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COMPARISON OF DISPLACEMENT VENTILATION AND MIXING VENTILATION FOR INDOOR ENVIRONMENT CONDITIONS IN OFFICES: PHYSICAL CALCULATIONS

СРАВНЕНИЕ НИЗКОПОДВИЖНЫХ ВОЗДУХОРАСПРЕДЕЛИТЕЛЕЙ И ДИФФУЗОРОВ ДЛЯ ОБЕСПЕЧЕНИЯ ПОДХОДЯЩИХ МИКРОКЛИМАТИЧЕСКИХ УСЛОВИЙ В ОФИСНЫХ ПОМЕЩЕНИЯХ: ФИЗИЧЕСКИЕ РАСЧЕТЫ.

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Annotation*: In this century all technologies are advancing fast. Now buildings are heated using district heating systems, electricity or heat pumps. Instead of natural ventilation systems usually mechanical ventilation systems are installed in the buildings. An interest of improving efficiency of office work, while indoor environment conditions are changed, is growing increasingly. If we desire to create better quality of indoor air, it is not enough to know the temperatures of inside and outside air. Nowadays, it must also be considered other factors of thermal comfort and indoor air quality. The main purpose of this article is to find out which ventilation system, displacement or mixing ventilation is better for offices. Also it is relevant to find out what impact the ventilation system has on the employees and how it can affect the owner of the building. Another aim is to find out differences between displacement and mixing ventilation system. Furthermore the thesis discusses the advantages and disadvantages of these types of ventilation. It is important to find out the optimal type of ventilation. After all, the most famous theoretical physicist Albert Einstein once said that “Everything should be made as simple as possible, but not simpler”. This rule is valid also in ventilation systems. It is significant to find the most suitable but at the same time the ventilation type which is simplest to install, because just in this case the productivity of the employees, indoor air quality will be improved. Also savings of the potential energy will be created. Well, and during a pandemic, this topic is becoming more and more relevant, not only in terms of people’s ability to work, but also in terms of people’s lives.*

Keywords: *displacement ventilation, mixing ventilation, office buildings, indoor climate, thermal comfort*

Introduction.

Nowadays, there are a lot of people who work in offices. In order to maintain the productivity of work, it is necessary to keep up the appropriate microclimate conditions indoors. Usually when people are working they start to yawn. It happens not because they are bored, but at that time the concentration of the carbon dioxide in the indoor air is too high. In this case is must to use properly balanced mechanical ventilation. The period when people are spending time in non-ventilated places is disadvantageous for their health; it reduces the efficiency of work and creates unpleasant feeling. Polluted air can cause many various health problems for people;

for example frequent headaches, allergies, insomnia and other diseases [2]. However if the place has appropriate ventilation system no discomfort is felt and also the productivity of people increases. Ventilation system is designed specifically to maintain the suitable under climate conditions which are safe, comfortable and healthy for humans [3].

Literature review.

People's ability to work is one of the most important factors influencing the results of any organization. The results of research conducted in recent years show a direct relationship between environmental microclimate parameters and human employability. Statistical studies in large Western companies or offices show that the average area per person is 20 m^2, but in the USA and China this area is only 10 m^2. However, despite the fact that the smaller the area, the lower the costs, but such efficient use of the area also has negative features. After all, the larger the number of employees, the higher the air pollution with carbon dioxide (CO_2). Air temperatures rise from people and equipment. In the last decade alone, the amount of heat emitted by computers per working day has increased from 1 kW to 12 kW. Therefore, it is very important to regulate the room temperature and ventilation so that the quality of the indoor microclimate does not deteriorate. Here, N. B. Kayea suggests using cool night air for ventilation. Mechanical ventilation alone makes it difficult to maintain the right air temperature, especially during the warm season, when the outdoor temperature is high. Air conditioners are then used that not only regulate the air temperature but also maintain the required humidity. When installing air conditioners, it is not necessary to run large diameter pipes necessary for mechanical ventilation [4].

According to Wargocki P. to achieve the best results of the office work, it is necessary to have the appropriate indoor environment. The indoor air quality has a direct connection with the preferably (high) performance probability of the employees [3]:

1. Two times bigger supply rate of the outdoor air can decrease a sickness of the employees approximately by 10% and it will increase the productivity of work approximately by 1,5%.
2. Decreasing the temperature which is above 24°C can increase the effectiveness of office work by 1,5% by every 1°C.
3. Increasing the temperature which is below 20°C can increase the effectiveness of office work by 2% by every 1°C.
4. The effectiveness of office work can be increased by 1% if the percentage of dissatisfied be reduced by 10%.

