A study of Variable Air Volume (VAV) systems in foundries

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SUMMARY

The focus on implementing cost efficiency energy efficiency measures will in all probability increase in the future, but it has been shown that trustworthy, site specific information are key features is increasing the adoption of such measures.

This study shows that Building Energy Simulation (BES) software gives trustworthy predictions of energy use and average temperature in the studied case, making it possible to study different HVAC control strategies. When coupled with CFD, it is also possible to study thermal comfort, ventilation efficiency, ventilation effectiveness and draught, giving an even wider range of decision support.

This study also shows that a VAV system is an interesting HVAC control technique for the studied foundry. In this case, the technical potential for reducing energy use in terms of both heat and electricity is predicted to be 30.3% and 28.9% respectively.

INTRODUCTION

An increasing focus on environmental issues, energy prices and competition will in all probability make the implementation of cost efficient energy efficiency measures within the energy intensive foundry industry even more necessary, especially for a country like Sweden, where industry has historically enjoyed one of the lowest energy prices in Europe [1]. The Swedish foundry industry accounts for about 2% (300,000 tons) of the entire European casting production. This makes it a relative large casting producing country per capita, with some 7,000 people employed in the industry.[2] Total energy use by Swedish foundries is about 1 TWh. [2] Support processes such as heating, ventilation and air conditioning (HVAC) within industrial premises are an important issue, as they are related to both energy cost and indoor climate management as well as to the health of the occupants. HVAC in industrial premises account for nearly 30% of the total industrial energy use in Sweden. Furthermore, it has been shown that energy efficiency measures are more easily adopted if they are related to support processes, i.e. HVAC, lighting and compressed air, and not to the production process, as the largest technical barriers to energy efficiency are often related to the production process. This has been studied by Rohdin et al in [3-4]. This stresses the need for accurate and trustworthy information as they are key features in increasing the adoption of energy efficiency measures. One way to obtain this type of information is to use validated simulation methods.

The aim of this paper is to study energy use and thermal climate in a large Swedish light alloy foundry by means of energy simulation, CFD and measurements. The technical potential for using Variable Air Volume (VAV) systems is investigated using these methods.

The energy simulation software IDA ICE [5, 6] was used to perform the numerical energy simulation and the CFD software Fluent 6.2 [8] to perform the numerical flow simulations.

OBJECT DESCRIPTION

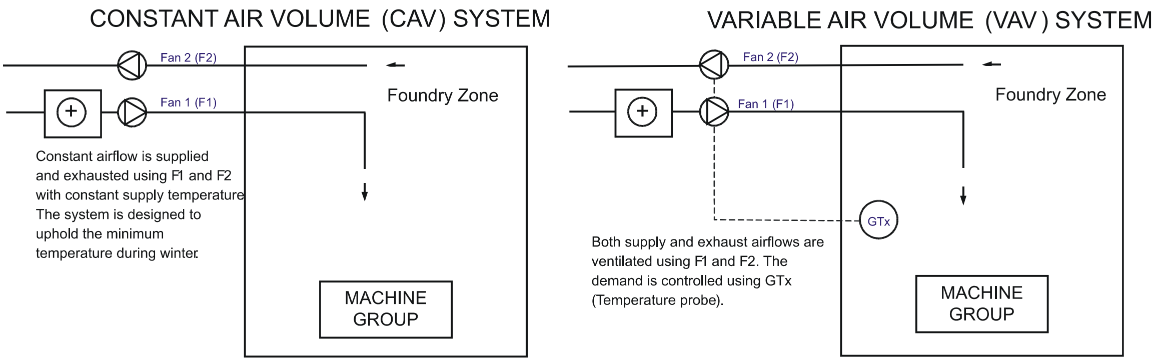
Energy use at a light allow casting facility

The relative proportions in the different processes are in line with the ”average” non-iron or steel foundry where melting and holding is estimated to be 40%, molding about 20% and support processes about 40%. [2] The light alloy casting facility presented in this paper has 44% melting/holding, 19% molding and about 37% support processes, see Table 1.

