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Personal Ventilation Modeling Using a CFD Analysis

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ABSTRACT

The growing trend for energy savings has resulted in tightening the building envelope, so the risk of contaminant accumulation and cross contamination is growing. Often, traditional mechanical ventilation systems that are installed in airtight buildings are not efficient in providing the proper amount of fresh air for individuals and do not protect them from cross contamination. Personal ventilation is an alternative to traditional ventilation systems as it provides fresh and purified air directly to the breathing zone. Not only does this method, in many cases, improve the thermal comfort of occupants, but also protects them from cross contamination from other occupants. In this study an air terminal device was tested to see if it would protect the occupant from cross contamination under changing conditions of the flow rate. Different velocities were simulated using the AnsysFluent CFD program, thanks to which the velocity around the occupants face was shown. The chosen velocities were 15 L/s, 10 L/s, 5L/s and 1L/s. The results showed that when the air flow was low, the personal ventilation system may not be effective in protecting against cross contamination.

Keywords**:** Personal ventilation, indoor air quality, CFD simulation

1. INTRODUCTION

The growing energy consumption rate of the building sector [1] has caused the need for energy savings, as it consumes almost 40% of the worldwide mainland energy [2]. Savings are done by, among other, tightening the building envelope to prevent heat loss through it. This contains the heat inside and makes it possible to use less energy for heating purposes.

What is more, according to European Union regulations, all new buildings built after 31st December 2020 must be nearly zero energy buildings and new public buildings must be nearly zero energy building from 31st December 2018 [3]. Such buildings have zero net energy consumption, meaning that the total amount of energy used by the object should be equal to the amount of renewable energy created on the site on an annual basis [4]. Apart from being equipped with renewable sources of energy, the majority of buildings have a mechanical ventilation system and the uncontrolled airflow through the building envelope is limited to a minimum due to its air tightness. The need for energy savings and the growing trend for ecological buildings will influence the tightness of the building envelope making it more airtight which may be hazardous for human health.

On the other hand, due to our work related lifestyle, we are spending more and more time indoors with the total amount of time spent indoors up to 86% [5]. This phenomenon combined with airtight building envelopes may lead to contaminant accumulation within buildings. Buildings with airtight structures are usually equipped with a mechanical ventilation system that should maintain proper indoor air quality. However, in many cases they do not fulfill their tasks properly, contributing to poor air quality that has an effect on the performance and productivity of occupants [6].

Indoor air quality has an impact on human health and work abilities which has been shown in many publications [6-9]. The importance of proper ventilation methods to maintain proper indoor air quality is a growing concern, as current focus is aimed mainly at energy savings. New airtight buildings are often equipped with mixing ventilation systems or displacement ventilation systems. However, because each person has a different perception of thermal comfort and air quality, this type of ventilation may not provide proper indoor air quality. This type of ventilation does not protect occupants form cross contamination from other occupants or contamination that may occur if the ventilation system in equipped with a mixing chamber. Such chambers recirculate some of the discharged air back to the system for energy savings. This shows that these types of ventilation methods may not meet hygienic requirements. To meet individual needs for thermal comfort and good air quality, many researchers have proposed personal ventilation as an alternative to classic ventilation methods.

Personal ventilation improves the quality of inhaled air and in many cases the perceived thermal comfort. However, due to its nature, it may cause drought around the occupants face leading to discomfort. A series of CFD (Computer Fluid Dynamics) simulations where conducted in this study to determine if a personal ventilation system can protect an occupant from cross contamination at different flow rates.

2. PERSONAL VENTILATION

Personal ventilation is a type of ventilation system that provides fresh and clean air directly to the occupants breathing zone [10]. This is done to adapt the thermal conditions to the individual needs of occupants. What is more, such ventilation systems prevent cross contamination between occupants as they supply entirely fresh air directly to the face of the occupant. The stream form the system creates a boundary around the breathing zone. A lot of studies have proved that personal ventilation provides better indoor air quality and thermal comfort.

