Masteroppgave

NTNU
Norges teknisk-naturvitenskapelige universitet
Fakultet for ingeniørvitenskap
Institutt for energi- og prosessteknikk

Runar Lundøy

Positioning of sterile tables under laminar airflow ventilation and the effect on surgical site infections

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Veileder: Hans Martin Mathisen
Medveileder: Guangyu Cao
Juli 2022

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Preface

This master thesis was written at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology during the spring of 2022. The master thesis is a continuation of a project work completed during the fall of 2021. The project work focused on a comparison of laminar airflow ventilation and mixing ventilation in operating rooms, as well as their effectiveness against surgical site infections. Chapters 1 and 2 in this master thesis are inspired by or copied from the project work.

The project work and master thesis was a part of the research project POSIRED, a project owned by Norconsult.

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Summary

Surgical site infections (SSIs) are one of the most repeatedly reported health-associated infections world wide today. SSIs are considered as one of the most serious postoperative complications, as they are associated with increased morbidity and mortality, as well as extended therapy and elevated healthcare costs. Surgical site infections have long been associated with airborne contamination, as it has been firmly believed that the number of airborne bacteria is directly linked to the patients chance of contracting a SSI. Ventilation systems are therefore used as preventive measure, and since the late 1960's it has been believed that laminar airflow (LAF) ventilation systems are able to provide lower airborne contamination in operating rooms (ORs) compared to other ventilation solutions.

Studies investigating the efficiency of laminar airflow in OR environments find that the ventilation solution mainly provide a low air contamination within the laminar airflow canopy. When utilizing a smaller ceiling canopy, the area protected by the laminar airflow is reduced, which may result in equipment and instrument tables being placed in the boundary area or even outside of the laminar airflow. In these areas there is a risk of unwanted turbulent airflow resulting in increased bacterial contamination rates.

This master thesis investigated bacterial and particle contamination based on the positioning of sterile tables in a vertical laminar airflow OR environment. The thesis was intended to show the necessity of having vertical LAF systems large enough to ensure that all sterile equipment is placed inside the laminar airflow. Through the use of eight mock surgeries performed in an operating room at St. Olavs hospital in Trondheim, eight different positions for the sterile tables where investigated. Though the use of two air samplers and multiple blood agar plates, CFU was measured in the air around the sterile tables, as well as on the sterile table surfaces.

The results confirmed that the position of the sterile tables does matter in regards to bacterial and particle contamination. The results showed that the CFU level in the air is likely to be higher just outside or in the boundary area of the LAF, compared to inside the LAF. The result did on the other hand show that other factors can have a stronger affect on the CFU level in the air, as one measurement day showed a higher total CFU level inside the LAF compared to outside and in the boundary of the LAF. The particles measurements showed a similar result with the highest particle level measured on sterile table positions outside or in the boundary area of the LAF, while the lowest particle level was measured inside the LAF every measurement day.

The results from the blood agar plates showed that the total number of CFU landing on all surfaces were between ten times higher and two times higher outside of the LAF compared to inside the LAF. Interestingly, the relative humidity results indicated that relative humidity might influence the number of CFU landing on surfaces outside of the LAF. The number of CFU measured with blood agar plates outside of the LAF decreased for every measurement day, as the relative humidity increased every measurement day.

Sammendrag

Postoperative sårinfeksjoner er i dag en av de mest rapporterte helserelaterte infeksjonene i hele verden. Postoperative sårinfeksjoner regnes som en av de mest alvorlige postoperative komplikasjonene, gitt at de er assosiert med økt sykelighet og dødelighet, samt utvidet behov for terapi og økte helsekostnader. Infeksjoner i operasjonssåret har lenge vært assosiert med luftbåren forurensning, ettersom det har vært antatt at antallet luftbårne bakterier er direkte knyttet til pasientens sjanse for å få en postoperativ sårinfeksjon. Ventilasjonssystemer brukes derfor som et forebyggende tiltak og siden slutten av 1960-tallet har det vært antatt at laminære luftstrømsystemer (LAF) er i stand til å gi lavere luftbåren forurensning i operasjonsstuer sammenlignet med andre ventilasjonsløsninger.

Studier som undersøker effekten av laminær luftstrøm i operasjonsstuer, finner at ventilasjonsløsningen hovedsakelig gir en lav luftforurensning innenfor den laminære luftstrømmen begrenset av LAF-takets areal. Ved bruk av et mindre LAF-tak reduseres området som er beskyttet av den laminære luftstrømmen, noe som kan føre til at utstyr og instrumentbord plasseres i grenseområdet eller til og med utenfor den laminære luftstrømmen. I disse områdene er det en risiko for uønsket turbulent luftstrøm som kan resultere i en økt bakteriell kontaminering.

Denne masteroppgaven undersøkte hvordan bakterie- og partikkelforurensning påvirkes av å plassere sterile bord utenfor, i grensenområdet og innenfor den laminære luftstrømmen under simulert kirurgi. Oppgavens intensjon var å vise nødvendigheten av å ha LAF-tak store nok til å sikre at alt sterilt utstyr er plassert innefor den laminære luftstrømmen. Ved hjelp av åtte simulerte kirurgier utført på en operasjonsstue ved St. Olavs hospital i Trondheim, ble åtte forskjellige posisjoner for de sterile bordene undersøkt. Ved bruk av to luftprøvetakere og flere blodagarplater, ble bakterier på overflaten og i luften rundt de sterile bordene målt.

Resultatene bekreftet at plasseringen av de sterile bordene påvirker bakterie- og partikkelforurensning på og rundt de sterile bordene. Resultatene viste at antall bakterier i luften vil høyst sannsynlig være høyere like utenfor eller i grenseområdet til LAF-taket, sammenlignet med innenfor LAF-taket. Resultatet viste derimot at andre faktorer kan ha en sterkere påvirkning på antall bakterier i luften, da en måledag viste et høyere antall innefor LAF-taket sammenlignet med utenfor og i grensen til LAF-taket. Partikkelmålingene viste et lignende resultat med det høyeste partikkelnivået målt på sterile bord utenfor eller i grenseområdet til LAF-taket, mens det laveste partikkelnivået ble målt innenfor LAF-taket hver måledag.

Resultatene fra blodagarplatene viste at det totale antallet bakterier på alle overflater var mellom ti ganger høyere og to ganger høyere utenfor LAF-taket sammenlignet med innenfor LAF-taket. Resultatene fra målingene av relativ fuktighet viste at relativ fuktighet kan mulignes påvirke antall bakterier som lander på overflater utenfor LAF-taket. Antallet bakterier målt med blodagarplater utenfor LAF-taket sank for hver måledag, mens den relative fuktigheten økte hver måledag.

Contents

List of Figures

List of Tables

Abbreviations

BCP - Bacteria Carrying Particle

CFU - Colony Forming Unit

CV - Conventional Ventilation

HAI - Health Associated Infection/Health-care Associated Infection

HEPA - High-Efficiency Particulate Air

LAF - Laminar Airflow

MCP - Microbe Carrying Particle

MV - Mixed Ventilation

OR - Operating Room

PM - Particulate Matter

SSI - Surgical Site Infection

UDF - Unidirectional Flow

VLAF - Vertical Laminar Airflow

1 Introduction

Surgical Site Infections (SSIs) range between the leading and the second most commonly reported category of health-care associated infections(HAIs) worldwide (Bischoff et al., 2017). The use of antibiotics have shown to be one of the most effective measure against infections (Kjønniksen et al., 2002)(Evans, 2011), but with an increasing rate of antibiotic resistant bacteria (Phillips et al., 2006)(Lutro et al., 2014), it is crucial to use other methods to prevent the occurrence of SSIs. As bacteria found in surgical wounds often originate from the air (Oguz et al., 2017), the use of efficient ventilation systems in order to reduce the bacterial load in the air in the operating room is a common preventive measure (Langvatn et al., 2020).

Since the late 1960s, ventilation systems providing laminar airflow (LAF) has been viewed as the optimal ventilation solution for open surgery. This has been supported by multiple studies finding evidence of the laminar airflow systems ability to minimize the bacterial load in the operating room and reduce the occurrence of SSIs (Charnley and Eftekhar, 1969)(Lidwell et al., 1982)(Whyte, Hodgson, and Tinkler, 1982)(Langvatn et al., 2020)(Bonsanquet et al., 2013)(Jeong et al., 2013)(Kakwani, Yohannan, and Wahab, 2007)(Gruenberg et al., 2004). Laminar air flow systems work by sending a large homogeneous flow of air, with low turbulence and constant velocity, either vertically or horizontally through the operating room. With vertical laminar airflow systems, a parallel air stream moves from the ceiling directly on to the surgical field which carries away contaminated air and in theory creates a protective curtain of air around the patient (Langvatn et al., 2020)(McHugh, Hill, and Humphreys, 2015).

The protective area created by the laminar airflow is limited by the area of the LAF ceiling canopy (Agirman et al., 2020). As ventilation guidelines vary between countries, the requirement for minimum airflow and canopy size may also differ (Aganovic, 2019)(McHugh, Hill, and Humphreys, 2015). When utilizing a smaller ceiling canopy, the area protected by the laminar airflow is reduced, which may result in equipment and instrument tables being placed in the boundary area or even outside of the laminar airflow. In these areas there is a risk of unwanted turbulent airflow resulting in increased bacterial contamination rates (McHugh, Hill, and Humphreys, 2015)(Nilsson, Lundholm, and Friberg, 2010). This may in turn lead to a higher chance of surgical site infections as bacteria can be transported from sterile equipment placed on the sterile tables into the surgical wound (Diab-Elschahawi et al., 2011)(Whyte, Hodgson, and Tinkler, 1982)(Persson, 2019).

1.1 Objective and scope

The main objective of this master thesis is to investigate the effect on bacterial contamination by changing the position of sterile surgical tables under vertical laminar airflow ventilation. The objective is to understand the effect of placing the sterile surgical tables inside, in the boundary area, or outside of the laminar airflow.

In order to meet this objective the goal of the thesis is to answer the following research question: *Does the air contamination and number of bacteria on and around the sterile tables increase when the sterile tables are placed in the boundary area or outside of the vertical laminar airflow, compared to being placed inside the vertical laminar airflow?*

In order to answer the research question, multiple mock up surgeries were scheduled in an operating room with vertical laminar airflow at St. Olavs hospital in Trondheim, Norway. By using mock surgeries, various sterile table positions could be tested in a real surgical environment with simulated surgical procedures.

The hypothesis for the research question is that the CFU level and particle level will be higher outside and in the boundary area of the laminar airflow, compared to the inside of the laminar airflow for all mock surgeries. Based on this hypothesis the CFU level and particle level at the sterile table positions should gradually increase as the tables are moved from the inside of the LAF canopy to the outside.

The intention behind the research question is to help understand the limits of the laminar airflow's protective effect and the importance of placing sterile equipment inside the laminar airflow. It is also to add to the debate if today's laminar airflow canopies should have a minimum size requirement in order to insure that all sterile equipment are placed well within the boundary of the laminar airflow, or if the LAF ventilation system manages to provides a sufficient, low air contamination in the entire operating room.

1.2 Structure and methodology

In the following Chapter 2 the theory behind the thesis will be presented. The magnitude of surgical site infections will be discussed as well as how air contamination in operating rooms can lead to SSIs. Then some relevant factors found to increase air contamination such as activity, clothing and talking for surgical personnel will be introduced. Finally the ventilation solutions laminar airflow ventilation and conventional mixing ventilation will be discussed, with the main focused being on vertical laminar airflow used in the mock surgeries.

The methodology behind the mock surgeries are described in Chapter 3. The chapter shows the planning of the mock surgeries as well as equipment used to measure the indoor environment.

The results are presented in Chapter 4 where the results from the parameters relevant to answer the research question are shown. The research question and the results are then further discussed in Chapter 5 before a conclusion is presented in Chapter 6.

2 Theory

Chapter 2 presents the severity of surgical site infections and the connection between air contamination ans SSIs. The theory further presents how the presence, talking, clothing and activity level of surgical staff, as well as door openings and relative humidity, can affect airborne contamination and the risk of SSIs. Lastly, ventilation systems in operating rooms are discussed with an emphasis on vertical laminar airflow and the challenges related to this thesis.

2.1 Surgical site infections and airborne contamination

Health-care associated infections, also known to as nosocomial infections (Revelas, 2012), are defined as infections that occur while receiving health care, developed in a hospital or other health care facility that first appear 48 hours or more after hospital admission, or within 30 days after having received health care (Haque et al., 2018). Surgical Site Infection is a subgroup of healthcare-associated infections and are defined as infections that occur in or around the surgical wound after a surgical procedure (Disease Control and Prevention, 2010).

Although SSIs are considered among the most preventable HAIs (World Health Organization, 2018) with around 40 - 60 % of SSIs being identified as preventable (Odom-Forren, 2006), SSIs are one of the most repeatedly reported type of HAIs worldwide (Bao and Li, 2021)(Cao et al., 2018)(Liu et al., 2021)(Najjar and Smink, 2015). SSI are also considered as one of the most serious postoperative complications due to SSIs being associated with increased morbidity and mortality, as well as extended therapy and elevated healthcare cost (Persson, 2019)(Berg et al., 2019)(World Health Organization, 2018)(Aganovic, 2019)(Liu et al., 2021)(Beldi et al., 2009).

World wide, surgical site infection results in significant morbidity in patients undergoing surgery and the mortality rate associated with SSIs can reach up to 3% (Liu et al., 2021). Others have indicated that those diagnosed with SSIs face a 2 to 11-times increase in mortality (Najjar and Smink, 2015). WHO estimates that with an average, world wide mortality rate of 0.5%, over one million people die each year directly after a surgical procedure (Nasjonalt kunnskapssenter for helsetjenesten, 2010). Patients who develop SSI are also up to 60% more likely to spend time in an intensive care unit and have a readmission rate five times higher than those without SSI (Odom-Forren, 2006)(McHugh, Hill, and Humphreys, 2015)(Salkind and Rao, 2011). SSIs increase hospital stay on average by 7 to 13 days and increase average cost by 2.6 to 3 times per case (Beldi et al., 2009).

2.1.1 Airborne contamination

Surgical site infections have long been associated with airborne contamination, as it has been firmly believed that the number of airborne bacteria is directly linked to the patients chance of contracting a SSI. Air contamination is commonly expressed either as Bacteria Carrying Particles

(BCPs), microbe-carrying particles (MCPs) or Colony Forming Units (CFUs), and is measured per cubic air using an air sampler (Tshokey and Agampodi, 2016). Colony forming units or microbes are microorganism consisting mostly of bacteria, viruses and fungi (Quality and Health Care, 2019). The belief that airborne contamination is connected to surgical site infections has been largely based on research from Charnley and Eftekhar (1969), Lidwell et al. (1982) and Whyte, Hodgson, and Tinkler (1982) presented between the 1960s and 1980s.

In the 1960s, Charnley and Eftekhar (1969) found that one of the main routes of wound contamination was via the air in the operating room (OR), and by utilizing occlusive clothing on OR personnel, they achieved a 20-fold reduction of infection rates (Charnley and Eftekhar, 1969). A few years later, Charnley published the results for 5 800 total hip replacements performed under ultraclean air technology without the use of antibiotics. During that period of time, the incidence of deep wound infection fell from 7% to 0.5% due to the introduction of ultraclean air (Charnley, 1972)(Gruenberg et al., 2004). The term ultraclean air is commonly used describe airborne conditions that provides an average concentration of microbe carrying particles at the surgical wound of $\leq 10/\mathrm{m}^3$ (Whyte and Lytsy, 2019). After introducing a total-body exhaust gown and ultraclean ventilation the airborne microbial concentration was less than 1 $\mathrm{MCP/m^3}$ and the SSI rate was below 1% (Whyte, 2015).

Around 10 years later in 1982, Lidwell et al. (1982) found the occurrence of SSI in joint replacements to be correlated with the presence of airborne bacteria, and concluded that ultraclean room resulted in half as many re-operations as conventionally ventilated rooms (Lidwell et al., 1982)(Persson, 2019). The study was a multicentre randomised control trial and included over 8 000 patient undergoing knee or hip replacement surgery (James et al., 2015). Lidwell investigated the use of ultraclean air and exhaust suits in orthopaedic implant surgery and found a significant reduction of deep infection rates when compared with routine practices and procedures in conventional operating theatres.

The same year Whyte, Hodgson, and Tinkler (1982) monitored hip and knee arthoplasties performed in operating rooms using laminar airflow and conventionally-ventilated operations rooms. They found supporting evidence that the majority of bacteria washed out of wound came from the ambient air (Whyte, Hodgson, and Tinkler, 1982)(Persson, 2019). Their results indicated that 98% of bacteria in the patients' wound came directly or indirectly from the air when using conventional ventilation. They found that the source of contamination was the patient's skin in 2% of cases and theatre personnel in 98% of cases. In the latter, 30% of contaminants reach the wound directly via the air and 70% reach the wound via the hands of the surgical personnel or the instruments used (Whyte, Hodgson, and Tinkler, 1982).

The significance of airborne bacteria have since been controversial in terms of its contribution to increased SSI as the infections are multi-factorial in origin (McHugh, Hill, and Humphreys, 2015)(Dharan and Pittet, 2002). The connection between bacteria and infection is complicated as the creation of infection is dependant on several factors such as the bacteria's virulence, the patients health condition and the presence of foreign bodies (Kjønniksen et al., 2002)(Nasjonalt kunnskapssenter for helsetjenesten, 2010)(Smith et al., 2013)(Dharan and Pittet, 2002). Several studies have found a correlation between airborne contamination and surgical site infection (Charnley, 1972)(Charnley and Eftekhar, 1969)(Whyte, Hodgson, and Tinkler, 1982)(Lidwell et al., 1982), while others studies show that air contamination is not directly associated with wound contamination (Jonsson et al., 2014)(Pharm et al., 2015)(Dharan and Pittet, 2002). Holton and Ridgway (1992) have argued that once a certain level of air quality is achieved any further reductions in infection rates will be due to quality of aseptic technique. Bacteria and microbes in the surgical wound is still a necessity for the development of SSIs and it is therefore important to reduce the bacterial load in the air of the operating room in order to reduce the chance of developing a SSI (Pharm et al., 2015)(Beldi et al., 2009).

2.1.2 Presence and activity of surgical personnel during surgery

One of the mayor challenges in reducing air contamination in operating rooms is that during surgery, the surgical team has been found to be the main source of contaminants such as bacteria (Whyte, Hodgson, and Tinkler, 1982)(Liu et al., 2021)(Aganovic, 2019)(Dharan and Pittet, 2002)(Sadrizadeh et al., 2021). At the end of an operation it is assumed that at least 70 - 80% of surgery wounds are colonised by microbes. Most of the microbes originate from the patient or from air- and contact-contamination from the surroundings, especially from the surgical staff (Kjønniksen et al., 2002). During surgical procedures, bacteria-laden dust particles, textile fibres, and respiratory aerosols may be released from the surgical team into the air of the operating room (Diab-Elschahawi et al., 2011)(McHugh, Hill, and Humphreys, 2015). These may then settle on surgical instruments or directly enter the surgical wound resulting in SSIs (McHugh, Hill, and Humphreys, 2015)(Persson, 2019)(Cao et al., 2018).

Bennet and Branchman (1986) summarized the problem of bacterial contamination in operating theatres in 1986 by saying that the amount of particulate skin contamination in an operating theatre air is directly proportional to the number of staff in the theatre, the number of times the doors are opened, the surface area of skin exposed to the air and the amount of long hair uncovered (Lydon, Ingham, and Mourshed, 2013). Multiple studies have since then found supporting evidence that the surgical staff and even the patient it self to be among the main source of bacteria in the OR. Some studies found a strong correlation between the number of people present during surgery and the particle and bacteria level in the operating room (Rezapoor et al., 2018)(Beldi et al., 2009)(Sadrizadeh et al., 2014)(Lynch et al., 2009). Others also confirmed that the particle and bacteria level increased with increasing activity of the surgical personnel (Kirschbaum et al., 2020)(Pedersen et al., 2010)(Beldi et al., 2009). Brohus et al. (2008) found that occupants in the operating room has an emission rate of 180-600 CFU/min/person, depending on their activity level. Howorth (1985) found a much higher emission rate with each person dispersing at least 10,000 CFU/min while resting and up to 50,000 CFU/min during activity. Movement and activity from personnel also causes particles to become detached from surfaces and resuspended into the air (Hyytiäinen et al., 2018)(Wu et al., 2018).

