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VORTEX AIR DISTRIBUTION SYSTEM FOR BOILER HOUSE

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ABSTRACT

This article describes a new and more efficient Vortex Air Distribution system for a soda recovery boiler house. Essentially the technology utilises directional air supply of up to 150 m^3/s to compensate for heat gains of up to 2000 kW. Issues addressed include all stages of the design process from the Computational Fluid Dynamic (CFD) experiment and scale mock-up tests in the laboratory conditions to the field measurements after the system had been installed. The supply air is distributed into the building through specially designed air terminals. It forms the vortex flow around the boiler surfaces displacing the contaminated warm air towards the exhaust at the top of the boiler house utilising buoyancy forces. Having uniform direction of the air movement inside the boiler house ensures efficient ventilation of the building, preventing stagnant ventilation zones from being formed. The warm air stratified at the top of the boiler house is used in the combustion process thus significantly improving the energy efficiency of the boiler. The air distribution system successfully operates in the soda recovery boiler plant in Rauma, Finland since 1996.

KEYWORDS

air distribution, boiler house, energy, vortex air distribution system

INTRODUCTION

One of the project objectives was to design ventilation and air distribution system for the soda recovery boiler house to compensate for heat gains of up to 2000 kW. The main building is 78 m tall and 38 by 33 m in plan. The soda boiler is installed in the middle of the building and stretches up to almost total building height. The soda production process is fully automised, there are no permanent working places, only temporary working zones are used for inspection and service. Air temperature in the building should not drop below 10°C at the design winter temperature −26°C and maximum temperature should not exceed 35°C at the design summer temperature +26°C. The combustion air is taken from inside the boiler house to improve the energy efficiency of the combustion process.

The following main objectives were set while designing the air distribution system:

- The temperature inside the boiler house should be between 10 and 35°C through the entire period of operation.
- The air distribution should allow temperature stratification in the boiler house to maintain highest temperature at the apex of the building where air is taken for combustion process.
- Efficient ventilation of the whole boiler house should be achieved with minimum number of air terminals and therefore ductwork.

The last objective is considered essential due to the fact that boiler house is loaded with technological equipment and pipework and there is very limited space for installation of air terminals and ventilation ductwork.

METHODS

Air distribution solution

The solution required the design of a new type of both building air distribution system and air terminals. The concept was named Vortex Air Distribution system and is explained as follows. The air is stirred air around the boiler thus obtaining the uniformity of the air flow in the building. This will prevent stagnant zones without air circulation from being formed and allow convective flow rising along the boiler walls to stratify the air temperature along the building height.

The air distribution solution is illustrated on Figure 1. The supply air is stirred around the warm surface of the boiler, rising towards the exhaust at the top of the building utilising buoyancy forces. The air is exhausted at the top of the boiler where it is at the highest temperature and utilised for combustion. The air terminals are installed in the corners of the building at predetermined levels. They supply air in the form of compact jet at high velocities to ensure counter clock direction of the air flow in the building. The total supply air flow rate varies from 57 to 150 m^3/s depending on boiler load and outdoor temperature: up to 6 m^3/s of supply air to be distributed through each air terminal.

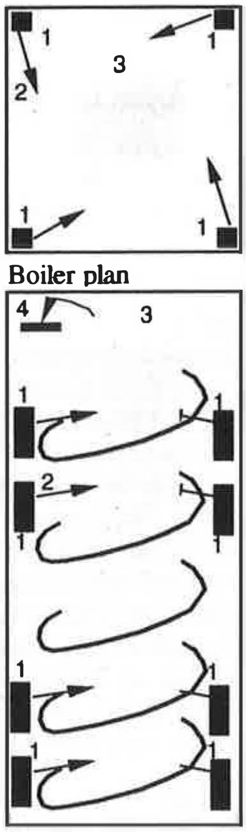

Figure 1 Air distribution principle

1- air terminal PDA, 2- direction of supply, 3- boiler, 4- exhaust air for combustion process

Mock-up measurements and CFD experiments

Mock-up measurements and CFD experiments were done by Halton Research Centre to investigate the air distribution solution.

