INSTATIONARY OPERATION OF A VENTILATION SYSTEM

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ABSTRACT

Ensuring the thermal comfort and improving the ventilation effectiveness are important goals designing ventilation systems. This study describes effects if the ventilation system of a room is run in an instationary operation mode. That means that the inflow velocities are varied in time. The influence of different periodic times of the variation of the inflow velocities is investigated numerically with CFD simulations. The CFD simulation setup is validated by comparing CFD results with experimental data (Aachen Model Room). This comparison shows very similar results for experimental and numerical data. The CFD results show a strong reduction of the occurring time-averaged velocities inside the Aachen Model Room and they show a destruction of large-scale structure like eddies if the ventilation system is run instationary. By varying the periodic time it can be shown that longer periodic times reduce the velocities stronger than shorter periodic times.

KEYWORDS

Room airflows, CFD, instationary boundary conditions

1 INTRODUCTION

Thermal comfort and the ventilation effectiveness are important criteria for the construction of modern building ventilation supply systems. Both criteria depend mainly on air flow structures. Large scale and stable flow structures can influence the thermal comfort and ventilation effectiveness negatively. A well-designed ventilation system concerning ventilation effectiveness reduces the energy consumption of the building.

The instationary operation of a ventilation system avoids large scale flow structures. In this study the influence of the periodic time of the variation of the inlet velocity on the air flow structure is investigated numerically by Computational Fluid Dynamics (CFD). The CFD results are validated with experimental data from the Aachen Model Room.

2 VENTILATION SETUP

The investigated ventilation system is a mixing ventilation system typically occurring e.g. in meeting rooms, train and aircraft cabins. The ventilation setup for this study has been described in different studies before (Kandzia, 2011), (Kandzia, 2013). To simplify the numerical setup the CFD simulations are conducted only isothermal to investigate the effect of the periodic time T during the instationary operation. Hence, effects occurring with higher internal heat loads as describe by Linke (Linke, 1962) are not considered in this paper. In this section the Aachen Model Room is described in detail and the experimental and numerical setup is explained.

2.1 Geometry and boundary conditions

The geometry of the Aachen model room is a simple cuboid with a length of 5 m, a width of 4 m and a height of 3 m (Figure 1). The supply air inlets are placed underneath the ceiling along the two long walls and they are built as slot diffusers with a height of 20 mm. To allow different inlet conditions along the whole length of the room, each slot diffuser is 1 m wide. Hence, 5 slot diffusers are place at each wall. With the aid of these inlet diffusers a plane wall jet enters the room. The exhaust air leaves the room above the floor. To investigate the influence of the periodic time during instationary operation three different cases are considered: The first case is the reference case. That means that the airflow rate at each diffuser is constant and the inlet velocity is 1.5 m/s. The second case is the “2D sine” case. The air flow fluctuates in form of a sine wave. The inlet velocities are calculated as:

$$v_{\mathrm{inflow1}} = 1.5\ \mathrm{m/s} + 0.5\ \mathrm{m/s} \cdot \sin(\omega t) \qquad (1)$$

$$v_{\mathrm{inflow2}} = 1.5\ \mathrm{m/s} + 0.5\ \mathrm{m/s} \cdot \sin(\omega t + \pi) \qquad (2)$$

with

$$\omega = (2\pi / T) \qquad (3)$$

The corresponding inflow velocities are shown in Figure 1. For the “2D sine” case the slot diffusers at one wall supply the air with v_{inflow1} and at the opposite wall the air is supplied with v_{inflow2}. The two different inflow velocities have a phase shift of π which means that the total air flow rate of the room does not change in time. The third case is the “3D sine” which means that for each diffuser the inflow velocity fluctuates as in case “2D sine” but the opposite and the neighboring diffuser have a phase shift of π. The different inflow boundary conditions are also shown in Figure 1. To classify the investigated periodic times the periodic time is defined as a factor times the nominal time constant τ_{n} of the room.

$$T = a \cdot \tau_{\mathrm{n}} \qquad (4)$$

with

$$\tau_{\mathrm{n}} = \frac{V_{\mathrm{room}}}{V_{\mathrm{room}}} \qquad (5)$$

Four cuboids are placed inside the cabin. These cuboids serves as heat sources for non-isothermal experiments but the heat sources are switched off for this study. The walls of the room are very well isolated and an adiabatic boundary condition can be assumed.