Bacteria are mainly attached to skin scales or granules (Liu et al., 2021) which are flat flakes of dead skin(Aganovic, 2019). The skin scale can have a size of up to 20 μm with a thickness of approximately 2-5 μm (Aganovic, 2019). It has been noted that the number of bacteria counted with colony-forming units are particles larger than 5 μm (Hansen et al., 2005) and that the diameter of bacteria carrying particles are approximately 10 μm (Memarzadeh and Manning, 2004). In an OR it has been suggested that the diameter of infectious particles ranges from 5 to 10 μm. Microorganisms associated with human disease and carryover are particles with aerodynamic diameters ranging from 4 to 20 μm (Liu et al., 2021). Humans shed approximately 10^6 - 10^7 of these skin particles during 24 hours, with around 10% of these carrying bacteria (Aganovic, 2019). Accordingly, the most common bacteria found in SSIs are Staphylococci that form part of our resident and transient skin flora (Persson, 2019). The normal skin flora of patients and healthcare workers are believed to cause more than half of all infections following clean surgery (McHugh, Hill, and Humphreys, 2015). Even more troubling is the fact that scientists have identified strains of these bacteria that are resistant to potent antibiotics, such as methicillin and vancomycin (Archer and Tenenbaum, 1980)(Hiramatsu et al., 1997) (Sieradzki et al., 1999)(Hiramatsu, 2001), which makes it even more important to prevent airborne bacterial contamination during surgery in order to reduce the use of antibiotics.

2.1.3 Relative humidity and airborne contamination

A factor proven to affect the behavior and survival of bacteria in the air, is relative humidity. In a hospital environment the ideal level of relative humidity 40 - 60% (Group, 2017)(Hospital, 2021). A low relative humidity of below 40% has shown to increase the infection rates of aerosolized particles (Wolkoff, 2018)(Noti et al., 2013) and healthcare associated infections (Taylor and Hugentobler, 2016). Germs and microorganism prosper in dry indoor air as droplets containing viruses will dry up, which preserves pathogens and keeps the droplet infectious (Group, 2017)(Hospital, 2021)(Noti et al., 2013). Low relative humidity increases microbes and spores ability to detach from surfaces and become aerosolized due occupant activity and traffic (Frankel, Hansen, and Madsen, 2013). It also increases the potential for particles to aerosolize as small droplets which hover longer and travel further distances (Wolkoff, 2018)(Taylor and Hugentobler, 2016). Health related consequences of low relative humidity is that the patient mucous membranes start to dry which increases the patient susceptibility to an infection (Wolkoff, 2018)(Davis et al., 2015).

2.1.4 Door openings and traffic during surgery

Modern operating rooms maintain excessive or positive pressure of approximately 20 Pa higher in the operating rooms than in the surrounding rooms in order to prevent infiltration of air (Hoffman et al., 2002)(Lydon, Ingham, and Mourshed, 2013). By having an excess pressure in the OR, together with a balanced inflow and outflow, a protective barrier is formed as well as a stable fluid flow structure. If the supplied air volume from the ventilation system is too low, the pressure inside the operating room will fall. If the operating room is unable to maintain excess pressure compared to adjacent rooms, there is a risk of dirty air from adjacent rooms infiltrating the operating room. Every time a door is opened, pressure inside the operating room is reduced and some the efficiency of the ventilation is temporarily lost (Lydon, Ingham, and Mourshed, 2013). Smith et al. (2013) found that if a door is opened during surgery, the expected number of CFU can be increased by over 69%. If a person enters through a door, the person will also transport a certain amount of air, especially in the wake behind the body. Through fluid simulations it has been shown that the flow of contaminated air that enters from near the base of the door can enter the clean zone and pass into the space between the surgeon and the patient. The consequence can be increased air contamination in the surgical area and an increased risk of SSI (Lydon, Ingham, and Mourshed, 2013).

2.1.5 Surgical clothing

Modern surgical clothing needs to satisfy multiple requirements in order to be used in a surgical environment. It should be comfortable, breathable, loose-fitting, keep users comfortable, and allow heat exchange between the body and the environment, while limiting bacteria carrying particles released from the staff skin (Sadrizadeh et al., 2021). As the skin of surgical staff has been found to be a major source of bacteria dispersed into the air, the operating teams wear clean surgical scrubs, surgical gowns and headgear in order to decrease bacterial contamination and lower surgical site infections (McHugh et al., 2014).

Clothing systems are directly associated with a persons source strength, meaning the mean bacteria emitted from one person per hour. It is generally agreed that clothing with a high protective capacity result in a lower source strength and reduce the particle concentration in the OR (Sadrizadeh et al., 2021). During light activity undressed humans shed around 25 000 - 40 000 bacteria per hour. With surgical clothing the shedding is reduced to 14 000 - 28 000 and with overall clean room clothing and high boots, the shedding will be between 780 - 2 240 bacteria per hour (Deutsche Gesellschaft für Krankenhaushygiene, 2018). The surgical clothing works as a filter which limits the number of particles released by the surgical staff and it is therefore important that the OR personnel wears clothing suitable for their specific activity (Sadrizadeh et al., 2021)(Blowers and McCluskey, 1965)(Dankert, Zijlstra, and Lubberding, 1979).

2.1.6 Talking and the use of surgical masks

Humans produce respiratory droplets by breathing, speaking and coughing. These respiratory droplets can potentially include bacteria, viruses and fungi (Atkinson et al., 2009). The amount of droplets released increase when talking compared to just breathing (Eiche and Kuster, 2020) and several studies have shown that bacterial contamination increase with the amount of talking and the volume of talking (Wen et al., 2011)(Mitchell and Hunt, 1991). Whispering and the use of surgical masks have been suggested as the most effective way to reduce respiratory bacteria (Wen et al., 2011). Talking quietly have been shown to reduce the bacterial contamination by a 2 to 7-fold compared to normal talking (Mitchell and Hunt, 1991). The airborne bacteria produced from speaking is on the other hand, unsubstantial compared to the bacteria produced from skin shedding from the surgical personnel (Mitchell and Hunt, 1991).

The use of surgical mask are a heavily debated as studies find contradicting results on the effectiveness of the surgical masks (Friberg et al., 2001). Multiple studies confirm that surgical masks are a necessity for surgical personnel in order to reduce oral bacteria dispersed close to the surgical area (Mitchell and Hunt, 1991)(Wen et al., 2011)(Hubble et al., 1996). Others find no evidence that the surgical mask reduce bacterial contamination and surgical site infections (Vincent and Edwards, 2016)(Tunevall, 1991). If surgical masks are used, the mask should be changed between surgeries, as bacterial count has been found to increase with the time the surgical mask is used (Zhiqing et al., 2018).

2.2 Ventilation systems in operating rooms

In modern operating rooms the ventilation system have several crucial task. The ventilation system should insure appropriate level of thermal comfort, humidity and air circulation (Cao et al., 2018). By providing clean air at an appropriate temperature and velocity the ventilation system should maintain acceptable air quality and thermal comfort for both the surgical staff and the patient (Khankari, 2018). The ventilation system should also minimize airborne bacteria and dilute indoor pollutants in order to reduce surgical site infections (Cao et al., 2018)(Khankari, 2018).

Operating rooms are commonly ventilated using a system delivering either a laminar airflow or conventional turbulent airflow (Langvatn et al., 2020)(Cao et al., 2018). Both laminar airflow systems and conventional ventilation systems a commonly equipped with high-efficiency particulate air (HEPA) filters which are developed to achieve a low level of airborne contamination in the supply airflow. HEPA filters should remove 99.97% of particles ≥ 0.3 μm in size (Smith et al., 2013)(Cao et al., 2018)(Dharan and Pittet, 2002). As a comparison, standard operating room ventilation without HEPA-filter remove 80 - 97% of particles ≥ 5 μm (Dharan and Pittet, 2002). As bacteria-carrying particles (BCP) in operating rooms range from 5 μm to 60 μm, and bacteria range from 1 μm to 15 μm, the HEPA filter provide a sterile supply air in regards to bacterial contamination (Cao et al., 2018).

It is common to divide operating rooms into two categories; ultraclean rooms with ultraclean air with < 10 CFU/m^3, and conventional or general operating rooms with < 100 CFU/m^3 (Helsetilsyn, 1997). Some surgical procedures have a higher risk of infection, such as implant and orthopedic surgeries, and are therefore recommended to be performed in an ultraclean atmosphere (Cao et al., 2018). Ultraclean conditions can only be achieved using laminar airflow ventilation as laminar flow systems are able to replace the old, dirty air with new air more often than conventional ventilation systems. In an operating room with laminar airflow, the air may be 'changed' in the operating room more than 300 times per hour compared to general positive pressure operating room rates of 15 - 25 air changes per hour. This gives the laminar flow systems the ability to achieve levels of colony forming units below 10 CFU/m^3 (James et al., 2015), compared with conventional ventilation ability to achieve between 50 - 100 CFU/m^3 if the ventilation system is well maintained. The air contamination can reach up to 500 CFU/m^3 if the conventional ventilation system is not well maintained (Tshokey and Agampodi, 2016).

2.2.1 Laminar Airflow ventilation

Laminar air flow systems, also know unidirectional flow (UDF) systems, work by sending a large homogeneous flow of air, with low turbulence and constant velocity, vertically through the operating room.

Figure 1: OR environment under vertical LAF ventilation (Stenstad, 2021)

When using a vertical laminar air flow system (VLAF), the air is supplied through a ceiling canopy placed directly above the operating area (McHugh, Hill, and Humphreys, 2015). The LAF canopy is usually between 1200 x 2400mm and 3200 x 3200mm in size (McHugh, Hill, and Humphreys, 2015) and introduces the parallel flow which moves from the ceiling to the floor, carrying away the contamination before being extracted close to the floor or the ceiling. The parallel, filtered air streams is introduced directly on to the surgical field which carries away contaminated air and in theory creates a protective curtain of air around the patient (Langvatn et al., 2020)(McHugh, Hill, and Humphreys, 2015).

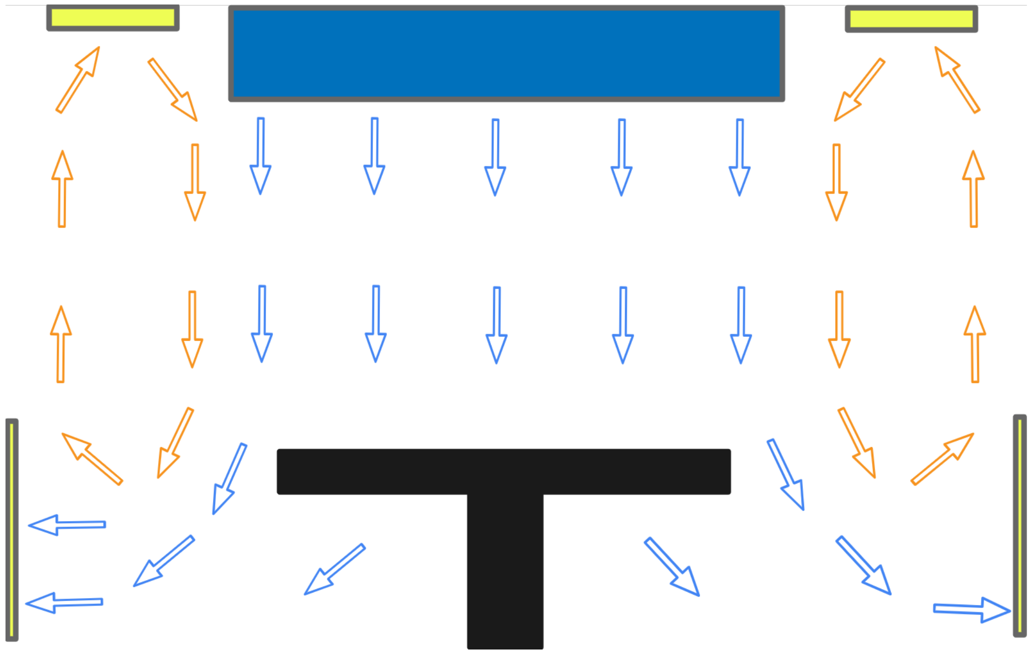


Figure 2: Illustration of a vertical laminar airflow system in an OR environment

Figure 2 shows the laminar airflow canopy (blue rectangle) in the ceiling supplying a vertical laminar airflow of fresh air (blue arrows). The air washes over the surgical area before either being extracted through the exhaust vents by the floor (yellow rectangle), or the air collides with the walls or other warmer objects causing the air to rise towards the ceiling (orange arrows). The air in then either extracted through the exhaust vents in the ceiling (yellow rectangle) or the air might circulate around the OR before being extracted.

Laminar air flow systems have been used during ultraclean surgery since the late 1960s based on the belief that it reduces the occurrence of SSI by reducing the CFU density in the air of operating room (Charnley and Eftekhar, 1969)(Langvatn et al., 2020). The idea to ventilate the operating room with a downward, ultraclean and laminar airflow has become standard since Charnley and Eftekhar (1969) in the 1960s, as well as Whyte, Hodgson, and Tinkler (1982), Lidwell et al. (1982) and Howorth (1985) in the 1980s, presented convincing proof of the methods effectiveness and the importance of utlraclean rooms (Persson, 2019).

Since then several studies have supported the fact that LAF systems are able to decrease airborne bacterial contamination and provide a cleaner surgical environment, compared to conventional turbulent ventilation (Rezapoor et al., 2018)(Kirschbaum et al., 2020)(Deutsche Gesellschaft für Krankenhaushygiene, 2018)(Nilsson, Lundholm, and Friberg, 2010). Majority of the studies confirm that the LAF is able to provide a lower airborne contamination only under the ceiling canopy

(McHugh, Hill, and Humphreys, 2015)(Taylor and Bannister, 1993), while some indicate that the LAF create a lower bacterial count even outside of the ceiling canopy (Kirschbaum et al., 2020).

2.2.2 Conventional mixing ventilation

A common alternative to laminar airflow systems are turbulent airflow systems, also referred to as mixing ventilation (MV) or conventional ventilation (CV) systems, which uses the dilution principle. With CV systems, turbulent air is introduced close to the ceiling at a high velocity causing the volume of air in the room to circulate and mix. This way, airborne contamination is diluted by mixing clean and contaminated air. When full mixing is achieved, the air will have a low and homogeneous contamination everywhere in the room (Langvatn et al., 2020).

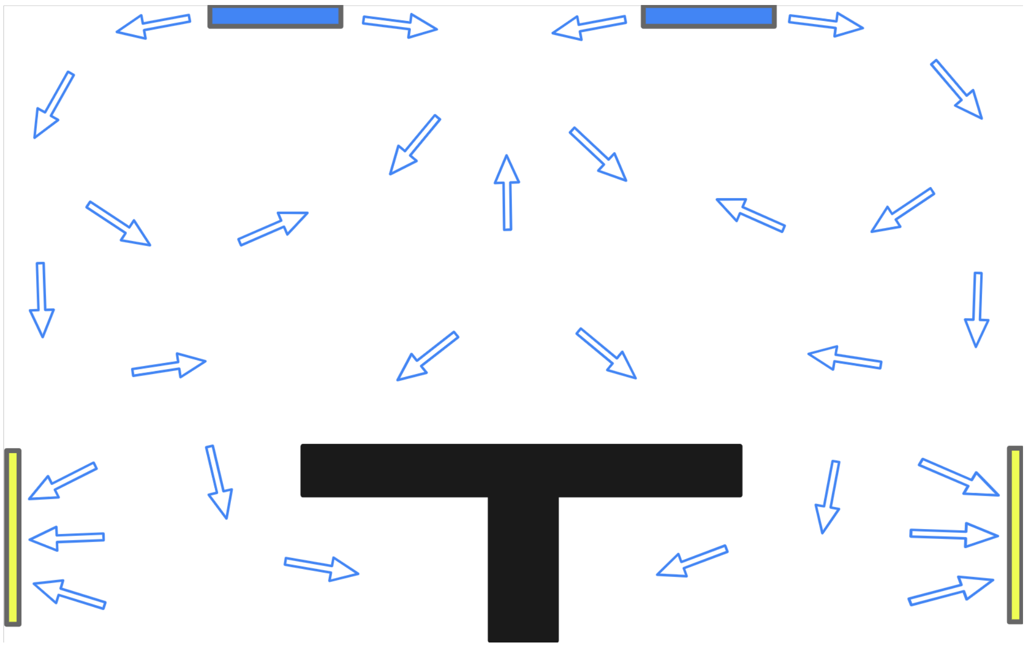


Figure 3: Illustration of a mixing ventilation system in an OR environment

Figure 3 shows how the air is supplied by vents in the ceiling at a high velocity causing the body of air in the OR to move and circulate. This causes the old and fresh air to mix before the air extracted by the floor.

2.2.3 The size of laminar ariflow canopies, boundary conditions and the placement of medical equipment under vertical laminar airflow

When assessing a vertical LAF system's ability to decrease bacterial contamination, an important factor to consider is the size of the LAF ceiling canopy (McHugh, Hill, and Humphreys, 2015). A common misconception is that all laminar systems have the same efficiency and guarantee particle- and bacteria-free conditions during surgery, regardless of the canopy size (Diab-Elschahawi et al., 2011). As ventilation guidelines vary between countries, the requirement for minimum airflow and diffuser size may also differ (Aganovic, 2019)(McHugh, Hill, and Humphreys, 2015).

Since 2002 the German Society for Hospital Hygiene, the Swiss Society for Hospital Hygiene and the Austrian Society for Hygiene, Microbiology and Preventive Medicine has worked together on defining uniform recommendations for ventilation and air-conditioning installations in hospitals and surgical units (German Society for Hospital Hygiene(DGKH), Swiss Society for Hospital Hygiene(SGSH) and the Austrian Society for Hygiene, Microbiology and Preventive Medicine(ÕGHMP), 2002). Their common recommendation is to ensure adequate protection of the operating table and instrument table, a protected area measuring around 2800 x 2800 mm is needed. This will require a low turbulence displacement-flow ceiling panel measuring 3200 x 3200 mm (German Society for Hospital Hygiene(DGKH), Swiss Society for Hospital Hygiene(SGSH) and the Austrian Society for Hygiene, Microbiology and Preventive Medicine(ÕGHMP), 2002)(Deutsche Gesellschaft für Krankenhaushygiene, 2018). Several studies have shown the impact of canopy size on bacterial counts in the surgical area, where the minimum size of a LAF ceiling distribution system has been recommended to be at least 3200 x 3200 mm for ultraclean surgery as they reduce the OR microbiological contamination compared to smaller-sized LAF systems (Langvatn et al., 2020)(Kirschbaum et al., 2020)(Hirsch et al., 2012)(Wagner, Schreiber, and Cohen, 2014)(Traversari, Heumen, and Hoksbergen, 2019)(Benen, Wille, and Clausdorff, 2013)(Agirman et al., 2020). Alas, many hospitals use smaller ceiling distribution systems, measuring 1200 x 2400 mm (Diab-Elschahawi et al., 2011).

The majority of studies assessing LAF systems efficiency to reduce bacterial contamination does not consider the impact of the LAF ceiling size (McHugh, Hill, and Humphreys, 2015). One study who took this into consideration noted a significantly decreased bacterial contamination rate on the surgical instrument table in the larger sized LAF system (5180mm x 3800mm) as compared under the smaller LAF (3800mm x 1200mm), which had bacterial numbers similar to an operating room without LAF (Diab-Elschahawi et al., 2011). The authors measured CFU per square meter per hour on the instrument table and found mean of 48.03 CFU/m^2/h for larger sized LAF system compared to 1870.27 CFU/m^2/h for smaller LAF systems, and 2159.43 CFU/m^2/h in ORs where no LAF system was used (Diab-Elschahawi et al., 2011).

Agirman et al. (2020) found that the size of the LAF canopy has a decisive role on the air velocity and contamination distribution in the OR. By increasing the size of the LAF canopy from 1.8m x 2.4m to 3.2m x 3.2m, the amount of particles deposited on the operating table could be reduced by 73% for 5 μm particles, by 39% for 10 μm particles and by 32% for 20μm particles. They observed a higher air velocity in the projection area of the LAF canopy which increased with the size of the LAF canopy. Therefore, a larger LAF canopy lead to a larger area of high air velocity, which could be expected to lead to a more effective sweeping effect in the surgical area. Outside the LAF projection area, a relative low air velocity was observed.