Taheri et al. [11] conducted a field study concerning indoor conditions in an office space equipped with a displacement ventilation as well as personal ventilation systems. The results suggest that the combined operation of the above mentioned systems provides in general acceptable indoor environmental conditions. Lipczynska et al. [12] also conducted a study in an office space, where personal ventilation was used in combination with a chilled ceiling and mixing ventilation. The results showed that the personal ventilation system improved thermal conditions and was up to nearly 10 times more efficient in delivering clean air at workstations than mixing ventilation systems, which resulted in strong protection of occupants from cross-infection. Bolashikov et al. [13] also studied the effect of personal ventilation in a workspace using a thermal mannequin. The study showed that thanks to the personal ventilation system, the air velocity around the face increased and more clean air was inhaled.

Bogdan et al. [14] presented a study examining the influence of the breathing process on the perception of the thermal environment during the use of a personal ventilation system and a thermal mannequin. The results showed that the breathing air jets have the potential to influence the users' thermal sensation. Dalewski et al. [15] preformed a study on the influence of ductless personalized ventilation in conjunction with displacement ventilation and compared it with displacement ventilation alone and mixing ventilation using live subjects. The results showed that the percentage dissatisfied with air movement decreased with the personal ventilation system. Melikov et al. [16] studied the effect of personal ventilation on people's health, comfort, and performance in a warm and humid environment using human subjects. The results showed that using personal ventilation significantly improved the perceived air quality and thermal sensation as well as decreased the intensity of Sick Building Syndrome symptoms to those prevailing in a comfortable room environment without personal ventilation.

These examples show that personal ventilation is optimal for providing better indoor air quality, especially in office environments. It improves the thermal comfort of occupants and the perceived air quality. This is why it was decided to continue research on this topic.

3. METHODS

The aim of the study was to conduct a CDF simulation of a personal ventilation system and to see how the velocity of fresh air changed around the human subject when the inlet air flow changed.

Many authors in their studies measure only one inlet velocity of the personal ventilation air. Others claim that occupants can regulate the venation system in certain ranges. However, few measure how the change of ventilation velocity and flow rate influences the effectiveness of the personal ventilation system.

To determine if a personal ventilation system works properly regardless of the flow rate through the ventilation system, a series of CFD simulations were carried out. The air flow terminal device was based on the one used by [16] and [17]. It is a round air unit of the diameter of 180 mm with a series of 5 mm holes, thorough which, fresh air was supplied. The setup of the simulation is shown in Figure 1 in which the occupant and air terminal device are displayed. The air device was placed at a distance of 70 cm, in front of the face of the test mannequin. This distance was established to simulate the length of a work desk. The air flow rate was moderated from 15 L/s to 1 L/s to see how the velocity changed around the face of the occupant.

