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HEAT LOAD ELIMINATION BY USING DISPLACEMENT VENTILATION IN A CLASSROOM

OGRANICZENIE OBCIĄŻENIA CIEPLNEGO W SALI LEKCYJNEJ PRZY ZASTOSOWANIU WENTYLACJI WYPOROWEJ

A b s t r a c t

The target of this contribution is to know if we can use displacement ventilation for the so-called free cooling of a room. What flow rate of air do we need in order to sufficiently reduce the thermal loads in the classroom? We search for the answer to this question by using CFD tools. We only use air from the exterior without any cooling system.

Keywords: *displacement ventilation*, *free cooling*, *CFD*

S t r e s z c z e n i e

Celem pracy jest analiza zastosowania wentylacji wyporowej w tzw. swobodnym chłodzeniu pomieszczenia. Jaka ilość wymian powietrza jest wymagana, aby wystarczająco zmniejszyć obciążenia termiczne w klasie? Szukamy odpowiedzi na to pytanie za pomocą narzędzi CFD. Używamy jedynie powietrza zewnętrznego bez układu chłodzącego.

Słowa kluczowe: *wentylacja wyporowa*, *swobodne chłodzenie*, *CFD*

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1. Introduction

The object of this analysis is the classroom of the Civil engineering faculty in Kosice. This room is situated on the fourth floor in the loft of the building. The heat loads from students and solar radiation cause the indoor temperature to increase greatly during the summer months (for example May or June) of the academic year. The classroom is currently only naturally ventilated (i.e. by opening the windows). This method of ventilation is very inefficient. For this reason we would like to use displacement ventilation in the classroom in order to achieve efficient air exchange. We could also use this method of ventilation to reduce heat load from students and solar radiation.

2. Experiment

The classroom used in our CFD analysis is shown below. It has been modelled using the software package ANSYS/CFX (ANSYS 2012). The base proportions of the room are: length 11.0 m, width 6.0 m and height from 1.9 to 4.5 m. The slope of the roof is 23°. The classroom commonly accommodates 30 students. We can see the placement of the desks in Fig. 1. We compare two variants in our CFD analysis of displacement ventilation. The first is variant A where the rate of air exchange is 6 times per hour (volume flow rate is 1 260 m^3/h (mass flow rate is 0.42 kg/s) across 4 inlets). In variant B we calculate with the rate of air exchange at 20 times per hour (volume flow rate is 4 200 m^3/h (mass flow rate is 1.4 kg/s) across 4 inlets).

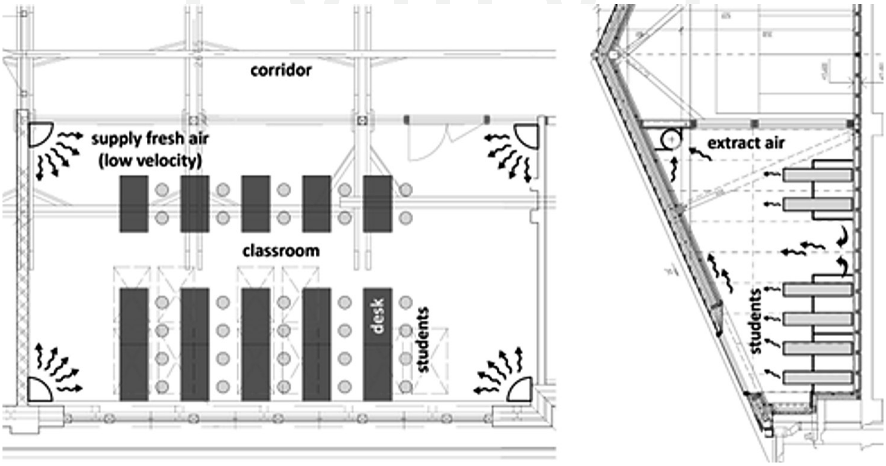

Fig. 1. Scheme of the classroom with displacement ventilation

2.1. Geometrical and physical model

Students sitting in the classroom were approximately modelled as cylinders with a height of 1.4 m and a volume of 75 litres – the volume of the average human body. The boundary and initial conditions of the task are written in the table below (Table 1). For CFD calculation, unstructured tetrahedral mesh was used in the domain (Fig. 2) with non-isothermal flow, heat transfer by convection and radiation S2S, gravitation model and *k*-epsilon turbulence model. The calculation process was ended when the residual target 1E-4 was achieved.

