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Publication date:
1997

Document Version
Publisher's PDF, also known as Version of record

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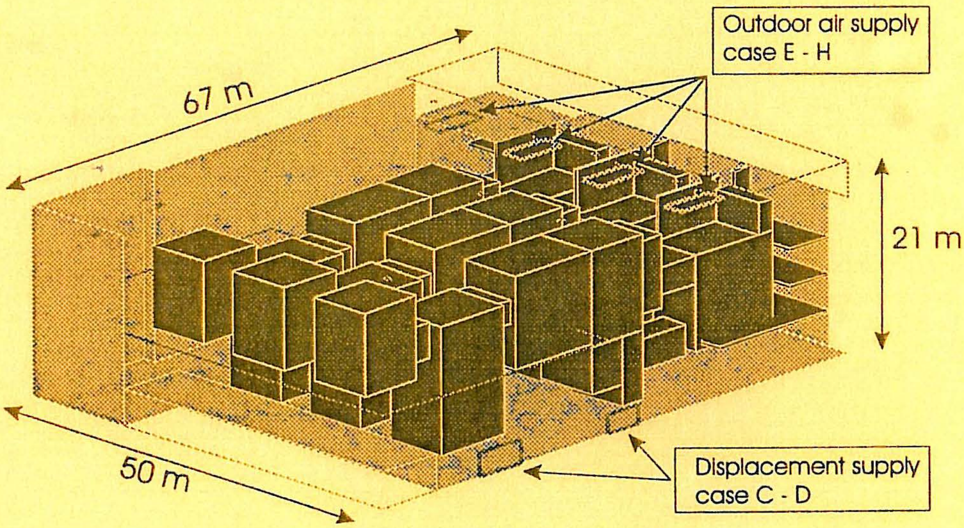

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DECEMBER 1997 ISSN 1395-7953 R9745

Printed at Aalborg University

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Application of CFD in Investigation of Ventilation Strategies for Improvement of Working Environment in a Waste Incineration Plant

by

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ABSTRACT

In this study CFD was applied to investigate the ability of different ventilation systems and strategies to improve working conditions in a waste incineration plant. The plant, I/S Amagerforbrænding, had expanded to supply both district heating and power. Because of that too high temperatures were generated in the working zones and measures to reduce these levels had to be taken.

Different possible solutions were suggested. CFD calculations of the indoor environment was included in the decision making process and resulted in valuable new information which was very helpful in the decision process. Especially in evaluation of effects of combined solutions the calculations proved to be valuable and contributed to secure reliable solutions to complicated ventilation problems.

The investigation showed that displacement ventilation with an increased supply air flow rate at floor level was not the best solution in this case with work stations distributed in the whole hall and not only close to the floor. A solution with low momentum air supply at ceiling level proved to give a more even temperature distribution in the hall and was also much more effective since lower supply air temperatures were possible without causing draft problems.

BUILDING AND PROBLEM DESCRIPTION

I/S Amagerforbrænding is one of Denmarks largest waste incineration plants which each day handle waste from 500.000 people in Copenhagen. The heat from 50.000 kg waste/h is used for both district heating and power. The waste incineration plant includes four separate incineration lines each consisting of three revolving grates and one rotary kiln, where the waste burns at temperatures above 1000 °C. The flue gases are then cooled in steamboilers for power production and boilers for hot water production for district heating before they through a purifying process end in the plants 150 m chimney. The volume of the incineration hal is 65 000 m^3 (L $\times$ W $\times$ H = 67 m $\times$ 50 m $\times$ 21 m), see figure 2. I/S Amagerforbrænding was build in 1972 and has successively been renovated and latest been enlarged with a fourth line, power production and flue gas purification. Because of this, heat generation has increased considerably and the existing ventilation system cannot fulfil the operational requirements any longer.

The existing displacement ventilation system is designed to supply 120 000 m^3/h through devices at floor level. The supply air has a temperature level of minimum 15-17 °C to ensure acceptable thermal comfort conditions. Air is exhausted through roof fans and through exhausts at the slag conveyor belts at a designed amount of 110 000 m^3/h. The purpose of the ventilation is besides removal of excess heat also to ensure acceptable temperature conditions at work stations at floor level, to ensure overpressure in the hall, to minimise contaminant levels in room air, to minimise drafts and to work as smoke ventilation.

