IMPROVEMENT OF INDOOR AIR QUALITY IN CLASSROOMS BASED ON AGE OF AIR PARAMETERS AND FANGER’S PREDICTED MEAN VOTE METHOD

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Ahmetcan YETİŞ

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We approve the thesis of **Ahmetcan YETİŞ**

Examining Committee Members:

Assoc. Prof. Dr. Ziya Haktan KARADENİZ
Department of Energy Systems Engineering, İzmir Institute of Technology

Prof. Dr. Mousa MOHAMMADPOURFARD
Department of Energy Systems Engineering, İzmir Institute of Technology

Assoc. Prof. Dr. Mehmet Akif EZAN
Engineering Department of Mechanical Engineering Thermodynamics, Dokuz Eylül University

25 August 2023

Assoc. Prof. Dr. Ziya Haktan KARADENİZ
Supervisor, Department of Energy Systems Engineering
İzmir Institute of Technology

Prof. Dr. Gülden Gökçen AKKURT
Co-Supervisor, Department of Energy Systems Engineering
İzmir Institute of Technology

Prof. Dr. Gülden Gökçen AKKURT
Head of the Department of Energy Systems Engineering

Prof. Dr. Mehtap EANES
Dean of the Graduate School of Engineering and Sciences

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ABSTRACT

IMPROVEMENT OF INDOOR AIR QUALITY IN CLASSROOMS BASED ON AGE OF AIR PARAMETERS AND FANGER’S PREDICTED MEAN VOTE METHOD

Indoor air quality in classrooms is an important research topic today. Studies have shown that poor or inadequate indoor air quality has negative effects on students' performance and active participation in classes. The aim of this study is to examine the local air velocity and air age parameters to determine the ventilation needs of crowded, but limited-sized classrooms that are not connected to a central ventilation system, and to investigate the applicability of ventilation systems that can provide adequate indoor air quality.

In the study, a primary school classroom with a capacity of 30 students was examined. Ventilation requirement is determined per person according to “ASHRAE 62.1-2022” Standard and “Building Bulletin 101” directive. For ventilation of the classrooms, counter-fluid heat recovery ventilation units mounted embedded in the wall. It is aimed to reduce the total volume allocated for the ventilation device in the classroom compared to the use of a single device. To slow down fresh air entering the room at high speed and mix it before reaching breathing zone, blowing directions of the neighboring devices are intersected. With these information, a classroom model was created to be analyzed with the Computational Fluid Dynamics method. In addition, another classroom model was created for investigating personal ventilation scenario.

By a comparative analysis, average air velocities, age of air values around heads of students and students' perception of indoor air quality according to Fanger's "Predicted Average Vote" method were investigated.

ÖZET

HAVA YAŞI PARAMETRELERİNE VE FANGER'İN ÖNGÖRÜLEN ORTALAMA OY YÖNTEMİNE GÖRE SINIFLARDA İÇ HAVA KALİTESİNİN İYİLEŞTİRİLMESİ

Sınıflardaki iç hava kalitesi günümüzün önemli bir araştırma konusudur. Yapılan araştırmalar, kötü veya yetersiz iç hava kalitesinin öğrencilerin performansı ve derslere aktif katılımı üzerinde olumsuz etkileri olduğunu göstermiştir. Bu çalışmanın amacı, merkezi havalandırma sistemine bağlı olmayan kalabalık ancak sınırlı büyüklükteki sınıfların havalandırma ihtiyaçlarını belirlemek için yerel hava hızı ve hava yaşı parametrelerini incelemek ve bu gereksinimleri karşılayabilecek havalandırma sistemlerinin uygulanabilirliğini araştırmaktır.

Çalışmada 30 öğrenci kapasiteli bir ilköğretim okulu sınıfı incelenmiştir. Havalandırma ihtiyacı "ASHRAE 62.1-2022" Standardı ve "Building Bulletin 101" direktifine göre kişi başı olarak belirlenmiştir. Dersliklerin havalandırılmasında duvara gömülü olarak monte edilen karşı akışkanlı ısı geri kazanımlı havalandırma üniteleri kullanılmıştır. Bu sayede sınıftaki havalandırma cihazı için ayrılan toplam hacmin tek bir cihaz kullanımına göre azaltılması amaçlanmıştır. Odaya yüksek hızda giren taze havanın yavaşlatılması ve solunum bölgesine ulaşmadan karıştırılması için komşu cihazların üfleme yönleri kesiştirilmiştir. Bu bilgilerle, Hesaplamalı Akışkanlar Dinamiği yöntemiyle analiz edilecek bir sınıf modeli oluşturulmuştur. Bu modelin yanı sıra kişisel havalandırma senaryosu da farklı bir model ile incelenmiştir.

Karşılaştırmalı analizle, Fanger'in "Öngörülen Ortalama Oy" yöntemine göre öğrencilerin iç mekan hava kalitesi algıları ve ortalama hava hızları incelenmiştir.

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CHAPTER 1

INTRODUCTION

Schools are educational institutions that prepare individuals for their future lives. It is very important that the classrooms, where students spend most of their time, can offer an ideal educational environment. Classrooms are places where the number of individuals per area is high and therefore their sizing and design should be given great importance. The large student population increases the emission of indoor pollutants, therefore, negatively affecting the indoor air quality of the classrooms. In addition, school environments can host various organic or inorganic pollutants such as NO_X, CO_2, O_3, particulate matter (PM), aerosols, bacteria, and fungi species that may adversely affect the health of these sensitive individuals (Chatzidiakou, Mumovic, and Summerfield 2012) Proper ventilation in classrooms is effective for providing a healthy educational environment and maintaining the performance of students and teachers.

Children have a higher metabolism than adults. In addition, since their respiratory tract is still under development, they are more sensitive to environmental effects. Exposure to indoor pollutants has been observed to adversely affect the development of the respiratory tract in children (Berglund, Maroni, and Mblhave, n.d.). For this reason, for children to grow up healthily, the classrooms where they spend a significant part of their daily lives must have ideal indoor air quality.

With the proliferation of studies examining indoor air quality in schools, standards and regulations have been established by various institutions or organizations around the world, aiming to protect indoor air quality in classrooms. These regulations are a guide for ensuring indoor air quality in educational environments such as classrooms. The standards aim to protect indoor air quality according to parameters such as the area of the place and the number of individuals in it, to limit the pollutants that can be found in the indoor environment, and to create an ideal educational environment by providing thermal and acoustic comfort.

1.1. Energy Consumption of Buildings and School Environments

When it comes to energy use and greenhouse gas emissions, the building industry is dominating. Final Energy Consumption of the Sectors from 2020 to 2035 is anticipated in the "National Energy Plan" released in Türkiye in 2022. The plan states that in 2020, the residential and service sectors' final energy consumption will account for 40% of all energy consumption. However, in 2035, this rate is predicted to drop to 35% (TÜRKİYE ULUSAL ENERJİ PLANI, 2022).

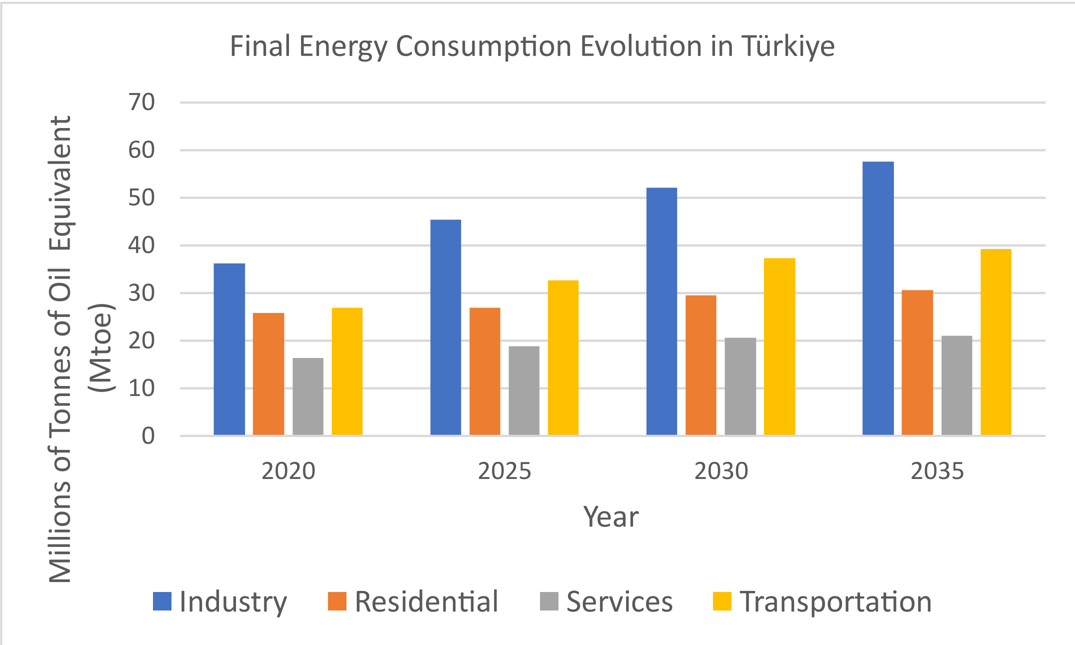


Figure 1. Final Energy Consumption Evolution in Türkiye (TÜRKİYE ULUSAL ENERJİ PLANI, 2022)

In the context of their study on energy use in buildings, Ortiz et al. estimated that between 20% and 40% of the total energy used in developed nations is consumed by buildings. It was additionally stated that this rate is expected to keep rising in the future due to rising population and comfort demands. The study's findings showed that HVAC systems account for over half of all energy use in buildings and directly contribute 10 to 20% of all energy use in developed nations (Pérez-Lombard, Ortiz, and Pout 2008).

In another study by Pereira et al, the distribution of the average energy consumption of schools in the United States was examined. It has been observed that more than half of the energy consumption in schools is used to improve the quality of the indoor environment (Dias Pereira et al. 2014).

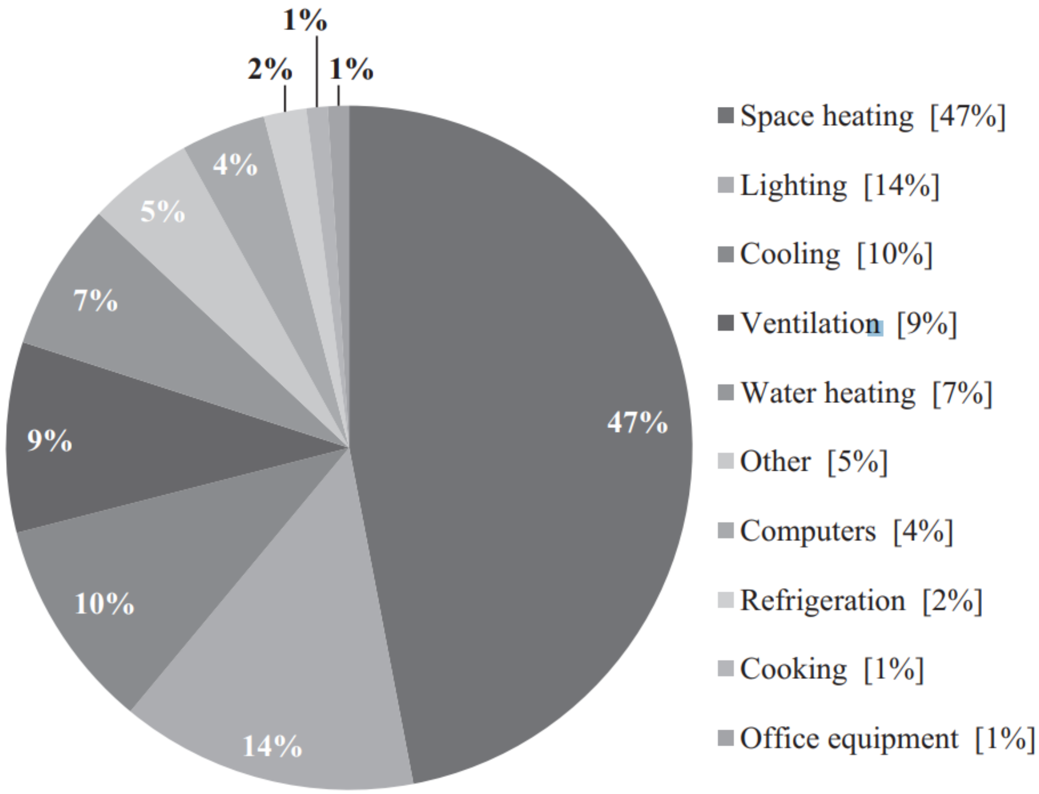


Figure 2. Average energy consumption of schools in the USA (Dias Pereira et al. 2014)

In another study examining the energy consumption of schools in England, primary schools, secondary schools, and academies were examined and it was stated that approximately 80% of educational institutions do not have mechanical ventilation or air conditioning. Within the scope of the study, it was observed that fossil fuel consumption decreased between 21 and 24 percent compared to previous years. However, it has been revealed that excessive dependence on mechanical ventilation increases electricity consumption, which indirectly increases fossil fuel consumption (Godoy-Shimizu et al. 2011).

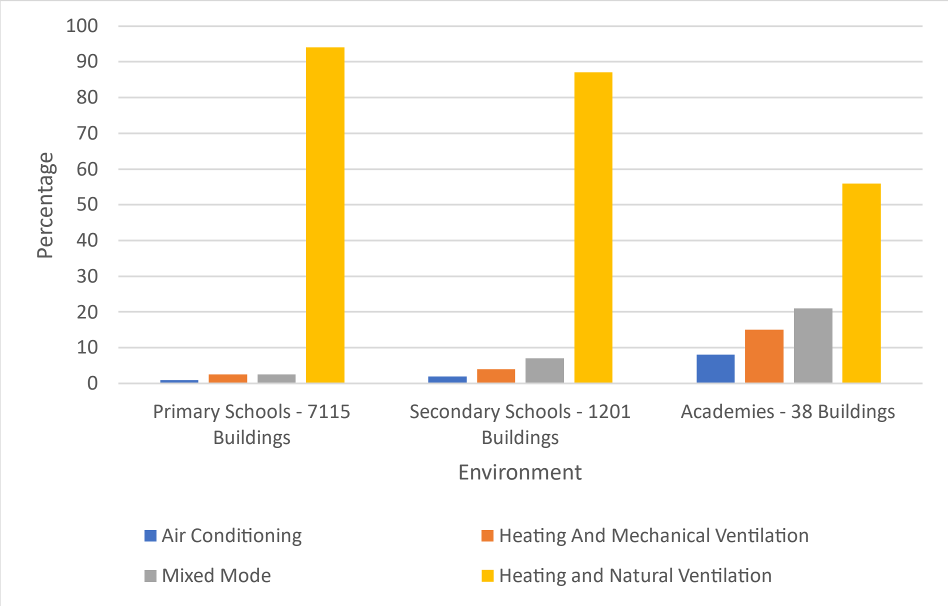


Figure 3. HVAC Variation in the UK (as of 2011) (Godoy-Shimizu et al. 2011)

Along with reducing fossil fuel consumption in schools, making buildings energy efficient is also of great importance. Reducing the share of buildings in final energy consumption is possible only by increasing energy efficiency.

1.2. Indoor Environmental Quality in Educational Environments

Indoor environmental quality (IEQ) is a critical factor in the health and performance of students and teachers in academic institutions. IEQ parameters, including thermal, acoustic, and lighting conditions and indoor air quality, affect the quality of teaching and learning, academic achievement, and the health and behavior of children. Several studies have explored the influence of IEQ parameters on academic performance.

1.2.1. Effects of Indoor Environmental Quality Parameters on Learning Performances of Children

Brink et al (Brink et al. 2021) did a thorough literature review. Indoor air quality, thermal, acoustic, and lighting conditions have been identified as significant elements determining the quality of teaching and learning. By utilizing the Cochrane Collaboration Method, systematic database searches were conducted to find pertinent scientific evidence. 21 papers with a high level of relevance and quality were chosen after the screening procedure. The gathered data demonstrated that students' short-term academic performance and learning quality can both benefit from indoor environmental quality (IEQ). However, it was not yet possible to determine how each factor affected the effectiveness of the instruction and long-term academic success (Brink et al. 2021). Similarly, Yusoff and Sulaiman (Wan Yusoff and Sulaiman 2014) highlighted the need of measuring and improving IEQ performance in the context of sustainable campuses. Several studies have been conducted to evaluate students' and instructors' subjective assessments of IEQ characteristics such as thermal comfort, illumination, and indoor air quality (Kraus and Novakova 2019).

Studies also took a look at the effect of IEQ characteristics on student health and behavior. In Australian research, Alizadeh et al (Alizadeh et al. 2023) discovered that IEQ characteristics such as indoor air quality and illumination impacted the health and behavior of children, particularly those with attention deficit hyperactivity disorder (ADHD). Anemia in preschool children has been shown to have a detrimental impact on cognition, motor development and growth, academic performance, immunity, and susceptibility to infections (Baranwal, Baranwal, and Roy 2014).

IEQ parameter improvements have also been connected to higher academic success. According to Ito and Murakami's (Ito and Murakami 2010) study, enhancing the indoor environmental quality of school buildings can result in significant advantages related to better academic performance. According to Poropat's meta-analysis (Poropat 2014), conscientiousness and openness showed two of the greatest relationships with academic success. low indoor environmental conditions, on the other hand, have been linked to low academic performance, according to Graham et al (Graham, Zotter, and Camacho 2009).

1.2.2. The Impact of Indoor Air Quality on Children's Health and Academic Performance

Indoor air quality (IAQ) is a critical aspect in ensuring that students, instructors, and support staff in schools have a safe, healthy, productive, and comfortable learning environment (Annesi-Maesano et al. 2013). Although poor indoor air quality affects individuals of all ages, children are more susceptible to its negative consequences (e.g., respiratory disorders) (Mainka and Zajusz-Zubek 2015). Recent research has found that air pollution, particularly particulate matter (PM), offers a considerable danger to children, especially those in their early childhood, with continuous exposure connected to unfavorable health consequences such as impaired cognitive function. (Gayer et al. 2018). Several research (Annesi-Maesano et al. 2013) have found that IAQ influences children's attendance and academic achievement. Poor air quality in school classrooms has been documented across the world, including in urban and rural preschools in Poland, as well as kindergarten classes equipped with air purifiers in Germany. Outdoor sources have an impact on air quality in open-air classrooms in cities (Kaewrat et al. 2021). The importance of strong steps to prevent detrimental environmental variables including low IAQ in primary and preschool settings has been emphasized (Sá et al. 2019). According to research, increasing air ventilation rates can enhance indoor air quality, but the effect on cognitive function is inconsistent. Greening schools and boosting children's outside time, on the other hand, have consistently good benefits on cognitive and physical activity (Fernandes et al. 2023). While school surroundings cannot be completely controlled, maintaining appropriate indoor air quality is critical for children's health and well-being (Stauffer et al., 2019).

1.2.3. The Link between IAQ, Health Issues in the Academic Performance of Students

Indoor air quality (IAQ) in educational institutions is a major public health concern since it can induce allergies, hypersensitivity reactions, airway inflammation, malignancies, and infections (Mainka and Zajusz-Zubek 2015). Children, particularly younger children, are more exposed to air pollution than older children because they spend more time indoors and have less mature immune systems and bodies (Mainka and Zajusz-Zubek 2015). Several national and international research initiatives have previously been carried out over the last two decades to examine the relationship between IAQ pollutants and health outcomes for children in public settings, as well as to enhance children's health and well-being (Szabados et al. 2021). In 2004, a study called the Health Effects of the School Environment (HESE) was launched, which collected data on IAQ levels and health outcomes from over twenty-one schools in five countries (Szabados et al. 2021). SEARCH (School Environment and Respiratory Health of Children) investigated the relationship between IAQ and children's respiratory health in 10 primary schools with 735 students in 44 classes (Matic et al. 2017).

Poor IAQ can induce asthma, lung cancer, dizziness, exhaustion, headaches, allergies, hypersensitivity reactions, airway inflammation, and infections (Rahane et al. 2022). Total volatile organic compounds, carbon monoxide, and ozone have all been related to a variety of health impacts in newborns, toddlers, and children under the age of four (Chinathamby et al. 2020). Studies conducted in Malaysia emphasize the significance of indoor air pollution in influencing respiratory health, particularly among school-aged children (Choo and Jalaludin 2015). There is a need to prioritize future IAQ and health concerns, investigate potential ways to enhance IAQ and promote children's health and well-being (Rahane et al. 2022).

1.3. Factors Affecting IAQ in Educational Settings

Poor indoor air quality in classrooms contributes to a variety of health issues, including respiratory tract illnesses, asthma, and allergies. Furthermore, it increases numerous elements that have a detrimental impact on academic achievements, such as distraction, absenteeism, cognitive performance, and lack of perception. According to research, contaminants such as volatile organic compounds (VOCs), carbon dioxide (CO_2), and particulate matter (PM), as well as low thermal and acoustic comfort, can all contribute to these issues.

1.3.1. Impact of CO_2 Concentration on Indoor Air Quality in Classrooms

Carbon dioxide (CO_2) concentration is a crucial measure of indoor air quality and is influenced by factors such as ventilation rate, occupancy, and outside air pollution. Excess CO_2 levels have been found in studies to have detrimental effects on students' cognitive performance and health (Shaughnessy et al. 2006), (Zemitis, Bogdanovics, and Bogdanovica 2021).

Some research has looked into the relationship between indoor CO_2 concentration and student performance, finding a connection between ventilation rate and math exam outcomes (Shaughnessy et al. 2006). Other research has focused on determining the effectiveness of ventilation techniques in terms of indoor air quality and energy consumption. Controlled ventilation can lower indoor CO_2 levels, but it may result in higher energy use. When ventilation periods leading to the air exchange rate required by standards are used, CO_2 concentrations can fall below 1000 ppm, but ventilation losses can account for up to 36% of the total energy required for classroom area heating. On the other hand, when the same air exchange rate is used through mechanical ventilation systems fitted with heat recovery units, the contribution of ventilation energy loss is reduced to 5% and the overall energy savings is greater than 30%. Such energy savings were discovered to be significantly greater in occupancy scenarios represented by more densely occupied classrooms (Stabile et al. 2019).

1.3.2. Volatile Organic Compounds (VOCs) and their effects on Indoor Air Quality

Many types of research have been conducted to investigate the detrimental consequences of volatile organic compound exposure in classrooms on the health and well-being of instructors and children. At room temperature, volatile organic compounds are dangerous molecules that quickly mix with indoor air. The primary sources of volatile organic compounds include furniture, construction materials, cleaning chemicals, and the metabolic processes of people in the area. Volatile organic compounds can refer to a wide range of contaminants. Because many volatile organic chemicals can be detected at higher concentrations indoors than outdoors, the idea of total volatile organic compounds is also commonly utilized today (Mølhave et al., n.d.).

The World Health Organization (2010) (Executive summary. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO. 2021) has linked various volatile organic compounds, such as benzene and formaldehyde, to a variety of health issues in addition to their carcinogenic attributes. However, it is difficult to assess the health impacts of all volatile organic compounds since their sensitivities differ from person to person. However, the existence of volatile organic compounds in the school environment and its impact on children has been the topic of several investigations. For example, Sofuolu et al. discovered that the formaldehyde content was the highest among volatile organic compounds in their investigations in the school environment. They discovered significant quantities of naphthalene, toluene, and benzene, as well as formaldehyde, in the classrooms where they did their research (Sofuoglu et al. 2011).

There are additional studies that suggest that excessive levels of volatile organic compounds in classrooms produce irritation (Willers et al. 1996), dry mouth (Norback' 1995), and negative health impacts (Wargocki et al. 2002), (Z. Bako-Biro 2004), (Wolkoff 2008).

1.3.3. Particulate Matter and its Impact on Indoor Air Quality

Particulate matter is the broad term for small solid or liquid particles of varying sizes and compositions present in the air. Metabolic activities, combustion processes, paint, cleaning products, and furniture are all sources of particle matter. Outside aspects such as construction, traffic, and car emissions are considered particulate matter sources along with interior sources.

Much research has been conducted to investigate the impact of particulate matter exposure on human health. Particulate matter exposure by children and teachers in the school environment is an important research topic due to its harmful impacts on health. According to this research, PM exposure causes respiratory and circulatory diseases, hypertension (Brook et al. 2010) colds, and itchy rashes. (Janssen et al. 2003).

1.3.4. Effects of NO_2 and O_3 on Indoor Air Quality and Health

Outdoor and indoor sources of air pollution, such as NO_2 and O_3, can have an impact on classroom air quality (Bozkurt et al. 2015). Outdoor air pollution infiltration causes high NO_2 and O_3 concentrations, which are important indoor air pollutants with negative health impacts (Che et al. 2021). The high NO_2 concentrations in the classroom suggest that outside sources contribute considerably to indoor NO_2 levels and that NO_2 is predominantly controlled by sources within buildings. The concentration of indoor NO2 in a city school classroom ranged between 46.40 to 77.83 g/m^3, which is approximately 0.8 times that of outdoor NO_2 in (Kaewrat et al. 2021). O_3 concentrations, on the other hand, are greater in rural regions near cities due to ozone distillation (Bozkurt et al. 2015).

The impact of air pollutants on human health might vary depending on concentration and period of exposure. Nonsmokers' lung function can be affected by outdoor air pollution such as NO_2, PM_{10}, O_3, and $PM_{2.5}$ (Zhou et al. 2016). Indoor air pollutants such as NO_2 and O_3 can be reduced by lowering ambient air pollution and infiltrating outdoor pollution (Che et al. 2021). Some of the elements that influence indoor NO, NO_2, and O_3 concentrations in classrooms include ventilation rates, deposition velocities, UV infiltration rates, and filtration (Halios and Helmis 2010).

Air pollution is one of the elements that contribute to the variability in combined particle and gaseous pollutants' human health risk, with $PM_{2.5}$, NO_2, and O_3 having a substantial association with daily total indoor air risk (Hossain, Che, and Lau 2022). COVID-19 lockdowns influence air pollutant concentrations such as NO_2 and O_3, as well as the health impacts linked with them (Chen et al. 2021). NO2 emissions can be reduced by limiting interior sources, installing adequate ventilation systems, and minimizing outside pollution sources ("Potential Sources, Formation Routes, and Health Effects of Nitrogen Dioxide (NO2) on Indoor Air Quality, Human Health, Safety, and the Environment: A Review" 2021).

1.4. Strategies for Improving IAQ in Educational Settings

Indoor air quality (IAQ) in educational environments is critical for health, well-being, and academic performance (Daisey, Angell, and Apte 2003). Evidence shows that active and passive ventilation solutions, as well as focused pollution source mitigation in schools, can enhance IAQ when combined with general awareness (Daisey, Angell, and Apte 2003). It is critical to highlight that window opening and air penetration alone are insufficient to provide adequate ventilation and increase IAQ (Poza-Casado et al. 2021). Ventilation systems must be installed in educational facilities to prevent energy waste and enhance indoor air quality (Poza-Casado et al. 2021). Inadequate IAQ monitoring may have an impact on tenants' academic performance [9].

Preserving architectural characteristics while increasing IAQ is a key difficulty in historic buildings, and low-invasive, low-cost, smart CO2-based alerting systems have been proposed to control natural ventilation and increase IAQ (Avella et al. 2021). Because traditional measures such as window opening may not be effective in cold locations, low-cost alternatives to increase IAQ in naturally ventilated schools must be researched (Uotila and Saari 2023). It is critical to explore and apply various ventilation systems, reduce pollution sources, and frequently monitor indoor air quality in schools (Daisey, Angell, and Apte 2003)(Poza-Casado et al. 2021) To provide a healthy learning environment, educational facilities must have appropriate ventilation and minimal levels of indoor contaminants.

1.4.1. Standards Take on Improving Indoor Environmental Quality

The energy crisis that emerged as a result of the 1973 oil crisis was a forerunner in the development of new technological improvements in the field of energy efficiency in many regions of the world. This process had an impact on the HVAC industry, and standards to improve energy efficiency in the building sector began to develop. However, while this situation improves building energy efficiency, it has resulted in a deterioration in ventilation quality. The difficulties of IAQ have been momentarily brushed aside, and the development trend was defined by increasing the airtightness of buildings and decreasing ventilation rates. As a result of this aptitude, minimum ventilation rates as low as 2.5 l/s per person (5 cfm) were implemented. Simultaneously, stronger limitations on thermal transmissivity losses through the building envelope were enforced. As a result, even though the ventilation rate had been lowered, air change accounted for a bigger share of the overall heating and cooling load of a structure. This resulted in an astonishing, albeit hazardous, worsening in IAQ in northern European nations with harsh winter temperatures and highly stringent laws for energy use (Avgelis and Papadopoulos 2004). In response to this issue, European nations took action, norms, and laws were established, and these studies were implemented to improve indoor air quality. The main issue here is that these standards have yet to materialize at the worldwide level. The criteria supplied by the standards have a broad range due to factors such as varying climatic conditions and geographical characteristics of the nation.

Table 1 informs about standards and their guidelines for classroom environments. In this study further examination of Building Bulletin 101, ASHRAE 62.1 2019, ASHRAE 55:2017 standards have been conducted.

Table 1. Comparison between standards regarding Indoor Air Quality in classroom environments

Type Of Space	Category	m^3/h per occupant	m^3/h per m^2	Air Velocity (m/s)		Temperature (°C)		Sound Level (dB)
				Min	Max	Min	Max	
ASHRAE 62.1:2019 ASHRAE 55:2017								
Primary Schools Occupant: 31 Area: 39.2 m^2	-	18	2.16	0.2	0.8	20	24	-
Building Bulletin 101 August 2018, United Kingdom								
Primary Schools Occupant: 31 Area: 39.2 m^2	-	10,8-28,8	-	0.15	0.3	20	25	35
Le Règlement Sanitaire Départemental Type (RSDT), France								
Primary Schools Occupant: 31 Area: 39.2 m^2	-	15	-	-	-	-	-	-
EN 15251:2012								
Very Low Polluting Building								
Primary Schools	I	36	1.8	-	-	20	24	-
Occupant: 31	II	25.2	1.26					
Area: 39.2 m^2	III	14.4	0.72					
Low Polluting Building								
Primary Schools	I	36	3.6	-	-	20	24	-
Occupant: 31	II	25.2	2.52					
Area: 39.2 m^2	III	14.4	1.44					
Non Low Polluting Building								
Primary Schools	I	36	7.2	-	-	20	24	-
Occupant: 31	II	25.2	5.04					
Area: 39.2 m^2	III	14.4	2.88					
D2 National Building Code of Finland, Indoor Climate and Ventilation of Buildings, Regulations and Guidelines 2012								
Primary Schools Occupant: 31 Area: 39.2 m^2	-	28.8	21.6	0.2	0.3	20	22	33-38

1.4.1.1. Building Bulletin 101's (BB101) take on Indoor Environmental Quality

The UK Department for Education's Building Bulletin 101 (BB101) is a design guide that contains recommendations and performance standards for various environmental aspects in classrooms.

For schools, BB101 recommends a temperature range of 20-25°C. This temperature range provides a comfortable thermal environment for both students and teachers. The guidance recommends installing efficient heating and cooling systems capable of maintaining the specified temperature range throughout the year. It recommends considering insulation, solar management, and adequate thermal comfort settings.

To maintain a calm and pleasant study environment, BB101 specifies suggested maximum background noise levels. During educational activities, background noise levels in classrooms should not exceed 35 decibels (dB), by the standard. The guide recommends reverberation time, which is the time it takes for sound to decay by 60 decibels after a sound source is turned off. For schools, BB101 recommends a reverberation time of 0.6-0.8 seconds.

For average occupied areas in schools, BB101 recommends a minimum ventilation rate of 3-8 liters per second per person (l/s/person). This contributes to the maintenance of appropriate interior air quality by diluting and eliminating contaminants while also guaranteeing an adequate supply of fresh outside air. The advice further suggests that CO2 levels are being monitored and controlled as an indicator of indoor air quality. It suggests keeping CO2 levels under 1,500 parts per million (ppm) during educational activities and under 1,000 ppm during more busy hours. It emphasizes the significance of reducing indoor pollution sources such as emissions from building materials, furniture, and cleaning chemicals. It recommends utilizing low-emission products and employing effective cleaning procedures to maintain healthy interior air quality.

There are no particular guidelines for average air velocity in classrooms in BB101. However, it underlines that airflow should not cause occupants discomfort or draughts. Adequate air circulation should be maintained without causing drafts or uneven air distribution. To achieve these, Standard advises maintaining air velocity between 0,15 and 0.30 m/s relative to temperature differences ("Building Bulletin 101: Guidelines on Ventilation, Thermal Comfort and Indoor Air Quality in Schools" 2018).

1.4.1.2. Recommendations of ASHRAE 62.1-2019 and ASHRAE 55-2017 on Indoor Environmental Quality

ASHRAE 62.1-2019 and ASHRAE 55-2017 are two key standards developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) that address ventilation, thermal comfort, and indoor air quality in various building types, including classrooms. While these standards do not specifically focus on acoustic performance, average air velocity, or air age, they provide valuable recommendations for thermal conditions and indoor air quality in classrooms.

ASHRAE 62.1-2019: Ventilation Rates and Indoor Air Quality standard specifies minimum ventilation rates for classrooms based on occupancy. It recommends a ventilation rate of at least 7.5 liters per second per person (l/s/person) for typical classrooms. Higher rates may be required for specialized classrooms or during periods of increased occupancy. Standard also includes requirements to maintain acceptable indoor air quality. It addresses factors such as outdoor air quality, contaminant control, and air filtration. The standard encourages the use of effective filtration systems to remove particulate matter and recommends periodic maintenance and cleaning of ventilation equipment.

Standard also provides thermal comfort guidelines based on the acceptable temperature range for occupants. It suggests a typical range of 20-24°C for summer cooling conditions and 20-23.5°C for winter heating conditions. The standard recommends maintaining air velocities below certain limits to prevent discomfort. For sedentary activities in classrooms, ASHRAE 55-2017 suggests average air velocities below 0.25 meters per second (m/s) or 50 feet per minute (fpm) minimize draft effects ("ANSI/ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality" 2019).

1.4.2. Concept of Age of Air in Indoor Environmental Quality and Aim of Study

The average period it takes for the air in a space to be replaced by fresh air is referred to as the Age of Air. In many studies, the idea of the "age of air" is frequently employed to measure indoor air quality. Factors such as ventilation rate, room size, air exchange efficiency, and the presence of pollution sources all impact the age of air. The age of the air is significant because it influences the concentration and distribution of indoor air contaminants. Pollutants can build in a space with limited ventilation or a low air exchange rate, resulting in poor indoor air quality. On the other hand, a faster ventilation rate and effective air exchange can assist dilute and eliminate contaminants, resulting in better air quality.

There are, however, no commonly acknowledged criteria for the age of air in a room. As indicated in the preceding chapter, several organizations and guidelines make recommendations for indoor air quality and ventilation rates to maintain occupant comfort and health. While there is no set requirement for mean air age, these guidelines normally seek to ensure appropriate ventilation to manage indoor air contaminants and maintain acceptable indoor air quality. These standards primarily affect ventilation rate, room size, air exchange efficiency, and air pollutant sources.

The technical capabilities of today allow efficient and rapid age of air computations for determining indoor air quality. The study intends to highlight the relevance of air age calculations by investigating a concept ventilation model based on the restrictions stated by the standards mentioned in the previous chapter to enhance indoor air quality in schools.

CHAPTER 2

METHODOLOGY

2.1. Research Design and Approach

To examine the ventilation quality in the classroom and the designed ventilation method, numerical analyzes were made using three-dimensional computational fluid dynamics software. The class model is shown in Figure 4. The classroom model was taken from a classroom in Nihat Gündüz Secondary School located in Işıkkent district of İzmir, Turkey. This class has been the subject of many studies in the fields of air conditioning and ventilation.

The classroom model measures 6.28m x 6.24m x 2.88m. In the classroom, thirty students sit in single rows with a desk section of 0.62 m x 0.44 m x 0.11 m and a seating area of 0.60 m x 0.24 m x 0.01 m, the teacher sitting in front of him, 1.07 m x 0.59 m x 0.1m. They are sitting in a chair measuring 0.6 m x 0.29 m x 0.01 m with a table measuring 11 m. The classroom also has a 0.86 m x 0.38 m x 1.83 m cabinet. In the student and teacher models, to simplify the model and speed up the calculations, the legs were joined so that there was no space in the middle, and volume was added around the area where the individuals sat. The legs of the desk, table, and chairs are not included in the model.

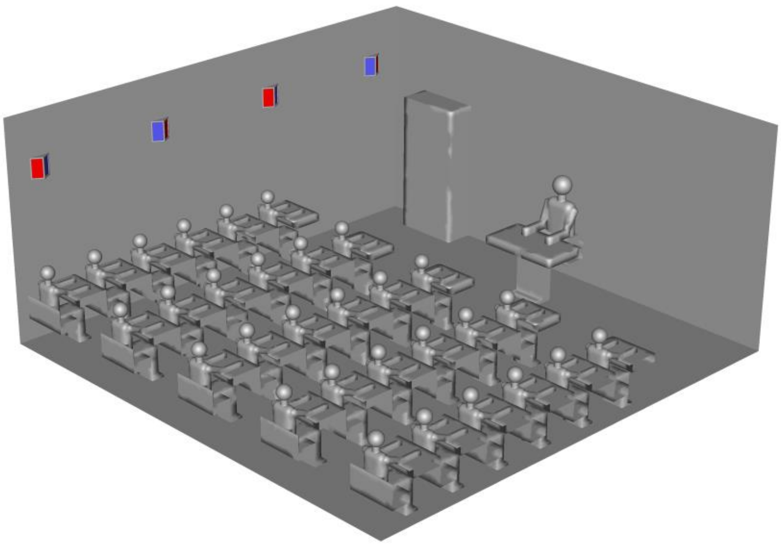


Figure 4. Classroom Model

In the design of the model ventilation system, 4 heat recovery devices with equal capacity were used. Heat recovery devices are placed in holes of 0.26 m x 0.26 m dimensions and opened on the exterior wall of the classroom with 1.8 m intervals. The device is a recuperative heat recovery device, making an angle of 32 degrees between the supply and exhaust diffusers and the wall. In this way, it is aimed to prevent short-circuiting of the airflow between the exhaust line and the supply line. The face areas of the supply and exhaust diffusers are 0.24 m x 0.13 m. In Figure 5, details for the model used in the investigations are given.

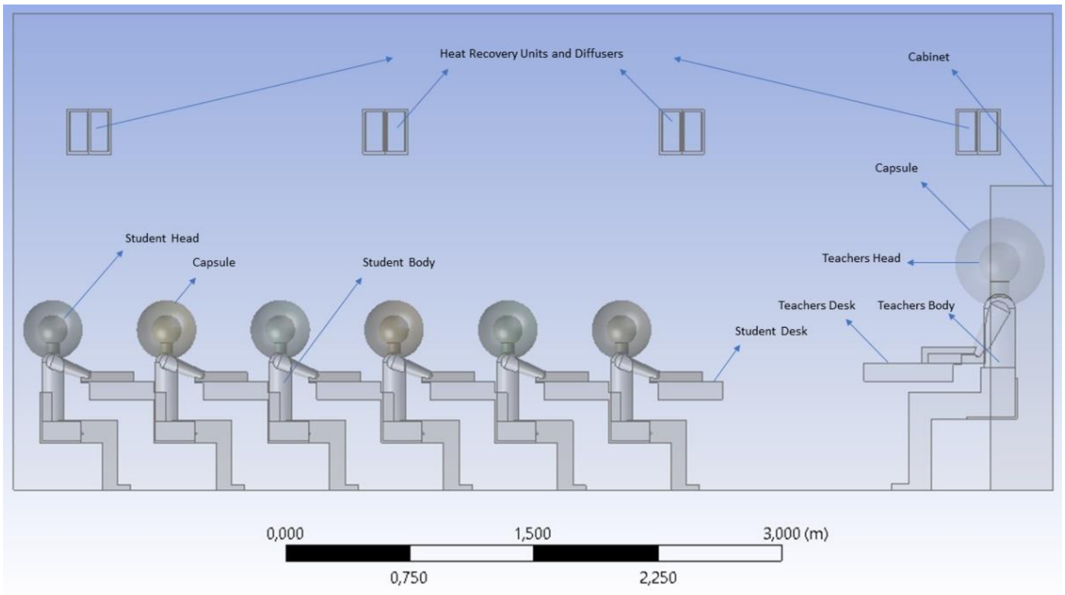


Figure 5. Side View of Classroom Model

The diffusers of the ventilation units facing each other are intended to perform the same function. It is desired to reduce the air velocities rapidly by ensuring the mixing of the air streams coming out of the supply diffusers by operating the opposite sides in the same mode. In this way, it is ensured that high-speed air draughts are prevented in the occupied zone. Heat recovery devices are placed at a height of 1.6 m or 2.0 m from the floor. In addition, the effect of angling the diffusers was investigated by allowing the heat recovery devices to blow at an angle of 5° and 10° horizontally toward the floor.

2.2. Description of the Case Study or Numerical Setup

To determine the ventilation quality in the classroom, certain measurement points should be created on the classroom model. In Figure 6, the measurement points are shown as green capsules around the heads of the students. On these surfaces, air velocity to which the students are exposed will be measured according to the ventilation rates determined by the standards for the classroom environment, and the air age around the head of the students will also be calculated. Capsule surfaces are located at a distance of 9 cm from the students' heads.

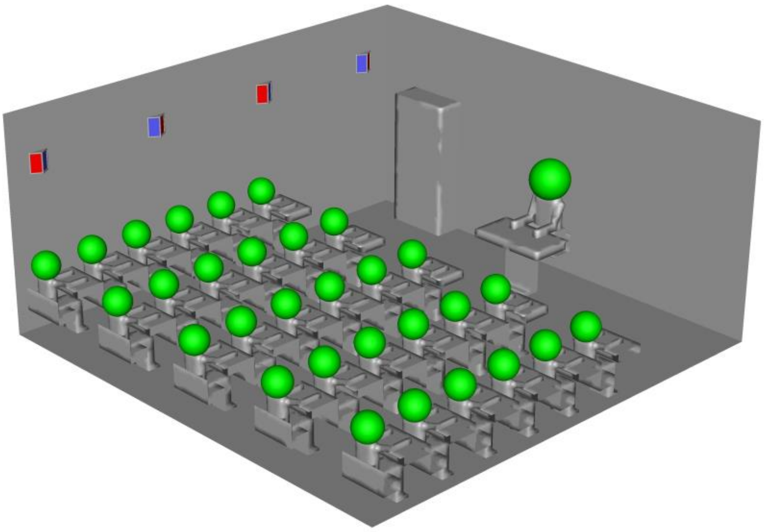


Figure 6. Classroom model with measurement Locations (Green Capsules)

2.2.1. Determination of Required Ventilation Rates

ASHRAE 62.1 “Ventilation for Acceptable Indoor Air Quality” and Building Bulletin 101 “Guidelines on Ventilation, Thermal Comfort and Indoor Air Quality in Schools” standards have been adhered to calculate required ventilation rates in the classroom. In this way, it is aimed to see the effect of models or systems being prepared according to different standards on indoor air quality.

2.2.1.1. Calculating Ventilation Needs Based on ASHRAE 62.1 Ventilation for Acceptable Indoor Air Quality Standard

The ASHRAE 62.1 standard was created by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers to determine the minimum and recommended airflow rates and other measurement parameters, aiming to minimize the negative effects of indoor air quality on human health according to different space types.(“ANSI/ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality” 2019).

Classroom environments are classified as Class 1 environments by the standard, which means they have "air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odor.". The standard allows the transfer of Class 1 category air to any space. The following equation is used to calculate the ventilation flow rate within the scope of the standard.(“ANSI/ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality” 2019).

$$V_{bz} = R_p \times P_z + R_a \times A_z$$

In this equation, A_z stands for the surface area of the space that needs to be ventilated (in m^2), P_z is the number of people in the space, $R_p$is the amount of outside aairflowperperson according to the space type to be determined from Table 6−1 in the Standard, R_a the amount of airflow based on the unit surface area of the space that needs to be determined from Table 6-1. The floor of the classroom is 39.2 m^2. There are 31 individuals in total in the class, including 1 teacher and 30 students. Based on this data, the total ventilation flow rate is determined to be 645.1 m^3/h by ASHRAE 62.1 (“ANSI/ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality” 2019).

2.2.1.2. Determination of Ventilation Rate by Building Bulletin 101

Building Bulletin 101, the Ventilation of School Buildings directive contains standards for school buildings based on ventilation, thermal comfort, and indoor air quality. The directive was created in the UK by the Education and Skills Funding Agency under the Ministry of Education ("Building Bulletin 101: Guidelines on Ventilation, Thermal Comfort and Indoor Air Quality in Schools" 2018).

The standard specifies the ventilation rates for the concentration of various pollutants such as CO_2, CO, NO_2, PM_{10}, etc., and the limit values for various spaces within the school building, such as laboratories, toilets, gymnasiums, classrooms, and dining halls. According to the standard, the ventilation requirement of classroom environments should be determined according to one of the values of 2.3 l/s/m^2 or 8 l/s/person. The larger of these values should be selected. When the flow rate is computed based on the 39.2 m^2 floor area and population of 30+1 population, 324.5 m^3/h of ventilation is required for the area and 892.8 m^3/h for the population. In this study, a higher flow rate of 892.8 m^3/h was selected by the standard.("Building Bulletin 101: Guidelines on Ventilation, Thermal Comfort and Indoor Air Quality in Schools" 2018).

As a result, the ventilation requirement of the classroom model was determined as 643 m^3/h and 892.8 m^3/h for ASHRAE 62.1 and BB 101 standards, respectively. To make the calculations more explainable and to make the applicability of the system more possible, the ventilation values of the class model were determined as 600 and 800 m^3/h. In addition, a 400 m^3/h ventilation value will be examined to examine the indoor air quality in the class at a low air flow rate. This will allow us to compare the outcomes of three different ventilation flow rates for the classroom setting. Table 2 shows the required ventilation rates according to numerous standards in addition to the aforementioned standards above.

Table 2. According to various standards, the quantity of ventilation flow rates required based on the case analysis's criteria

Type Of Space	Category	m^3/h per occupant	m^3/h per m^2	m^3/h occupant	m^3/h area	m^3/h Total
ASHRAE 62.1:2019 ASHRAE 55:2017						
Primary Schools Occupant: 31 Area: 39.2 m^2	**-**	**18.0**	**2.2**	**558.0**	**84.7**	**642.7**
Building Bulletin 101 August 2018, United Kingdom						
Primary Schools Occupant: 31 Area: 39.2 m^2	**-**	**10,8-28,8**	**-**	**334.8-892.8**	**-**	**334.8-892.8**
Le Règlement Sanitaire Départemental Type (RSDT), France						
Primary Schools Occupant: 31 Area: 39.2 m^2	**-**	**15.0**	**-**	**465.0**	**-**	**465.0**
EN 15251:2012						
Very Low Polluting Building						
Primary Schools	**I**	**36.0**	**1.8**	**1116.0**	**70.6**	**1186.6**
Occupant: 31	**II**	**25.2**	**1.3**	**781.2**	**49.4**	**830.6**
Area: 39.2 m^2	**III**	**14.4**	**0.7**	**446.4**	**28.2**	**474.6**
Low Polluting Building						
Primary Schools	**I**	**36.0**	**3.6**	**1116.0**	**141.1**	**1257.1**
Occupant: 31	**II**	**25.2**	**2.5**	**781.2**	**98.8**	**880.0**
Area: 39.2 m^2	**III**	**14.4**	**1.4**	**446.4**	**56.4**	**502.8**
Non Low Polluting Building						
Primary Schools	**I**	**36.0**	**7.2**	**1116.0**	**282.2**	**1398.2**
Occupant: 31	**II**	**25.2**	**5.0**	**781.2**	**197.6**	**978.8**
Area: 39.2 m^2	**III**	**14.4**	**2.9**	**446.4**	**112.9**	**559.3**
D2 National Building Code of Finland, Indoor Climate and Ventilation of Buildings, Regulations and Guidelines 2012Regulations and Guidelines 2012						
Primary Schools Occupant: 31 Area: 39.2 m^2	**-**	**28.8**	**21.6**	**892.8** **Whichever value is higher.**	**846.7**	**892.8**

2.2.2. Governing Equations of Numerical Setup

The class model was analyzed in a pressure-based pseudo transient solver. Mass conservation of the velocity field (continuity) is achieved by solving a pressure equation. In the coupled pressure-based algorithm, a coupled system of equations consisting of momentum and pressure-based continuity equations is solved.

The k – ε turbulence model is one of the most common methods used today to examine the characteristics of turbulent flows in computational fluid dynamics applications. It can be examined under three sub-titles: “Standard”, “RNG” and the relatively new development “realizable” k – ε model. The realizable k – ε model differs from the other models mentioned in two main aspects.

- The realizable k-ε model contains a new formulation for the turbulent viscosity.
- A new transport equation for the dissipation rate, ε has been derived from an exact equation for the transport of the mean-square vorticity fluctuation.

A model is considered to be "realizable" if it satisfies specific mathematical restrictions on Reynolds stresses that are in line with the physics of turbulent flows. Both the regular k-model and the RNG k-model are not realizable.

The realizable k- model has the immediate advantage of better predicting the spreading rate of both planar and round jets. Furthermore, it is expected to perform better for flows that involve rotation, boundary layers subjected to severe adverse pressure gradients, separation, and recirculation.

For gradients, the least square cell based method was applied. This method is similar to the node-based gradient method in irregular, highly skewed meshes. However, both methods have better performance than the cell-based gradient method. Finally, calculating the least squares gradient requires less computational power.

Second-order accuracy is desired in the calculation of momentum, pressure, k – ε and age of air parameters. In this approach, a higher level of accuracy is achieved on the cell faces by expanding the Taylor series around the cell center(“ANSYS FLUENT 12.0 Theory Guide” 2009).

In this section, the parameters of the solver are explained and the governing equations of the analysis are given. Equations and detailed reviews of the mentioned methods and models are available in the Ansys Fluent User Guide. Each parameter of the study was analyzed with the solver mentioned in this section. In the next sections, the mesh used in the analyzes and then the validation of the analyzes performed with the selected model are examined.

2.3. Validating Numerical Model and Setup

Before performing a numerical analysis of the class model, it is important to assess the solver's precision and the model's mesh quality. The features of airflow and the turbulence model will be checked with the experimental studies after selecting the appropriate mesh model, and then the applicability of the solver will be assessed. Selection of the appropriate mesh structure

Creating a proper mesh for numerical analysis is essential to proceed with the study. However, increasing the number of elements in the model will lead to the prolongation of the analysis time. For this reason, the Normalized Root Mean Square (NRMS) method will be used to select the appropriate mesh. The percentage difference between the models was examined by performing analyses with the meshes created with different parameters. As a result, the mesh model with the least percentage difference and the shortest analysis time was selected.