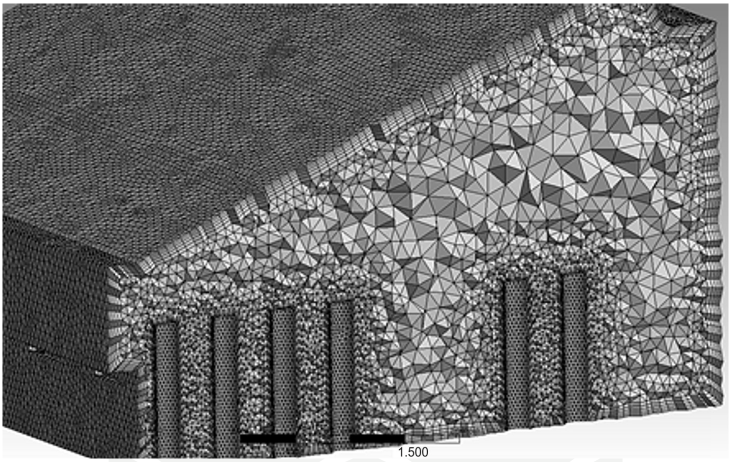

Fig. 2. Tetrahedral mesh

Table 1

Boundary and initial conditions for CFD analysis

External wall	U = 0.29 [W/(m^2·K)], surface emissivity = 0.91	
Roof	U = 0.20 [W/(m^2·K)], surface emissivity = 0.91	
Windows	U = 2.5 [W/(m^2·K)], surface emissivity = 0.15, surface transmissivity = 0.75	
Roof windows	U = 2.0 [W/(m^2·K)], surface emissivity = 0.15, surface transmissivity = 0.75	
	Variant A	Variant B
Exterior	Air temperature = 22 [°C] Air density = 1.197 [kg/m^3]	Air temperature = 22 [°C] Air density = 1.197 [kg/m^3]
Inlets	Number = 4 Total mass flow rate = 0.42 [kg/s] Air temperature = 22 [°C]	Number = 4 Total mass flow rate = 1.4 [kg/s] Air temperature = 22 [°C]
Outlet	Average static pressure	Average static pressure
Students	Number = 30 Heat flux = 60 [W/m^2] Body volume = 75 [litres] Body surface area = 1.8 [m^2] Surface emissivity = 0.93	Number = 30 Heat flux = 60 [W/m^2] Body volume = 75 [litres] Body surface area = 1.8 [m^2] Surface emissivity = 0.93
Solar gain	On the floor plane after transmission of windows = 4 056 [W]	On the floor plane after transmission of windows = 4 056 [W]

In our CFD simulation the body of a student was approximately modelled as a cylinder with heat flux 60 W/m^2.

3. Discussion of the CFD results

The density of the supply air is higher than the air density in the classroom. Why? Because the temperature of the supply air is lower than the air temperaturein the classroom. The supply air falls to the floor from the low velocity inlets (large area) and it is consequently distributed within the room. The mass flow rate in the first variant A is 0.105 kg/s across each inlet. In this case the supply air falls quickly to the floor surface as we can see in Fig. 3. In variant B the supply air also falls to the floor, but more slowly. The mass flow rate of supply air is 0.35 kg/s across each inlet: higher than in variant A. Supply air at 22°C can reach further from the air inlet than in variant A (Fig. 4).

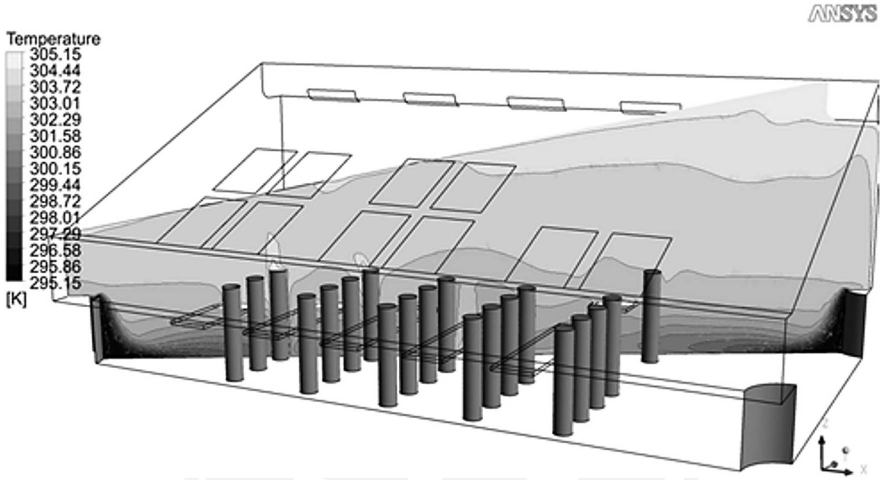

Fig. 3. Reach of supply air at 22 °C in the classroom (rate of air exchange is 6 times per hour)