When utilizing a smaller ceiling canopy, the area protected by the laminar airflow is reduced, which may result in equipment and instrument tables being placed in the boundary area or even outside of the laminar airflow. In these areas there is a risk of unwanted turbulent airflow resulting in increased bacterial contamination rates (McHugh, Hill, and Humphreys, 2015)(Nilsson, Lundholm, and Friberg, 2010). SSIs can originate from unsterile instruments and implants exposed for a long period of time outside the area of protection created by the LAF ceiling (Bible et al., 2013)(Chosky, Modha, and Taylor, 1996). To ensure the absence of microorganisms before use, instruments are cleaned, disinfected and sterilized. For the instruments to remain sterile it is therefore important that both the surgical field and as many instrument tables as possible are placed within the LAF ceiling area of protection (Deutsche Gesellschaft für Krankenhaushygiene, 2018). As seen in figure 4 there can be a lot of equipment and staff present in the OR during surgical procedures. In the figure the boundary of the LAF canopy is visible and its very apparent that it is challenging to keep all sterile equipment and sterile surgical staff inside the protective laminar airflow.

Figure 4: OR environment under vertical LAF ventilation (Stenstad, 2021)

Several studies have investigated the effect on bacterial contamination of placing sterile table and instrument tables outside of the laminar airflow. Traversari, Heumen, and Hoksbergen (2019) found that the CFU level at the instrument table significantly increased when placed just outside of the LAF canopy, compared to it being placed inside the canopy. In their study the CFU level at the instrument table never exceeded 10 CFU/m^3 but they still concluded that the placement of the instrument table is critical in order to achieve acceptable CFU levels. Similar results were reported by Smith et al. (2013), who measured bacterial counts inside and outside the LAF area and found 36.6% lower bacterial count inside the LAF canopy. In contradiction, Da Cost et al. (2008) found it unnecessary to keep the instruments under the laminar airflow as they did not found any difference in contamination while the instrument table is placed outside of the clean airflow.

One study investigating compliance with best practice in the placing of instruments tables and other sterile devices within the clean airflow stream and found a compliance rate of as low as 6%. This indicates that some cases of SSI may be attributed to poor adherence to other basic infection practices, including the inappropriate placement of sterile tables in theatres with a LAF system (Korne et al., 2011). Another study reviewed the compliance with basic principles of SSI prevention in operating room using laminar airflow and suggested that over-reliance on LAF may lead to a slackness and lack of discipline in theatre protocol adherence where operators believe that the LAF will minimise SSI without the necessity to comply with best practice (Madhavan et al., 1999)(McHugh, Hill, and Humphreys, 2015).

Based on the presented theory, it is assumed that the laminar airflow efficiency is reduced with an increasing distance from the center of the LAF canopy, due to the lower air velocity. In the boundary area, the air velocity and turbulence become more similar to the outside of the laminar airflow. After the air from the LAF canopy reaches the floor. the air moves along the ground before rising due to thermal plumes or from colliding with the room walls. The air will then rise and may circulate in the room if it's not extracted through any of the exhaust vents. This circulating air is illustrated by the orange arrows in Figure 2. Due to this recirculating airflow, it is theorized that the air close to the boundary and outside of the LAF has a higher turbulence compared to the rest of the OR, as air is introduced from multiple directions causing the airflow to collide. This may result in air contamination being continuously reintroduced to surfaces causing bacteria and particles to settle on equipment or tables placed in the boundary or outside of the laminar airflow.

3 Method

The following section describe the process of planning and performing the mock surgeries used to simulated real surgery in a vertical laminar airflow environment. The first sections 3.1 and 3.2 describe the OR environment and the ventilation systems installed in the OR. These sections are necessary in order to understand the positioning of the sterile tables discussed in Section 3.3. From the OR environment and the positioning of the sterile table, the positioning of the measurement equipment is described in Section 3.4. Based on the boundaries and limitation of the OR environment, the available measuring equipment, the planned positions for the sterile tables and a review of two recorded surgeries, the planning and execution of the mock surgeries are described in Section 3.5. The sections are presented in this order to clarify the choices made for the mock surgery.

3.1 Surgical environment

The operating room used for the mock surgeries is operating room 8 located at the "Bevegelsessenteret" at St. Olavs Hospital in Trondheim, Norway. The operating room is a part of *"The Operating Room of the Future(FOR), a research infrastructure that facilitates research and development within the surgical disciplines, with emphasis on minimally invasive image guided patient care and medical technology."* (Operating Room of the Future, 2018). As a the operating room is a part of this research infrastructure, the operating room is commonly used to test new equipment and technology, as well as perform experiments. Pictures of the operating room is presented in Figure 5 and 6 and a 3D overview of the operating room is presented in Figure 7, 8 and 9.

Figure 5: Northwest oriented picture of the operating room

Figure 6: Southwest oriented picture of the operating room

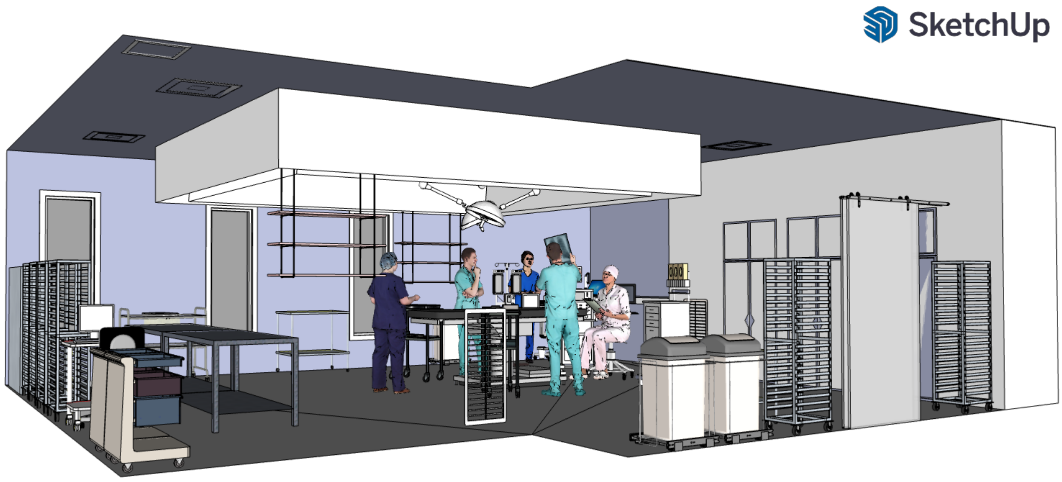


Figure 7: Southwest oriented view of the 3D model of the operating room (Source: Appendix A)

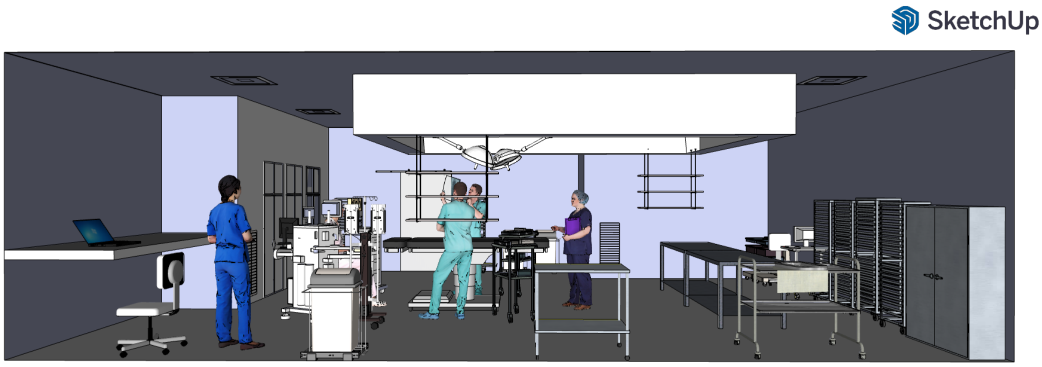


Figure 8: North oriented view of the 3D model of the operating room (Source: Appendix A)

The Figures 7, 8 and 9 were created in the modeling tool SketchUp and the model is assembled by using multiple 3D-objects made by various creators. As each object has an individual owner, a reference list for each object in the model can be found in Appendix A. The objects used in this 3D model are not exact copies of the objects present in the actual operating room, but are similar in appearance and function. The intention of the model is only to give an understanding of the operating environment, not describe the operating room in detail. As no 3D model of a laminar airflow canopy was available, the canopy is illustrated with the white square in the ceiling.

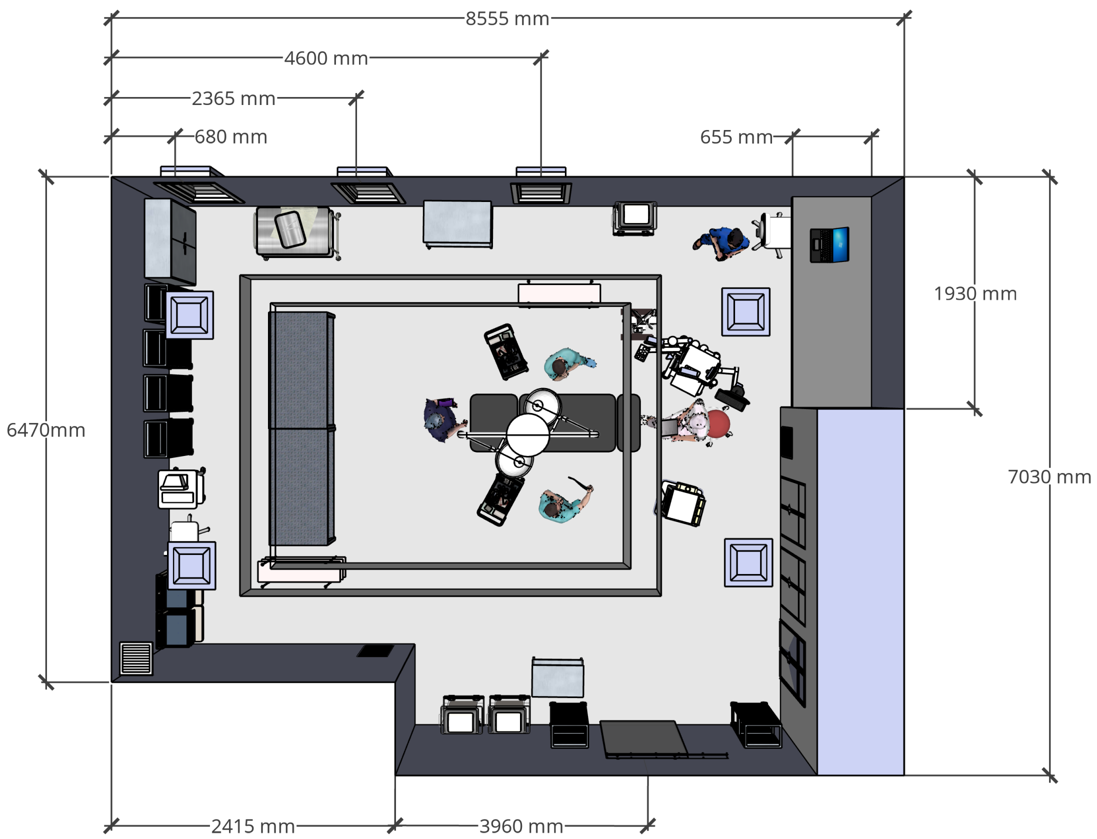


Figure 9: 3D model of the operating room with room measurements (Source: Appendix A)

Figure 9 show the 3D model of the OR from above. Similar view will be used further in this thesis were positions in the OR is referred as "Top" and "Bottom" of the OR. Top refers to the half of the operating room close to the windows and the Bottom refers to the half or the OR by the door. Compass directions will also be used to describe placements in the OR and it is therefore important to know that south refers to the wall with windows, north is the wall with the door, west is the wall with the computer table and East is the wall behind the sterile tables.

Operating room 8 has a floor area of 56.58 m^2 with a room height of 3 m. The OR has one entrance which consist of a sliding door which is opened and closed using a touch-free sensor. The door is located on the north wall and is connected to an adjacent corridor. The door can be seen in the bottom of Figure 9. The door measures 1.5 m x 2.0 m and has a small, round window at center 1.7 m above the ground. The room has three windows on the south wall measuring 1.0 m x 2.5 m. The west wall consists of a computer table and cabinet filled with equipment commonly used during surgery. The east wall is used for storage of equipment and desk with a computer for a notary to sit and observe during procedures.

Figure 10: Indoor climate display in the operating room

The operating room is equipped with interactive display where surgical personnel can control the indoor environment. On this display the temperature, humidity, pressure, number of door openings are displayed. The user can change temperature, lighting, adjust ventilation system settings and reset the number of door openings. The display can be seen in figure 10. Here the temperature is displayed in the top left corner followed by pressure difference between the OR and the adjacent corridor. In the bottom left corner is the number of door openings and the top right show the ventilation mode currently activated. The menu on the right corner is where the user can change the various indoor variables mentioned. The user can also adjust the ventilation scenario which selects the capacity the ventilation system is running on. The operating room has a resting scenario where the ventilation system runs on reduced capacity, as wells as a surgery scenario where the ventilation system runs at full capacity. This will be discussed further in chapter 3.2.

3.2 The ventilation system

The ventilation system in operating room 8 consist of a vertical laminar airflow system. A simplified illustration of the laminar airflow can be seen in Figure 11 where supplied airflow is shown in blue and exhausted airflow is shown in yellow.

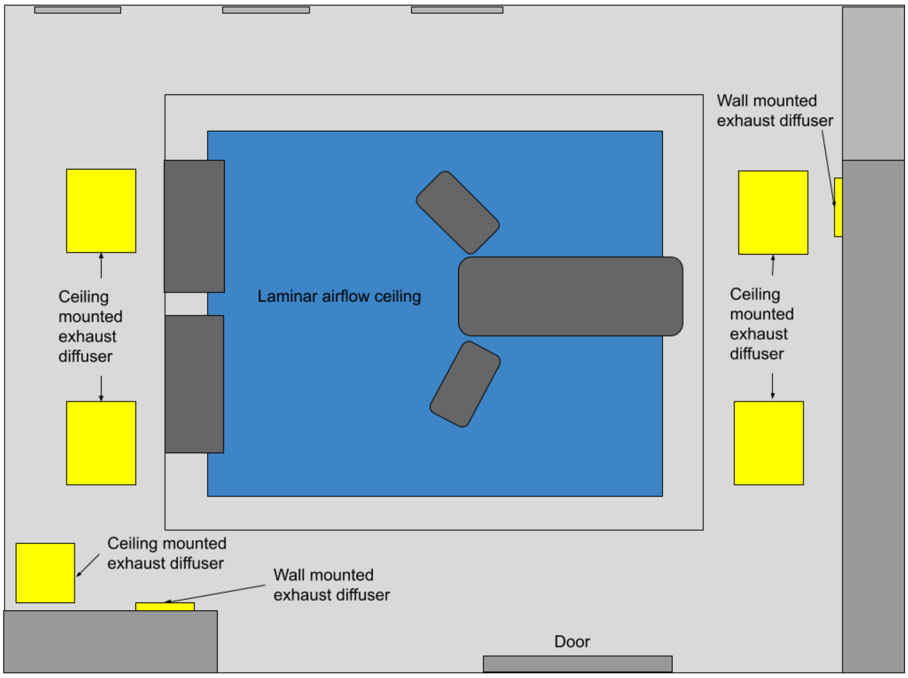


Figure 11: Simple drawing of the ventilation system in Operating room 8

Figure 12: Ceiling mounted overflow exhaust vent placed in the north-east corner of the ceiling

(a) Ceiling mounted exhaust vents

(b) Wall mounted exhaust vents

Figure 13: Pictures showing (a) the ceiling mounted exhaust vents located in a square pattern in the ceiling, and (b) the wall mounted exhaust vent located at the north and west wall of the OR

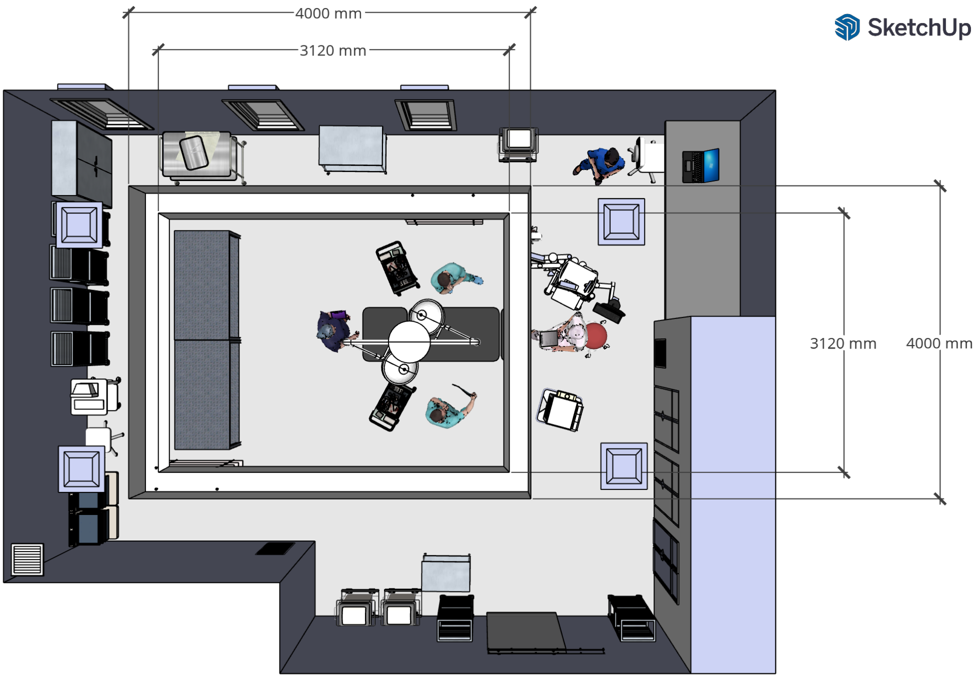


Figure 14: Top view of 3D model of Operating room 8 with measurements for LAF Canopy (Source: Appendix A)

As shown in Figure 14 the LAF canopy has a quadratic form, measuring 4m x 4m on the outer sides, and 3.12m x 3.12m on the inner sides. The LAF canopy has an 1.1m skirt with two surgical lamps and four screens mounted inside the LAF canopy. These are visible in Figure 5 and 6.

Figure 15: Picture showing the grey floor marking indicating the center of the LAF canopy and the blue tape indicating the inside of the LAF canopy

On the floor of the operating room, there was a thin, grey line indicating the square circumference of the LAF canopy. This grey line can be seen on the floor in Figure 15. The square formed on the floor by this grey line indicated the center of the edge around the LAF canopy, and was intended to visualize the boundary of the laminar airflow. For this study, the inside of the laminar airflow was defined as the area inside the inner circumference of the LAF canopy. The separation between inside and outside of the laminar airflow was a vertical line drawn from the inner edges of the LAF canopy and down to the floor. By using a laser placed on the inner edge of the LAF canopy pointing down on the floor, the boundary of the laminar airflow was marked on the floor using blue tape as seen in Figure 15. The difference between the grey marking on the floor and the blue tape marking was 460 mm.

Figure 16: Picture showing the inside of the LAF canopy in blue and center of the LAF canopy in dark grey

Figure 16 illustrates the blue and grey floor marking on the actual LAF canopy. The blue and grey line in Figure 16 vertically align with the floor marking in similar color. The reasoning behind this definition of the boundary of the laminar airflow is the fact that within the square made by the blue marking one can assume that there is a fully developed vertical laminar airflow. This is assuming the ventilation system supply air has a high enough velocity to reach the floor before being significantly disturbed by thermal plumes or other obstacles. If the boundary was moved further out, closer to the grey line, then air which is affected by the boundary conditions of the the laminar airflow would be included in the air defined as laminar airflow. This would mean that airflow defined as inside the laminar airflow would include a portion of non laminar airflow.