The benefits of the appropriate indoor environment by using proper ventilation system are not only for employees. The biggest intention to improve the indoor environment should be from building owner.

Corgnati S. P. claims that effectiveness of the ventilation system in office or other type of building can be assessed using two different methods [6]:

1. The effectiveness of removal contaminant ε_c:

This method defines the duration thought which airborne contaminant is eliminated from indoor air. The effectiveness is calculated by Equation 1:

$$\varepsilon_c = \frac{c_e - c_s}{c_{mean} - c_s} \quad (1)$$

where: ε_c- the effectiveness of removal contaminant, c_e - the contaminant concentration in the exhaust, c_s - the contaminant concentration in the supply, c_{mean} - the mean concentration in the room

2. The air change method:

This method defines the quantity of times through which the air is eliminated from the room during one hour. The air change is calculated by Equation 2:

$$n = \frac{q_v}{V} \quad (2)$$

where: n - air change rate [h^{-1}], q_v - air flow rate [m^3/h], V - volume of the room [m^3].

After the air change rate is calculated, the nominal time constant can be easily found. The nominal time constant shows how long the air will be inside the space until it is extracted. This value can be calculated by Equation 3:

$$T_n = \frac{1}{n} \quad (3)$$

where: T_n- nominal time constant [h], n - air change rate [h^{-1}].

It is very important to solve the issues of indoor microclimate in time, but most administrations try to choose the easiest way - to install an air conditioning system. The air conditioners are switched on in the maximum mode, windows and doors are closed - this causes a devastating effect on air quality. Therefore, hoping to create a work-friendly environment exacerbates the situation. Mattheos Santamouris, project manager at Renson, said: "Air conditioning without ventilation is the worst solution." Therefore, it is very important to choose smart rather than quick solutions. In this article, we will try to talk more about the two main types of mechanical ventilation in office buildings. They are displacement and mixing ventilation. Figure 1 shows the differences of air distribution in mixing and displacement ventilation.

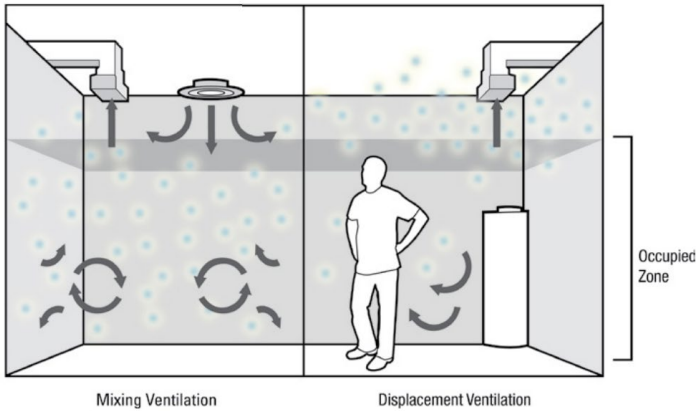


Figure 1. Mixing and displacement ventilation

Briefly about displacement ventilation. In such a system the supply air usually goes close to the floor and it has low velocity it means that the supply air goes across the floor it displaces warm air. In the room with displacement ventilation system the

cold air will slowly leave the diffuser and travel along the floor into the space. When the supply air meets a heat source, for example an employee, a customer or even a computer, the heat will cause the air to rise. In this convection air lifts contaminants up and out of the occupied zone. This also pulls supply air up across the person providing them with comfort and fresh air (in this case employees who are working in the office can more easily to acquire the information which is given). This means that the quality of work will be improved.

Displacement ventilation is an emerging alternative to traditional mix flow air distribution systems. This type of ventilation systems is well suited for areas with high ceilings. In the summertime cooling configuration, the cold air is supplied at a low velocity by diffusers near the ground and warmed by occupants and equipment. This warm air will raise taking pollutants with it and is collected for exhaust at the ceiling level. Displacement ventilation not only translates to energy savings from reduced fan usage and higher acceptable supply air temperatures, but it also raises indoor air quality.