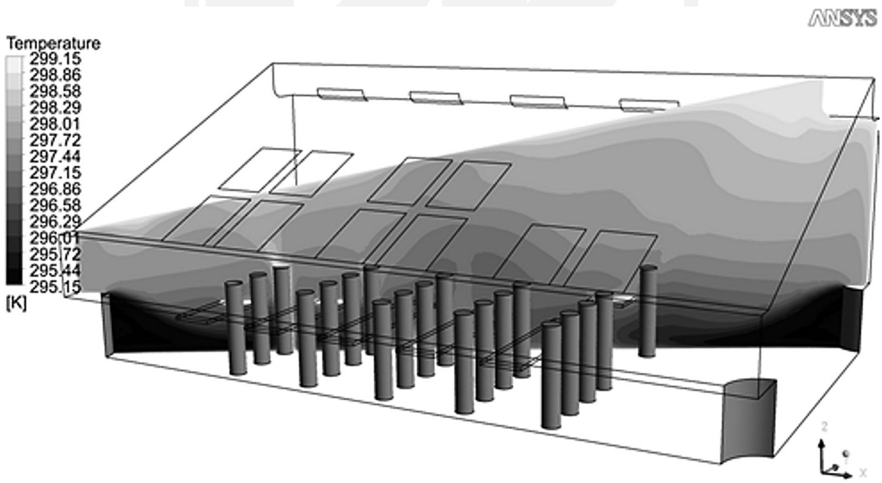

Fig. 4. Reach of supply air at 22°C in the classroom (rate of air exchange is 20 times per hour)

The main advantage of displacement ventilation is the air buoyancy that is formed from the air temperature gradient. The air at a higher temperature (caused by the heat load) is moved directly upwards to the ceiling of the classroom. We can see this effect in Figures 5 and 6. The mass flow rate of supply air and heat load from students and solar radiation are the main factors that influence the temperature gradient of air in the classroom. If we look at Figure 5, where the rate of air exchange is 6 times per hour we can see a change in air temperature from 26°C to 32°C between ankle and head level. If we increase the mass flow rate of the supply air (to a rate of air exchange of 20 times per hour), the air temperature in the classroom decreases, ranging from 22.5°C to 25°C between ankle and head level (Fig. 6).

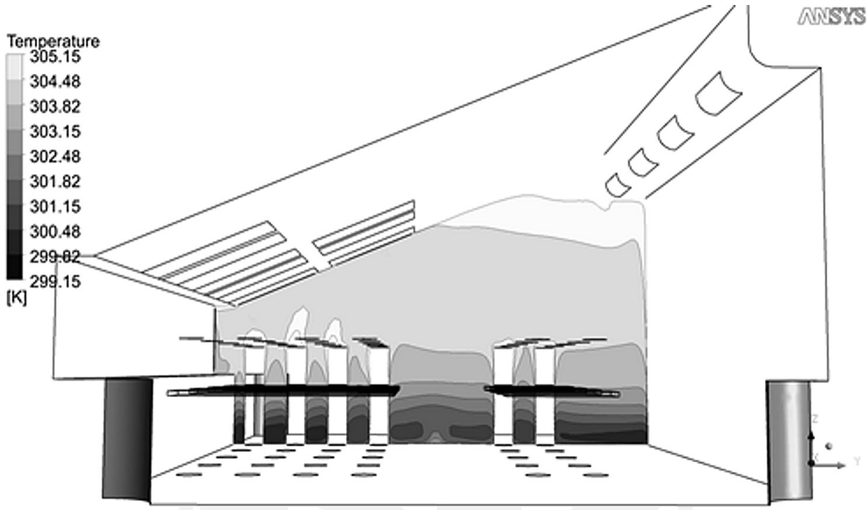

Fig. 5. Air temperature gradient in the classroom (rate of air exchange is 6 times per hour)

