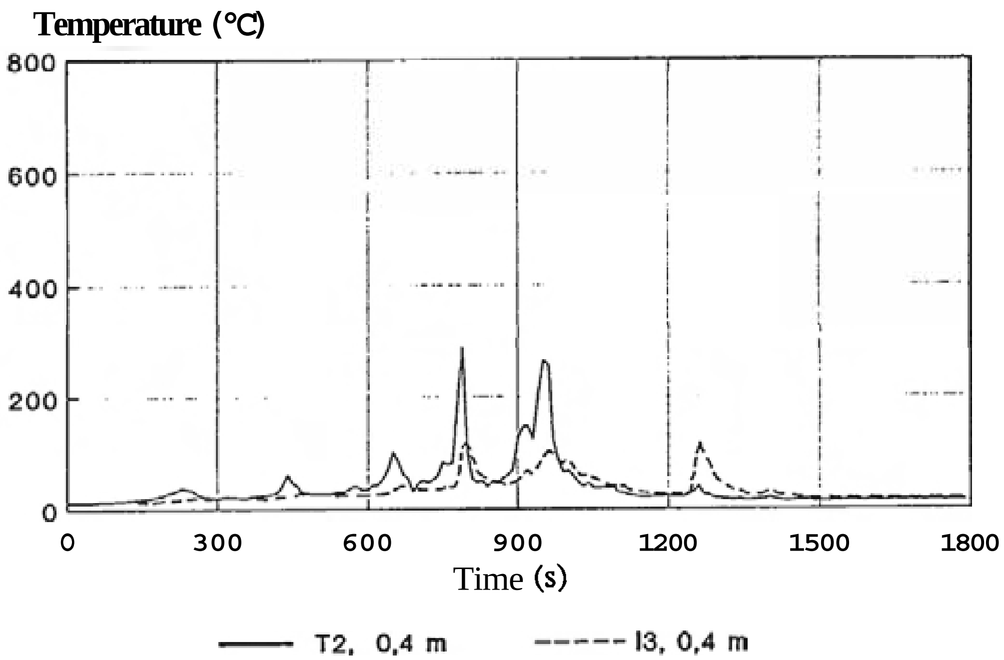


Fig. 7. Temperature of gases in the fire compartment in test 26 measured with bare thermocouples and suction pyrometers. a) T10 and T1, b) T6 and 12, c) T2 and 13. The numbers indicate the elevation of the thermocouples from the floor of the fire compartment.

c)


Temperature (°C)
800
600
400
200
0
0
300
600
900
1200
1500
1800
Time (s)
T2, 0,4 m
I3, 0,4 m