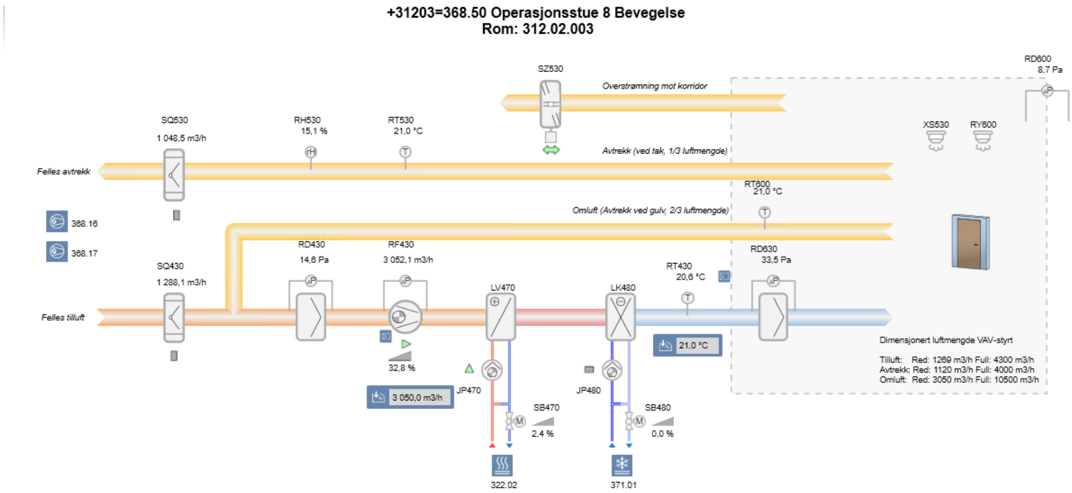


Figure 17: System scheme of the ventilation system for Operating Room 8

The ventilation system in Operating Room 8 utilizes recirculating air from the operating room. Figure 17 shows a system scheme of the ventilation system. In the figure the air extracted from the OR is shown in yellow and the air supplied to the room is shown in blue. In the top of the figure, an exhaust duct with an overflow damper is shown. The duct connects the operating room and the adjacent corridor, and allows the operating room to exhaust air to the corridor if the pressure difference between the OR and the corridor exceeds its threshold. This is the ceiling exhaust vent shown in Figure 12. The overflow exhaust vent is located in the lower left corner of Figure 11 and 14.

Below the overflow duct in Figure 17 is another exhaust duct is shown with a damper, a temperature sensor and a humidity sensor. The air being transported through this exhaust duct is the air extracted from the OR through the four ceiling vents forming a square in the ceiling in Figure 11. A picture of the ceiling mounted vents can be seen in Figure 13a. These ceiling exhaust vents extracts 1/3 of the total exhausted air from the OR. The remaining 2/3 of exhausted air is extracted through the wall mounted exhaust vents and recirculated in the supply air. A picture of the wall mounted exhaust vents can be seen in Figure 13b.

In the bottom left of Figure 17, fresh air enters the system before being mixed with the extracted air from the operating room. This creates a supply air mix consisting of 1/3 fresh air and 2/3 recirculated air. Before being reintroduced to the operating room, the air passes through a HEPA-filter which ensures clean supply air before the air is introduced to the operating room. Temperature sensors are located in the duct with recycled air and in the supply duct before the air enters the room. A heating and cooling battery is installed in the supply duct, ensuring that air is introduced with the desired temperature.

The ventilation system has the following ventilation characteristic given in the bottom right of Figure 17:

Table 1: Airflow in the ventilation system based on selected ventilation scenario

	Reduced capacity [m^3/h]	**Full capacity [m^3/h]**
Fresh air	1269	4300
Exhaust air	1120	4000
Supply air	3050	10500

As seen in table 1, the ventilation system have two different modes which are reduced capacity and full capacity. As mentioned in chapter 3.1, the ventilation scenario is selected on the wall display shown in Figure 10. During all mock surgeries the ventilation scenario was set to surgery scenario, meaning that the ventilation system operated at full capacity. The temperature was also set to 22 °C. After completing all mock surgeries, all data from the sensor in the ventilation system were controlled and analyzed. It was confirmed that the ventilation rates and temperatures in the OR were similar during all mock surgeries. As these results did not contribute to conclusion, they are included in Appendix F.

3.3 Sterile tables

The main goal of the study is to evaluate the bacterial contamination of two sterile tables present in the OR, based on the sterile tables being placed inside, in the boundary and outside of the laminar airflow. In operating room 8, there were two sterile tables used during real surgery.

Figure 18: Both sterile tables seen from the front with the back aligned with the grey floor marking

Figure 19: Both sterile tables seen from the side with the back aligned with the grey floor marking

Figure 20: Picture showing the amount of sterile equipment on the sterile tables during real surgery

The sterile tables has a surface area of 650 mm x 1500 mm, and a height of 700mm. The positions for the sterile tables seen inn Figure 18 and 19 is the position used during the recorded surgeries, and is the position normally used for the sterile tables during real surgeries at St. Olavs hospital.

Figure 20 is a picture from a real knee arthroplasty performed in operating room 8. The picture shows how much equipment that can be present on these tables during real surgery.

In order to find the ideal position for the sterile tables, multiple position needed to be tested. Following is the position investigated during the mock surgeries, moving form inside the laminar airflow to the outside:

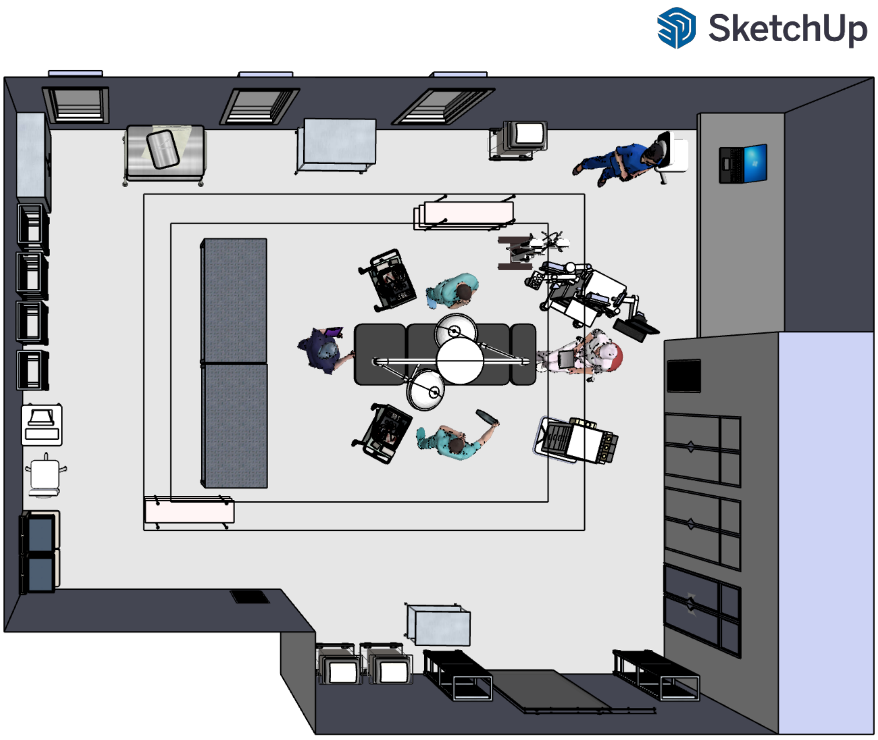


Figure 21: 3D model of the sterile tables positioned inside the LAF

In Figure 21, 22, 23 and 24, the grey and blue floor marking is illustrated. The smaller square is the blue floor marking which is aligned with the inner sides of the LAF canopy. The larger square is the grey floor marking, indicating the center of the LAF canopy. As the mentioned in 3.2 the blue floor marking is regarded as the boundary between inside and outside of the laminar airflow in this study.

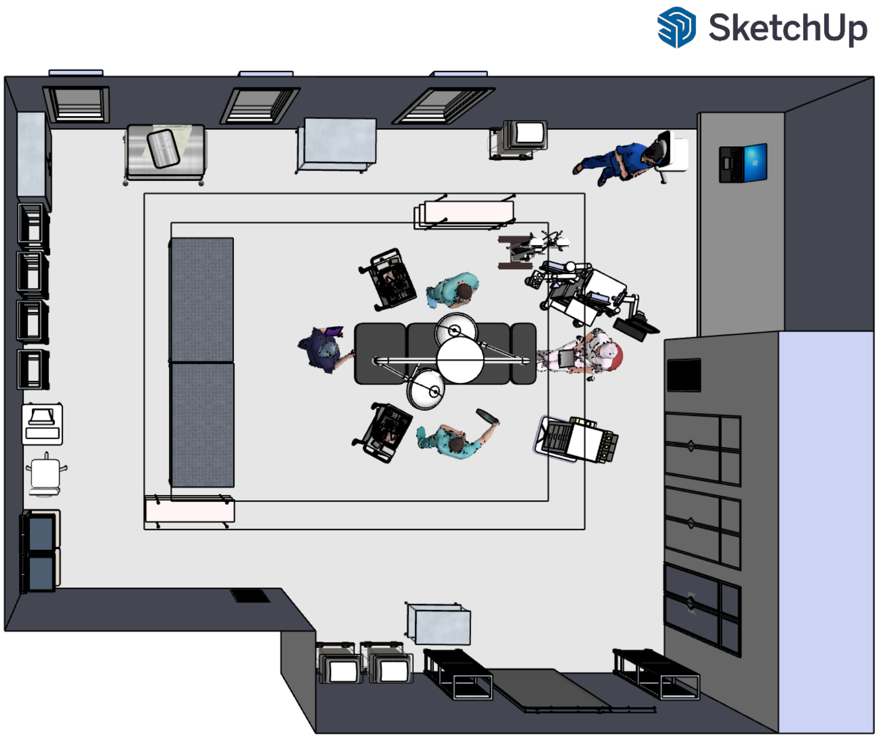


Figure 22: 3D model of the sterile tables placed inside the LAF with the back of the tables aligned with the boundary of the LAF

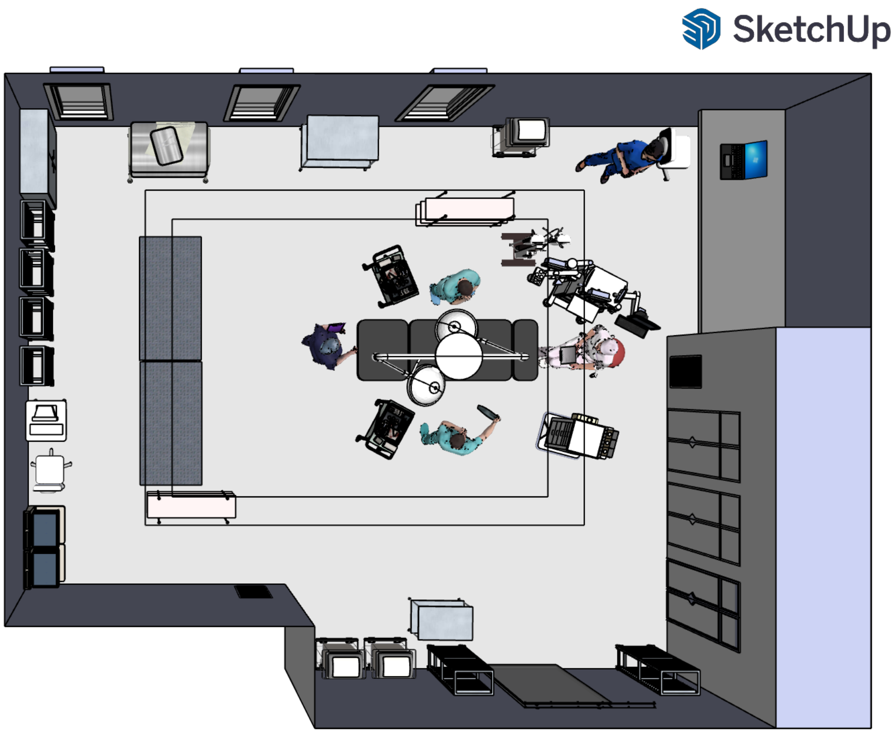


Figure 23: 3D model of the sterile tables positioned with the center of the table in boundary of the LAF

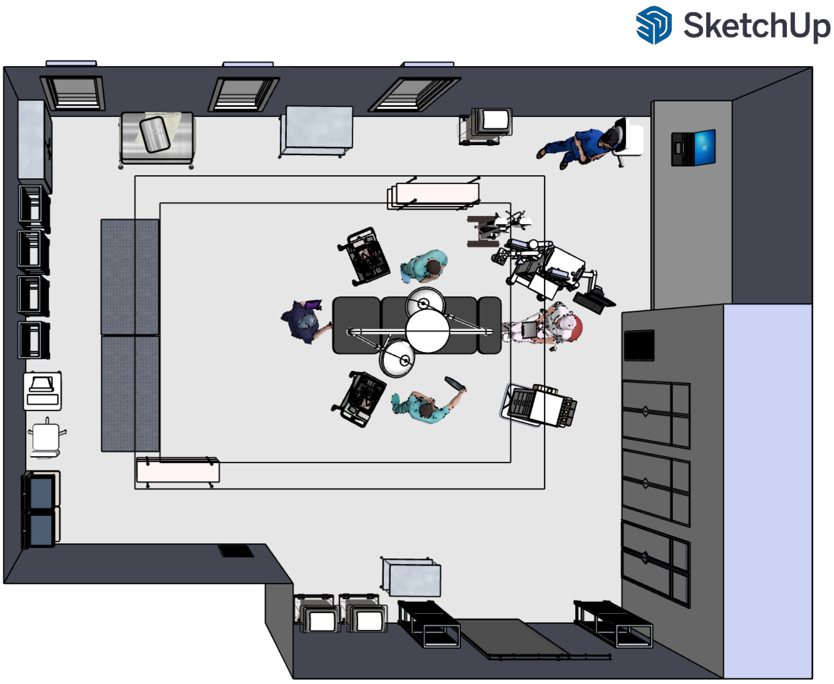


Figure 24: 3D model of the sterile tables positioned outside of the LAF with the front aligned with the boundary of the LAF

In order to get sufficient measurement for the different positions for the sterile tables, one mock surgery was planned for each of the positions shown in Figure 21, 22, 23 and 24. This meant that minimum of four mock surgeries were need to measure all positions. Each position needed to be measured minimum of two times in order to strengthen the results, creating the need for eight mock surgeries. In order to be able to account for differences in the measurement days, it was decided to measure at least one position inside, in the boundary and outside of the LAF each measurement day. This was done as a safety measure in case any unexpected factors would effect a measurement day. Based on this, four measurement days with two mock surgeries each were planned with the following position for the sterile tables:

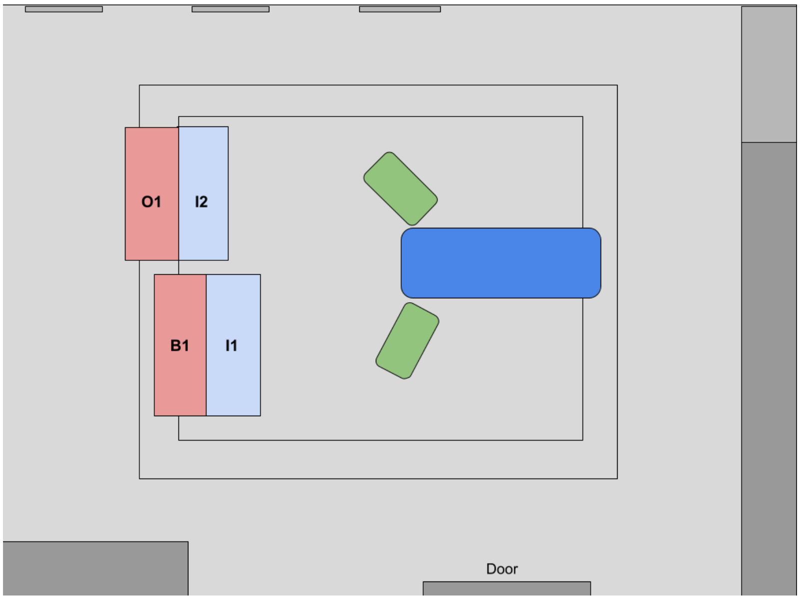


Figure 25: Sterile table positions for the first and third measurement day

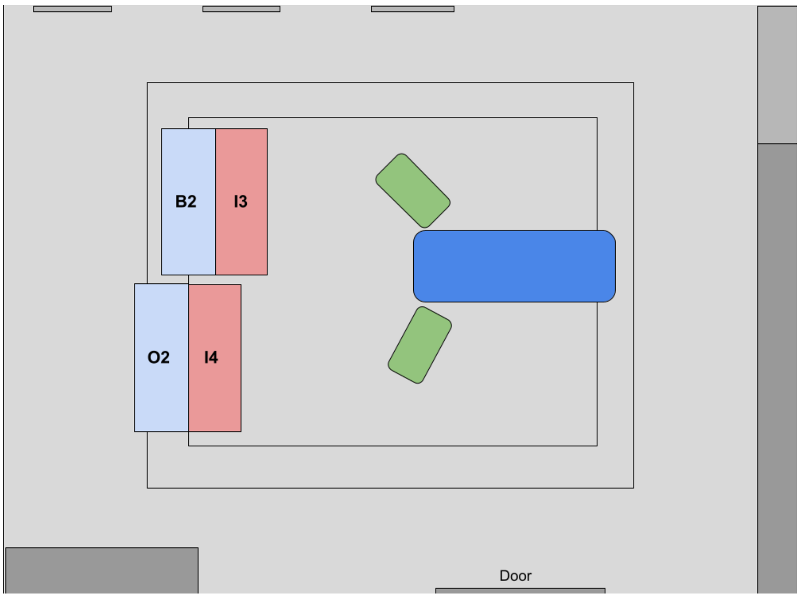


Figure 26: Sterile table positions for the second and fourth measurement day

Figure 25 and 26 show the positions planned for four measurement days, with Figure 25 planned for the first and third measurement day and Figure 26 for the second and forth measurement day. This meant that all positions shown in Figure 21, 22, 23 and 24 would be measured twice, while measuring one position inside, in the boundary and outside during each measurement day.

In Figure 25 and 26 the operating table is shown in dark blue color and the instrument tables in green color. The sterile tables are colored in light blue and light red with light blue being the positions planned for the first mock surgery of the measurement day, and light red being the position planned for the second mock surgery of the measurement day. The names of the positions indicate "I" for inside the laminar airflow, "B" for boundary and "O" for outside of the laminar airflow. As in previous figures, the smaller square is the blue floor marking which is aligned with the inner sides of the LAF canopy, and the larger square is the grey floor marking, indicating the center of the LAF canopy.

Figure 27: Picture of sterile position O1 and B1

Figure 27 shows position O1 and B1 being prepared before a mock up surgery. The difference between Position O1 and B1 is 325 mm, meaning half the length of the sterile tables short side.

3.4 Measurement equipment and sensors

Several parameters where measured on multiple points in the operating room in order to provide a sufficient description of the OR's indoor environment during the mock surgeries. The equipment used during the measurements is summarized in Table 2:

Table 2: Equipment used for measurements during mock surgery at St.Olavs Hospital

#	**Product name**	**Denomination**	**Parameters**	**Interval**
2	Air Ideal 3P	Active sampler	CFU/m^3	10 min
60	Blood agar	Passive sampler	CFU/m^2	90 min
6	AirThings View Plus	AirThings	Air temperature, humidity, barometric pressure, CO_2, VOC, light, sound level, PM2.5	5 min
7	Gemini TinyTag TGP-4500	TinyTag	Air temperature, humidity, dew point	10 s
4	TSI Aerotrak 9306-04	Aerotrak	Particles of size PM0.3, PM0.5, PM1.0, PM3.0, PM5.0 and PM10.0 μm	10 s
1	AirDystSys 5000	Anemometer	Air velocity, air temperature, draught rate, air turbulence	2 s

PM = Particulate Matter

In Table 2, the first column show the total number for each measurement equipment used during the mock surgeries. The number of passive samplers is the maximum number used per mock surgery. The column with denominations is the name used for the equipment in the following chapters of this thesis. The final column show the measurement interval used for each sensor. For the sensors AirThings and TinyTag it is the parameters air temperature and relative humidity which are of interest. These parameters are measured to ensure that all mock surgeries are performed under similar conditions for the indoor climate. For the Anemometer, the air velocity and air turbulence are the important parameters are they ensure that the laminar airflow provides similar airflow and washing effect during all mock surgeries.

A description of the products AirThings view Plus and AirDystSys 5000, as well as an overview of the accuracy of each product is listed in Appendix B. The following Sections 3.4.1, 3.4.2, 3.4.3 and 3.4.4 will discuss the passive samplers, active samplers the Aerotrak particle counter and the TinyTag sensor as these sensors are the most essential in order to understand the air pollution and indoor environment in the operating room.