Renovations and enlargements of the plant have increased heat generation considerably and as a consequence temperature levels especially in the top of the hall have become much too high. The high temperatures cause reading errors from the plants electronical measurement equipment as well as the equipments lifetime is reduced appreciably. The high temperatures are also unsatisfactory in relation to the working conditions for service and maintenance especially in the top of the plant.

ANALYSIS OF COMFORT CONDITIONS AND VENTILATION SYSTEM

In the winter 1993-94 comfort conditions and the ventilation system were analysed by measurements of temperature levels within the plant and volume flows and temperature levels in the ventilation system.

Excess heat is generated from large surfaces on kilns, boilers, filter bags and flue gas purifying plants with surface temperatures of 50-60 °C and from the rotary kilns with surface temperatures of 180-200 °C. The air flow in the hall is characterised by large rising convective air currents especially close to the kilns and a clear temperature stratification. Figure 1 shows measured mean temperatures for one week in selected positions in the hall. Air was supplied at floor level at a temperature of 17 °C and infiltration occurred at several openings with an outdoor air temperature of about 3 °C. There was a clear stratification in the hall and very high temperatures in the top with an exhaust air temperature through roof fans of 41 °C. The circle marked temperatures were measured below and above a rotary kiln but high temperatures were also measured in other positions in the hall. Air temperatures as high as 50-60 °C were found in some working areas close to the ceiling.

Volume flow measurements in the ventilation system and of infiltration showed that the ventilation system did not perform as designed and that there were very large infiltration air flows through openings in the construction. The ventilation system supplied only 85 000 m3/h, three exhaust fans 41 000 m3/h and infiltration had an amount of about 60 000 m3/h. All air was exhausted through roof fans and fans for air supply to kilns creating an underpressure in the hall and causing unwanted air flows and draft problems. Even if the ventilation system only supplied 70% of the expected volume flow the total ventilation rate was 155% of the original design value.

The total effect including heat generated by motors, equipment etc. was estimated to be about 730 kW for each incineration line corresponding to 2.2 MW with three out of four incineration lines running.

POSSIBLE TECHNICAL SOLUTIONS

The target for a new solution is that air temperatures are lowered from about 50 °C to 40 °C, that infiltration/exfiltration is minimised and that the ventilation system secures overpressure in the hall.

In principle there are two ways to reduce temperature levels and improve working conditions; reduce heat load or increase ventilation capacity. The proposed solutions used one or both ways. In all proposals it was assumed that the existing displacement ventilation system was renovated to deliver the designed amount and that the construction was tightened.

Particularly the rotary kilns have high surface temperatures. A possible solution to reduce heat load was therefore to shield the rotary kilns, and thereby reduce their surface temperature from 180-200 °C to 70-80 °C. Other heat sources in the plant have much larger dimensions and much lower surface temperatures (50-60 °C), which make shielding unpractical and less efficient.

It was not possible to increase the capacity of the existing ventilation system beyond its design capacity. An increase of ventilation capacity in the hall could therefore only take place by design of an additional system. Two different layouts were suggested. The first layout was a displacement system supplying heated low momentum outdoor air at floor level with a capacity of 120 000 m^3/h and a supply air temperature of 15-17 °C. Exhaust through roof fans was increased correspondingly. The original displacement principle was maintained. The second layout was a ventilation system supplying low momentum outdoor air at ceiling level also with a capacity of 120 000 m^3/h. Air was supplied between incineration lines and dropped towards the floor. On the way the cold air entrained warm air from the surroundings. If the inlet temperature was not too low the air would stop before it reached the floor, it would only cool the top of the hall and not cause any drafts. The supply air device was provided with recirculation to control inlet air temperature at a minimum level of about 5 °C and exhaust was increased by roof fans.

The complicated picture of heat sources and air flows in this large incineration hall makes it difficult to estimate the effect of the different solutions and especially in cases where different solutions is combined. It was therefore decided to supplement the basis for decision with CFD calculations. These calculations were carried out in close co-operation between building owner, technical consultant and research institute.