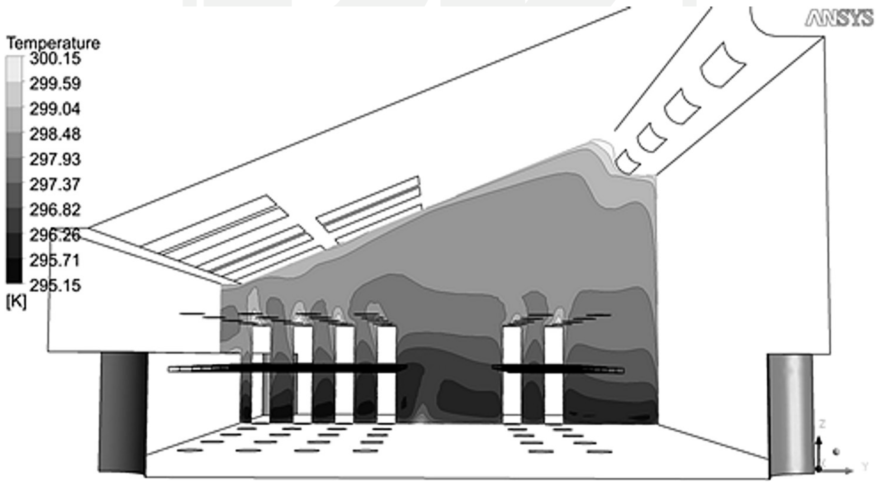

Fig. 6. Air temperature gradient in the classroom (rate of air exchange is 20 times per hour)

The next figures (Fig. 7, 8) show air temperature at the plane which is 200 mm above the floor. If we use a higher rate of air exchange we can stop the extreme rise in air temperature in the room. However, the question is: what will the air velocity be around the students? Figures 9 and 10 can offer the answer to this question.

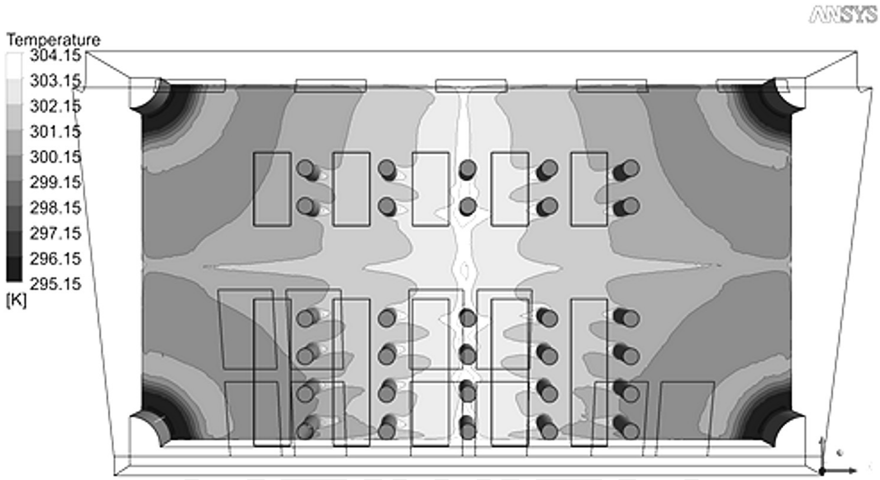

Fig. 7. Air temperature at the plane 200 mm above the floor (rate of air exchange is 6 times per hour)

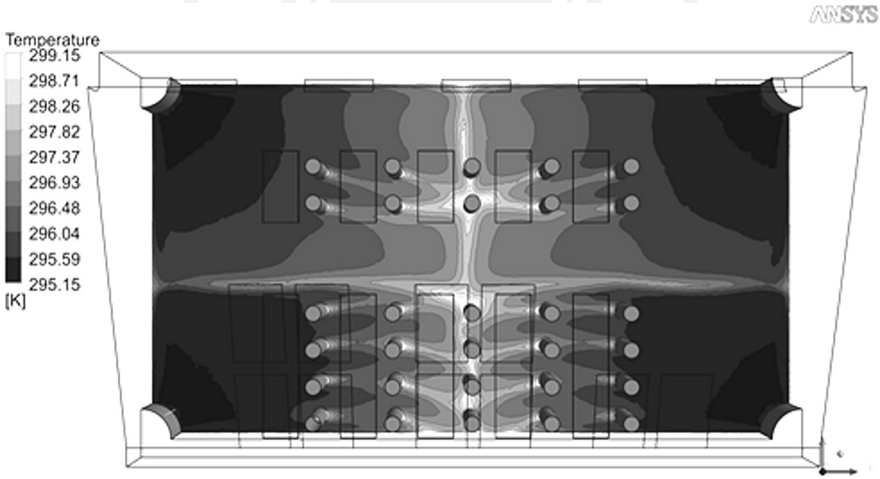

Fig. 8. Air temperature at the plane 200 mm above the floor (rate of air exchange is 20 times per hour)