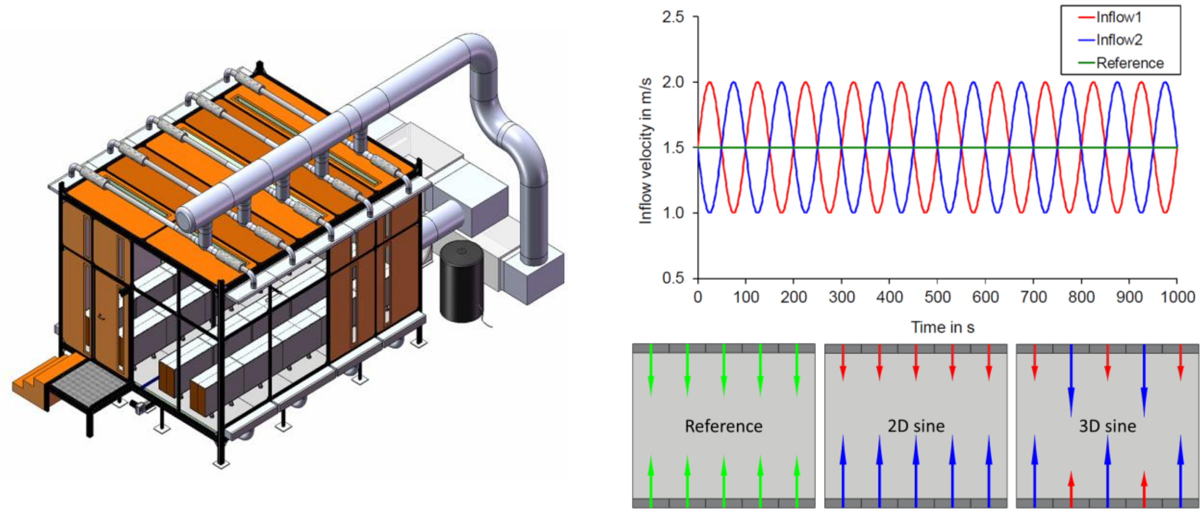


Figure 1: Experimental setup of the Aachen Model Room (left) and different conditions of the supply air (right)

2.2 Numerical Setup

Figure 2 shows the mesh for the CFD simulation. It consists of about 10 million hexahedral cells. The Simulations has been conducted with the commercial Software Ansys® CFX. The k-ω Baseline Model by Menter (Menter, 1994) is applied as turbulence model. The Walls are adiabatic and the inlets are modelled with an uniform velocity distribution. The simulations are run in transient mode with a time step of 0.25 s and a total simulation time of 1000 s according to the experiments.