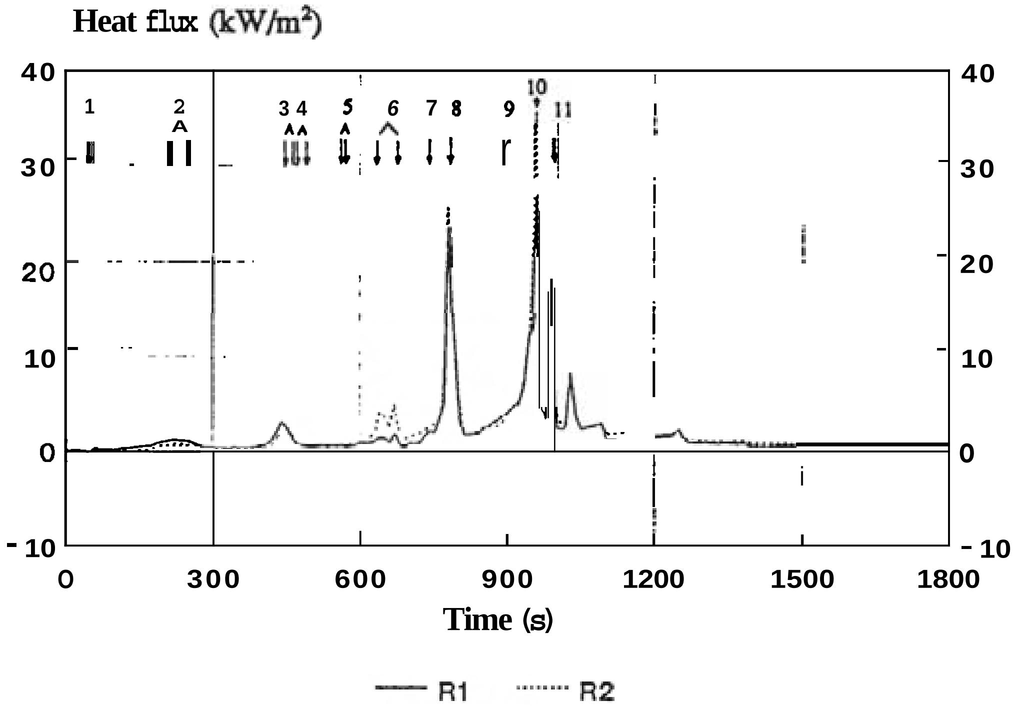


Fig. 8. The heat flux as a function of time in test 26.

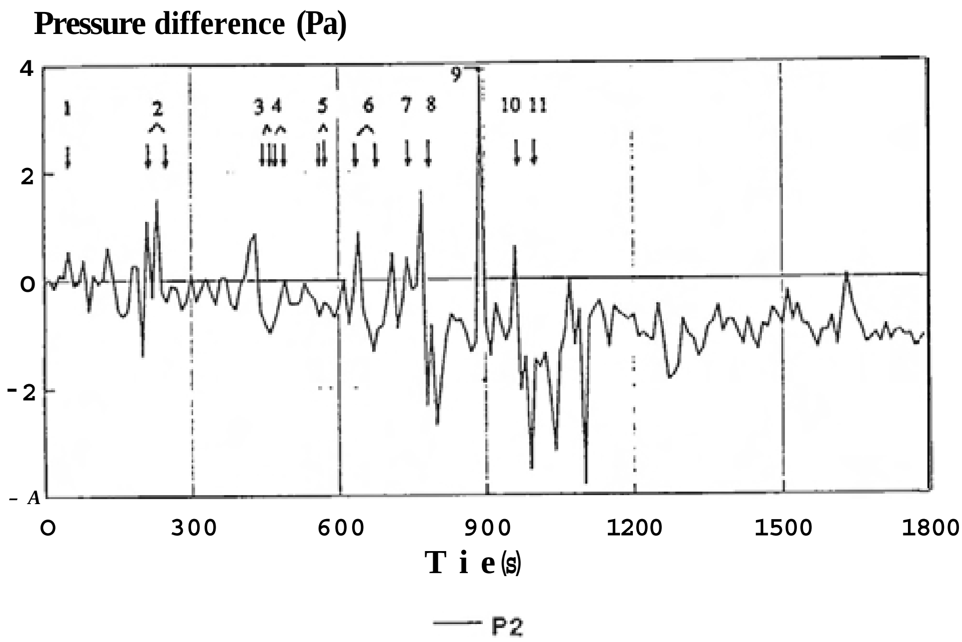


Fig. 9. The pressure difference between the fire compartment and the surrounding as a function of time in test 26.

Test 27,4 particle boards

Table 1. Observations made during test 27. The nurnbered events are recorded in the measured results plotted as a Function of time.