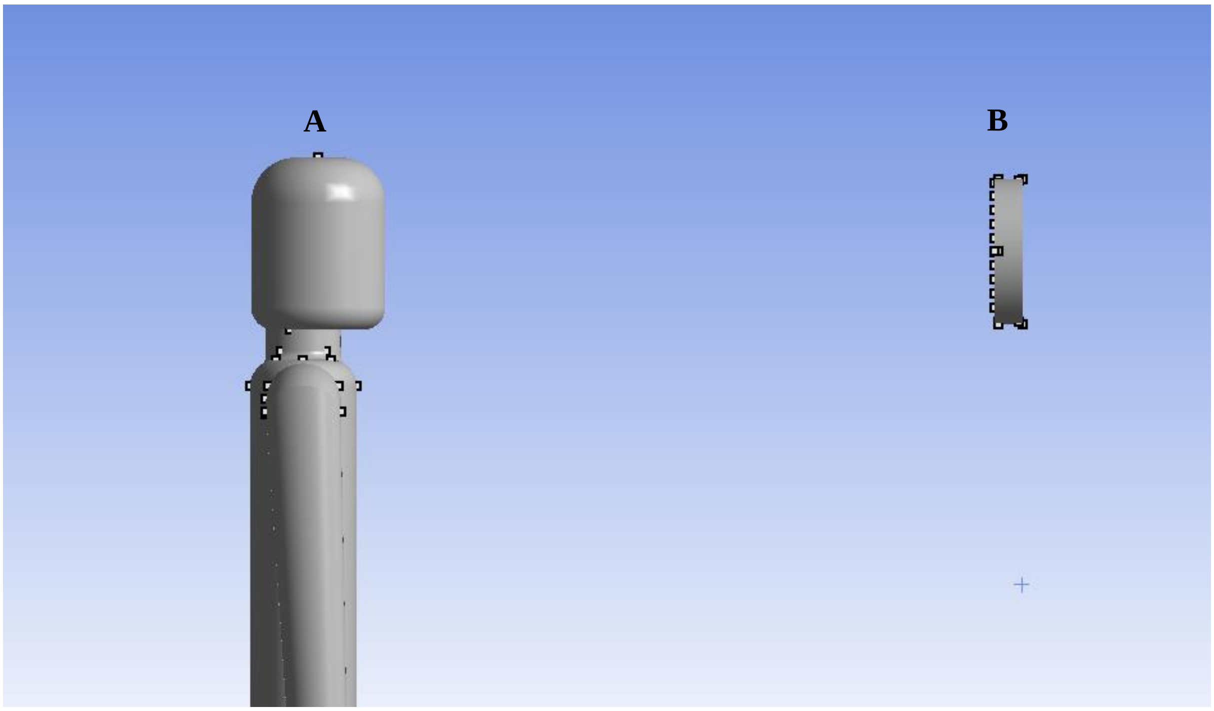

Figure 1. Layout of the test objects in the Ansys modeler. A: view of the upper body of the sitting occupant, B: air terminal device (air inlet)

The simulation program used to do the project was AnsysFluent; a CFD program that has the capability needed to model airflows, turbulences and contaminant distribution in complex geometries [18]. The simulation was done using the standard k-ε turbulence model.

The program has been used for studding personal ventilation methods by, among others, Makhoul et al [19] to reflect the conditions within a room equipped with an integrated ceiling diffuser and personalized ventilator coaxial. Liu et al. [20] used the program in similar simulations. They conducted a study on the performance of different personal ventilation nods. Many other authors have used the program for airflow simulations when considering the indoor air quality [20-23], which is why the program was chosen to conduct the simulations in this study.

4. RESULTS

4. 1. Maximum flow rate

The first simulation was conducted for the velocity of 15 L/s of air that flew through the air terminal device. The results are shown in Figure 2. The results show that the velocity near the air terminal device is quite high. The velocity near the face of the occupant is significantly lower, however is still quite high and may cause drought near the face.