Three different models were determined for the classroom model. These models are defined as C08-75, C20-50, and C20-75 models. The parameters of the mesh can be seen in Table 1. The mesh structure is 0.05 m on the body of the students and the teacher, and 0.005 m on the diffuser faces in each model. The main features that distinguish the described models from each other are the element dimensions of the mesh structure around the head, in the capsules, and the general volume.

Table 3. Mesh Parameters of C08-75 Model, C20-50 Model and C20-75 Model

	Model: C08-75	Model: C20-50	Model: C20-75
Geometry	Element Size (m)	Element Size (m)	Element Size (m)
Capsules	0.008	0.02	0.02
Head	0.008	0.02	0.02
Diffuser Faces	0.005	0.005	0.005
Volume	0.075	0.05	0.075
Student Bodies	0.05	0.05	0.05
Teacher Body	0.05	0.05	0.05

Class mesh structures are required to have high element quality, low skewness, and high orthogonal quality values. Mesh statistics of these three models are given in Table 4.

Table 4. Mesh statistics for models

Model	Statistics		Element Quality (Higher is better)		Skewness (Lower is better)		Orthagonal Quality (Higher is better)	
	Nodes	Elements	Average (0<X<1)	Standard Deviation	Average (0<X<1)	Standard Deviation	Average (0<X<1)	Standard Deviation
C08-75	2628655	15173282	0.834	0.084	0.231	0.103	0.768	0.101
C20-50	1672823	9557614	0.843	0.083	0.217	0.099	0.782	0.098
C20-75	864363	4869340	0.836	0.088	0.228	0.105	0.771	0.104

The mesh structure of the C08-75 model is visualized in Figure 7. The element size is 0.008 m in the head and surrounding capsules, and 0.075 m in the general volume. The mesh structure has more than 15 million elements.

a) b)

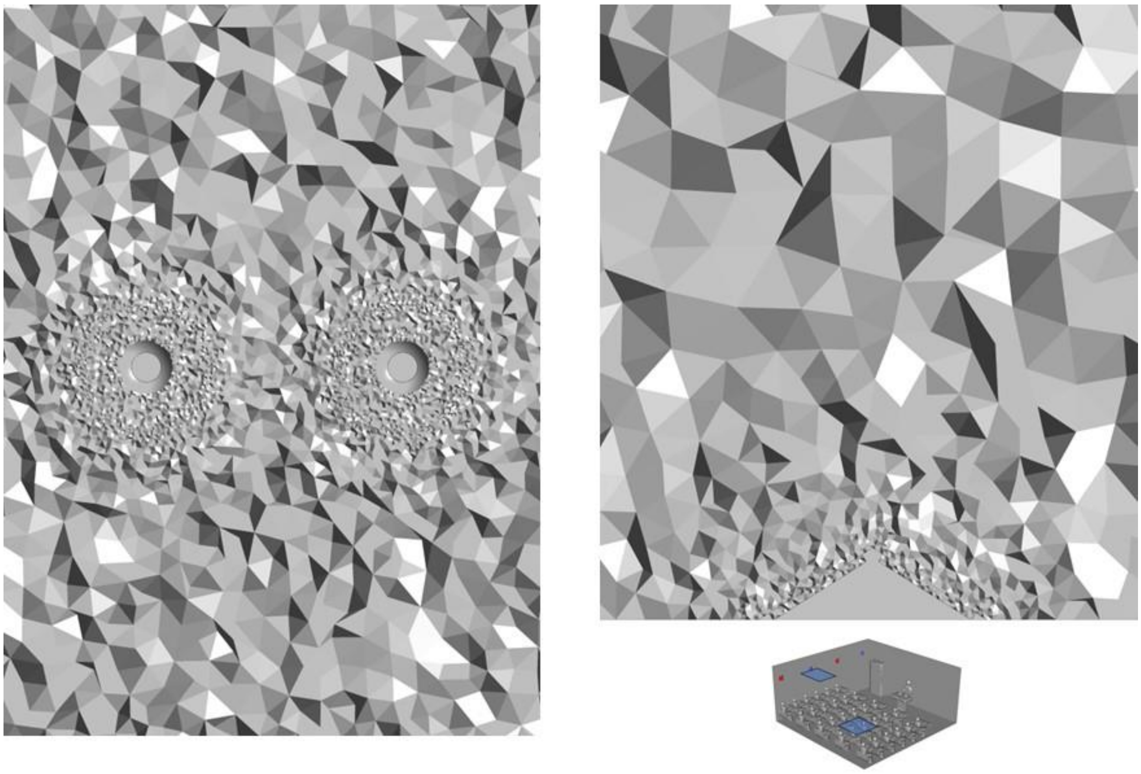


Figure 7. Mesh Structure of C08-75 Model (a) around student heads (b) around diffusers. The class model on the corner of the figure shows location

The C20-50 model is an interim model when compared between C08-75 and C20-75. The model can be examined in Figure 8. It has 9.6 million elements and has a comparable mest quality to the C08-75 model. Figure 8 shows the mesh structure of the C20-50 model.

a) b)

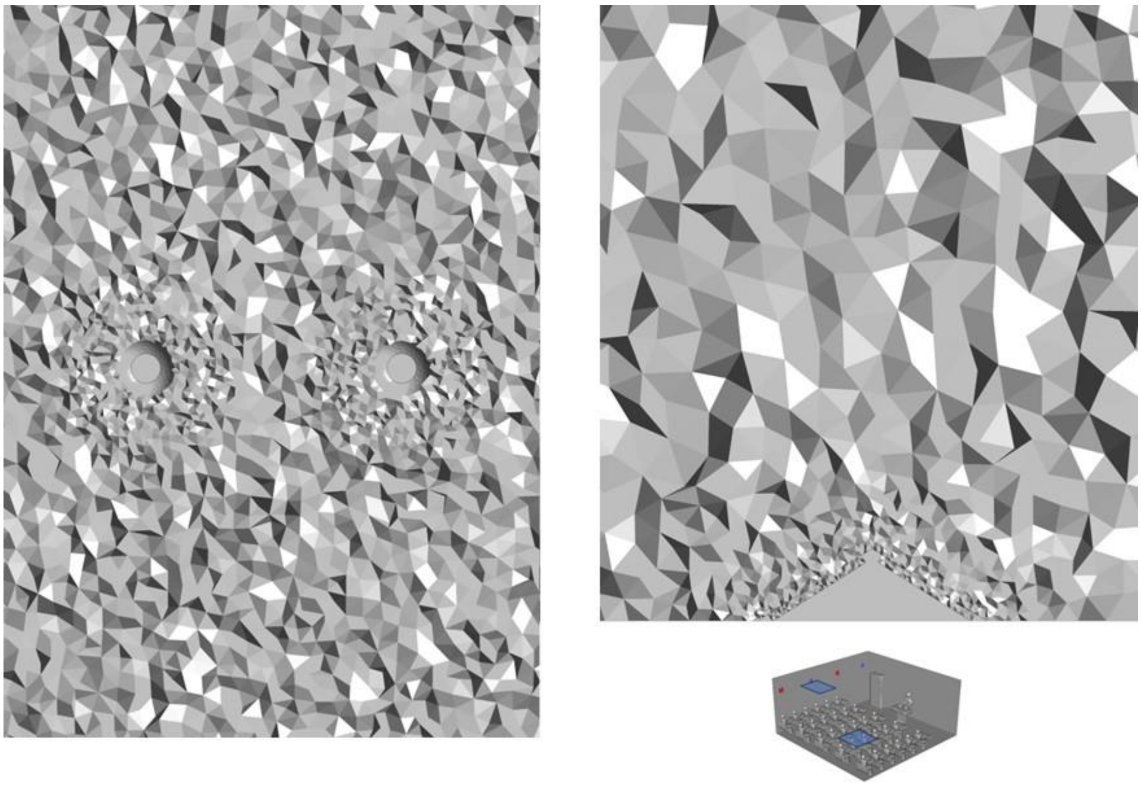


Figure 8. Mesh Structure of C20-50 Model (a) around student heads (b) around diffusers

The C20-75 model has the least amount of elements compared to the other two models mentioned. There are elements of 0.02 m around the head and on the capsule surfaces, and 0.075 m in the volume of the space, as in the C08-75 model. There are approximately 4.9 million meshes in the model. The mesh structure of the C20-75 model can be seen visually in Figure 9. It has comparable quality to both C20-50 and C08-75 models.

(a) (b)

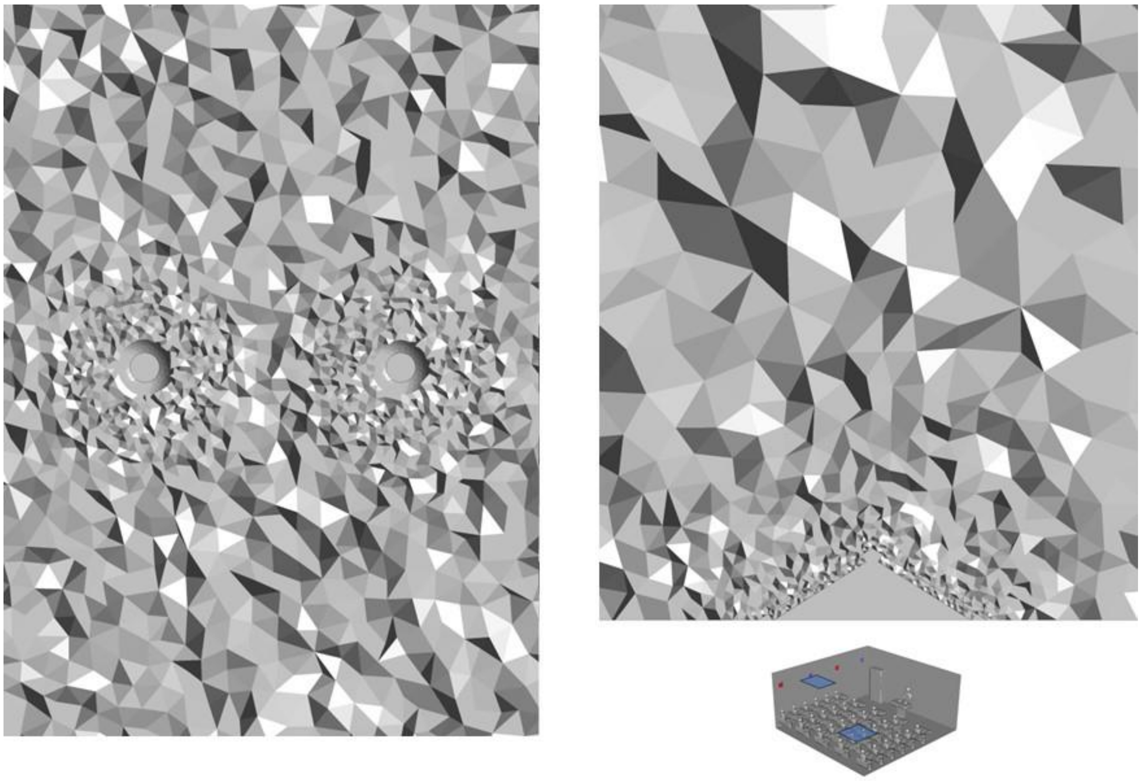


Figure 9. Mesh Structure of C20-75 Model (a) around student heads (b) around diffusers

When all three models are examined, it is seen that the element quality, skewness, and orthogonal quality values are close to each other. Although the C08-75 model has more than 3 times the number of elements than the C20-75 model, it can be seen from the mesh statistics that the mesh structures of these models do not differ greatly from each other. After this stage, analysis was made for each model to select the model to be used in the study, and the results were compared with each other with the NRMS method.

2.3.1. Analysing Models with Normalised Root Mean Squared Error (NRMS) Method

In statistical modeling, and especially in regression analysis, one way of measuring the quality of model fit is the RMS method. (Also called Root Mean Square Deviation). It is defined by the formula below. “n” is the number of data, y_i is the measured data, and $\hat{y}_i$ is the predicted data.

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}$$

The normalized root mean squared error (NRMS) is the definition of statistical error for comparing different data in different scales. The NRMS approach is employed as a method for comparing data of several meshes. The formula of the NRMS method is given below. It can be obtained by dividing the RMS value by the mean of the measured values.

$$NRMS = \frac{RMS}{\bar{y}}$$

A computational fluid dynamics study was carried out for all three models as described in the preceding section to determine the class model. The ventilation flow rate for the class was identified to be 800 m^3/h for each model. The analysis process involves 2000 iterations. The average air velocity around each student's head was discovered as a result of the analyses. The NRMS value compares the average air velocity data for each model around the students' heads. Figure 9 displays the calculated average air velocity values for the students in the front row of the C08-75 model over the course of the simulation. Appendix A contains graphs showing how iteration affects the average air velocity values for each model over the whole class. When Figure 10 is analyzed, it can be observed that the average air velocity values stabilize as the number of iterations rises while the standard deviation for some students falls.

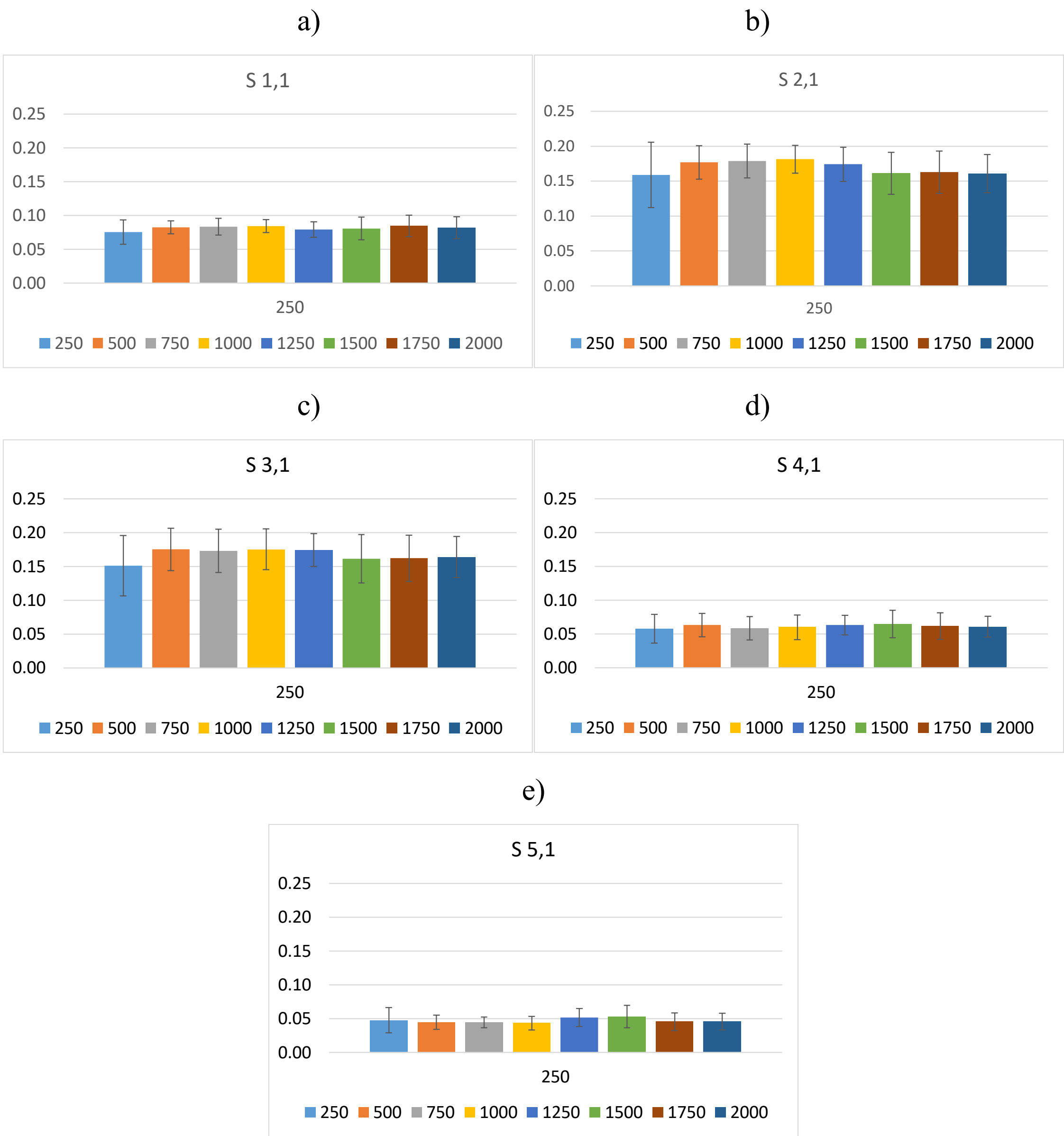


Figure 10. Graphs show mean of average velocity values per 250 iteration for the C20-75 model. In this scenario, HRV unit placed 2.0 m above the floor, total air flow is 800 m^3/h, and diffuser angle is 5°. a), b), c), d), e) graphs are representing the front row of students.

The RMS and NRMS values were produced by comparing the three models after evaluating the average air velocity for each model around the students' heads. Table 5 displays the percentage differences between the models as a result. The C08-75 model differs from the C20-50 model by 8% and the C20-75 model by 8.5%, respectively, as shown in the table. Additionally, the C20-50 and C20-75 versions differ by 6.2%.

While there is a 0.5% NRMS value difference between the C08-75 model and the C20-50 and C20-75 models, there is a 6.2% NRMS value difference between the C20-50 and C20-75 models. This difference is a result of fluctuations in the average velocity values that were observed during the numerical analysis. All of the NRMS values that were obtained as a result of the model comparisons are under 10%.

Table 5. RMS, NRMS, and percentage differences between models

	C08-75 & C20-50	C20-50 & C20-75	C08-75 & C20-75
RMS	0.007	0.006	0.008
NRMS	0.080	0.062	0.085
%	8	6.2	8.5

As a result, analyses will proceed with the C20-75 model in the following sections to reduce analysis times.

2.3.2. Difficulties of Steady State Flow Analysis and Data Collection Procedures

The study's parameters were chosen as the C20-75 model in the previous section. This part explains the settings under which these parameters will be investigated, the data that is planned to be obtained as a result of the analysis of the models, and the acceptability of these data.

When Figure 10 and Figure 11 were examined, it has been observed that steady-state analysis is not showing a consistent pattern. Figure 11 shows the average air velocity/iteration graphs of the students in the front row. In this analysis heat recovery devices with a total flow rate of 800 m^3/h, are placed at 2.0 m above the ground, and diffusers of units are angled 10° ve 5° towards the ground. Average air Velocities per iterations Graphs for all parameters are available in Appendix B. In these graphs, it is observed that the average air velocities around the heads are fluctuating continuously during the analysis. These fluctuation ranges are different for each student. For this reason, it can be misleading for solutions that only utilized the last iteration of analysis.

Gori et al. Experimented with flow evolution of a turbulent submerged rectangular free jet of air with Particle Image Geometry visualizations. In this experiment, average

Particle Image Velocimetry (PIV) visualizations and measurements were created by an ensemble of 100 instantaneous velocity samples with a 5 Hz acquisition rate to examine the undisturbed region of flow. By this information, when Figure 10 is examined, it is observed that the volatility decreased and a more stable result was observed in the graphics prepared with the average of each 250 iterations. For this reason, the average air velocity analysis made in the following sections will be calculated as the average of the last 500 iterations.

In Appendix B, graphs of the average air velocity around the head of the students per iteration for each parameter of the classroom model can be examined. When the 800-200-10 (800 m^3/h flow rate, 200 cm device height, 10° diffuser angle) model in Appendix B is examined. In this graph mean value of average velocity around students' heads is 0.096 m/s. And standard deviation of this mean value was calculated as +-21.8%.

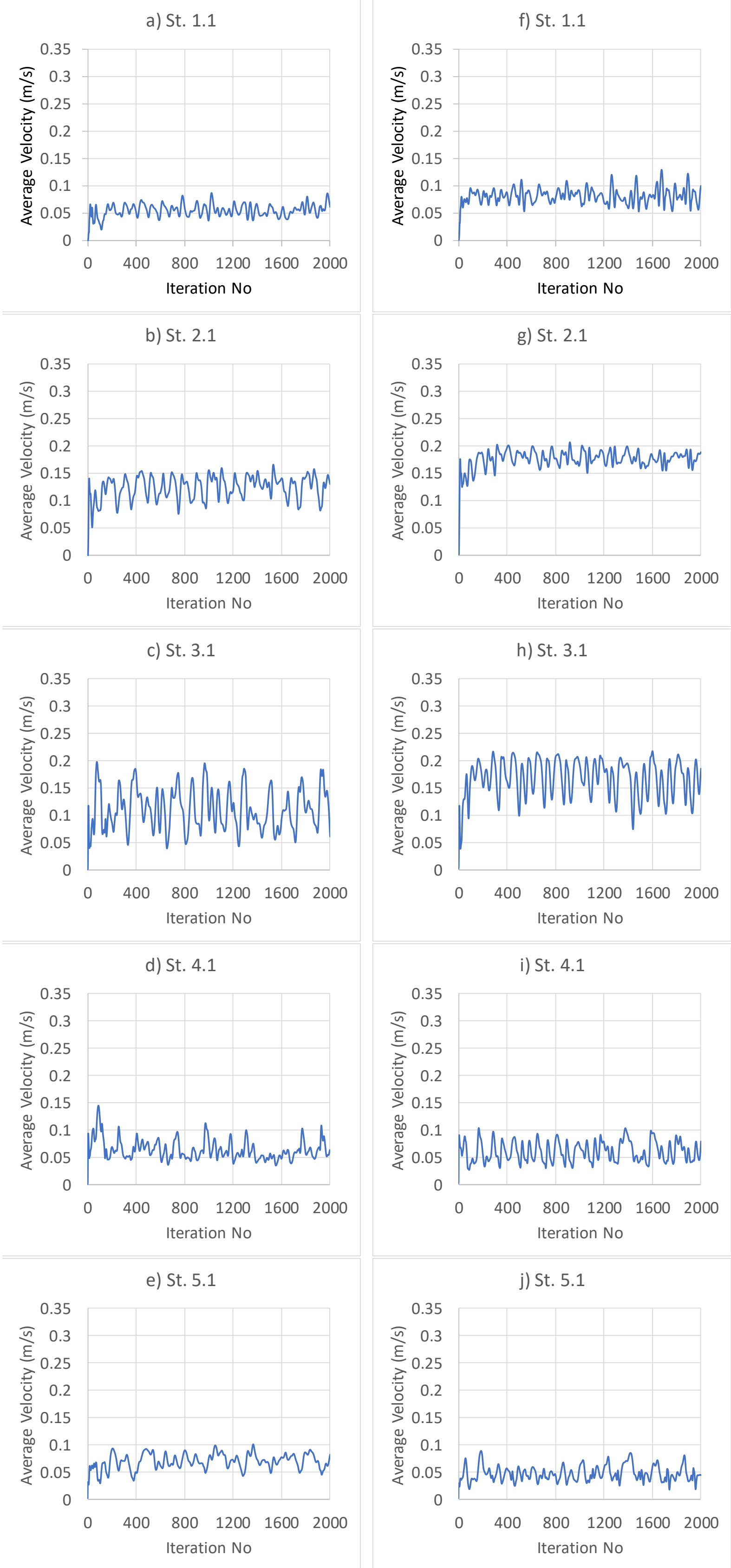


Figure 11. Average air velocities per iteration around students' heads at 800 m^3/h. a), b), c), d), e) are the front row of students when the air diffuser is angled 10° downwards. f), g), h), i), j) are the front row of students when the air diffuser angled 5° downwards.

In this section, it is stated how the fluctuation of the average air velocity values depending on the iteration will affect the calculation process in the analyzes to be made. In conclusion, in further experiments for every parameter average values of the last 500 iterations will be taken. In addition, the ratio of the average standard deviation of the average air velocity around the head to the overall average air velocity was calculated as approximately +-21%. This fluctuation in the air flow has revealed the need to examine the flow model. In the next section, the airflow model of the classroom model is examined through experimental studies.

2.3.3. Analyzing Flow Model

Once the mesh of the class model had been chosen, the accuracy of the solver was evaluated by comparing the numerical analysis data to those from the experimental study. Venuta et al., one of the two experimental analyses that were examined, uses numerical and experimental modeling to examine the development of fluid flow and mass transfer in a rectangular free-air jet. They investigated the flow characteristics of free jet flows by performing numerical and experimental evaluations at various Reynolds numbers (Di Venuta et al. 2018).

Another study to be compared is “Experiment and Large-Eddy Simulation on Free Air Jets Issuing from a Rectangular Nozzle with Deflectors” by Ouchi et al.. This study aimed to place a diverter inside a rectangular duct to develop a passive flow control method. The study examining the effect of the angling of the deflectors on the characteristic of free flow takes place at the Reynolds number value of 9000.

The investigation of the solver and the air flow model of the class model was carried out in two stages. First, the solver was compared with the mentioned studies, and then the air flow in the classroom model was examined according to the results obtained.A model resembling the numerical study conducted by Ouchi et al. was developed to compare the two studies. (Ouchi et al. 2021). The model's dimensions are 0.6 m in length, 0.42 m in height, and 0.45 m in depth. A 0.42 m × 0.45 m surface has a 0.65 m x 0.03 m and 0.1 m long duct in the middle that serves as the supply point. Figure 12 depicts the model that will be used to investigate the solver. This flow model has similar mesh characteristics compared to the C20-75 model.

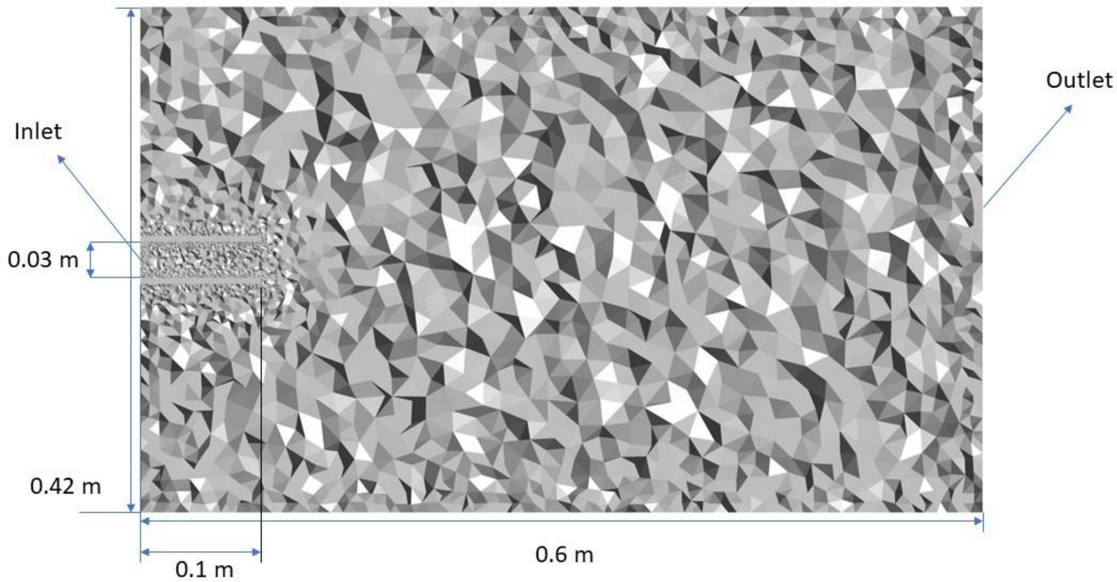


Figure 12. The mesh in which the solver model will be analyzed

To examine the solver, a flow model was created based on the Reynolds numbers in both studies. Reynolds number is calculated by the formula below.

$$Re = \frac{\rho . u . d_h}{\mu}$$

In this equation, ρ is density (kg/m^3), u is the linear velocity of the fluid passing through the cross-sectional area (m/s), d_h is the hydraulic diameter (m), μ is the dynamic viscosity (Ns/m^2). The air temperature is taken as 15 °C in the model. According to this temperature value, the air velocities were calculated as 3.723 m/s for the study of Venuta et al. (Re=10400) and as 3.22 m/s for the study of Ouchi et al. (Re=9000).

The comparison of the airflow model of the analysis based on the 10400 Reynolds number in the study of Venuta et al. can be seen in Figure 13.

(a) (b)

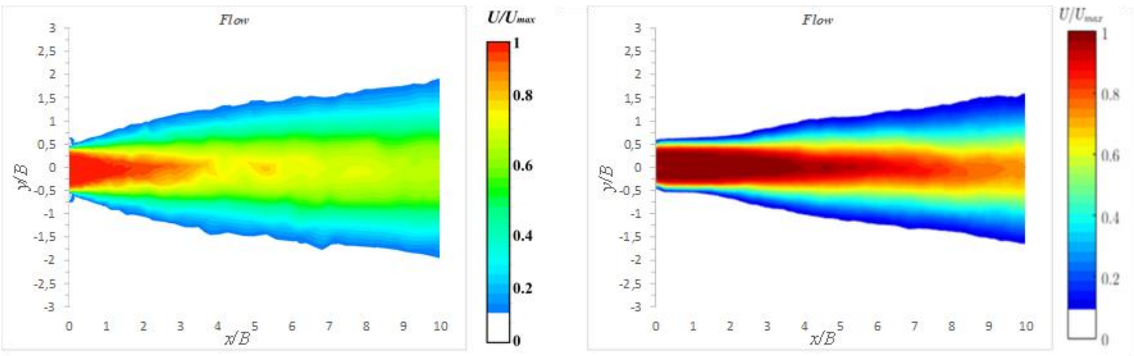


Figure 13. Flow Characteristics of Two Similar Cases (a) Numerical Flow Model of case study, (b) experimental PIV (b) results at Re = 10,400 (Di Venuta et al. 2018).

In Figure 14, linear velocities of free flow at certain distances obtained from numerical and experimental (Di Venuta et al. 2018) studies are given.

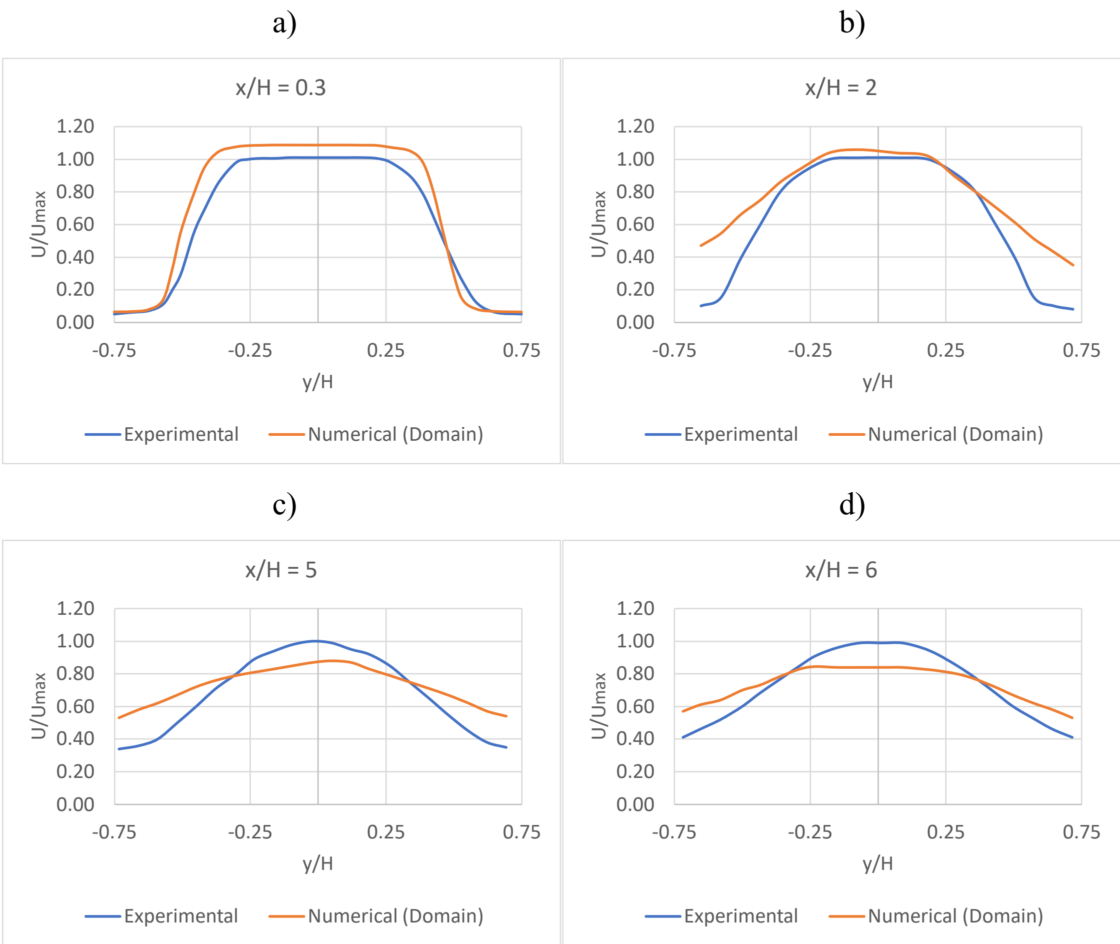
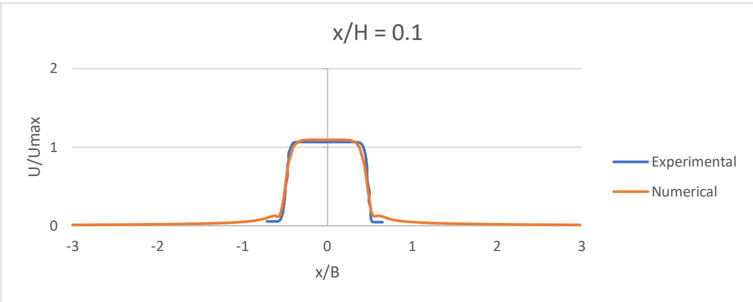


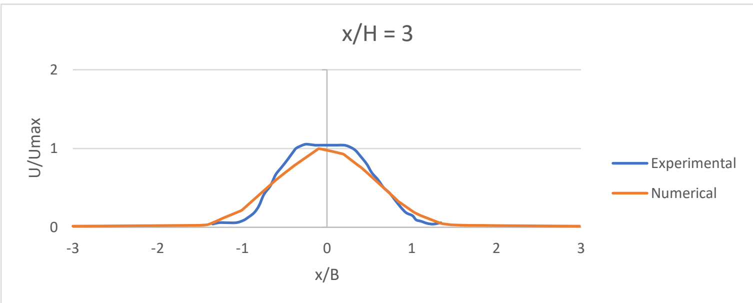
Figure 14. Comparison between experimental (PIV) results of Venuta et al., domain model and the classroom model used in this study. a), b), c), d) figures are measurement distances of x/H at 0.3, 2, 5, and 6 respectively.

Figure 15 displays the linear velocity graphs at specific locations that Ouchi et al.'s experimental investigation and this study's numerical solver were able to produce. Calculating the differences between the data sets involved comparing the percentage differences between the data lines of each graph. The NRMS method, which was employed in the previous part to choose the model with the proper mesh, was applied in the calculation. As a result, Table 6 provides discrepancies between the numerical model and the other two experimental experiments.

(a)



(b)



(c)

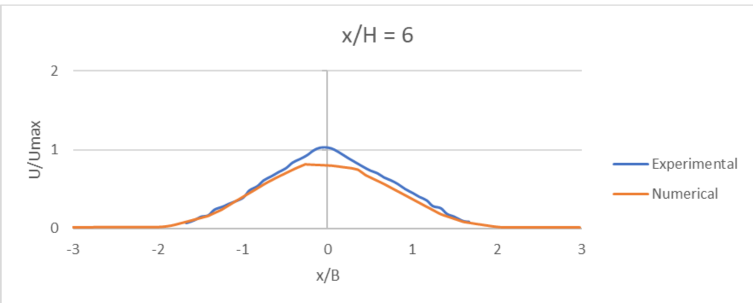


Figure 15. Experimental (Ouchi et al. 2021) and Numerical profiles of mean streamwise velocity ū/U0 in the x-y plane. (a), (b), and (c) are measurement distances of x/H at 0,1, 3, and 6 respectively.

Table 6. NRMS value of Numerical Setup compared to different experimental Models

	Re = 9000	Re = 10400
	Ouchi et al. 2021	Venuta et al. 2018
NRMS	0.166	0.224

After comparing the solver with the studies by Venuta et al and Ouchi et al, these studies were also compared with an analysis performed in the classroom model. In the image below, the flow model of a heat recovery unit is seen in the analysis performed with a flow rate of 400 m^3/h and a diffuser angle of 5^o degrees.

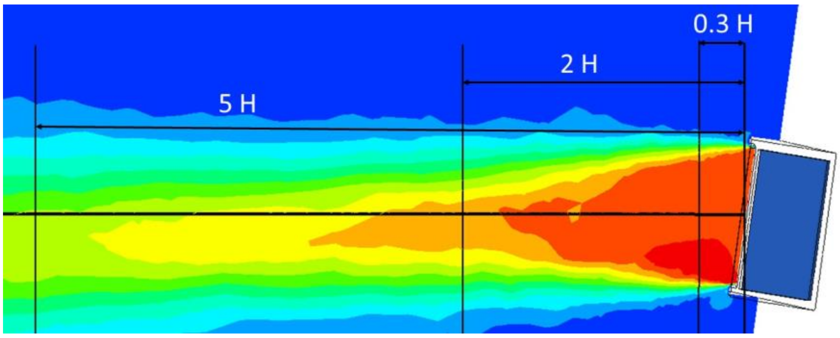


Figure 16. Flow Visualization of classroom model at 200 m^3/h per unit with 5^o downwards diffuser angle

The comparison of the flow in the classroom model with the study by Venuta et al and the analysis examining the solver is given in Figure 17. While the similarity of the flow model at x/H = 0.3 to the other two studies was observed, it was observed that this similarity decreased at increasing distances. Table 7 shows the comparison of the Classroom model with the study by Venuta et al.

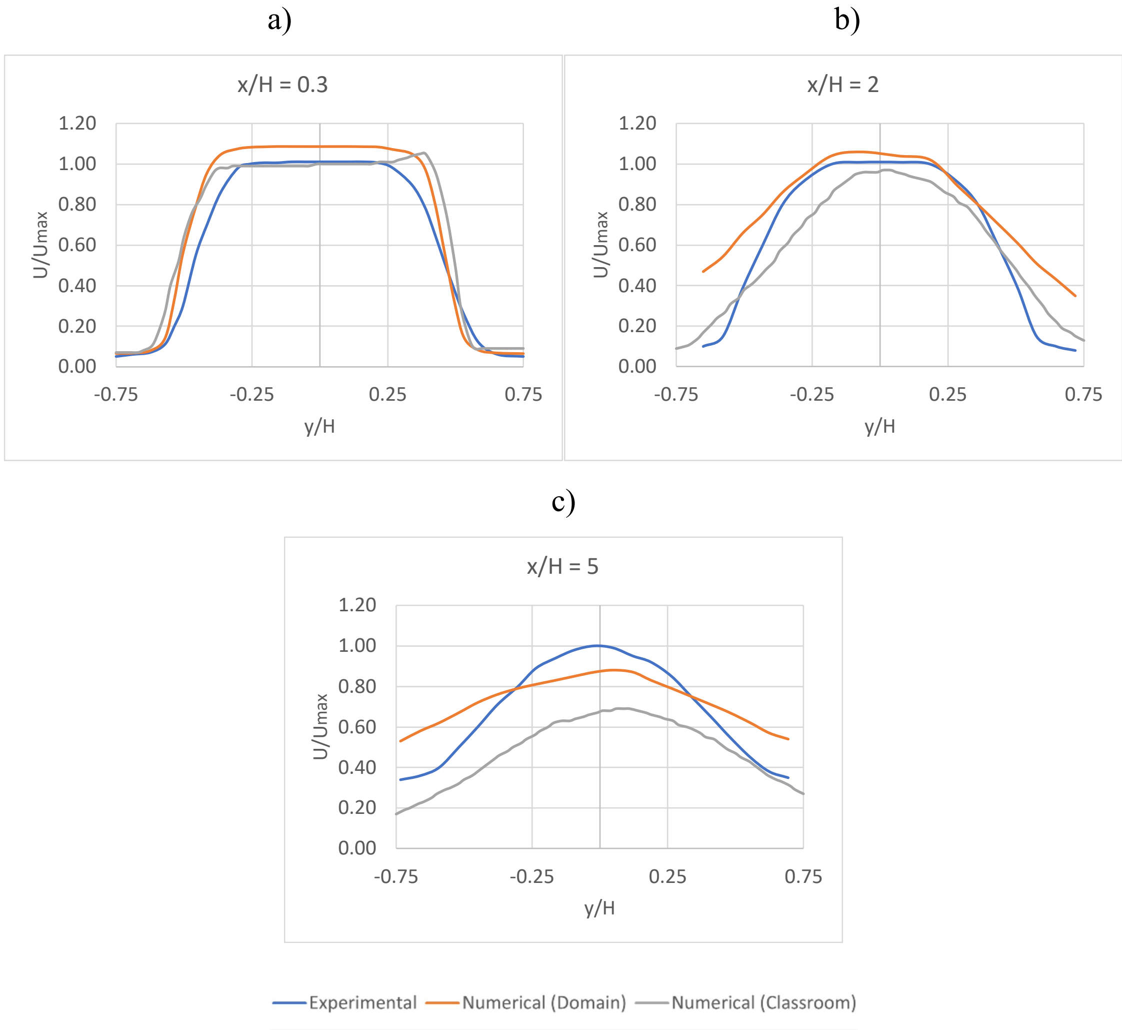


Figure 17. Comparison between experimental (PIV) results of Venuta et al. and the classroom models results at Re=10400 used in this study. a), b), c) figures are measurement distances of x/H at 0.3, 2 and 5 respectively.

Table 7. Comparison between experimental (PIV) results of Venuta et al. and the classroom models results at Re=10400 with NRMS method.

x/H	0.3	2	5
NRMS	0.239	0.214	0.463

As a result, when we compare the numerical solver with the experimental models, there is a difference of up to 22.4%. In the previous section, the effects of the fluctuation that occur when the free jet flow is analyzed by steady-state analysis are mentioned. The importance of calculating the mean value as in PIV applications is explained. Flow inside classroom model is also investigated and compared with the rest of studies. It has been observed that flow inside classroom is effecting the overall flow structure. At 0.3 and 2 x/H distances, flow discrepancies are similar to domain analysis, But at x/H = 5 because of flow crossing air flow characteristic is different than mentioned models. Numerical Analyses examined in this section belongs to the values of the last iteration for each model. Small number of measurement points shared in mentioned studies led to the inability to obtain average velocity values as intended.

2.3.4. Age of Air and Air Change Efficiency

In addition to delivering enough conditioned air to the space, it is crucial to distribute that air evenly across the surrounding area to improve indoor air quality and provide comfortable conditions (Mathisen H.M., Nielsen P.V., and Moser A. 2004).

The age of air is a statistical concept based on the age distribution of air components in a space. The air in a given volume is a mixture of air components that have undergone different periods from the moment they enter the room. The local average air age is a measure of indoor air quality that gives the average time spent by the air components at a point. When the air in the space is in a full mixing state, the average local air age is equal at every point of the space. If there is a shortcut between the supply and suction points, the air age in this region will be lower than in other regions. (Mathisen H.M., Nielsen P.V., and Moser A. 2004).

The ratio of the real air exchange value to the theoretically fastest exchange rate at the same ventilation rate is used to calculate air exchange efficiency, which is a measurement of how quickly air is transferred. The piston flow allows for the room's fastest and most efficient air exchange. Local air exchange rates in a piston flow are always equal to the lowest air exchange rate anywhere. Below is given the equation for air exchange efficiency (Mathisen H.M., Nielsen P.V., and Moser A. 2004).

$$\varepsilon^a = \frac{\tau_n}{2\langle\tau\rangle} x100 \quad [\%]$$

τ_n is the nominal time constant, τ is the average air age of the space. The air exchange efficiency obtained gives information about the ventilation characteristics of the space. (Mathisen H.M., Nielsen P.V., and Moser A. 2004).

Table 8. Flow conditions in a room according to air change efficiency value

Flow Pattern	Air Change Efficiency
Ideal Piston Flow	100%
Displacement Flow	50 % ≤ εa ≤ 100 %
Fully Mixed Flow	50%
Short Circuit Flow	≤ 50%

The average age of air values around the pupils' heads was computed within the parameters set out in the present study. After the calculation, each student's local air exchange efficiencies were also calculated, and the flow parameters were reviewed.

2.3.4.1. Investigation of Air Age by Numerical Analysis

To investigate Age of Air inside classroom, analyses have been made with ANSYS Fluent. To investigate Age of Air a User Defined Function (UDF) is created according to ANSYS User Guide. In this section creation of this UDF is explained.

The mean age of fluid result control can be used to compute the local mean age of any fluid in the unit of seconds. The diffusion term is used to calculate the age of fluid. For turbulent flows, the overall diffusion coefficient is calculated as:

$$\Gamma = D\rho + \frac{\mu_{eff}}{Sc_t}$$

Where Γ is the diffusion term, and μeff is the effective viscosity. Turbulent Schmidt number (Sc_t) and Diffusion coefficient D can be defined. The diffusion coefficient controls the laminar diffusion rate.

Mean Age of Air (MAA) has been solved as an additional transport scalar following the equation:

$$\frac{\partial}{\partial x_i}(\rho u_i \phi - \Gamma \frac{\partial \phi}{\partial x_i}) = S_\phi$$

where ϕ is the MAA scalar, ρu_i is the mass flow rate, $\Gamma = 2.88\rho \times 10^{-5} + \mu_{eff}/0.7$ is the diffusion coefficient of ϕ for the mixture air and $S\phi$ is the source term, which depends on the density of the air mixture (Juan Abantoa et al. 2004).

Table 9. Description of diffusion term arguments used in UDF

	Term
	C_R(c,t)
Diffusion Coefficient (D)	2.88e-05 m^2/s (Air)
	C_MU_EFF(c,t)
Turbulent Schmidt Number (Sct)	0.7

DEFINE_DIFFUSIVITY is used to specify the diffusivity for the species transport equations (e.g., mass diffusivity) or for user-defined scalar (UDS) transport equations (“ANSYS FLUENT 12.0 Theory Guide” 2009).

Table 10. DEFINE_DIFFUSIVITY term and description of arguments

Macro	Description
DEFINE_DIFFUSIVITY(name, c, t, i)	Defines UDS and species diffusivities
Argument Type	
symbol, name	UDF name.
cell_t, c	Cell index.
Thread, t	Pointer to cell thread on which the diffusivity function is to be applied.
int, i	Index that identifies the species or user-defined scalar.
Function returns	REAL

There are four arguments to DEFINE_DIFFUSIVITY: name, c, and t, and i. Name, the name of the UDF. c, t, and i are variables that are passed by the ANSYS FLUENT solver to UDF. UDF will need to compute the diffusivity only for a single cell and return the real value to the solver.

DEFINE_SOURCE can be used to specify custom source terms for the different types of solved transport equations in ANSYS FLUENT (except the discrete ordinates radiation model) including:

- mass
- momentum
- k-ε
- energy (also for solid zones)
- species mass fractions
- P1 radiation model
- user-defined scalar (UDS) transport
- granular temperature (Eulerian, Mixture multiphase models)

There are five arguments to DEFINE_SOURCE: name, c, t, dS, and eqn. name, the name of the UDF. c, t, dS, and eqn are variables that are passed by the ANSYS FLUENT solver to UDF. The source term derivatives may be used to linearize the source term if they enhance the stability of the solver(Juan Abantoa et al. 2004).

Table 11. DEFINE_SOURCE term and description of arguments

Macro	Description
DEFINE_SOURCE(name, c, t, dS, eqn)	**Defines source terms**
Argument Type	
symbol name	**UDF name.**
cell_t c	**Index that identifies cell on which the source term is to be applied.**
Thread *t	**Pointer to cell thread.**
real dS[]	**Array that contains the derivative of the source term with respect to the dependent variable of the transport equation.**
int eqn	**Equation number.**
Function returns	**REAL**

The generated UDF is given in Appendix F. The first part of UDF, named mean_age_diff, computes the diffusivity for the mean age of air using a user-defined scalar. Note that the mean age of air calculations do not require that energy, radiation, or species transport calculations have been performed. UDF will need to compute the real source term only for a single cell and return the value to the solver, but there are choices like, setting the implicit term dS[eqn] to $\partial S/\partial \phi$, or forcing the explicit solution of the source term by setting it equal to 0.0 as included in second part of the UDF.

uds-0 = 0.0 at all inlets and outlets in model. This function can be executed as an interpreted or compiled UDF. For this reason, the following section has been added to the current UDF code. In the end UDF included in Appendix F is used for evaluating mean age of air inside classroom environment.

In this section, first of all, the the air age calculation equations and Define macros of UDF are examined. Afterwards, the UDF used in the analyzes created according to these parameters. In the analyzes made for each parameter, this UDF was used to calculate mean age of air in the classroom environment (“ANSYS FLUENT 12.0 Theory Guide” 2009).

2.3.5. Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) Investigation

The acceptable extent of thermal and environmental effects at specific metabolic rates and clothing levels of people in the area is determined by ASHRAE Standard 55:2020, "Thermal Environmental Conditions for Human Occupancy". The guideline does not precisely define the space's boundaries, since the metabolic rate and level of clothing will differ from person to person. It does provide details about the building's indoor air quality, though.

On a seven-point thermal sensation scale, the Predicted Mean Vote (PMV) index attempts to calculate the average value of a group of people's votes. When a person's internal heat production equals their internal heat loss, they have reached thermal equilibrium. In Figure 18, the PMV sensation scale can be visualized (“ANSI/ASHRAE Standard 55-2020 Thermal Environmental Conditions for Human Occupancy” 2020).