The air velocity in variant A achieves values from 0.075 to 0.15 m/s around the students (Fig. 9). The air velocity in variant B is between 0.1 and 0.3 m/s (Fig. 10). These values are measured at the plane 200 mm above the floor. Our regulations state that the maximum air velocity around the students is 0.25 m/s for this activity (teaching). On the basis of these

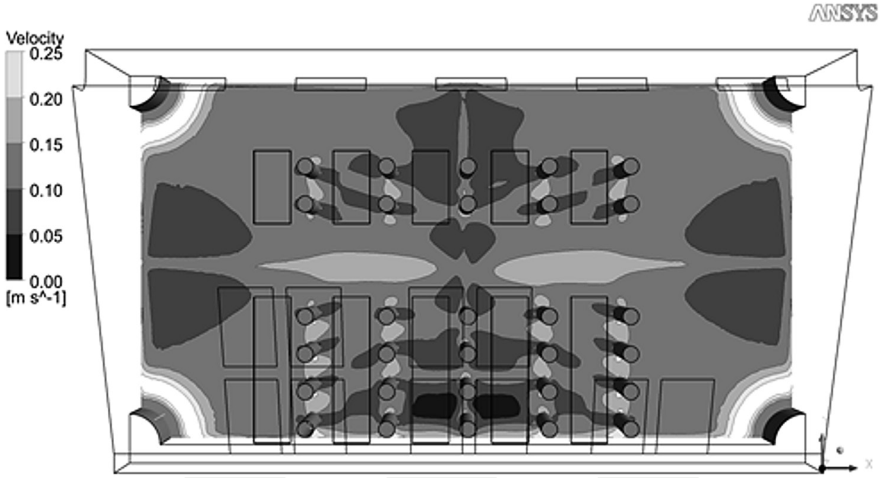

Fig. 9. Air velocity at the plane 200 mm above the floor (rate of air exchange is 6 times per hour)

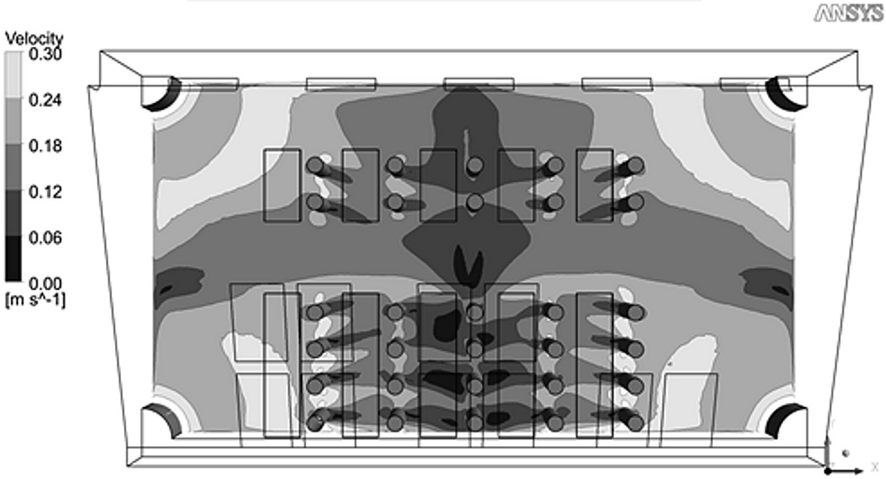

Fig. 10. Air velocity at the plane 200 mm above the floor (rate of air exchange is 20 times per hour)

results we can predict that some students in the front section of the room near the air inlets could theoretically experience some discomfort.

4. Conclusions

The results from this CFD simulation show that an air exchange rate of 6 times per hour is insufficient to stop the extreme rise in air temperature in the classroom. We can stop this rise in air temperature if we use the higher rate of air exchange of 20 times per hour (0.35 kg/s across each inlet). The supply air temperature is constantly 22°C in both compared variants.

Currently, we only use natural ventilation through the windows in the classroom. This system is very inefficient. The working conditions in the classroom are very difficult for the students and teachers during the summer months (May and June). If we used displacement ventilation with sufficient rate of air exchange we could provide for effective air exchange in the room, and in parallel we could reduce the heat load from students and solar radiation. It would be free cooling. The target is not to reduce the air temperature in the classroom below the outside temperature, but to reduce it to the value of the outside temperature.

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References

[1] Knizova K., Kovac M., *Influence of natural and mechanical ventilation on elimination of heat load in the loft space*, Visnik Nacionaľnogo universitetu Ľvivska politechnika: Teorija i praktika budivnictva, vol. 756, 2013, 95-100.

[2] ANSYS CFX Introduction, Release 12.0, 2012, ANSYS Inc., Canonsburg, USA.