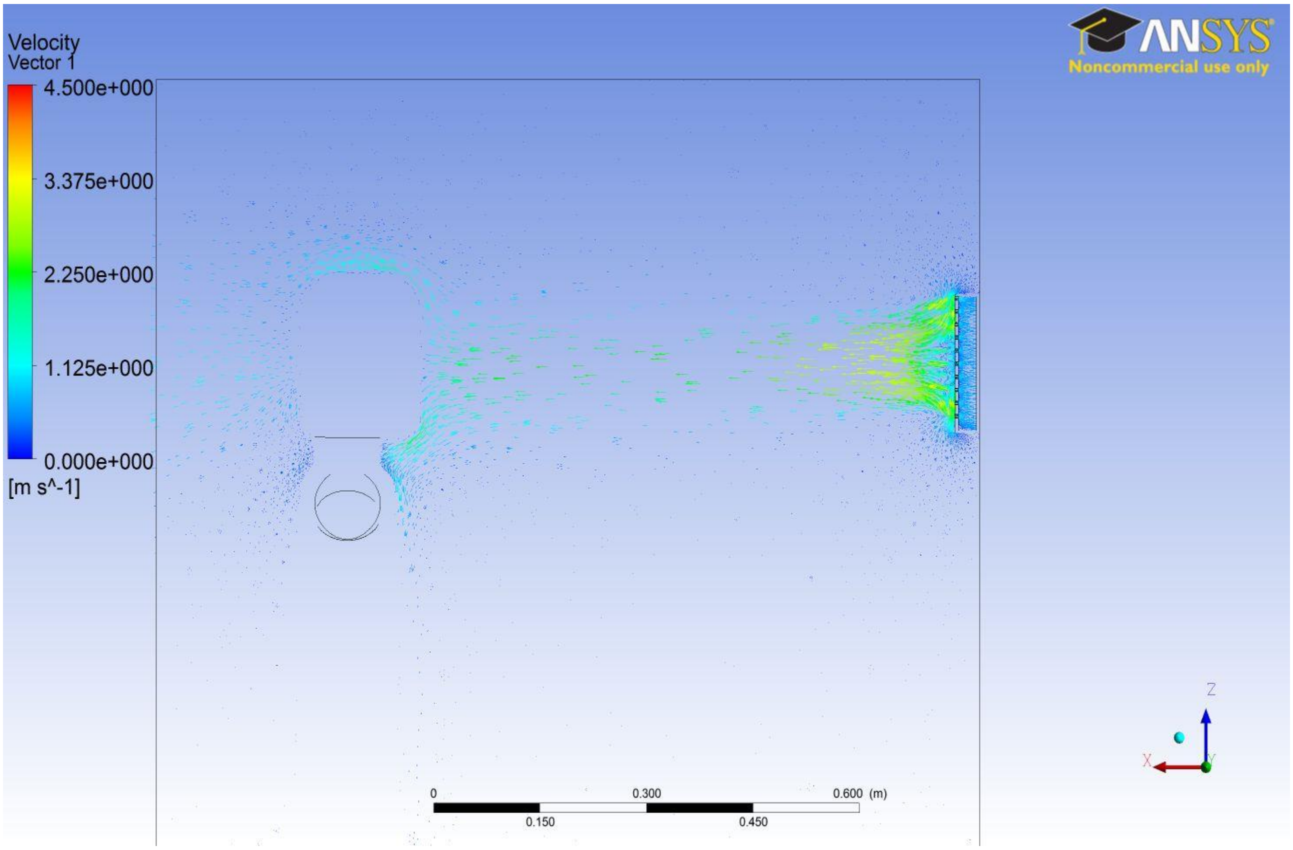

Figure 2. Maximum flow rate through the personal ventilation system.

The velocity near the occupant lowers to 0.8 m/s which is higher than the velocity recommended to maintain thermal comfort (0.2 -0.3 m/s). This may cause discomfort for the occupant and the feeling of drought. However, the higher velocity may be more efficient in preventing cross contamination from other occupants and protect the occupant from harmful microelements.

4. 2. Medium flow rate

The medium follow rate was set to 10 L/s. The results of this flow rate are shown in Figure 3. It shows that the velocity around the occupant face is lower than in the first case. The velocity lowered to around 0.4 m/s near the occupants face. The velocity is still higher than the velocity recommended for thermal comfort but research has shown that slightly increased velocity around the face may be preferred by occupants as it improves improve the perceived air quality [15].