The second type of ventilation we are considering is Mixing ventilation. In this ventilation type the fresh air gets into the offices or the other places from the top of the room [1]. Mixing ventilation means that the fresh air is mixed with local air and all contaminants also are mixed. Accordingly the concentration of contaminants is less than it is specified in the regulations of indoor air quality [2]. In mixing ventilation system the extract air goes out from the outlet devices which are also located at the ceiling. The main requirement for mixing ventilation is that a trajectory of the supply air must be the same when the supply air temperature and quantity are changing [1]. For this purpose, the supply air is goes through two streams, a fundamental and directional. The flow rate of the main steam is changing and the deflector is not. This allows giving such a volume of motion for the supply air, which gives constant flow path when gravitational forces are changing.

Research methodology.

The main purpose of the measurements was to compare two types of ventilation: displacement ventilation and mixing ventilation. And to find out which ventilation system is better for offices and also to analyse what impact it has to indoor environment conditions. All measurements were performed in a laboratory in a room specially designed for the experiment (XAMK University). The size of this room 6,8×3m. During an experimental part the different heights of the room were used. First of all, the measurements were done using 2,65m height of the room, and later 3,1m height was used. Consequently, the volume of the room varies between 54,06m^3 and 63,24m^3.

In the first part of measurements, the test room was made up as office space for one person (Figure 2).

A floor surface for one person was 20,4m^2 which is more than 12m^2/person. According the regulations LV 05-10440 the air flow from supply air device 13 dm^3/s were used. Also the same quantity of air was extracted from the room using one extract air device.

In the second part of measurements, the test room was made up as 4-person office space (Figure 3).

Figure 2. A test room simulated as 1-person office room

Figure 3. A test room simulated as 4-person office room

A floor surface for four persons was 5,1m^2/person, which is less than 12m^2/person. So according to the regulations LV 05-10440 the air flow from supply air device 11dm^3/s per person were used. The same amount of air was extracted from the test room using four extract air devices.

During the measurements three different devices were used: two devices of mixing ventilation and displacement ventilation device. Both mixing ventilation devices were installed in the ceiling. All supply and extract air devices are made by "FläktGroup" company.

We used this equipment to perform the study (Figure 4):

a) **b)** **c)** **d)**

Figure 4. Equipment used in the study

To measure the air flow in the circular supply and extract air devices the air flow hood Swema Flow 236 was used (Figure 4 a). To measure the air flow from semi-circular wall-mounted supply air terminal micro manometer Swema Man 8 was used

(Figure 4 b). Flow meausuring hood AccuBalance 8370 was used to measure the air flow from multi-nozzle rectangular diffuser (Figure 4 c). Data were obtained in four different heights which are important for sitting and standing person:

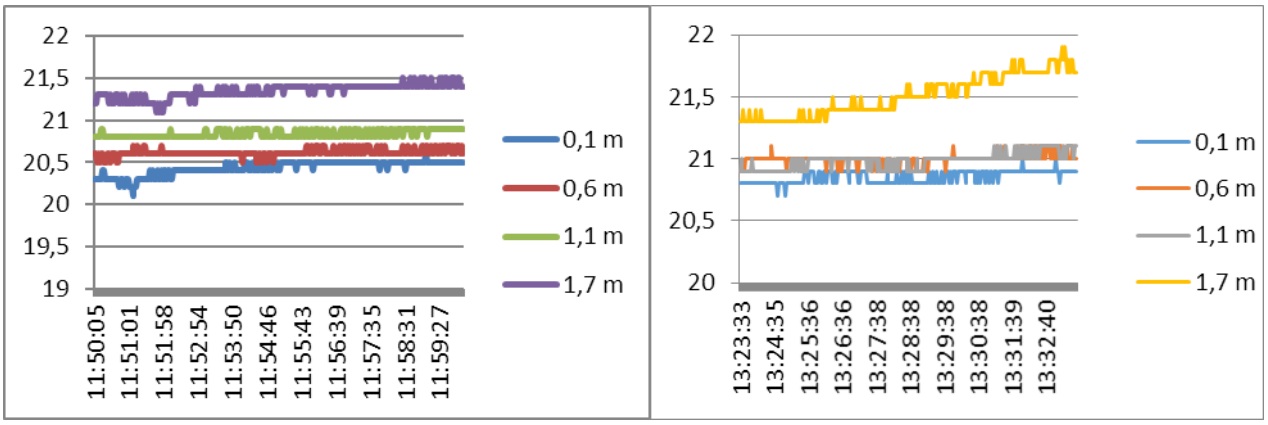
1. 0,1m (foot level);
2. 0,6m (knee level);
3. 1,1m (head level for a sitting person);
4. 1,7m (head level for a standing person).