No.	Time (s)	Time (min:s)	Event
	0		Data acquisition was started
	60	0:60	Ignition
1	252	4:12	The burning gas layer was extinguished with a water mist jet, the fire was completely extinguished
2	442	7:22	The wood crib was re-ignited.
3	864	14:24	The burning gas layer was extinguished with a water mist jet
4	940	15:40	The burning gas layer was extinguished with a water mist jet
5	1027	17:07	The ceiling boards in the fire compartment had Fallen down
6	1200	20:00	The fire was extinguished with water

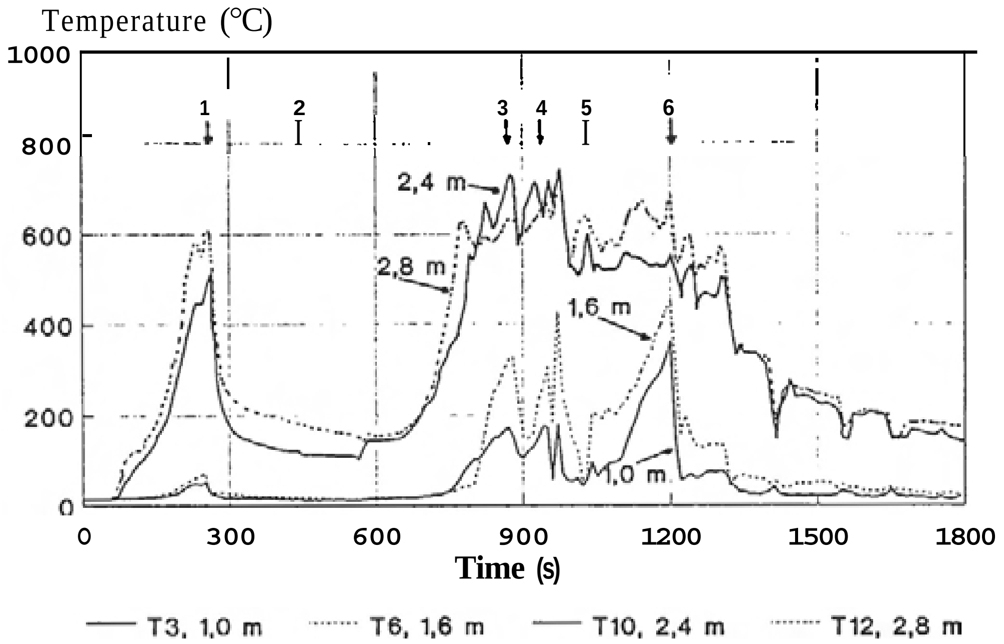


Fig. 1. The temperatures T3, T6, T10 and T12 in the fire compartment as a function of time in test 27. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

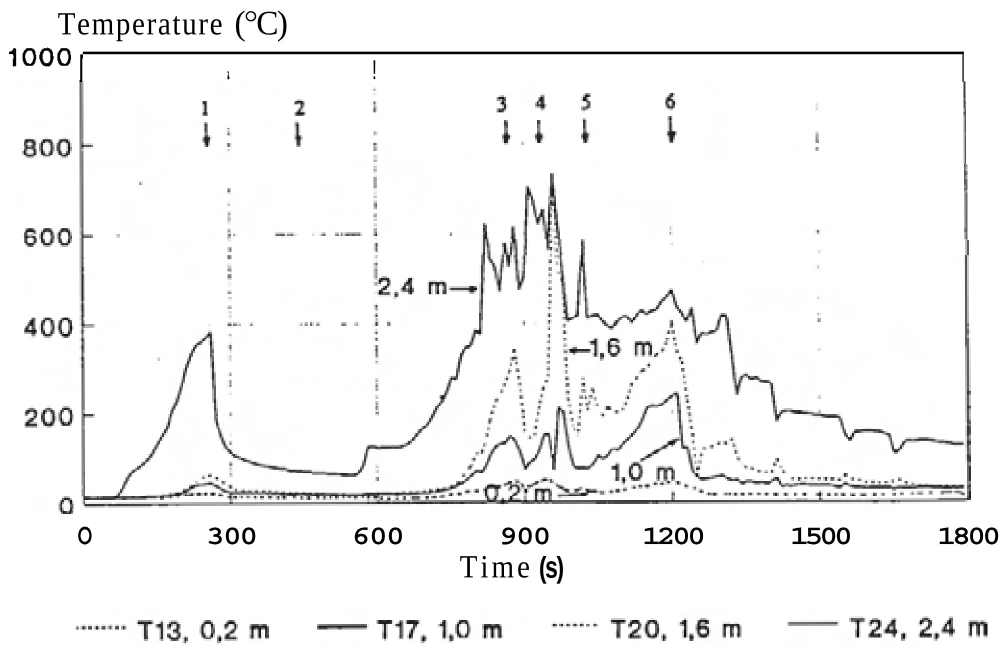


Fig. 2. The temperatures T13, T17, T20 and T24 in the observation room as a function of time in test 27. The numbers indicate the elevation of the thermocouples from the floor of the observation room.