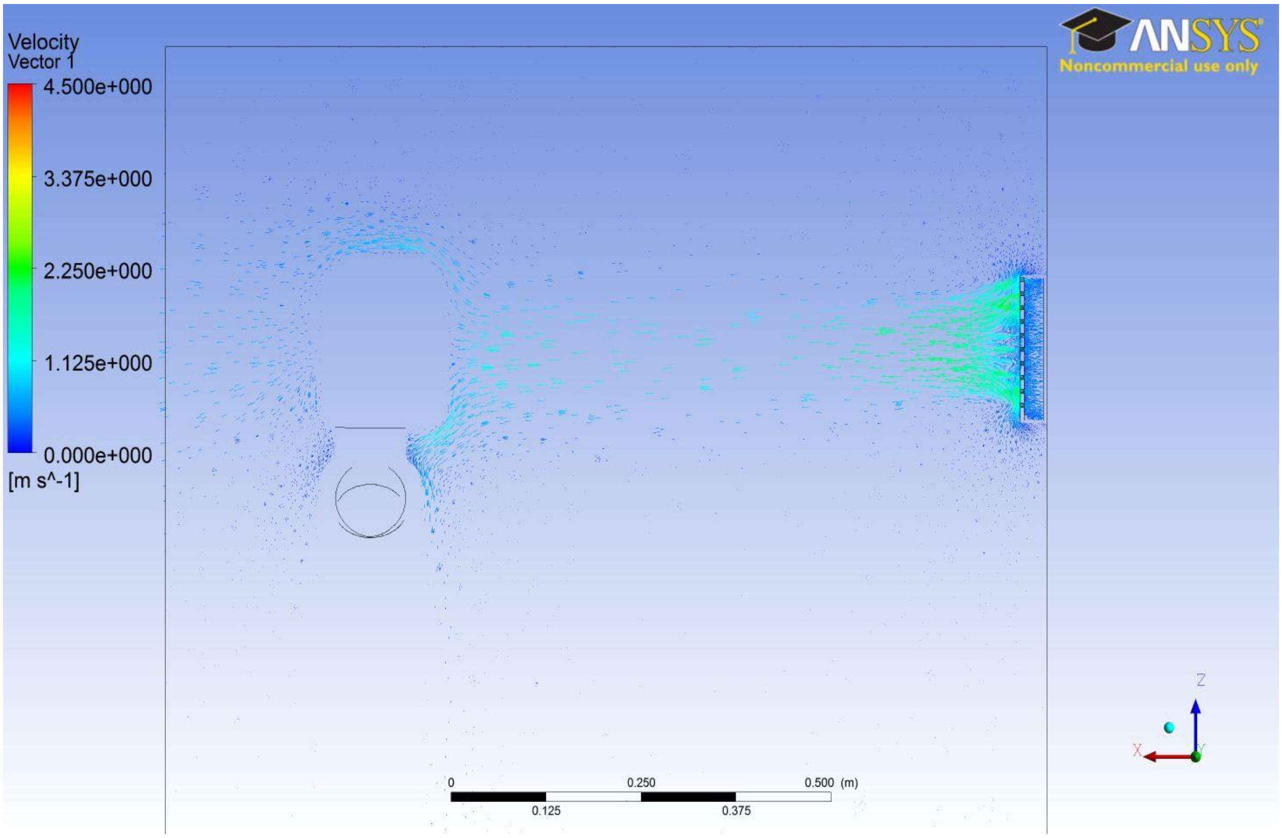

Figure 3. Medium flow rate through the personal ventilation system.

4. 3. Minimum flow rate

The minimal flow rate was assumed to be 5 L/s. The results of this simulation are shown in Figure 4, in which the velocity vectors are shown. The figure presents that the velocity round the occupant is significantly lower than the first two cases. This may be a flaw in the design of personal ventilation systems which are often tested in one or two cases of flow rates. The air velocity in this case may be too low to protect the occupant from cross contamination. This may be an issue in such cases where the personal ventilation system can be controlled by the occupant to provide individual ventilation. Such cases were done by, among others, Taheri et al [11] were the occupant could control the flow rate to provide individual comfort for each individual.

Because of this, an additional simulation was conducted with the mass flow from the ventilation system lowered to 1 L/s. The results are shown in figure 5. This figure shows that the air velocity is very low and practically has no effect on the occupant. This means that the occupant has no protection from cross contamination as the air slows down before it reaches the occupants face.