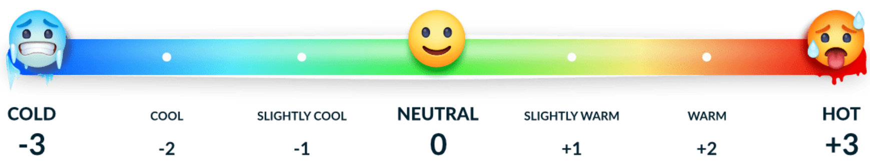


Figure 18. PMV sensation Scale (Sebastian Guenther 2023)

The formulas used to calculate the PMV value and the explanation of each parameter in these formulas are given below.

$$PMV = [0{,}303 exp(-0{,}036.M) + 0{,}028].$$

$$\begin{Bmatrix} (M-W) - 3{,}05.10^{-3}.[5733 - 6{,}99.(M-W) - \rho_a] - 0{,}42[(M-W) - 58{,}15] \\ -1{,}7.10^{-5}.M.((5867 - \rho_a) - 0{,}0014.M.(34 - t_a) \\ -3{,}96.10^{-8}.f_{cl}.[(t_{cl} + 273)^4 - (\bar{t_r} + 273)^4] - f_{cl}.h_c.(t_{cl} - t_a) \end{Bmatrix}$$

$$t_{cl} = 35{,}7 - 0{,}0028.(M-W) - I_{cl}.\{3{,}96.10^{-8}.f_{cl}.[(t_{cl} + 273)^4 - (\bar{t_r} + 273)^4] + f_{cl}.h_c.(t_{cl} - t_a)\}$$

$$h_c \begin{Bmatrix} 2{,}38.|t_{cl} - t_a|^{0{,}25} & for\ 2{,}38.|t_{cl} - t_a|^{0{,}25} > 12{,}1.\sqrt{v_{ar}} \\ 12{,}1.\sqrt{v_{ar}} & for\ 2{,}38.|t_{cl} - t_a|^{0{,}25} < 12{,}1.\sqrt{v_{ar}} \end{Bmatrix}$$

$$f_{cl} \begin{Bmatrix} 1{,}00 + 1{,}290.I_{cl}\ for\ I_{cl} \leq 0{,}078\ m^2.K/W \\ 1{,}05 + 0{,}645.I_{cl}\ for\ I_{cl} > 0{,}078\ m^2.K/W \end{Bmatrix}$$

M is the metabolic rate, The unit of the ratio of a person's metabolic activities and the conversion of chemical energy to heat and mechanical work to body surface area. (W/m^2)

W is the efective mechanical power, (W/m^2)

I_{cl} is the clothing insulation, Unit expressing thermal insulation from clothing and accessories, (m^2.K/W)

f_{cl} is the clothing surface area factor,

t_a is the air temperature, (°C)

t_r is the mean radiant temperature, (°C)

v_{ar} is the relative air velocity, (m/s)

pa is the water vapour partial pressure, (pascals, Pa)

h_c is the convective heat transfer coefficient, (W/(m^2.K))

t_{cl} is the clothing surface temperature, (°C)

Note 1 metabolic unit = 1 met = 58.2 W/m^2, 1 clothing unit = 1clo = 0.155 m^2. °C/W.

After computing the PMV, it is possible to identify the Predicted Percent Dissatisfied index (i.e., too hot or too chilly). In essence, the PPD provides the proportion of persons expected to experience local disturbance. A person's body's unwanted cooling or warmth is the primary cause of local discomfort. Air currents, very large vertical temperature changes between the ankles and the head, and/or floor temperature are common causes ("ANSI/ASHRAE Standard 55-2020 Thermal Environmental Conditions for Human Occupancy" 2020). The PPD sensation scale can be visualized in Figure 19.

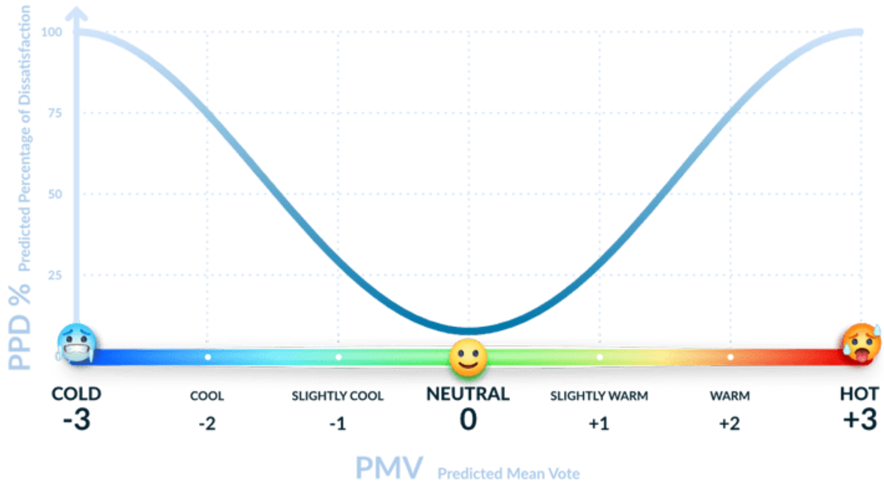


Figure 19. PPD Scale (Sebastian Guenther 2023)

The formula used to calculate the PPD value is given below.

$$PPD = 100 - 95exp[-(0{,}0335PMV^4 + 0{,}2179PMV^2)]$$

According to ASHRAE 55 which uses both PMV and PPD indices, thermal comfort can be attained based on an individual's satisfaction rate of at least 80% or more. 10% of the population may be unsatisfied due to whole-body discomfort (all factors affecting PMV are given), and 10% may be unsatisfied due to local or partial-body discomfort (fewer factors than whole-body).(“ANSI/ASHRAE Standard 55-2020 Thermal Environmental Conditions for Human Occupancy” 2020).

The suggested thermal limit on the PMV 7-point scale is -0.5 to 0.5 to comply with ASHRAE 55. This limit is increased by ISO 7730 by providing several indoor ambient ranges. , ISO 7730 defines hard limits of sensation scales between -0.5 to +0.5 for new buildings and -0.7 to +0.7 for existing buildings. (Sebastian Guenther 2023).

The PPD can vary from 5% to 100% depending on the measured PMV value. These comfort ratings will change depending on wherever the building's occupants are located. To achieve ASHRAE 55:2020 and ISO 7730 comfort guidelines, comfort ranges should not exceed 10%, or 15% PPD at any point in the area respectively (Sebastian Guenther 2023).

The analysis methods used in this paper are based on an isothermal environment. The values for dry air and the dry bulb temperatures were determined separately by 1-

degree steps between 20 and 26 C. Due to their smaller body size and surface area than adults, children have higher metabolic activity levels than adults. Children are also more susceptible to air currents and temperatures (Havenith 2007). The pupil's metabolic rate was determined as 1.1 (Havenith 2007), while the clo value was estimated to be 0.8 for the summer and 1 for the winter (Havenith 2007). The annual relative humidity values belonging to the city of İzmir in Türkiye are used as an indicator for the relative humidity value. (On average, January is the most humid month, at 75.0%. On average, July is the least humid month, at 51.0%. The average annual percentage of humidity is 64 %) ("Average Humidity in Izmir (Aegean Region)" 2023).

CHAPTER 3

RESULTS

In this section, the simulations performed with the C20-75 mesh model and the solver are explained in previous sections. Using the C20-75 mesh configuration, two different ventilation scenarios were prepared in which the heat recovery devices were placed 160 and 200 cm above the ground. In these two models, it is also aimed to investigate the effects of throw angle, therefore, 5° and 10° angles downward to the floor are defined for both models. Finally, simulations were carried out for each of these four models, examining the ventilation flow rates of 400 m^3/h, 600 m^3/h, and 800 m^3/h. Classification and definition of each analysis were made as “Total hourly flow rate”-“Height of the heat recovery device from the ground”-“Diffuser blowing angle”. For example, the analysis named “800-200-10” represents a simulation with a total flow rate of 800 m^3/h, where the height of the device is 200 cm and the vent blowing angle is 10°.

In addition to the aforementioned ventilation scenarios, the model was also examined with personal ventilation, piston ventilation and ventilation scenarios with reduced number of heat recovery devices.

For each analysis, the variation of the average air velocity around the head of the students depending on the iteration is given in Appendix B. In Appendix C, the velocity values measured around the head and the airflow in the classroom are visualized according to the analyzes made for each parameter. Table 12. shows each parameters investigated in this study.

Table 12. Description of Ventilation scenarios for a) Wall type Ventilation b) Personal and Piston Ventilation Scenarios

a)

Model	HRV Height (m)	Air Flow (m³/h)	Unit Count	Diffuser Angle (°)	Setup Description	Mean Air Velocities of Students	Mean Age of Air of Model (s)	Mean Age of Air of Students Heads (s)	Air Change Efficiency of Model (Ea-avg)	Air Change Efficiency of Students	PMV-PDD Value (20-26 °C) (%)
C20-75	1.6	400	4	5	C20-75/400-160-5	✓	✓	✓	✓	✓	✓
				10	C20-75/400-160-10	✓	✓	✓	✓	✓	✓
		600		5	C20-75/600-160-5	✓	✓	✓	✓	✓	✓
				10	C20-75/600-160-10	✓	✓	✓	✓	✓	✓
		800		5	C20-75/800-160-5	✓	✓	✓	✓	✓	✓
				10	C20-75/800-160-10	✓	✓	✓	✓	✓	✓
	2	400		5	C20-75/400-200-5	✓	✓	✓	✓	✓	✓
				10	C20-75/400-200-10	✓	✓	✓	✓	✓	✓
		600		5	C20-75/600-200-5	✓	✓	✓	✓	✓	✓
				10	C20-75/600-200-10	✓	✓	✓	✓	✓	✓
		800		5	C20-75/800-200-5	✓	✓	✓	✓	✓	✓
				10	C20-75/800-200-10	✓	✓	✓	✓	✓	✓
	2	400	2	5	C20-75/400-200-5-2	✓	✓	✓	✓	✓	✓

b)

Model	Air Flow (m³/h)	Setup Description	Mean Air Velocities of Students	Mean Age of Air of Model (s)	Mean Age of Air of Students Heads (s)	Air Change Efficiency of Model (Ea-avg)	Air Change Efficiency of Students	PMV-PDD Value (20-26 °C) (%)
C20-75	200	Personal Ventilation	✓	✓	✓	✓	✓	✓
	400		✓	✓	✓	✓	✓	✓
	600		✓	✓	✓	✓	✓	✓
	800	Piston Flow	✓	✓	✓	✓	✓	✓

In this section, depending on the height, angle, and ventilation flow rates, each student's
a) Average air velocities around the head,
b) Average and local weather age values,
c) Local and general air exchange efficiencies
d) PMV and PPD values were examined.

3.1. Wall Mounted Ventilation Scenarios

By comparing the results obtained, it has been observed under which working conditions the concept model provides the appropriate comfort conditions. Average air velocities and air exchange efficiencies of different ventilation rates at 200 cm device height and 10° blowing angle are shown in Figure 20. In the analysis made with a device height of 200 cm and a vent angle of 10°, a) represents the students in the farthest row from the diffuser. For example, number 1.1 refers to the student in the front row.

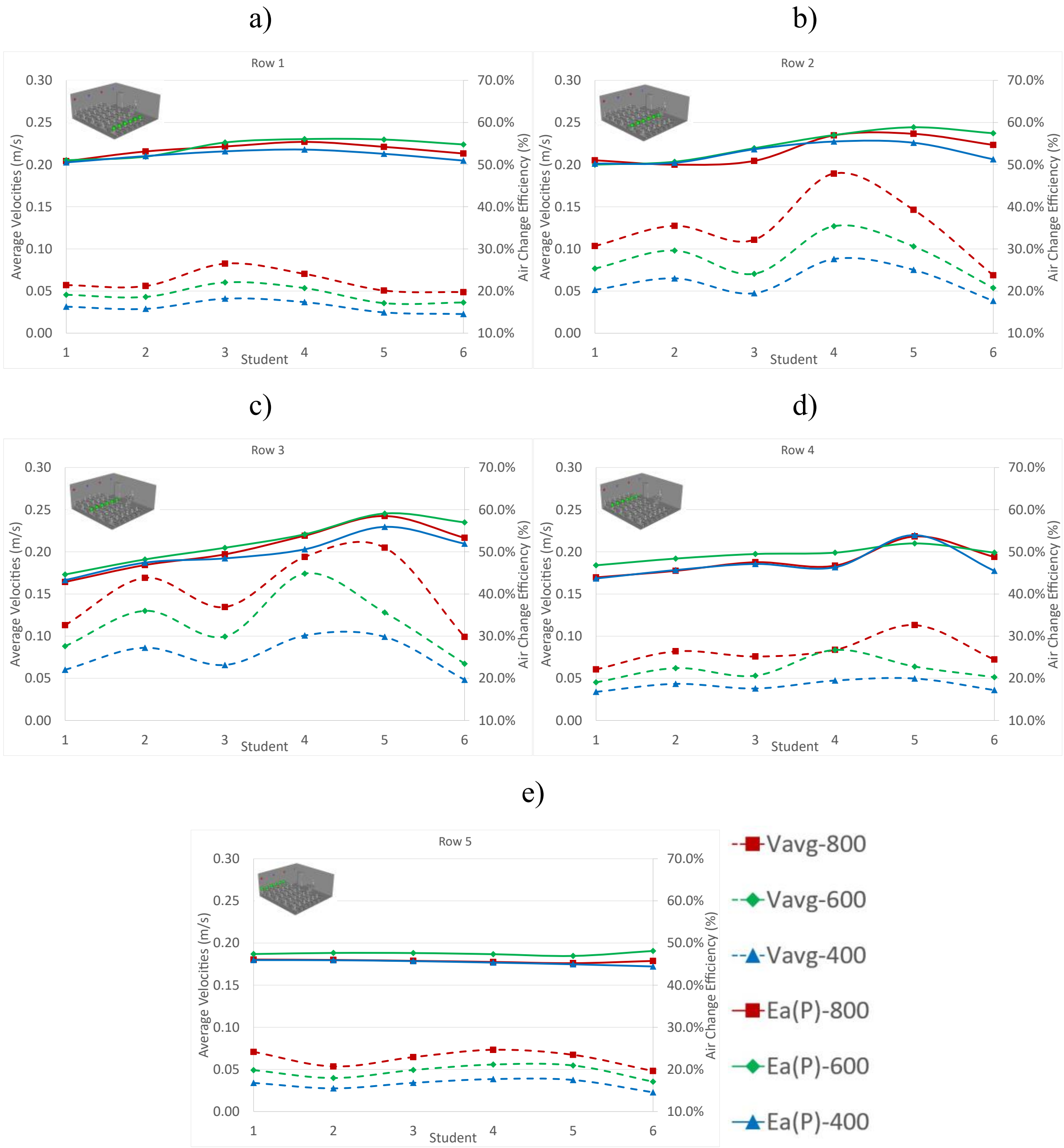


Figure 20. Average air velocities and air change efficiencies around the heads of students. Continuous lines represent avg velocities and dotted lines represent air change efficiencies.

For the 200-10 (200 cm device height and 10° vent angle) model, the results of the analyzes at 800, 600, and 400 m^3/h flow rates are given in Tables 13, 14, and 15, respectively. Tables include average air velocities, overall and local mean age of air values, and average and local air exchange efficiencies.

Table 13. Results of C20-75/800-200-10 Model

Vavg-800-10-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.06	0.06	0.08	0.07	0.05	0.05
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.10	0.13	0.11	0.19	0.15	0.07
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.11	0.17	0.13	0.19	0.21	0.10
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.06	0.08	0.08	0.08	0.11	0.07
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.07	0.05	0.06	0.07	0.07	0.05

Ea(P)-800-10-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	50.8%	53.1%	54.3%	55.4%	54.2%	52.6%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	51.0%	50.0%	50.9%	56.9%	57.3%	54.7%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	42.8%	46.9%	49.4%	53.8%	58.5%	53.3%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	43.9%	45.5%	47.5%	46.7%	53.6%	48.8%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	46.1%	46.0%	45.8%	45.5%	45.2%	45.7%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	800.00	[m^3/s]
AoA Avg	485.01	[s]
AoA Avg (0,8m-1,2m)	493.83	[s]
Ea Avg	50.75%	
Ea(P) (0,8m-1,2m)	50.22%	

Table 14. Results of C20-75/600-200-10 Model

Vavg-600-10-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.05	0.04	0.06	0.05	0.04	0.04
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.08	0.10	0.07	0.13	0.10	0.05
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.09	0.13	0.10	0.17	0.13	0.07
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.05	0.06	0.05	0.08	0.06	0.05
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.05	0.04	0.05	0.06	0.05	0.04

Ea(P)-600-10-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	51.0%	51.9%	55.2%	56.1%	55.9%	54.8%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	50.0%	50.7%	53.9%	57.0%	58.9%	57.5%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	44.6%	48.2%	51.0%	54.2%	59.1%	57.0%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	46.8%	48.4%	49.5%	49.8%	52.0%	49.8%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	47.4%	47.6%	47.6%	47.3%	46.9%	48.1%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	600.00	[m^3/s]
AoA Avg	642.17	[s]
AoA Avg (0,8m-1,2m)	639.73	[s]
Ea Avg	51.11%	
Ea(P) (0,8m-1,2m)	51.30%	

Table 15. Results of C20-75/400-200-10 Model

Vavg-400-10-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.03	0.03	0.04	0.04	0.02	0.02
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.05	0.07	0.05	0.09	0.08	0.04
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.06	0.09	0.07	0.10	0.10	0.05
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.03	0.04	0.04	0.05	0.05	0.04
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.03	0.03	0.03	0.04	0.04	0.02

Ea(P)-400-10-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	50.5%	52.0%	53.2%	53.6%	52.6%	51.0%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	50.2%	50.4%	53.6%	55.5%	55.2%	51.3%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	43.3%	47.4%	48.5%	50.6%	55.9%	51.9%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	43.7%	45.7%	47.1%	46.3%	54.0%	45.5%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	45.9%	45.9%	45.7%	45.4%	45.0%	44.4%

Volume Total	109.37	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	400.00	[m^3/s]
AoA Avg	978.88	[s]
AoA Avg (0,8m-1,2m)	1002.88	[s]
Ea Avg	50.29%	
Ea(P) (0,8m-1,2m)	49.09%	

The models of the local age of air values around the head of the students are shown in Figure 21.

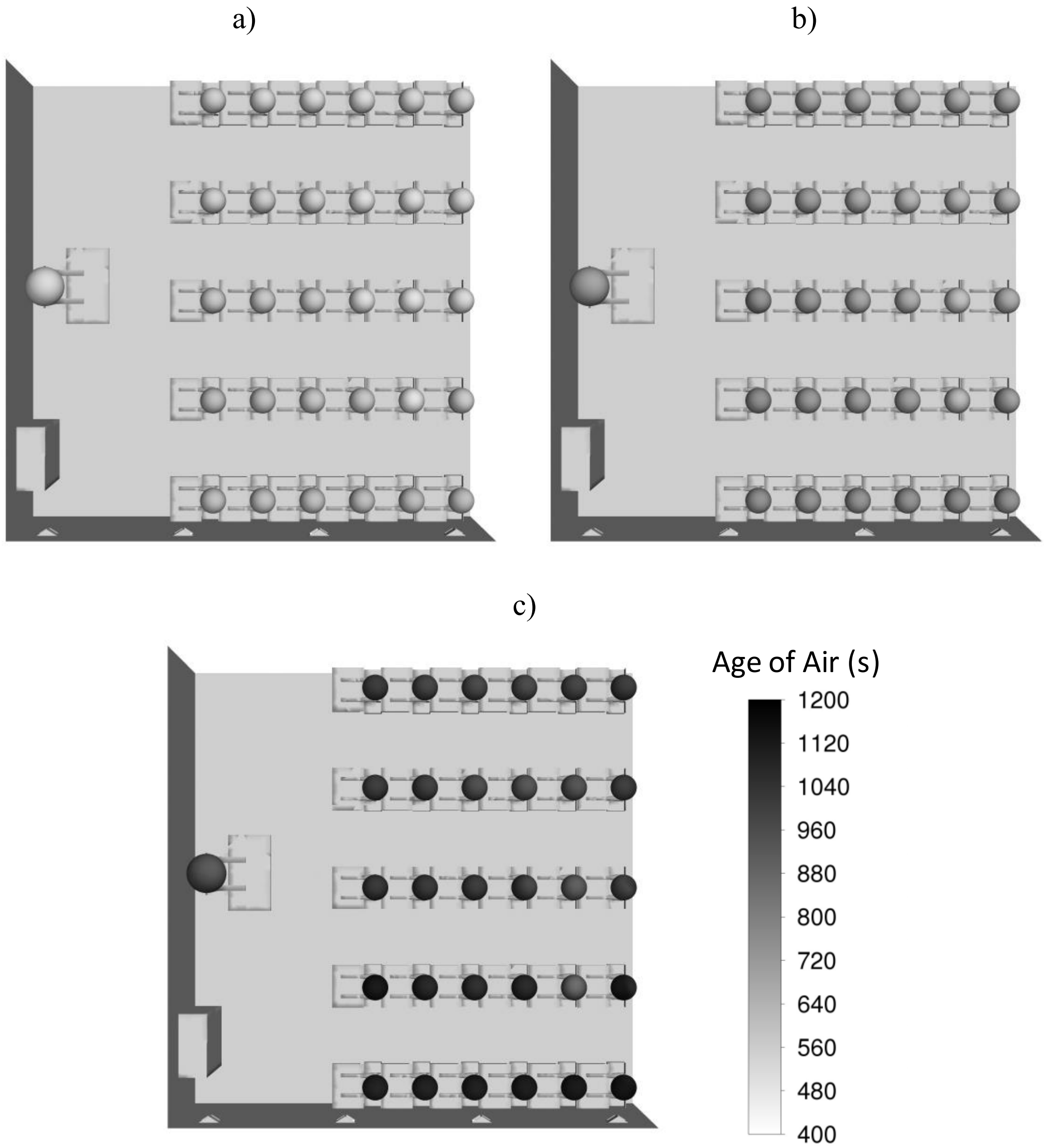


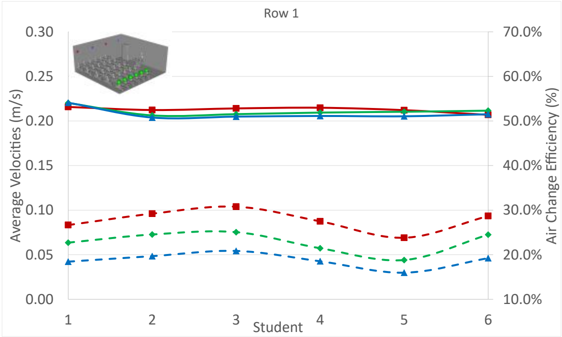
Figure 21. Local Age of Air values of individuals inside the classroom for 200 cm unit height and 10-degree diffuser angle ventilation scenario.

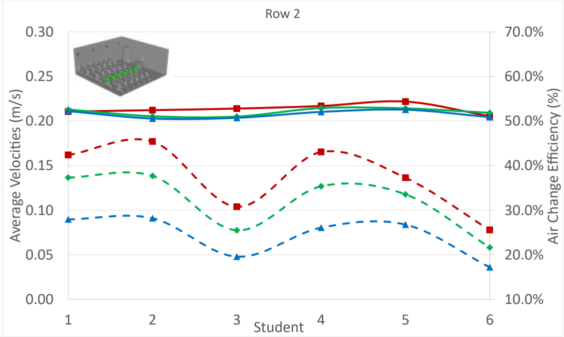
When the analyzes made on the flow rates were examined, it was seen that the average values of the air speeds around the head and the local air ages are in inverse proportion. However, it should be noted that the air exchange efficiencies are at similar values.

The perception that air speeds can create on students will be examined with PMV and PPD values in further sections. When the analyzes were examined, it was seen that the increase in the flowrate, has increased the amount of fresh air around the head of the students. It also has been observed that the air exchange efficiency in the classroom is close to 50%. This shows that the air characteristic in this model is suitable for the Full mixture condition.

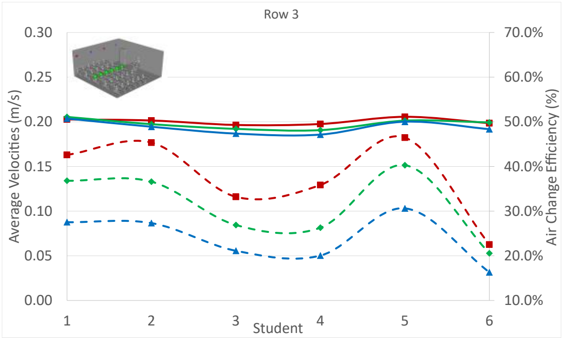
Figure 22 shows the average air velocities and air exchange efficiencies of different ventilation rates at a height of 200 cm and a blowing angle of 5°.

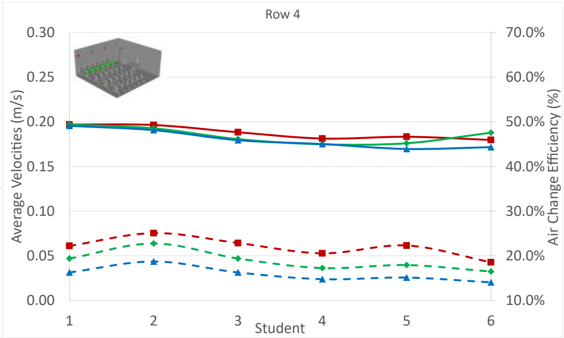
a) b)





c) d)





e)

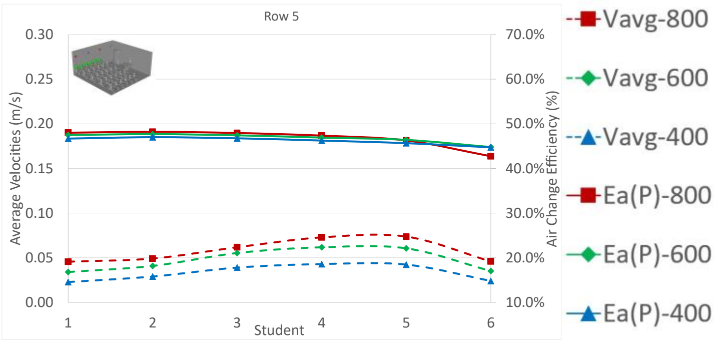


Figure 22. Average air velocities and air change efficiencies around the heads of students. Heat Recovery Units placed 2.0 m above the floor, attached to the facade wall, and diffusers with 5° diffuser angle and figures a), b), c), d), e) are ranging between row 1(front row) to row 5 respectively.

For the 200-5 (200 cm device height and 5° vent angle) model, the results of the analyzes at 800, 600, and 400 m^3/h flow rates are given in Tables 16, 17, and 18, respectively. Tables include average air velocities, overall and local mean age of air values, and average and local air exchange efficiencies.

Table 16. Results of C20-75/800-200-5 Model

Vavg-800-5-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.08	0.10	0.10	0.09	0.07	0.09
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.16	0.18	0.10	0.17	0.14	0.08
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.16	0.18	0.12	0.13	0.18	0.06
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.06	0.08	0.06	0.05	0.06	0.04
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.05	0.05	0.06	0.07	0.07	0.05

Ea(P)-800-5-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	53.1%	52.5%	52.8%	53.0%	52.4%	51.4%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	52.1%	52.4%	52.8%	53.4%	54.4%	51.1%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	50.5%	50.3%	49.3%	49.5%	51.1%	49.7%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	49.4%	49.3%	47.7%	46.3%	46.7%	45.9%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	48.0%	48.2%	47.9%	47.3%	46.3%	42.7%

Volume Total	109.37	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	800.00	[m^3/s]
AoA Avg	479.03	[s]
AoA Avg (0,8m-1,2m)	494.68	[s]
Ea Avg	51.39%	
Ea(P) (0,8m-1,2m)	49.91%	

Table 17. Results of C20-75/600-200-5 Model

Vavg-600-5-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.06	0.07	0.08	0.06	0.04	0.07
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.14	0.14	0.08	0.13	0.12	0.06
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.13	0.13	0.08	0.08	0.15	0.05
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.05	0.06	0.05	0.04	0.04	0.03
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.03	0.04	0.06	0.06	0.06	0.04

Ea(P)-600-5-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	54.0%	51.3%	51.5%	51.9%	52.1%	52.3%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	52.6%	51.1%	51.0%	52.9%	52.8%	51.8%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	51.1%	49.5%	48.4%	48.1%	50.3%	49.9%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	49.4%	48.5%	46.1%	45.0%	45.2%	47.6%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	47.5%	47.7%	47.4%	46.9%	46.4%	44.8%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	600.00	[m^3/s]
AoA Avg	639.52	[s]
AoA Avg (0,8m-1,2m)	664.85	[s]
Ea Avg	51.32%	
Ea(P) (0,8m-1,2m)	49.36%	

Table 18. Results of C20-75/400-200-5 Model

Vavg-400-5-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.04	0.05	0.05	0.04	0.03	0.05
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.09	0.09	0.05	0.08	0.08	0.04
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.09	0.09	0.06	0.05	0.10	0.03
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.03	0.04	0.03	0.02	0.03	0.02
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.02	0.03	0.04	0.04	0.04	0.02

Ea(P)-400-5-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	55.5%	55.2%	54.0%	53.6%	53.4%	53.2%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	52.9%	57.6%	50.6%	50.0%	51.0%	51.7%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	47.7%	56.7%	47.6%	40.5%	68.7%	62.2%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	49.9%	47.7%	46.5%	46.9%	48.3%	49.6%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	49.4%	48.8%	46.2%	46.1%	46.0%	46.7%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	400.00	[m^3/s]
AoA Avg	964.82	[s]
AoA Avg (0,8m-1,2m)	1011.76	[s]
Ea Avg	51.02%	
Ea(P) (0,8m-1,2m)	48.66%	

The models of the local age of air values around the head of the students for 200-5 model at each flow rate are shown in Figure 23.

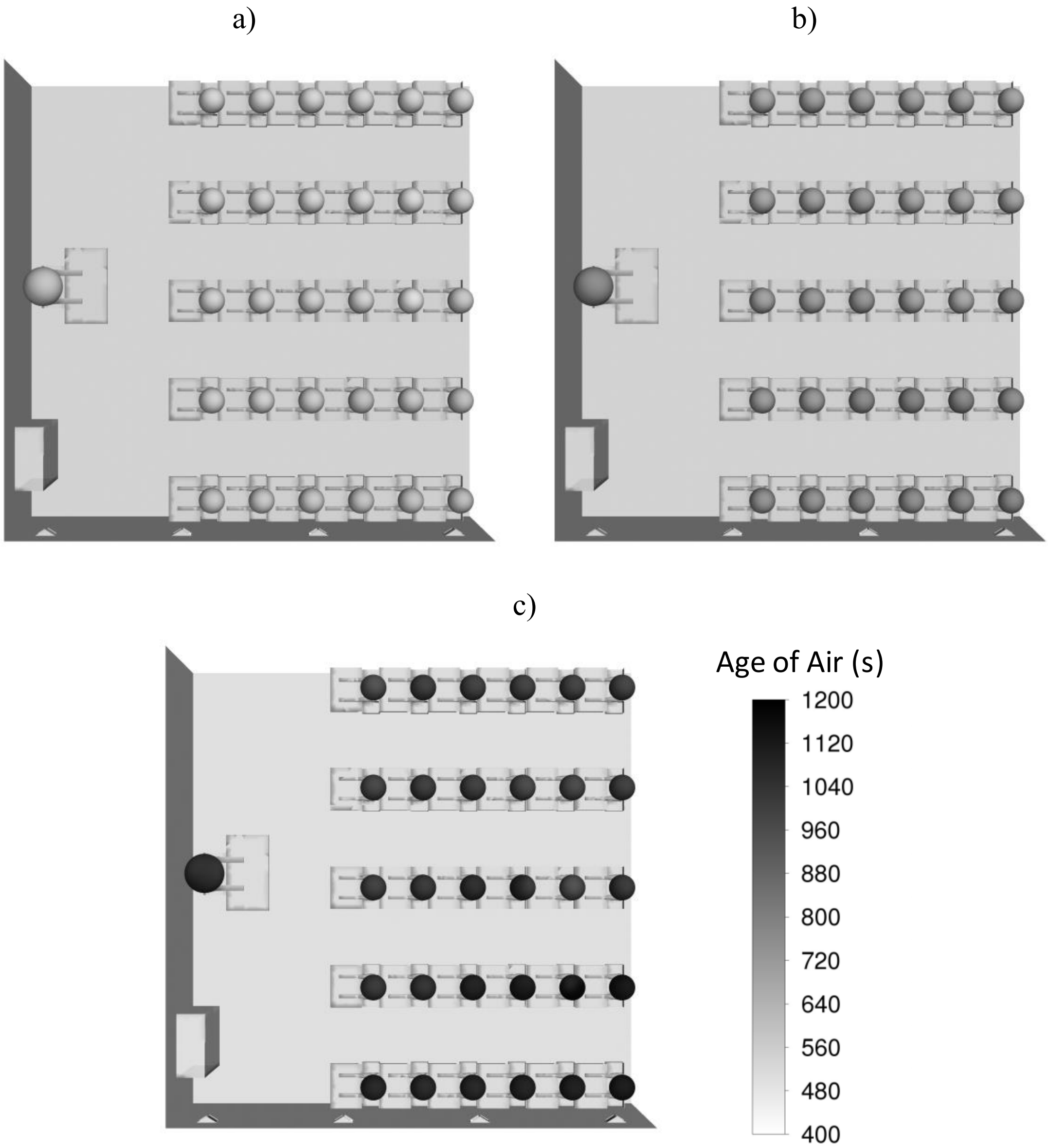


Figure 23. Local Age of Air values of individuals inside the classroom for 200 cm unit height and 5-degree diffuser angle ventilation scenario.

When the analyzes made on the flow rates were examined at 200 cm unit height and 5-degree vent angle, it was seen that the average values of the air speeds around the heads increades with flow rate and the local air ages decreased in inverse proportion to these parameters. However, it should be noted that the air exchange efficiencies are at similar values in each flow rate. When the analyzes were examined, it was seen that the increase in the flowrate, has increased the amount of fresh air around the head of the students like previously in 200-10 model. It also has been observed that the air exchange efficiency in the classroom is close to 50%. This shows that the air characteristic in this model is also suitable for the full mixture condition.

Average air velocities and air exchange efficiencies of different ventilation rates at 160 cm height and 10° blowing angle are shown in Figure 24. The analysis results for the 160-10 model at 800, 600, and 400 m^3/h flow rates are shown in Tables 19, 20, and 21, respectively.

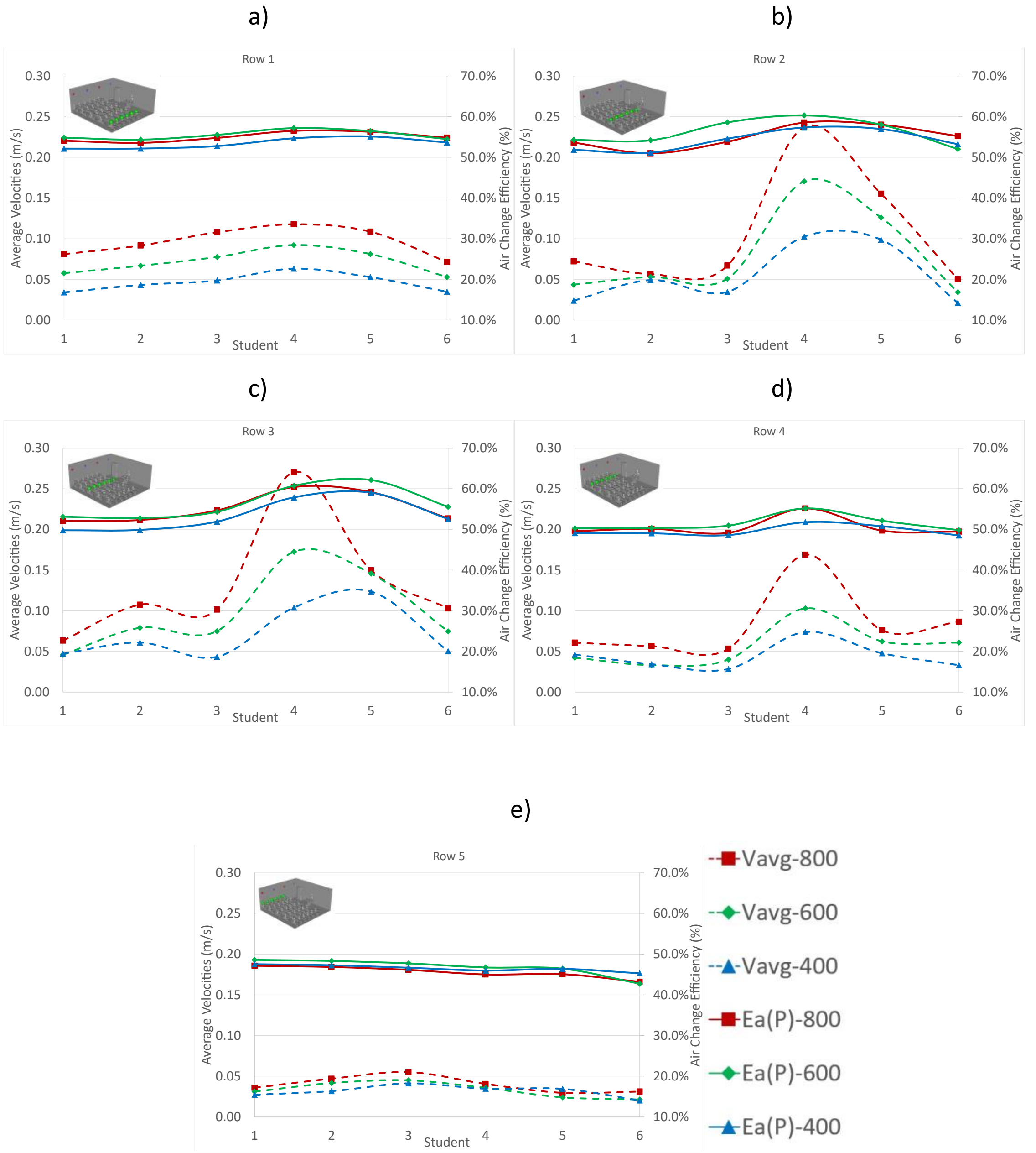


Figure 24. Average air velocities and air change efficiencies around the heads of students. Heat Recovery Units placed 1.6 m above the floor, attached to the facade wall, and diffusers with 10° diffuser angle and figures a), b), c), d), e) are ranging between row 1(front row) to row 5 respectively.

Table 19. Results of C20-75/800-160-10 Model

Vavg-800-10-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.08	0.09	0.11	0.12	0.11	0.07
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.07	0.06	0.07	0.24	0.16	0.05
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.06	0.11	0.10	0.27	0.15	0.10
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.06	0.06	0.05	0.17	0.08	0.09
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.04	0.05	0.06	0.04	0.03	0.03

Ea(P)-800-10-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	54.1%	53.6%	54.8%	56.5%	56.3%	54.8%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	53.6%	51.0%	53.8%	58.6%	58.0%	55.2%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	52.0%	52.3%	54.7%	60.4%	59.1%	52.7%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	49.6%	50.1%	49.2%	55.1%	49.7%	49.4%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	47.1%	46.8%	46.1%	45.0%	45.1%	43.2%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.32	[m^3]
Volume Flow Rate	800.00	[m^3/s]
AoA Avg	482.72	[s]
AoA Avg (0,8m-1,2m)	474.39	[s]
Ea Avg	50.99%	
Ea(P) (0,8m-1,2m)	51.89%	

Table 20. Results of C20-75/600-160-10 Model

Vavg-600-10-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.06	0.07	0.08	0.09	0.08	0.05
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.04	0.05	0.05	0.17	0.13	0.03
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.05	0.08	0.07	0.17	0.15	0.07
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.04	0.03	0.04	0.10	0.06	0.06
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.03	0.04	0.05	0.04	0.02	0.02

Ea(P)-600-10-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	54.8%	54.3%	55.5%	57.2%	56.5%	54.5%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	54.3%	54.2%	58.6%	60.3%	58.0%	52.0%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	53.1%	52.8%	54.3%	60.7%	62.1%	55.5%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	50.3%	50.4%	50.9%	55.1%	52.1%	49.8%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	48.6%	48.3%	47.7%	46.7%	46.4%	42.7%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.32	[m^3]
Volume Flow Rate	600.00	[m^3/s]
AoA Avg	623.23	[s]
AoA Avg (0,8m-1,2m)	620.58	[s]
Ea Avg	52.66%	
Ea(P) (0,8m-1,2m)	52.89%	

Table 21. Results of C20-75/400-160-10 Model

Vavg-400-10-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.03	0.04	0.05	0.06	0.05	0.03
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.02	0.05	0.03	0.10	0.10	0.02
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.05	0.06	0.04	0.10	0.12	0.05
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.05	0.03	0.03	0.07	0.05	0.03
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.03	0.03	0.04	0.03	0.03	0.02

Ea(P)-400-10-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	52.1%	52.1%	52.8%	54.7%	55.1%	53.6%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	51.8%	51.2%	54.6%	57.3%	56.9%	53.2%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	49.8%	49.9%	51.9%	57.9%	59.0%	52.6%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	49.1%	49.0%	48.6%	51.8%	50.8%	48.5%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	47.5%	47.3%	46.7%	46.0%	46.4%	45.3%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	400.00	[m^3/s]
AoA Avg	964.71	[s]
AoA Avg (0,8m-1,2m)	961.61	[s]
Ea Avg	51.03%	
Ea(P) (0,8m-1,2m)	51.20%	

The models of the local age of air values around the head of the students for 160-10 model at each flow rate are shown in Figure 25.

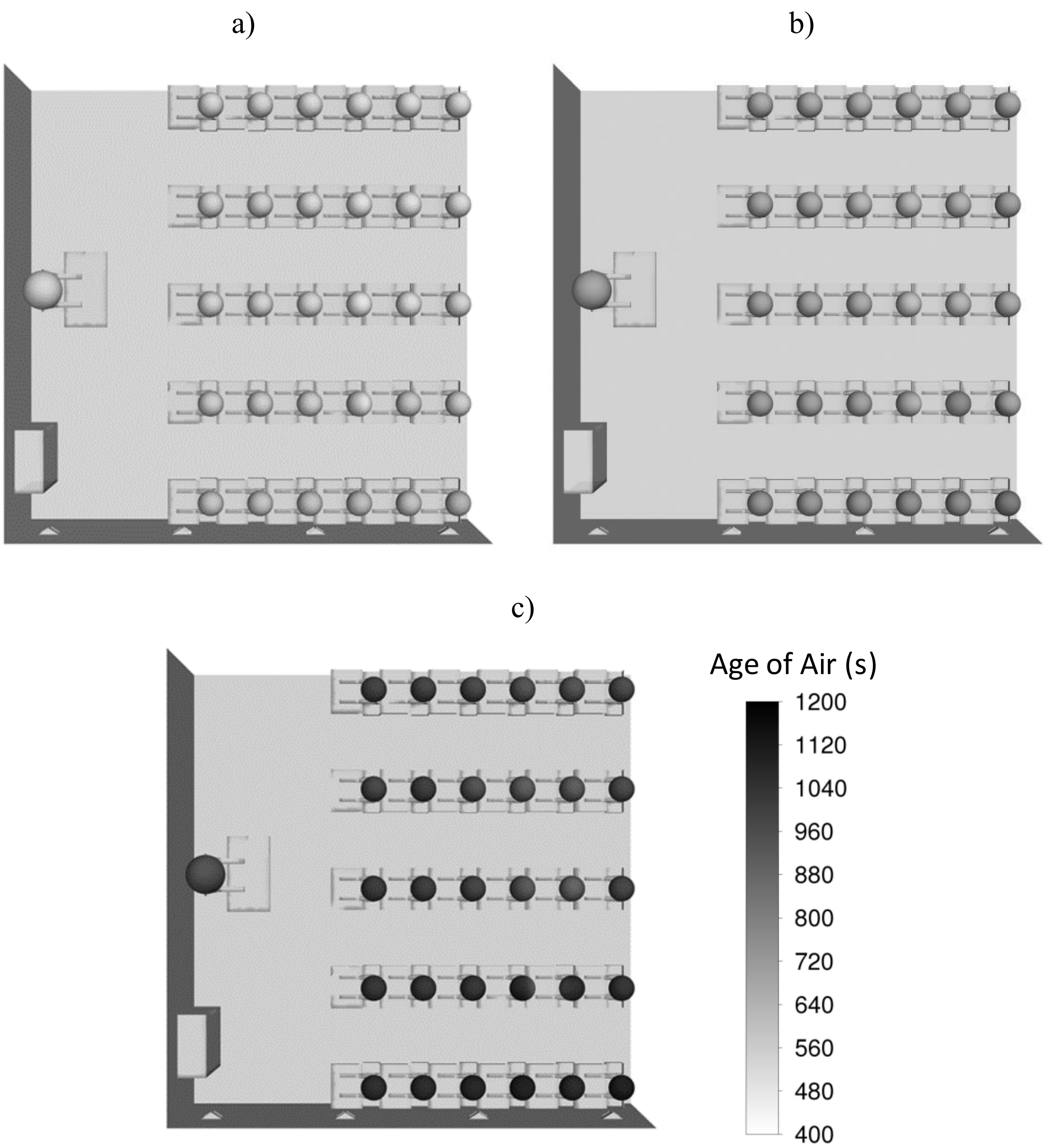


Figure 25. Local Age of Air values of individuals inside the classroom for 160 cm unit height and 10-degree diffuser angle ventilation scenario.

When the analyzes made on the flow rates were examined at 160 cm unit height and 10-degree vent angle, similar results have been observed compared to other parameters mentioned. However, at 160 cm unit height local air change efficiencies around students heads are slightly increased when compared to 200 cm diffuser height.

When the analyzes were examined, it was seen that the increase in the flowrate, has increased the amount of fresh air around the head of the students like previousmodels. It also has been observed that the air exchange efficiency in the classroom is close to 50%. This shows that the air characteristic in this model is also suitable for the full mixture condition.

Average air velocities and air exchange efficiencies of different ventilation rates at 160 cm height and 5° blowing angle are shown in Figure 26. The analysis results for the 160-10 model at 800, 600, and 400 m^3/h flow rates are shown in Tables 22, 23, and 24, respectively.

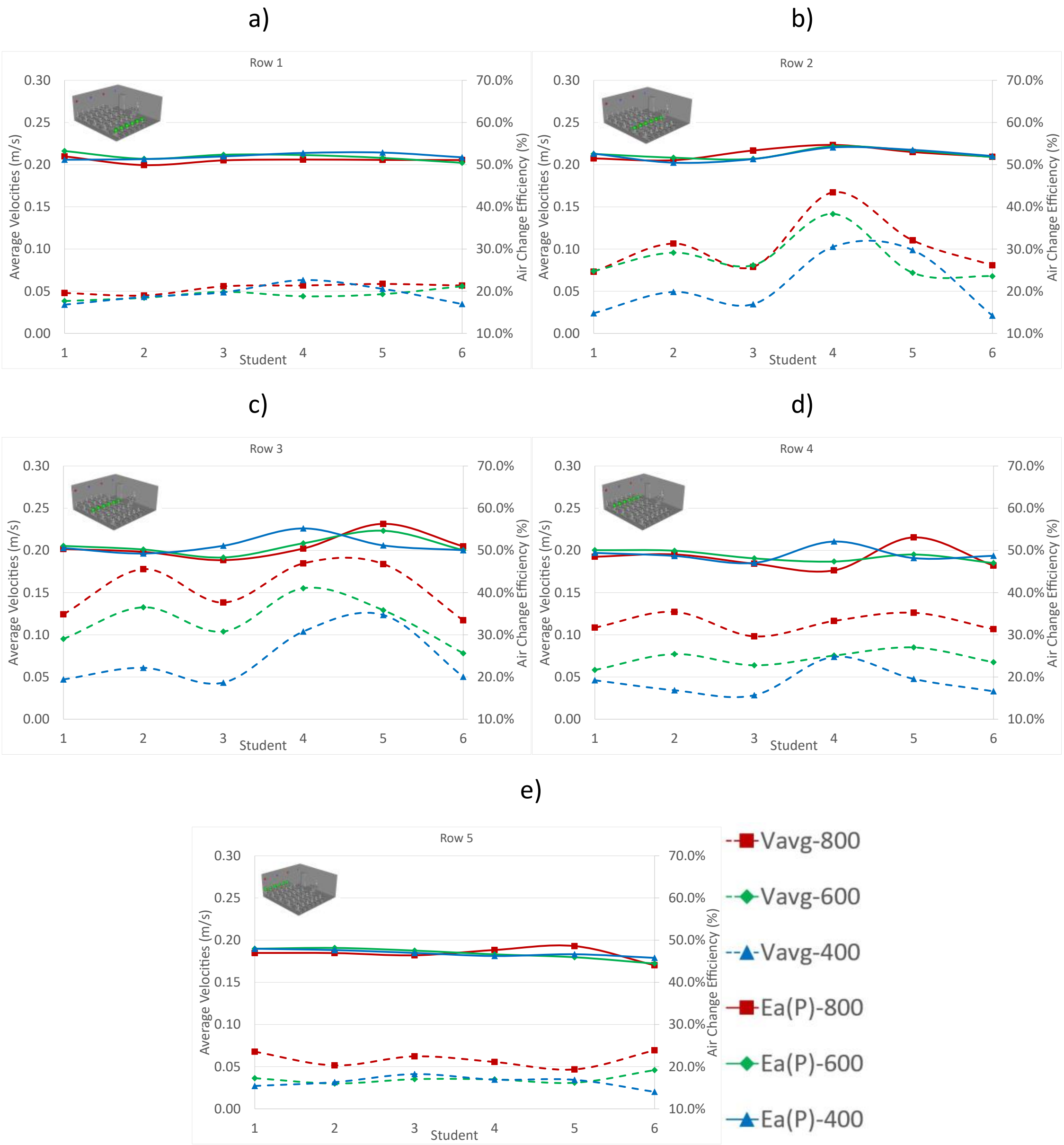


Figure 26. Average air velocities and air change efficiencies around the heads of students. Heat Recovery Units placed 1.6 m above the floor, attached to the facade wall, and diffusers with 5° diffuser angle and figures a), b), c), d), e) are ranging between row 1(front row) to row 5 respectively.

