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CFD Simulations – Efficient Tool for Designers of Industrial HVAC Applications

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Abstract

The aim of this study is to design industrial ventilation in the production hall. With respect to the many parameters which influence the appropriate proposal of industrial ventilation that need to be considered, there is a good chance for miscalculations when design the industrial ventilation. Especially when the heat loads from technology threaten the stability of construction of the building. There are two different ways of solution of aeration in the aluminium plant. There is only a natural ventilation using outside air in case of melting of aluminium and an adiabatic cooling for air inlet combined with natural ventilation. The results and practice has shown, that to use only an outside air is not sufficient and the temperature in the hall is really very high. Adiabatic cooling decreases the air inlet temperature in the production hall and improves the working conditions. A thermovision mapping of the technology was used prior to start the CFD modelling. The simulation emphasize the important effect of design and location of different elements on the functionality of ventilation proposal.

Keywords

CFD simulation, aeration, industrial ventilation, adiabatic cooling, thermovision

1 Introduction

Fast growing demand of new cars on the market influence the production capacities of suppliers. This might usually be limited with the size of the production hall, and production line capacities. To install a new technology, suppose very serious proposal, static assessment, serious control of heat loads and efficient ventilation system. The big thermal flows an aeration which is based on physical principles might be an interesting solution [1, 2]. This kind of ventilation is used to ventilate the dirty and hot technologies like cement production, power plants or metallurgic plans. An important advantage of this technical solution is a low investment and running costs, and absence of big ventilation ducts [3]. It allows useful ventilate hot air polluted by oil aerosol.

Regardless of design standards, it is very important to verify correctness of the proposed solution by computational fluid dynamics (CFD) simulations, The CFD simulations present a tool to analyze system involving mass and heat transfer and the related phenomena in more thorough sophisticated way, using computer models to predict and to provide a view of the flow fields.

2 Aeration and adiabatic cooling

Ventilation system that would cope with the high heat loads associated with smelting ensured that desirable temperatures guarantees low running cost. Aeration is based on calculation of neutral pressure plane (NPP), natural or powered air inlet and known heat loads. It is strongly recommended to calculate very carefully the heat loads from the building itself and also from the technology. If there is material flow, it allows more accurate calculation of aeration. At the same time it is necessary to say, that aeration is influenced by outside condition. Installation of ventilators on the roof construct supposes statically assessment. The most critical for the aeration calculation seems to be the height of the building and also the thermal gradient [4, 5].

If there is a very low thermal gradient, the driven force for aeration is missing and system doesn't work properly.

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It is recommended to measure the parameters especially the temperature under the ceiling to have correct input data. A very important parameter is the position of technology itself. Based on heat load production is possible to define the cold production halls ($q < 30$ W/m^3), hot production halls ($30 < q \leq 80$ W/m^3) or a very hot production halls ($q \geq 80$ W/m^3). The aeration is appropriate for hot and very hot production halls.

Adiabatic cooling is also known as evaporative cooling. Evaporative cooling systems provide a sustainable, efficient and cost-effective alternative to conventional air conditioning, particularly with those industrial and semi-industrial facilities which do not require an absolutely constant internal temperature at all times and where these buildings are generally simply too large for conventional air conditioning to be cost-effective.

How does evaporative cooling work? Warm outdoor air is passing across a desorption medium, energy is exchanged and a significant reduction of air temperature is achieved [3, 6]. The warmer and drier the outdoor air, the more efficient the evaporative cooling process is.

3 Simulation model

The Reynolds Averaged, steady state CFD Model of the aeration of production hall is used (Fig. 1). The flow is turbulent (k-ε) without chemical reactions. The fvDOM model is used: Finite Volume Discrete Ordinates Model. Emissivity and absorption are estimated both of value 0.5 [7, 8].

Limit conditions:

- atmospheric pressure: 101.325 kPa,
- building dimensions: length 56 m, width 13 m,
- height 12.8 m,
- building envelope factor BF 0.30.

Data calculated:

- total heat loads: 1370 kW,
- high difference Δh: 7 m,
- outdoor temperature t_1: 31.3/22.2 °C,
- indoor temperature t_2: 45.0 °C,
- air inlet volume: 8x 29 250 m^3/h,
- labyrinth area – aerodynamic: 34.85 m^2.

4 Short model description

Adiabatically adjusted air is distributed in the production area via eight pieces of textile diffusers (Fig. 2). A strong impact is kept on air speed in the working area to guarantee air speed no more than 0.2–0.5 m/s if possible. There are some technical limits like cranes and steel construction which influenced the position of adiabatic coolers and length of textile diffusers.