APPLICATION OF CFD IN EVALUATION OF SOLUTIONS

A three-dimensional computer model was made including the hall and plant geometry and locations of inlets and outlets for the ventilation system. Figure 2 outlines the main features of the geometry. It was chosen to model a working situation with only three of the four incineration lines running so only these are included in the model.

A preliminary calculation was made for the above-mentioned measured situation. Measured air flows, inlet temperatures and surface temperatures on kilns, boilers, filter bags and flue gas purification plants were used as boundary conditions for the calculations, while room air temperatures were used for comparison with results. This was done to adjust the model and to ensure that necessary simplifications did not influence the accuracy too much. The existing situation, with a very complicated plant geometry, many and very different heat sources, pipelines and floor gratings, is not possible to model without using a range of simplification, approximations and modifications. It is very difficult to estimate the consequences of these and a comparison of calculated results against measurements is a good way to adjust and evaluate the model. Figure 1 shows a reasonable correspondence between the calculated air temperatures in the middle of the hall and measured temperatures in a number of location.

The modified model was used to calculate the thermal conditions in the hall in different cases applying one or more of the suggested solutions. The different cases are shown in table 1. It should be emphasised that case A is different from the measured situation as it shows the situation when the ventilation system functions as designed e.g. without infiltration from outside and with a supply air flow rate of 120 000 m^3/h

Figures 3 and 4 show the calculated thermal conditions in the incineration plant in the cases C and E. Isotherms are in both cases shown in two vertical planes, one between two incineration lines and one across all lines at the location of the rotary kilns. The additional displacement ventilation system in case C will primarily cool the lower part of the hall (0-6m) and increase the area with acceptable conditions, but there will still be very high temperatures and unacceptable temperatures in the upper part of the hall. The results show a clear stratification in the hall and stable air flow conditions with cool air supplied at floor level, convective currents along heat sources and exhaust at ceiling level. The existing displacement ventilation system in case E with half the air flow capacity as in case C cools only the lowest 2-3 m of the hall. Supply of outdoor air (10 °C) at ceiling level creates a quite different situation in the rest of the hall. The air flow conditions become unstable because of the confrontation between the warm rising convective currents and the descending cold inlet air flow. The temperature level in the top of the hall will decrease considerably depending on the outdoor air temperature without influencing temperature conditions at floor level and the temperature stratification will be small. In this way it is possible to cool the hall more effectively with air of a much lower temperature (5-10 °C) than with displacement ventilation (15-17 °C).

DISCUSSION

The results from all cases are compared in figure 5. The comparison is based on the calculated vertical temperature distribution in the midlle of the hall. The results show large variations in temperature levels and gradients obtained in the different cases. The different inlet temperatures result in different cooling capacities and the different systems result in quite different air flow patterns. Air supplied at floor level with a temperature of 15-17 °C results in low temperatures at floor level, large temperature gradient in the middle of the room and high temperatures at ceiling level. Air supplied at ceiling level with a temperature of 3-10 °C results in more even temperature distribution in the hall and lower temperatures at the top of the hall because of larger cooling capacity.

Shielding of the rotary kilns as an independent solution was not enough to ensure acceptable working conditions, but in combination with supply of heated air at floor level acceptable temperatures were obtained. So even if the surface temperatures of the rotary kilns were very high (180-200 °C), they were not the largest heat sources due to their relatively small surface area.

Supply of outdoor air at ceiling level could solve the temperature problems and combined with shielding of the kilns almost even temperature conditions in the hall were obtained. The air flow conditions with supply of outdoor air at ceiling level become unstable because of the confrontation between the warm rising convective currents and the descending cold inlet air flow. Calculations show that the cold inlet air will not reach the occupied zone close to the floor, but it should be expected that cold inlet air from time to time will penetrate the hot air layer and reach the floor level. However, this will not result in any comfort problems because only average conditions are considered important.

CONCLUSION

In the large incineration hall air flow patterns are dominated by convective currents from several very different heat sources and the interaction between these currents and the ventilation system is crucial for the ventilation effectiveness. Application of CFD in the investigation of suitable ventilation strategies for improvement of the working environment in I/S Amagerforbrændingen resulted in a very useful description of the complex conditions which were helpful in the evaluation of solutions and also gave a valuable basis for the design phase.