The velocity of air was measured using omnidirectional anemometer Swema 03. The device is presented in Figure 4 d. The values where were received at 1,1 m height of the room.

Research results and their analysis.

The experiments were performed 4 times, their duration was always the same and lasted after 10 min. In the measurement case 1 and 2 the test room was simulated to 1-person office room. And in the measurement case 3 and 4 the test room was simulated to 4-person office space. The temperature of supply air was 18°C in every case.

First of all measurements have been done in test room which was made as 1-person office room. The sum of internal heat loads was 673W. The height of the room was 2,65m and the air flow was 13dm^3/s. The values of temperature when displacement ventilation is operated are presented in (Figure 5 a). In the same conditions the measurements were performed also with mixing ventilation system. The values of temperature when mixing ventilation is operated are presented in (Figure 5 b).

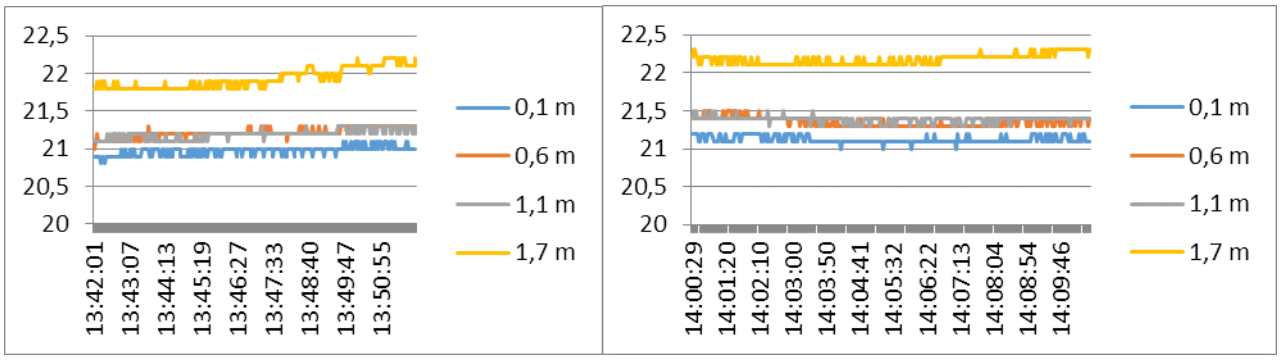


a) **b)**

Figure 5. Indoor air temperature in a one-person office with a room height of 2.65 m with different ventilation methods

According to the graphical data (Figure 5 a) we can see a tendency that in displacement ventilation system the supply air goes across the floor. It means the temperatures in different levels of the room are not the same. In the higher level the temperature is bigger than in previous one. However the situation in mixing ventilation system is different (Figure 5 b). The temperatures in occupied zone, where a simulated human was standing, are approximately the same. It confirmed the fact that in this type of ventilation system the supply air mixed with room air right away.

The second test was performed by changing only one parameter, that is, increasing the height of the room to 3.1 m. Temperature values for different ventilation modes are given (Figure 6 a, b).



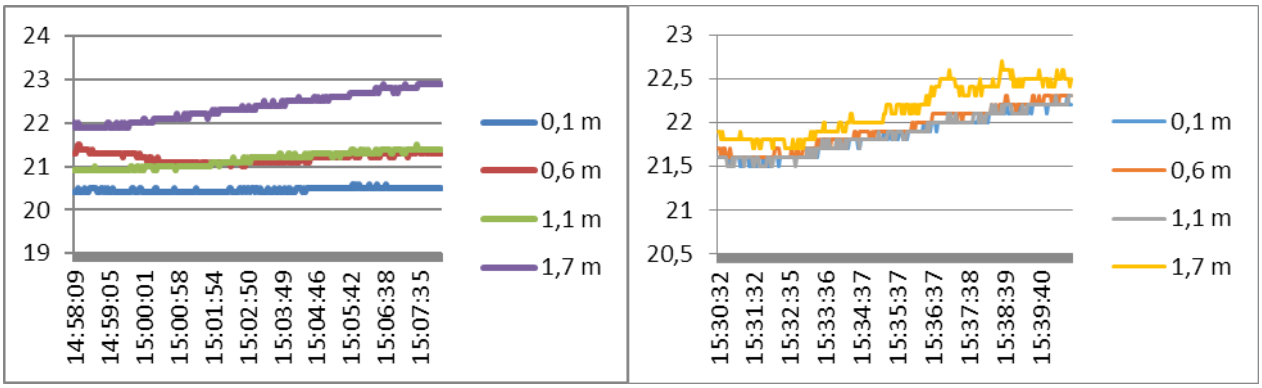
a) **b)**

Figure 6. Indoor air temperature in a one-person office with a room height of 3.1 m with different ventilation methods

Analogously in measurement case 2 there is similar values as in measurement case 1. This congruence can be explained because of very low designed air flow (13dm^3/s). However the temperatures are more convenient while displacement ventilation is used. So in this case it is easier to get comfortable indoor environment conditions using displacement ventilation.