Table 1. Presentation of energy use, energy split on different processes and basic data for the foundry.

Description	Data
Total floor Area	2 744 m2
Ceiling height	12 m
U-value walls	~2 W/m^{2}K
U-value floor	0.3 W/m^{2}K
U-value roof	~0.6 W/m^{2}K
Airflow	45.5 m^3/s
Q_{trans}	~6 600 W/K
Q_{vent}	55 200 W/K
Total Energy use	17 200 MWh/year
Energy use/m^2	3 865 kWh/m^2
Production	~2 100 000 kg/year

Process	Energy use [MWh]	%
Melting, holding	7 700	44
Casting etc.	3 200	19
Cooling (product)	650	4
	11 550	67
Ventilation	900	5
Space heating	4 500	26
Lighting	250	2
Compressed air	Not allocated	
	5 650	33



Constant airflow is supplied and exhausted using F1 and F2 with constant supply temperature The system is designed to uphold the minimum temperature during winter.

Both supply and exhaust airflows are ventilated using F1 and F2. The demand is controlled using GTx (Temperature probe).

Figure 1. Schematic description of the CAV used today and the purposed VAV system.

THE MODELS

Geometry

The casting facility is 28 m wide and 98 m long, giving an area of 2 744 m^2, see Figure 2. The ceiling height is 12 m. In the facility, there are 16 machine groups (M in the figure) with their associated furnaces (F), and two melting furnaces (MF). Two types of metal are processed in the facility: aluminum and magnesium. Machine groups M1, M2, M4, M12, and M14 process aluminum and the rest magnesium. Air is supplied through 20 displacement supply devices (SD) along the long walls. The exhaust air is evacuated by local exhaust systems located over the machine groups and melting furnaces. All walls are interior walls as the foundry is surrounded by assembly, storage, and other facilities.

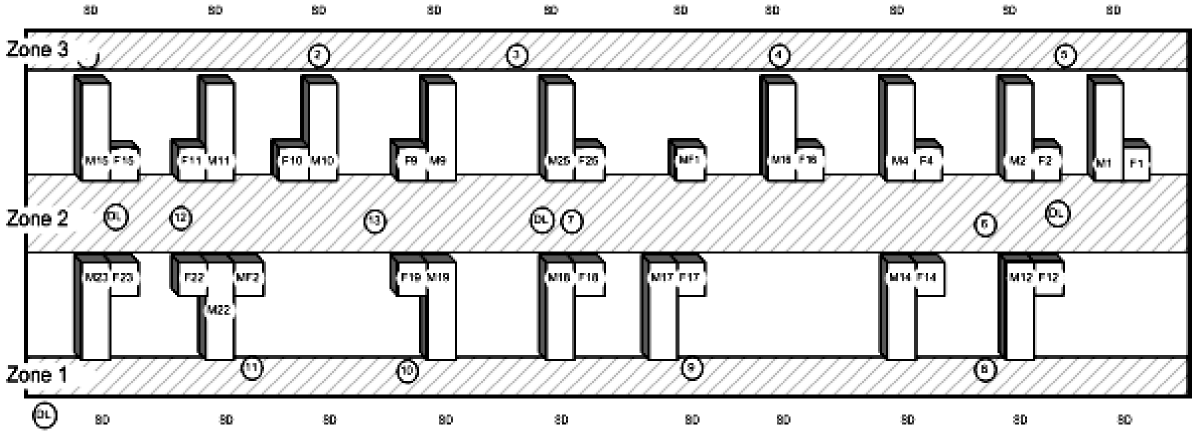


Figure 2. Machine plan of the casting facility.