Table 22. Results of C20-75/800-160-5 Model

Vavg-800-5-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.05	0.04	0.06	0.06	0.06	0.06
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.07	0.11	0.08	0.17	0.11	0.08
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.12	0.18	0.14	0.18	0.18	0.12
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.11	0.13	0.10	0.12	0.13	0.11
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.07	0.05	0.06	0.06	0.05	0.07

Ea(P)-800-5-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	52.0%	49.9%	51.0%	51.2%	51.1%	51.1%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	51.5%	51.1%	53.4%	54.7%	53.0%	51.9%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	50.3%	49.6%	47.7%	50.4%	56.3%	51.0%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	48.5%	49.1%	46.8%	45.3%	53.1%	46.4%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	47.0%	46.9%	46.4%	47.7%	48.6%	44.0%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m	15.32	[m^3]
Volume Flow Rate	800.00	[m^3/s]
AoA Avg	482.72	[s]
AoA Avg (0,8m-1,2m	494.92	[s]
Ea Avg	50.99%	
Ea(P) (0,8m-1,2m)	49.74%	

Table 23. Results of C20-75/600-160-5 Model

Vavg-600-5-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.04	0.04	0.05	0.04	0.05	0.06
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.07	0.10	0.08	0.14	0.07	0.07
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.10	0.13	0.10	0.16	0.13	0.08
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.06	0.08	0.06	0.08	0.09	0.07
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.04	0.03	0.04	0.03	0.03	0.05

Ea(P)-600-5-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	53.2%	51.4%	52.3%	52.3%	51.6%	50.4%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	52.5%	51.7%	51.4%	54.3%	53.4%	51.8%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	51.1%	50.2%	48.3%	51.7%	54.7%	50.1%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	50.1%	49.9%	48.1%	47.4%	49.0%	47.0%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	48.0%	48.2%	47.5%	46.6%	46.0%	44.5%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m	15.32	[m^3]
Volume Flow Rate	600.00	[m^3/s]
AoA Avg	639.72	[s]
AoA Avg (0,8m-1,2m	656.12	[s]
Ea Avg	51.30%	
Ea(P) (0,8m-1,2m)	50.02%	

Table 24. Results of C20-75/400-160-5 Model

Vavg-400-5-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.03	0.04	0.05	0.06	0.05	0.03
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.02	0.05	0.03	0.10	0.10	0.02
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.05	0.06	0.04	0.10	0.12	0.05
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.05	0.03	0.03	0.07	0.05	0.03
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.03	0.03	0.04	0.03	0.03	0.02

Ea(P)-400-5-160	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	51.2%	51.3%	51.9%	52.8%	52.9%	51.7%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	52.6%	50.5%	51.3%	54.1%	53.5%	52.0%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	50.6%	49.3%	51.1%	55.2%	51.2%	50.1%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	49.4%	48.7%	47.0%	52.1%	48.2%	48.7%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	48.0%	47.6%	47.0%	46.2%	46.6%	45.8%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m	15.32	[m^3]
Volume Flow Rate	400.00	[m^3/s]
AoA Avg	966.01	[s]
AoA Avg (0,8m-1,2m	981.32	[s]
Ea Avg	50.96%	
Ea(P) (0,8m-1,2m)	50.17%	

The models of the local age of air values around the head of the students for 160-5 model at each flow rate are shown in Figure 27.

a)

b)

c)

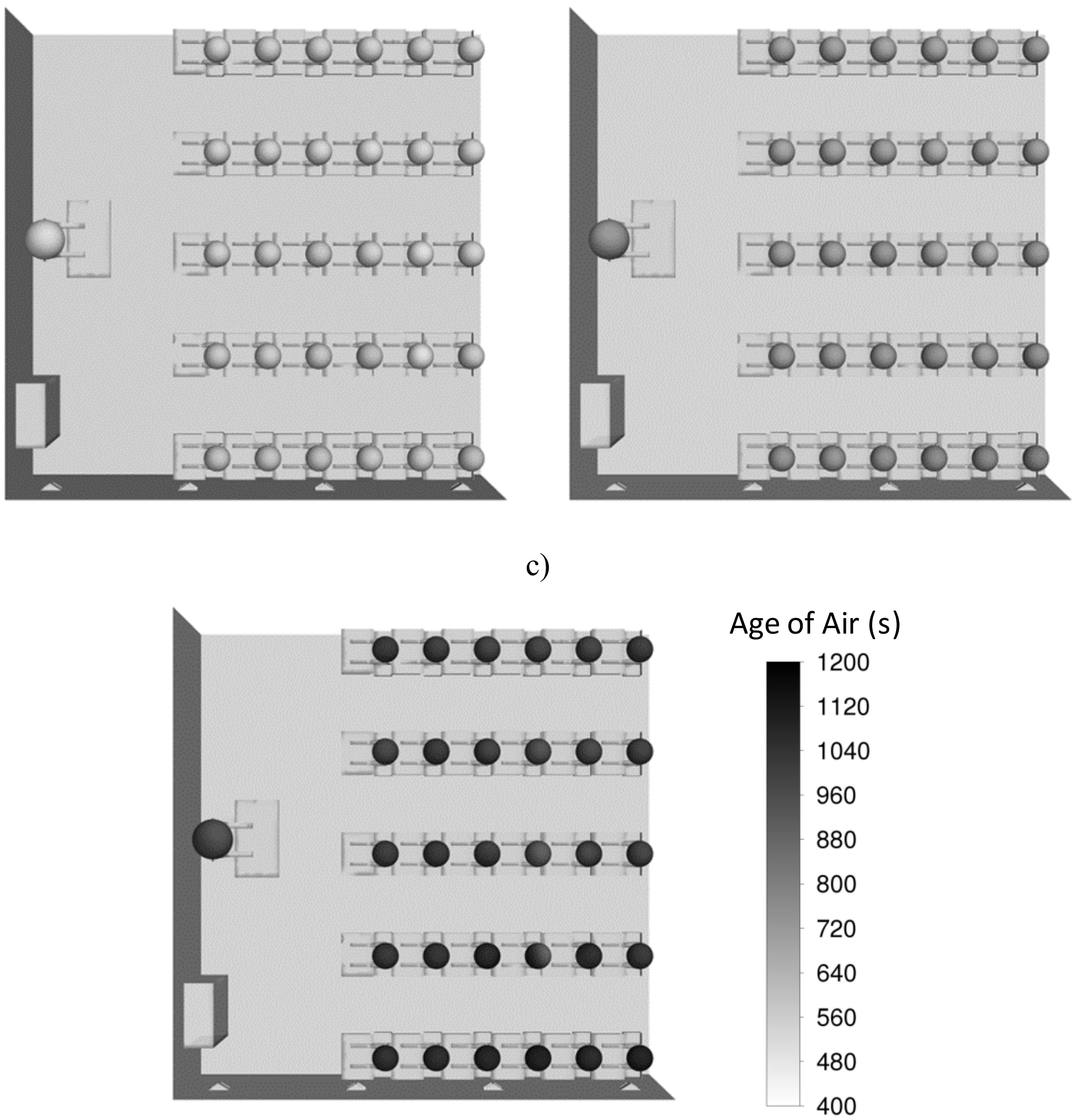


Figure 27. Local Age of Air values of individuals inside the classroom for 160 cm unit height and 5-degree diffuser angle ventilation scenario.

When the analyzes made on the flow rates were examined at 160 cm unit height and 5-degree vent angle, it was seen that the average values of the air speeds around the head and the local air ages increased in inverse proportion similar to other cases mentioned. It should also be noted that the air exchange efficiencies are at similar values in each flow rate.

When the analyzes were examined, it was seen that the increase in the flowrate, has increased the amount of fresh air around the head of the students like previous models. It also has been observed that the air exchange efficiency in the classroom is close to 50%. This shows that the air characteristic in this model is also suitable for the full mixture condition.

When wall mounted systems are investigated, it is seen that increase in flow rate results in better ventilation for each parameter. While air change efficiencies are similar for each parameter, it must be noted that local age of air values are increasing in inverse proportion with flow rate.

Effects of air flows on students perception in indoor quality will be investigated with PMV and PPD values.

As a result of the analyzes in which wall-mounted HRV devices are examined, it is seen that these types of models meet the full mixing condition. It can be said that the increase in air speeds and flow rates can ensure the continuity of the freshness of the air by reducing the local air ages. In the next sections, the effects of personal ventilation, piston flow and reduced number of heat recovery devices will be examined.

3.2. Investigating Personal Ventilation

In this section, the effects of personal ventilation on indoor air quality in the classroom model will be examined with the parameters in the previous section. Figure 28 shows the personal ventilation system added to the classroom model. There is a 5x28 cm diffuser on the supply faces. Air flow is normal to surface. The dimensions of the suction grilles are 3x15 cm. The personal ventilation system has a pressure drop of 20 Pa.

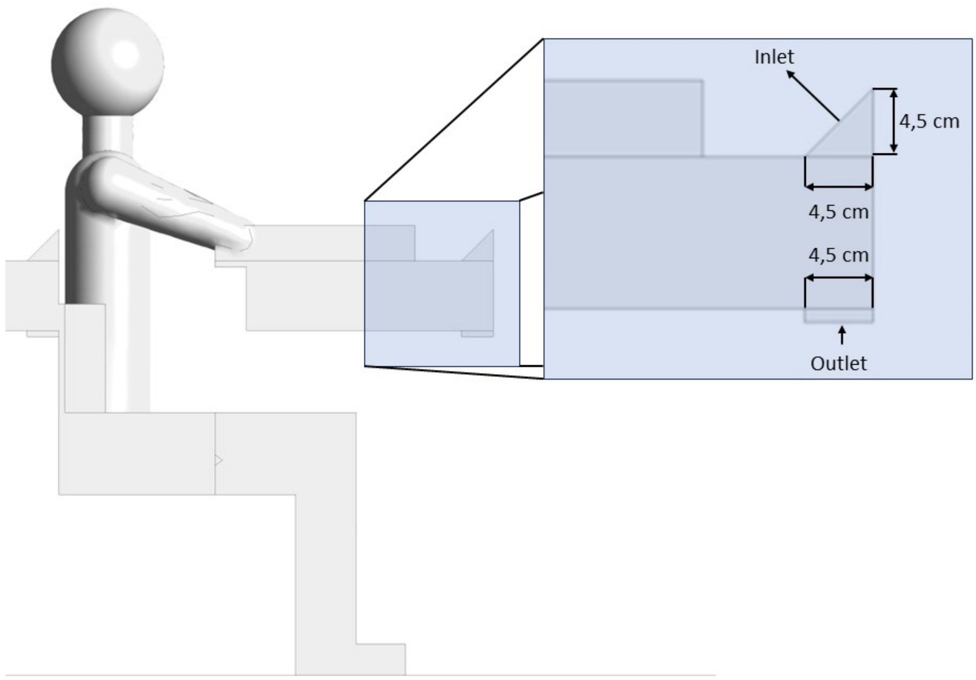
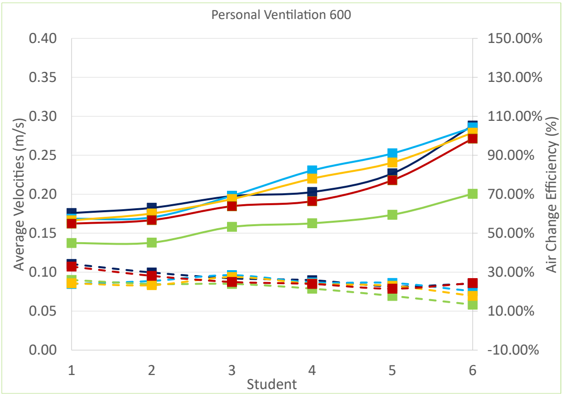


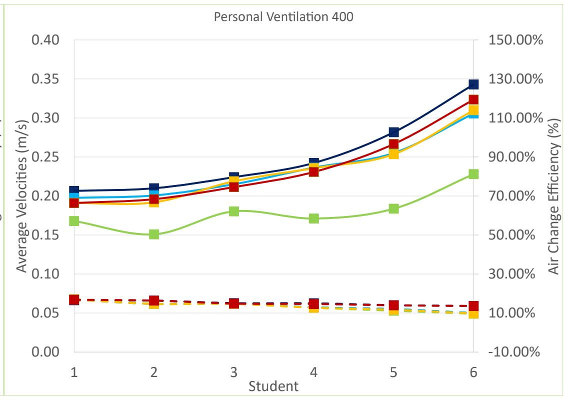
Figure 28. Desk model created for personal ventilation system

Average air velocities and air exchange efficiencies of different ventilation rates for personal ventilation are shown in Figure 29. The analysis results for the personal ventilation model at 600, 400, and 200 m^3/h flow rates are shown in Tables 25, 26, and 27, respectively.

a)



b)



c)

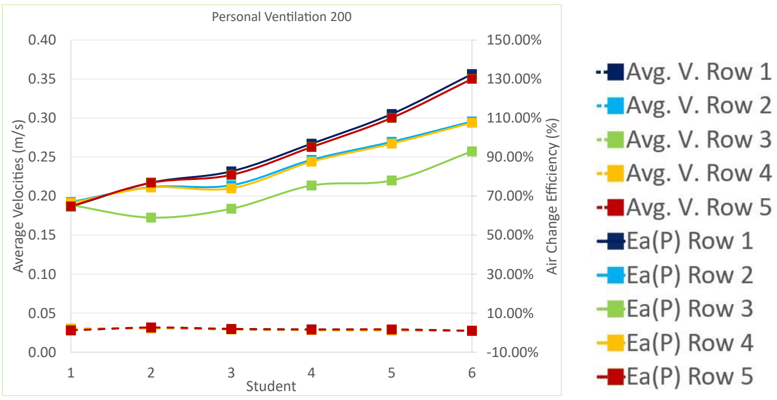


Figure 29. Average air velocities and air change efficiencies around the heads of students for personal ventilation scenario a), b), c) graphs are showing results for 600, 400, 200 m^3/h respectively.

Table 25. Results of Personal Ventilation at 600 m^3/h

Personal Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	0.11	0.10	0.09	0.09	0.08	0.09
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	0.08	0.09	0.10	0.09	0.09	0.08
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	0.09	0.08	0.08	0.08	0.07	0.06
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	0.09	0.08	0.09	0.09	0.08	0.07
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	0.11	0.10	0.09	0.08	0.08	0.09

Ea(P) PV-600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	60.4%	63.0%	69.1%	71.2%	80.7%	105.2%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	57.4%	58.1%	69.2%	82.2%	91.0%	104.3%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	44.9%	45.1%	53.2%	55.1%	59.5%	70.2%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	56.6%	60.1%	67.5%	78.0%	86.3%	101.5%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	54.9%	56.7%	63.8%	66.4%	77.2%	98.5%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	603.04	[m^3/s]
AoA Avg	633.45	[s]
AoA Avg (0,8m-1,2m)	492.43	[s]
Ea Avg	51.81%	
Ea(P) (0,8m-1,2m)	66.65%	

Table 26. Results of Personal Ventilation at 400 m^3/h

Personal Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	0.07	0.07	0.06	0.06	0.06	0.06
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	0.07	0.06	0.06	0.06	0.06	0.05
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	0.07	0.06	0.06	0.06	0.05	0.05
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	0.07	0.06	0.06	0.06	0.05	0.05
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	0.07	0.07	0.06	0.06	0.06	0.06

Ea(P) PV-400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	72.6%	74.0%	79.7%	86.9%	102.7%	127.2%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	69.0%	70.3%	76.1%	84.6%	92.0%	112.3%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	57.2%	50.3%	62.1%	58.4%	63.5%	81.2%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	66.5%	66.8%	77.6%	84.3%	91.5%	114.0%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	66.4%	68.4%	74.6%	82.3%	96.6%	119.4%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	400.00	[m^3/s]
AoA Avg	990.23	[s]
AoA Avg (0,8m-1,2m)	639.17	[s]
Ea Avg	49.72%	
Ea(P) (0,8m-1,2m)	77.02%	

Table 27. Results of Personal Ventilation at 200 m^3/h

Personal Vent. 200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.03	0.03	0.03	0.03	0.03	0.03
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.03	0.03	0.03	0.03	0.03	0.03
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.03	0.03	0.03	0.03	0.03	0.03
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.03	0.03	0.03	0.03	0.03	0.03
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.03	0.03	0.03	0.03	0.03	0.03

Ea(P) PV-200	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	64.7%	76.9%	82.7%	96.9%	112.1%	132.5%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	67.0%	74.6%	75.5%	88.6%	97.8%	108.2%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	65.4%	59.0%	63.5%	75.4%	78.0%	92.9%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	66.5%	74.4%	74.0%	87.6%	96.9%	107.6%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	64.8%	76.8%	80.9%	95.1%	110.1%	130.1%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	200.00	[m^3/s]
AoA Avg	2044.65	[s]
AoA Avg (0,8m-1,2m)	1199.91	[s]
Ea Avg	48.15%	
Ea(P) (0,8m-1,2m)	82.06%	

The models of the local age of air values around the head of the students for personal ventilation scenarios at each flow rate are shown in Figure 30.

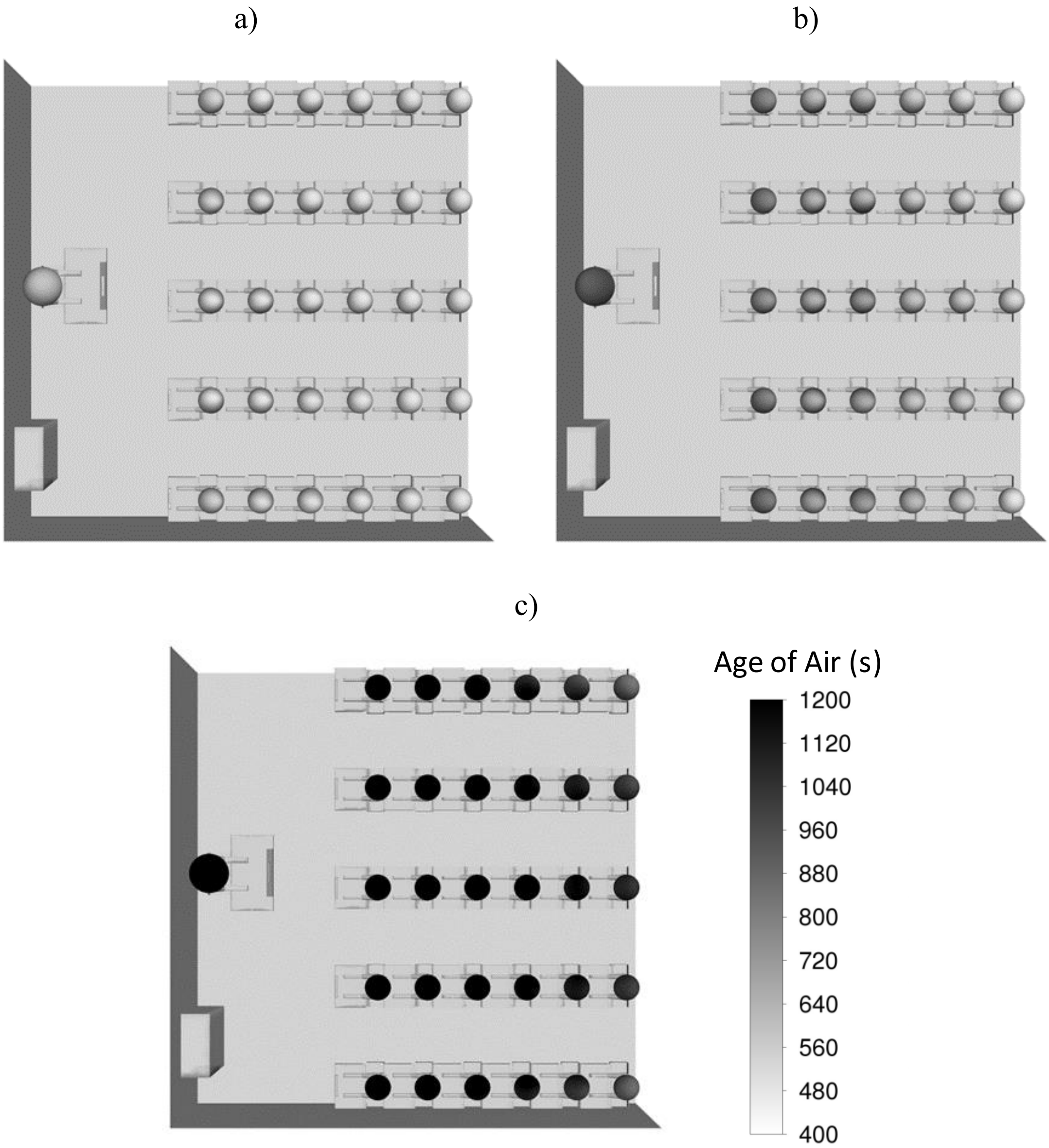


Figure 30. Local Age of Air values of individuals inside the classroom for personal ventilation scenario a), b), c) subfigures are showing results for 600, 400, 200 m^3/h respectively.

When the analyzes made in this section are examined, it is seen that the personal ventilation system increases the local air exchange efficiency compared to ventilation scenarios investigated before. Compared to the ventilation model examined in the previous section, it was determined that the overall average air age of the model was similar, but the local air ages around the head were much lower in personal ventilation.

Another situation observed in personal ventilation is that the local air exchange efficiency increases towards the back row. Although the amount of ventilation for each student is the same, the direction of ventilation causes an increase in airflow towards the back row. This also ensures that the local air age decreases towards the back rows. For this reason, it can be said that with the correct distribution of air flow rates, it can be said that the distribution of local air exchange efficiency and local age of air values in the classroom can be made more equal. In next section Piston Ventilation will be investigated.

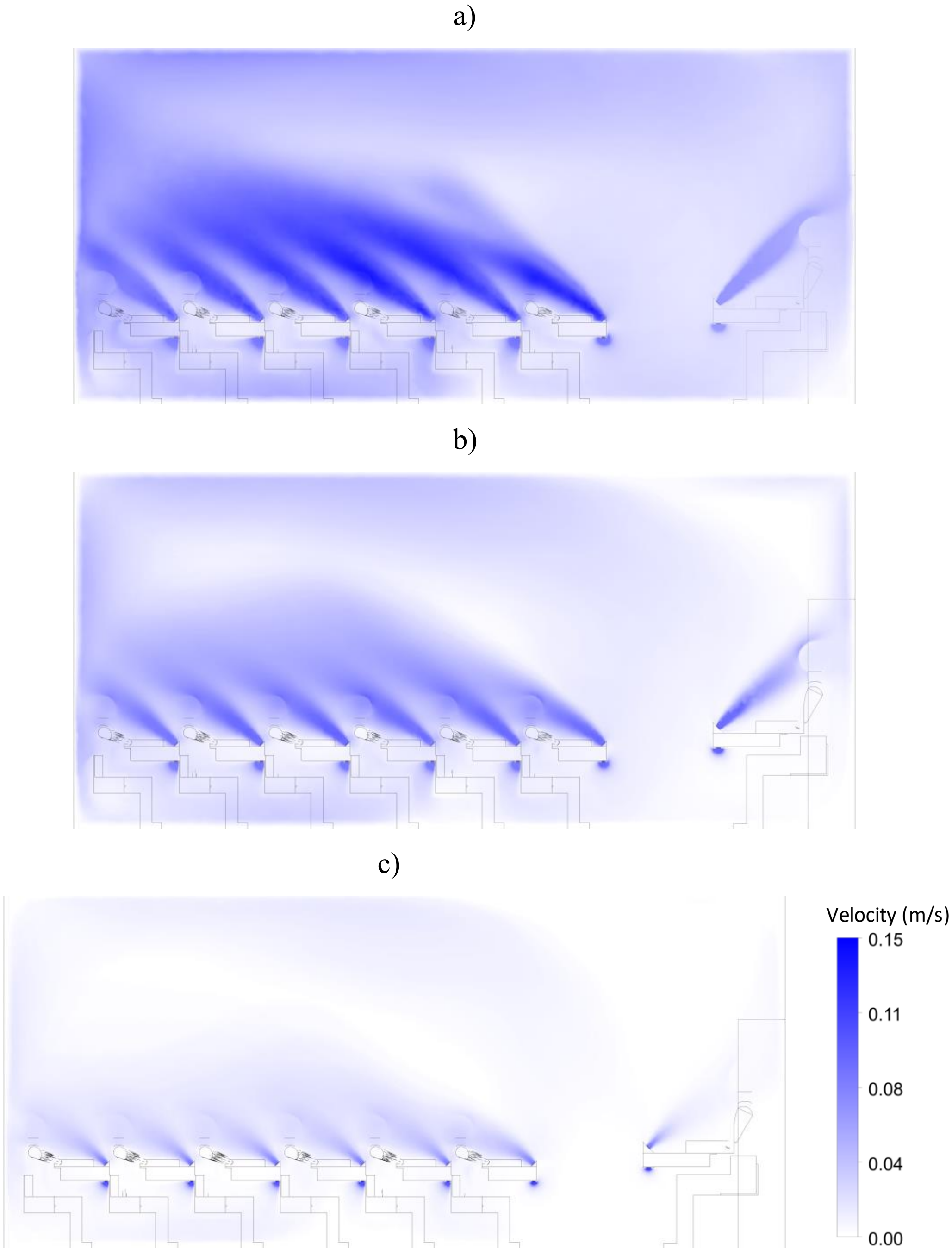


Figure 31. Air flow inside classroom for personal ventilation scenario, a), b), c) subfigures are 600, 400, 200 m^3/h respectively

3.3. Piston Ventilation Scenario

In the piston ventilation model, it is aimed to reach the ideal piston flow. The feed of the model is determined as the ceiling and the suction surface as the floor. Therefore, the model is not realistic. The air flow rate of the model was determined as 800 m^3/h.

In Figure 32, local air velocities and air exchange efficiencies of the piston ventilation system are given.

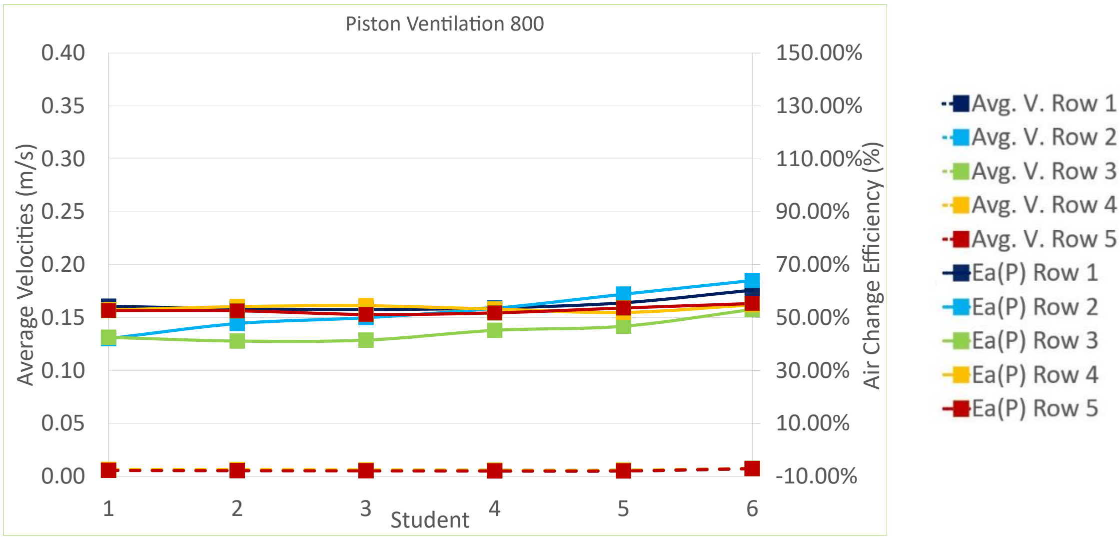


Figure 32. Average air velocities and air change efficiencies around the heads of students for piston ventilation scenario at 800 m^3/h flow rate

The analysis results for the piston ventilation model at 800 m^3/h flow rate are shown in Table 28.

Table 28. Results of Piston Ventilation at 800 m^3/h

Piston Vent. 800	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Avg. Velocity	0.01	0.01	0.01	0.01	0.01	0.01
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Avg. Velocity	0.01	0.01	0.01	0.01	0.01	0.01
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Avg. Velocity	0.01	0.01	0.01	0.01	0.01	0.01
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Avg. Velocity	0.01	0.01	0.01	0.01	0.01	0.01
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Avg. Velocity	0.01	0.01	0.01	0.01	0.01	0.01

Ea(P) Piston F. 800	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	54.3%	53.3%	53.0%	53.6%	55.6%	60.4%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	42.0%	47.8%	50.0%	53.5%	58.8%	64.0%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	42.5%	41.1%	41.5%	45.2%	46.7%	53.1%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	52.8%	54.1%	54.5%	53.2%	51.9%	54.8%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	52.6%	52.5%	51.2%	51.8%	53.6%	55.3%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	800.00	[m^3/s]
AoA Avg	322.00	[s]
AoA Avg (0,8m-1,2m)	480.20	[s]
Ea Avg	76.44%	
Ea(P) (0,8m-1,2m)	51.26%	

The model of the local age of air values around the head of the students for piston ventilation with 800 m^3/h flow rate is shown in Figure 33.

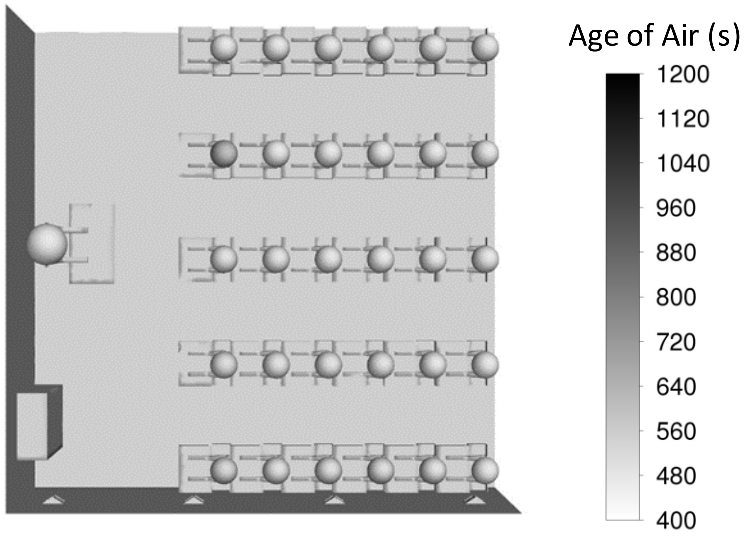


Figure 33. Local Age of Air values of individuals inside the classroom for piston ventilation scenario at 800 m^3/h flow rate

When the local average air exchange efficiency of the piston ventilation system is examined, it is seen that this value is approximately 50%, not different from other models. Figure 34 should be consulted to examine the reason for this situation. Here, it is seen that the air is directed towards the regions that hinder its passage less. It has been observed that current resistances occur at the points where the air flow is blocked or changed.

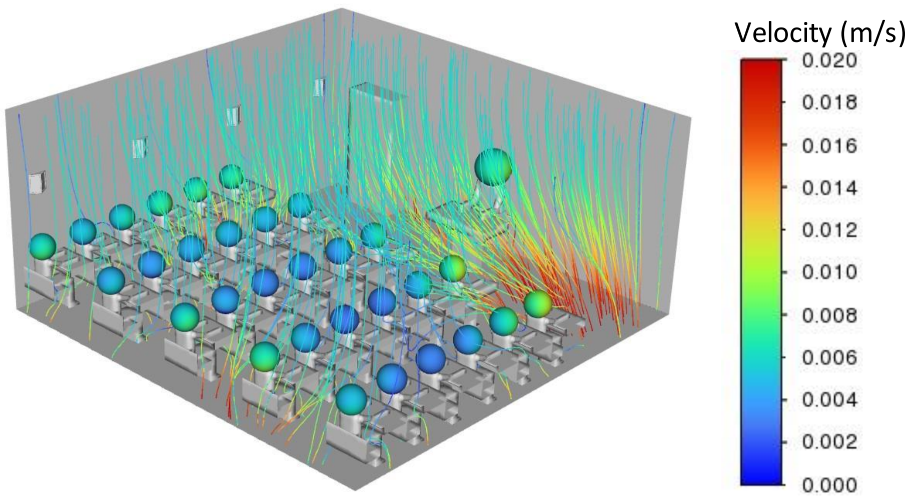


Figure 34. Classroom flow model for piston ventilation

3.4. Reduced HRV Unit Count Scenario

It is stated that the Heat Recovery device used in the study provides ventilation in 3 stages (100-150-200 m^3/h). For this reason, in this section, it is aimed to examine the usability of 2 devices instead of 4 at 400 m^3/h flow. The local air velocities and air exchange efficiencies of the system with two HRV units are given in Figure 35.

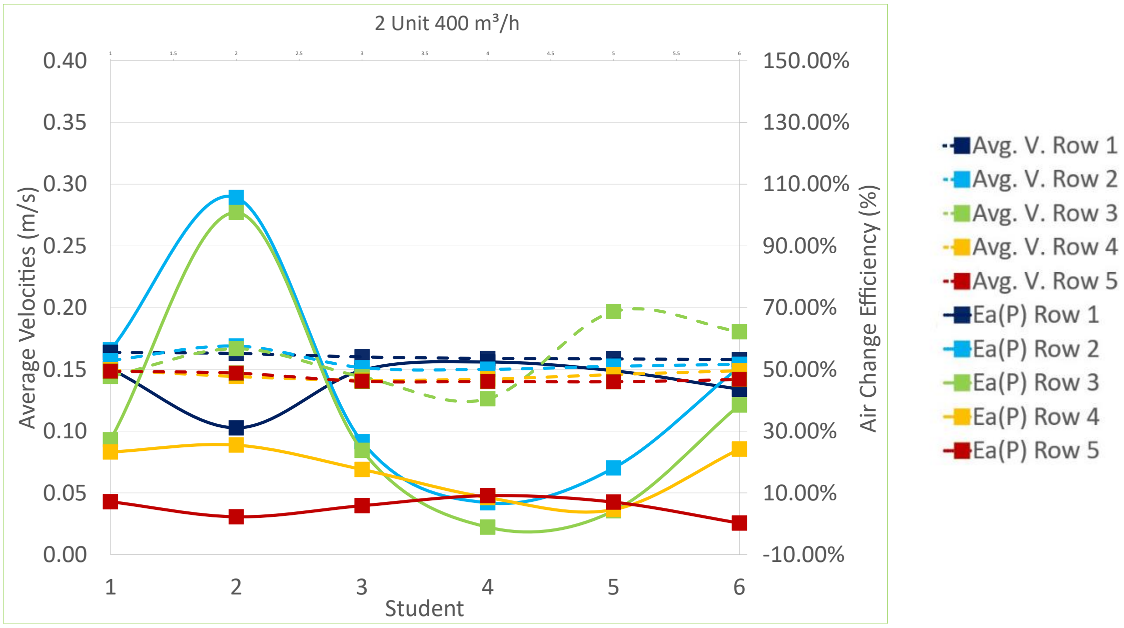


Figure 35. Average air velocities and air change efficiencies around the heads of students for reduced number of ventilation unit scenario at 400 m^3/h flow rate

The analysis results for the system with two HRV units at 400 m^3/h flow rate is shown in Table 29.

Table 29. Results of 2 HRV unit with 400 m^3/h

2 Unit 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	0.15	0.10	0.15	0.16	0.15	0.13
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	0.17	0.29	0.09	0.04	0.07	0.15
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	0.09	0.28	0.08	0.02	0.04	0.12
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	0.08	0.09	0.07	0.05	0.04	0.09
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	0.04	0.03	0.04	0.05	0.04	0.03

Ea(P) 2 Unit 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row 1 (Far)	55.5%	55.2%	54.0%	53.6%	53.4%	53.2%
	S 2,1	S 2,2	S 2,3	S 2,4	S 2,5	S 2,6
Row 2	52.9%	57.6%	50.6%	50.0%	51.0%	51.7%
	S 3,1	S 3,2	S 3,3	S 3,4	S 3,5	S 3,6
Row 3	47.7%	56.7%	47.6%	40.5%	68.7%	62.2%
	S 4,1	S 4,2	S 4,3	S 4,4	S 4,5	S 4,6
Row 4	49.9%	47.7%	46.5%	46.9%	48.3%	49.6%
	S 5,1	S 5,2	S 5,3	S 5,4	S 5,5	S 5,6
Row 5	49.4%	48.8%	46.2%	46.1%	46.0%	46.7%

Volume Total	109.40	[m^3]
Volume (0,8m-1,2m)	15.36	[m^3]
Volume Flow Rate	400.00	[m^3/s]
AoA Avg	973.81	[s]
AoA Avg (0,8m-1,2m)	972.60	[s]
Ea Avg	50.55%	
Ea(P) (0,8m-1,2m)	50.62%	

The model of the local age of air values around the head of the students for two HRV units at 400 m^3/h flow rate is shown in Figure 36.

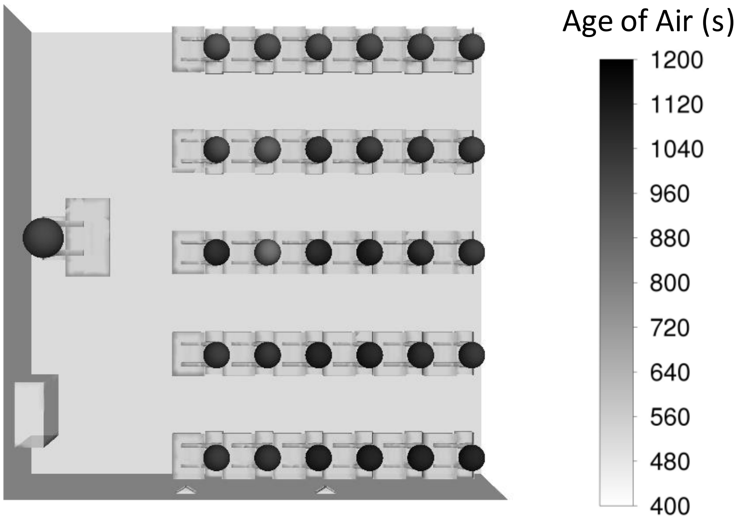


Figure 36. Local Age of Air values of individuals inside the classroom for reduced number of ventilation unit scenario at 400 m^3/h flow rate

When the analysis performed with 2 units is examined, it is seen that the highest air velocities in the space are more than the systems with 4 units. In addition, the air exchange efficiency and air age values are similar to the 4-unit models. The graphs in which age of air figures are examined in comparison can be seen in Annex D.

In this section, analyzes for each parameter are examined. As a result of the examinations, it can be said that Personal ventilation systems provide the best indoor air quality for students. In the parameters in which wall-mounted devices are examined, the effect of Flow rate on local air velocities, air exchange efficiency and air age has been investigated. Depending on the air flow, it was seen that the local air age has an inverse proportion and the local air velocities have a linear proportion. Depending on the results of the analysis, it can be said that less number of devices can be used in case the required flow rate is low.

Individuals' perceptions of indoor air quality depending on these parameters were examined in the next section with PMV and PPD calculations.

3.5. Evaluating Predicted Average Vote and Predicted Percent Dissatisfied Parameters

After calculating the average air velocity around the head with the analyzes made in each parameter, PMV vs PPD values were measured for the students in the classroom. Relative humidity values were selected according to the province of Izmir in Türkiye. Relative humidity values for summer and winter conditions were determined as 51% and 73%, respectively. The metabolic rate of the students was determined as 1.1 met (64,02 W/m^2), and the clo value was determined as 0.8 for the summer condition and 1 for the winter condition. The environment was considered isothermal and analyzes were performed according to this boundary condition. To calculate the PMV value, the internal temperature of the class will be between 20-26 °C by calculating the PMV value for each temperature. Calculations for all ambient temperatures can be found in Appendix D.

PPD values were calculated for summer and winter conditions at 25 °C and 22°C, respectively for wall type ventilation scenarios. For personal, piston and reduced unit ventilation scenarios PPD values are calculated between 20 and 26 °C, Corresponding graphs are shown in Figure 37 and Figure 38 for wall type ventilation scenarios. For personal, piston and reduced unit ventilation scenarios, these values are shown in figures between 39 and 43.

These values have been reviewed according to the ASHRAE 55:2020 standard. In the figures, the values are indicated with green if they are below the 10% PPD value accepted by the standard, and red if they are abov

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.0%	8.5%	7.9%	7.5%	7.8%	9.1%	8%	0.39
Row-2	9.1%	9.1%	9.1%	5.5%	6.6%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	7.9%	8.1%	5.3%	6.7%	8.1%	0.01	0.09
Row-4	9.1%	9.1%	9.1%	6.3%	9.1%	8.8%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	8.5%	9.0%	9.1%	9%	0.42
Row-2	9.1%	9.1%	9.1%	6.3%	7.3%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	9.1%	9.1%	6.3%	6.8%	9.1%	0.01	0.06
Row-4	9.1%	9.1%	9.1%	8.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.43
Row-2	9.1%	9.1%	9.1%	8.1%	8.2%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	9.1%	9.1%	8.0%	7.4%	9.1%	0.00	0.03
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.0%	9.1%	9.1%	9.1%	8%	0.39
Row-2	8.0%	7.2%	7.8%	6.0%	6.8%	9.1%	PPD Std D.	PMV Std. D.
Row-3	7.7%	6.3%	7.1%	6.0%	5.8%	8.2%	0.01	0.08
Row-4	9.1%	9.0%	9.1%	8.9%	7.7%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.42
Row-2	9.1%	8.2%	9.1%	7.3%	8.1%	9.1%	PPD Std D.	PMV Std. D.
Row-3	8.7%	7.2%	8.2%	6.2%	7.2%	9.1%	0.01	0.05
Row-4	9.1%	9.1%	9.1%	8.9%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.44
Row-2	9.1%	9.1%	9.1%	8.7%	9.1%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	8.8%	9.1%	8.1%	8.2%	9.1%	0.00	0.01
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	8%	0.38
Row-2	9.1%	7.9%	9.1%	6.4%	7.8%	9.1%	PPD Std D.	PMV Std. D.
Row-3	7.3%	6.2%	7.0%	6.1%	6.1%	7.6%	0.01	0.07
Row-4	7.8%	7.3%	8.2%	7.6%	7.3%	7.9%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.42
Row-2	9.1%	8.3%	9.1%	6.9%	9.1%	9.1%	PPD Std D.	PMV Std. D.
Row-3	8.4%	7.1%	8.0%	6.6%	7.2%	9.1%	0.01	0.05
Row-4	9.1%	9.1%	9.1%	9.1%	8.8%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.43
Row-2	9.1%	9.1%	9.1%	8.1%	8.2%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	9.1%	9.1%	8.0%	7.4%	9.1%	0.00	0.03
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.3%	8.0%	8.7%	9.1%	8.4%	8%	0.38
Row-2	6.5%	6.2%	8.0%	6.4%	7.0%	9.1%	PPD Std D.	PMV Std. D.
Row-3	6.4%	6.2%	7.6%	7.2%	6.1%	9.1%	0.01	0.08
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.41
Row-2	7.0%	7.0%	9.1%	7.3%	7.5%	9.1%	PPD Std D.	PMV Std. D.
Row-3	7.1%	7.1%	8.9%	9.0%	6.7%	9.1%	0.01	0.05
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.44
Row-2	8.6%	8.6%	9.1%	9.1%	8.9%	9.1%	PPD Std D.	PMV Std. D.
Row-3	8.7%	8.8%	9.1%	9.1%	8.0%	9.1%	0.00	0.01
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

Figure 37. Calculated PPD values for each parameter in summer (met 1.1, clo 0.8, RH 51%, T 25°C)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.0%	5.0%	5.0%	5.1%	5%	0.03
Row-2	5.1%	5.1%	5.1%	5.8%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.0%	5.0%	6.2%	5.1%	5.0%	0.00	0.08
Row-4	5.1%	5.1%	5.1%	5.2%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.06
Row-2	5.1%	5.1%	5.1%	5.2%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.2%	5.1%	5.1%	0.00	0.05
Row-4	5.1%	5.1%	5.1%	5.0%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.07
Row-2	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	0.00	0.02
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.03
Row-2	5.0%	5.0%	5.0%	5.4%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.2%	5.0%	5.4%	5.5%	5.0%	0.00	0.08
Row-4	5.1%	5.1%	5.1%	5.1%	5.0%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.06
Row-2	5.1%	5.0%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.0%	5.0%	5.2%	5.0%	5.1%	0.00	0.04
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.08
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	0.00	0.01
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.03
Row-2	5.1%	5.0%	5.1%	5.2%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.3%	5.0%	5.3%	5.3%	5.0%	0.00	0.07
Row-4	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.06
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.0%	5.0%	5.1%	5.0%	5.1%	0.00	0.04
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.07
Row-2	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	0.00	0.02
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.0%	5.1%	5.1%	5.1%	5%	0.03
Row-2	5.2%	5.3%	5.0%	5.2%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.2%	5.3%	5.0%	5.0%	5.3%	5.1%	0.00	0.07
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.05
Row-2	5.0%	5.0%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.0%	5.1%	5.1%	5.1%	5.1%	0.00	0.05
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.08
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.1%	5.0%	5.1%	0.00	0.01
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

Figure 38. Calculated PPD values for each parameter in winter (met 1.1, clo 1.0, RH 75%, T 22°C)

Summer Season

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
20	Row-1	26.1%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-5	25.6%	24.4%	24.4%	24.4%	24.4%	24.4%

PPD Avg	PMV Avg
0.245	-0.957
PPD Std D.	PMV Std. D.
0.004	0.009

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
21	Row-1	16.2%	15.1%	14.7%	14.7%	14.7%	14.7%
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-5	15.9%	14.7%	14.7%	14.7%	14.7%	14.7%

PPD Avg	PMV Avg
0.148	-0.680
PPD Std D.	PMV Std. D.
0.003	0.012

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
22	Row-1	9.4%	8.8%	8.3%	8.3%	8.3%	8.3%
	Row-2	8.3%	8.3%	8.6%	8.3%	8.3%	8.3%
	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
	Row-4	8.3%	8.3%	8.4%	8.3%	8.3%	8.3%
	Row-5	9.2%	8.5%	8.3%	8.3%	8.3%	8.3%

PPD Avg	PMV Avg
0.084	-0.403
PPD Std D.	PMV Std. D.
0.003	0.014

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
23	Row-1	5.7%	5.5%	5.4%	5.3%	5.3%	5.3%
	Row-2	5.3%	5.3%	5.4%	5.3%	5.3%	5.3%
	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
	Row-4	5.3%	5.3%	5.4%	5.3%	5.3%	5.3%
	Row-5	5.7%	5.4%	5.3%	5.3%	5.3%	5.3%

PPD Avg	PMV Avg
0.053	-0.127
PPD Std D.	PMV Std. D.
0.001	0.017

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
24	Row-1	5.2%	5.3%	5.4%	5.4%	5.5%	5.5%
	Row-2	5.5%	5.5%	5.3%	5.5%	5.5%	5.5%
	Row-3	5.4%	5.5%	5.5%	5.5%	5.5%	5.5%
	Row-4	5.5%	5.5%	5.4%	5.5%	5.5%	5.5%
	Row-5	5.2%	5.3%	5.5%	5.5%	5.5%	5.5%

PPD Avg	PMV Avg
0.055	0.148
PPD Std D.	PMV Std. D.
0.001	0.019

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
25	Row-1	7.8%	8.2%	8.5%	8.6%	9.0%	8.8%
	Row-2	8.8%	8.7%	8.3%	8.8%	8.8%	9.1%
	Row-3	8.6%	8.9%	8.8%	9.1%	9.1%	9.1%
	Row-4	8.8%	8.9%	8.4%	8.8%	9.0%	9.1%
	Row-5	7.9%	8.4%	8.7%	8.8%	9.1%	8.8%

PPD Avg	PMV Avg
0.087	0.421
PPD Std D.	PMV Std. D.
0.003	0.020

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
26	Row-1	13.7%	14.4%	14.8%	15.0%	15.6%	15.3%
	Row-2	15.3%	15.1%	14.6%	15.2%	15.3%	16.1%
	Row-3	15.0%	15.4%	15.3%	15.8%	16.1%	16.1%
	Row-4	15.3%	15.5%	14.7%	15.3%	15.5%	16.1%
	Row-5	13.9%	14.6%	15.2%	15.3%	15.8%	15.3%

PPD Avg	PMV Avg
0.152	0.694
PPD Std D.	PMV Std. D.
0.006	0.020

Winter Season

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	9.9%	9.3%	8.9%	8.9%	8.9%	8.9%
Row-2	8.9%	8.9%	9.1%	8.9%	8.9%	8.9%
Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
Row-4	8.9%	8.9%	9.0%	8.9%	8.9%	8.9%
Row-5	9.7%	9.0%	8.9%	8.9%	8.9%	8.9%

PPD Avg	PMV Avg
0.090	-0.435
PPD Std D.	PMV Std. D.
0.002	0.012

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	6.1%	5.9%	5.7%	5.6%	5.6%	5.6%
Row-2	5.6%	5.6%	5.8%	5.6%	5.6%	5.6%
Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Row-4	5.6%	5.6%	5.7%	5.6%	5.6%	5.6%
Row-5	6.1%	5.8%	5.6%	5.6%	5.6%	5.6%

PPD Avg	PMV Avg
0.057	-0.182
PPD Std D.	PMV Std. D.
0.001	0.015

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	5.0%	5.0%	5.1%	5.1%	5.1%	5.1%
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-5	5.0%	5.1%	5.1%	5.1%	5.1%	5.1%

PPD Avg	PMV Avg
0.051	0.072
PPD Std D.	PMV Std. D.
0.000	0.017

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	6.5%	6.8%	7.1%	7.2%	7.4%	7.3%
Row-2	7.3%	7.2%	6.9%	7.3%	7.3%	7.4%
Row-3	7.1%	7.3%	7.3%	7.4%	7.4%	7.4%
Row-4	7.3%	7.4%	7.0%	7.3%	7.4%	7.4%
Row-5	6.6%	7.0%	7.2%	7.3%	7.4%	7.3%

PPD Avg	PMV Avg
0.072	0.324
PPD Std D.	PMV Std. D.
0.002	0.017

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	10.9%	11.4%	11.8%	11.9%	12.4%	12.1%
Row-2	12.2%	12.0%	11.6%	12.1%	12.1%	12.5%
Row-3	11.9%	12.2%	12.2%	12.5%	12.6%	12.6%
Row-4	12.1%	12.3%	11.7%	12.2%	12.3%	12.6%
Row-5	11.0%	11.6%	12.0%	12.2%	12.5%	12.1%

PPD Avg	PMV Avg
0.120	0.577
PPD Std D.	PMV Std. D.
0.004	0.018

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	18.1%	18.8%	19.3%	19.5%	20.1%	19.8%
Row-2	19.8%	19.5%	19.0%	19.7%	19.7%	20.6%
Row-3	19.5%	19.8%	19.8%	20.3%	20.6%	20.6%
Row-4	19.8%	20.0%	19.2%	19.8%	20.0%	20.6%
Row-5	18.3%	19.1%	19.6%	19.8%	20.3%	19.7%

PPD Avg	PMV Avg
0.197	0.832
PPD Std D.	PMV Std. D.
0.006	0.017

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	28.3%	29.1%	29.6%	29.8%	30.5%	30.2%
Row-2	30.3%	29.9%	29.3%	30.1%	30.1%	31.1%
Row-3	29.8%	30.3%	30.2%	30.8%	31.6%	31.5%
Row-4	30.2%	30.4%	29.5%	30.2%	30.5%	31.6%
Row-5	28.5%	29.4%	30.0%	30.2%	30.8%	30.1%

PPD Avg	PMV Avg
0.301	1.088
PPD Std D.	PMV Std. D.
0.008	0.017

Figure 39. Calculated PPD values for personal ventilation at 600 m³/h in summer and winter season

Summer Season

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.244	-0.955
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	PPD Std D.	PMV Std. D.
20	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.000	0.000
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.147	-0.677
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	PPD Std D.	PMV Std. D.
21	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.000	0.000
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.084	-0.403
	Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.
22	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.003	0.014
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.053	-0.118
	Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	PPD Std D.	PMV Std. D.
23	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.000	0.000
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.055	0.162
	Row-2	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	PPD Std D.	PMV Std. D.
24	Row-3	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.000	0.000
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.091	0.442
	Row-2	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	PPD Std D.	PMV Std. D.
25	Row-3	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.000	0.000
	Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.161	0.723
	Row-2	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	PPD Std D.	PMV Std. D.
26	Row-3	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.000	0.000
	Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%		
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%		