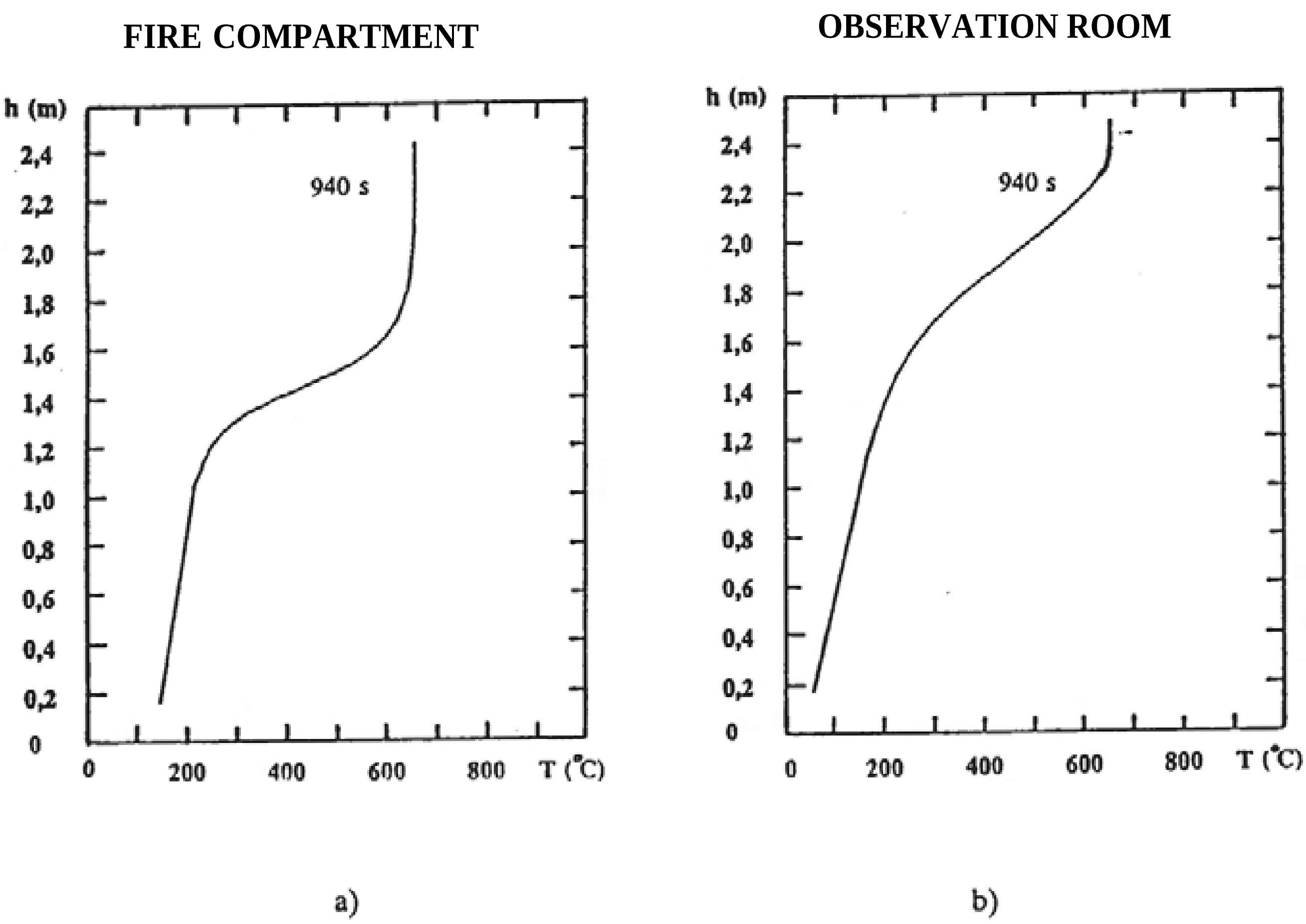


Fig. 3. The vertical temperature distributions in test 27 at test time 940 s. The buming gas layer has reached the protective shield in the observation room and is extinguished at test time 