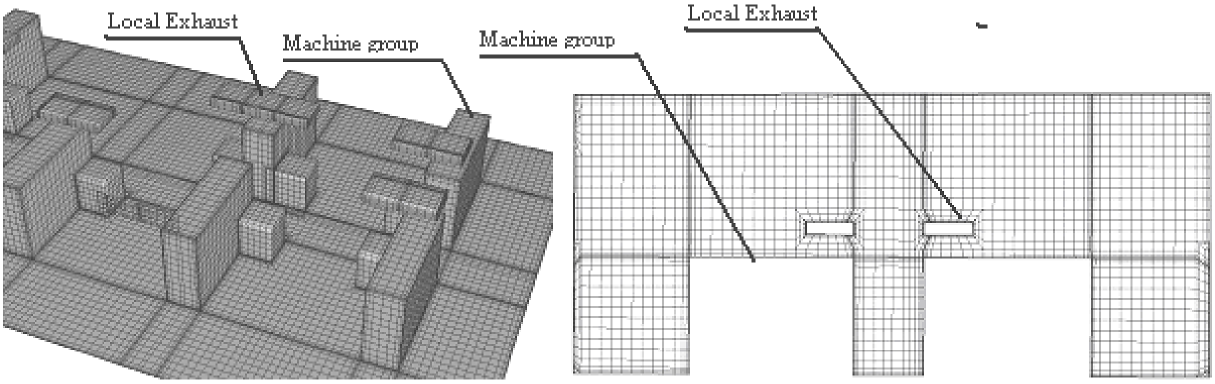


Figure 3. Part of the mesh shown for part of the facility and in section.

CFD Model

Icepack [7] was used to generate the 3-D structured grid shown in Figure 3. The mesh is non-conformal at the interface between wall and coarse region of the model. Fluent 6.2 [8] was used to numerically simulate the thermal climate in the casting facility. The governing equations were solved with a segregated scheme and discretized spatially with a second order upwind scheme. The near-wall treatment used in this model was the standard wall function. The first numerical point was always located at y+>8. The wall boundaries were modeled using the no-slip condition with constant wall temperature. The supply air was modeled as a mass flow inlet with a constant flow rate, and the outlets were modeled using mass flow and pressure outlets. For a more extensive description of the CFD model, where turbulence models and meshing are explained in detail and the model is compared with measurements, see [8]. The Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) are found in ISO 7730 [9], and were implemented in FLUENT by means of a user defined interface (UDF). The calculation of mean age of air was also implemented using a UDF. The Draught Rating (DR) and ventilation efficiency and ventilation effectiveness has been implemented using custom field functions.

Building Energy Simulation Model

IDA ICE 3.0 was used to numerically simulate the energy use aspects of the foundry's construction and HVAC systems. Measured power for the different machine groups and other gains was used as input. The CAV HVAC system, illustrated in Figure 4, was modeled using measured values for supply air temperature, air flows and outdoor temperature. The model was then compared with measured values of the indoor air temperature measurements. The comparison is seen in Figure. 4. A study of time-step independence was made and a maximum of 5 minutes was chosen.

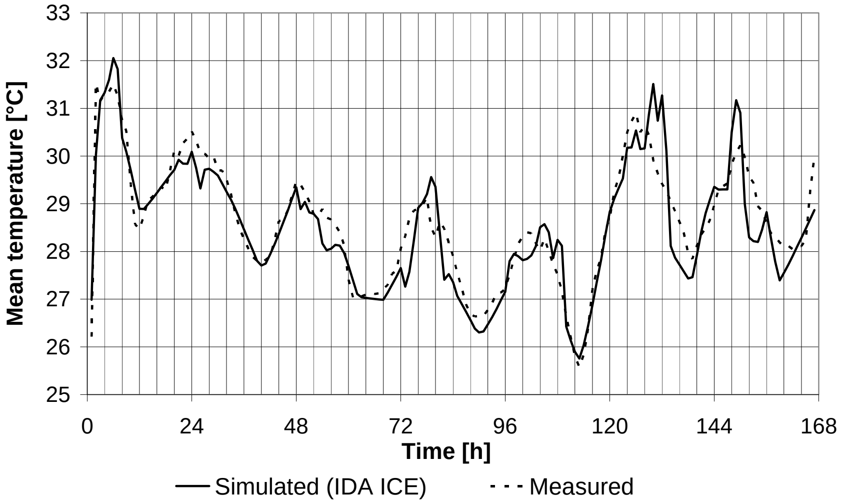


Figure 4. Simulated and measured average temperatures for the entire volume in the facility.