The investigation showed that displacement ventilation with an increased supply air flow at floor level was not the best solution in this case with work stations distributed in the whole hall and not only close to the floor. A solution with low momentum air supply at ceiling level proved to give a more even temperature distribution in the hall and was also much more effective since lower supply air temperatures were possible without causing draft problems.

Based on the results of the CFD calculations, I/S Amagerforbrænding has decided to establish supply of air at ceiling level as a first step in the improvement of the working conditions. Because of lack of space it is chosen to construct two ventilation systems with a design capacity of 75 000 m^3/h each, which are connected to the same ductwork and with low velocity supply between the incineration lines. The assumption of low inlet velocity in the CFD calculations is followed as far as possible by air inlet through many large openings. It is expected that the new system will be running in the autumn of 1997. As the second step shielding of the kilns is just initiated with preparation of design proposal.

The CFD calculations carried out have produced a well-documented basis for decision for I/S Amagerforbrænding to implement improvements of working conditions and have also resulted in a well-defined basis for design.

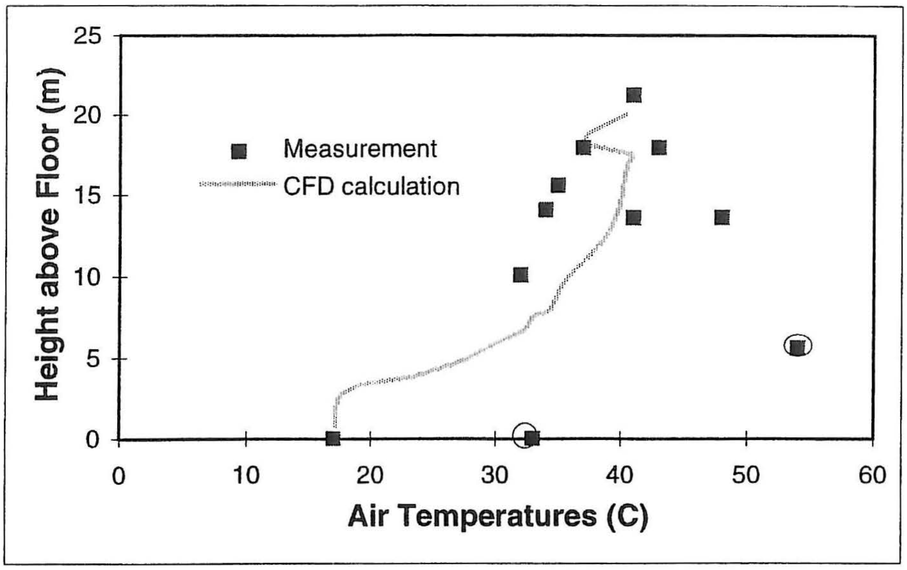

Figure 1. Measured air temperature levels in incineration plant, 23 -29 November 1993.