940 s (Observation 4). The elevations h are relative to the Floor of the respective room. a) fire compartment, b) observation room.

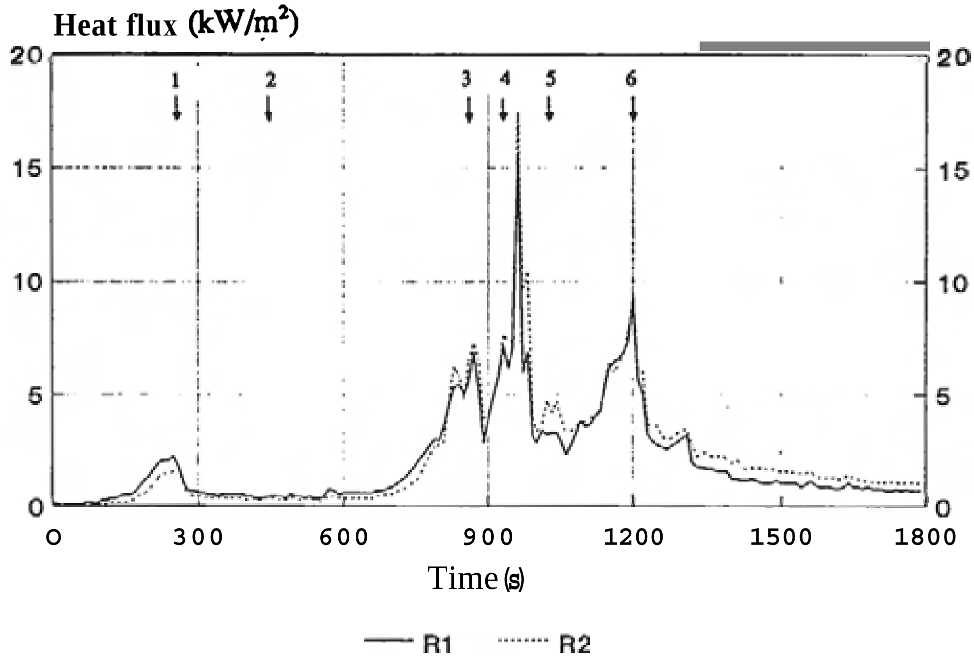


Fig. 4. The heat flux as a function of time in test 27.