Winter Season

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.089	-0.431
Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.000	0.000
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.056	-0.175
Row-2	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.000	0.000
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.051	0.081
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.000	0.000
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.074	0.339
Row-2	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.000	0.000
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.126	0.598
Row-2	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.000	0.000
Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.206	0.857
Row-2	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	PPD Std D.	PMV Std. D.
Row-3	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.000	0.001
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.315	1.118
Row-2	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	PPD Std D.	PMV Std. D.
Row-3	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.000	0.000
Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		

Figure 40. Calculated PPD values for personal ventilation at 400 m³/h in summer and winter season

Summer Season / Winter Season

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.244	-0.955	Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.089	-0.431
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	PPD Std D.	PMV Std. D.	Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	PPD Std D.	PMV Std. D.
20	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.000	0.000	Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.000	0.000
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%			Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%			Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.147	-0.677	Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.056	-0.175
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	PPD Std D.	PMV Std. D.	Row-2	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	PPD Std D.	PMV Std. D.
21	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.000	0.000	Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.000	0.000
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%			Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%			Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.083	-0.398	Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.051	0.081
	Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.	Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
22	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.000	0.000	Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.000	0.000
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%			Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%			Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.053	-0.118	Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.074	0.339
	Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	PPD Std D.	PMV Std. D.	Row-2	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	PPD Std D.	PMV Std. D.
23	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.000	0.000	Row-3	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.000	0.000
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%			Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%			Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.055	0.162	Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.126	0.598
	Row-2	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	PPD Std D.	PMV Std. D.	Row-2	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	PPD Std D.	PMV Std. D.
24	Row-3	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.000	0.000	Row-3	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.000	0.000
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%			Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%			Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.091	0.442	Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.206	0.856
	Row-2	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	PPD Std D.	PMV Std. D.	Row-2	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	PPD Std D.	PMV Std. D.
25	Row-3	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.000	0.000	Row-3	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.000	0.000
	Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%			Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%			Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.161	0.723	Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.315	1.118
	Row-2	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	PPD Std D.	PMV Std. D.	Row-2	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	PPD Std D.	PMV Std. D.
26	Row-3	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.000	0.000	Row-3	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.000	0.000
	Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%			Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%			Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		

Figure 41. Calculated PPD values for personal ventilation at 200 m³/h in summer and winter season

Summer Season								Winter Season						
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
20	Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
21	Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	Row-2	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
22	Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
	Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
23	Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
	Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	Row-2	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	Row-3	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
24	Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
	Row-2	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	Row-2	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
	Row-3	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	Row-3	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
25	Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
	Row-2	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	Row-2	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
	Row-3	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	Row-3	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
	Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
26	Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
	Row-2	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	Row-2	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
	Row-3	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	Row-3	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
	Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

Case	Summer PPD Avg	Summer PMV Avg	Summer PPD Std D.	Summer PMV Std. D.	Winter PPD Avg	Winter PMV Avg	Winter PPD Std D.	Winter PMV Std. D.
20	0.244	-0.955	0.000	0.000	0.089	-0.431	0.000	0.000
21	0.147	-0.677	0.000	0.000	0.056	-0.175	0.000	0.000
22	0.083	-0.398	0.000	0.000	0.051	0.081	0.000	0.000
23	0.053	-0.118	0.000	0.000	0.074	0.339	0.000	0.000
24	0.055	0.162	0.000	0.000	0.126	0.598	0.000	0.000
25	0.091	0.442	0.000	0.000	0.206	0.856	0.000	0.000
26	0.161	0.723	0.000	0.000	0.315	1.118	0.000	0.000

Figure 42. Calculated PPD values for piston ventilation at 800 m³/h in summer and winter season

Summer Season

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
20	Row-1	31.7%	24.9%	31.6%	32.5%	31.6%	29.5%
	Row-2	33.7%	46.9%	24.4%	24.4%	24.4%	32.0%
	Row-3	24.4%	45.8%	24.4%	24.4%	24.4%	27.7%
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%

PPD Avg	PMV Avg
0.277	-1.028
PPD Std D.	PMV Std. D.
0.059	0.125

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
21	Row-1	20.2%	15.4%	20.1%	20.7%	20.0%	18.6%
	Row-2	21.6%	31.7%	14.7%	14.7%	14.7%	20.3%
	Row-3	14.7%	30.8%	14.7%	14.7%	14.7%	17.3%
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%

PPD Avg	PMV Avg
0.172	-0.749
PPD Std D.	PMV Std. D.
0.044	0.121

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
22	Row-1	11.8%	8.9%	11.7%	12.1%	11.7%	10.8%
	Row-2	12.7%	19.3%	8.3%	8.3%	8.3%	11.9%
	Row-3	8.4%	18.7%	8.3%	8.3%	8.3%	10.0%
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%

PPD Avg	PMV Avg
0.099	-0.469
PPD Std D.	PMV Std. D.
0.028	0.116

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
23	Row-1	6.7%	5.6%	6.7%	6.9%	6.7%	6.3%
	Row-2	7.1%	10.6%	5.4%	5.3%	5.3%	6.8%
	Row-3	5.4%	10.3%	5.3%	5.3%	5.3%	6.0%
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%

PPD Avg	PMV Avg
0.060	-0.189
PPD Std D.	PMV Std. D.
0.013	0.110

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
24	Row-1	5.0%	5.2%	5.0%	5.0%	5.0%	5.0%
	Row-2	5.0%	5.9%	5.4%	5.5%	5.5%	5.0%
	Row-3	5.4%	5.8%	5.5%	5.5%	5.5%	5.1%
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%

PPD Avg	PMV Avg
0.054	0.091
PPD Std D.	PMV Std. D.
0.003	0.104

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
25	Row-1	6.7%	8.1%	6.7%	6.6%	6.7%	7.1%
	Row-2	6.4%	5.2%	8.5%	9.1%	9.1%	6.7%
	Row-3	8.5%	5.2%	8.9%	9.1%	9.1%	7.4%
	Row-4	8.9%	8.7%	9.1%	9.1%	9.1%	8.8%
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%

PPD Avg	PMV Avg
0.081	0.373
PPD Std D.	PMV Std. D.
0.013	0.097

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
26	Row-1	11.9%	14.2%	11.9%	11.7%	12.0%	12.6%
	Row-2	11.3%	8.5%	14.9%	16.1%	16.1%	11.8%
	Row-3	14.8%	8.7%	15.4%	16.1%	16.1%	13.2%
	Row-4	15.5%	15.1%	16.1%	16.1%	16.1%	15.3%
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
0.143	0.655
PPD Std D.	PMV Std. D.
0.023	0.089

Winter Season

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	12.1%	9.5%	12.1%	12.4%	12.0%	11.2%
Row-2	13.0%	18.9%	8.9%	8.9%	8.9%	12.2%
Row-3	8.9%	18.4%	8.9%	8.9%	8.9%	10.5%
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%

PPD Avg	PMV Avg
0.104	-0.494
PPD Std D.	PMV Std. D.
0.026	0.104

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	7.2%	6.0%	7.2%	7.4%	7.2%	6.8%
Row-2	7.7%	11.0%	5.7%	5.6%	5.6%	7.3%
Row-3	5.7%	10.7%	5.6%	5.6%	5.6%	6.4%
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%

PPD Avg	PMV Avg
0.064	-0.239
PPD Std D.	PMV Std. D.
0.014	0.100

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	5.1%	5.0%	5.1%	5.1%	5.1%	5.0%
Row-2	5.2%	6.4%	5.1%	5.1%	5.1%	5.1%
Row-3	5.1%	6.3%	5.1%	5.1%	5.1%	5.0%
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%

PPD Avg	PMV Avg
0.052	0.019
PPD Std D.	PMV Std. D.
0.003	0.095

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	5.8%	6.7%	5.8%	5.7%	5.8%	6.0%
Row-2	5.6%	5.0%	7.1%	7.4%	7.4%	5.8%
Row-3	7.0%	5.0%	7.3%	7.4%	7.4%	6.3%
Row-4	7.4%	7.2%	7.4%	7.4%	7.4%	7.3%
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%

PPD Avg	PMV Avg
0.068	0.277
PPD Std D.	PMV Std. D.
0.008	0.090

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	9.4%	11.2%	9.4%	9.3%	9.5%	9.9%
Row-2	9.0%	6.9%	11.8%	12.6%	12.6%	9.4%
Row-3	11.7%	7.0%	12.2%	12.6%	12.6%	10.4%
Row-4	12.3%	12.0%	12.6%	12.6%	12.6%	12.1%
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%

PPD Avg	PMV Avg
0.112	0.537
PPD Std D.	PMV Std. D.
0.017	0.084

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	16.1%	18.6%	16.2%	15.9%	16.2%	16.9%
Row-2	15.5%	12.1%	19.3%	20.6%	20.6%	16.0%
Row-3	19.2%	12.4%	19.9%	20.6%	20.6%	17.5%
Row-4	20.0%	19.5%	20.6%	20.6%	20.6%	19.8%
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%

PPD Avg	PMV Avg
0.186	0.797
PPD Std D.	PMV Std. D.
0.025	0.078

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	25.9%	28.8%	26.0%	25.6%	26.0%	26.8%
Row-2	25.2%	20.9%	29.7%	31.5%	31.6%	25.8%
Row-3	29.6%	21.2%	30.3%	31.5%	31.5%	27.6%
Row-4	30.4%	29.9%	31.6%	31.5%	31.5%	30.2%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
0.290	1.061
PPD Std D.	PMV Std. D.
0.031	0.072

Figure 43. Calculated PPD values for reduced number of HRV unit with 400 m³/h in summer and winter season

CHAPTER 4

CONCLUSION AND DISCUSSION

In this study, to increase the indoor air quality in schools, a concept ventilation application was carried out to effectively ventilate a classroom environment that is not part of any central or decentralized ventilation system, targeting the existing building stock, within the limits determined by the standards. In this process, the flow values required for the ventilation of the class were evaluated within the framework of the relevant standards. Then, with the analysis made within the framework of certain parameters, the speed values in the head circumference of the students, the air exchange efficiency, and the air age values were measured and the PMV and PPD values were measured to obtain information about the perceptions of the individuals.

When the average air velocity values are examined in general, it can be said that it is below the value of 0.25 m/s. However, when the graphs in Annex C are examined, it should be noted that the local air velocities are higher than 0.25 m/s, except for the model in which 200 cm device height and 5° diffuser angle are examined at a ventilation flow rate of 800 m^3/h.

It was observed that the air velocities around the head showed a better distribution in the analysis conditions where the devices were placed at a height of 200 cm from the ground. When the tables and visuals in Appendix B and Appendix C are examined, it was determined that the students directly under the diffusers were exposed to more air velocity in the analyzes where the device height of 200 cm was examined, compared to the analyzes made at other heights. It has been shown that devices placed at this height provide a more efficient response.

When the air exchange efficiencies in each parameter were examined, it was seen that the analyzes had an air exchange efficiency of about 55%. When the local air exchange efficiency is examined, it is seen that the air exchange efficiency of the students under the diffusers decreases below 50% according to the parameter, and this efficiency increases as they move away from the devices. When the average air exchange efficiency is examined, the class model exhibits a ventilation character close to the full mixture model.

When the visuals in Appendix E are examined according to the ASHRAE 55:2020 standard, it is seen that the average PMV value closest to neutral in the class is obtained at 23 °C for winter, and this temperature value is 24 °C for summer. In the calculations made according to this PMV value, it was determined that these values were also the temperature at which the PPD value was most appropriate.

Personal ventilation, piston ventilation and reduced HRV unit count is also investigated apart from wall mounted unit scenarios. Personal ventulation gave best results compared to other parameters. Personal ventilation can be investigated further to enhance energy efficiencies of systems further. It can be said that indoor air quality can be maintained at lower flow rates by improving the ventilation distribution.

4.1. Limitations of the Study and Suggestions for Future Research

Most crucial drawback is that the study is carried out in a numerical environment and is not adequately supported by experimental data. It is possible to examine the accuracy of the study in time-dependent analyzes, thermal analyses, or experimental studies.

In future studies, it is important to perform time-dependent analyzes of numerical analyzes, including thermal equations, for the improvement of the current system. The suitability of the ventilation system in different climatic regions can be examined.

The economic and physical effects of reducing or increasing the number of devices according to the flow requirement can be examined. New analyzes can be carried out with different types of vents, which can enable the diffusers of the devices to distribute the air more efficiently.

4.2. Final Thoughts and Concluding Remarks

The study aimed to investigate the applicability of Mono HRV units, which have become widespread in residential ventilation as an alternative to central ventilation systems, in the school environment. The study also aimed to examine the effect of personal ventilation on indoor air quality in classrooms. It has been observed that personal ventilation solutions provide a better ventilation scenario compared to other parameters examined in the study. But when the situation of current school buildings is examined, installation and operating costs are still an obstacle to the widespread adoption of personal ventilation systems. while mono units create more affordable costs in terms of installation and operation, while creating a solution to increase indoor air quality. This study has revealed that applications that can be made with mono units for a classroom environment are possible with the examinations made in the numerical environment.

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APPENDIX A

COMPARATIVE ANALYSIS OF C08-75, C20-50 AND C20-75 MODELS

Informative note:

I. Total ventilation rate in each analysis is set to 800 m^3/h, heat recovery units are placed at 200 cm height, and inlet diffusers are set with a downward angle of 5°

II. X-axis represents the iteration number,

III. Each column represents an average air velocity of 250 iterations. Each column also consists of its respective standard deviation value.

IV. Y-axis represents the average air velocity in m/s.

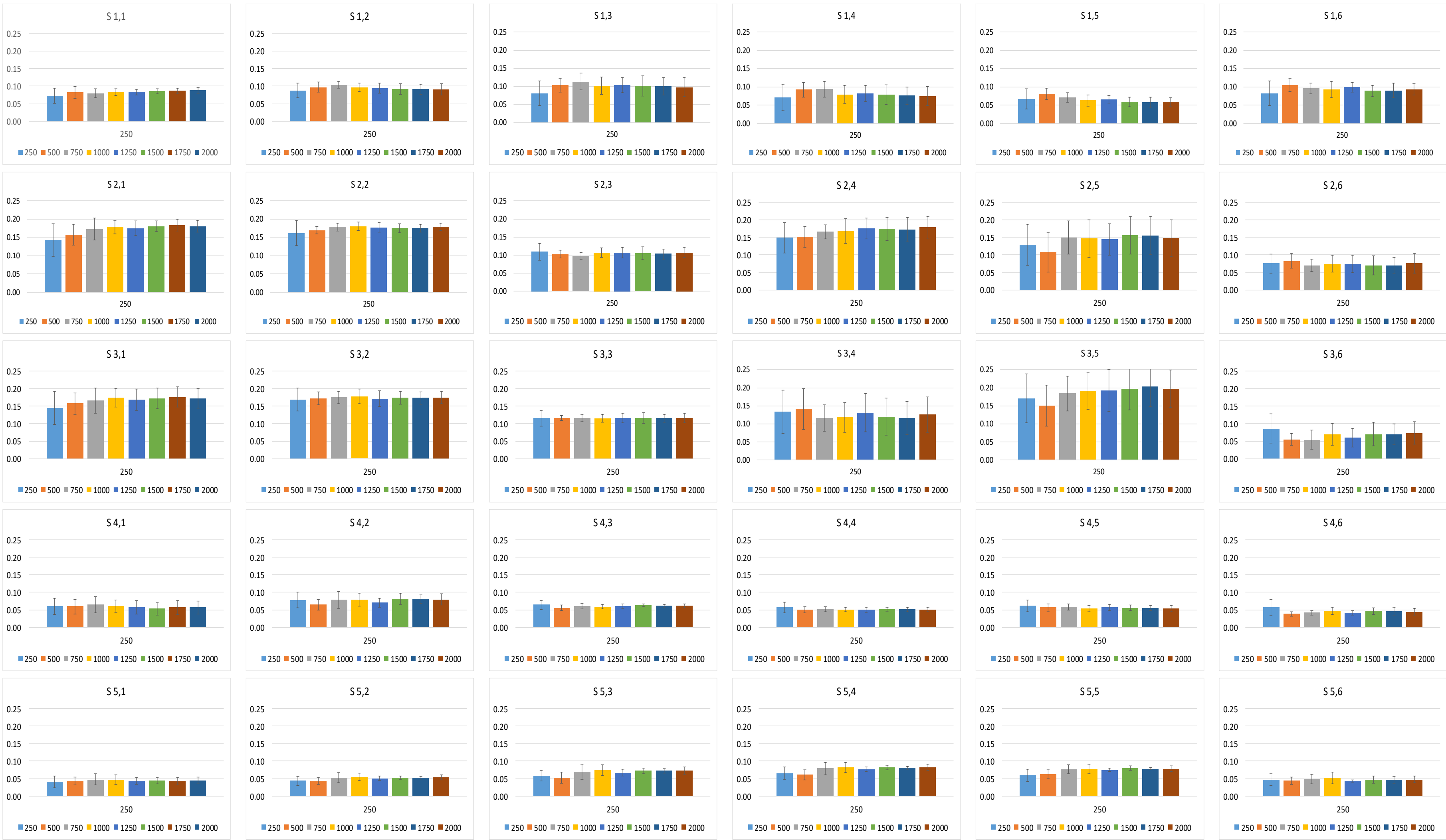

Figure 44. C08-75 Mesh Model 800-200-5

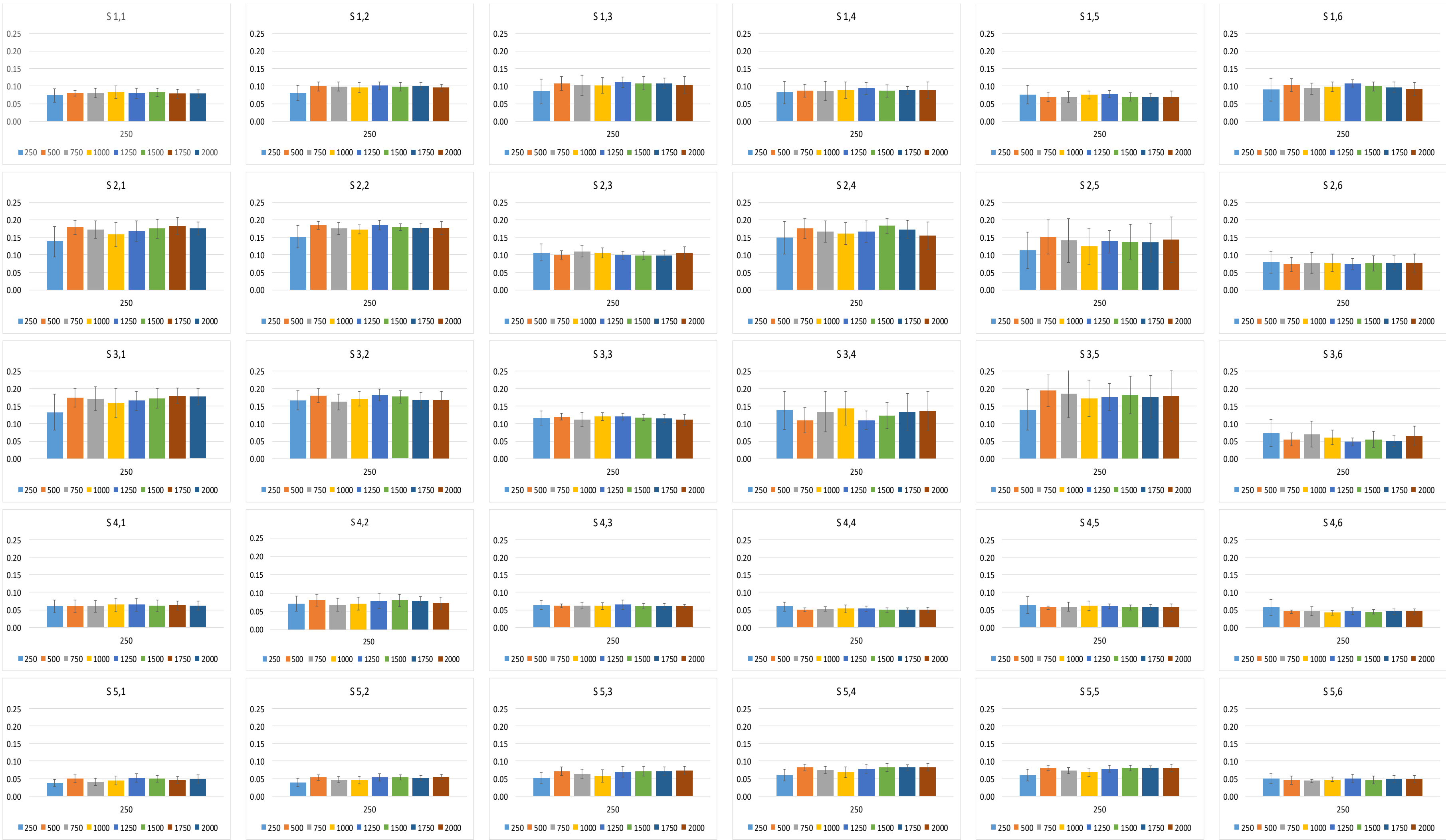

Figure 45. C20-50 Mesh Model 800-200-5

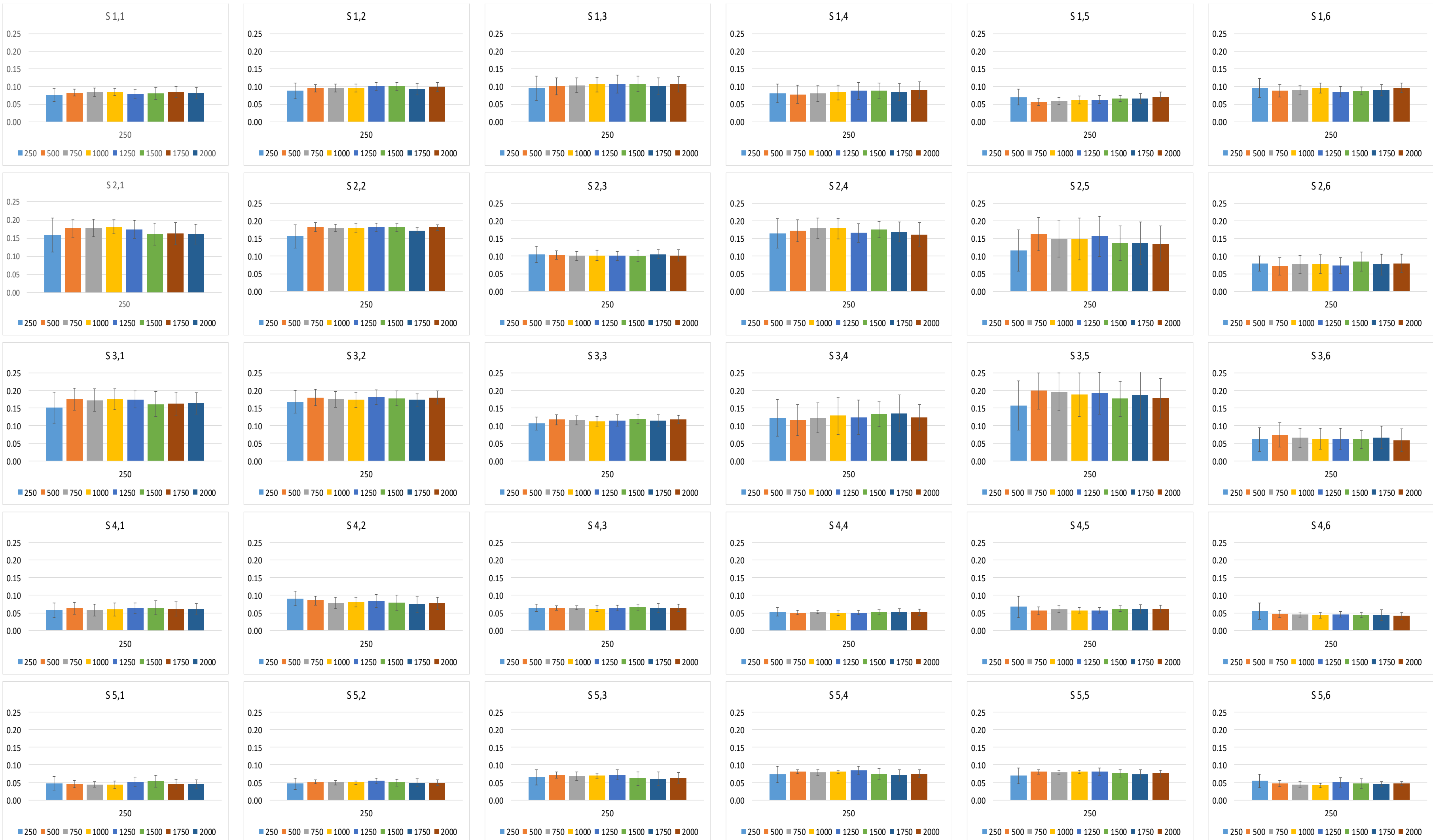

Figure 46. C20-75 Mesh Model 800-200-5

APPENDIX B

LINE CHARTS OF ANALYSIS WITH C20-75 MODEL

Informative note:

I. Analysis has three separate parameters; Total ventilation rate (in m^3/h), HRV units height (in cm), and Diffuser angle (in degrees). A total of twelve analyses have been performed.