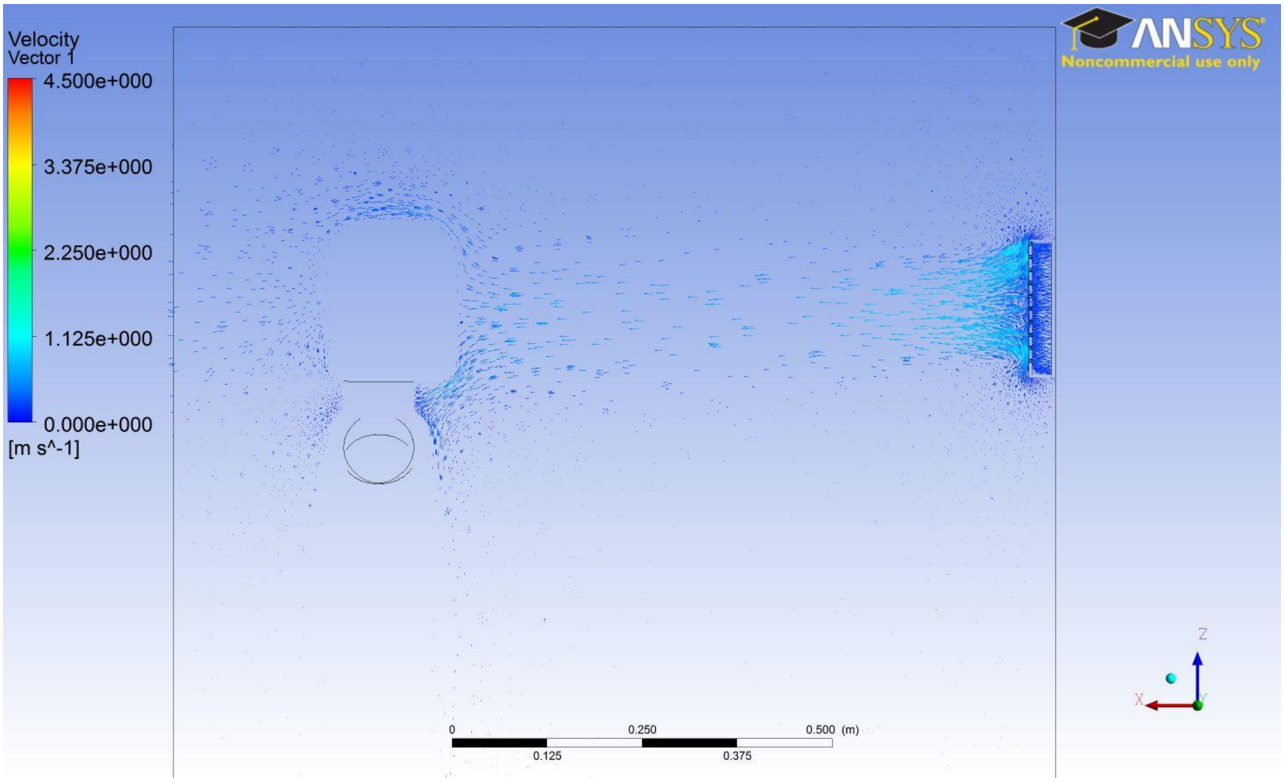

Figure 4. Minimum flow rate through the personal ventilation system.