The nominal time constant was calculated : in the first test it is 1.16 h and in the second 1.35 h. It is possible to make a conclusion that in both cases the employee who will be working in that indoor environment feel discomfort factors such as sleepiness, tiredness and his work will be not efficient. The air flow must be increased for this type of space.

Further, the experiments were fought using the same ventilation methods, only now they were simulated in the office premises of 4 persons. First, the height of the room was 2.65 m. (Figure 7 a, b).



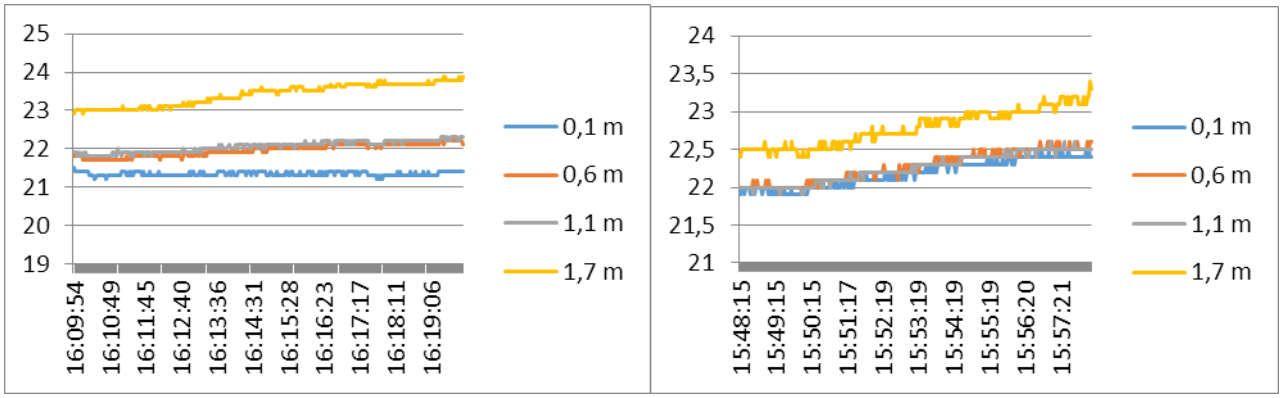
a) **b)**

Figure 7. Indoor air temperature in a 4-person cabinet with a room height of 2.65 m with different ventilation methods

From these graphs, the differences from the previous ones are very clear. The graphical data from Figure 7 a, b shows the variations between displacement and mixing ventilation in more accurate way. In both cases the temperatures during the

time are getting higher. It happens because in the internal heat load is more than 2 times bigger than in test room which was simulated to 1-person office room. However, the indoor environment conditions for employees who are usually sitting during the work are more convenient with displacement ventilation system.

And in the last test, the same measurements were made by changing the height of the room to 3.1 m. Other parameters were the same as in measurement case 3. And here again we see the temperature differences between the two ways of ventilating the room (Figure 8 a, b).



a) **b)**

Figure 8. Room air temperature in a 4-person cabinet with a room height of 3.1 m with different ventilation methods

We see that the results of the last two tests in the workroom of four people are similar. According to the classification LV 05-10440 the class S2 the temperature of a level 1,1m is too high for both ventilation systems. The idea is that in the space 4 computers, 4 simulated humans were used which created a large amount of internal heat load (1306W).

According to the recommendations LV 05-10440 category 2, the air velocity must be less than 0,17m/s. The value of air velocity is very important for draft sensation. The size of air velocity was measured during every experiment at 1,1m height of the room. The values are showed in (Figure 9).