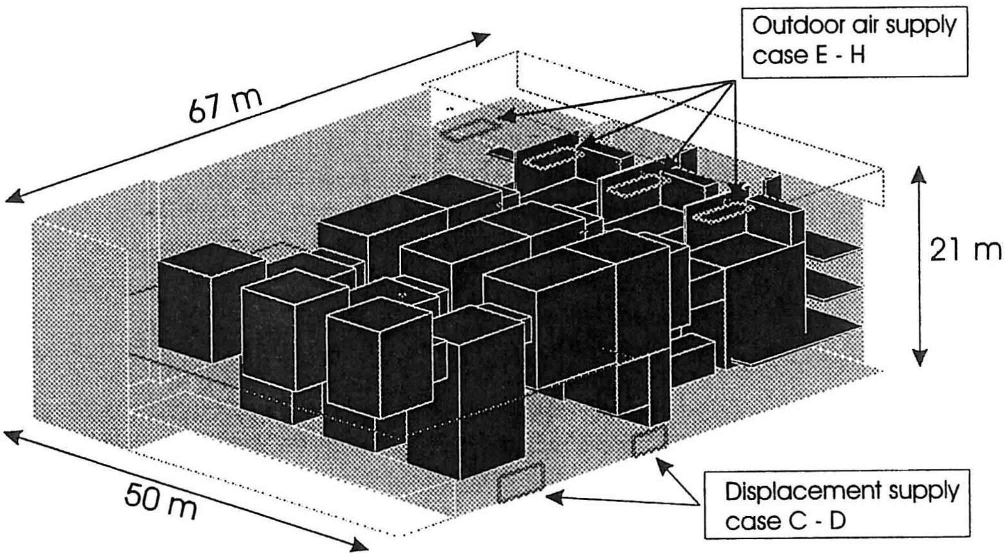

Figure 2. Outline of main geometry of hall, plant and ventilation system.

Table 1. Calculated cases covering different ventilation solutions.

Case	Description
A	Existing ventilation system with designed performance
B	As A with shielding of kilns
C	As A supplemented with an additional displacement ventilation system
D	As C with shielding of kilns
E	As A supplemented with additional supply of outdoor air (10 C) at ceiling level
F	As E with shielding of kilns
G	As A supplemented with additional supply of outdoor air (3 C) at ceiling level
H	As G with shielding of kilns