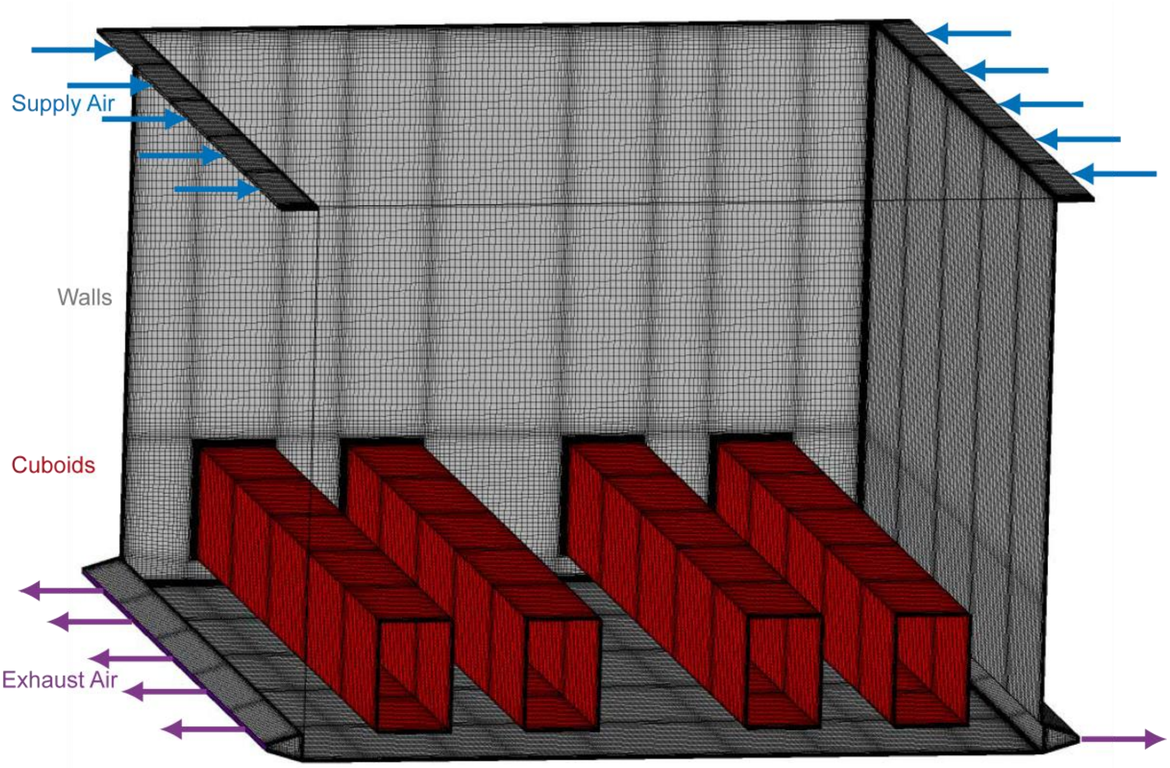


Figure 2: Mesh and boundary conditions for the CFD simulations

2.3 Validation

The numerical setup can be validated with experimental data obtained from measurements at the Aachen Model Room test bench. Inside the test bench, a traverse system with 12 omni-directional velocity probes and resistance thermometer is installed. With the aid of this traverse system the flow field inside the room can be measured in detail. In Figure 3 the comparison between experimental data and numerical data is done with the aid of time averaged velocities. The measurement points are in three different heights in a plane in the middle of the room. The plane is the same plane where the CFD results in Figure 4 and Figure 5 are presented. The Figure 3 shows well the airflow structure inside the Aachen Model Room for the reference case. The plane jets are colliding in the middle of the room and they are deflected downwards. The velocity peak in the middle is well visible. On both sides of this downward jet two large and stable eddies are established. In the lower height the velocity distribution is quite constant along the whole room width.

In the first height of 2.50 m (Figure 3a) the experimental and CFD data fit very well. This is also valid for the lowest height of 1.10 m (Figure 3c). At the height of 1.70 m (Figure 3b) some differences between CFD and experiment are visible. The minimum on both sides of the downward jet is much stronger in CFD than it is in the experiment. In CFD the center of the two large eddies is exactly at 1.70 m height while it is a little bit lower in reality. That means that the location of eddy centers cannot be predicted perfectly in CFD with two-equation turbulence models but the difference of the location is small. Based on this comparison the numerical setup is suitable for the following variation of the periodic time constant.