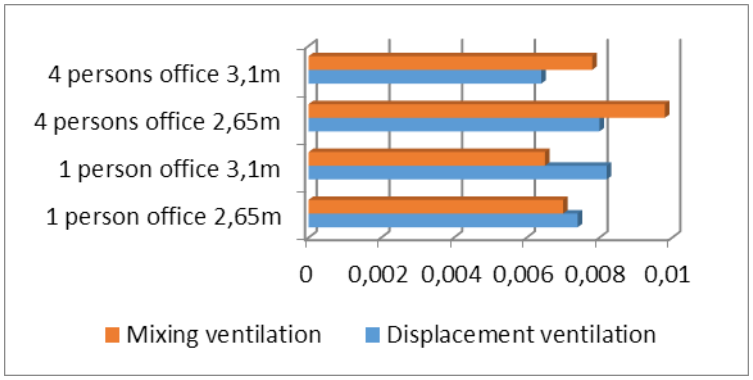


Figure 9. Air velocities during different measurements

According to the measured results, the air velocity doesn't reach the air velocity values which are given in recommendations. It means that there are no possibilities to air drought.

We will try to briefly describe the results obtained. According to the regulation

LV 05-10440 in class 2 a main temperature in the room should be 21.5°C. This value can fluctuate between 20.5°C and 22.0°C. The temperatures which were recorded in the test room which was simulated as one person office room are given and compared in (Figure 10).

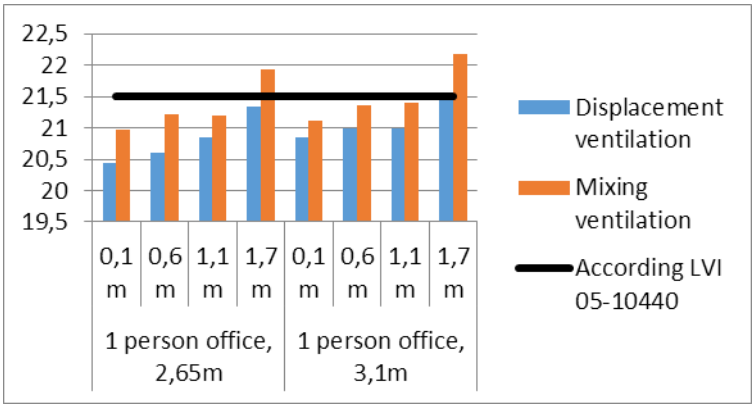


Figure 10. Comparison of temperatures in one person office

From the diagram we can see the temperatures which were received using the mixing ventilation system are closer to the values which are given in the regulations. Consequently, in this case for both heights it is better to use a mixing ventilation system if the comfortable indoor environment conditions are the main goal.

The situation of air temperatures in the test room which was simulated as four person's office also is analyzed. According to the regulation the temperature values stay the same. The temperature values which were given in this type of office space are presented in (Figure 11).

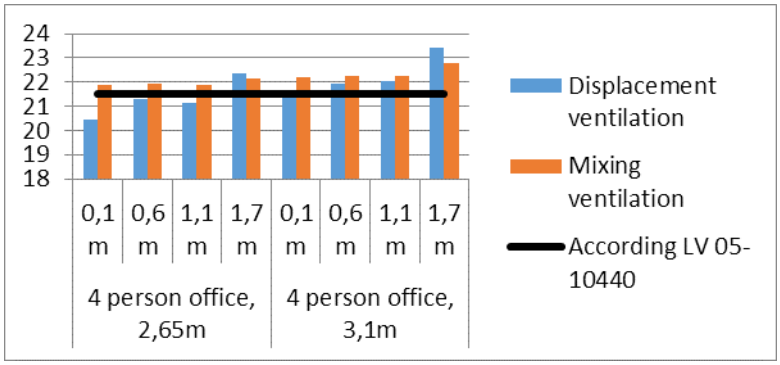


Figure 11. Comparison of temperatures in 4-person office

Seeing that the a workplace is adapted for seated work the most important temperatures must be on the levels 0.1m, 0.6m, 1.1m. On the strength of the temperatures which were received in 4-person office space the temperatures are superior and closer to values in the regulations using displacement ventilation system.

Conclusions.

This study was designed to compere two different types of ventilation: displacement ventilation and mixing ventilation. Also to find out which of these systems are more suitable for offices? And to analyze what impact it has on productivity and performance.

Here are some of them:

1. Better final findings can be made from the measurement results of test room

which was simulated to 4-person office place. Whereas the floor area stayed the same size (20.4m²) and work places for four people occupy the biggest part of the room. It isn't easy to find an appropriate place for displacement ventilation for such type of space. It is possibility to use two units of displacement ventilation diffusers in different places of the room.