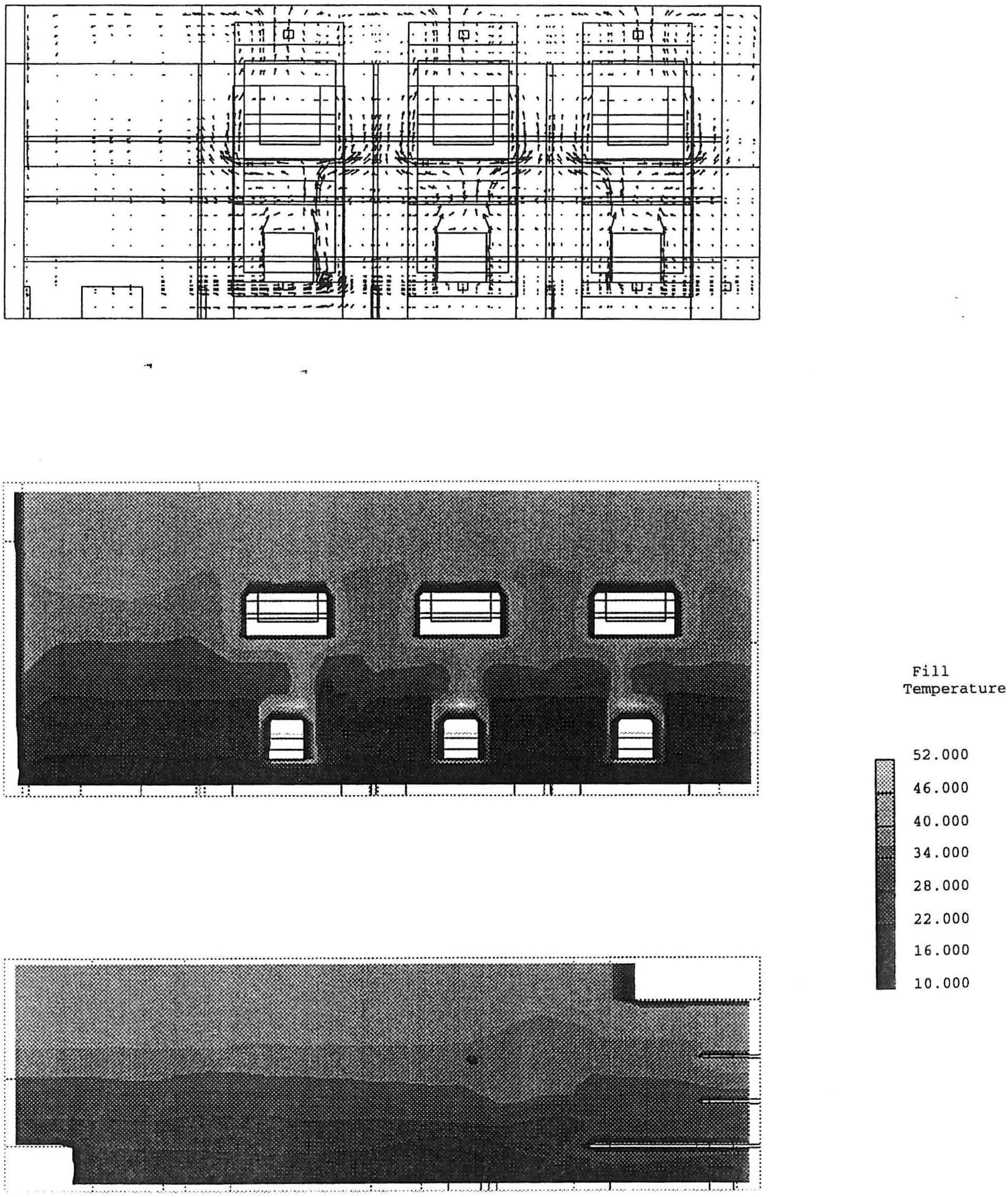

Figure 3. Calculated air flow and temperature conditions in the incineration plant in case C in two vertical planes - one across all lines at the location of the rotary kilns and one between two incineration lines.