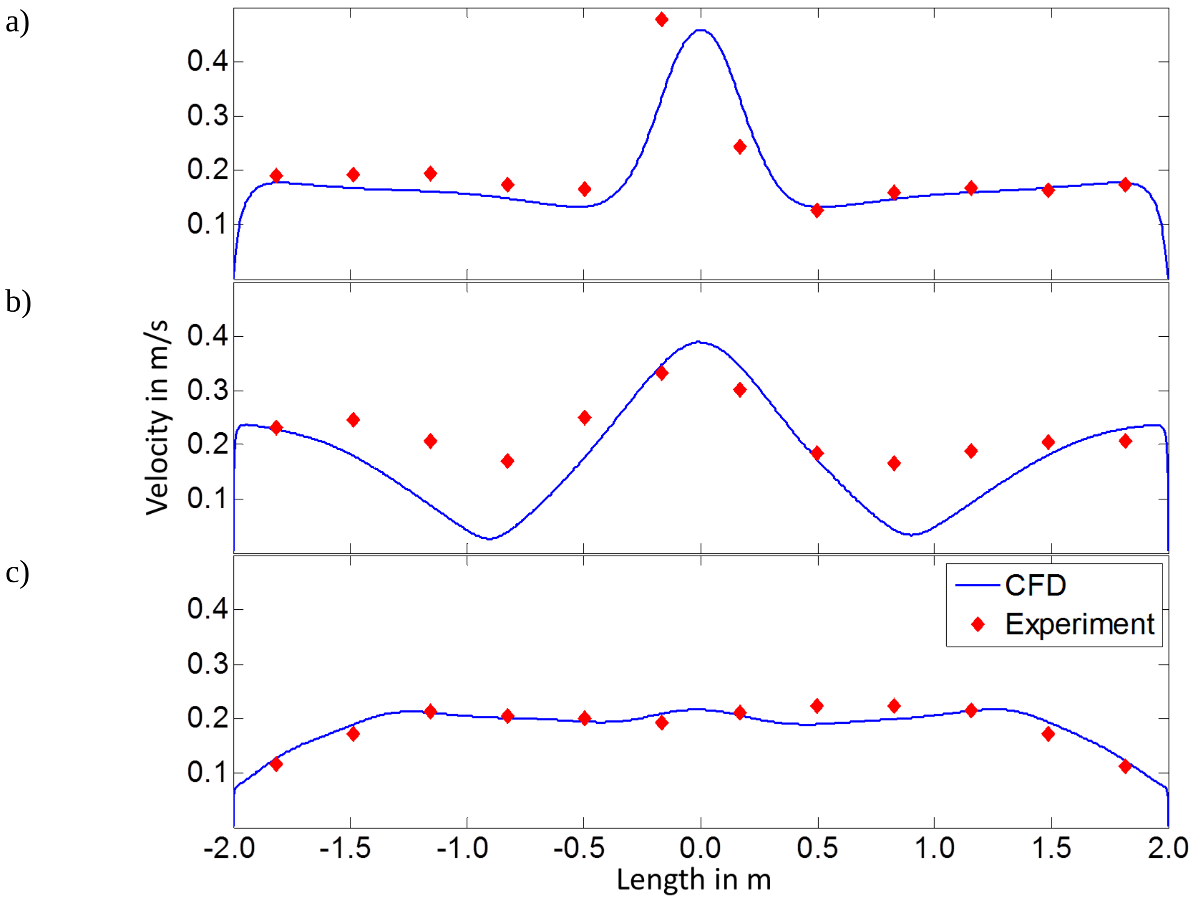


Figure 3: Comparison of the CFD simulation result and experimental data in three different heights: a) 2.50 m, b) 1.70 m, c) 1.10 m

3 RESULTS

The results of the CFD for the reference case is shown in Figure 4 as a contour plot of the time averaged velocity in the middle of the room. The air flow structure described in section 2.3 is well visible. The structure is very symmetric and the occurring velocities in the colliding jet are higher than 0.5 m/s. Two large and stable eddies exist on both sides of the colliding jet. The velocities at the edge of the eddies are still pretty high with values between 0.20 m/s and 0.25 m/s.

Figure 5 shows the results in the same plane with the same contour plot as in Figure 4. The results for the “2D sine” case are listed on the left side and the results of the “3D case” on the right side. In the first row the periodic time is a eighth of the nominal time constant, on the second row a quarter of the nominal time constant, on the third row the half of the time constant, on the fourth equal to the nominal time constant and in the last row 2.5 times the time constant.