3.4.1 Passive sampler

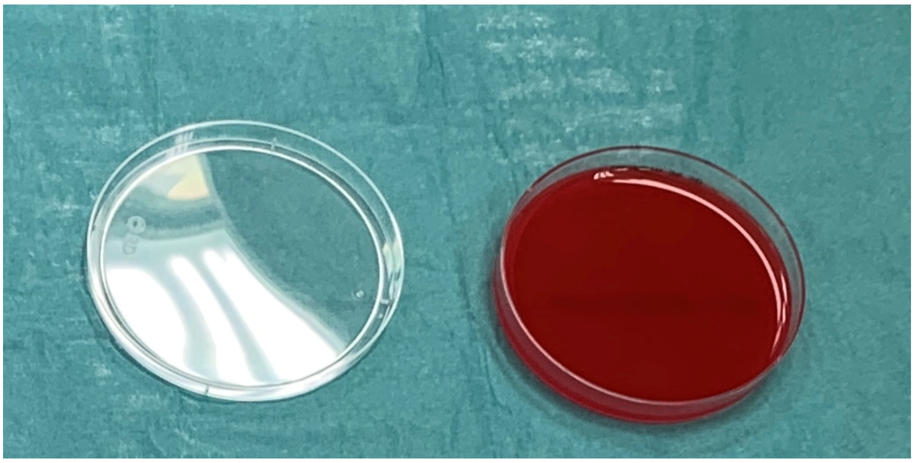


Figure 28: Blood agar plate used as a passive sampler

During all mock surgeries, blood agar plates were used as passive samplers. Blood agar is a rich food source and growth medium for bacteria. When bacteria come in contact with the blood agar, the bacteria will produce enzymes to break apart the blood cells in the blood agar. The amount of blood cells broken down by the enzymes can be used to distinguish the bacteria present on the blood agar plate (Encyclopedia.com, 2019). The blood agar used in the mock surgeries consisted of 5-7% bovine blood (Pedersen, 2019) and came in petri dishes measuring 90 mm in diameter.

The blood agar plates were provided by the department for medicinal microbiology at St. Olavs hospital. The blood agar was picked up every measurement day at 08:30 before the first mock surgery of the day. The blood agar plates were positioned around the operating room and the lid was removed shortly before each mock surgery started. Particles and bacteria present in the air in the operating room would then land on the blood agar plates exposed surfaces during the mock surgery. When each mock surgery was finished, the lid was placed back on the blood agar plate. The number of minutes the blood agar plates were open each mock surgery is shown in Table 3:

Table 3: Number of minutes the passive samplers were open during each mock surgery

	04.03.22	**11.03.22**	**18.03.22**	**25.03.22**
Mock surgery 1	96	88	83	84
Mock surgery 2	84	84	83	83

Each mock surgery was scheduled to last approximately 90 minutes with the passive samplers being open the same amount of time, but after repeating the mock surgery multiple times the timing decreased as performing the mock surgery went smoother.

After the blood agar had been used for the measurements, they were returned to the department for medical microbiology before 15:00 each measurement day. There the blood agar plates were then incubated for 48 hours in order to let the bacteria develop on the blood agar plate, before being analyzed by bio engineers at St. Olavs hospital. A bio engineer counted the bacteria colonies formed on the blood agar plate and used statistical analysis to find the probable number of colony forming units present on the blood agar plate. Statistical analysis is necessary in order to determine if a bacterial colony originated from one or more bacteria carrying particles present on the blood agar plate (Pedersen, 2019).

3.4.2 Active sampler

(a) Active sampler AirIdeal 3P from Biomerieux

(b) Filter for AirIdeal 3P

Figure 29: Pictures showing (a) Active sampler AirIdeal 3P from Biomerieux and (b) the filter placed on top of the active sampler

As the passive samplers measured the number of CFU/m^2 impacting on different surfaces, two active sampler were used in order to measure the air contamination (CFU/m^3) in the operating room. The two active air samplers used were the model AirIdeal 3P from Biomérieux seen in Figure 29a. The active sampler consist of three main components; the machine, a filter and blood agar plates. The blood agar plates are placed on top of the machine with the filter being placed over the blood agar plate. The active air sampler works by drawing in the surrounding air at a constant suctioning volume of 100L/min causing the particles in the air to collide with a blood agar plate at a velocity of less than 20 m/s. The air is drawn in using a turbine which pulls the air through a filter consisting of a perforated plate with 0.6 mm holes. The filter is shown in Figure 29b. The filter has a grid pattern and ensures spacing between the CFU which collides with the blood agar, making it easier to count the bacteria colonies and analyze the bacteria after incubation of the blood agar (Biomérieux Industry, 2012).

During the mock surgeries, one blood agar plate was used per measurement and the active sampler was set to run for 10 minutes per measurement. This means that 1000L of air impacted each blood agar plate used during one measurement with the active sampler. After each day of measurements, the blood agar plates used in the active sampler where delivered to the department for medicinal microbiology at St.Olavs hospital where they were analyzed together with the passive samplers.

In the user manual for the AirIdeal 3P, tables for statistical analysis for CFU are provided. It is here stated that the statistical calculations of number of CFU present on the blood agar are based on the formula for Feller's law (Biomérieux Industry, 2012).

3.4.3 Aerotrak particle counter

Figure 30: Picture of a TSI Aerotrak 9301

In order to investigate the particle distribution in the air during the mock surgeries, four handheld Aerotrak particle counters were used to measure particles of size PM0.3, PM0.5, PM1.0, PM3.0, PM5.0 and PM10 μm. The Aerotrak has a flow rate of 2.85 L/min and draws in the surrounding air through the metal tube seen in the top of Figure 30.

As described in Section 2.1.1 bacteria carrying particles are commonly $\geq$ PM5.0 μm, meaning that it is only particles of size PM5.0 and PM10.0 μm which is relevant for this study. During the mock surgeries the Aerotrak had a 10 second sampling period, providing an accurate description of the particle concentration in the air at all times.

From the user manual, it is stated that the Aerotrak has counting efficiency 50% for particles of size PM0.3 μm and 100% for particles of size >PM0.45 μm (TSI Incorporated, 2022).

3.4.4 Gemini TinyTag TGP-4500

Figure 31: Picture of Gemini TinyTag monitor

Seven Gemini TinyTag TGP-4500 were used during the mock surgeries. The TinyTag sensors measures temperature and humidity, but also calculates dew point. Compared to the AirThings sensor the TinyTag sensor measures less parameters, but has more frequent sensor interval providing more accurate measurements for temperature and relative humidity. Sensor insterval used during the mock surgeries was 10 seconds.

Table 4: Sensor specification for Gemini TinyTag TGP-4500 (Gemini Data Loggers, 2018)

Parameter	**Sensor interval**	**Sensor accuracy**	**Measurement range**
Temperature	1 second to 10 days	NA*	-25.0 to + 85 $°C$
Relative humidity	1 second to 10 days	±3% at 25$°C$	NA*

**NA = Not Available*

3.4.5 Equipment placement during mock surgery

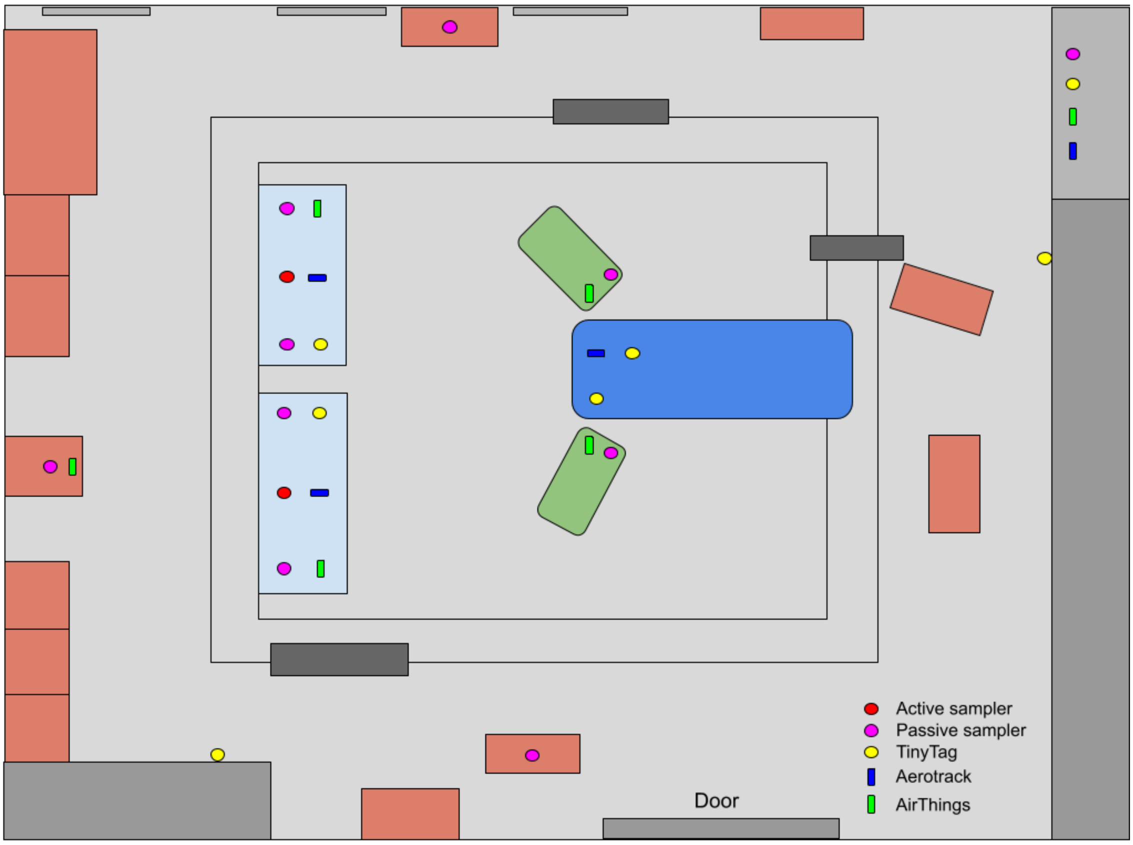


Figure 32: Equipment positioning during mock surgery

Figure 32 shows the placement of the equipment and sensors during the mock up surgeries. The placements can be divided into three groups; the sterile tables, the operating area and the computer table. The main area of focus is the sterile tables which include the two large metal tables shown in a light blue color in Figure 32. The operating area refers to the operating table (blue color) and the instrument tables (green color) placed in the center of the laminar airflow. The computer table is the area outside the laminar airflow in the top right corner of Figure 32. Present at all three position is at least one Aerotrak sensor, a TinyTag sensor, a AirThings sensor and a passive sampler. With all these sensors in these three position it was possible to compare the indoor environment inside, in the boundary area and outside of the laminar airflow.

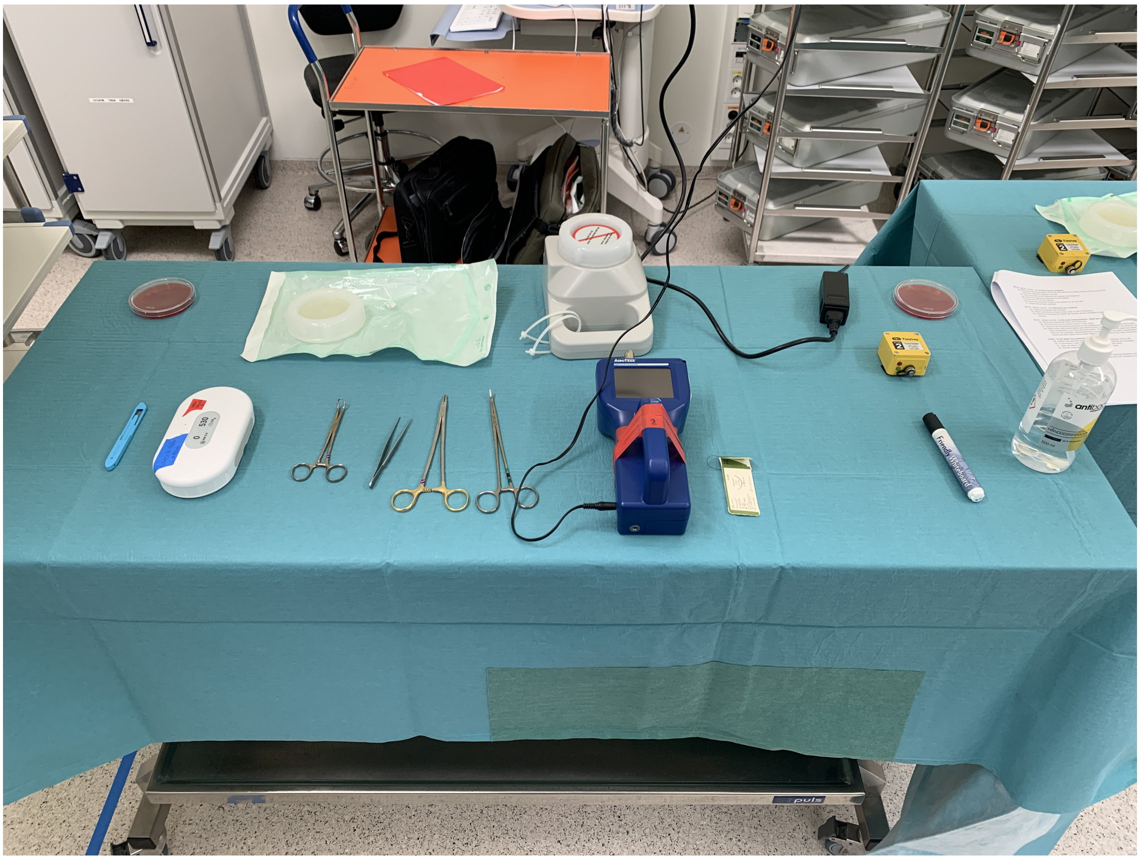


Figure 33: Overview of equipment placed on sterile tables

In Figure 33, the majority of the equipment is displayed on a sterile surgical table. In the top corners, the passive samplers are placed with the white active sampler in the middle of the table. In the top right corner a yellow TinyTag sensor is visible. In the lower left corner a white AirThings sensor is placed with the blue Aerotrak particle counter visible in the middle of the table.

On the sterile table, the active samplers are positioned at the center of the sterile tables where sterile equipment are likely to be placed during real surgery. The Aerotrak particle counter is facing the active sampler in order to measure particles in the same area as the active sampler. Two passive sampler are placed on each side of the active sampler in order to catch CFU on the outer edges of the sterile tables. As the AirThings sensors measure multiple parameters, it is placed on the outer edge of the sterile tables as this is an area assumed to be more exposed to the boundary conditions of the laminar airflow.

Figure 34: Overview of equipment placed on instrument tables

Figure 34 show the placement of equipment in the operating area. A passive sampler is placed on each instrument table close to the surgical area. The passive samplers are placed in this corner as it is closest to the surgeons and is therefore assumed to be the area most exposed to CFU due to the surgeons activity. The Aerotrak is positioned as close to surgical area as possible in order to measure particles in the area where the surgical wound would be present during real surgery. Two TinyTags are placed on the operating table close to the surgical area. One is placed inside the surgical lights and one is placed outside of the surgical light. This is due to the surgical light likely increasing the temperature registered by the TinyTag. By placing one TinyTag outside the of light, the heat contribution from the surgical lights can be easier be understood when comparing the results. The reason why the TinyTags sensors are placed closest to the surgical area is due to the TinyTags having a 10 second measurement interval, compared to the AirThings 5 minute measurement interval. This means that the results from the TinyTag can be compared to the results from the Aerotrak, which also has a 10 second measurement interval.

3.5 The mock surgeries

In order to test all the positions for the sterile tables discussed in 3.3, eight mock surgeries where performed on the dates 04.03.22, 11.03.22, 18.03.22 and 25.03.22. All days were Fridays as this was the only day of the week where the hospital had no planned surgeries for operating room 8, meaning that the OR was available to be used for research. The hours available was limited by the work hours of the staff responsible for the active sampler and analysis of the blood agar at St. Olavs hospital. As mentioned in Section 3.4.1 and 3.4.2, the active sampler and blood agar were picked up at 08:30 and returned before 15:00 each measurement day. This created a window of approximately 5 hours where the active and passive samplers could be used, accounting for transportation and a preparation period. Based on this, the daily schedule was prepared as seen in Figure 35.

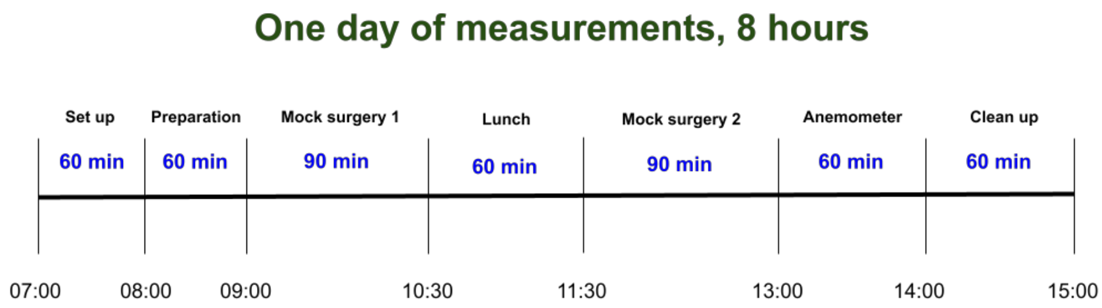


Figure 35: Plan for one day of measurements

To create consistency in the mock surgeries, all Fridays where planned to be as similar as possible. Each Friday consisted of 2 mock surgeries lasting approximately 90 minutes each with a 60 minute break between the two mock surgeries. Each measurement day started with a set up period were two participants would set up all measurement devices and prepare the operating room for the mock surgeries. The preparation time before the first surgery and the lunch break before the second surgery involved all participants leaving the OR during these time periods. The breaks was scheduled in order to let the OR "rest" before each surgery in order for the indoor climate to be as similar as possible for both surgeries. It was also in order to let the participants rest and recuperate between each surgery. The preparation period before the first surgery was used to go through the plan for the day and discuss previous measurements. After both surgeries were finished, 60 minutes was scheduled used the anemometer i.e. the AirDistSys 5000, which measure air velocity and air turbulence. Lastly, 60 minutes were dedicated to cleaning the operating room before personnel from St. Olavs hospital properly sterilized the operating room.

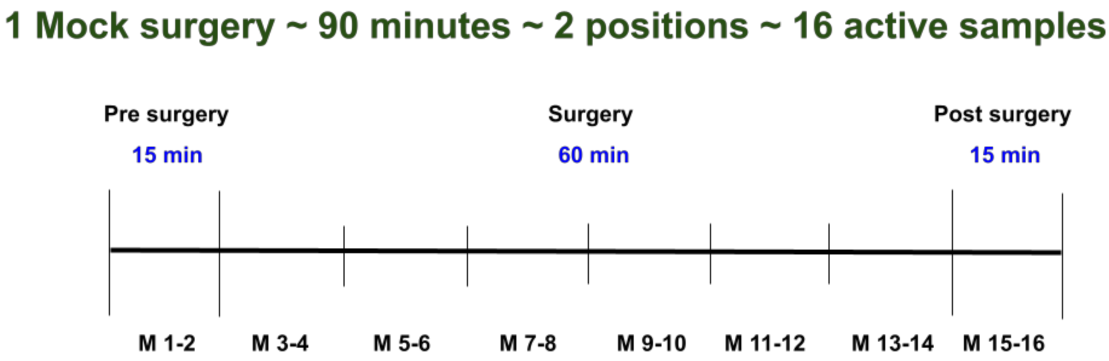


Figure 36: Plan for one mock surgery

Figure 36 show the schedule for one mock surgery lasting 90 minutes. Each mock surgery were divided into a 15 minute pre surgery period, a 60 minute surgery period and a 15 minute post surgery period. The total length of the mock surgery left room for 8 active samples of 10 minutes each per active sampler, as well as time to change the blood agar and restart the active samplers. As two active samplers were used during each mock surgery, a total of 16 active samples were taken per mock surgery. These are shown as M1 - M16 in the bottom of Figure 36. The activities performed in the pre surgery, surgery and post surgery periods will be discussed in Section 3.5.4.