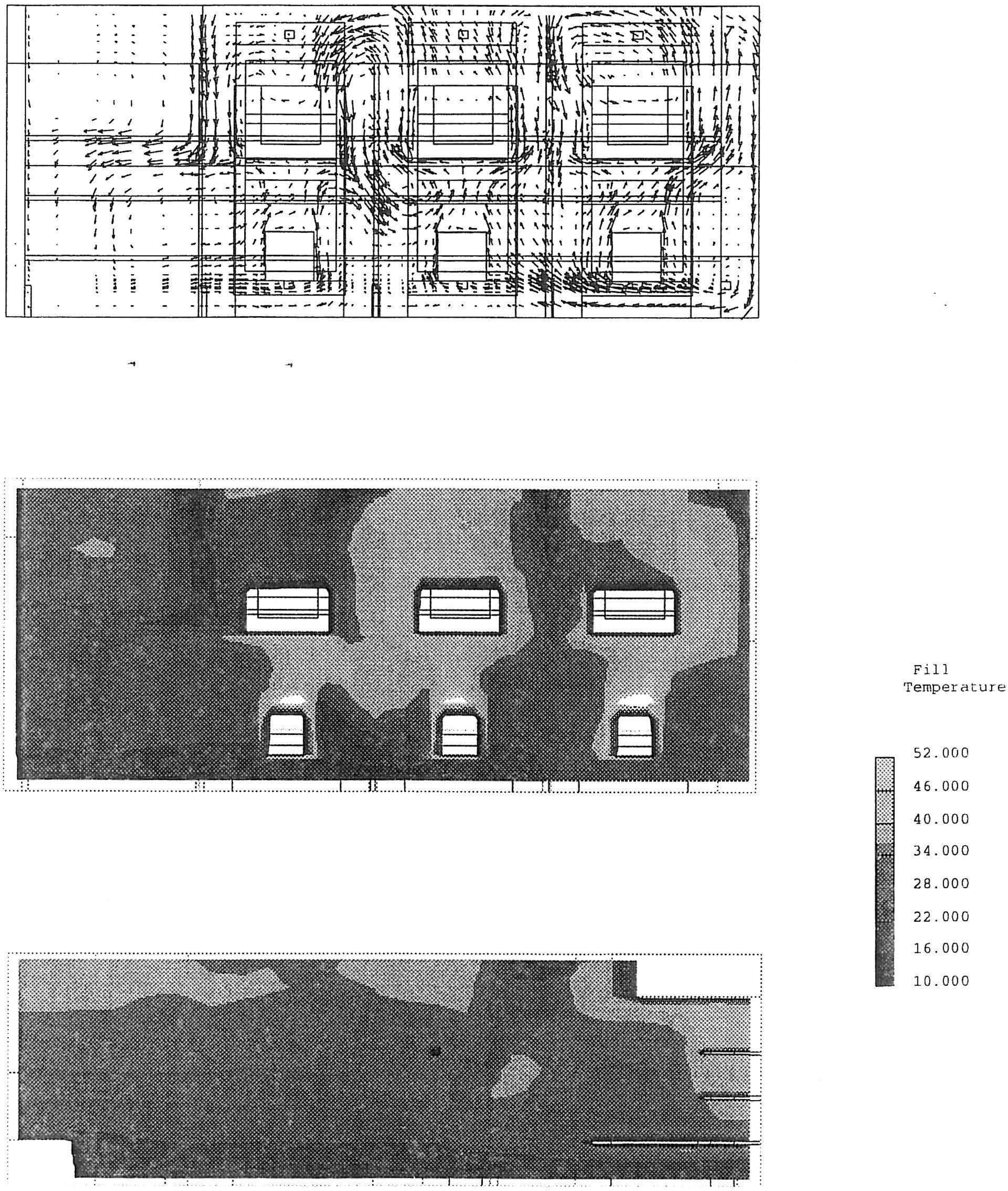

Figure 4. Calculated air flow and temperature conditions in the incineration plant in case E in two vertical planes - one across all lines at the location of the rotary kilns and one between two incineration lines.

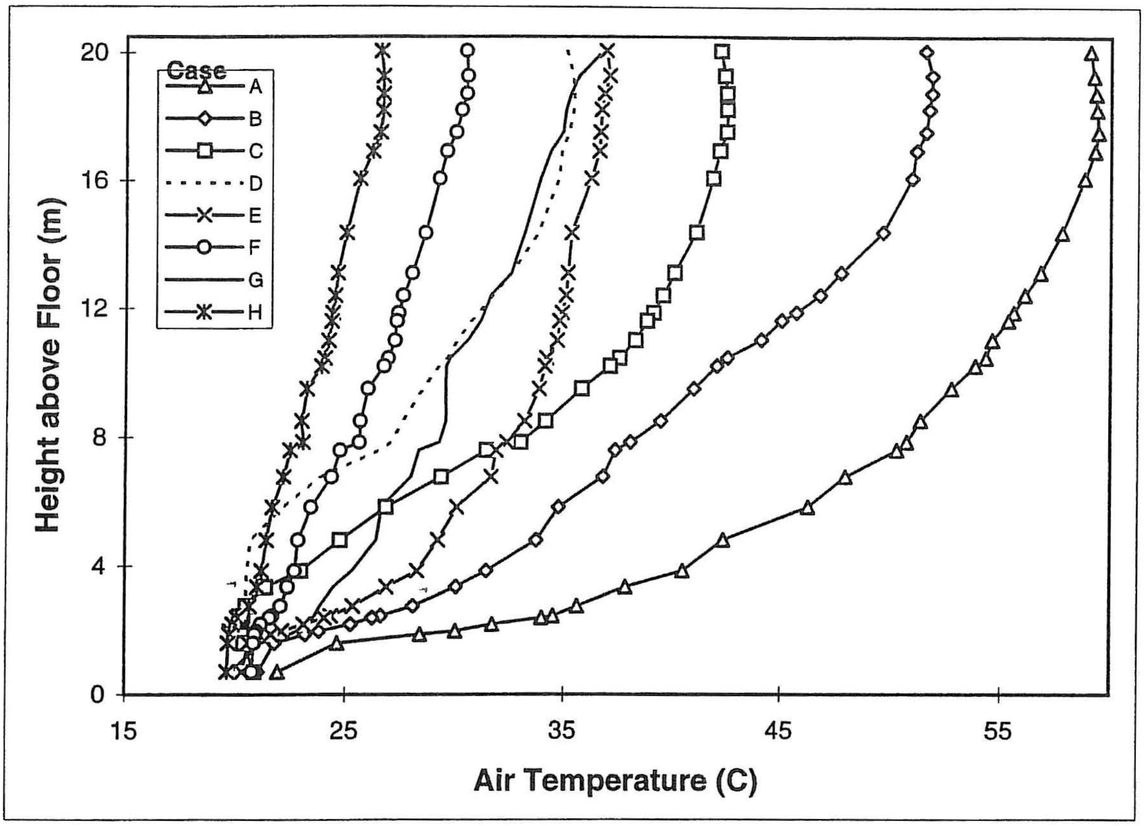

Figure 5. Comparison of vertical temperature distribution in the middle of the hall in the calculated cases.

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