For a short periodic time $T = 0.125 \cdot \tau_n$ and the “2D case” the velocities in the colliding jet are lower than in the reference case but the region of the colliding downward jet is wider than in the reference case. The large eddies still exist on the left and right side. For the “3D case” with the same nominal time constant the colliding jet region is only marginally visible and the large eddies disappear as well. The level of the velocities is clearly lower than in the reference case.

Doubling the periodic time $T = 0.25 \cdot \tau_n$ results in weaker but still visible colliding jet for the “2D case” while the results for the “3D case” are almost the same as for the smaller periodic time. With a periodic time $T = 0.5 \cdot \tau_n$ the colliding jet area disappears also in the “2D case” but the eddies are still visible but much weaker.With higher periodic times $T = \tau_n$ and $T = 2.5 \cdot \tau_n$ the results of the “2D case” and the “3D case are similar. The colliding jet area disappears as well as the large structures on both sides and the velocity level is clearly lower than in the reference case.

The instationary operation of a ventilation system reduces the occurring velocities and it destroys large and stable structures like eddies. The reason for this is the better mixing by increasing the velocity gradients between the jets and the surrounding air in the “2D case” and by introducing an additional velocity gradient between the neighboring jets in the “3D case”. These effects can be found as well in experimental data published by Kandzia (Kandzia, 2011).The influence of the periodic time T can be also seen in Figure 5. The effect of the instationary operation increases with a longer periodic time T while the air flow structure in the “2D case” with the short periodic time $T = 0.125 \cdot \tau_n$ is still similar to the reference case with time-constant operation mode.