It's important to note that the mean temperature in the occupied zone is lower than the mean temperature as the temperature stratification in this facility is rather high.

VAV VS. CAV IN A FOUNDRY

Two different HVAC control strategies are compared, a CAV system and a VAV system, described in Figure 1. To compare these, both the energy use of the different strategies and their impact on comfort and ventilation effectiveness are studied. Two different methods are used: BES to study energy and power use and a CFD model to study indoor air related parameters.

Energy use aspects

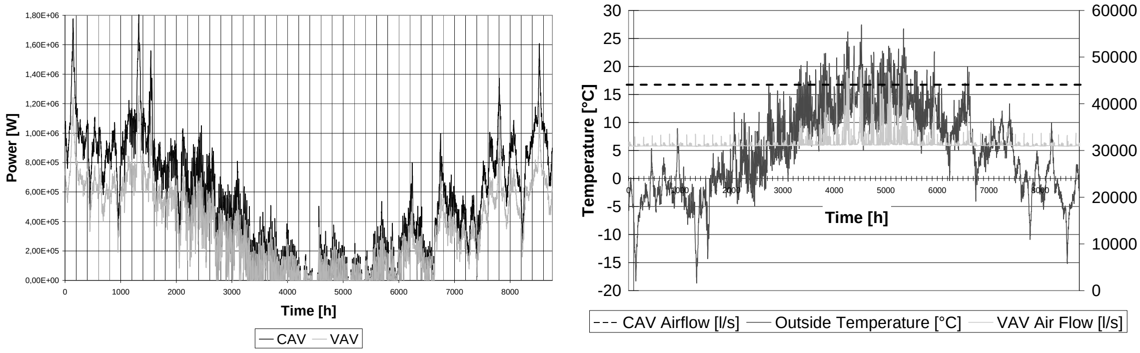


Figure 5. Power used by the heater for the CAV and VAV case (left). Airflows CAV and VAV case.

The mean power for the CAV case is 507 kW and for the VAV case 354 kW. The maximum power for the CAV case is 1.8 MW and 1.25 MW for the VAV case, indicating a decrease in maximum power of 31% from the present case. The energy used for heating the supply air decreases from 4.45 GWh (CAV) to 3.10 GWh (VAV). In addition, the power used by fans is predicted to decrease from 874 MWh to 621 MWh.

Ventilation and thermal comfort aspects

Two different cases have been identified from the energy simulations for further study:
Outside temperature below 14°C, when the supply temperature is 16°C. The VAV system delivers 31 m^3/s.
Outside temperature is 21°C, and the supply temperature 23°C. The VAV system delivers up to full flow of 45.5 m^3/s

To predict changes in comfort for the different cases, both PPD, PMV, and DR [9], were calculated and are shown in Figures 6-9. To predict changes in the function of the ventilation, both ventilation efficiency and ventilation effectiveness were calculated. The Air Exchange efficiency is defined as:

$$\eta_a = \frac{\tau_n}{2 \cdot \tau_i}, \qquad (1)$$

where t_n is the nominal time constant and t_i the average time a particle resides in the facility. The ventilation's effectiveness for heat distribution or heat removal (ε_t) is a measure of how effective the ventilation system is in removing the heat produced internally in the occupied zone and is defined as:

$$\varepsilon_t = \frac{T_o - T_i}{T_{local} - T_i}, \qquad (2)$$

where T_i and T_o are the supply and exhaust air temperatures respectively and, T_{local}, represents the local temperature in the occupied zone. The ventilation effectiveness is presented in Figures 10-12.