II. X-axis represents the iteration number,

III. Y-Axis represents the average air velocity around the head in m/s.

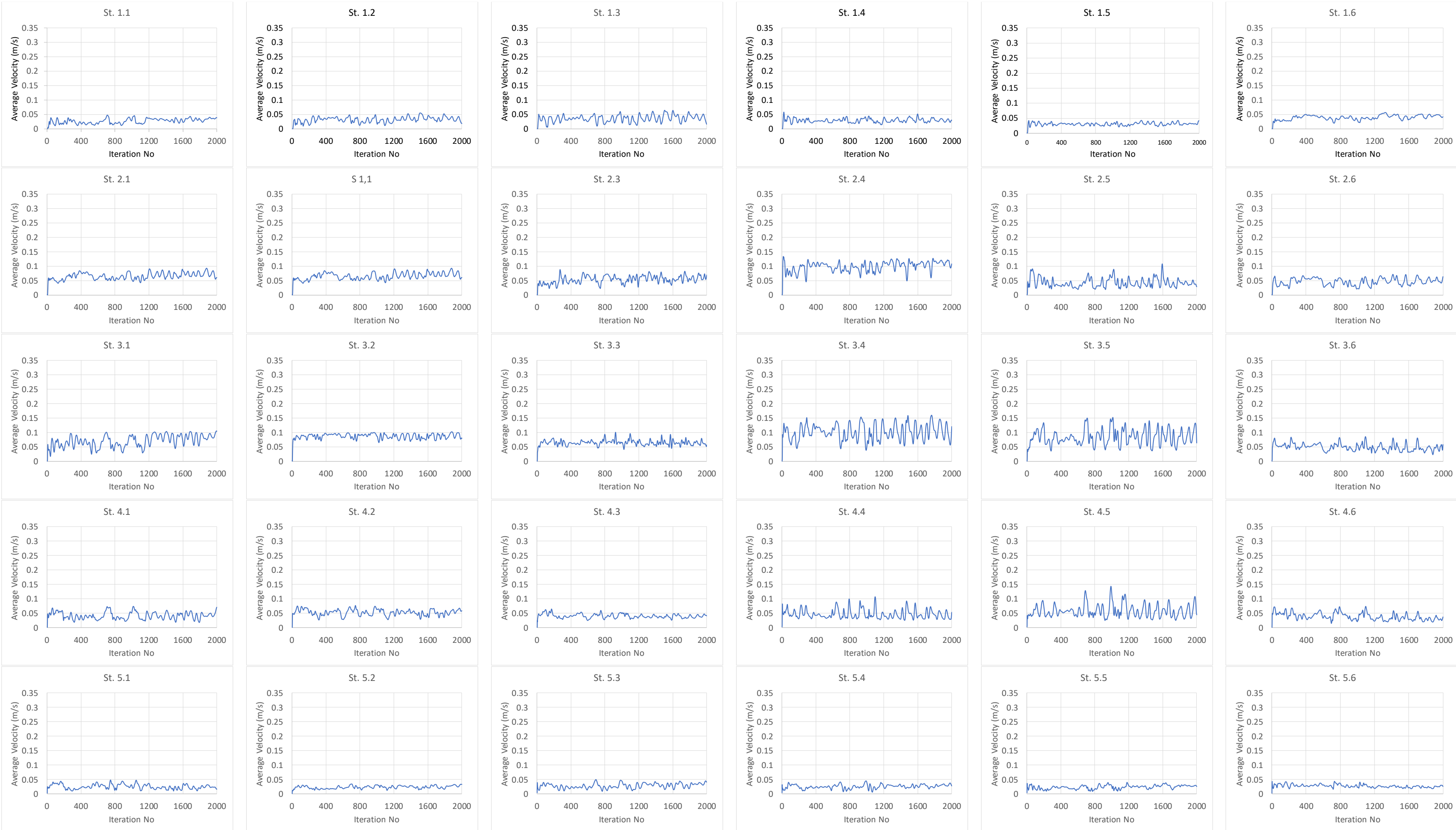

Figure 47. C20-75/400-160-5

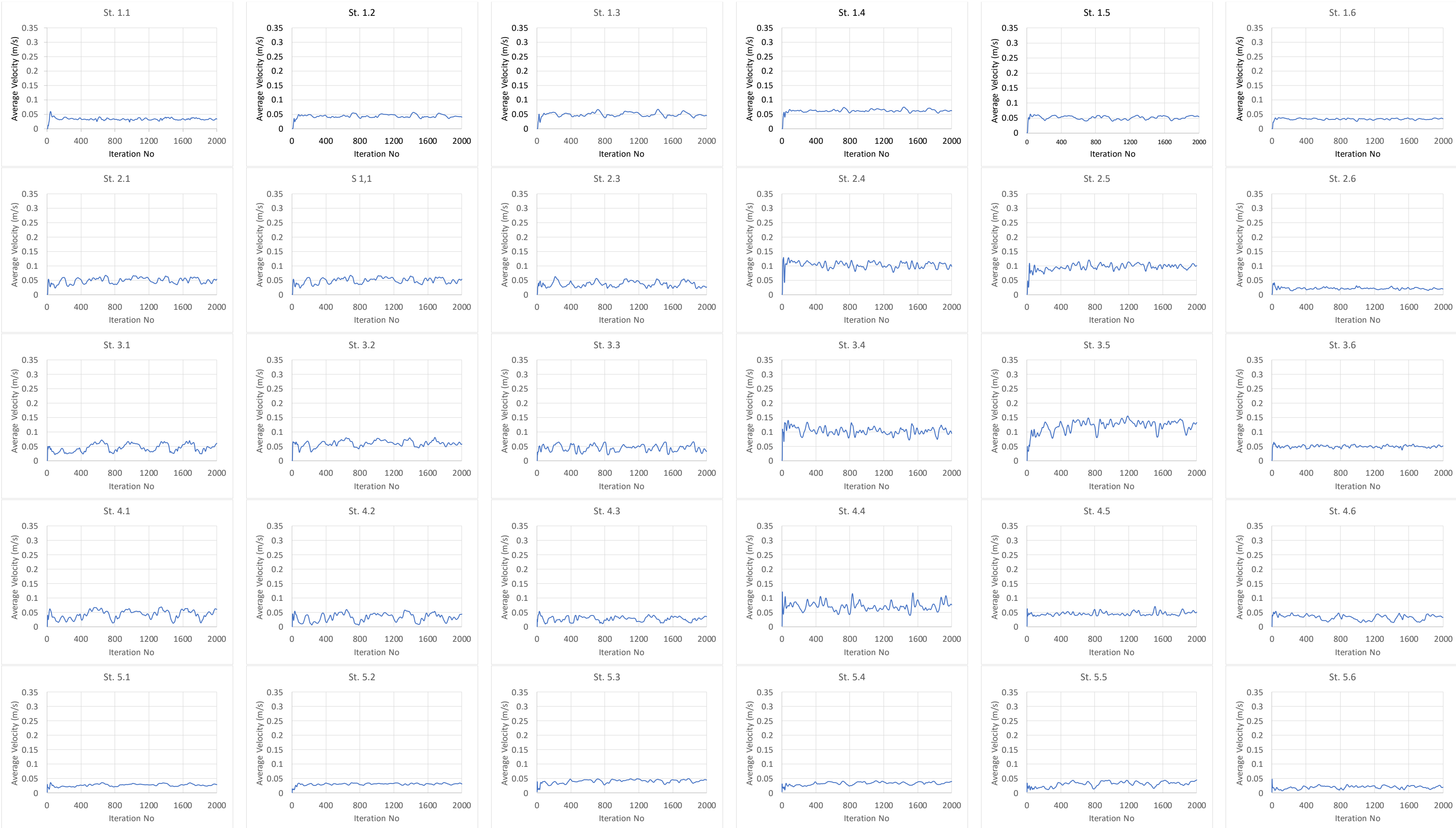

Figure 48. C20-75/400-160-10

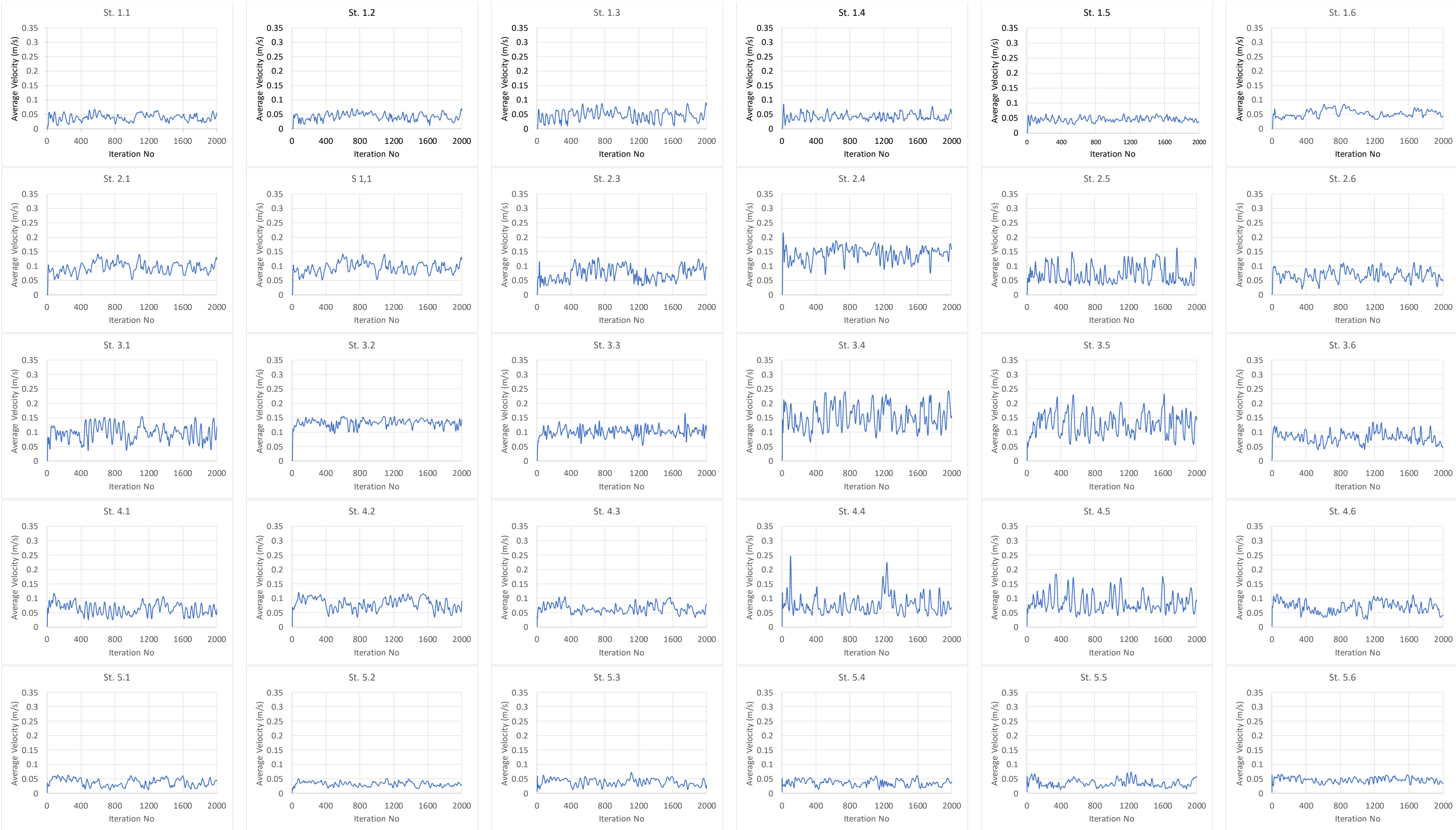

Figure 49. C20-75/600-160-5

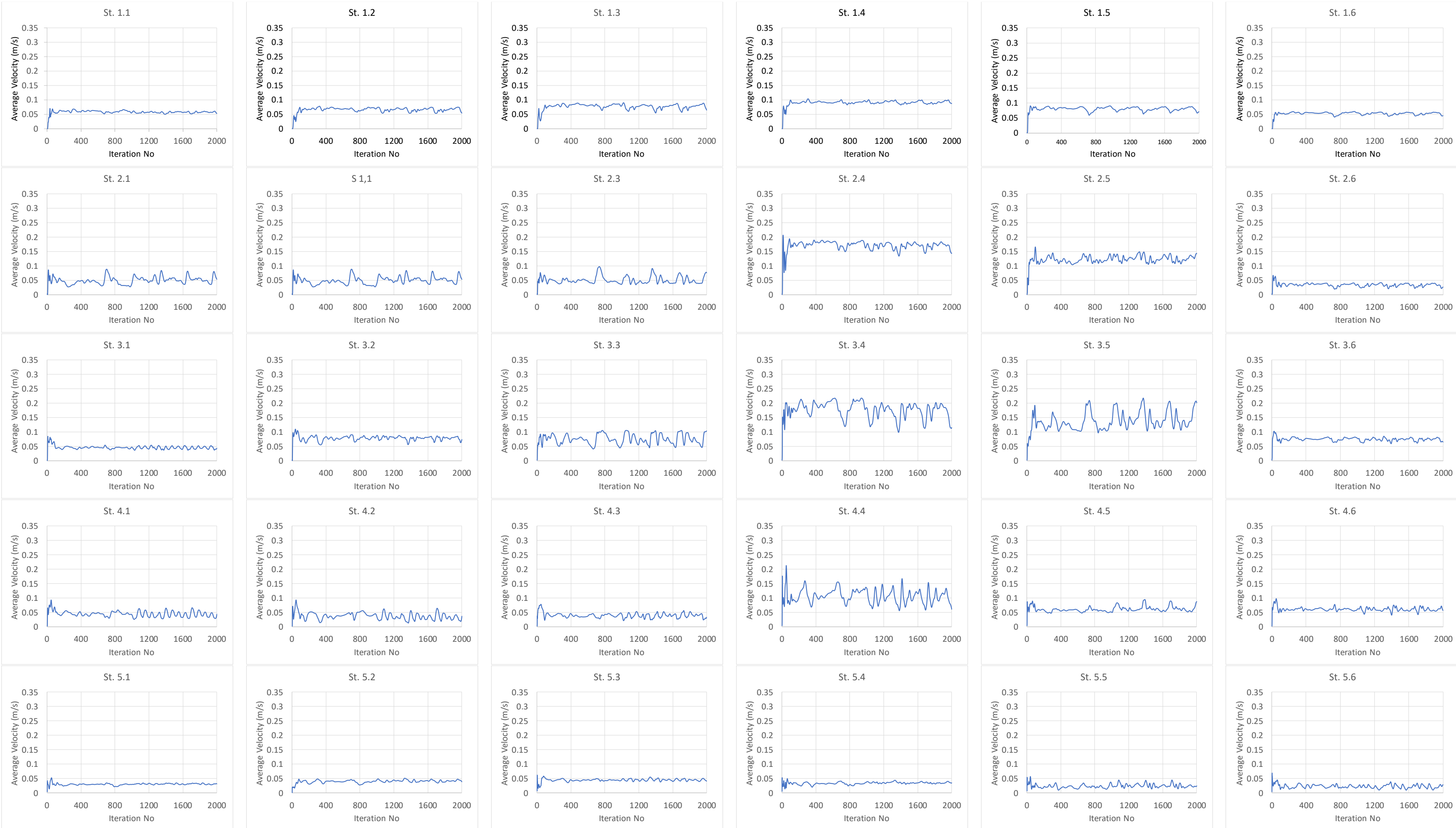

Figure 50. C20-75/600-160-10

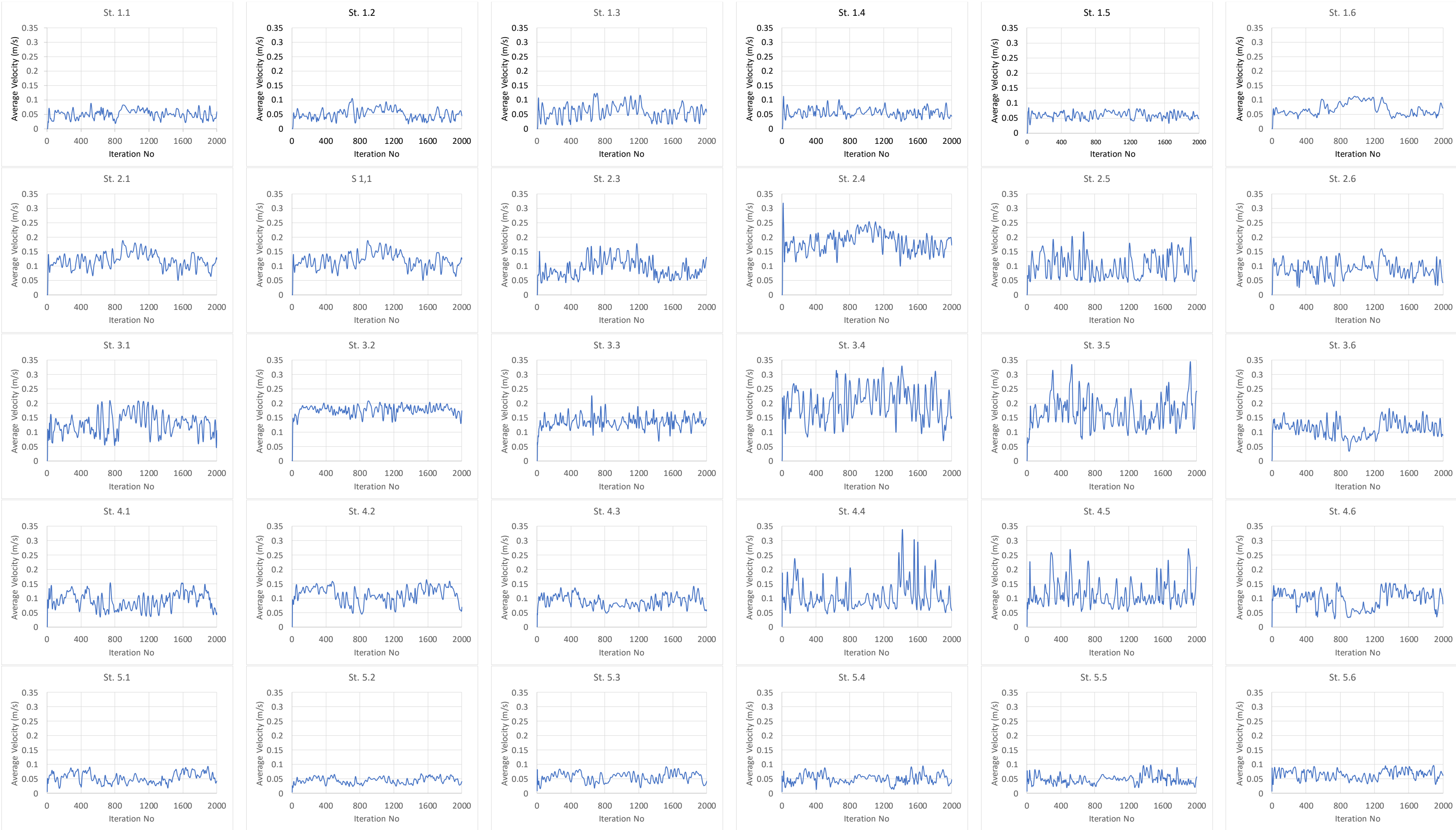

Figure 51. C20-75/800-160-5

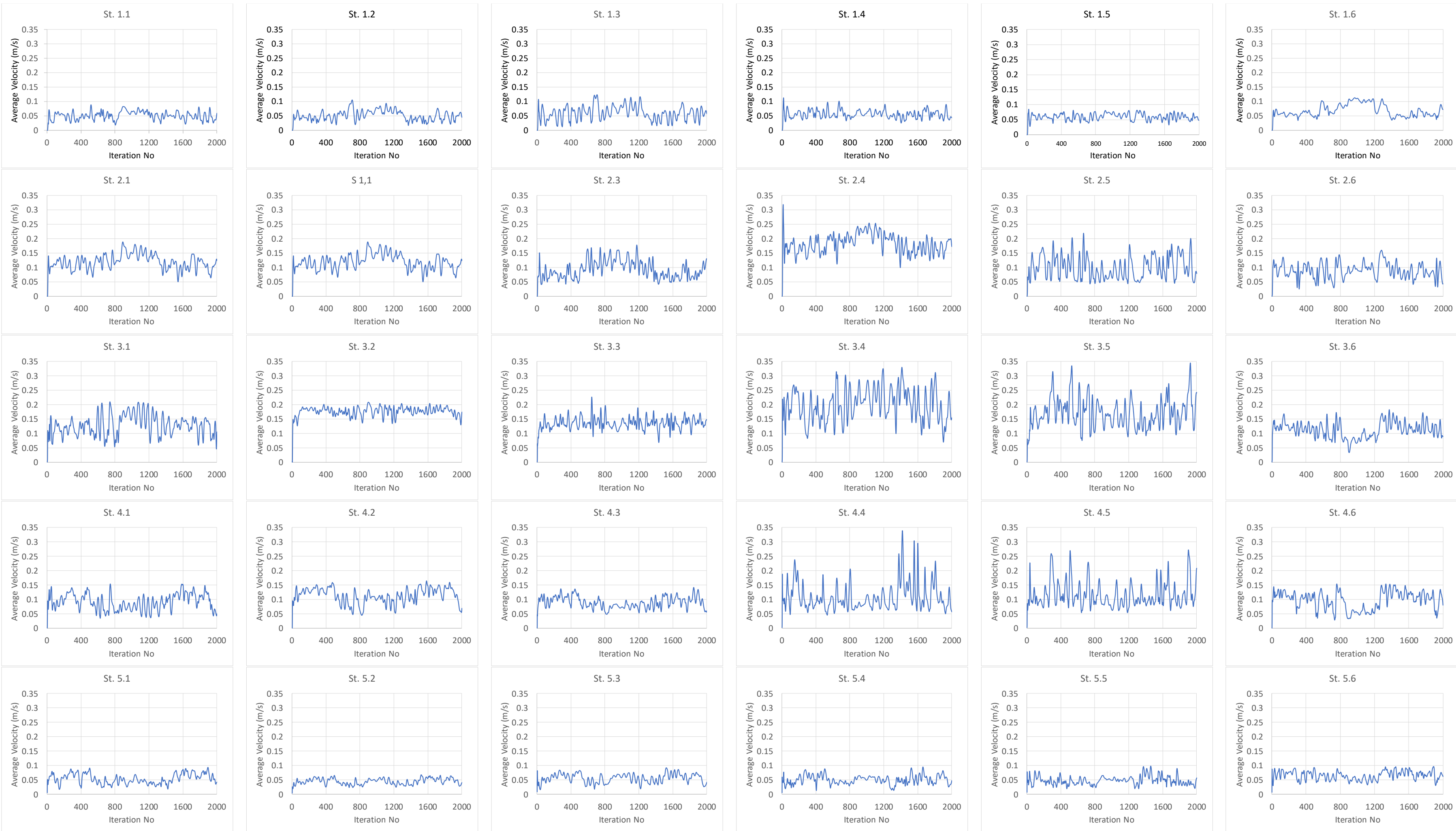

Figure 52. C20-75/800-160-10

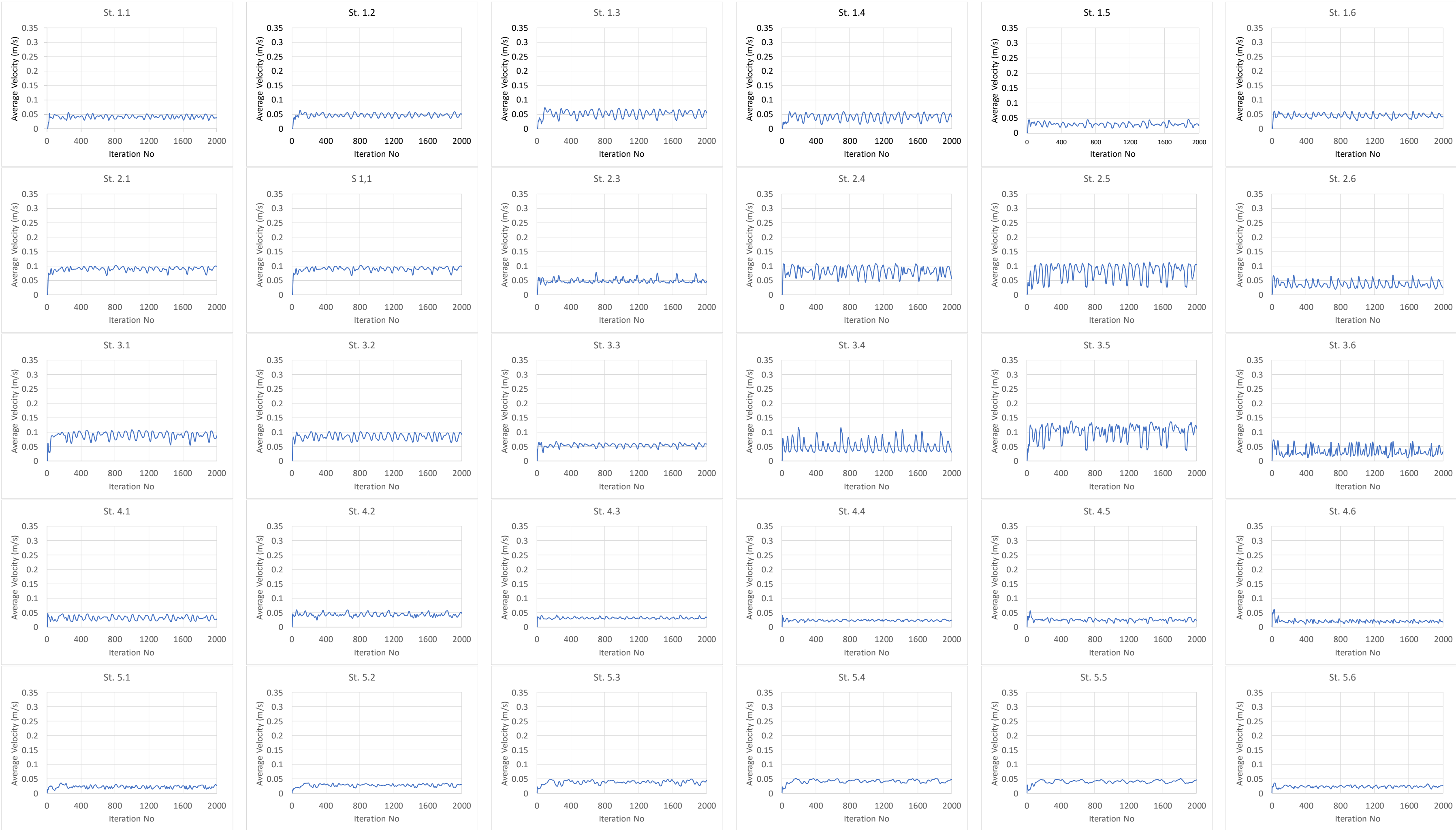

Figure 53. C20-75/400-200-5

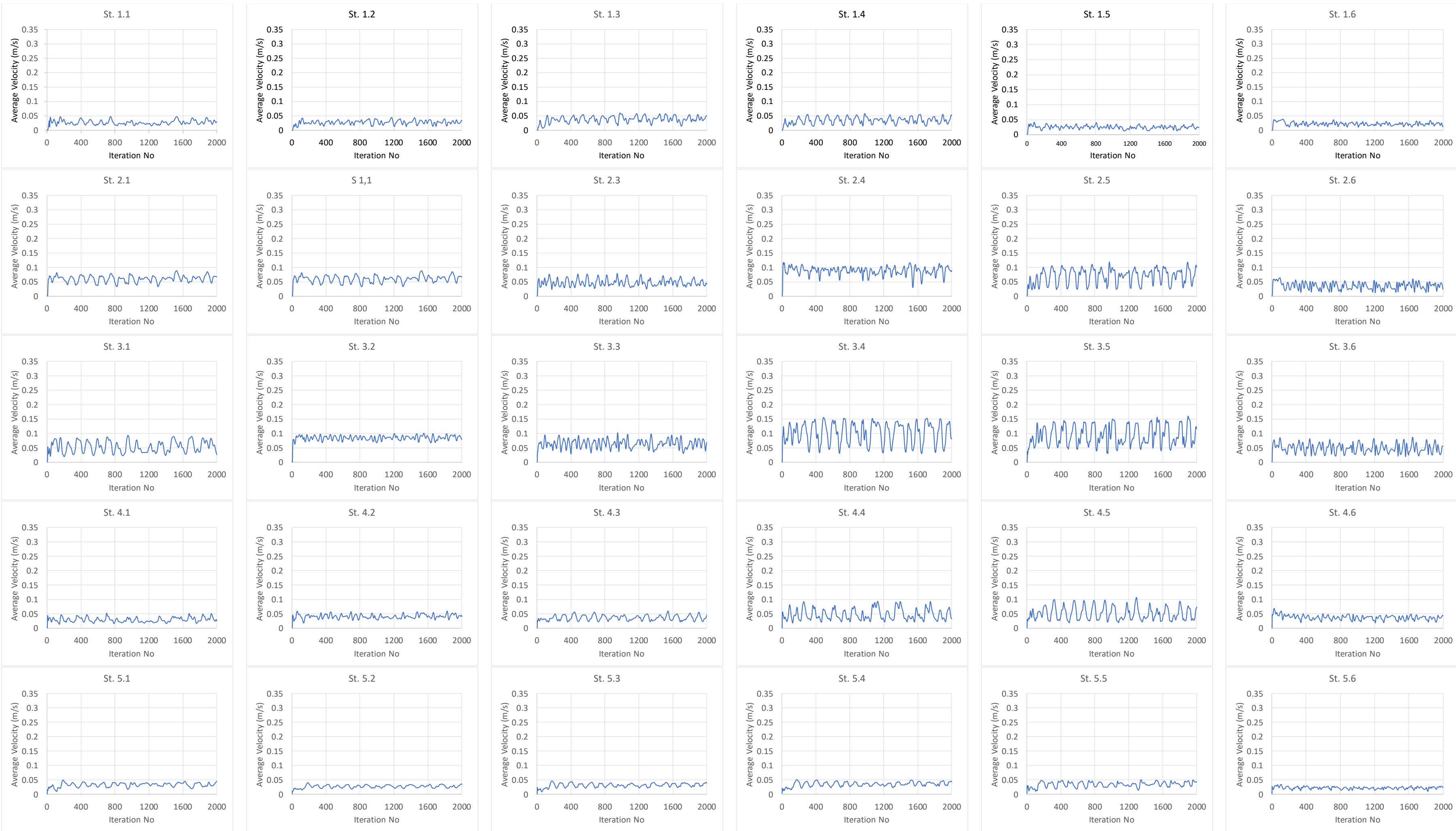

Figure 54. C20-75/400-200-10

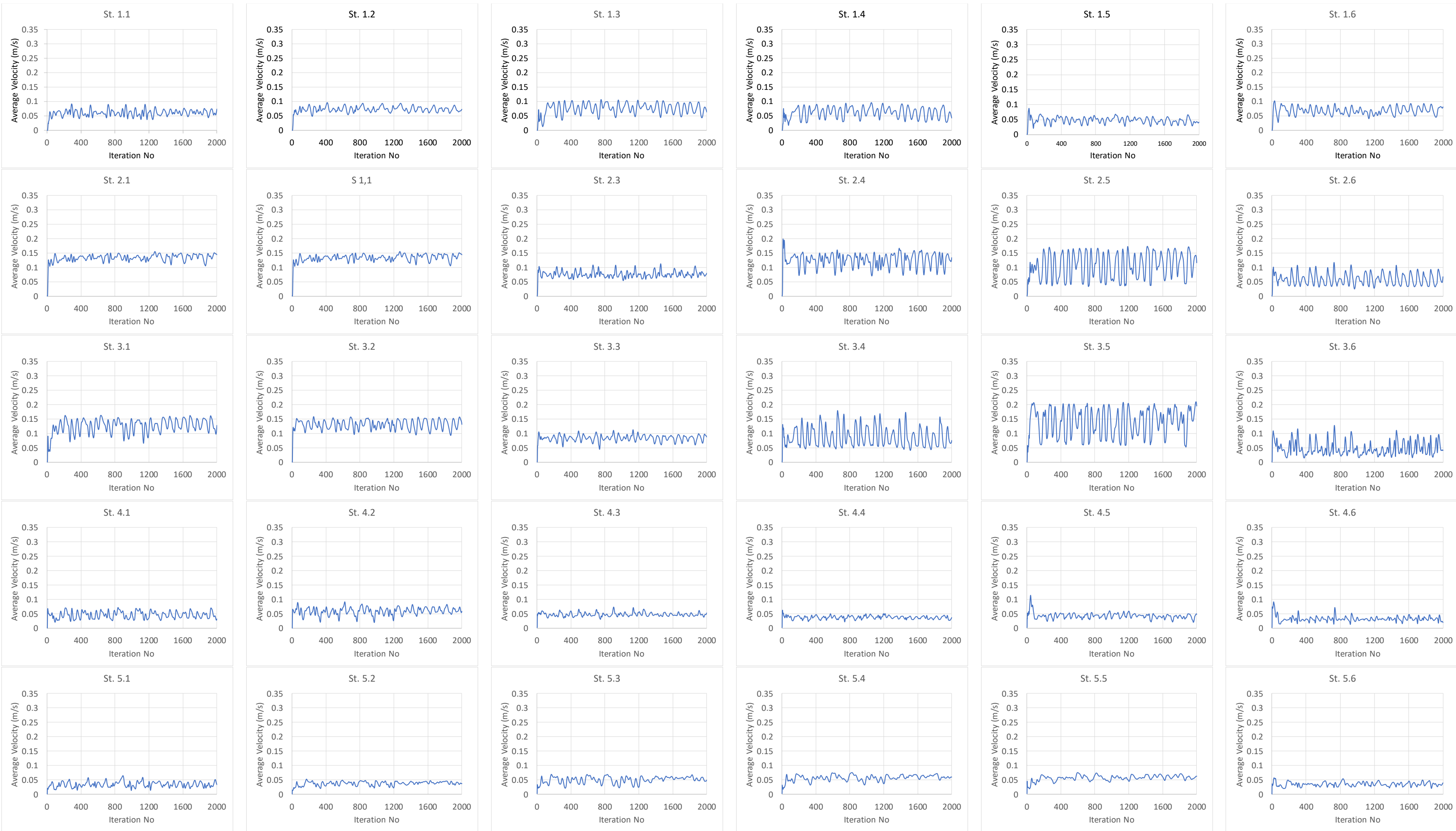

Figure 55. C20-75/600-200-5

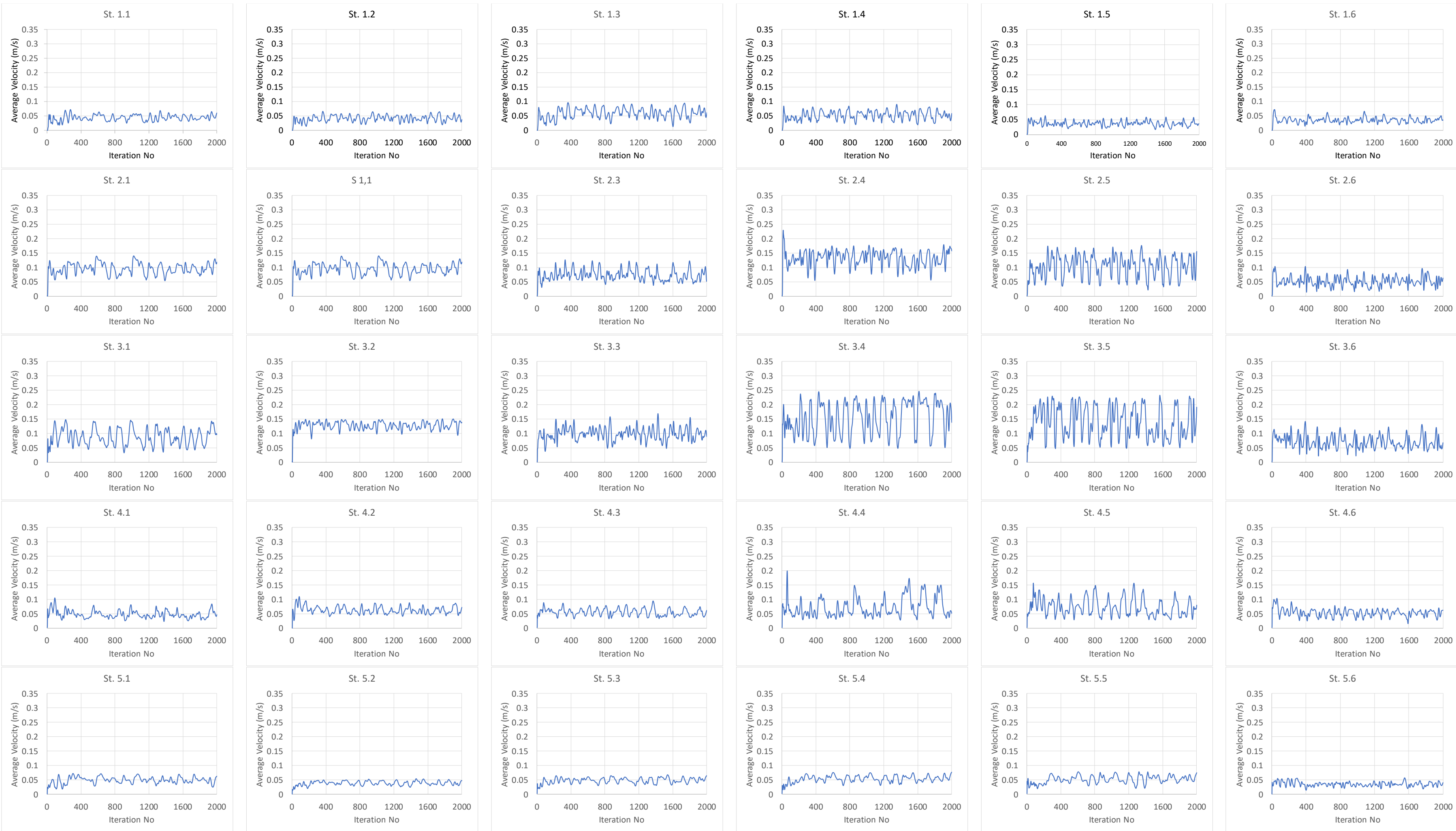

Figure 56. C20-75/600-200-10

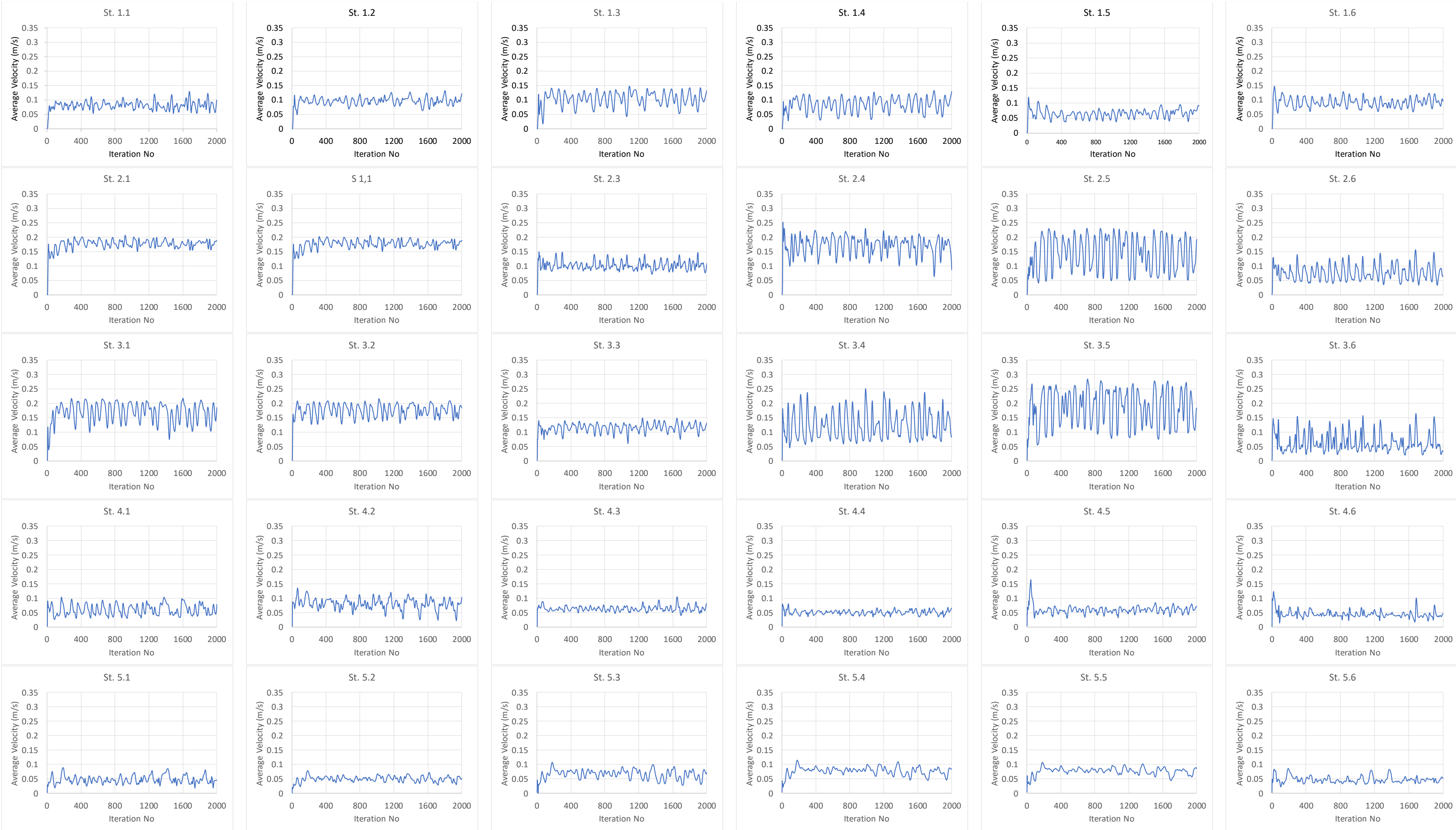

Figure 57. C20-75/800-200-5

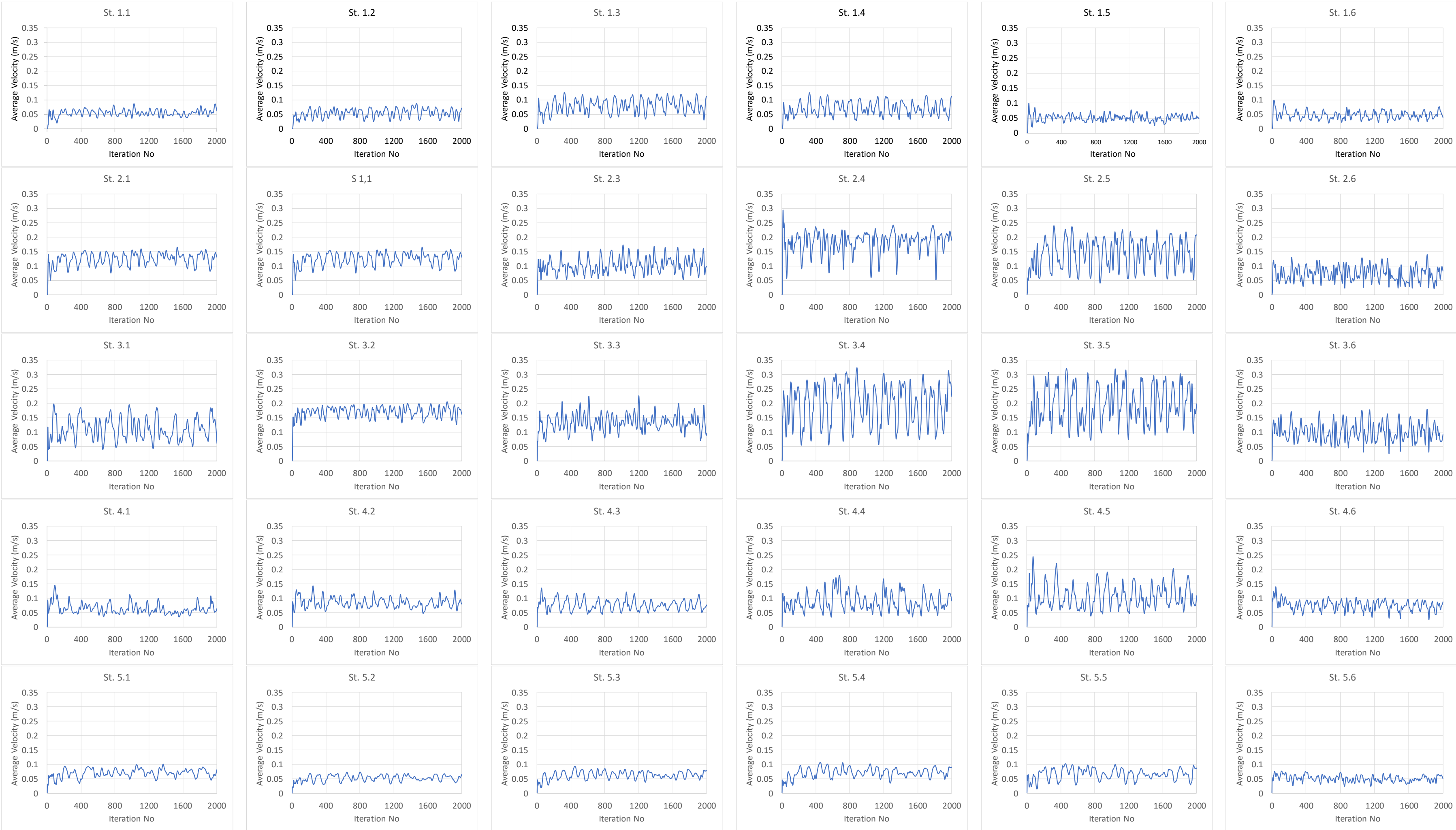

Figure 58. C20-75/800-200-10

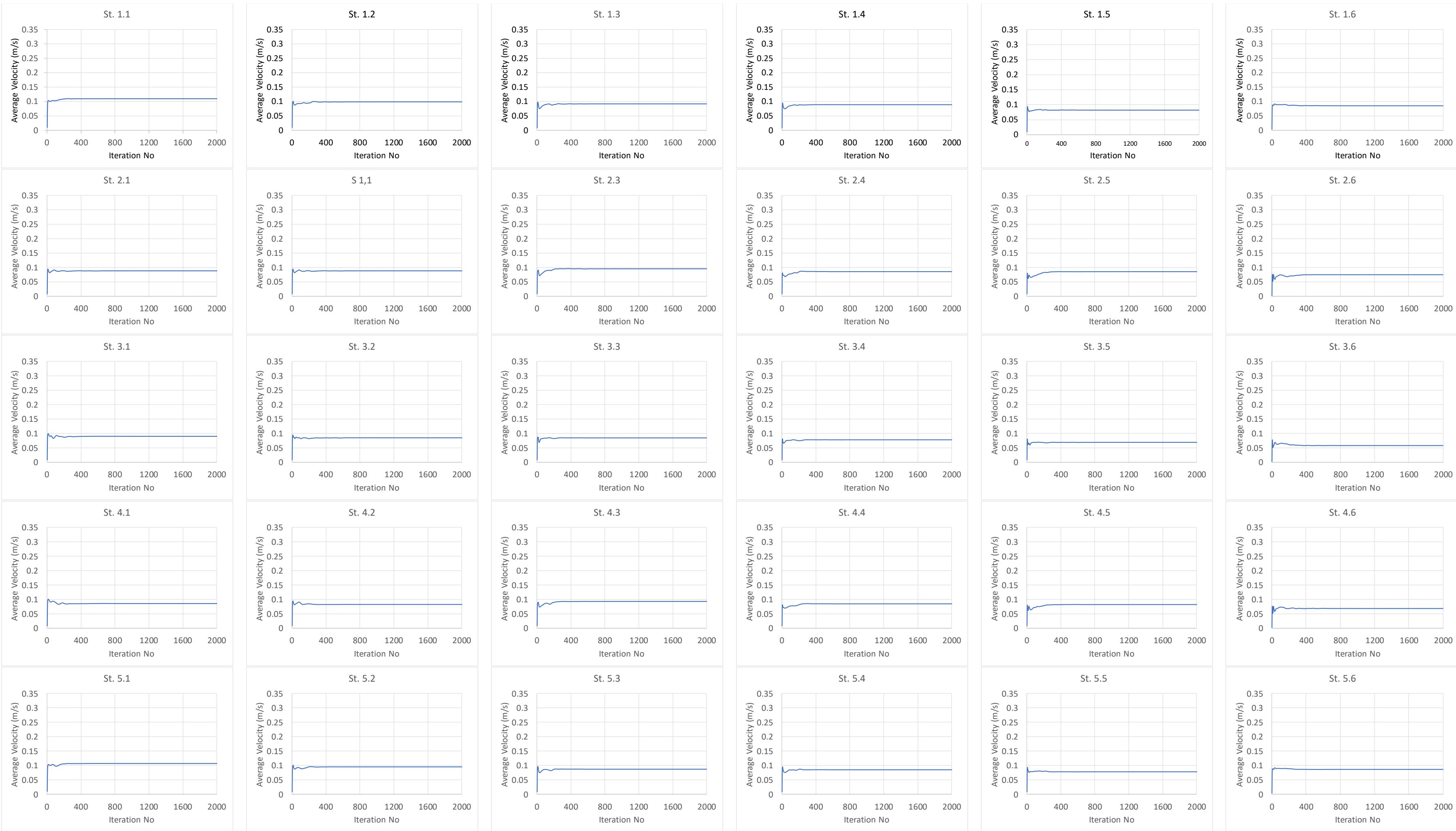

Figure 59. C20-75/ Personal Ventilation-600

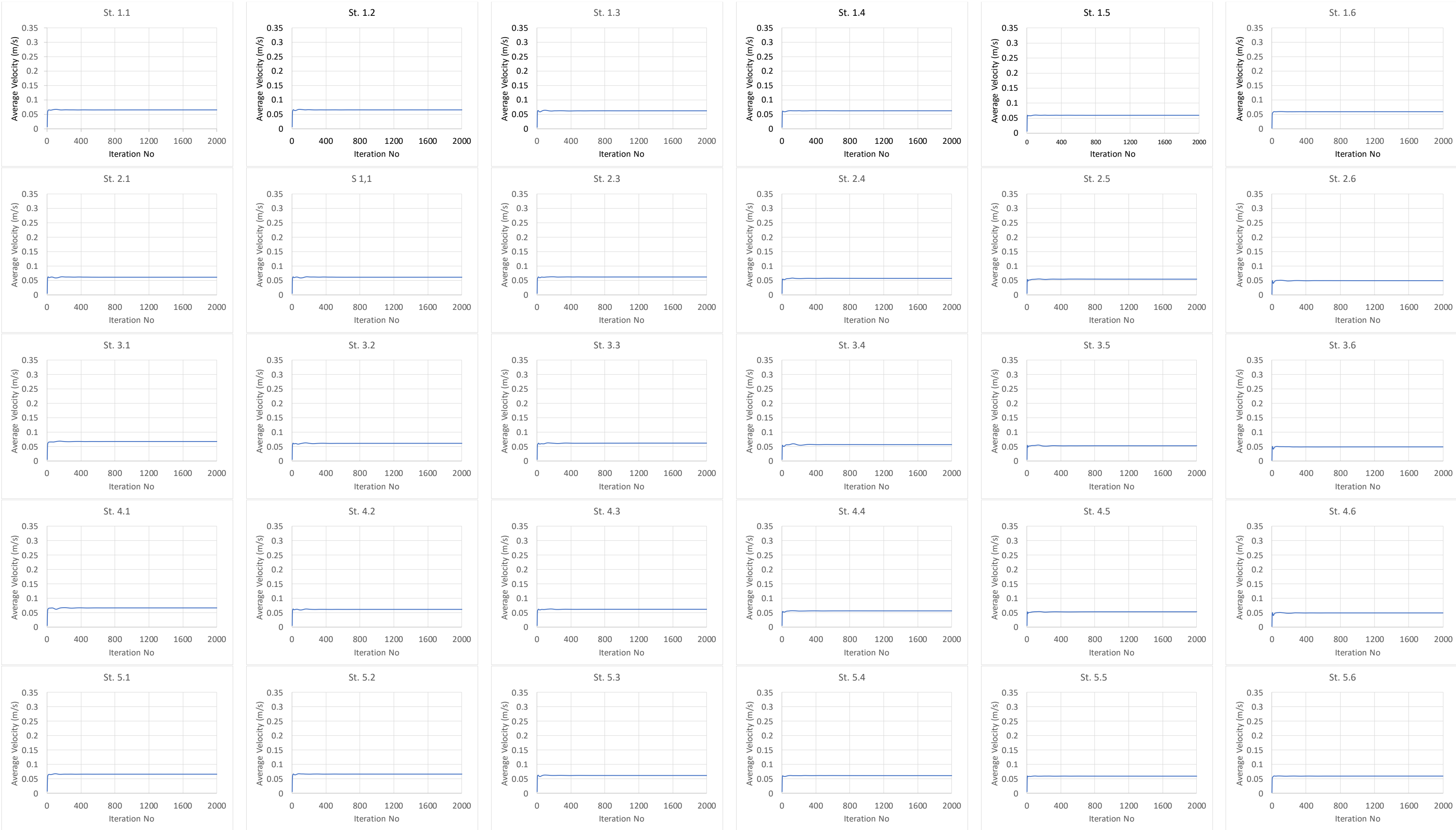

Figure 60. C20-75/ Personal Ventilation-400

Figure 61. C20-75/ Personal Ventilation-200

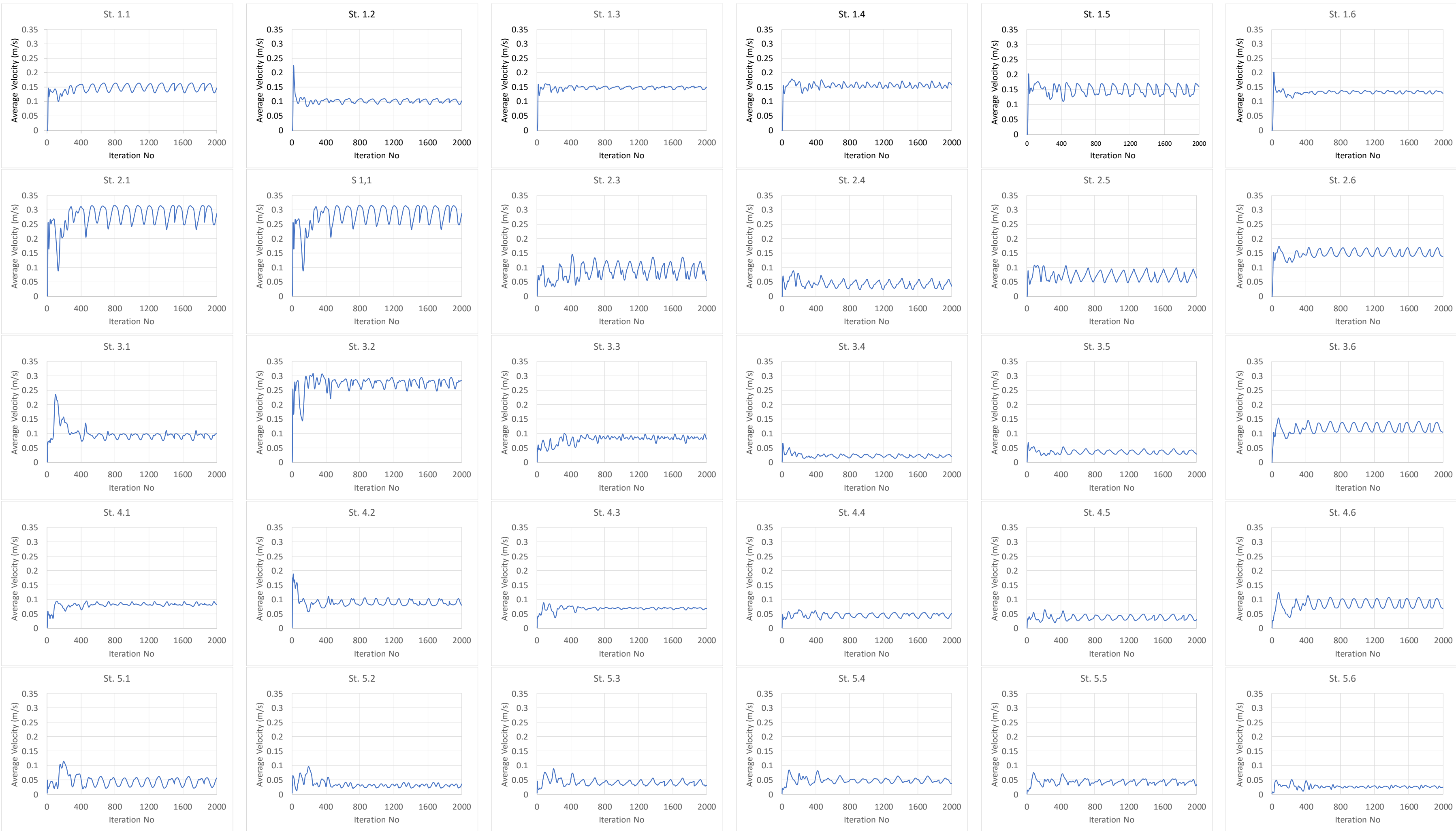

Figure 62. C20-75/2-HRV-400

Figure 63. C20-75/ Piston Ventilation-800

APPENDIX C

VISUAL GRAPHICS OF AVERAGE AIR VELOCITIES

Informative note:

I. It must be noted that velocity contour profiles inside the classroom environment and around individual heads are nor on the same scale.

II. For every analysis there will be an isometric and a top view of the classroom showing velocity profiles.

III. In this section for 12 different parameters there are a total number of 24 figures for velocity profiles.

a) b)

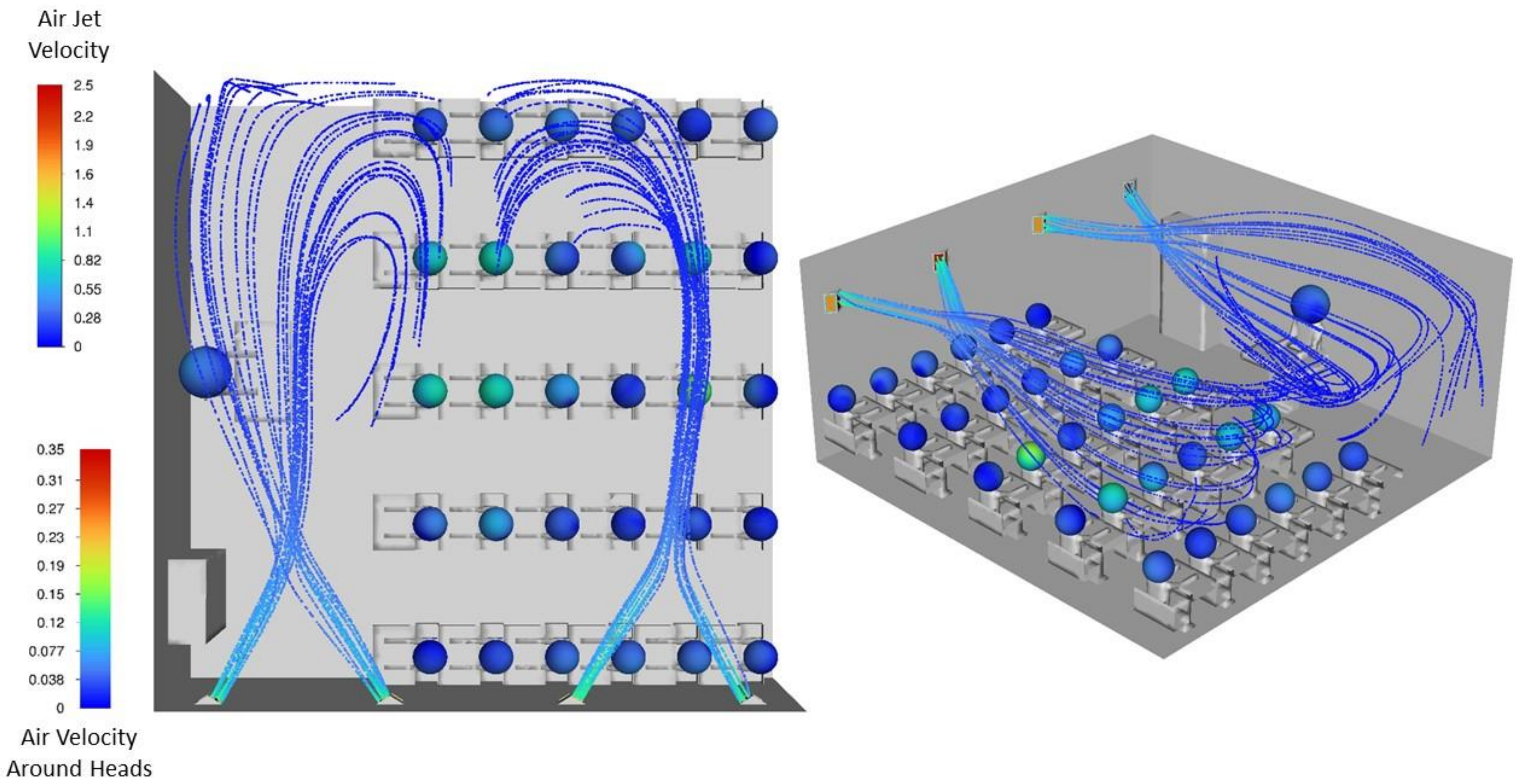

Figure 64. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/400-200-5 a)Top View, b)Isometric View

a) b)

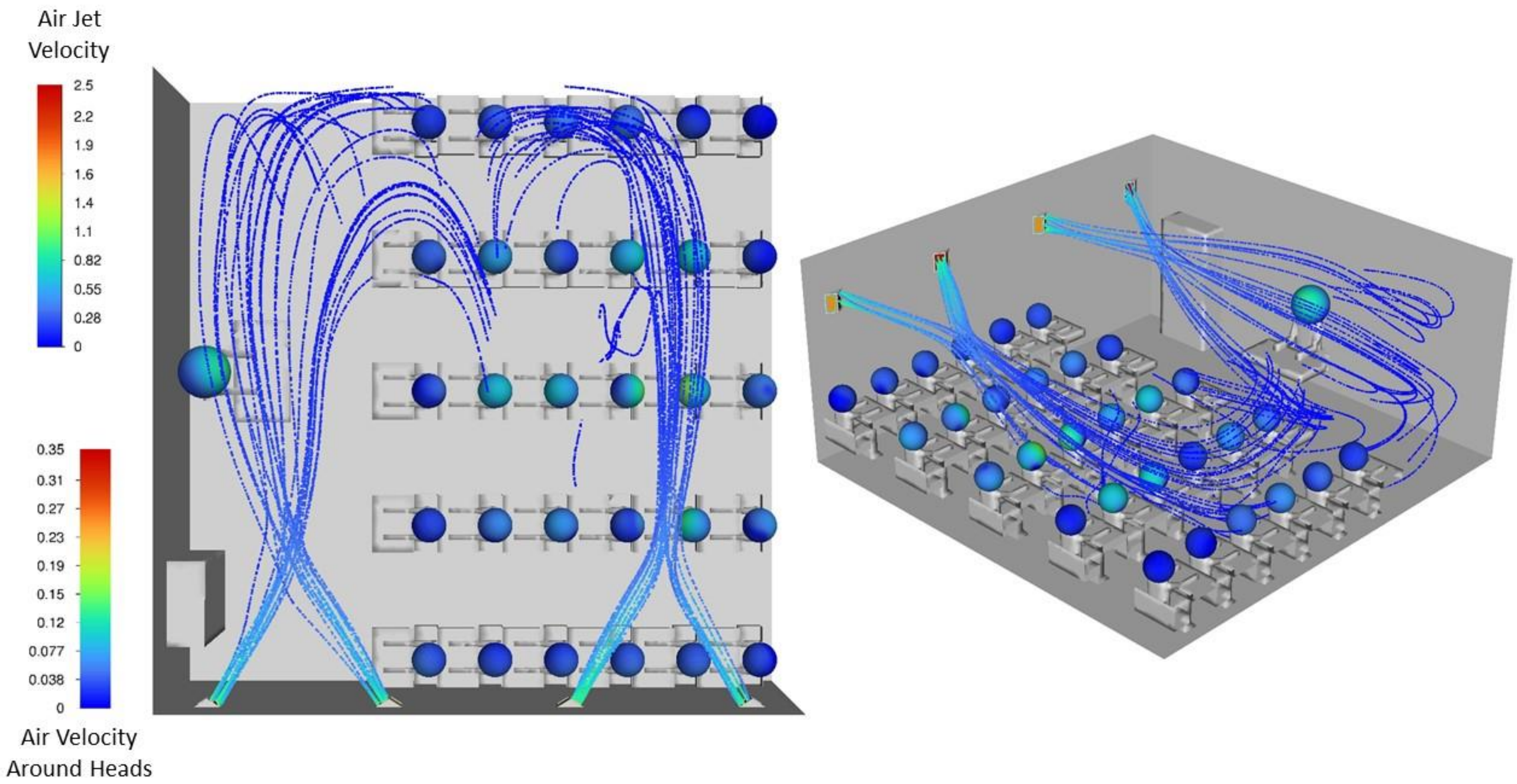

Figure 65. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/400-200-10 a)Top View, b)Isometric View

a) b)

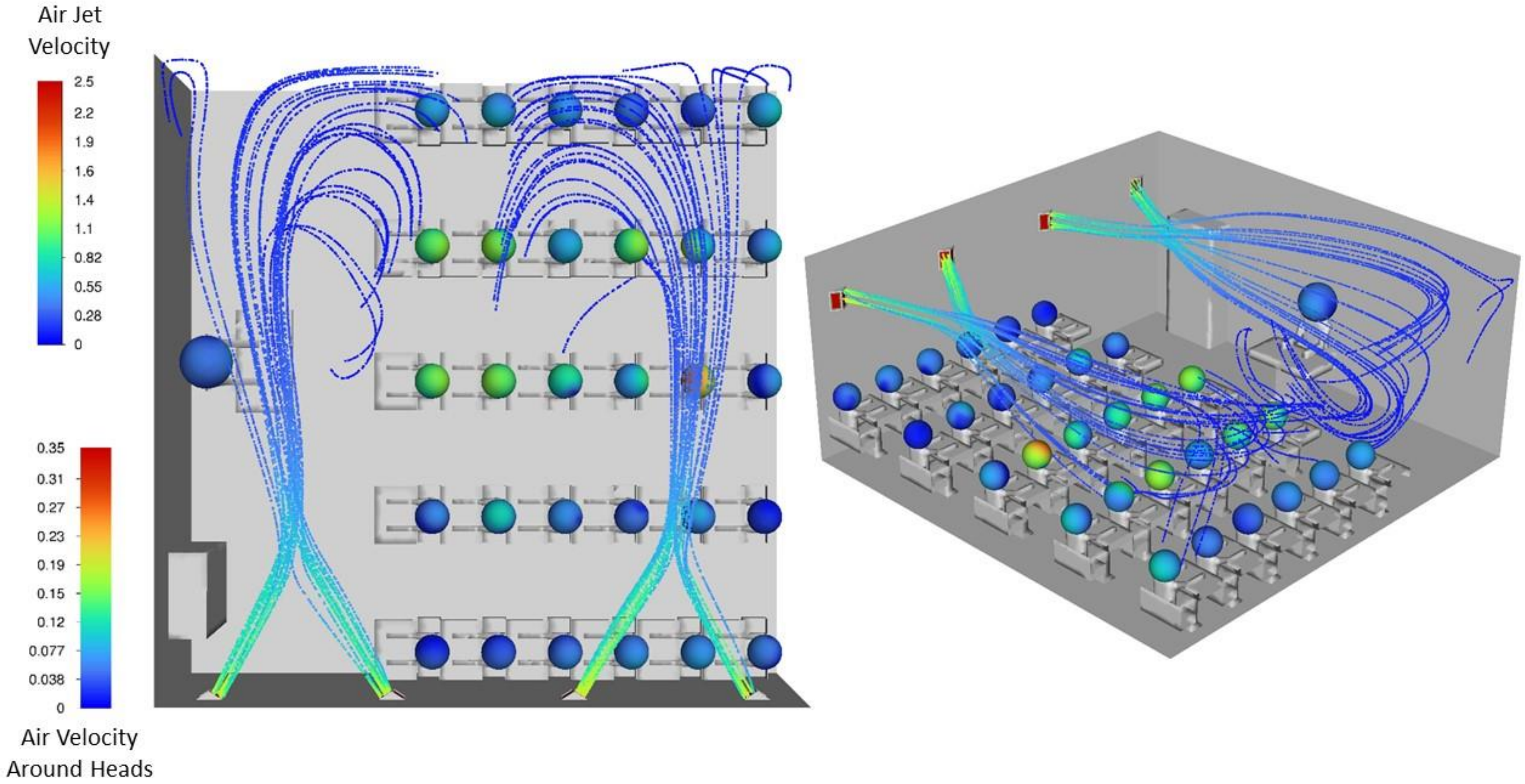

Figure 66. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/600-200-5 a)Top View, b)Isometric View

a) b)

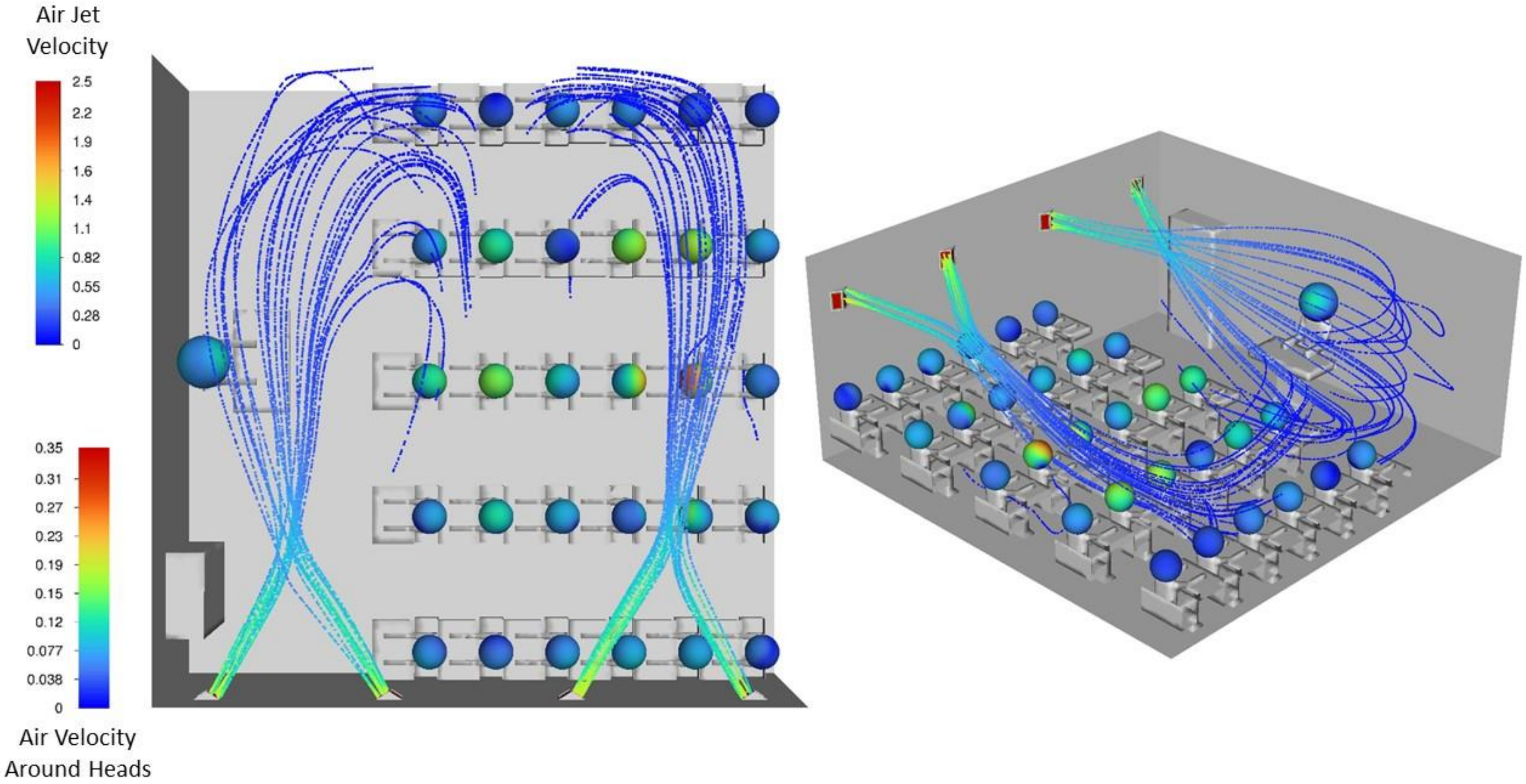

Figure 67. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/600-200-10 a)Top View, b)Isometric View

a) b)

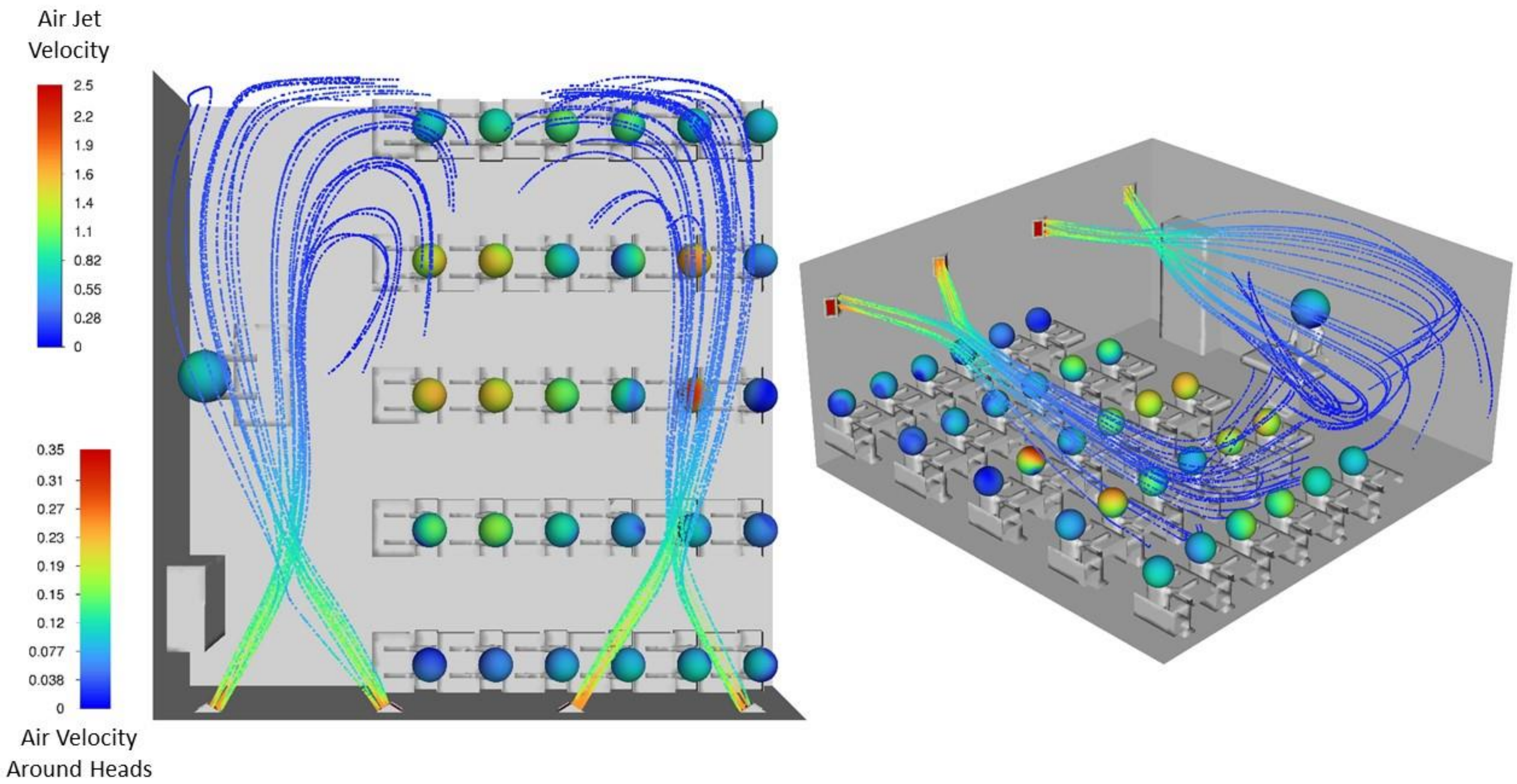

Figure 68. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/800-200-5 a)Top View, b)Isometric View

a) b)