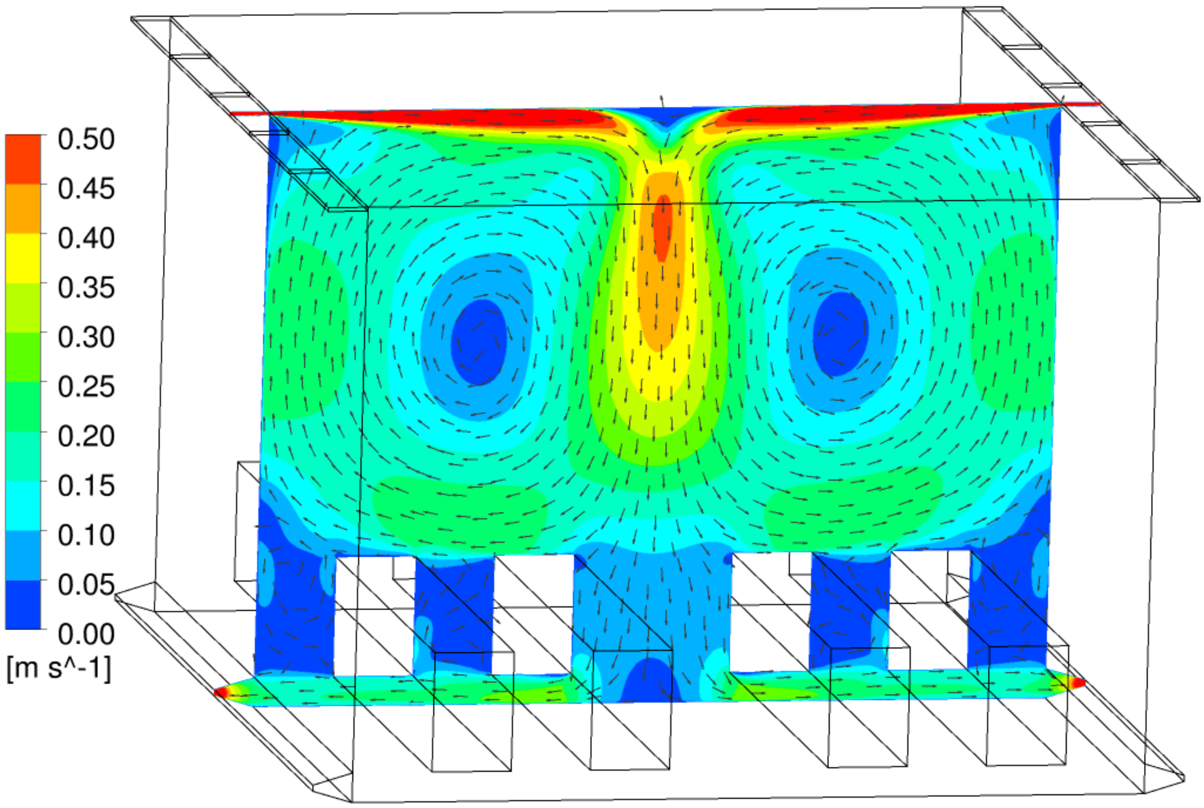
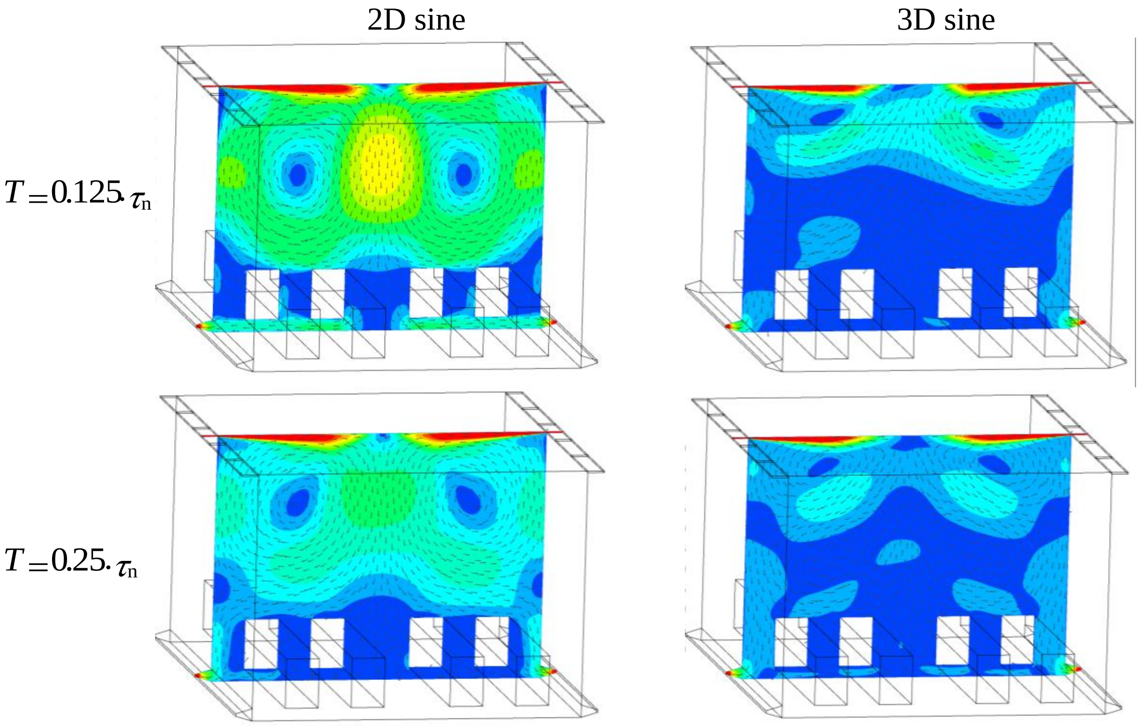