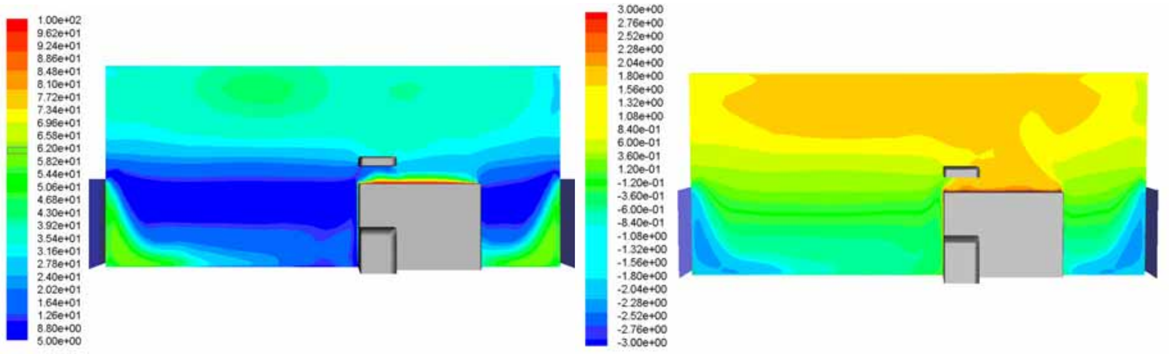


Figure 6. PPD and PMV 16 °C CAV with 45.5 m^3/s airflow.

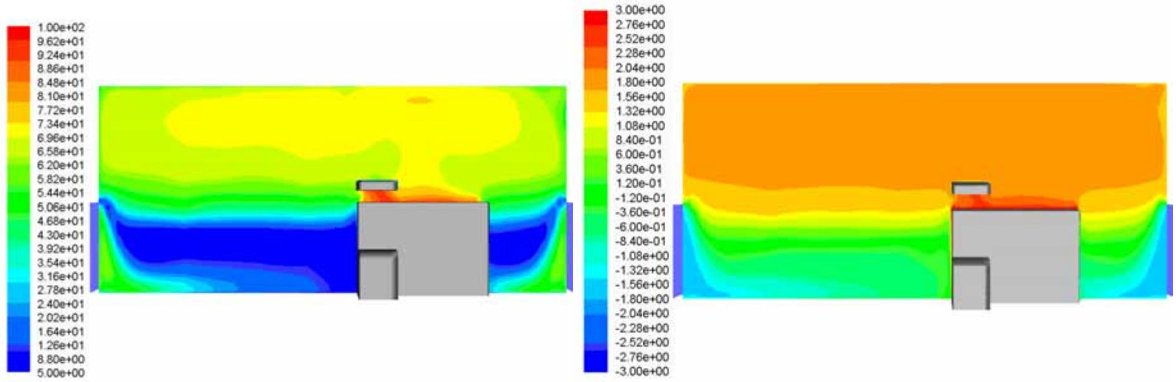


Figure 7. PPD and PMV 16 °C VAV with 31,0 m^3/s airflow.