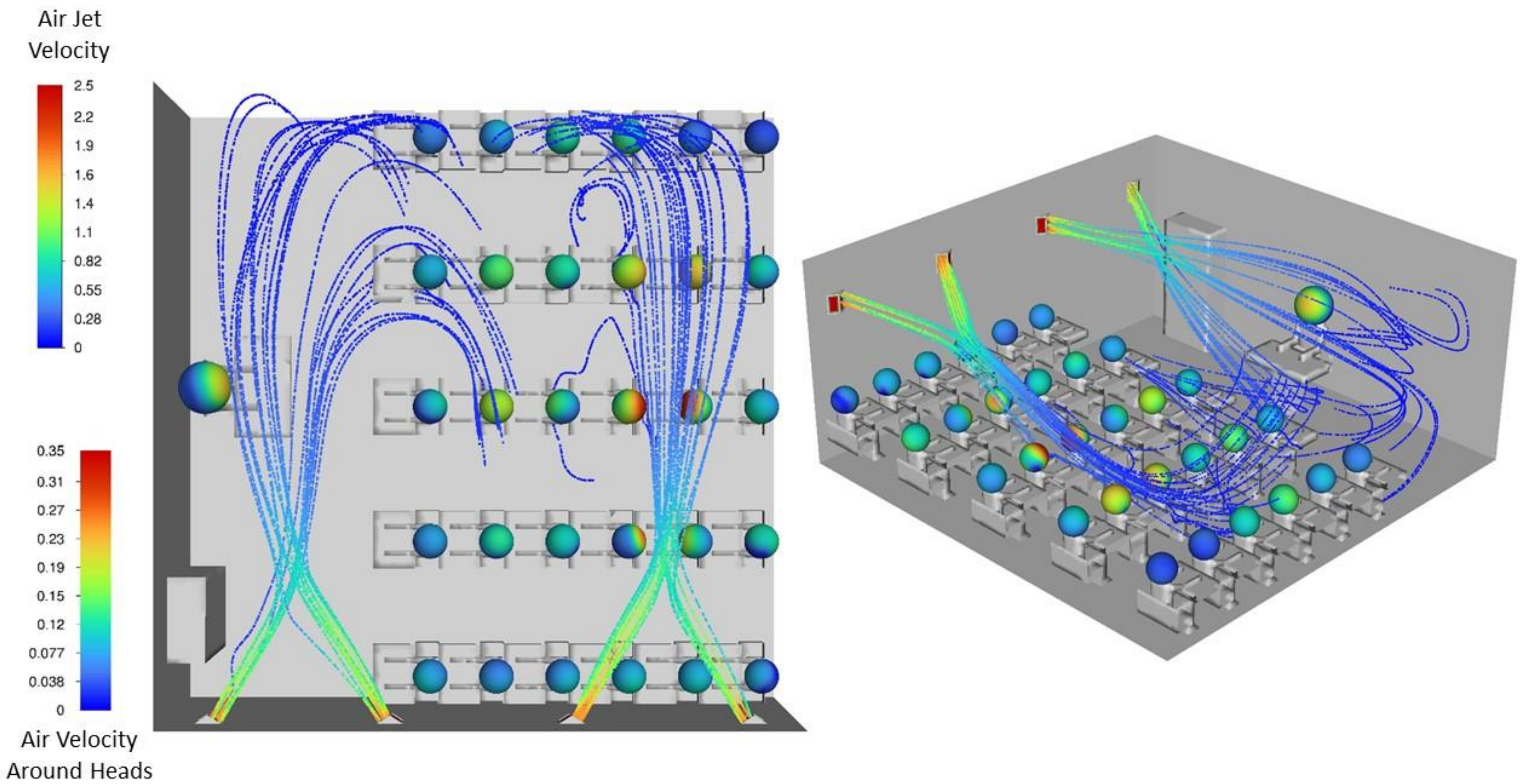

Figure 69. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/800-200-10 a)Top View, b)Isometric View

a) b)

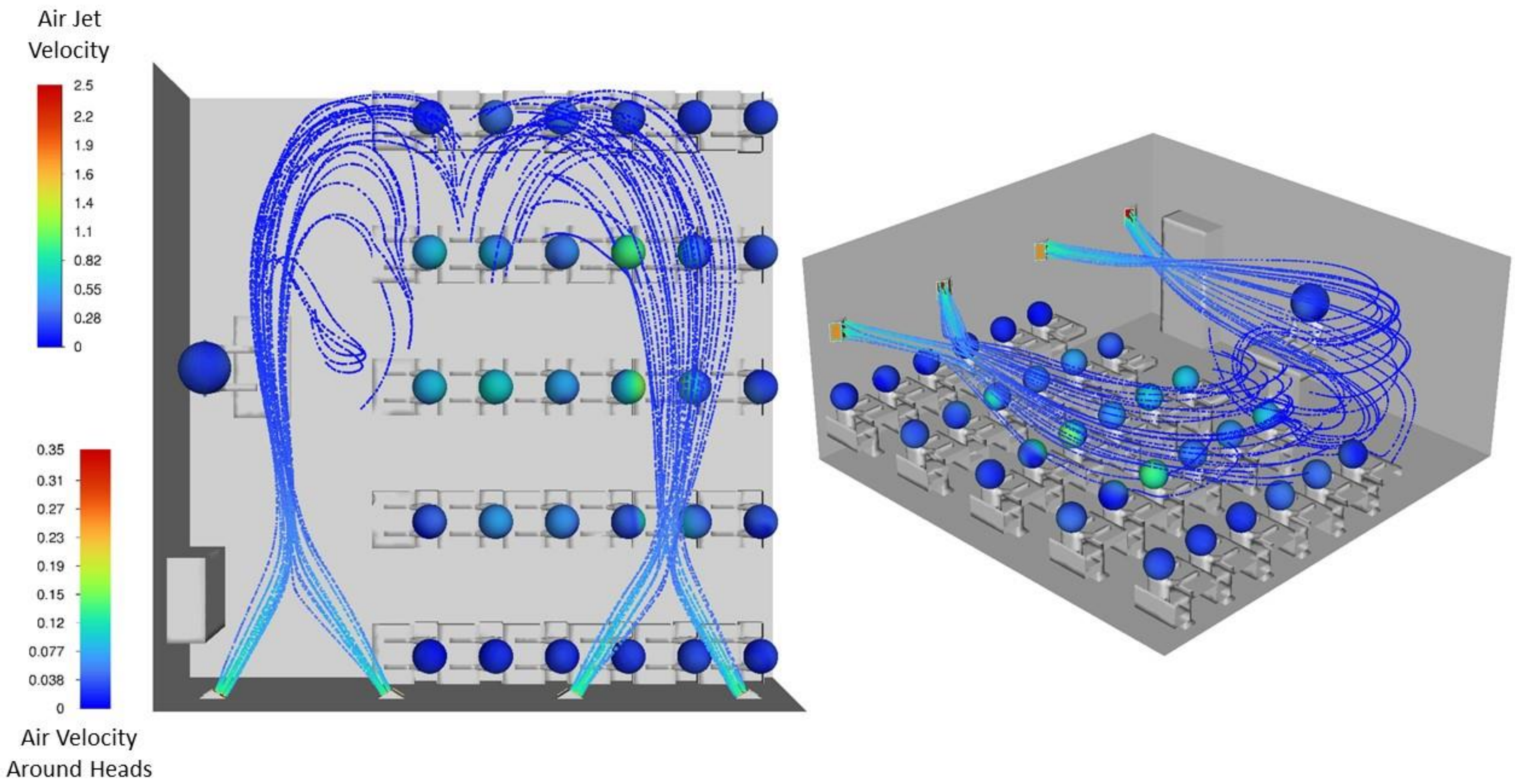

Figure 70. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/400-160-5 a)Top View, b)Isometric View

a) b)

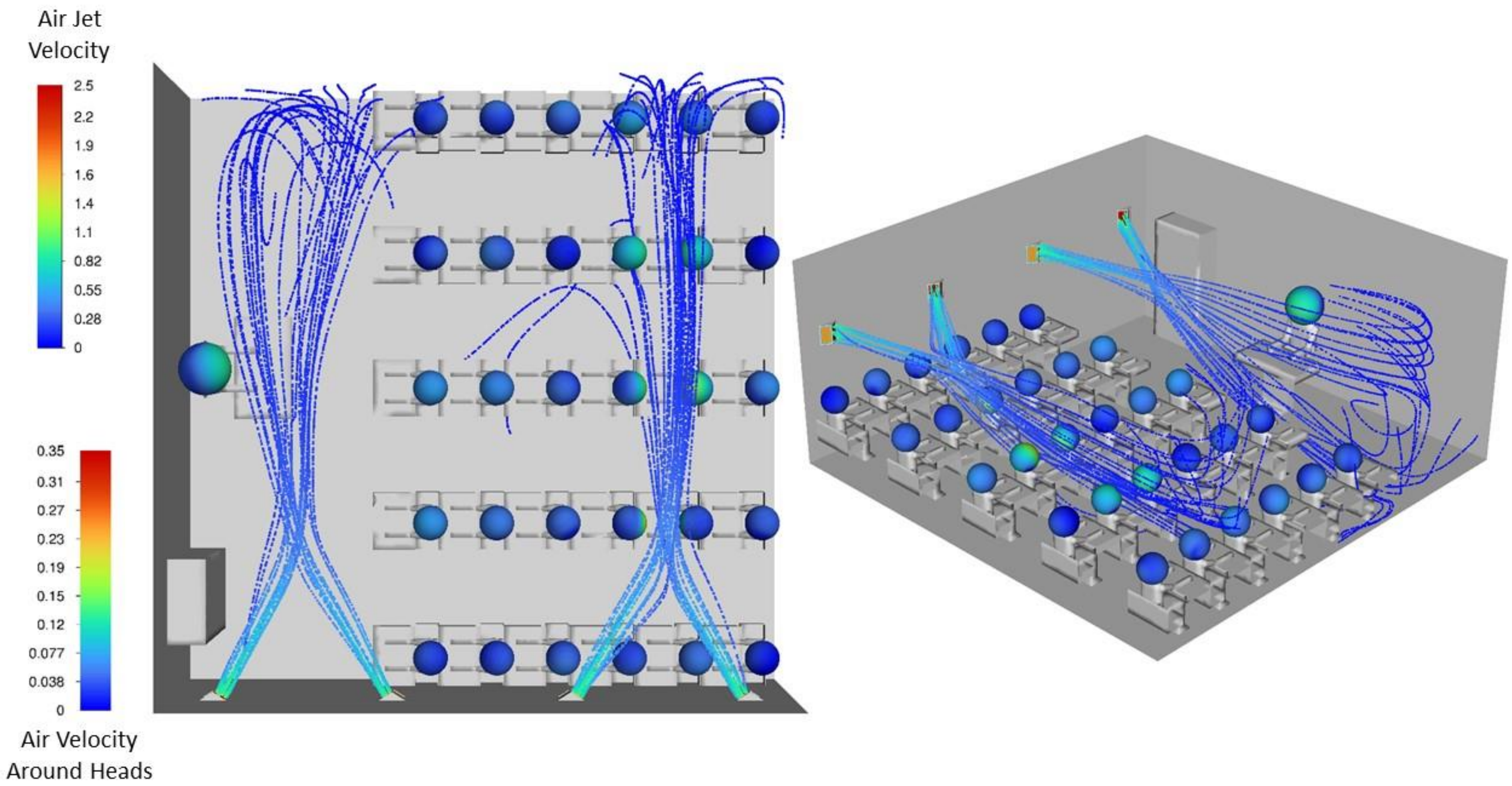

Figure 71. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/400-160-10 a)Top View, b)Isometric View

a) b)

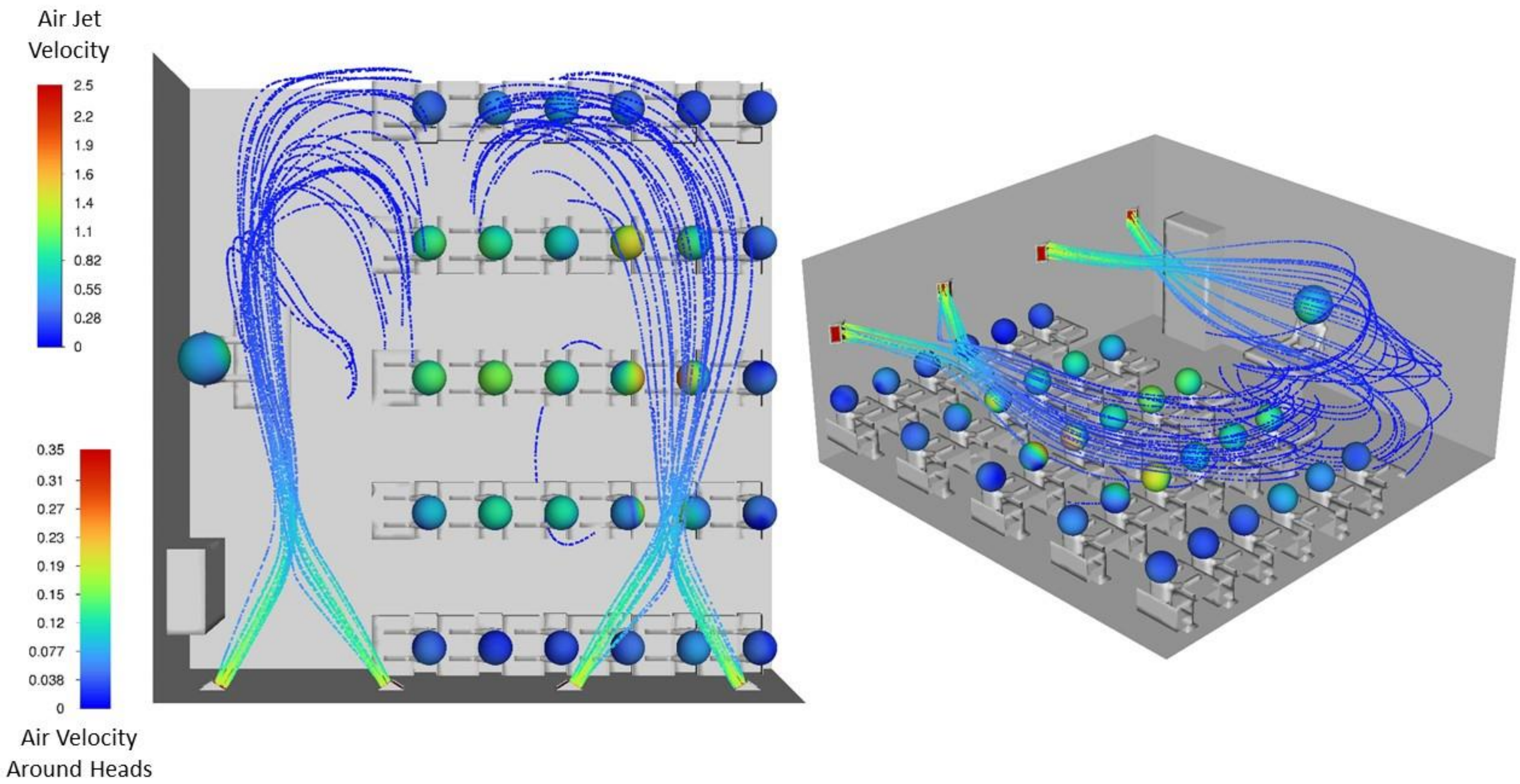

Figure 72. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/600-160-5 a)Top View, b)Isometric View

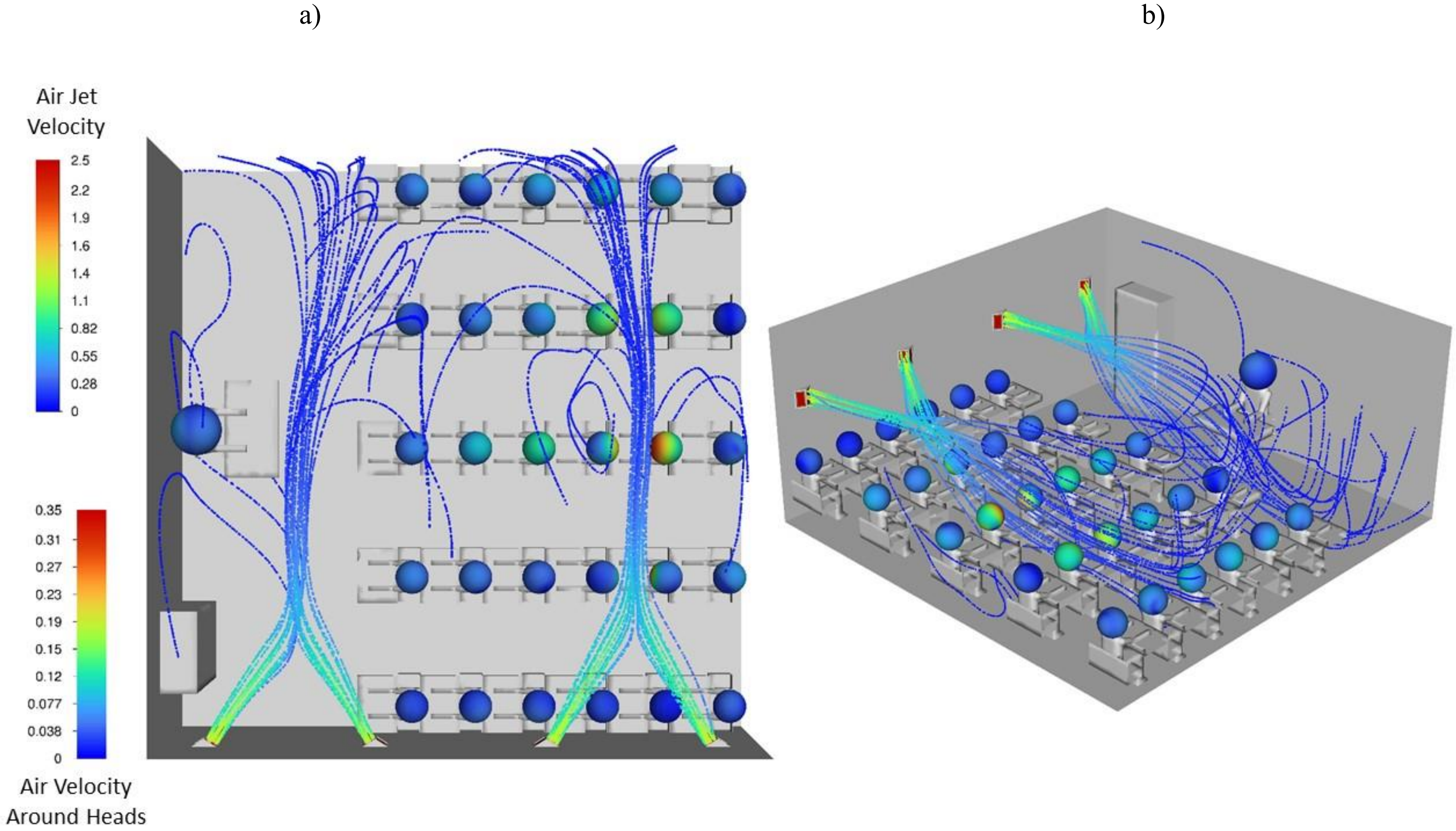

Figure 73. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/600-160-10 a)Top View, b)Isometric View

a) b)

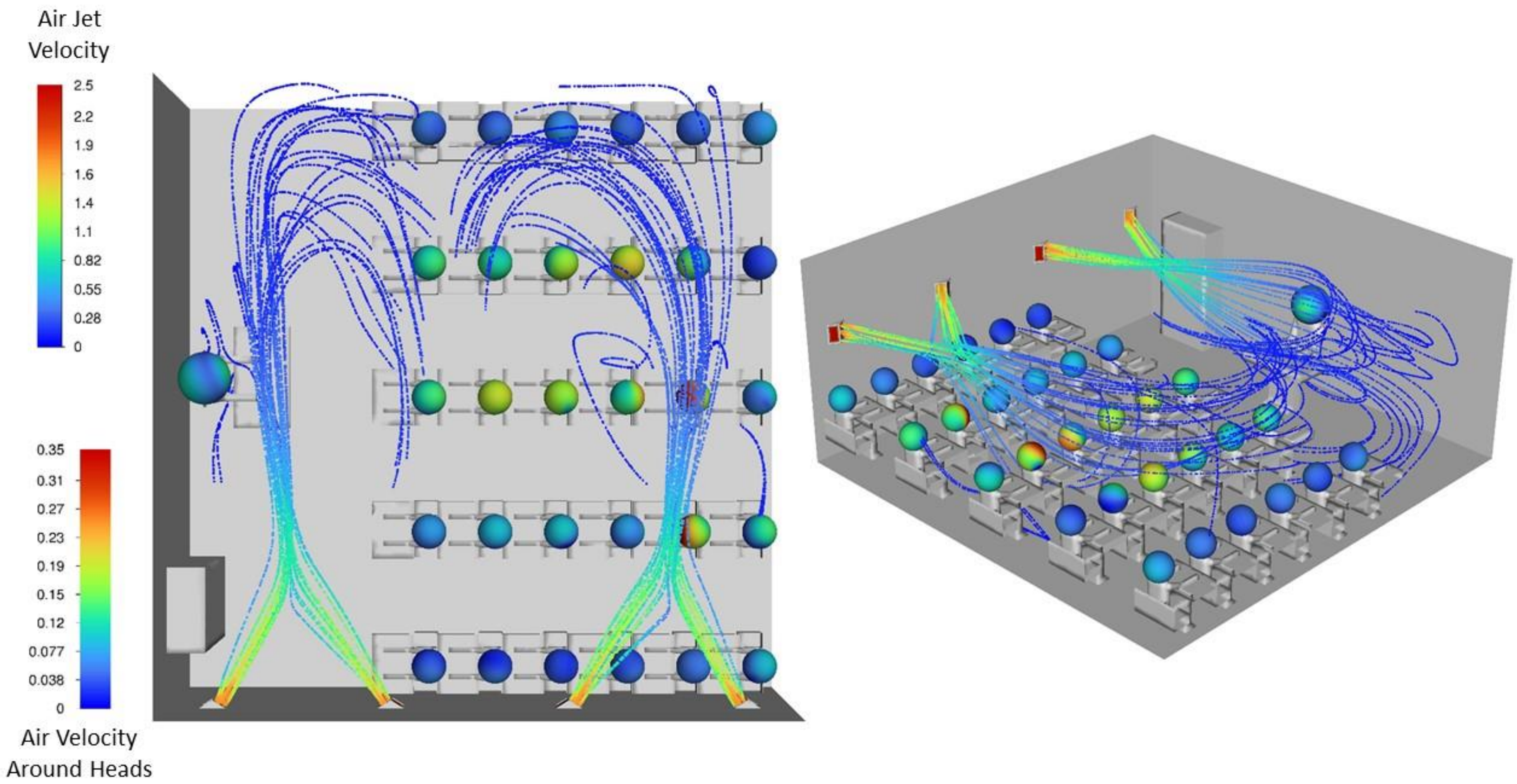

Figure 74. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/800-160-5 a)Top View, b)Isometric View

a) b)

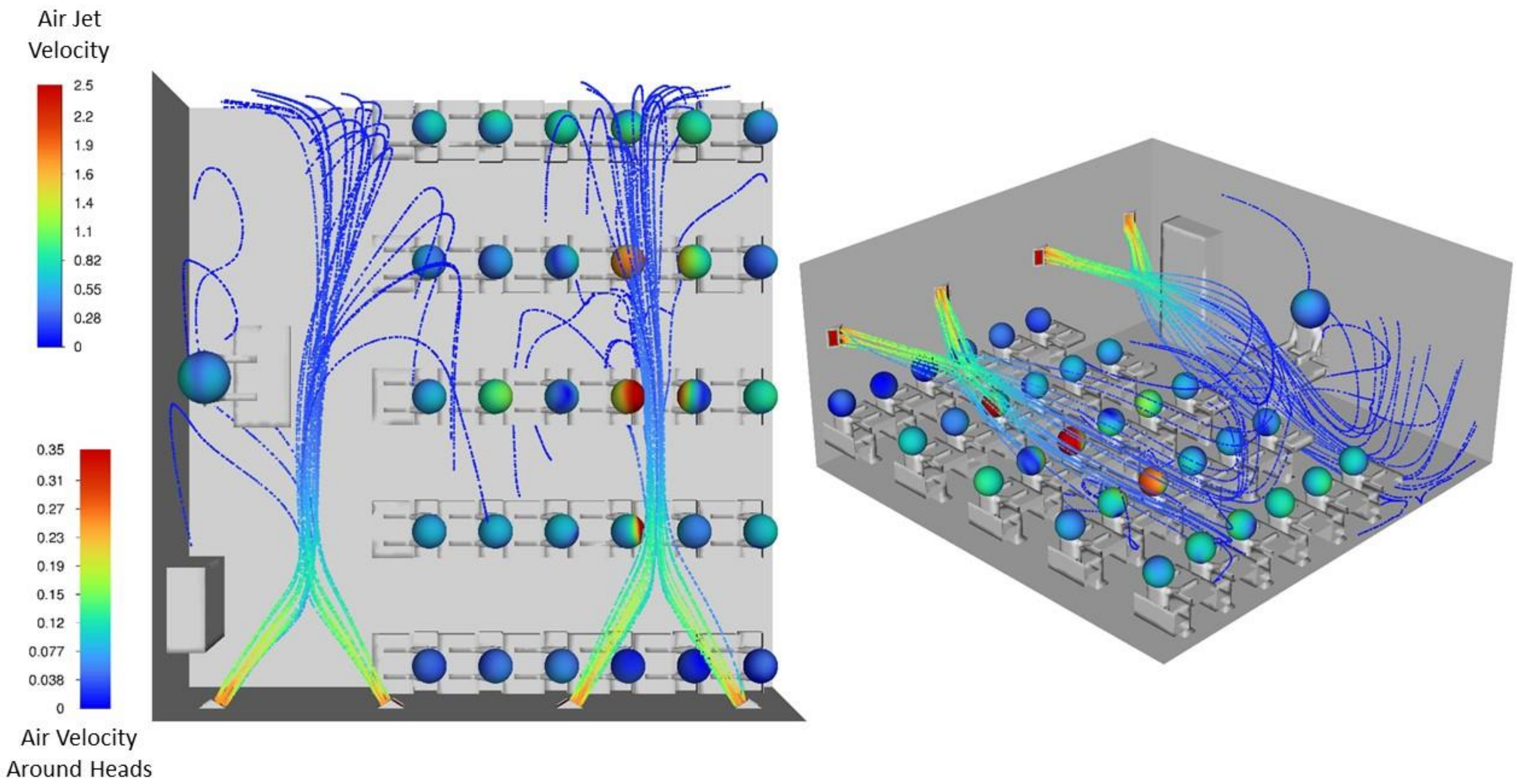

Figure 75. Velocity contours around heads and pathlines inside the classroom environment of model C20-75/800-160-10 a)Top View, b)Isometric View

APPENDIX D

LOCAL AGE OF AIR VALUES OF INDIVIDUALS IN EACH PARAMETER

Informative Note:

I. Similar Flow Rates are shown in same figures.

II. Total dark and white contours may have higher Age of Air values

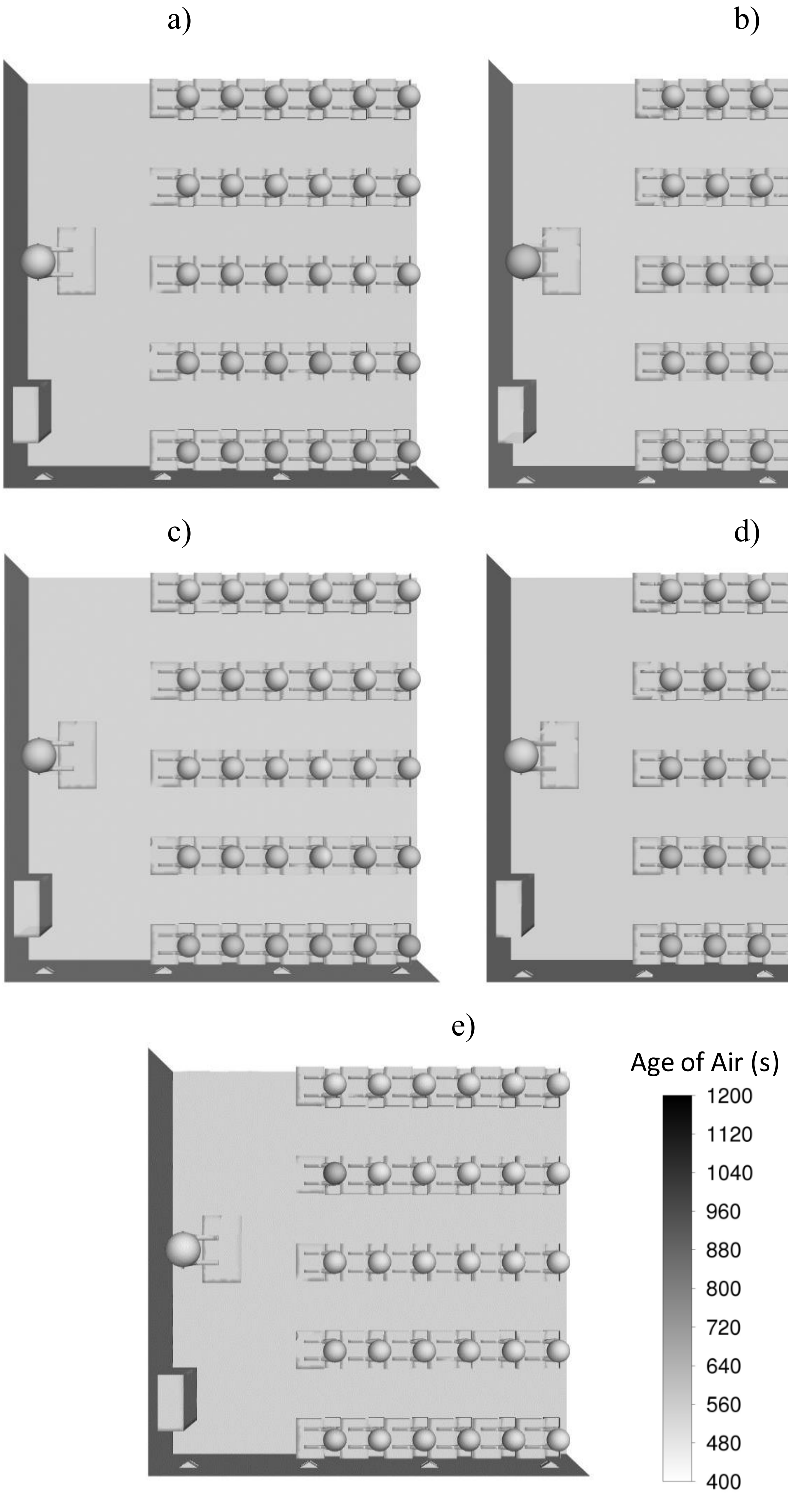

Figure 76. Comparison of local age of air of parameters with 800 m^3/h flow rate, a) 800-5-160, b) 800-5-200, c) 800-10-160, d) 800-10-200, e) Piston Ventilation-800

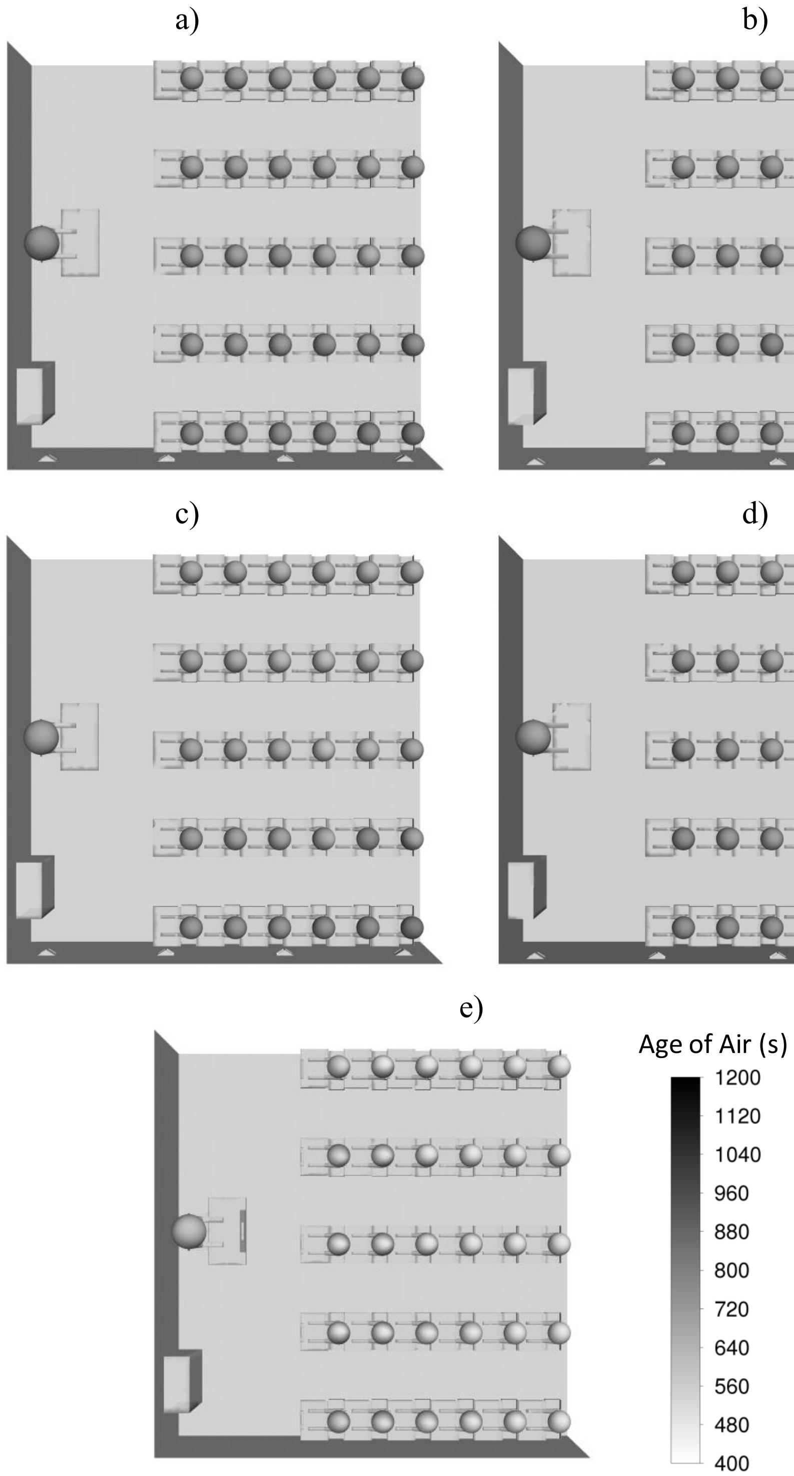

Figure 77. Comparison of local age of air of parameters with 600 m^3/h flow rate, a) 600-5-160, b) 600-5-200, c) 600-10-160, d) 600-10-200, e) Personal Ventilation-600

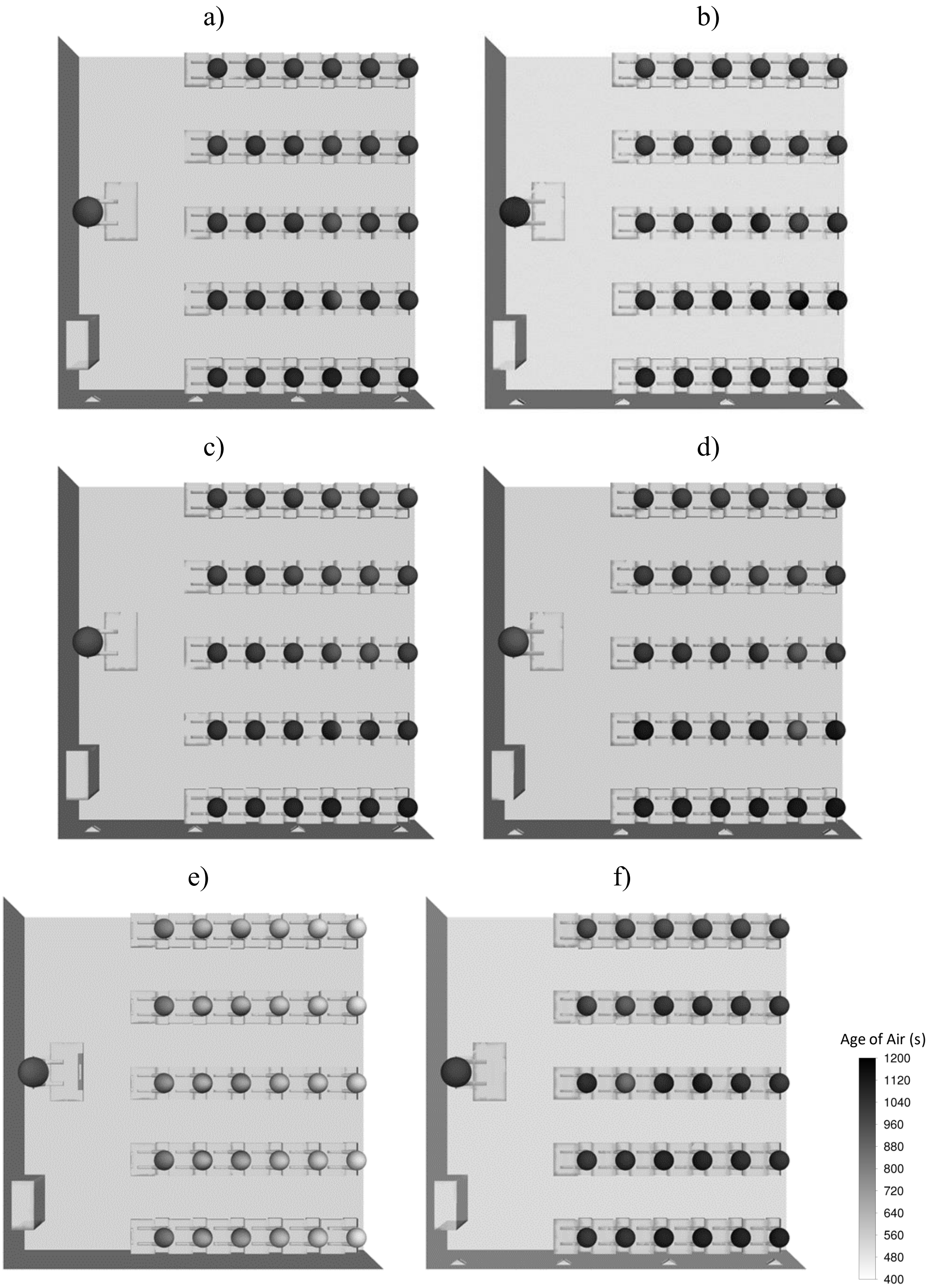

Figure 78. Comparison of local age of air of parameters with 400 m^3/h flow rate, a) 400-5-160, b) 400-5-200, c) 400-10-160, d) 400-10-200, e) Personal Ventilation-400, f) 2 HRV Unit-400

APPENDIX E

PMV AND PPD TABLES OF EACH PARAMETER

Informative note:

I. Every parameter has summer and winter conditions.

II. Steady-state and isothermal analyses have been made with all parameters.

III. For summer conditions metabolic rate is accepted as 1.1, the clothing insulation rate is 0.8, the relative humidity is 51%, and the temperature is between 20-26 °C.

IV. For winter conditions metabolic rate is accepted as 1.1, the clothing insulation rate is 1.0, the relative humidity is 75%, and the temperature is between 20-26°C.

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	25.7%	27.2%	25.8%	24.4%	27%	-1.01
Row-2	24.4%	24.4%	24.4%	41.8%	32.4%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	25.6%	24.7%	45.2%	31.7%	24.9%	0.05	0.11
Row-4	24.4%	24.4%	24.4%	34.1%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	25%	-0.98
Row-2	24.4%	24.4%	24.4%	34.3%	28.4%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	24.4%	24.4%	34.6%	31.1%	24.4%	0.03	0.06
Row-4	24.4%	24.4%	24.4%	24.9%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	25%	-0.96
Row-2	24.4%	24.4%	24.4%	24.9%	24.3%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	24.4%	24.4%	25.1%	28.0%	24.4%	0.01	0.02
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	27%	-1.01
Row-2	25.0%	28.6%	26.1%	36.6%	31.2%	24.4%	PPD Std D.	PMV Std. D.
Row-3	26.5%	34.2%	29.6%	37.2%	38.4%	24.3%	0.04	0.09
Row-4	24.4%	24.4%	24.4%	24.4%	26.5%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	25%	-0.97
Row-2	24.4%	24.4%	24.4%	28.5%	24.9%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	29.0%	24.4%	34.8%	28.7%	24.4%	0.02	0.05
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	24%	-0.95
Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	24.4%	24.4%	24.6%	24.3%	24.4%	0.00	0.00
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	27%	-1.01
Row-2	24.4%	25.5%	24.4%	33.9%	26.1%	24.4%	PPD Std D.	PMV Std. D.
Row-3	28.1%	35.2%	30.1%	36.1%	36.0%	27.1%	0.04	0.08
Row-4	25.8%	28.6%	24.4%	27.0%	28.4%	25.5%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	25%	-0.97
Row-2	24.4%	24.4%	24.4%	30.6%	24.4%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	29.3%	25.1%	32.4%	28.8%	24.4%	0.02	0.05
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	25%	-0.96
Row-2	24.4%	24.4%	24.4%	24.9%	24.3%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	24.4%	24.4%	25.1%	28.0%	24.4%	0.01	0.02
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	25.1%	24.4%	24.4%	24.4%	27%	-1.01
Row-2	33.2%	35.1%	25.1%	33.7%	29.8%	24.4%	PPD Std D.	PMV Std. D.
Row-3	33.4%	35.1%	26.9%	28.8%	35.8%	24.4%	0.04	0.09
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	26%	-0.98
Row-2	29.9%	30.1%	24.4%	28.5%	27.2%	24.4%	PPD Std D.	PMV Std. D.
Row-3	29.5%	29.4%	24.4%	24.4%	31.9%	24.4%	0.02	0.05
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	24%	-0.96
Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	PPD Std D.	PMV Std. D.
Row-3	24.4%	24.4%	24.4%	24.4%	25.0%	24.4%	0.00	0.00
Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

Figure 79. Calculated PPD values for each parameter for summer at T=20°C (met 1.1, clo 0.8, RH 51%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	9.8%	10.3%	9.8%	8.9%	10%	-0.48
Row-2	8.9%	8.9%	8.9%	16.6%	12.4%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	9.7%	9.4%	18.1%	12.1%	9.5%	0.02	0.09
Row-4	8.9%	8.9%	8.9%	13.2%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.45
Row-2	8.9%	8.9%	8.9%	13.2%	10.8%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	13.3%	11.9%	8.9%	0.01	0.06
Row-4	8.9%	8.9%	8.9%	9.5%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.44
Row-2	8.9%	8.9%	8.9%	9.5%	9.2%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	9.5%	10.6%	8.9%	0.00	0.02
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	10%	-0.48
Row-2	9.5%	10.8%	9.9%	14.2%	11.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	10.1%	13.2%	11.2%	14.5%	15.0%	9.3%	0.02	0.08
Row-4	8.9%	8.9%	8.9%	8.9%	10.1%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.45
Row-2	8.9%	9.2%	8.9%	10.8%	9.5%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	11.0%	9.3%	13.4%	10.9%	8.9%	0.01	0.04
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.43
Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	9.4%	9.3%	8.9%	0.00	0.01
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	10%	-0.48
Row-2	8.9%	9.7%	8.9%	13.1%	9.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	10.7%	13.6%	11.5%	14.0%	13.9%	10.3%	0.02	0.07
Row-4	9.8%	10.8%	9.2%	10.2%	10.8%	9.7%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.45
Row-2	8.9%	9.1%	8.9%	11.6%	8.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	9.0%	11.1%	9.5%	12.4%	10.9%	8.9%	0.01	0.04
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.44
Row-2	8.9%	8.9%	8.9%	9.5%	9.2%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	9.5%	10.6%	8.9%	0.00	0.02
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	9.1%	9.5%	8.9%	8.9%	8.9%	10%	-0.48
Row-2	12.7%	13.6%	9.5%	13.0%	11.3%	8.9%	PPD Std D.	PMV Std. D.
Row-3	12.8%	13.6%	10.2%	11.0%	13.9%	8.9%	0.02	0.08
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.46
Row-2	11.4%	11.5%	8.9%	10.8%	10.3%	8.9%	PPD Std D.	PMV Std. D.
Row-3	11.2%	11.2%	8.9%	8.9%	12.2%	8.9%	0.01	0.05
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	9%	-0.43
Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	8.9%	9.5%	8.9%	0.00	0.01
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

Figure 80. Calculated PPD values for each parameter for winter at T=20°C (met 1.1, clo 1.0, RH 75%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	16.0%	17.0%	16.0%	14.7%	17%	-0.73
Row-2	14.7%	14.7%	14.7%	27.8%	20.6%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	15.9%	15.3%	30.3%	20.1%	15.4%	0.04	0.11
Row-4	14.7%	14.7%	14.7%	21.9%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	15%	-0.70
Row-2	14.7%	14.7%	14.7%	22.1%	17.8%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	14.7%	14.7%	22.2%	19.7%	14.7%	0.02	0.06
Row-4	14.7%	14.7%	14.7%	15.4%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	15%	-0.68
Row-2	14.7%	14.7%	14.7%	15.4%	15.0%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	14.7%	14.7%	15.5%	17.6%	14.7%	0.01	0.02
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	17%	-0.73
Row-2	15.5%	18.0%	16.3%	23.7%	19.8%	14.7%	PPD Std D.	PMV Std. D.
Row-3	16.5%	21.9%	18.7%	24.2%	25.1%	15.0%	0.03	0.09
Row-4	14.7%	14.7%	14.7%	14.7%	16.5%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	15%	-0.70
Row-2	14.7%	14.9%	14.7%	17.9%	15.4%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	18.2%	15.1%	22.4%	18.0%	14.7%	0.02	0.05
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	15%	-0.68
Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	14.7%	14.7%	15.2%	15.0%	14.7%	0.00	0.00
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	17%	-0.73
Row-2	14.7%	15.8%	14.7%	21.8%	16.2%	14.7%	PPD Std D.	PMV Std. D.
Row-3	17.6%	22.7%	19.0%	23.3%	23.3%	16.9%	0.03	0.08
Row-4	16.0%	17.9%	14.9%	16.8%	17.8%	15.8%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	15%	-0.70
Row-2	14.7%	14.7%	14.7%	19.4%	14.7%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	18.5%	15.5%	20.7%	18.1%	14.7%	0.02	0.05
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	15%	-0.68
Row-2	14.7%	14.7%	14.7%	15.4%	15.0%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	14.7%	14.7%	15.5%	17.6%	14.7%	0.01	0.02
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	15.5%	14.7%	14.7%	14.7%	17%	-0.73
Row-2	21.3%	22.6%	15.5%	21.6%	18.8%	14.7%	PPD Std D.	PMV Std. D.
Row-3	21.4%	22.6%	16.8%	18.1%	23.1%	14.7%	0.03	0.09
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	16%	-0.71
Row-2	18.9%	19.0%	14.7%	17.9%	17.0%	14.7%	PPD Std D.	PMV Std. D.
Row-3	18.6%	18.5%	14.7%	14.7%	20.3%	14.7%	0.02	0.05
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	15%	-0.68
Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	PPD Std D.	PMV Std. D.
Row-3	14.7%	14.7%	14.7%	14.7%	15.5%	14.7%	0.00	0.00
Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

Figure 81. Calculated PPD values for each parameter for summer at T=21°C (met 1.1, clo 0.8, RH 51%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.7%	6.1%	6.3%	6.1%	5.6%	6%	-0.22
Row-2	5.6%	5.6%	5.6%	9.6%	7.4%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	6.1%	5.9%	10.5%	7.2%	6.0%	0.01	0.09
Row-4	5.6%	5.6%	5.6%	7.7%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.7%	5.6%	5.6%	6%	-0.20
Row-2	5.6%	5.6%	5.6%	7.8%	6.6%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	7.8%	7.1%	5.6%	0.01	0.05
Row-4	5.6%	5.6%	5.6%	6.0%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.18
Row-2	5.6%	5.6%	5.6%	6.0%	5.9%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	6.0%	6.5%	5.6%	0.00	0.02
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.23
Row-2	6.0%	6.6%	6.2%	8.3%	7.1%	5.6%	PPD Std D.	PMV Std. D.
Row-3	6.2%	7.7%	6.8%	8.4%	8.7%	5.9%	0.01	0.08
Row-4	5.6%	5.6%	5.6%	5.6%	6.2%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.20
Row-2	5.6%	5.8%	5.6%	6.6%	6.0%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	6.7%	5.9%	7.9%	6.6%	5.6%	0.00	0.05
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.18
Row-2	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	5.9%	5.9%	5.6%	0.00	0.01
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.23
Row-2	5.6%	6.0%	5.6%	7.7%	6.1%	5.6%	PPD Std D.	PMV Std. D.
Row-3	6.5%	8.0%	6.9%	8.2%	8.2%	6.3%	0.01	0.07
Row-4	6.1%	6.6%	5.8%	6.3%	6.6%	6.1%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.19
Row-2	5.6%	5.8%	5.6%	7.0%	5.6%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.8%	6.7%	6.0%	7.4%	6.6%	5.6%	0.00	0.04
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.18
Row-2	5.6%	5.6%	5.6%	6.0%	5.9%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	6.0%	6.5%	5.6%	0.00	0.02
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.8%	6.0%	5.6%	5.6%	5.7%	6%	-0.23
Row-2	7.5%	8.0%	6.0%	7.6%	6.8%	5.6%	PPD Std D.	PMV Std. D.
Row-3	7.6%	8.0%	6.3%	6.6%	8.1%	5.6%	0.01	0.08
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.20
Row-2	6.8%	6.9%	5.6%	6.6%	6.3%	5.6%	PPD Std D.	PMV Std. D.
Row-3	6.8%	6.7%	5.6%	5.6%	7.3%	5.6%	0.00	0.05
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	6%	-0.18
Row-2	5.6%	5.7%	5.6%	5.6%	5.6%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	5.6%	6.0%	5.6%	0.00	0.01
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