Figure 4: Velocity distribution in the middle of the room for the reference case



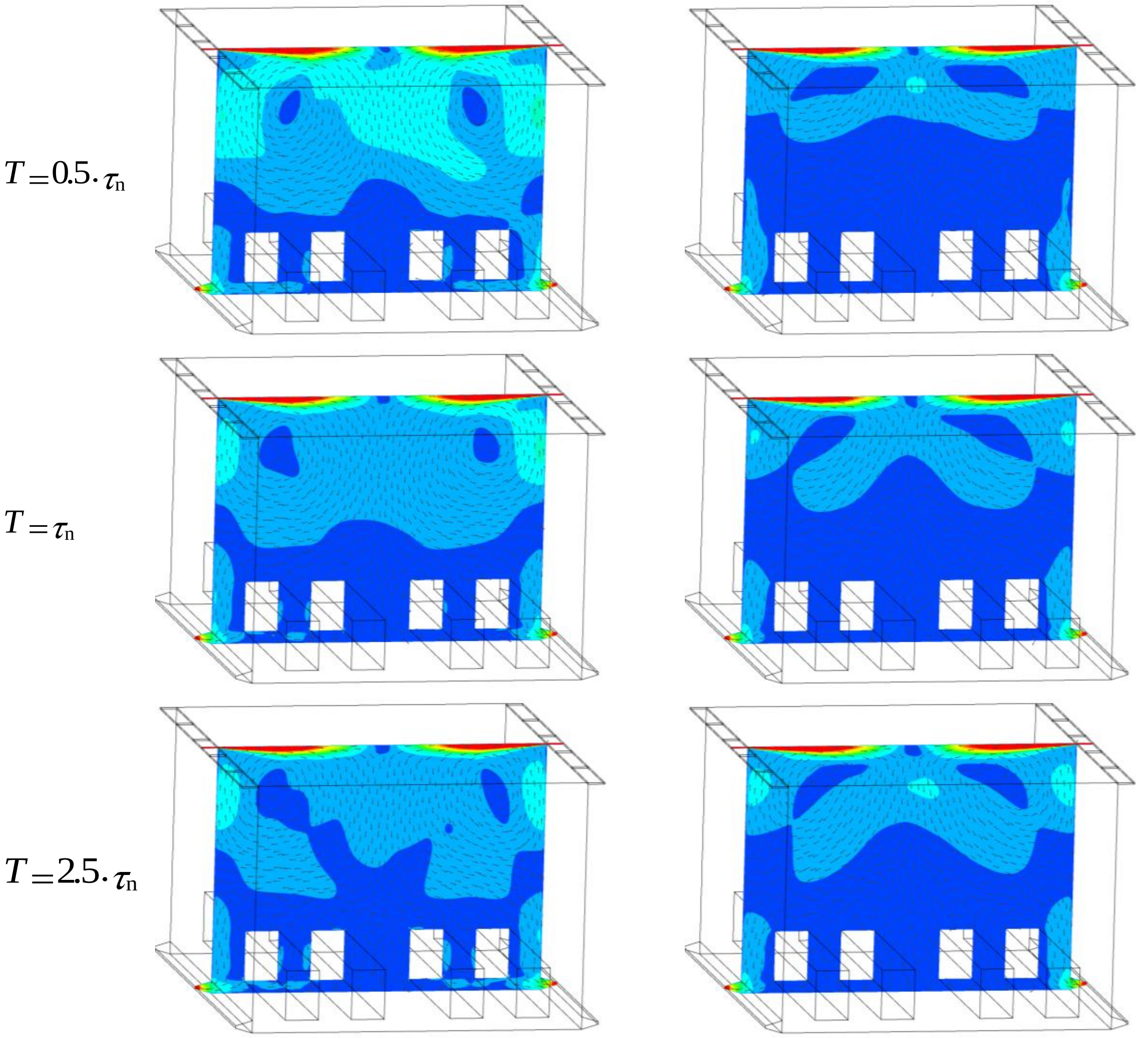


Figure 5: Velocity distribution in the middle of the room for different periodic times