Figure 2 shows the model of the boiler house built in 1:20 scale. The purpose of the mock-up measurements was to investigate the air flow pattern from air terminals and temperature stratification in the boiler house. The boiler heat input into the building was simulated with heated electrical wire, scaled models of air terminals were used to simulate air distribution devices. Temperature inside the model of the boiler house was measured with PT100 temperature censors, connected to Hewlett Packard data logger. Smoke was used to visualise the flow pattern from air terminals and general air motion inside the model.

Since it is difficult to simulate both turbulent air jets and convective heat transfer from boiler surfaces in scaled experiment, the air distribution and general air motion were considered as primary objective to be studied on the scale model. Temperature measurements were used only to verify the temperature gradient along the building height.

The CFD experiments were carried on to simulate temperature and air distribution in the boiler house in both summer and winter conditions. The CFD software package Flovent was used.

RESULTS

Mock-up measurements and CFD experiment

Both CFD and mock-up tests with smoke visualisation showed that air terminals provide uniform vortex air motion around the boiler through the whole building ensuring efficient air exchange.

Measured air temperatures and CFD simulations confirmed that vortex air distribution system allows temperature stratification with the highest temperature recorded at the top of the building.

The discharge velocity from the air terminals should be 6,5 – 7 m/s to ensure "vortex flow" in the building.

The CFD simulations indicated higher temperature stratification in the building in winter conditions resulting in low temperature at the ground level. There was suggested to install a separate system re-circulating part of the air from the apex of the building and supply it at the ground level in case temperature drops below the design level.

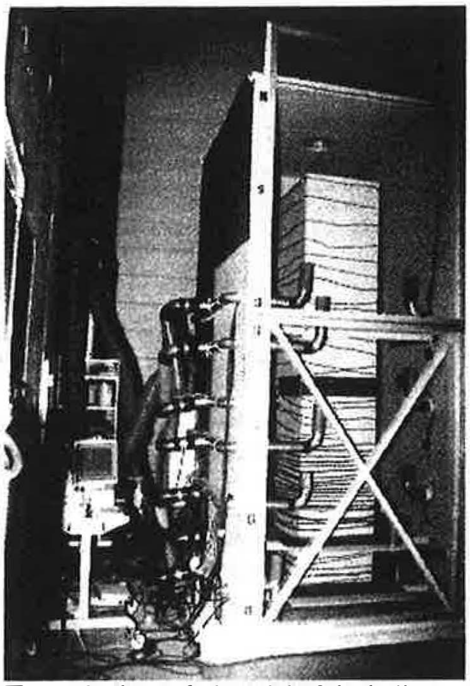

Figure 2 The scaled model of the boiler house

The CFD simulation results are presented in Appendix 1 on Figures 4 and 5. Figure 4 shows velocity distribution in the characteristic cross-sectional view of the boiler house. Figure 5 illustrates the temperature distribution in the vertical cross-sectional view of the building.

Air terminals

The Vortex Air Distribution system for the boiler house requires special air terminals capable of supplying large quantities of air with high velocity. The discharge velocity from air terminals during mock-up measurements and CFD simulations was estimated to be 6.5 – 7 m/s.

Halton developed modular air terminal PDA with adjustable direction and opening of the supply outlets especially for this project. The air terminals, installed in the boiler house, are shown on Figure 3.

PDA is designed to supply up to 8 m^3/s of air, providing at the same time flexibility of selecting direction of air supply and outlet velocity. Each PDA unit consists of modules that can be assembled together up to 5 pieces in one unit.

In case there is a need to provide ventilation of the certain spot in the building, temporary working zone for example, one or several nozzles of PDA can be adjusted to supply air directly to the spot. This PDA advantage has been utilised during the installation process of the technological equipment.