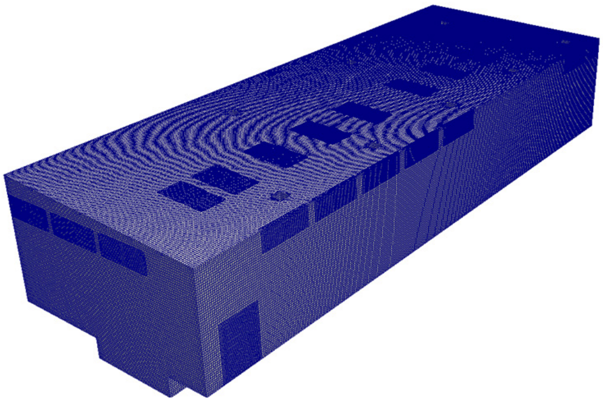

Fig. 1 3D model of industry production hall's envelope; mesh used 0.25

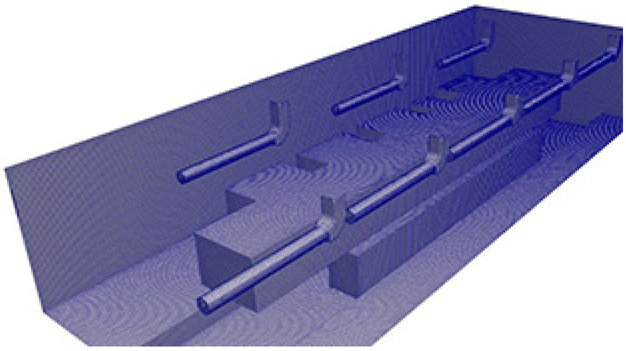

Fig. 2 3D model of industry production hall's interior; mesh used 0.25

A special steel construction is used for both adiabatic coolers and labyrinth ventilators (Fig. 3) not to affect the stability of construction of the building. Technology is installed in the middle of the hall which allowed both side air inlet. As part of the design process, combined temperature data/humidity/dew point loggers are used to be able online monitor conditions, allowing us to understand the full extent of the overheating problem and design an effective system. A system is running full automatically via ModBusTCP/IP peripheria.

The results from monitoring are recorded in the Table 1 and graphically shown on Fig. 4.

The calculated results from monitoring are recorded in the Table 2.

Fig. 3 Labyrinth ventilators and adiabatic coolers installed on the roof

Table 1 Measurements of relative humidity and temperature in real time

Point Nº.	Relative humidity (%)	Temperature (°C)	Point Nº.	Relative humidity (%)	Temperature (°C)
1	70.30	23.30	**14**	49.40	24.70
2	69.10	23.40	**15**	51.70	24.60
3	70.50	23.40	**16**	57.50	24.00
4	72.20	23.30	**17**	59.70	24.00
5	72.50	23.60	**18**	60.40	24.10
6	70.00	24.10	**19**	60.00	23.90
7	66.60	24.40	**20**	58.70	23.70
8	57.70	24.70	**21**	58.80	23.50
9	53.40	25.00	22	59.30	23.30
10	55.60	24.80	**23**	59.60	23.20
11	52.80	24.80	**24**	58.40	23.20
12	52.80	24.80	**25**	58.50	23.50
13	49.60	24.90	**26**	59.80	23.40

5 Results and discussion

In presented results we would like to show how the temperature will change looking at the height from the bottom to the top of the hall (points 1–26). Shape temperature of the production line is considered to be 60 °C. The most critical is to keep the temperature in living area 1.50-1.75 m from bottom and also to guarantee that the temperature under the roof will not exceed 45 °C.

According to EN ISO 7730:2006 [10] the air speed in working zone is one of the most critical parameters and should be guaranteed. Air speed is the second parameter, which is a subject of our investigation. The results of CFD revealed functionality of the proposed model but also

Table 2 Calculated results of measurements

Point Nº.	Saturated water vapour pressure (Pa)	Parcial water vapour pressure (Pa)	Specific humidity (g/kg_{da})	Enthalpy (kJ/kg_{da})
1	2012.32	2012.32	0.01277	56.02
2	1989.93	1989.93	0.01263	55.76
3	2030.25	2030.25	0.01289	56.42
4	2066.71	2066.71	0.01313	56.92
5	2113.15	2113.15	0.01343	58.00
6	2102.50	2102.50	0.01336	58.34
7	2036.64	2036.64	0.01293	57.56
8	1796.39	1796.39	0.01138	53.92
9	1692.51	1692.51	0.01071	52.52
10	1741.37	1741.37	0.01102	53.12
11	1653.67	1653.67	0.01046	51.68
12	1653.67	1653.67	0.01046	51.68
13	1562.74	1562.74	0.00987	50.30
14	1537.98	1537.98	0.00972	49.69
15	1600.01	1600.01	0.01011	50.60
16	1716.72	1716.72	0.01086	51.89
17	1782.40	1782.40	0.01129	52.97
18	1814.15	1814.15	0.01149	53.59
19	1780.64	1780.64	0.01128	52.83
20	1721.25	1721.25	0.01089	51.65
21	1703.55	1703.55	0.01078	51.16
22	1697.45	1697.45	0.01074	50.85
23	1695.77	1695.77	0.01073	50.72
24	1661.63	1661.63	0.01051	50.16
25	1694.86	1694.86	0.01072	51.02
26	1722.11	1722.11	0.01090	51.36