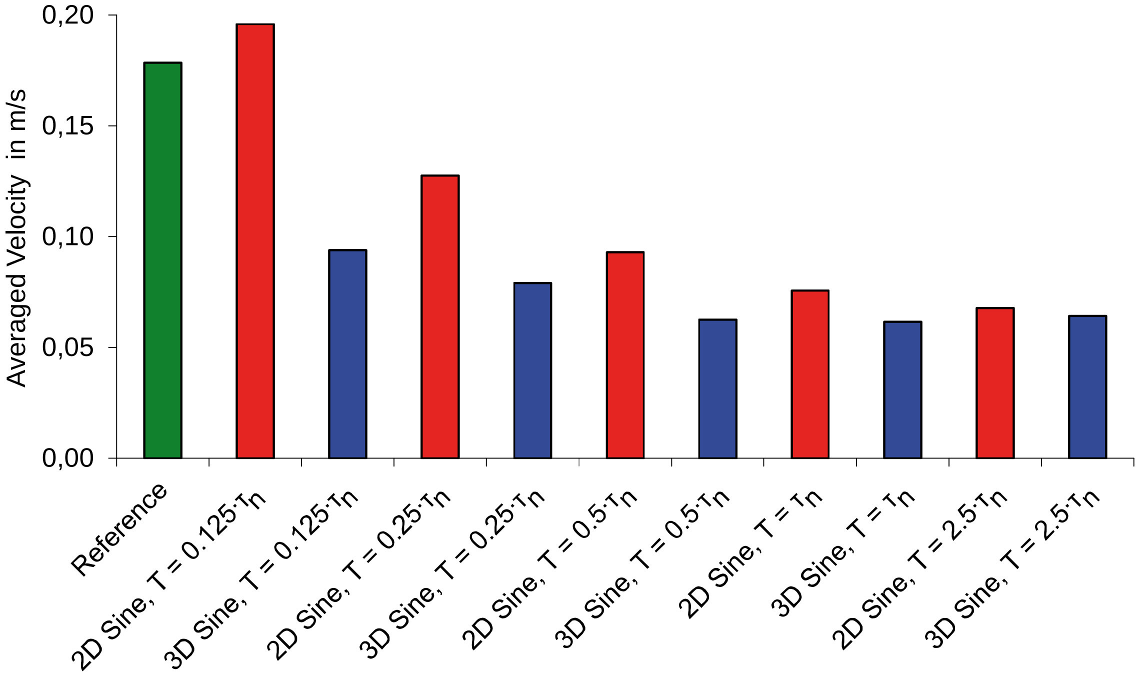


Figure 6: Averaged velocity inside the room

In Figure 6 the time-averaged velocity obtained by CFD simulations is averaged in the whole volume of the room. All eleven cases are listed in the diagram in Figure 6 and the influence of an increasing periodic time T can be seen. The volume-averaged velocity in the reference case is about 0.18 m/s and it increases up to 0.20 m/s for the “2D sine” with $T = 0.125 \cdot \tau_n$. but it decreases down to 0.09 m/s for the “3D sine” case even with the short periodic time of $T = 0.125 \cdot \tau_n$. With increasing periodic times T the volume-averaged velocity is decreasing for the “2D sine” but for the “3D sine” the volume-averaged velocity is almost constant for periodic times longer than $T = 0.5 \cdot \tau_n$.

4 CONCLUSIONS

This study shows results of CFD simulations of the Aachen Model Room with an instationary operation mode of the ventilation system. The results of the simulations confirm the results published by Kandzia (Kandzia, 2011). The occurring velocities in the Aachen Model Room can be reduced by operating the ventilation system in an instationary mode. Beside the velocity reduction large flow structure like eddies can be destroyed by the instationary effects.

The effect of the periodic time T of the operation mode has a strong influence on the results. The instationary effects are stronger with longer periodic times T. The periodic time of the instationary mode should be at least in the same dimension as the nominal time constant τ_n of the room.

The CFD simulations have been conducted only isothermal for this study. The effect of introducing heat sources into the room has to be investigated in further studies. The influence of the instationary operation mode of ventilation systems on the ventilation effectiveness has to be considered in future as well.

5 ACKNOWLEDGEMENTS

Grateful acknowledgement is made for financial support by research association for air and drying technology FLT (promotional reference 622270) and by German Research Foundation DFG (promotional reference AOBJ 579043).

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