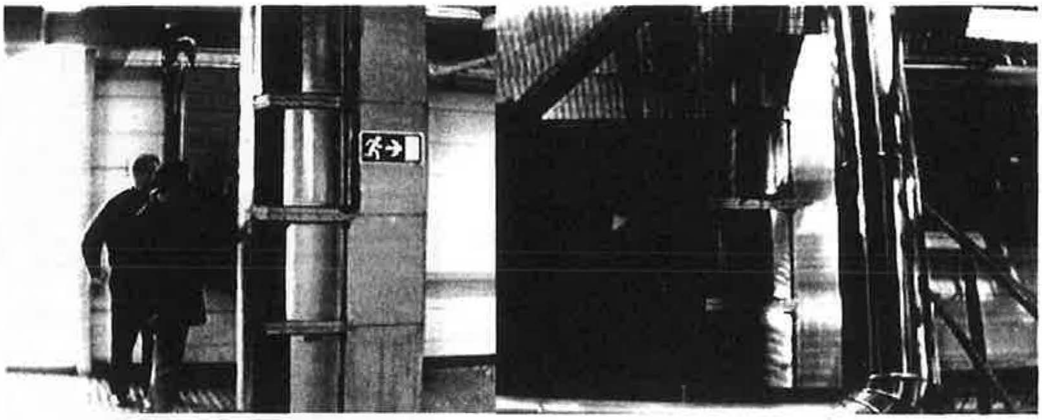

Figure 3 Air terminals PDA installed in the boiler house.
Each nozzle of the four models can be adjusted to change direction of supply air jet, discharge velocity and air flow rate.

Field measurements

The purpose of the measurements was to investigate the efficiency of Vortex Air Distribution system, temperature and velocity in the boiler house.

Measured

- air temperature, velocity and direction at representative points inside the boiler house
- total air flow rate, supplied by the main air handling unit and air flow rate at single supply devices installed at the upper levels

Measurement equipment

Temperature and velocity were measured by two thermo-anemometers ALNOR Compuflow GGA-65p. Smoke visualisation method was used to determine direction of air flow.

Measurement results

- There was established steady counter-clock direction of the air movement inside the boiler house at all levels. The magnitude of velocity varied from 1,4 m/s to 0,2 m/s. The maximum velocity was recorded at the ground level (+9,500) and minimum velocity - at the top levels (over + 75,400) and at the levels where no air terminals were installed.
- Temperature inside the boiler house was within the target levels and varied from 21.8°C at the ground level (+9,500) to 34,9°C at the top level (+77,300). The data is presented in Table 1.

Table 1. Air temperature and velocity measurements inside the boiler house

Level, m	Temperature, °C	Velocity, m/s
9,500	21,8..22,1	0,6..1,4
13,950	21,8..23,9	0,2..0,9
16,800	25,1	0,2..0,9
22,000	23,8..24,2	0,4..0,6
24,900	24,6..25,0	0,2..0,3
34,200	22,6..23,8	0,21..0,3
50,400	18,6..25,5	0,6
54,300	26,4	n/a
58,200	24,2..26,4	0,5..0,9

61,200	24,3..27,3	0,2..0,6
64,500	26,3	n/a
70,800	28,6..30,6	0,4..1,3
75,400	30,9	n/a
77,300	34,9	n/a

DISCUSSION

1. The Vortex Air Distribution system can be successfully applied in the tall industrial buildings with high heat load.
2. The Vortex Air Distribution system proved to be efficient. Temperature and velocity measurements confirm steady, uniform movement of the air in the boiler house around the boiler that ensures the efficient ventilation of the whole boiler house. Temperature in the building was within the specified limits.
3. New modular air terminals PDA with adjustable direction and opening of the supply outlets meet the requirements of the Vortex Air Distribution system and provide efficient ventilation of the boiler house.
4. Application of the PDA air terminals with supply air flow rate up to 8 m^3/s (5 m^3/s in this particular application) compared to air distribution system with multiple air terminals makes possible to reduce significantly the number of air terminals installed in the building, hence diminish the ductwork, time required for its installation and corresponding costs.