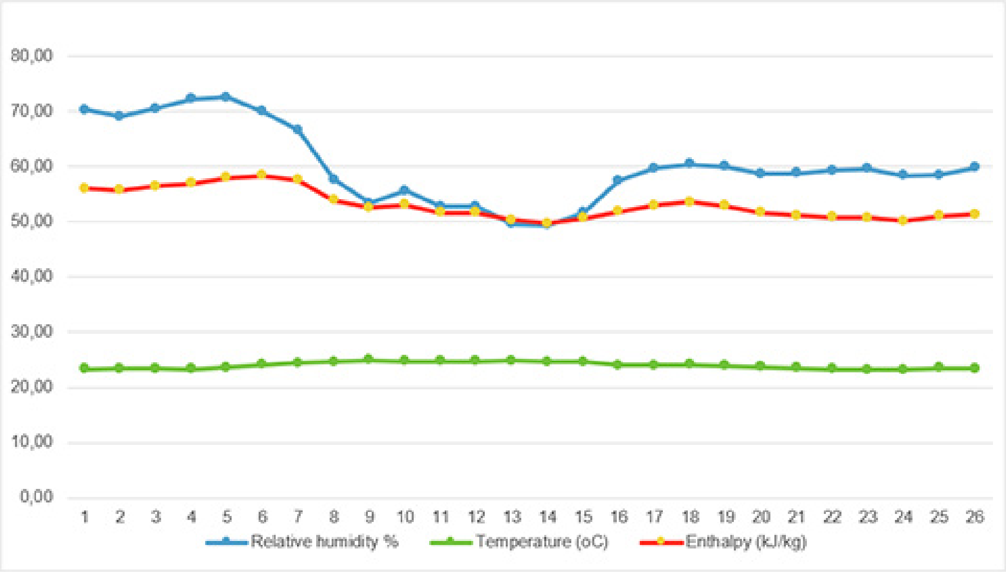

Fig. 4 Measurements of relative humidity and temperature [9]

revealed where limits of our proposal are. Production line significantly contributes to the total heat loads and preheat the surrounded air. Adiabatically cooled air is slowly falling down and allow more efficient aeration of the hot air. This allows much better working conditions for the people [11, 12].

Working class is 2a [13]; the production of metabolic heat by humans $q_M = 161 – 200$ W/m^2 defined at a clothing resistance $R_{cl} = 0.64$ clo and allowed temperature in summer is 30 °C. This is guaranteed according to the CFD and also measure in real situations after the production line is installed. Consequently, the supply ventilation air is better distributed in front of the production line. This space is usually used as a communication and for material flow [14, 15].

The CFD model indicates (Fig. 5–Fig. 8) that worse air distribution is behind the line, where the gas burners and chimneys are installed. Curve lined shape of the production line keeps the hot air and prevents efficient ventilation. A duct inlet would be preferable, but this is not possible due technology and space limits.

The thermovision slides of the production line is showed on the Fig. 9.

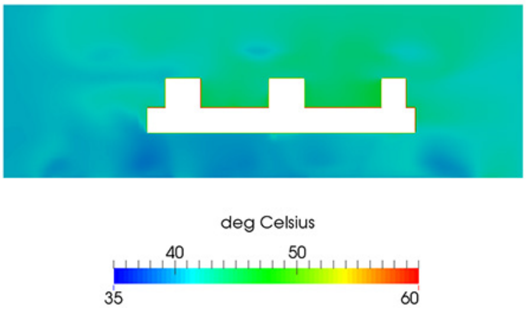

Fig. 5 Ground plan - Temperature in the height of 1.0 m over the floor, temperature varies between 26 – 45 °C, shape temperature 60 °C

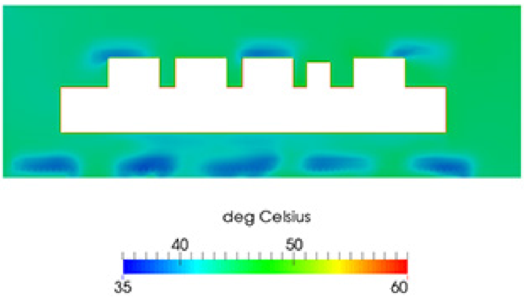

Fig. 6 Ground plan - Temperature in the height of 6.0 m over the floor, temperature varies between 26–35 °C, shape temperature 60 °C