Figure 82. Calculated PPD values for each parameter for winter at T=21°C (met 1.1, clo 1.0, RH 75%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	9.3%	9.8%	9.3%	8.3%	10%	-0.45
Row-2	8.3%	8.3%	8.3%	16.6%	12.1%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.3%	9.2%	8.9%	18.3%	11.8%	9.0%	0.02	0.10
Row-4	8.3%	8.3%	8.3%	12.9%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	9%	-0.42
Row-2	8.3%	8.3%	8.3%	13.0%	10.3%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.3%	8.3%	8.3%	13.1%	11.5%	8.3%	0.01	0.06
Row-4	8.3%	8.3%	8.3%	9.0%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8%	-0.40
Row-2	8.3%	8.3%	8.3%	8.9%	8.7%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.3%	8.3%	8.3%	9.0%	10.2%	8.3%	0.00	0.02
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	10%	-0.45
Row-2	9.0%	10.4%	9.4%	14.0%	11.6%	8.3%	PPD Std D.	PMV Std. D.
Row-3	9.6%	12.9%	10.9%	14.3%	14.9%	8.7%	0.02	0.09
Row-4	8.3%	8.3%	8.3%	8.3%	9.6%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	9%	-0.42
Row-2	8.3%	8.7%	8.3%	10.4%	9.0%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.3%	10.6%	8.8%	13.2%	10.4%	8.3%	0.01	0.05
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8%	-0.40
Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.3%	8.3%	8.3%	8.8%	8.7%	8.3%	0.00	0.01
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	10%	-0.46
Row-2	8.3%	9.2%	8.3%	12.8%	9.4%	8.3%	PPD Std D.	PMV Std. D.
Row-3	10.2%	13.4%	11.1%	13.8%	13.7%	9.8%	0.02	0.08
Row-4	9.3%	10.4%	8.7%	9.8%	10.3%	9.2%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	9%	-0.42
Row-2	8.3%	8.5%	8.3%	11.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.5%	10.8%	9.0%	12.1%	10.5%	8.3%	0.01	0.05
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8%	-0.40
Row-2	8.3%	8.3%	8.3%	8.9%	8.7%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.3%	8.3%	8.3%	9.0%	10.2%	8.3%	0.00	0.02
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.5%	9.0%	8.3%	8.3%	8.4%	10%	-0.46
Row-2	12.5%	13.3%	9.0%	12.7%	11.0%	8.3%	PPD Std D.	PMV Std. D.
Row-3	12.5%	13.3%	9.7%	10.5%	13.6%	8.3%	0.02	0.09
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	9%	-0.43
Row-2	11.0%	11.1%	8.3%	10.4%	9.8%	8.3%	PPD Std D.	PMV Std. D.
Row-3	10.8%	10.8%	8.3%	8.3%	11.9%	8.3%	0.01	0.06
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8%	-0.40
Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.
Row-3	8.3%	8.3%	8.3%	8.3%	9.0%	8.3%	0.00	0.01
Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

Figure 83. Calculated PPD values for each parameter for summer at T=22°C (met 1.1, clo 0.8, RH 51%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.0%	5.0%	5.0%	5.1%	5%	0.03
Row-2	5.1%	5.1%	5.1%	5.8%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.0%	5.0%	6.2%	5.1%	5.0%	0.00	0.08
Row-4	5.1%	5.1%	5.1%	5.2%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.06
Row-2	5.1%	5.1%	5.1%	5.2%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.2%	5.1%	5.1%	0.00	0.05
Row-4	5.1%	5.1%	5.1%	5.0%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.07
Row-2	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	0.00	0.02
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.03
Row-2	5.0%	5.0%	5.0%	5.4%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.2%	5.0%	5.4%	5.5%	5.0%	0.00	0.08
Row-4	5.1%	5.1%	5.1%	5.1%	5.0%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.06
Row-2	5.1%	5.0%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.0%	5.0%	5.2%	5.0%	5.1%	0.00	0.04
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.08
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	0.00	0.01
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.03
Row-2	5.1%	5.0%	5.1%	5.2%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.3%	5.0%	5.3%	5.3%	5.0%	0.00	0.07
Row-4	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.06
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.0%	5.0%	5.1%	5.0%	5.1%	0.00	0.04
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.07
Row-2	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.0%	5.0%	5.1%	0.00	0.02
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.0%	5.1%	5.1%	5.1%	5%	0.03
Row-2	5.2%	5.3%	5.0%	5.2%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.2%	5.3%	5.0%	5.0%	5.3%	5.1%	0.00	0.07
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.05
Row-2	5.0%	5.0%	5.1%	5.0%	5.0%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.0%	5.1%	5.1%	5.1%	5.1%	0.00	0.05
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	5%	0.08
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.1%	5.0%	5.1%	0.00	0.01
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

Figure 84. Calculated PPD values for each parameter for winter at T=22°C (met 1.1, clo 1.0, RH 75%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.4%	5.7%	5.9%	5.7%	5.3%	6%	-0.17
Row-2	5.3%	5.3%	5.3%	9.1%	6.8%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.3%	5.7%	5.5%	10.1%	6.7%	5.6%	0.01	0.10
Row-4	5.3%	5.3%	5.3%	7.2%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.4%	5.3%	5.3%	6%	-0.14
Row-2	5.3%	5.3%	5.3%	7.3%	6.1%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.3%	5.3%	5.3%	7.3%	6.6%	5.3%	0.01	0.06
Row-4	5.3%	5.3%	5.3%	5.6%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5%	-0.13
Row-2	5.3%	5.3%	5.3%	5.6%	5.5%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.3%	5.3%	5.3%	5.6%	6.0%	5.3%	0.00	0.02
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	6%	-0.17
Row-2	5.6%	6.1%	5.7%	7.8%	6.6%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.8%	7.2%	6.3%	7.9%	8.2%	5.5%	0.01	0.09
Row-4	5.3%	5.3%	5.3%	5.3%	5.8%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5%	-0.14
Row-2	5.3%	5.5%	5.3%	6.1%	5.6%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.3%	6.2%	5.5%	7.4%	6.1%	5.3%	0.00	0.05
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5%	-0.12
Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.3%	5.3%	5.3%	5.5%	5.5%	5.3%	0.00	0.01
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	6%	-0.18
Row-2	5.3%	5.6%	5.3%	7.2%	5.7%	5.3%	PPD Std D.	PMV Std. D.
Row-3	6.1%	7.5%	6.4%	7.6%	7.6%	5.9%	0.01	0.08
Row-4	5.7%	6.1%	5.5%	5.9%	6.1%	5.6%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5%	-0.14
Row-2	5.3%	5.4%	5.3%	6.5%	5.3%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.4%	6.3%	5.6%	6.8%	6.2%	5.3%	0.00	0.05
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5%	-0.13
Row-2	5.3%	5.3%	5.3%	5.6%	5.5%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.3%	5.3%	5.3%	5.6%	6.0%	5.3%	0.00	0.02
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.4%	5.6%	5.3%	5.3%	5.4%	6%	-0.18
Row-2	7.0%	7.4%	5.6%	7.1%	6.3%	5.3%	PPD Std D.	PMV Std. D.
Row-3	7.0%	7.4%	5.9%	6.2%	7.6%	5.3%	0.01	0.08
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	6%	-0.15
Row-2	6.4%	6.4%	5.3%	6.1%	5.9%	5.3%	PPD Std D.	PMV Std. D.
Row-3	6.3%	6.3%	5.3%	5.3%	6.7%	5.3%	0.00	0.06
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5%	-0.12
Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	PPD Std D.	PMV Std. D.
Row-3	5.3%	5.3%	5.3%	5.3%	5.6%	5.3%	0.00	0.01
Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

Figure 85. Calculated PPD values for each parameter for summer at T=23°C (met 1.1, clo 0.8, RH 51%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.1%	6.6%	6.4%	6.6%	7.4%	7%	0.29
Row-2	7.4%	7.4%	7.4%	5.1%	5.7%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.4%	6.6%	6.8%	5.0%	5.8%	6.7%	0.01	0.08
Row-4	7.4%	7.4%	7.4%	5.6%	7.4%	7.3%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.1%	7.4%	7.4%	7%	0.32
Row-2	7.4%	7.4%	7.4%	5.6%	6.2%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.4%	7.4%	7.4%	5.5%	5.9%	7.4%	0.01	0.05
Row-4	7.4%	7.4%	7.4%	6.7%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.33
Row-2	7.4%	7.4%	7.4%	6.7%	6.9%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.4%	7.4%	7.4%	6.7%	6.2%	7.4%	0.00	0.02
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.29
Row-2	6.7%	6.2%	6.5%	5.4%	5.8%	7.4%	PPD Std D.	PMV Std. D.
Row-3	6.5%	5.6%	6.0%	5.3%	5.3%	6.8%	0.01	0.07
Row-4	7.4%	7.4%	7.4%	7.4%	6.5%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.32
Row-2	7.4%	6.9%	7.4%	6.2%	6.7%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.2%	6.1%	6.8%	5.5%	6.2%	7.4%	0.00	0.04
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.34
Row-2	7.4%	7.4%	7.4%	7.2%	7.4%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.4%	7.3%	7.4%	6.8%	6.8%	7.4%	0.00	0.01
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.28
Row-2	7.4%	6.6%	7.4%	5.6%	6.5%	7.4%	PPD Std D.	PMV Std. D.
Row-3	6.2%	5.5%	6.0%	5.4%	5.4%	6.4%	0.01	0.07
Row-4	6.6%	6.2%	6.9%	6.4%	6.2%	6.6%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.32
Row-2	7.4%	7.0%	7.4%	5.9%	7.4%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.0%	6.1%	6.7%	5.7%	6.1%	7.4%	0.00	0.04
Row-4	7.4%	7.4%	7.4%	7.4%	7.3%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.33
Row-2	7.4%	7.4%	7.4%	6.7%	6.9%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.4%	7.4%	7.4%	6.7%	6.2%	7.4%	0.00	0.02
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	6.9%	6.7%	7.2%	7.4%	7.0%	7%	0.29
Row-2	5.6%	5.5%	6.7%	5.6%	6.0%	7.4%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.5%	6.4%	6.1%	5.4%	7.4%	0.01	0.07
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.31
Row-2	6.0%	6.0%	7.4%	6.2%	6.4%	7.4%	PPD Std D.	PMV Std. D.
Row-3	6.0%	6.1%	7.3%	7.4%	5.8%	7.4%	0.01	0.05
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7%	0.33
Row-2	7.2%	7.1%	7.4%	7.4%	7.4%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.2%	7.3%	7.4%	7.4%	6.7%	7.4%	0.00	0.01
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

Figure 86. Calculated PPD values for each parameter for winter at T=23°C (met 1.1, clo 1.0, RH 75%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.4%	5.2%	5.1%	5.2%	5.5%	5%	0.11
Row-2	5.5%	5.5%	5.5%	5.4%	5.0%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.5%	5.2%	5.3%	5.7%	5.0%	5.2%	0.00	0.09
Row-4	5.5%	5.5%	5.5%	5.0%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.4%	5.5%	5.5%	5%	0.14
Row-2	5.5%	5.5%	5.5%	5.0%	5.1%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.5%	5.5%	5.5%	5.0%	5.0%	5.5%	0.00	0.06
Row-4	5.5%	5.5%	5.5%	5.2%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5%	0.15
Row-2	5.5%	5.5%	5.5%	5.2%	5.3%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.5%	5.5%	5.5%	5.2%	5.1%	5.5%	0.00	0.02
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5%	0.11
Row-2	5.2%	5.0%	5.2%	5.1%	5.0%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.0%	5.0%	5.1%	5.2%	5.3%	0.00	0.08
Row-4	5.5%	5.5%	5.5%	5.5%	5.1%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5%	0.14
Row-2	5.5%	5.3%	5.5%	5.0%	5.2%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.5%	5.0%	5.3%	5.0%	5.0%	5.5%	0.00	0.05
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	6%	0.16
Row-2	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.5%	5.5%	5.5%	5.3%	5.3%	5.5%	0.00	0.01
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5%	0.10
Row-2	5.5%	5.2%	5.5%	5.0%	5.2%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.0%	5.1%	5.1%	5.1%	0.00	0.07
Row-4	5.2%	5.0%	5.3%	5.1%	5.1%	5.2%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5%	0.14
Row-2	5.5%	5.3%	5.5%	5.0%	5.5%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.3%	5.0%	5.2%	5.0%	5.0%	5.5%	0.00	0.05
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5%	0.15
Row-2	5.5%	5.5%	5.5%	5.2%	5.3%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.5%	5.5%	5.5%	5.2%	5.1%	5.5%	0.00	0.02
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.3%	5.2%	5.5%	5.5%	5.4%	5%	0.10
Row-2	5.0%	5.1%	5.2%	5.0%	5.0%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.1%	5.1%	5.0%	5.1%	5.5%	0.00	0.08
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5%	0.13
Row-2	5.0%	5.0%	5.5%	5.0%	5.1%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.0%	5.0%	5.5%	5.5%	5.0%	5.5%	0.00	0.06
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	6%	0.16
Row-2	5.4%	5.4%	5.5%	5.5%	5.5%	5.5%	PPD Std D.	PMV Std. D.
Row-3	5.5%	5.5%	5.5%	5.5%	5.2%	5.5%	0.00	0.01
Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

Figure 87. Calculated PPD values for each parameter for summer at T=24°C (met 1.1, clo 0.8, RH 51%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.4%	11.8%	11.0%	10.6%	10.9%	12.5%	12%	0.55
Row-2	12.5%	12.6%	12.6%	7.6%	9.3%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.6%	11.0%	11.3%	7.1%	9.4%	11.2%	0.02	0.08
Row-4	12.6%	12.6%	12.6%	8.9%	12.5%	12.1%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.5%	11.8%	12.4%	12.6%	12%	0.58
Row-2	12.6%	12.6%	12.6%	8.9%	10.2%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.6%	12.5%	12.5%	8.8%	9.6%	12.5%	0.01	0.05
Row-4	12.6%	12.6%	12.6%	11.2%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12%	0.59
Row-2	12.6%	12.6%	12.6%	11.2%	11.4%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.6%	12.6%	12.6%	11.2%	10.3%	12.6%	0.01	0.02
Row-4	12.6%	12.6%	12.6%	12.5%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.3%	12.6%	12.6%	12.6%	11%	0.55
Row-2	11.2%	10.2%	10.8%	8.4%	9.5%	12.6%	PPD Std D.	PMV Std. D.
Row-3	10.7%	8.9%	9.9%	8.3%	8.1%	11.4%	0.01	0.07
Row-4	12.6%	12.4%	12.5%	12.2%	10.7%	12.5%		
Row-5	12.6%	12.6%	12.6%	12.5%	12.6%	12.6%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12%	0.58
Row-2	12.5%	11.4%	12.6%	10.2%	11.2%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.0%	10.1%	11.4%	8.8%	10.2%	12.6%	0.01	0.04
Row-4	12.6%	12.6%	12.6%	12.3%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12%	0.59
Row-2	12.6%	12.6%	12.6%	12.0%	12.5%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.6%	12.1%	12.6%	11.3%	11.4%	12.6%	0.00	0.01
Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	11%	0.54
Row-2	12.5%	11.0%	12.5%	9.0%	10.9%	12.4%	PPD Std D.	PMV Std. D.
Row-3	10.3%	8.7%	9.8%	8.5%	8.5%	10.6%	0.01	0.06
Row-4	10.9%	10.2%	11.4%	10.6%	10.2%	11.0%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12%	0.58
Row-2	12.5%	11.6%	12.4%	9.7%	12.5%	12.6%	PPD Std D.	PMV Std. D.
Row-3	11.6%	10.0%	11.2%	9.3%	10.1%	12.5%	0.01	0.04
Row-4	12.6%	12.5%	12.6%	12.5%	12.2%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12%	0.59
Row-2	12.6%	12.6%	12.6%	11.2%	11.4%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.6%	12.6%	12.6%	11.2%	10.3%	12.6%	0.01	0.02
Row-4	12.6%	12.6%	12.6%	12.5%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.3%	11.6%	11.2%	12.0%	12.6%	11.7%	11%	0.55
Row-2	9.1%	8.7%	11.2%	9.0%	9.9%	12.5%	PPD Std D.	PMV Std. D.
Row-3	9.1%	8.7%	10.6%	10.1%	8.6%	12.6%	0.01	0.07
Row-4	12.6%	12.5%	12.6%	12.6%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.5%	12.5%	12.6%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.5%	12.5%	12.6%	12.6%	12.5%	12%	0.57
Row-2	9.9%	9.8%	12.5%	10.2%	10.6%	12.6%	PPD Std D.	PMV Std. D.
Row-3	9.9%	10.0%	12.2%	12.4%	9.4%	12.6%	0.01	0.05
Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12%	0.59
Row-2	11.9%	11.8%	12.6%	12.5%	12.2%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.0%	12.1%	12.6%	12.6%	11.2%	12.6%	0.00	0.01
Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

Figure 88. Calculated PPD values for each parameter for winter at T=24°C (met 1.1, clo 1.0, RH 75%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.0%	8.5%	7.9%	7.5%	7.8%	9.1%	8%	0.39
Row-2	9.1%	9.1%	9.1%	5.5%	6.6%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	7.9%	8.1%	5.3%	6.7%	8.1%	0.01	0.09
Row-4	9.1%	9.1%	9.1%	6.3%	9.1%	8.8%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	8.5%	9.0%	9.1%	9%	0.42
Row-2	9.1%	9.1%	9.1%	6.3%	7.3%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	9.1%	9.1%	6.3%	6.8%	9.1%	0.01	0.06
Row-4	9.1%	9.1%	9.1%	8.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.43
Row-2	9.1%	9.1%	9.1%	8.1%	8.2%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	9.1%	9.1%	8.0%	7.4%	9.1%	0.00	0.03
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.0%	9.1%	9.1%	9.1%	8%	0.39
Row-2	8.0%	7.2%	7.8%	6.0%	6.8%	9.1%	PPD Std D.	PMV Std. D.
Row-3	7.7%	6.3%	7.1%	6.0%	5.8%	8.2%	0.01	0.08
Row-4	9.1%	9.0%	9.1%	8.9%	7.7%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.42
Row-2	9.1%	8.2%	9.1%	7.3%	8.1%	9.1%	PPD Std D.	PMV Std. D.
Row-3	8.7%	7.2%	8.2%	6.2%	7.2%	9.1%	0.01	0.05
Row-4	9.1%	9.1%	9.1%	8.9%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.44
Row-2	9.1%	9.1%	9.1%	8.7%	9.1%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	8.8%	9.1%	8.1%	8.2%	9.1%	0.00	0.01
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	8%	0.38
Row-2	9.1%	7.9%	9.1%	6.4%	7.8%	9.1%	PPD Std D.	PMV Std. D.
Row-3	7.3%	6.2%	7.0%	6.1%	6.1%	7.6%	0.01	0.07
Row-4	7.8%	7.3%	8.2%	7.6%	7.3%	7.9%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.42
Row-2	9.1%	8.3%	9.1%	6.9%	9.1%	9.1%	PPD Std D.	PMV Std. D.
Row-3	8.4%	7.1%	8.0%	6.6%	7.2%	9.1%	0.01	0.05
Row-4	9.1%	9.1%	9.1%	9.1%	8.8%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.43
Row-2	9.1%	9.1%	9.1%	8.1%	8.2%	9.1%	PPD Std D.	PMV Std. D.
Row-3	9.1%	9.1%	9.1%	8.0%	7.4%	9.1%	0.00	0.03
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	8.9%	8.3%	8.0%	8.7%	9.1%	8.4%	8%	0.38
Row-2	6.5%	6.2%	8.0%	6.4%	7.0%	9.1%	PPD Std D.	PMV Std. D.
Row-3	6.4%	6.2%	7.6%	7.2%	6.1%	9.1%	0.01	0.08
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.41
Row-2	7.0%	7.0%	9.1%	7.3%	7.5%	9.1%	PPD Std D.	PMV Std. D.
Row-3	7.1%	7.1%	8.9%	9.0%	6.7%	9.1%	0.01	0.05
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9%	0.44
Row-2	8.6%	8.6%	9.1%	9.1%	8.9%	9.1%	PPD Std D.	PMV Std. D.
Row-3	8.7%	8.8%	9.1%	9.1%	8.0%	9.1%	0.00	0.01
Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

Figure 89. Calculated PPD values for each parameter for summer at T=25°C (met 1.1, clo 0.8, RH 51%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.1%	19.3%	18.3%	17.7%	18.2%	20.6%	19%	0.81
Row-2	20.6%	20.6%	20.6%	13.3%	15.9%	20.6%	PPD Std D.	PMV Std. D.
Row-3	20.6%	18.3%	18.7%	12.5%	16.1%	18.6%	0.02	0.07
Row-4	20.6%	20.6%	20.6%	15.4%	20.6%	19.7%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.4%	19.3%	20.1%	20.6%	20%	0.83
Row-2	20.6%	20.6%	20.6%	15.3%	17.3%	20.6%	PPD Std D.	PMV Std. D.
Row-3	20.6%	20.3%	20.6%	15.2%	16.3%	20.6%	0.02	0.05
Row-4	20.6%	20.6%	20.6%	18.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20%	0.85
Row-2	20.6%	20.6%	20.6%	18.6%	18.8%	20.6%	PPD Std D.	PMV Std. D.
Row-3	20.6%	20.6%	20.6%	18.5%	17.4%	20.6%	0.01	0.02
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.0%	20.6%	20.6%	20.6%	19%	0.81
Row-2	18.5%	17.2%	18.1%	14.7%	16.3%	20.6%	PPD Std D.	PMV Std. D.
Row-3	18.0%	15.4%	16.8%	14.5%	14.2%	18.8%	0.02	0.06
Row-4	20.6%	20.1%	20.6%	19.9%	18.0%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20%	0.83
Row-2	20.5%	18.9%	20.6%	17.2%	18.6%	20.6%	PPD Std D.	PMV Std. D.
Row-3	19.6%	17.0%	18.8%	15.2%	17.1%	20.6%	0.01	0.04
Row-4	20.6%	20.6%	20.6%	19.9%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20%	0.85
Row-2	20.6%	20.6%	20.6%	19.6%	20.6%	20.6%	PPD Std D.	PMV Std. D.
Row-3	20.6%	19.7%	20.6%	18.7%	18.8%	20.6%	0.00	0.01
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	19%	0.80
Row-2	20.6%	18.4%	20.3%	15.4%	18.1%	20.2%	PPD Std D.	PMV Std. D.
Row-3	17.3%	15.0%	16.6%	14.8%	14.8%	17.7%	0.02	0.06
Row-4	18.2%	17.2%	18.9%	17.8%	17.2%	18.3%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20%	0.83
Row-2	20.6%	19.0%	20.2%	16.5%	20.6%	20.6%	PPD Std D.	PMV Std. D.
Row-3	19.1%	16.9%	18.5%	15.9%	17.1%	20.4%	0.01	0.04
Row-4	20.6%	20.5%	20.6%	20.6%	19.8%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20%	0.85
Row-2	20.6%	20.6%	20.6%	18.6%	18.8%	20.6%	PPD Std D.	PMV Std. D.
Row-3	20.6%	20.6%	20.6%	18.5%	17.4%	20.6%	0.01	0.02
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.0%	19.0%	18.5%	19.6%	20.6%	19.2%	19%	0.81
Row-2	15.6%	15.1%	18.5%	15.5%	16.7%	20.4%	PPD Std D.	PMV Std. D.
Row-3	15.6%	15.1%	17.8%	17.1%	14.9%	20.6%	0.02	0.06
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20%	0.83
Row-2	16.7%	16.6%	20.4%	17.2%	17.7%	20.6%	PPD Std D.	PMV Std. D.
Row-3	16.8%	16.9%	19.9%	20.1%	16.1%	20.6%	0.02	0.05
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20%	0.85
Row-2	19.5%	19.4%	20.6%	20.2%	19.9%	20.6%	PPD Std D.	PMV Std. D.
Row-3	19.6%	19.7%	20.6%	20.6%	18.6%	20.6%	0.00	0.01
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

Figure 90. Calculated PPD values for each parameter for winter at T=25°C (met 1.1, clo 1.0, RH 75%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	15.6%	14.9%	13.9%	13.3%	13.8%	16.1%
Row-2	16.1%	16.1%	16.1%	9.4%	11.7%	16.1%
Row-3	16.1%	13.9%	14.2%	8.8%	11.9%	14.2%
Row-4	16.1%	16.1%	16.1%	11.2%	16.0%	15.2%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
15%	0.67
PPD Std D.	PMV Std. D.
0.02	0.08

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	15.9%	14.8%	15.6%	16.1%
Row-2	16.1%	16.1%	16.1%	11.2%	12.9%	16.1%
Row-3	16.1%	15.8%	16.1%	11.1%	12.1%	16.1%
Row-4	16.1%	16.1%	16.1%	14.2%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
15%	0.70
PPD Std D.	PMV Std. D.
0.01	0.05

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	16.1%	16.1%	16.1%	14.2%	14.4%	16.1%
Row-3	16.1%	16.1%	16.1%	14.1%	13.1%	16.1%
Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
16%	0.71
PPD Std D.	PMV Std. D.
0.01	0.03

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	15.5%	16.1%	16.1%	16.1%
Row-2	14.1%	12.9%	13.7%	10.6%	12.0%	16.1%
Row-3	13.6%	11.2%	12.5%	10.5%	10.1%	14.4%
Row-4	16.1%	15.6%	16.0%	15.4%	13.6%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
15%	0.67
PPD Std D.	PMV Std. D.
0.02	0.07

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	16.0%	14.5%	16.1%	12.9%	14.2%	16.1%
Row-3	15.1%	12.7%	14.4%	11.1%	12.8%	16.1%
Row-4	16.1%	16.1%	16.1%	15.4%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
15%	0.70
PPD Std D.	PMV Std. D.
0.01	0.05

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	16.1%	16.1%	16.1%	15.1%	16.1%	16.1%
Row-3	16.1%	15.2%	16.1%	14.3%	14.4%	16.1%
Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
16%	0.72
PPD Std D.	PMV Std. D.
0.00	0.02

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	16.1%	14.0%	15.8%	11.3%	13.7%	15.7%
Row-3	13.0%	10.9%	12.4%	10.7%	10.8%	13.4%
Row-4	13.8%	12.9%	14.4%	13.4%	12.9%	13.9%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
14%	0.66
PPD Std D.	PMV Std. D.
0.02	0.07

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	16.1%	14.6%	15.7%	12.2%	16.1%	16.1%
Row-3	14.6%	12.6%	14.1%	11.7%	12.8%	15.9%
Row-4	16.1%	15.9%	16.1%	16.1%	15.3%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
15%	0.70
PPD Std D.	PMV Std. D.
0.01	0.05

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	16.1%	16.1%	16.1%	14.2%	14.4%	16.1%
Row-3	16.1%	16.1%	16.1%	14.1%	13.1%	16.1%
Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
16%	0.71
PPD Std D.	PMV Std. D.
0.01	0.03

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	15.5%	14.6%	14.1%	15.2%	16.1%	14.8%
Row-2	11.5%	11.0%	14.1%	11.4%	12.5%	15.9%
Row-3	11.4%	11.0%	13.4%	12.8%	10.8%	16.1%
Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
14%	0.67
PPD Std D.	PMV Std. D.
0.02	0.07

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	12.5%	12.4%	15.9%	12.9%	13.3%	16.1%
Row-3	12.6%	12.6%	15.4%	15.6%	11.9%	16.1%
Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
15%	0.69
PPD Std D.	PMV Std. D.
0.01	0.05

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-2	15.0%	14.9%	16.1%	15.7%	15.4%	16.1%
Row-3	15.1%	15.2%	16.1%	16.1%	14.1%	16.1%
Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
16%	0.72
PPD Std D.	PMV Std. D.
0.00	0.02

Figure 91. Calculated PPD values for each parameter for summer at T=26°C (met 1.1, clo 0.8, RH 51%)

PPD-800-10-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	30.6%	29.7%	28.5%	27.8%	28.4%	31.5%
Row-2	31.4%	31.5%	31.5%	22.4%	25.7%	31.5%
Row-3	31.5%	28.5%	28.9%	21.4%	26.0%	28.8%
Row-4	31.5%	31.5%	31.5%	25.0%	31.1%	30.1%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
30%	1.07
PPD Std D.	PMV Std. D.
0.03	0.06

PPD-600-10-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	30.9%	29.6%	30.6%	31.5%
Row-2	31.5%	31.5%	31.5%	25.0%	27.3%	31.5%
Row-3	31.5%	30.8%	31.2%	24.9%	26.2%	31.2%
Row-4	31.5%	31.5%	31.5%	28.8%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
30%	1.10
PPD Std D.	PMV Std. D.
0.02	0.04

PPD-400-10-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	31.5%	31.5%	31.5%	28.8%	29.1%	31.5%
Row-3	31.5%	31.5%	31.5%	28.7%	27.4%	31.5%
Row-4	31.5%	31.5%	31.5%	31.3%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
31%	1.11
PPD Std D.	PMV Std. D.
0.01	0.02

PPD-800-10-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	30.5%	31.6%	31.5%	31.5%
Row-2	28.8%	27.2%	28.2%	24.1%	26.1%	31.5%
Row-3	28.1%	25.0%	26.8%	24.0%	23.5%	29.1%
Row-4	31.5%	30.5%	31.1%	30.3%	28.1%	31.4%
Row-5	31.6%	31.5%	31.5%	31.3%	31.5%	31.5%

PPD Avg	PMV Avg
29%	1.07
PPD Std D.	PMV Std. D.
0.03	0.06

PPD-600-10-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	31.0%	29.2%	31.6%	27.2%	28.8%	31.5%
Row-3	30.0%	27.0%	29.1%	24.8%	27.1%	31.5%
Row-4	31.5%	31.5%	31.5%	30.4%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
30%	1.10
PPD Std D.	PMV Std. D.
0.02	0.04

PPD-400-10-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	31.5%	31.5%	31.5%	30.0%	31.1%	31.5%
Row-3	31.5%	30.1%	31.5%	29.0%	29.1%	31.5%
Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
31%	1.11
PPD Std D.	PMV Std. D.
0.01	0.02

PPD-800-5-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	31.3%	28.6%	30.8%	25.1%	28.3%	30.6%
Row-3	27.4%	24.6%	26.6%	24.3%	24.4%	27.8%
Row-4	28.4%	27.2%	29.2%	27.9%	27.3%	28.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.6%

PPD Avg	PMV Avg
29%	1.07
PPD Std D.	PMV Std. D.
0.02	0.06

PPD-600-5-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	31.3%	29.4%	30.6%	26.4%	31.5%	31.5%
Row-3	29.4%	26.9%	28.7%	25.7%	27.1%	30.9%
Row-4	31.5%	30.9%	31.5%	31.1%	30.2%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
30%	1.10
PPD Std D.	PMV Std. D.
0.02	0.04

PPD-400-5-160	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	31.5%	31.5%	31.5%	28.8%	29.1%	31.5%
Row-3	31.5%	31.5%	31.5%	28.7%	27.4%	31.5%
Row-4	31.5%	31.5%	31.5%	31.3%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
31%	1.11
PPD Std D.	PMV Std. D.
0.01	0.02

PPD-800-5-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	30.4%	29.3%	28.7%	30.0%	31.6%	29.5%
Row-2	25.4%	24.7%	28.7%	25.2%	26.7%	30.9%
Row-3	25.3%	24.7%	27.9%	27.1%	24.4%	31.5%
Row-4	31.5%	31.1%	31.5%	31.5%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.4%	31.3%	31.5%

PPD Avg	PMV Avg
29%	1.07
PPD Std D.	PMV Std. D.
0.03	0.06

PPD-600-5-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.4%	31.1%	31.5%	31.5%	31.4%
Row-2	26.7%	26.6%	30.9%	27.2%	27.8%	31.5%
Row-3	26.8%	26.9%	30.3%	30.5%	25.9%	31.5%
Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
30%	1.09
PPD Std D.	PMV Std. D.
0.02	0.04

PPD-400-5-200	S 1	S 2	S 3	S 4	S 5	S 6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	29.8%	29.7%	31.5%	30.7%	30.3%	31.5%
Row-3	30.0%	30.1%	31.5%	31.5%	28.8%	31.5%
Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
31%	1.11
PPD Std D.	PMV Std. D.
0.01	0.02

Figure 92. Calculated PPD values for each parameter for winter at T=26°C (met 1.1, clo 1.0, RH 75%)

Summer Season

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	26.1%	24.4%	24.4%	24.4%	24.4%	24.4%	0.245	-0.957
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	PPD Std D.	PMV Std. D.
20	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.004	0.009
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
	Row-5	25.6%	24.4%	24.4%	24.4%	24.4%	24.4%		
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	16.2%	15.1%	14.7%	14.7%	14.7%	14.7%	0.148	-0.680
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	PPD Std D.	PMV Std. D.
21	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.003	0.012
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
	Row-5	15.9%	14.7%	14.7%	14.7%	14.7%	14.7%		
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	9.4%	8.8%	8.3%	8.3%	8.3%	8.3%	0.084	-0.403
	Row-2	8.3%	8.3%	8.6%	8.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.
22	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.003	0.014
	Row-4	8.3%	8.3%	8.4%	8.3%	8.3%	8.3%		
	Row-5	9.2%	8.5%	8.3%	8.3%	8.3%	8.3%		
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	5.7%	5.5%	5.4%	5.3%	5.3%	5.3%	0.053	-0.127
	Row-2	5.3%	5.3%	5.4%	5.3%	5.3%	5.3%	PPD Std D.	PMV Std. D.
23	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.001	0.017
	Row-4	5.3%	5.3%	5.4%	5.3%	5.3%	5.3%		
	Row-5	5.7%	5.4%	5.3%	5.3%	5.3%	5.3%		
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	5.2%	5.3%	5.4%	5.4%	5.5%	5.5%	0.055	0.148
	Row-2	5.5%	5.5%	5.3%	5.5%	5.5%	5.5%	PPD Std D.	PMV Std. D.
24	Row-3	5.4%	5.5%	5.5%	5.5%	5.5%	5.5%	0.001	0.019
	Row-4	5.5%	5.5%	5.4%	5.5%	5.5%	5.5%		
	Row-5	5.2%	5.3%	5.5%	5.5%	5.5%	5.5%		
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	7.8%	8.2%	8.5%	8.6%	9.0%	8.8%	0.087	0.421
	Row-2	8.8%	8.7%	8.3%	8.8%	8.8%	9.1%	PPD Std D.	PMV Std. D.
25	Row-3	8.6%	8.9%	8.8%	9.1%	9.1%	9.1%	0.003	0.020
	Row-4	8.8%	8.9%	8.4%	8.8%	9.0%	9.1%		
	Row-5	7.9%	8.4%	8.7%	8.8%	9.1%	8.8%		
	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
	Row-1	13.7%	14.4%	14.8%	15.0%	15.6%	15.3%	0.152	0.694
	Row-2	15.3%	15.1%	14.6%	15.2%	15.3%	16.1%	PPD Std D.	PMV Std. D.
26	Row-3	15.0%	15.4%	15.3%	15.8%	16.1%	16.1%	0.006	0.020
	Row-4	15.3%	15.5%	14.7%	15.3%	15.5%	16.1%		
	Row-5	13.9%	14.6%	15.2%	15.3%	15.8%	15.3%		

Winter Season

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	9.9%	9.3%	8.9%	8.9%	8.9%	8.9%	0.090	-0.435
Row-2	8.9%	8.9%	9.1%	8.9%	8.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.002	0.012
Row-4	8.9%	8.9%	9.0%	8.9%	8.9%	8.9%		
Row-5	9.7%	9.0%	8.9%	8.9%	8.9%	8.9%		
PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	6.1%	5.9%	5.7%	5.6%	5.6%	5.6%	0.057	-0.182
Row-2	5.6%	5.6%	5.8%	5.6%	5.6%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.001	0.015
Row-4	5.6%	5.6%	5.7%	5.6%	5.6%	5.6%		
Row-5	6.1%	5.8%	5.6%	5.6%	5.6%	5.6%		
PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	5.0%	5.0%	5.1%	5.1%	5.1%	5.1%	0.051	0.072
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.000	0.017
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.0%	5.1%	5.1%	5.1%	5.1%	5.1%		
PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	6.5%	6.8%	7.1%	7.2%	7.4%	7.3%	0.072	0.324
Row-2	7.3%	7.2%	6.9%	7.3%	7.3%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.1%	7.3%	7.3%	7.4%	7.4%	7.4%	0.002	0.017
Row-4	7.3%	7.4%	7.0%	7.3%	7.4%	7.4%		
Row-5	6.6%	7.0%	7.2%	7.3%	7.4%	7.3%		
PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	10.9%	11.4%	11.8%	11.9%	12.4%	12.1%	0.120	0.577
Row-2	12.2%	12.0%	11.6%	12.1%	12.1%	12.5%	PPD Std D.	PMV Std. D.
Row-3	11.9%	12.2%	12.2%	12.5%	12.6%	12.6%	0.004	0.018
Row-4	12.1%	12.3%	11.7%	12.2%	12.3%	12.6%		
Row-5	11.0%	11.6%	12.0%	12.2%	12.5%	12.1%		
PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	18.1%	18.8%	19.3%	19.5%	20.1%	19.8%	0.197	0.832
Row-2	19.8%	19.5%	19.0%	19.7%	19.7%	20.6%	PPD Std D.	PMV Std. D.
Row-3	19.5%	19.8%	19.8%	20.3%	20.6%	20.6%	0.006	0.017
Row-4	19.8%	20.0%	19.2%	19.8%	20.0%	20.6%		
Row-5	18.3%	19.1%	19.6%	19.8%	20.3%	19.7%		
PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	28.3%	29.1%	29.6%	29.8%	30.5%	30.2%	0.301	1.088
Row-2	30.3%	29.9%	29.3%	30.1%	30.1%	31.1%	PPD Std D.	PMV Std. D.
Row-3	29.8%	30.3%	30.2%	30.8%	31.6%	31.5%	0.008	0.017
Row-4	30.2%	30.4%	29.5%	30.2%	30.5%	31.6%		
Row-5	28.5%	29.4%	30.0%	30.2%	30.8%	30.1%		

Figure 93. Calculated PPD values for personal ventilation at 600 m³/h in summer and winter season

Summer Season

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
20	Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.244	-0.955
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	PPD Std D.	PMV Std. D.
	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.000	0.000
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
21	Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.147	-0.677
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	PPD Std D.	PMV Std. D.
	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.000	0.000
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
22	Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.084	-0.403
	Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.
	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.003	0.014
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
23	Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.053	-0.118
	Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	PPD Std D.	PMV Std. D.
	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.000	0.000
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
24	Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.055	0.162
	Row-2	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	PPD Std D.	PMV Std. D.
	Row-3	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.000	0.000
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
25	Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.091	0.442
	Row-2	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	PPD Std D.	PMV Std. D.
	Row-3	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.000	0.000
	Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

	PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
26	Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.161	0.723
	Row-2	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	PPD Std D.	PMV Std. D.
	Row-3	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.000	0.000
	Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%		
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%		

Winter Season

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.089	-0.431
Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	PPD Std D.	PMV Std. D.
Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.000	0.000
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.056	-0.175
Row-2	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	PPD Std D.	PMV Std. D.
Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.000	0.000
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.051	0.081
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.000	0.000
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.074	0.339
Row-2	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	PPD Std D.	PMV Std. D.
Row-3	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.000	0.000
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.126	0.598
Row-2	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	PPD Std D.	PMV Std. D.
Row-3	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.000	0.000
Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.206	0.857
Row-2	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	PPD Std D.	PMV Std. D.
Row-3	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.000	0.001
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

PPD-Per. Vent. 400	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.315	1.118
Row-2	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	PPD Std D.	PMV Std. D.
Row-3	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.000	0.000
Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		

Figure 94. Calculated PPD values for personal ventilation at 400 m³/h in summer and winter season

Summer Season

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
20	Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%

PPD Avg	PMV Avg
0.244	-0.955
PPD Std D.	PMV Std. D.
0.000	0.000

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
21	Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%

PPD Avg	PMV Avg
0.147	-0.677
PPD Std D.	PMV Std. D.
0.000	0.000

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
22	Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
	Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%

PPD Avg	PMV Avg
0.083	-0.398
PPD Std D.	PMV Std. D.
0.000	0.000

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
23	Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
	Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%

PPD Avg	PMV Avg
0.053	-0.118
PPD Std D.	PMV Std. D.
0.000	0.000

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
24	Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
	Row-2	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
	Row-3	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%

PPD Avg	PMV Avg
0.055	0.162
PPD Std D.	PMV Std. D.
0.000	0.000

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
25	Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%
	Row-2	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%
	Row-3	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%
	Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%

PPD Avg	PMV Avg
0.091	0.442
PPD Std D.	PMV Std. D.
0.000	0.000

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
26	Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
	Row-2	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
	Row-3	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
	Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
0.161	0.723
PPD Std D.	PMV Std. D.
0.000	0.000

Winter Season

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%

PPD Avg	PMV Avg
0.089	-0.431
PPD Std D.	PMV Std. D.
0.000	0.000

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Row-2	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%

PPD Avg	PMV Avg
0.056	-0.175
PPD Std D.	PMV Std. D.
0.000	0.000

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%

PPD Avg	PMV Avg
0.051	0.081
PPD Std D.	PMV Std. D.
0.000	0.000

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
Row-2	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
Row-3	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%

PPD Avg	PMV Avg
0.074	0.339
PPD Std D.	PMV Std. D.
0.000	0.000

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
Row-2	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
Row-3	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%

PPD Avg	PMV Avg
0.126	0.598
PPD Std D.	PMV Std. D.
0.000	0.000

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
Row-2	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
Row-3	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%

PPD Avg	PMV Avg
0.206	0.856
PPD Std D.	PMV Std. D.
0.000	0.000

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-2	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-3	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
0.315	1.118
PPD Std D.	PMV Std. D.
0.000	0.000

Figure 95. Calculated PPD values for personal ventilation at 200 m³/h in summer and winter season

Summer Season

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
20	Row-1	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.244	-0.955
	Row-2	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	PPD Std D.	PMV Std. D.
	Row-3	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%	0.000	0.000
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
21	Row-1	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.147	-0.677
	Row-2	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	PPD Std D.	PMV Std. D.
	Row-3	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%	0.000	0.000
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
22	Row-1	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.083	-0.398
	Row-2	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	PPD Std D.	PMV Std. D.
	Row-3	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	0.000	0.000
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
23	Row-1	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.053	-0.118
	Row-2	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	PPD Std D.	PMV Std. D.
	Row-3	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	0.000	0.000
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
24	Row-1	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.055	0.162
	Row-2	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	PPD Std D.	PMV Std. D.
	Row-3	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	0.000	0.000
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
25	Row-1	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.091	0.442
	Row-2	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	PPD Std D.	PMV Std. D.
	Row-3	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0.000	0.000
	Row-4	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
26	Row-1	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.161	0.723
	Row-2	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	PPD Std D.	PMV Std. D.
	Row-3	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%	0.000	0.000
	Row-4	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%		
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%		

Winter Season

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
20	Row-1	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.089	-0.431
	Row-2	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	PPD Std D.	PMV Std. D.
	Row-3	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%	0.000	0.000
	Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		
	Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
21	Row-1	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.056	-0.175
	Row-2	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	PPD Std D.	PMV Std. D.
	Row-3	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	0.000	0.000
	Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		
	Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
22	Row-1	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.051	0.081
	Row-2	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	PPD Std D.	PMV Std. D.
	Row-3	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%	0.000	0.000
	Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		
	Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
23	Row-1	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.074	0.339
	Row-2	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	PPD Std D.	PMV Std. D.
	Row-3	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	0.000	0.000
	Row-4	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		
	Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
24	Row-1	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.126	0.598
	Row-2	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	PPD Std D.	PMV Std. D.
	Row-3	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	0.000	0.000
	Row-4	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		
	Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
25	Row-1	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.206	0.856
	Row-2	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	PPD Std D.	PMV Std. D.
	Row-3	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	0.000	0.000
	Row-4	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		
	Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%		

	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6	PPD Avg	PMV Avg
26	Row-1	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.315	1.118
	Row-2	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	PPD Std D.	PMV Std. D.
	Row-3	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%	0.000	0.000
	Row-4	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		
	Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%		

Figure 96. Calculated PPD values for piston ventilation at 800 m³/h in summer and winter season

Summer Season

20	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
	Row-1	31.7%	24.9%	31.6%	32.5%	31.6%	29.5%
	Row-2	33.7%	46.9%	24.4%	24.4%	24.4%	32.0%
	Row-3	24.4%	45.8%	24.4%	24.4%	24.4%	27.7%
	Row-4	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%
	Row-5	24.4%	24.4%	24.4%	24.4%	24.4%	24.4%

PPD Avg	PMV Avg
0.277	-1.028
PPD Std D.	PMV Std. D.
0.059	0.125

21	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
	Row-1	20.2%	15.4%	20.1%	20.7%	20.0%	18.6%
	Row-2	21.6%	31.7%	14.7%	14.7%	14.7%	20.3%
	Row-3	14.7%	30.8%	14.7%	14.7%	14.7%	17.3%
	Row-4	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%
	Row-5	14.7%	14.7%	14.7%	14.7%	14.7%	14.7%

PPD Avg	PMV Avg
0.172	-0.749
PPD Std D.	PMV Std. D.
0.044	0.121

22	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
	Row-1	11.8%	8.9%	11.7%	12.1%	11.7%	10.8%
	Row-2	12.7%	19.3%	8.3%	8.3%	8.3%	11.9%
	Row-3	8.4%	18.7%	8.3%	8.3%	8.3%	10.0%
	Row-4	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
	Row-5	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%

PPD Avg	PMV Avg
0.099	-0.469
PPD Std D.	PMV Std. D.
0.028	0.116

23	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
	Row-1	6.7%	5.6%	6.7%	6.9%	6.7%	6.3%
	Row-2	7.1%	10.6%	5.4%	5.3%	5.3%	6.8%
	Row-3	5.4%	10.3%	5.3%	5.3%	5.3%	6.0%
	Row-4	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
	Row-5	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%

PPD Avg	PMV Avg
0.060	-0.189
PPD Std D.	PMV Std. D.
0.013	0.110

24	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
	Row-1	5.0%	5.2%	5.0%	5.0%	5.0%	5.0%
	Row-2	5.0%	5.9%	5.4%	5.5%	5.5%	5.0%
	Row-3	5.4%	5.8%	5.5%	5.5%	5.5%	5.1%
	Row-4	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
	Row-5	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%

PPD Avg	PMV Avg
0.054	0.091
PPD Std D.	PMV Std. D.
0.003	0.104

25	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
	Row-1	6.7%	8.1%	6.7%	6.6%	6.7%	7.1%
	Row-2	6.4%	5.2%	8.5%	9.1%	9.1%	6.7%
	Row-3	8.5%	5.2%	8.9%	9.1%	9.1%	7.4%
	Row-4	8.9%	8.7%	9.1%	9.1%	9.1%	8.8%
	Row-5	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%

PPD Avg	PMV Avg
0.081	0.373
PPD Std D.	PMV Std. D.
0.013	0.097

26	PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
	Row-1	11.9%	14.2%	11.9%	11.7%	12.0%	12.6%
	Row-2	11.3%	8.5%	14.9%	16.1%	16.1%	11.8%
	Row-3	14.8%	8.7%	15.4%	16.1%	16.1%	13.2%
	Row-4	15.5%	15.1%	16.1%	16.1%	16.1%	15.3%
	Row-5	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%

PPD Avg	PMV Avg
0.143	0.655
PPD Std D.	PMV Std. D.
0.023	0.089

Winter Season

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	12.1%	9.5%	12.1%	12.4%	12.0%	11.2%
Row-2	13.0%	18.9%	8.9%	8.9%	8.9%	12.2%
Row-3	8.9%	18.4%	8.9%	8.9%	8.9%	10.5%
Row-4	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%
Row-5	8.9%	8.9%	8.9%	8.9%	8.9%	8.9%

PPD Avg	PMV Avg
0.104	-0.494
PPD Std D.	PMV Std. D.
0.026	0.104

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	7.2%	6.0%	7.2%	7.4%	7.2%	6.8%
Row-2	7.7%	11.0%	5.7%	5.6%	5.6%	7.3%
Row-3	5.7%	10.7%	5.6%	5.6%	5.6%	6.4%
Row-4	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Row-5	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%

PPD Avg	PMV Avg
0.064	-0.239
PPD Std D.	PMV Std. D.
0.014	0.100

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	5.1%	5.0%	5.1%	5.1%	5.1%	5.0%
Row-2	5.2%	6.4%	5.1%	5.1%	5.1%	5.1%
Row-3	5.1%	6.3%	5.1%	5.1%	5.1%	5.0%
Row-4	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%
Row-5	5.1%	5.1%	5.1%	5.1%	5.1%	5.1%

PPD Avg	PMV Avg
0.052	0.019
PPD Std D.	PMV Std. D.
0.003	0.095

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	5.8%	6.7%	5.8%	5.7%	5.8%	6.0%
Row-2	5.6%	5.0%	7.1%	7.4%	7.4%	5.8%
Row-3	7.0%	5.0%	7.3%	7.4%	7.4%	6.3%
Row-4	7.4%	7.2%	7.4%	7.4%	7.4%	7.3%
Row-5	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%

PPD Avg	PMV Avg
0.068	0.277
PPD Std D.	PMV Std. D.
0.008	0.090

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	9.4%	11.2%	9.4%	9.3%	9.5%	9.9%
Row-2	9.0%	6.9%	11.8%	12.6%	12.6%	9.4%
Row-3	11.7%	7.0%	12.2%	12.6%	12.6%	10.4%
Row-4	12.3%	12.0%	12.6%	12.6%	12.6%	12.1%
Row-5	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%

PPD Avg	PMV Avg
0.112	0.537
PPD Std D.	PMV Std. D.
0.017	0.084

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	16.1%	18.6%	16.2%	15.9%	16.2%	16.9%
Row-2	15.5%	12.1%	19.3%	20.6%	20.6%	16.0%
Row-3	19.2%	12.4%	19.9%	20.6%	20.6%	17.5%
Row-4	20.0%	19.5%	20.6%	20.6%	20.6%	19.8%
Row-5	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%

PPD Avg	PMV Avg
0.186	0.797
PPD Std D.	PMV Std. D.
0.025	0.078

PPD-Per. Vent. 600	S 1,1	S 1,2	S 1,3	S 1,4	S 1,5	S 1,6
Row-1	25.9%	28.8%	26.0%	25.6%	26.0%	26.8%
Row-2	25.2%	20.9%	29.7%	31.5%	31.6%	25.8%
Row-3	29.6%	21.2%	30.3%	31.5%	31.5%	27.6%
Row-4	30.4%	29.9%	31.6%	31.5%	31.5%	30.2%
Row-5	31.5%	31.5%	31.5%	31.5%	31.5%	31.5%

PPD Avg	PMV Avg
0.290	1.061
PPD Std D.	PMV Std. D.
0.031	0.072

Figure 97. Calculated PPD values for 2 HRV Unit with 400 m³/h in summer and winter season

APPENDIX F

USER DEFINED FUNCTION FOR EVALUATING AGE OF AIR

```
#include "udf.h"
DEFINE_DIFFUSIVITY(mean_age_diff, c, t, i)
{
return C_R(c,t)*2.88e-05 + C_MU_EFF(c,t) / 0.7;
}
DEFINE_SOURCE(mean_age_source, c, t, dS, eqn)
{
dS[eqn]=0; return C_R(c,t);
}
```