2. If the all results are summed up, it can be predicted that mixing ventilation for 4-person office space is superior option than displacement ventilation. In both cases (with the room height 2.65 m and 3.1 m) when using a mixed ventilation method, the dissatisfaction of dissatisfied people is lower (8% and 7%) in proportion to values when displacement ventilation is used (13% and 7%).

According to the results (of measurements) it is possible to see a tendency that in displacement ventilation system the supply air goes across the floor. It means the temperatures in different levels of the room are not the same. In the higher level the temperature is getting higher than when room height is 2.6 m. However the situation in mixing ventilation system is different. The supply air comes into the room and it instantly mixes with the room air.

The most accurate results were received in the test room which was simulated to four persons' office space. More informative results were received using mixing ventilation system. The percentage of dissatisfied people in this case fluctuated between 8% and 7%. It means the efficiency of work will be increased and the comfortable indoor environment conditions will be obtained. Less important but still worth mentioning results was received when the height of the room was 3.1m. In that situation the displacement ventilation is also suitable choice. But it would be more difficult to find out an appropriate place for displacement ventilation diffuser in the room which would satisfy all four persons in the office.

The main implication of this study was clarified that the temperature differences of distinct levels in the room are higher in displacement ventilation than in mixing ventilation. However, the final conclusions show that with mixing ventilation systems it is easier to reach comfortable indoor environment conditions in office buildings.

Need for future research is important. For more accurate results the measurements must be performed not in test room but in real office rooms which one of them would have displacement ventilation system and another would have mixing ventilation system. In that case the measurements of contaminant concentration and CO2 level in the room also could be done. During these measurements which were done in the test room simulated humans were used. For this reason the results of the measurements in the laboratory cannot be as accurate as it can be in real situation.

During these measurements when the test room was simulated to four person office space, in some cases the temperatures were not stable enough. In this case it would be effective to perform the same measurements for a longer period, for example 1 hour or even 8 hours as a full-time working day. Accordingly it will be possible to evaluate a quantity how much a space is warmed up during the longer period.

But the main conclusion is that the pace of life is tremendous and times are changing and to live comfortably, it is no longer enough to use windows and enjoy the fresh air, as our parents or grandparents did. High energy efficiency class houses

are extremely airtight, so they cannot ensure natural air circulation and no matter where, at home or in the offices, that feeling better will not be enough, especially in winter. After all, together with the open windows, various dirt and dust enter the house, and dust mites and mold accumulate in non-ventilated rooms, headaches often start to bother, and respiratory disorders can also occur. Air circulation in new construction homes is minimal, so expect a good microclimate, good performance results without a modern ventilation system is definitely not worth it.

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Резюме: *В этом веке все технологии стремительно развиваются. В настоящее время здания отапливаются с помощью систем централизованного теплоснабжения, электрических или тепловых насосов. Вместо систем естественной вентиляции здания обычно оборудуют системами механической вентиляции. Это делается в целях повышения эффективности работы офиса, так как условия окружающей среды в помещениях меняются. Если мы хотим улучшить качество воздуха в помещении, недостаточно знать температуру воздуха в помещении и на улице. Важными становятся и другие факторы теплового комфорта, а также качества воздуха в помещении. Основная цель данной статьи - выяснить, какая система вентиляции - вытеснением или смешиванием, больше подходит для офисов. Также важно выяснить, какое влияние система вентиляции оказывает на сотрудников и какое влияние это оказывает на владельца здания. Еще одна цель - выяснить, чем отличаются вытеснение и перемешивание в вентиляционной системе. Кроме того, в статье рассматриваются достоинства и недостатки этих видов вентиляции. Цель статьи - подобрать оптимальный тип вентиляции. Известный физик - теоретик Альберт Эйнштейн сказал, что «все должно быть как можно проще, но не хуже». Это правило касается и систем вентиляции. Важно найти наиболее подходящий, но в то же время самый простой в установке тип вентиляции, так как только тогда улучшится качество воздуха в помещении, а тем самым и производительность труда сотрудников. Кроме того, будет сохранена потенциальная энергия. Во время глобальной пандемии эта тема становится все более актуальной не только для трудоспособности людей, но и для их качества жизни.*

Ключевые слова*: вентиляция вытеснением, вентиляция смешиванием, офисные здания, микроклимат в помещении, тепловой комфорт.*

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