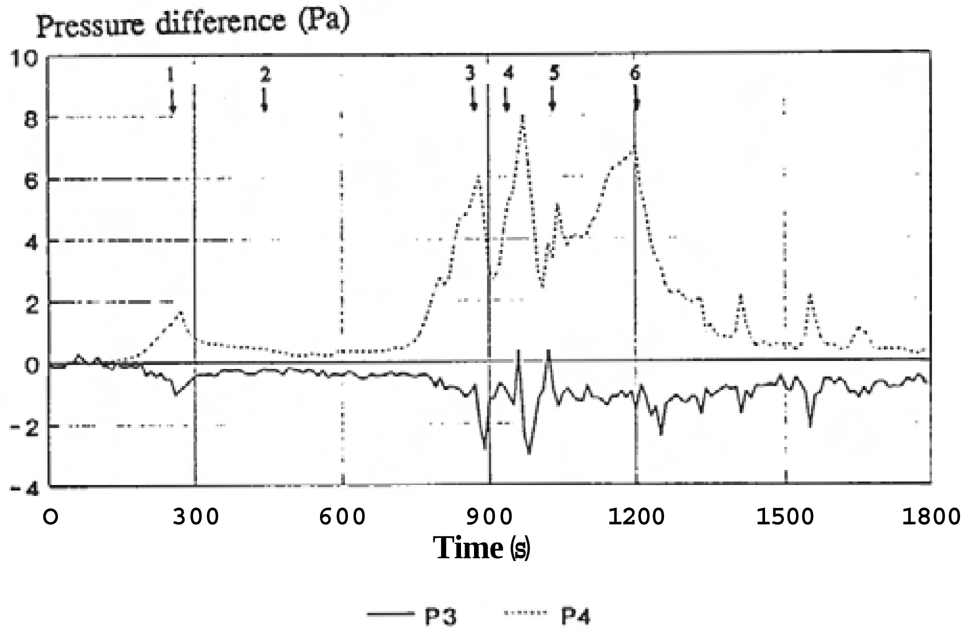


Fig. 5. The pressure difference between the observation room and the surrounding (P3) and between the upper and lower parts as a function of time in test 27.

Miniature model test, 8 kW methane burner and 3 particle boards

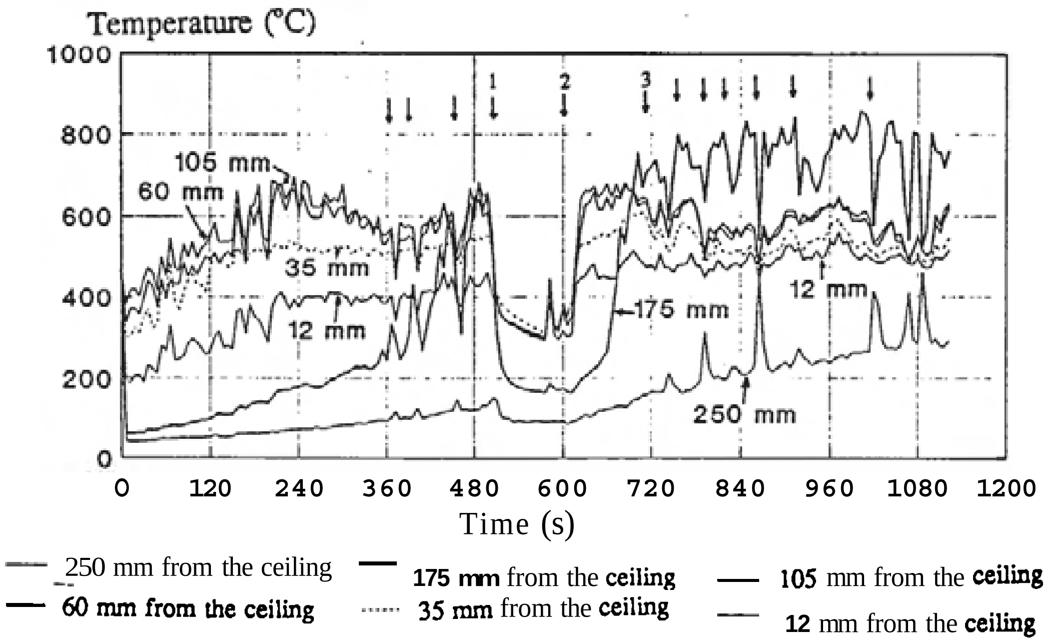


Fig. 1. The temperatures of the fire compartment in a miniature mode1 test as a function of time. The numbers indicate the distance of the thermocouple from the ceiling. The arrows show the times when the end door was closed for 3...4 seconds and then opened again. At point 1 the door was closed and the fire was completely extinguished, in point 2 the fire was re-ignited and in point 3 the door was closed partially (45 degrees).