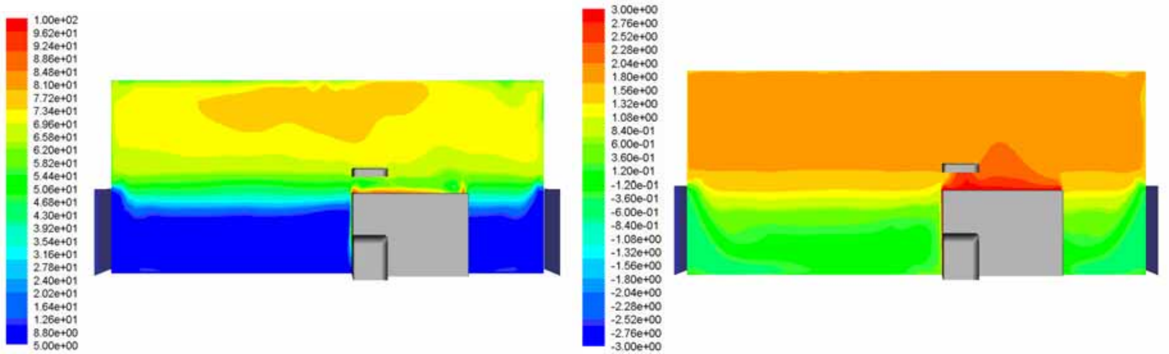


Figure 8. PPD and PMV 23 °C CAV with 45.5 m^3/s airflow.

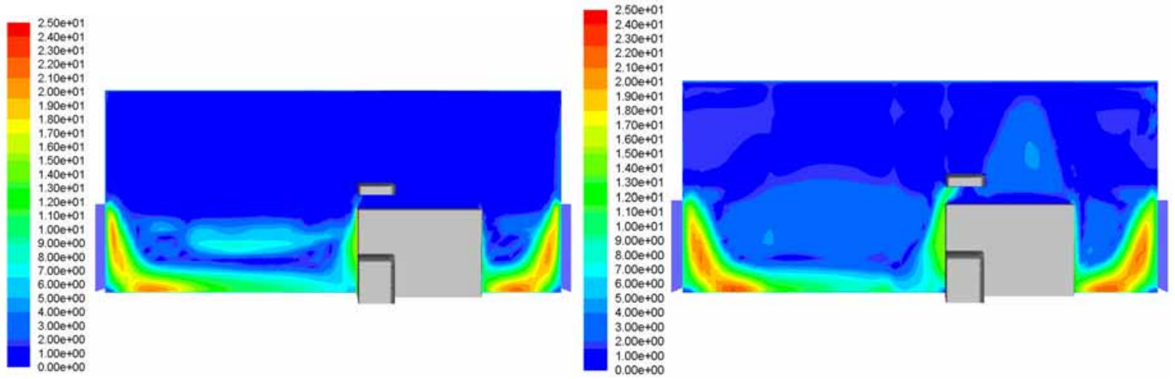


Figure 9. DR (Left) 16°C CAV, (Right) 16°C VAV. The draught decreases slightly when decreasing the flows.

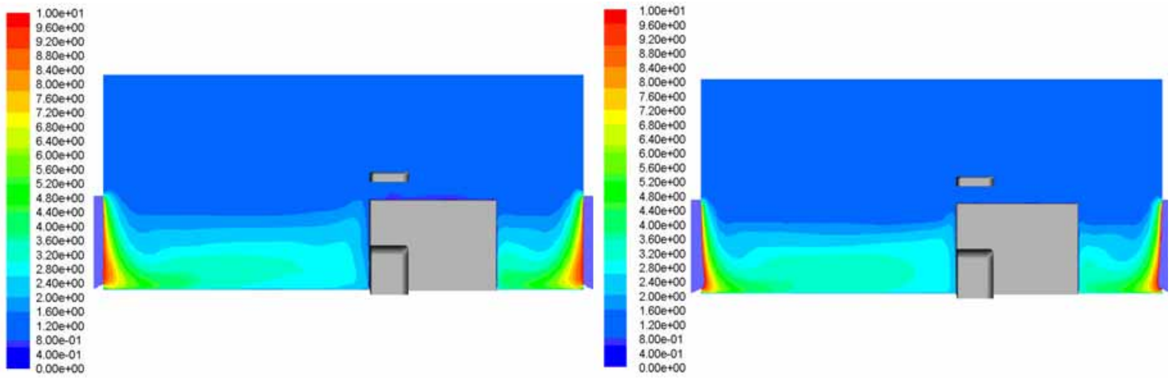


Figure 10-12. ε_t (left) CAV 16 °C (right) VAV 16°C.