3.5.1 Preparation for the mock surgeries

In an effort to preform the mock surgeries as similarly as possible to a real surgery performed in a laminar airflow OR environment, two recordings of real surgeries were reviewed. The recorded surgeries showed two primary total knee arthroplasties performed in operating room 8 at St. Olavs hospital, the same operating room used for the mock surgeries. The recorded surgeries gave a great insight in the different surgical staff present during surgery, their specific tasks and their activity level. The following sections describe the observed roles, activities, surgical equipment and clothing and how they were implemented in the mock surgeries.

As the recorded surgeries gave great insight in the surgical procedures, it was decided that all the mock surgeries would be recorded using a GoPro camera. This enabled the possibility to ensure that the mock surgeries were completed similarly and later made it easier to analyse the results from the mock surgeries.

3.5.2 Surgical staff observed during the recorded surgeries and roles imitated during the mock surgeries

Table 5 show the roles observed and the number of each role present during the recorded surgeries, as well as the number of the roles imitated during the mock surgery. Following the table is a short and general description of each role based on observations form the recorded surgeries.

Table 5: Roles present during the recorded surgeries and during the mock surgeries

Role	Recording 1	Recording 2	Mock surgery
Main surgeon	1	1	1
Assistant surgeon	1	1	1
Sterile nurse	2	1	1
Distribution nurse	1	1	1
Anesthesia nurse	2	2	1
Patient	1	1	1
Notary	1	1	0
Observer	1	1	0
Total	10	9	6

Main surgeon

The main surgeon performed all the main surgical activities and medical treatment during the procedure. This included any cutting, hammering, sewing or other activities in and around the surgical wound. The main surgeon was standing during the entire procedure and had a high activity level. During the surgery, the main surgeons was positioned inside the laminar airflow during the surgical procedure.

Assistant surgeon

The assistant surgeon aided the main surgeon during the surgical procedure. The assistant surgeon helped the main surgeon by re-position the patient, holding the surgical wound open, suctioning blood for the surgical wound, adjusting the surgical lamp and more. The assistant surgeon was standing during the entire surgery and had a medium activity level. The assistant surgeon was position inside the laminar airflow during the surgical procedures.

Sterile nurse

The sterile nurse had multiple task inside the laminar airflow during the surgical procedures. Before the each procedure, the sterile nurse would prepare the patient by covering the patient in sterile covers and cleaning the surgical area on the patient. While the surgeon performed the procedure, the sterile nurse would clean and prepare equipment for the surgeons to use. The sterile nurse would hand and receive equipment to and from the surgeons during the procedure. The sterile nurse also received any removed tissue or substance from the patient and helped clean the surgical area of blood and used bandages. The sterile nurse received equipment from the distribution nurse and would throw away any contaminated material or trash during the procedure. The sterile nurse had a high activity level and was located inside the laminar airflow during the surgical procedure.

Distribution nurse

The distribution nurse was responsible for most tasks outside of the laminar airflow. The distribution nurse delivered any equipment stored outside the of laminar airflow to the sterile nurse by opening the covering and dropping the equipment on the sterile tables without touching the equipment itself. This is to ensure that the equipment remains sterile after the covering is removed. The distribution nurse would also collect any equipment or information needed from outside of the operating room. The distribution nurse had a medium activity level was positioned outside of the laminar airflow during the surgical procedure.

Anesthesia nurse

The anesthesia nurse monitored the patients vital signs and administrated anesthesia. During the recorded surgeries, the anesthesia nurse was located by the patients head, just outside of the laminar airflow during the surgical procedure. The anesthesia nurse was mostly sitting and had a low activity level.

Patient

The patient was the person receiving health care. The patient was located on the operating table with the body inside the laminar airflow, and the head in the boundary area of the laminar airflow. The patient was laying unconscious on the operating table during the full length of both recordings.

Notary

The notary was responsible for taking notes during the surgical procedure and did not have any task related to the surgery itself. The notary logged all events during the procedure, as well as any other useful information. The notary was seated outside of the laminar airflow, with a low activity level, during the entire surgical procedure.

Observer

The observer was seated close to the notary and observed the surgery. The observer is commonly a trainee or someone who attends the surgery for learning purposes, and therefore does not contribute to the surgery in any capacity. The observer was seated outside of the laminar airflow, with low activity, during the entire surgical procedure.

Roles during the mock surgeries

As seen in table 5, some roles were excluded from the mock surgeries. These roles where excluded due to limitations in the number of volunteers available caused by the ongoing COVID-19 pandemic during the performed mock surgeries. The participants were therefore limited to the most critical roles present during the recorded surgeries. The roles of notary and observer were excluded due to these roles being the least necessary or critical roles needed in order to perform a surgery. The roles were also considered according to their effect on the indoor environment and air contamination in the operating room. The roles of notary, observer and anesthesia nurse were likely to have a minimal effect on the level of air contamination close to the sterile tables as these roles were seated outside of the laminar airflow during the surgeries. These roles also had a very low activity level during both of the observed surgeries. The mock surgeries therefore had the absolute minimum number of participants presumed necessary to complete a primary total knee arthroplasty, but a lower number of participants present than during a real primary total knee arthroplasty performed at St. Olavs hospital.

3.5.3 Surgical equipment

During the recorded knee arthroplasties, the surgeons used multiple tools and instruments to perform the surgeries. The surgical tools used are summarized in the following table:

Table 6: Surgical tools used by the surgeons during the recorded surgeries

Surgical equipment	Main surgeon	Assistant surgeon
Surgical saw	x	
Surgical drill	x	
Hammer and chisel	x	
Diathermy instrument	x	
Large syringe	x	
Scalpel	x	
Needle and thread	x	
Peang	x	x
Retractor		x
Suctioning tool		x

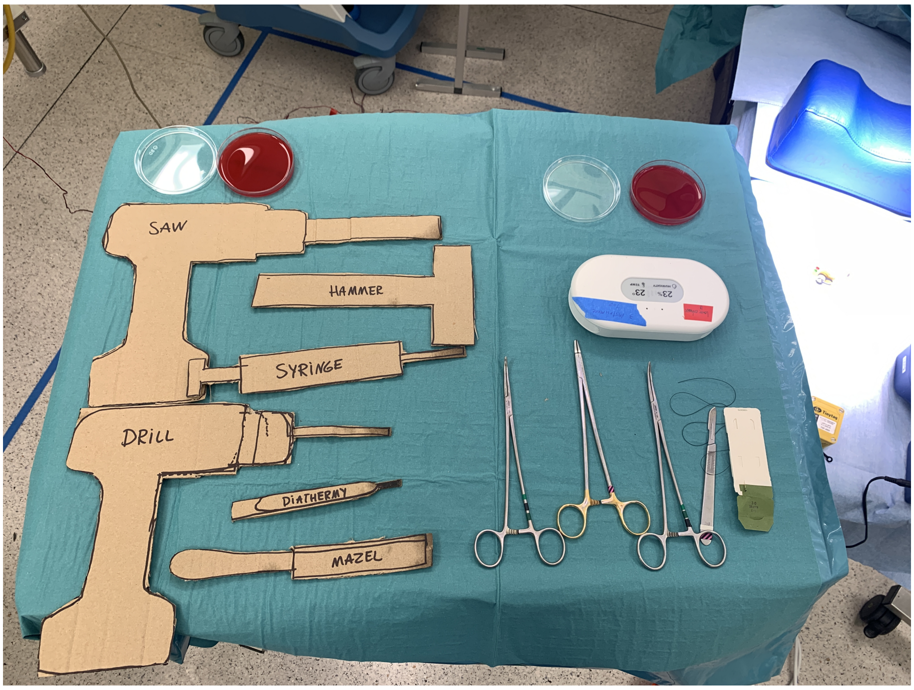
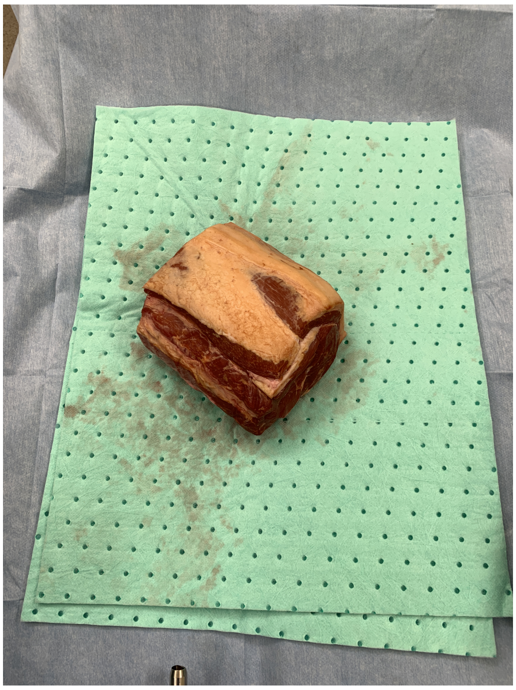


Figure 37: The main surgeons instrument table with cardboard cutouts of surgical instruments used during the mock surgeries

As most surgical equipment at St. Olavs hospital were reserved for real surgeries, the surgical tools used in the recorded surgeries were created from cardboard. Some surgical instruments such as scalpels and peangs were borrowed from personnel from "The Operating Room of the Future".



(a) Pork loin simulating a knee during the mock surgeries

(b) Surgeons operating on the pork loin

Figure 38: Pictures showing (a) pork loin and (b) the surgeons operating on a pork loin

To simulate realistic surgical activity and hand movements, the surgeons operated on a pork loin during the mock surgeries. The pork loins were intended to imitate a knee, which was operated on during the real recorded surgeries. A new pork loin was provided for each mock surgery and the weight of the pork loins ranged from 1.77 kg to 2.31 kg.

The activities that these surgical instrument were used for is described in Section 3.5.4. The use of the pork loin and the paper cutout of the surgical equipment insured that the activity and movements of the surgeons were as realistic as possible.

3.5.4 Activity and talking

While watching the recordings of the real knee arthroplasties, the main activities from the surgical staff were noted. Based on the recorded activities, Table 7 was created in order to summarize the surgical staff most repeated and distinct activity during the surgeries. The nine main activities performed by the main surgeon are included in the table, as well as the activities that the other surgical staff was performing during each of the main surgeons activities.

Table 7: Observed activities during recorded surgeries

#	**Main surgeon**	**Assistant surgeon**	**Sterile nurse**	**Distribution nurse**
1	Receiving instruments and material from the sterile nurse. Returns used instruments and material to sterile nurse.	Picking up instruments and equipment used to assist the main surgeon from the instrument table.	Delivering instruments to the main surgeon. Throws used material in the trash.	Gathering equipment and material from cabinets.
2	Surgical activity inside the wound. Using a scalpel for cutting and a peang for removing tissue.	Using a suctioning device to remove blood. Using a retractor to hold the wound open.	Receiving pieces of tissue using a tray and disposing of the tissue. Wipes of blood in the wound area.	Unpacking supplies at the sterile table.
3	Using a diathermy tool.	Using a suctioning device to remove blood. Using a retractor to hold the wound open.	Deliver and receive supplies to and from the distribution nurse.	Deliver and receive supplies to and from sterile nurse.
4	Using a surgical drill.	Using a retractor to hold the wound open and the knee in the correct position.	Cleaning instruments.	Resting position.
5	Using surgical hammer and chisel.	Using a retractor to hold the wound open and the knee in the correct position.	Moves equipment to and from the sterile table to and from the instrument tables. Cleaning and organizing equipment on the sterile table.	Gathering equipment and material from cabinets.
6	Using surgical saw.	Using a retractor to hold the wound open and the knee in the correct position.	Cleaning instruments.	Unpacking supplies at the sterile table.
7	Using a long peang to pull out larger pieces of tissue.	Using a suctioning device to remove blood. Using a retractor to hold the wound open.	Receiving pieces of tissue using a tray and disposing of the tissue. Wipes of blood in the wound area.	Resting position.
8	Using a large syringe.	Using a retractor to hold the wound open and the knee in the correct position.	Deliver and receive supplies to and from the distribution nurse.	Deliver and receive supplies to and from sterile nurse.
9	Sewing the wound shut.	Resting position.	Moving equipment from the instrument table to the sterile table. Cleaning and organizing equipment on the sterile table.	Resting position.

The observed activities in Table 7 was then translated into nine activities which could be repeated during the mock surgeries. These activities are shown in Table 8.

Table 8: Activities performed during the mock surgeries

#	Main surgeon	Assistant surgeon	Sterile nurse	Distribution nurse
1	Body rotations between the patient's knee and sterile nurse. Receive instruments from the nurse and place them close to the operating area. Pick up the instruments and return them to the sterile nurse.	Body rotations between the patient's knee and instrument table. Pick up instruments and place them close to the operating area. Pick the instruments back up and place them back on the instrument table.	Body rotations between the instrument table and the main surgeon. Pick up equipment from the instrument table and hand it to the main surgeon. Receive instruments from the main surgeon and place them on the instrument table.	Walking back and forth. Walk from base position, around the laminar area to a cabinet. Stand therefore for 10 seconds and then return to the base position.
2	Small and precise hand movements close to the wound. Receive scalpel and peang from the sterile nurse. Make an incision in the pork loin. Cut out pieces of the pork loin from the inside of the incision. Use the peang to pick out pieces and place them in the tray.	Hand movements close to the wound. Pretend to use the suction tool close to the wound while the main surgeon makes the incision. Move the suctioning tool back and forth over the wound. When the incision is finished, pick up an instrument from the instrument table and use it to hold the wound open while the main surgeon removes tissue. At the same time, pretend to use the suction tool close to the wound by moving it back and forth over the wound every time the main surgeon removes tissue.	Hand movements towards and away from the main surgeon. Hand movements towards and away from the wound. Hold up the tray when the main surgeon removes tissue. Wipe of the pork loin close to the incision after pieces are removed from the pork loin.	Hand movements over the sterile table. Walk from base position to sterile table. Pretend to open up multiple pieces of equipment and dropping them on the sterile table.
3	Small and precise hand movements close to the wound. Body rotations. Pretend to use the diathermy tool inside the wound. Changes position often by rotating the body to access the wound from a different angle.	Hand movements close to the wound. Pretend to use the suction tool close to the wound by moving it back and forth over the wound. Pick up an instrument from the instrument table and use it to hold the wound open while the main surgeon removes tissue.	Hand movements over the sterile table, towards and away from the distribution nurse. Move to the sterile table. Pretend to receive equipment from the distribution nurse and place them on the sterile table.	Hand movements over the sterile table, towards and away from the sterile nurse. Move to the sterile table. Pretend to receive equipment from the sterile nurse and place them on the sterile table.

4	Firm hand movements towards and away from the wound. Body rotations. Using both hands, pretend to drill holes in the open wound 3 times. Changes position after 3 times by rotating the body to access the wound from a different angle.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Hand movements over the instrument tables. Pick up equipment from the instrument tables and wipe them down.	Resting position. Stand still at the base position.
5	Firm hand movements towards and away from the wound. Body rotations. Pretend to use a hammer and chizel on the wound. Hold the chizel close to the wound and pretend to strike the chizel 3 times with the hammer. Changes position after 3 times by rotating the body to access the wound from a different angle.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Walking back and forth. Hand movement over tables. Pick up instruments from the instrument table and walk to the sterile table. Put the instruments down. Wait 5 seconds and pick them back up and walk back to the instrument table.	Walking back and forth. Walk from base position, around the laminar area to a cabinet. Stand therefore for 10 seconds and then return to the base position.
6	Firm hand movements towards and away from the wound. Body rotations. Pretend to use a surgical saw inside the wound. Move both hands back and forth towards the wound 3 times. Changes position after 3 times by rotating the body to access the wound from a different angle.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Hand movements over the instrument tables. Pick up equipment from the instrument tables and pretend to wipe them down.	Hand movements over the sterile table. Walk from base position to sterile table. Pretend to open up multiple pieces of equipment and drop it on the table.

7	Aggressive hand movements towards and away from the wound. Using a large peang, pretend to grab 3 pieces inside the wound and pull them out by force and place them in the tray. Changes position after 3 times by rotating the body to access the wound from a different angle.	Hand movements close to the wound. Pretend to use the suction tool close to the wound by moving it back and forth over the wound. Pick up an instrument from the instrument table and use it to hold the wound open while the main surgeon removes tissue.	Hand movements towards and away from the main surgeon. Hand movements towards and away from the wound. Hold up the tray when the main surgeon removes tissue. Wipe of the pork loin close to the incision.	Resting position. Stand still at the base position.
8	Firm hand movements towards and away from the wound. Body rotations. Pretend to use a large syringe and add substance into the wound 3 times. Do this by placing the syringe close to the wound and pretending to push the substance out of the syringe. Changes position after 3 times by rotating the body to access the wound from a different angle.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Hand movements over the sterile table, towards and away from the distribution nurse. Move to the sterile table. Pretend to receive equipment from the distribution nurse and place them on the sterile table.	Hand movements over the sterile table, towards and away from the sterile nurse. Move to the sterile table. Pretend to receive equipment from the sterile nurse and place them on the sterile table.
9	Small and precise hand movements close to the wound. Body rotations. Using needle and thread to sew close the incision in the pork loin.	Resting position. Stand still in the base position.	Walking back and forth. Hand movement over tables. Pick up instruments from the instrument table and walk to the sterile table. Put the instruments down. Wait 5 seconds and pick them back up and walk back to the instrument table.	Resting position. Stand still at the base position.

By using and repeating the described activities in Table 8, the mock surgeries could be repeated with similar amount of activity for the surgical staff at every measurement.

In order for each activity to be performed the same amount of time during every mock surgery, a PowerPoint was created displaying the activities for both surgeons, the sterile nurse and the distribution nurse. The anesthesia nurse and patient only had one activity and was therefore excluded from the PowerPoint. The PowerPoint had 18 slides, with each slide lasting 2 minutes and 40 seconds. This meant that the PowerPoint lasted a total of 48 minutes and that all 9 activities described in Table 8 were repeated twice during each mock surgery. For each slide, the participants would continuously repeat the activities described in the PowerPoint. The reason why each activity was performed two times each mock surgery was so that the activities which affected the sterile tables could be performed once on both sterile table positions. The PowerPoint lasted 48 minutes as the mock surgeries were scheduled to last 60 minutes, leaving room the surgeons to put on surgical clothing and prepare for the surgery before the PowerPoint was started.

When reviewing the recorded knee surgeries, the amount of talking from the surgical staff was also noted. As talking increases the amount of particles released to the air (Eiche and Kuster, 2020)(Wen et al., 2011)(Mitchell and Hunt, 1991), an effort was made to limit and standardize the amount of talking during the mock surgeries. The scheduled talking during the mock surgeries involved all participants repeating the English alphabet every time the slide changed on the PowerPoint. A sound was added to the PowerPoint to indicate the start of each talking period and a new activity. This means that every 2 minutes and 40 seconds, all participants talked for 15 - 20 seconds at a normal volume. This resulted in a much lower amount of talking than what was observed during the real surgeries, but ensured the same amount of talking during all mock surgeries. The patient also participated in the scheduled talking during the mock surgeries. During real surgery the patient would be unconscious due to the anesthesia, but in order to accumulate for the lower talking level during the mock surgeries, the patient also repeated the alphabet together with the other participants.

3.5.5 Positions and entry times for participants during the mock surgeries

From the recorded surgeries the position of all surgical staff was noted, as well as the time they entered the operating room.