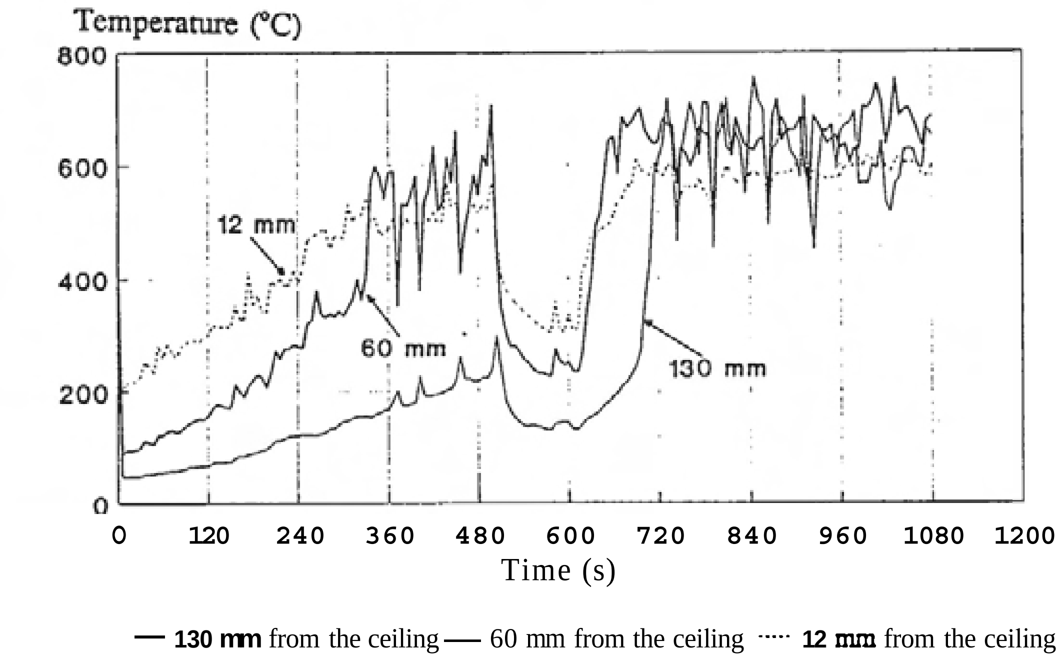


Fig. 2. The temperatures of the observation room in a miniature model test. The numbers indicate the distance of the thermocouple from the ceiling.

FIRE COMPARTMENT

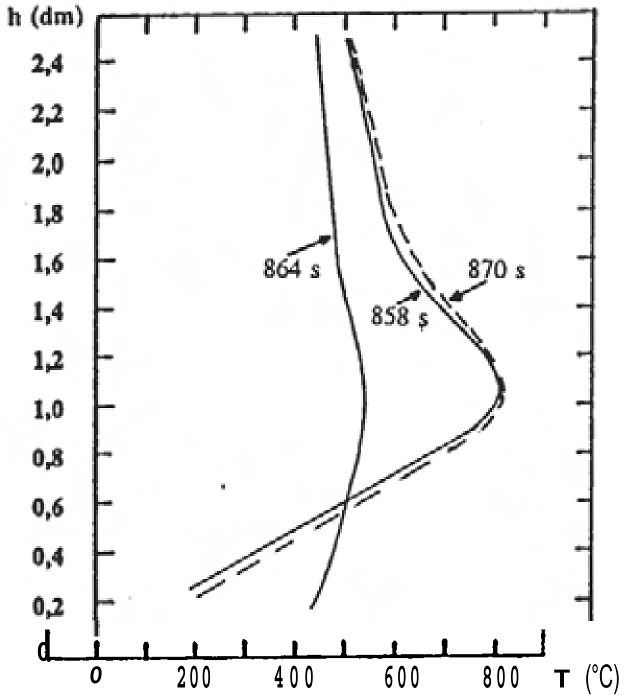


Fig. 3. The vertical temperature distributions in a miniature model test prior to closing and after opening of the end door. The door was closed at test time 860 s and opened at test time 865 s. The elevations h are relative to the floor of the fire compartment.

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