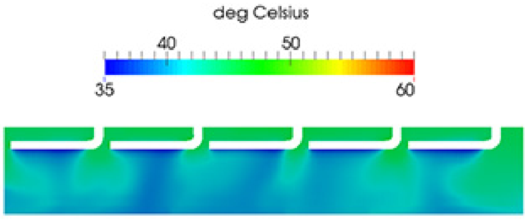

Fig. 7 Longitudinal section- temperature varies between 26–45 °C, shape temperature 60 °C

6 Conclusion

The results of CFD present the efficiency and functionality of the proposal. Based on this proposal, results combination of adiabatic cooling and labyrinth ventilators are installed. Testing period in real conditions confirmed the results obtained in CFD. Testing period was realized in the beginning of July 2018, when hot days are starting and maximum daily temperature might be up to 33-38 °C. All the data are measured using installed TESTO 175H1 dataloggers, where relative humidity (in %) and dry bulb temperature (in °C) is measured. Results are presented in the attached table and diagram obtained 16-th of July 2018.

It's necessary to assume, that adiabatic cooling is not accurate cooling and it strongly depends on outside conditions. If there is higher outside humidity, it will also be increased in the interior. CFD simulation has also proven that proper location of ventilation system is crucial for the efficiency and functionality. Aeration ventilation should be calculated for summer outdoor temperature (t_{ODA} = 25 °C) and winter conditions (t_{ODA} = 0 °C). Based on our experiences, we also recommend to calculate for supposed thermal range, especially for summer extreme, which might be critical.

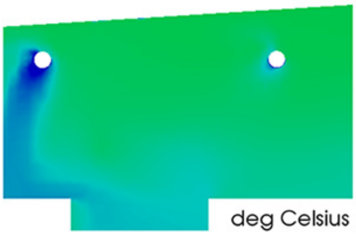

Fig. 8 Cross section- temperature varies between 26–45 °C, shape temperature 60 °C

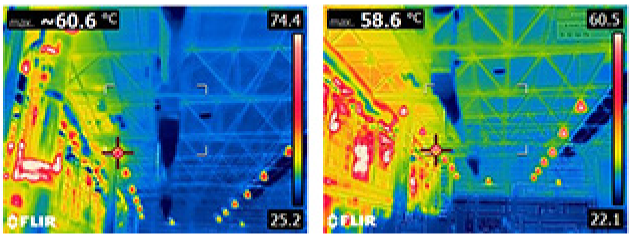

Fig. 9 Thermovision slide of the production line, shape temperature up to 60 °C

We also recommend to calculate the air inlet very carefully and the positions of inlet louvres. This might be the case where installed technology does not allow direct air inlet of the air, and a powered air inlet is recommended. There were very limited possibilities to install natural air inlet in presented project. We decided to combine adiabatic cooling, which significantly decrease air inlet temperature and at the same time thermal gradient and driving force of aeration are increased. According to the attached drawings, there is cold air immediately preheated. The special textile diffusers used in this project keep the inlet air blowing toward the floor.

As it was discussed above, there are some limits because of significant heat loads on the back of the production line and very complicated shape. Better air distribution would be achieved using perforated steel ducts, but this was not possible to install. Adiabatic cooling increases the thermal gradient, which reduced the volume of inlet air. But at the same time adiabatic cooling increases the relative humidity of the inlet air up to 90–95 % depending on efficiency of adiabatic cooler. Humidity inside the building is usually considered to be a limit value (70 %). This is also a limit value for working environmental conditions according to the valid standards [13, 16]. Depending on the character of the production this limit might also be lower.

It is necessary to assume, that adiabatic cooling is not accurate cooling and it strongly depends on outside conditions, as it was mentioned previously. In the presented study a dew point also plays a critical role, because of possible condensation of water vapors on steel construction of the hall. That is why we use combined sensors for temperature, humidity and calculated in real time dew point. All the data are acquired online and send to central computer (PLC). According to EN ISO 7730:2006 [10] not possible to have 100 % satisfied people, but if there is up to 10 % of unsatisfied people, it might be considered to be a successful installation. Testing period is used to reveal some weak points and adjust the technology.

Why is the CFD an efficient tool for designers of HVAC applications? CFD simulation allows us much more detailed dive into the problem. To calculate aeration, a designer can use known formulas, but does not guarantee the functionality of proposed solution. It only calculates the air volume which is necessary to remove calculated heat load. By using CFD we can see the thermal gradient. It allows the designer to find the best installation position of the vents or stagnant regions.

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