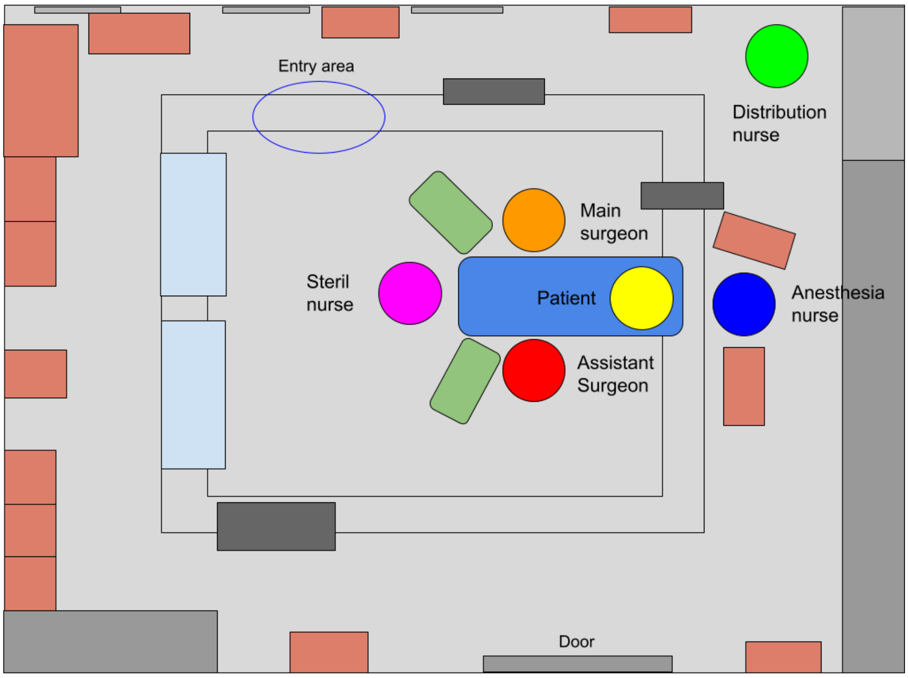


Figure 39: Positioning of participants during the mock surgeries

Figure 39 show the base positions for all participants present during the mock surgeries. This is position were the participants performed the majority of their activities during the mock surgeries, and were the participants would return when they were not performing any activities. In the top left corner, the blue, open circle indicate the entry area for all participants entering the laminar airflow. When the sterile nurse and surgeons entered the OR, they would walk from the door around the outer, left side of the LAF canopy before entering the laminar airflow. This is also were the sterile nurse and surgeons put on sterile clothing, which will be further discussed in Section 3.5.6. The positioning and entering of the laminar airflow was observed in the recorded surgeries and was therefore repeated in the mock surgeries.

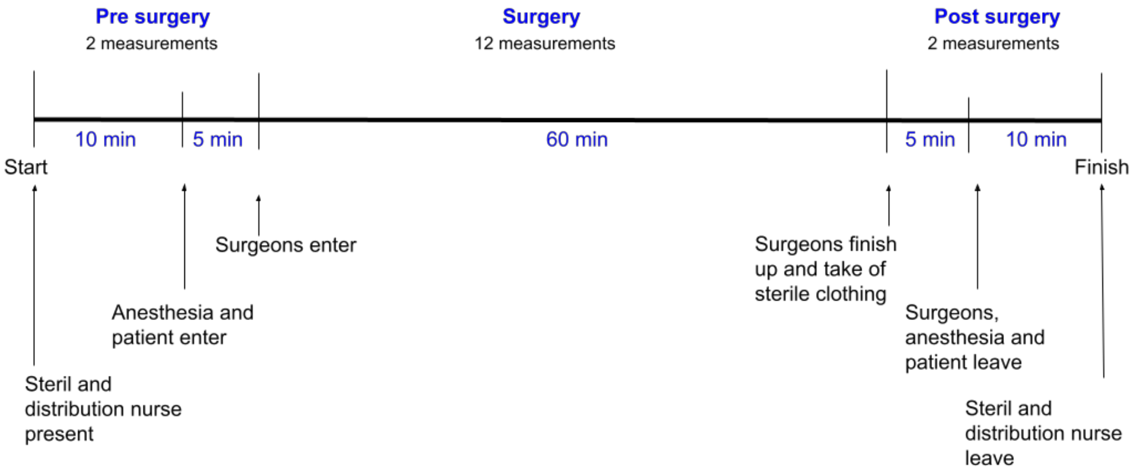


Figure 40: Schedule for entry for each role during one mock surgery

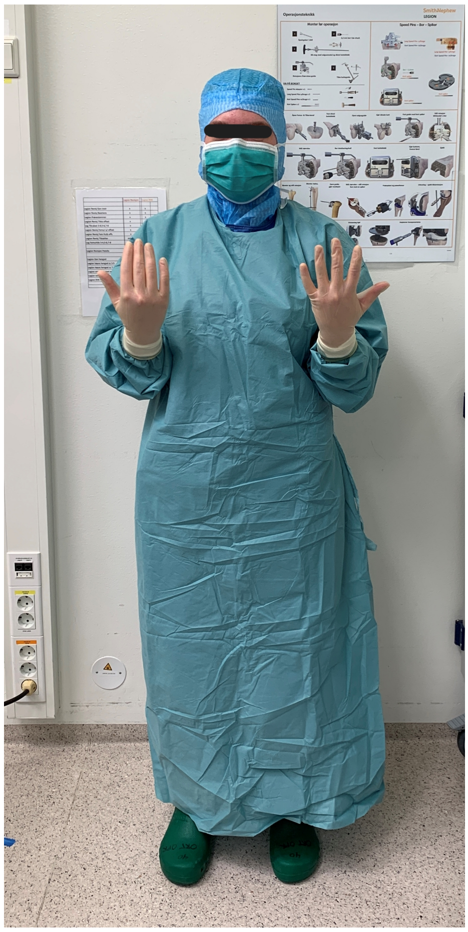
During the mock surgeries, the participants entered the OR in a similar fashion as observed during the recorded surgeries. Figure 40 shows the schedule for one mock surgery, with the time between when each surgical staff entering the operating room. During the recorded surgeries. the timing between the different roles entering was longer, but the timing has here been adjusted according to the 90 minutes available during each mock surgery.

Ten minutes before the start of the first measurement for every mock surgery, the distribution nurse and the sterile nurse would enter the OR. The sterile nurse would then prepare the equipment inside the LAF and the distribution nurse prepared all equipment outside the LAF. This included marking all blood agar plates and turning on all samplers except the active samplers. When all equipment were prepared both inside and outside the laminar airflow, the first measurement would start by opening all the passive samplers and starting the first measurement with the active samplers. This meant that when the first measurement started it was only the sterile nurse and distribution nurse present in the OR. The sterile nurse and distribution nurse would then perform activities simulating the OR being prepared for surgery. During this time the sterile nurse would put on sterile clothing, followed by walk back and forth between the instrument tables and the sterile tables. The sterile nurse would after ten minutes the anesthesia and patient would enter. The anesthesia nurse and sterile nurse would then prepare the patient for surgery and simulate giving the patient anesthesia before the surgeons would enter. After simulating surgery, the surgeons would leave the laminar airflow and take of the sterile clothing by the door. During the same period, the sterile nurse and anesthesia nurse would remove the covering from the patient. The surgeons, the patient and the anesthesia nurse would then leave the OR. The sterile nurse and distribution nurse would then stay in the OR and simulate cleaning up after the surgery. By repeating this entry pattern each mock surgery, the number of door openings period were limited three per mock surgery.

3.5.6 Surgical clothing

Surgical clothing used during the mock surgeries was chosen based on the recorded surgeries and the normal procedure at St. Olav hospital. Surgical clothing was provided by St. Olav hospital and consisted of two different clothing options:

(a) Scrubs used as base layer for all participants



(b) Sterile clothing used by surgeons and sterile nurse

Figure 41: Pictures showing (a) scrubs used by all participants and (b) sterile clothing used by participant inside the laminar airflow during the mock surgeries

Figure 41a shows the surgical scrubs used by all participants during all measurements. This included disposable shirt and pants, hair cap, surgical mask and footwear. All participant had to change into this outfit before entering the operating rooms or corridors connected to the operating rooms. The disposable top and bottom, as well hair cap was used during the entirety off the measurements day and disposed off after each measurement day. Surgical masks were commonly changed every mock surgery. The footwear belonged to St. Olavs hospital and were only allowed to be used inside the hospital. The distribution nurse, the anesthesia nurse and the patient wore the surgical outfit from Figure 41a during all of the mock surgeries. An error with the surgical clothing occurred during the first measurement where the distribution nurse did not wear sterile gloves during the first mock surgery. As the distribution nurse performed hand movement over the sterile tables were sterile instruments are located, the distribution should have worn sterile gloves. As this error was noticed before the second measurement day, the error was repeated during all mock surgeries in order for the error to have the same affect on the results for all measurement days.

Figure 41b shows the surgical clothing worn by all participants inside the laminar airflow during the mock surgeries. This included the two surgeons and the sterile nurse. This surgical outfit included a surgical cap covering the head and neck, a surgical gown and disposable gloves. Underneath the sterile clothing in Figure 41b, the participant wore the surgical scrubs shown in Figure 41a.

During the mock surgeries, the surgeons and the sterile nurse would enter the operating room with surgical scrubs seen in 41a, including the head wear from Figure 41b. The sterile nurse would put on the surgical gown and gloves on himself when entering the LAF and later help the surgeons put on their surgical gown and gloves when they entered LAF. This was done in order to keep the surgeons as sterile as possible before the surgery would start, similarly to what was observed during the recorded surgeries. The surgical gown and gloves came in individual wrapping and were presumed sterile before the surgeons got dressed. In order to keep the clothing as sterile as possible the sterile personnel kept their hands in the position shown in Figure 41b.

Figure 42: Photo of covering sheet separating the surgeons from the patient and anesthesia nurse

The patient was covered by sterile sheets in similar fashion as in the recorded surgeries. The patient body was covered by a sterile sheet while another sterile sheet was hung up between the surgeons and the anesthesiologist. The intention behind the sheet separating the surgeons and the anesthesiologist is presumed to be to hinder the patient from seeing the surgical wound if the patient were to wake up during the surgery, to shield the patient from any fluids and to shield the patient from the laminar airflow to avoid hypothermia.

4 Results

The following Section 4.1, 4.3 and 4.3 presents the CFU results from the active and passive samplers, as well as the particle results from the Aerotrak particle counter positioned at the sterile tables. The CFU results and particles are then compared in Section 4.4. Lastly, the relative humidity results from the TinyTags positioned on the sterile tables are included in Section 4.5.

The air temperature result from the AirThings and TinyTag sensors showed that the temperatures were very similar during all mock surgeries. As the results were similar, they did not effect he conclusion and is therefore included in Appendix C.1 and D.1. Under each results graph presented is a small comment summarizing the result. The results will be further summarized and discussed in Chapter 5.

Due to several problems with the AirDistSys 5000 anemometer, the results were discarded from the thesis. The anemometer was only used 3/4 measurement days due to time limitations on measurement day 18.03. The method used to measure air velocity and air turbulence was changed between the measurement days as possible improvements in the measurement method were discovered. There were also issues with some of the sensors, resulting in some parameters not being measured during measurement day 25.03. The results is therefore added in Appendix **??** and is not considered as a part of the results for this thesis.

4.1 Result from CFU measurements with active sampler

All result from the active samplers are presented with two graphs per measurement day, with one showing the overall result per position for the sterile tables and the second showing the result per active measurement for each sterile table position. Following the graphs are a short summary of the results.

4.1.1 Results from active sampler 04.03.22

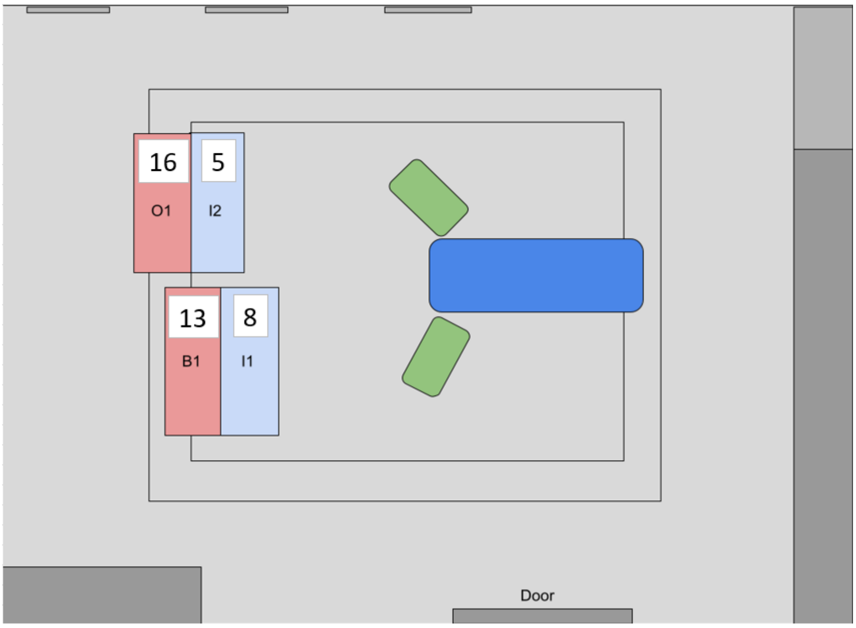


Figure 43: Total number of CFU/m^3 measured with active samplers for all sterile table positions on 04.03.22

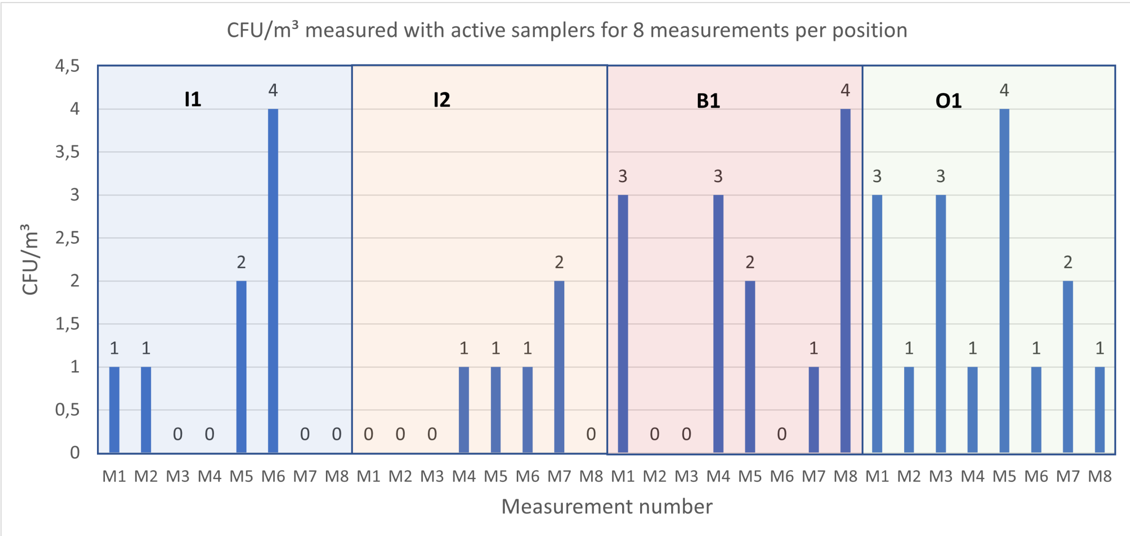


Figure 44: CFU/m^3 per measurement with the active samplers for all sterile table positions on 04.03.22

Figure 43 shows an overview of the positioning of the sterile tables with the total number of CFU measured for each position for the specified measurement day. The color of the sterile tables indicate if the positions were used during the first measurement of the day (blue) or the second measurement of the day (red).

Figure 44 shows CFU measured per sampling for each position with the active sampler. Here the position for the sterile tables are shown moving from inside the laminar airflow (left) to outside of the laminar airflow (right).

The results form figure 43 and 44 show a higher level of CFU/m^3 for the sterile table placed outside of the laminar airflow (O1), followed by the sterile table placed in the boundary area (B1). The lowest level of CFU/m^3 was measured inside the laminar airflow at position I2. The results show that when summarizing the number of CFU measured by both active samplers each mock surgery, the highest total CFU level is measured during the second mock surgery.

4.1.2 Results from active sampler 11.03.22

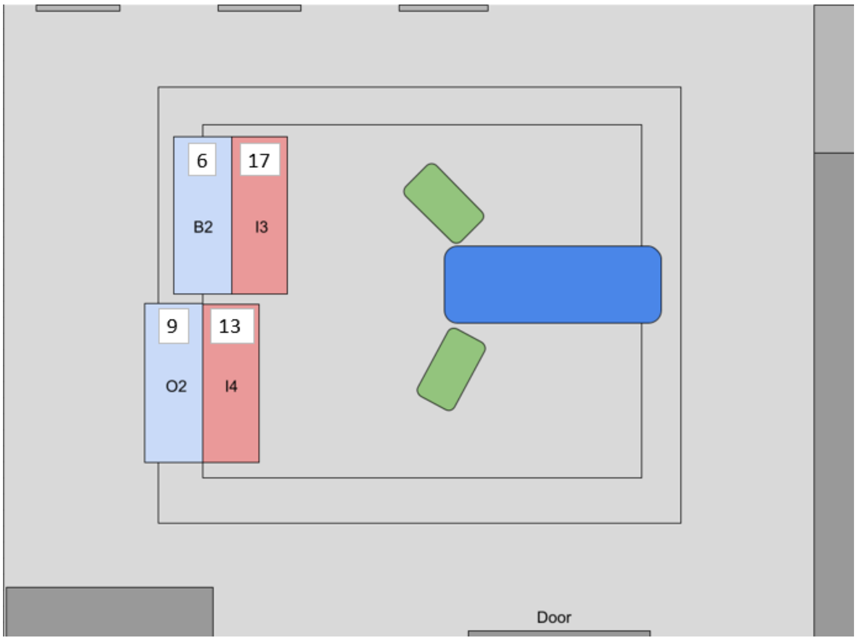


Figure 45: Total number of CFU/m^3 measured with active samplers for all sterile table positions on 11.03.22

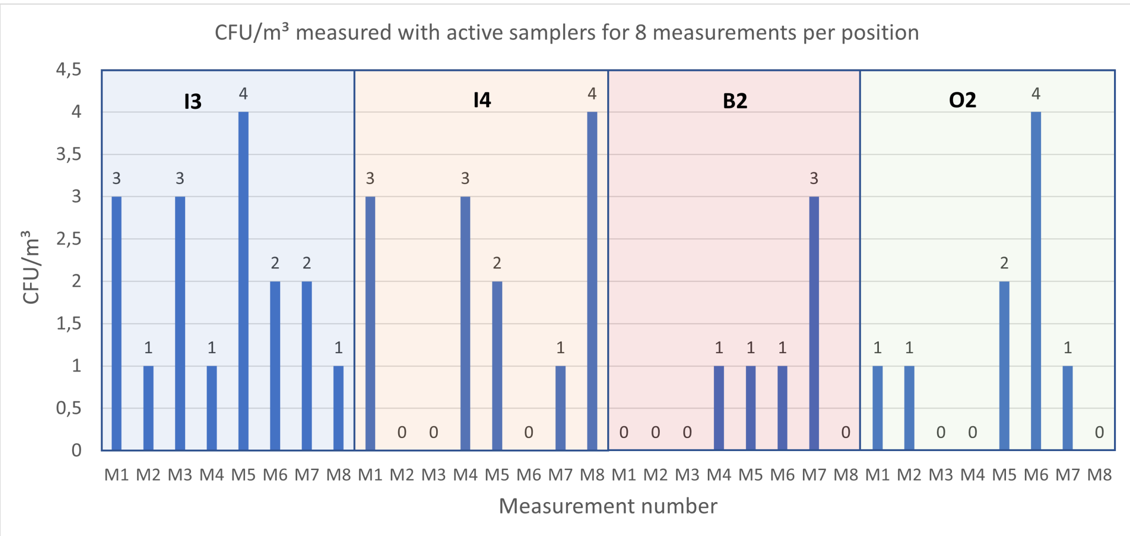


Figure 46: CFU/m^3 per measurement with the active samplers for all sterile table positions on 11.03.22

The results from 11.03 showed an opposite result compared to 04.03 with a higher level of CFU/m^3 measured at both sterile tables placed inside of the laminar airflow, followed by the tabled placed outside of the laminar airflow. The lowest level of CFU/m^3 was measured in the boundary area at position B2.

The similarities between the measurements on 04.03 and 11.03 include the fact that the position outside the laminar airflow (O2) has a higher CFU level than the position in the boundary area (B2). It is also reoccurring that the position farthest inside the laminar airflow (I3) has a higher CFU level than the position inside the laminar airflow closer to the boundary area (I4). The highest total CFU level was also measured during the second surgery of the measurement day.