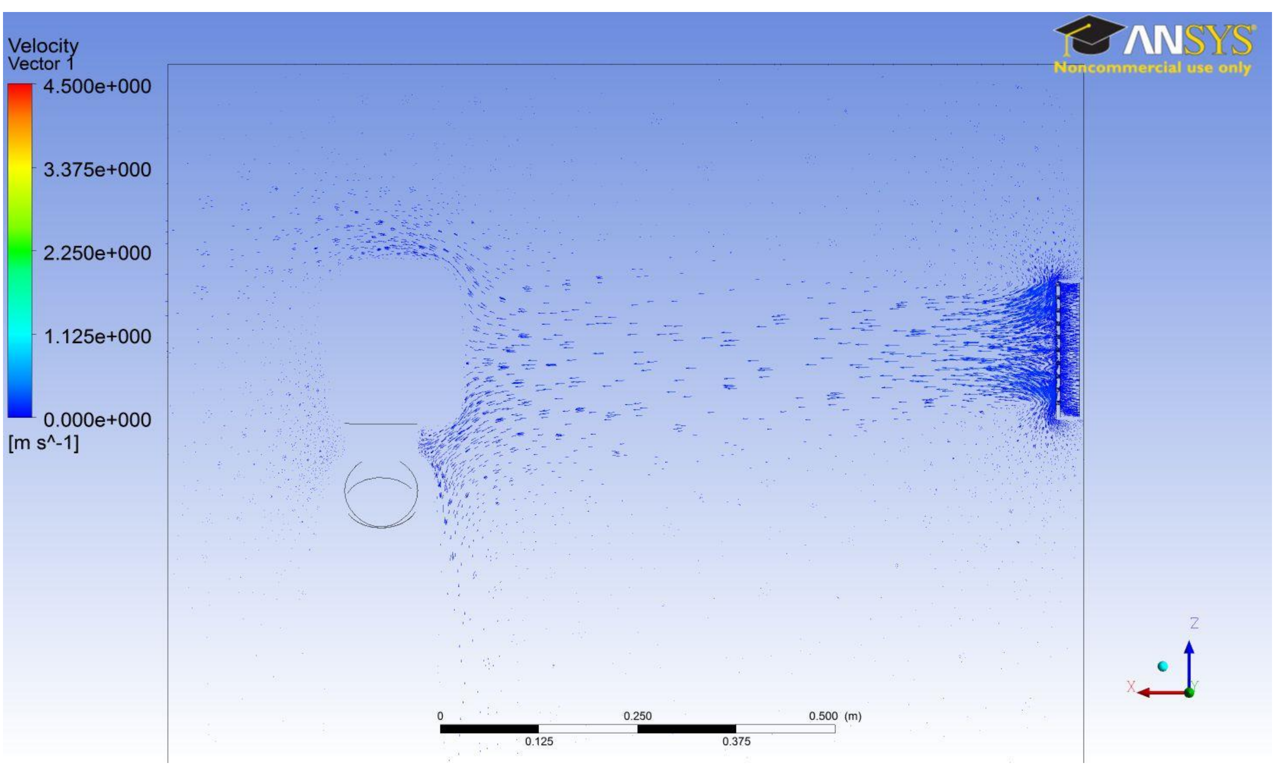

Figure 5. flow rate through the personal ventilation system equal to 1L/s.

5. CONCLUSIONS

The aim of the study was to determine the effectiveness of a personal ventilation system with different flow rates using a computer simulation program. This was done to determine, if the system could provide protection of the occupant from cross contamination.

Because of the growing trend for energy savings resulting in tightening the building envelope, the risk of contaminant accumulation and cross contamination is growing. Often, traditional mechanical ventilation systems that are installed in airtight buildings are not efficient in providing the proper amount of fresh air for individuals and do not protect them from cross contamination.

Personal ventilation is an alternative to traditional ventilation systems as it provides fresh and purified air directly to the breathing zone. Not only does this method in many cases improves the thermal comfort of occupants, but also protects them from cross contamination from other occupants.

In this paper an air terminal device was numerically tested to see if it would protect the occupant from cross contamination under changing conditions of the flow rate. Different velocities were simulated using the AnsysFluent CFD program, thanks to which the velocity around the occupants face was shown.

The results of the research showed that when the flow rate was high, it could cause high velocity around the face of the occupant. As the flow rate lowered, so did the velocity around the occupants face, meaning that the protection from cross contamination could be lower. The high velocity around the face that was received from the study has, in previous research, shown to not cause irritation for occupants in the majority of cases. However, the low velocity level when the flow rate is low causes the system to fail in its purpose of protection from contaminants. Future research on this subject should focus of new air terminal devices that maintain the same velocity around the occupant in spite of the changing flow rate. Such systems combined with the individual control of occupants could provide individual thermal comfort and protect from cross contamination.

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References

[1] L. Pérez-Lombard, J. Ortiz, and C. Pout, A review on buildings energy consumption information, *Energy Build.*, 40(3) (2008) 394-398.

[2] S. Baden, P. Fairey, P. Waide, and J. Laustsen, Hurdling Financial Barriers to Low Energy Buildings : Experiences from the USA and Europe on Financial Incentives and Monetizing Building Energy Savings in Private Investment Decisions, Proc. 2006 ACEEE Summer Study Energy Effic. Build., 2006 pp. 1-16.

[3] Directive 2010/31/EU, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. 2010, pp. 13-35.

[4] P. Torcellini, S. Pless, and M. Deru, Zero Energy Buildings: A Critical Look at the Definition Preprint, *ACEE Summer study*, 2 (2006) 15.

[5] N. E. Klepeis, W. C. Nelson, W. R. Ott, J. P. Robinson, a M. Tsang, P. Switzer, J. V Behar, S. C. Hern, and W. H. Engelmann, "The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants.," *J. Expo. Anal. Environ. Epidemiol.* 11(3) (2001) 231-252.