Appendix 1

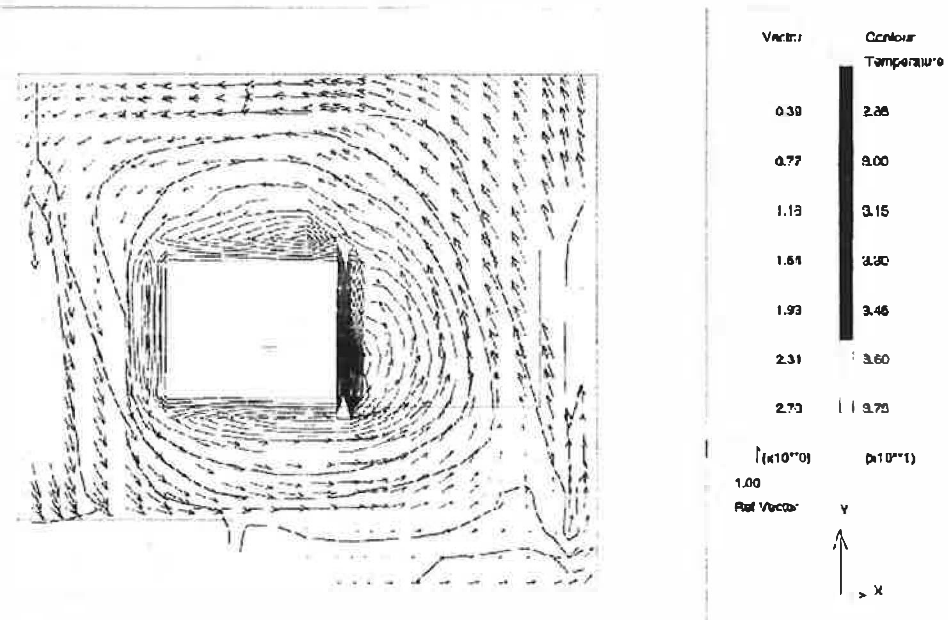

Figure 4 Velocity distribution in the characteristic cross-sectional view of the boiler house at height 3m. Velocity vectors indicate well established vortex movement of air around the boiler house. The airflow efficiently ventilates the whole space with no stagnant air circulation zones being formed.

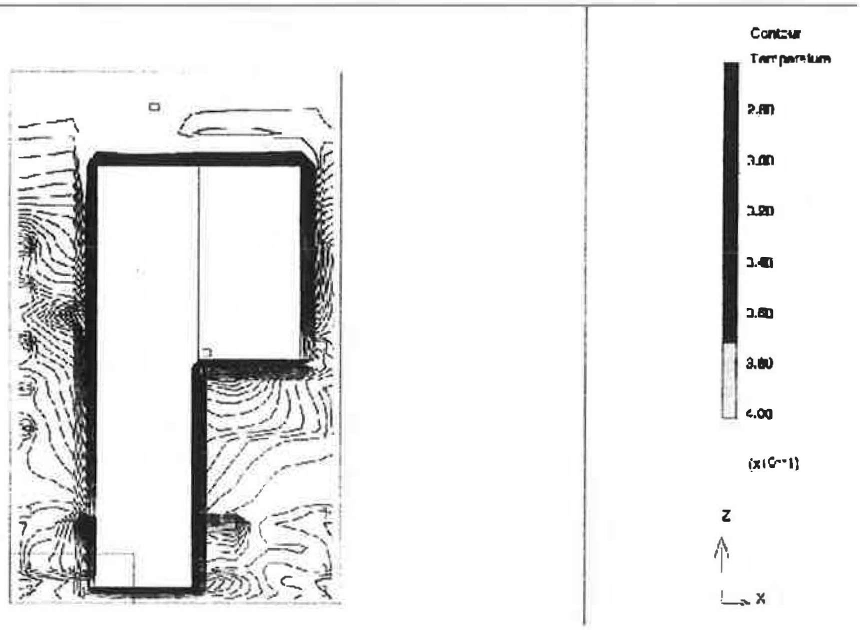

Figure 5 The temperature distribution in the vertical cross-sectional view of the building. The Vortex Air Distribution system allows temperature stratification in the boiler house to maintain highest temperature at the top of the building where air is taken for combustion process.