For the full flow winter case the air exchange efficiency is 70%, for the 31 m^3/s winter case 76%, and for the full flow summer case 60%. The lower efficiency for the summer case reflects the lower stratification, as the difference between supply air temperature and ambient air temperature is smaller.

The PPD index decreases slightly in the occupied zone when the air flows are lowered when the supply temperature is 16°C. The PMV index indicates that the air is too cold and the air velocity too high. For the summer case when the supply temperature is 23°C the PPD index decreases drastically, indicating a positive thermal sensation. The DR-index indicates that the draught in the supply region in the occupied zone decreases slightly when flows are decreased.

The ventilation's effectiveness for heat distribution or heat removal decreases slightly, see Figures 10 and 11, when the airflow is reduced. The ventilation effectiveness for the summer case is substantially lower due to a smaller difference between mean air temperature and supply temperature, indicating better functioning ventilation in terms of ventilation effectiveness during winter.

CONCLUDING DISCUSSION

The management of an industrial company requires decisions related to the management of production, maintenance, facilities, energy and labor issues, etc. This management is strongly related to the investment decision the organization has to make in order to achieve and maintain profitability, which is the overall goal of any company. The ability to make the 'correct' decision in relation to the overall goal is what separates a successful business from a failure.

This study shows that Building Energy Simulation software such as IDA ICE gives trustworthy predictions of energy use and average temperature in the studied foundry, making it possible to study different HVAC control strategies. When coupled with CFD, it is also possible to study thermal comfort, ventilation efficiency, ventilation effectiveness, and draught, providing an even wider range of decision support. The use of these simulation methods thus gives trustworthy and site specific information which can be used as effective decision support. The importance of site specific and trustworthy information is stressed by, for example, Stern and Aronsson (1984). [11]

This study also shows that a VAV system is an interesting HVAC control technique for the foundry industry. In this case the technical potential for reducing energy use in terms of both heat and electricity is predicted to be about 30% (heat 30.3% and electricity 28.9%). It is also shown that neither the thermal comfort nor the ventilation efficiency is predicted to be negatively affected. The thermal comfort is even predicted to increase. An additional positive effect of the VAV system is the reduced power usage during the cold season, when the demand for district heating and electricity is highest, which in some cases can reduce power related costs even further, since the maximum power demand is reduced.

ACKNOWLEDGEMENT

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REFERENCES

1. EEPO, Year 2002 Results. European Electricity Prices Observatory (EEPO). Brussels, Belgium: 2003.
2. Svensson I, Casting Handbook (Gjuteriteknisk Handbok), NRS Tryckeri AB, Huskvarna, Gjuteriföreningen, 2004.
3. P. Rohdin, P. Thollander, Barriers to and Driving Forces for Energy Efficiency in the Non-energy Intensive Manufacturing Industry in Sweden, Energy 31 (2006) 1500-108.
4. P. Rohdin, P. Thollander P Solding, Barriers to and drivers for energy efficiency in the Swedish foundry industry, Energy policy. Energy Policy 35 (2007) 672-677.
5. IDA ICE 3.0, IDA Indoor Climate and Energy 3.0 Reference manual, January 2002.
6. Bring, P. Sahlin and M. Vuolle, Models for Building Indoor Climate and Energy Simulations, Report of IEA Task 22, 1999.
7. IcePak 4.1, IcePak Reference Manuals, Fluent Inc, December 2003.FLUENT
8. Fluent 6.2, Fluent Reference Manuals, Fluent Inc, December 2001
9. P. Rohdin, B. Moshfegh, Numerical predictions of indoor climate in a light alloy casting facility, Proceedings of the 13th International Heat Transfer Conference, 2006
10. ISO 7730, Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local comfort criteria, 2005.
11. Stern, P.C., Aronsson, E. (Eds), 1984. Energy Use: The Human Dimension, New York.