[6] D. P. Wyon, The effects of indoor air quality on performance and productivity, *Indoor Air*, 14(7) (2004) 92-101.

[7] U. Satish, M. J. Mendell, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert, and W. J. Fisk, Is CO2 an indoor pollutant? direct effects of low-to-moderate CO2 concentrations on human decision-making performance, *Environ. Health Perspect.*, 120(12) (2012) 1671-1677.

[8] P. Strom-Tejsen, D. Zukowska, P. Wargocki, and D. P. Wyon, The effects of bedroom air quality on sleep and next-day performance, *Indoor Air*, 26(5) (2016) 679-686.

[9] J. S. Park and C. H. Yoon, The effects of outdoor air supply rate on work performance during 8-h work period, *Indoor Air*, 21(4) (2011) 284-290.

[10] A. K. Melikov, Personalized ventilation, *Indoor Air*, 17(s7) (2004) 157-167.

[11] M. Taheri, M. Schuss, A. Fail, and A. Mahdavi, A performance assessment of an office space with displacement, personal, and natural ventilation systems, *Build. Simul.*, 9(1) (2016) 89-100.

[12] A. Lipczynska, J. Kaczmarczyk, and A. K. Melikov, Thermal environment and air quality in office with personalized ventilation combined with chilled ceiling, *Build. Environ.*, 92 (2015) 603-614.

[13] Z. Bolashikov, Airflow characteristics in the breathing zone of a seated person using desk incorporated pair of confluent jets as personalized ventilation - Effect of supply velocities, *10th Int. Conf. Heal. Build.* 2 (2012) 1514-1519.

[14] A. Bogdan, B. Koelblen, and M. Chludzińska, Influence of a breathing process on the perception of the thermal environment using personalised ventilation, *Build. Environ.*, 96 (2016) 80-90.

[15] M. Dalewski, A. K. Melikov, and M. Vesely, Performance of ductless personalized ventilation in conjunction with displacement ventilation: Physical environment and human response, *Build. Environ.*, 81 (2014) 354-364.

[16] A. K. Melikov, M. A. Skwarczynski, J. Kaczmarczyk, and J. Zabecky, Use of personalized ventilation for improving health, comfort, and performance at high room temperature and humidity, *Indoor Air*, 23(3) (2013) 250-263.

[17] J. Kaczmarczyk, a. Melikov, Z. Bolashikov, L. Nikolaev, and P. O. Fanger, Human Response to Five Designs of Personalized Ventilation, *HVAC & R Res.*, 12(2) (2006) 36-384.

[18] ANSYS, ANSYS FLUENT Theory Guide. Inc. Release 14.0, (http://www.ansys.com), 2011.

[19] A. Makhoul, K. Ghali, and N. Ghaddar, Thermal comfort and energy performance of a low-mixing ceiling-mounted personalized ventilator system, *Build. Environ.*, 60 (2013) 126-136.

[20] T. Liu, Z. Liu, G. Li, and Z. Zuo, Comparative Study of Numerical Simulation of Indoor Thermal Environment in the Pattern of Personalized Ventilation and Stratum Ventilation, *Procedia Eng.*, 121 (2015) 785-791.

[21] J. M. Villafruela, I. Olmedo, M. Ruiz de Adana, C. Méndez, and P. V. Nielsen, CFD analysis of the human exhalation flow using different boundary conditions and ventilation strategies, *Build. Environ.* 62 (2013) 191-200.

[22] M. Ning, S. Mengjie, C. Mingyin, P. Dongmei, and D. Shiming, Computational fluid dynamics (CFD) modelling of air flow field, mean age of air and CO2 distributions inside a bedroom with different heights of conditioned air supply outlet, *Appl. Energy*, 164 (2016) 906-915.

[23] N. Szczepanik and J. Schnotale, CFD Simulations and Measurements of Carbon Dioxide Transport in a Passive House, in ICR2015: The 24th IIR International Congress of Refrigeration: Improving Quality of Life, Preserving the Earth, 2015.

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