4.1.3 Results from active sampler 18.03.22

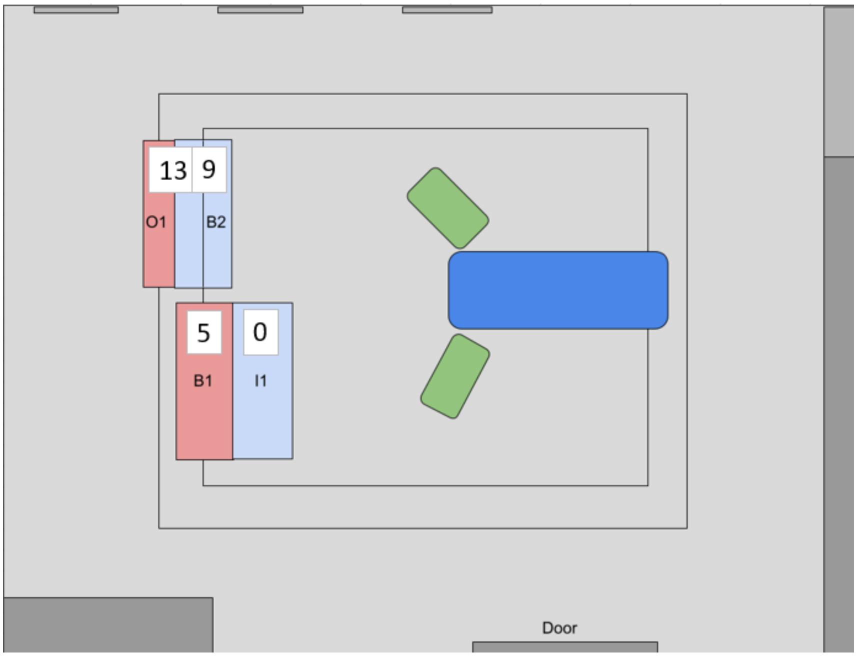


Figure 47: Total number of CFU/m^3 measured with active samplers for all sterile table positions on 18.03.22

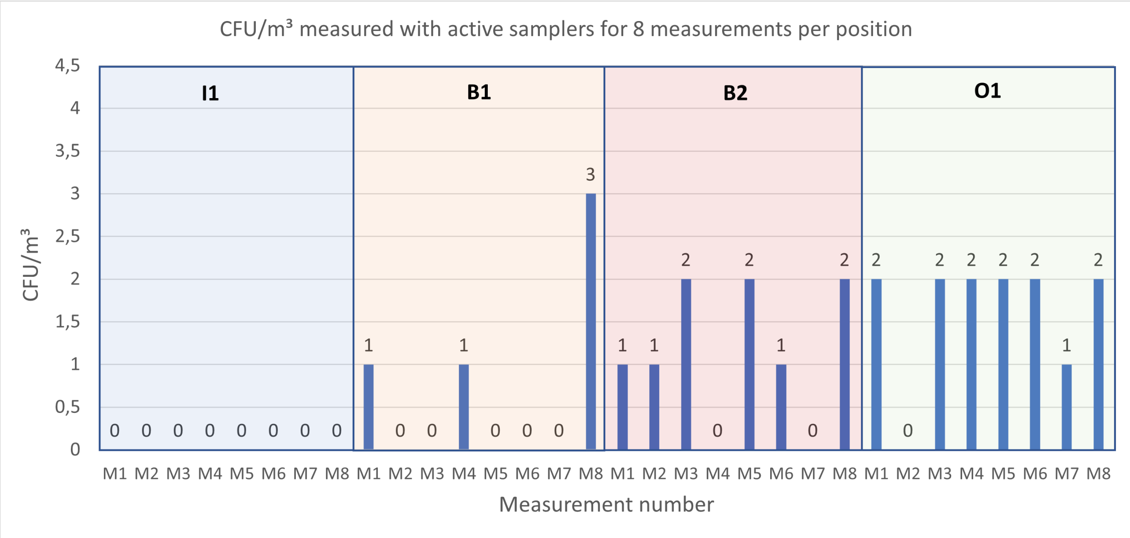


Figure 48: CFU/m^3 per measurement with the active samplers for all sterile table positions on 18.03.22

During the measurements on 18.03, both boundary position were tested in order to confirm a higher CFU level in the top area of the OR. The results showed a higher level of CFU at boundary position B2 compared to B1, confirming a higher CFU level in the top area of the OR.

The other results from 18.03 showed a similar result to 04.03 with the highest CFU level measured outside of the laminar airflow (O1), followed by the boundary position (B2). The lowest level was measured inside the laminar airflow, with 0 CFU/m^3 measured at position I1. Similarly to both 04.03 and 11.03, the highest total CFU level was measured during the second mock surgery.

4.1.4 Results from active sampler 25.03.22

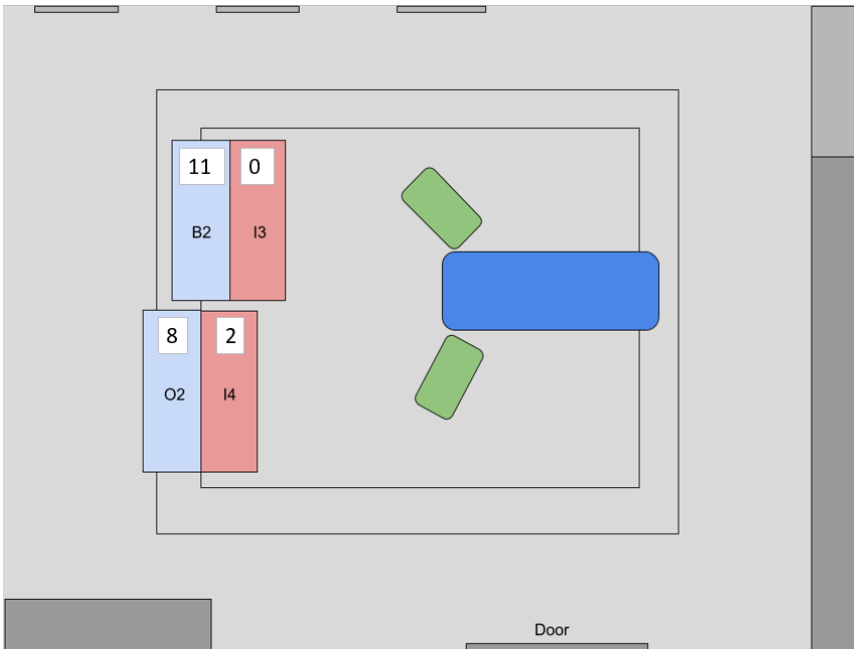


Figure 49: Total number of CFU/m^3 measured with active samplers for all sterile table positions on 25.03.22

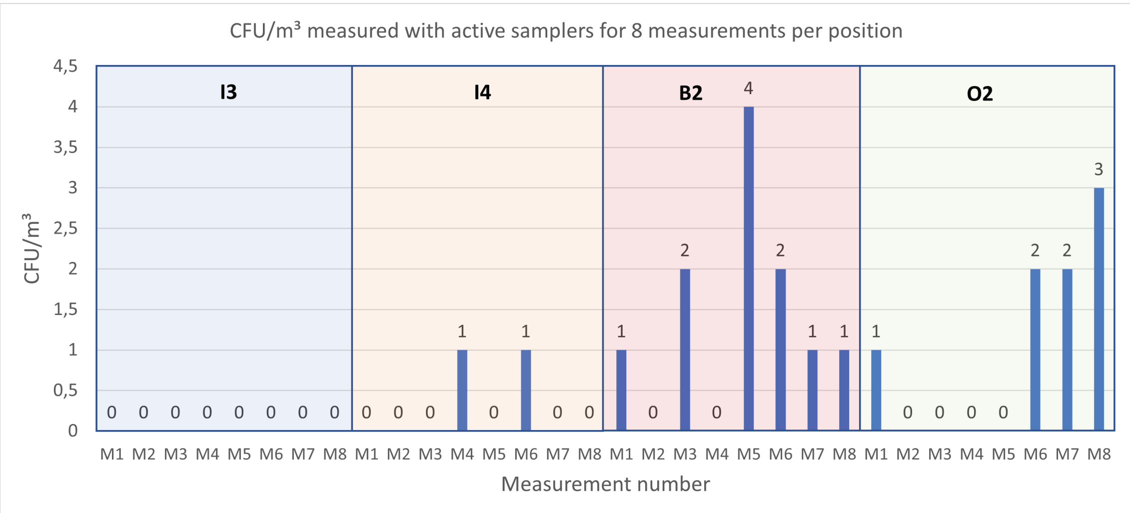


Figure 50: CFU/m^3 per measurement with the active samplers for all sterile table positions on 25.03.22

The measurement from 25.03. showed a different result compared to the previous measurement days. Unlike any the other measurement days, the highest CFU level was measured at the boundary position (B2) followed by the position outside of the laminar airflow (02). Also different from the other measurement days, is the fact that the highest total CFU level was measured during the first surgery of the day.

Similarly to 18.03, but different from 04.03 and 11.03, the position furthest inside the laminar airflow (I3) had the lowest CFU level with 0 CFU/m^3.

The positions for the sterile tables on 25.03 are the exact positions used on 11.03. Alas, the results are opposites. The highest CFU level measured on 11.03 was at position I3 with 17 CFU/m^3. On 25.03, 0 CFU/m^3 was measured at position I3. The position with the lowest CFU level on 11.03 was position B2, with this being the position with the highest CFU level on 25.03.

4.2 Results from CFU measurement with passive samplers

The result for the passive sampler are presented similar to the results from the active sampler. The results are divided into each measurement day with two graphs summarizing each measurement day.

The CFU level measured by the passive sampler are presented as CFU/m^2/min. As the petri dish with blood agar had a diameter of 90mm, the area of the petri dish is therefore calculated as $A = \pi * 0.045^2 = 0.0063617m^2$. By multiply the CFU result by $1/0.0063617 = 157.19007$, the CFU/m^2 was obtained. The CFU/m^2 was then divided on the number of minutes the individual passive samplers had been open, presented in Table 3.

4.2.1 Results from passive samplers 04.03.22

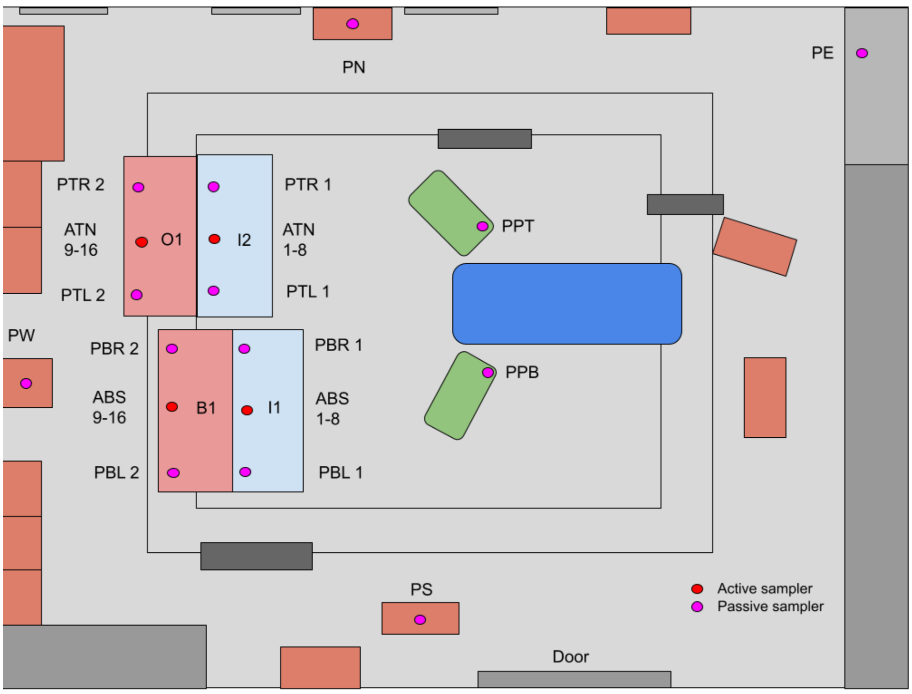


Figure 51: Positioning of active and passive samplers 04.03.22

Figure 51 shows the positioning of the active and passive samplers with the notation used for each sampler. Here passive samplers are shown in purple and active samplers shown in red.

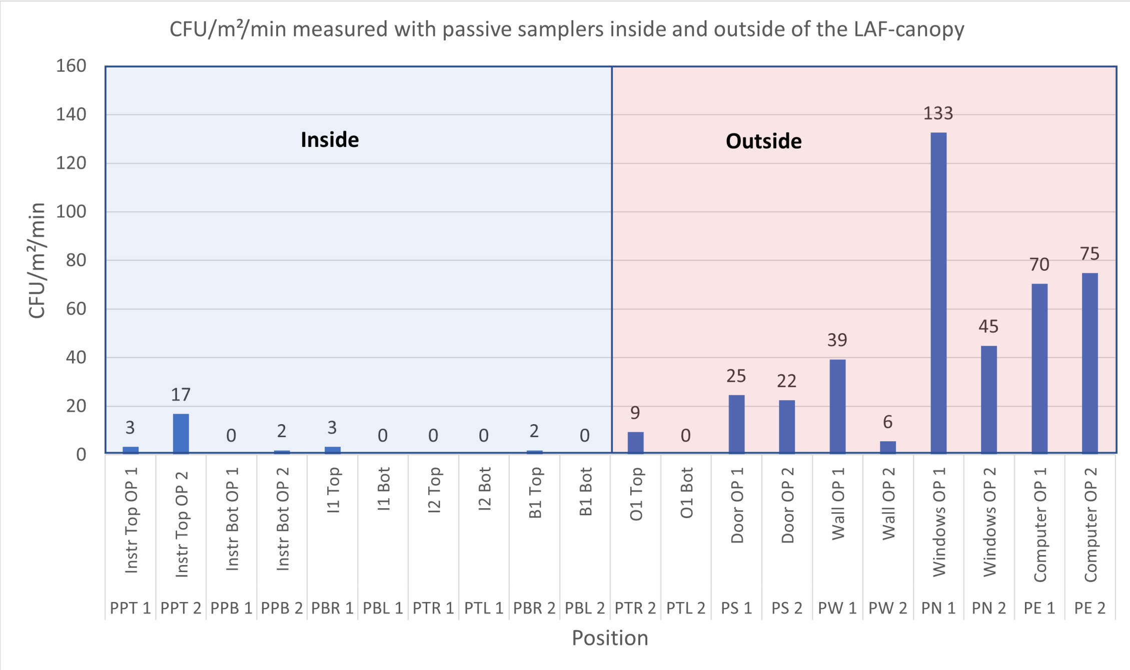


Figure 52: Results from CFU measurements with passive samplers 04.03.22

Figure 52 shows the results from the passive samplers inside of the laminar airflow on the left and the passive samplers outside of the laminar airflow on the right. The results from the inside of the laminar airflow start with both instrument tables, followed by the results from all the four sterile table positions. After the sterile table positions, the results from the outside of the laminar airflow shows the results from the passive samplers moving clockwise, according to Figure 51, starting from the door (position PS).

The notations under every bar in the Figure 52 is a short explanation for each position. OP 1 and 2 refer to mock surgery 1 or 2 for that measurement day. Top and bottom refers to placement according to the orientations of the Figures 51, 53, 55, 57, meaning Top refers to the area by the windows and Bottom is the area by the door. "Instr" is short for instrument table. The letters "R" or "L" refer to right or left respectively, and is marked according to the perspective of looking West to East in the OR.

The result from the passive sampler on 04.03 show a significant higher CFU level for the positions outside of the laminar airflow. The highest level was measured at position PN 1, the position close to the windows. The second highest CFU level was measured at the position PE, the position on the computer table. The lowest CFU level outside of the LAF was measured at the sterile table position outside of the laminar airflow. Opposite of the results from the active sampler, the highest CFU level is measured during the first mock surgery for the passive samplers.

The highest CFU level measured inside the laminar airflow was at the top instrument table by the main surgeon (PPT), followed by the passive sampler placed at the top of sterile table O1.

4.2.2 Results from passive samplers 11.03.22

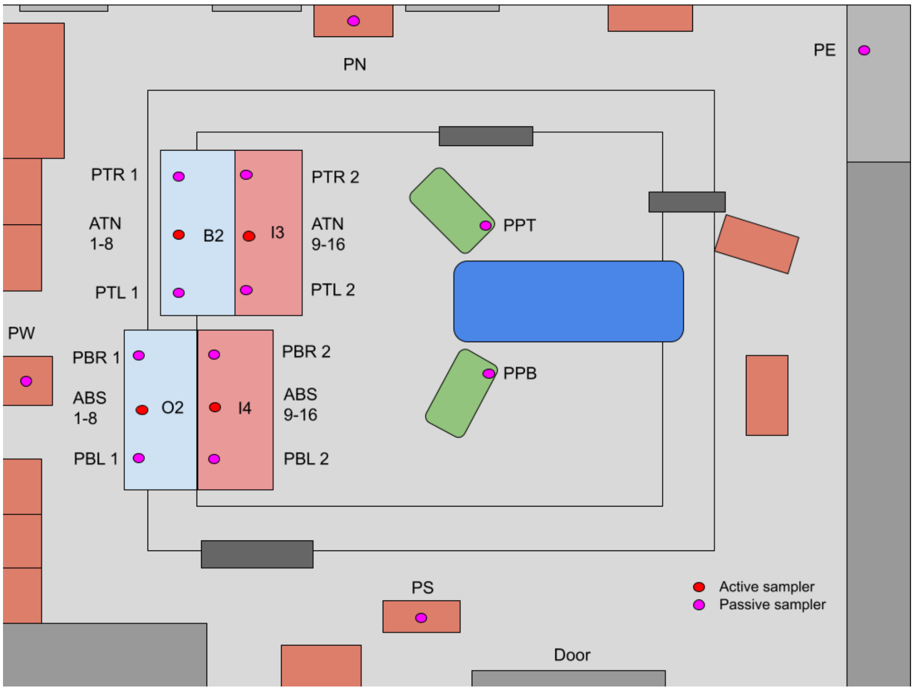


Figure 53: Positioning of active and passive samplers 11.03.22

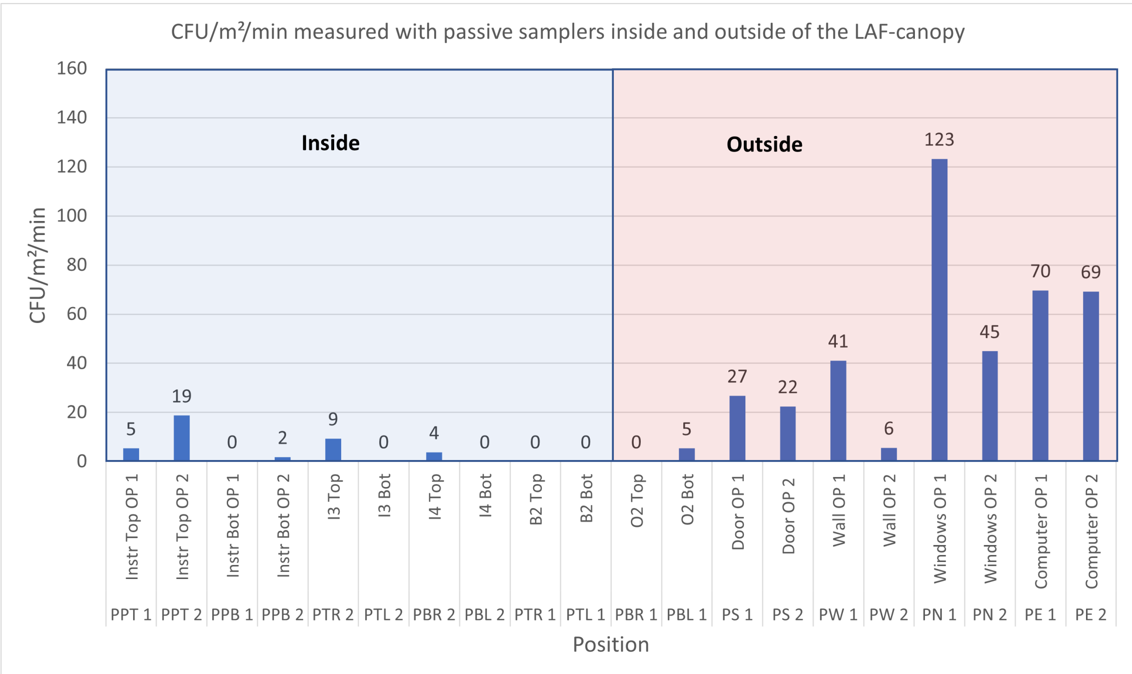


Figure 54: Results from CFU measurements with passive samplers 11.03.22

The results from 11.03. are very similar to the results from 04.03 with the highest CFU level occurring at the window position (PW) for the first surgery. Similarly, the second highest level is by the computer table (PE) and the lowest level was on the sterile table outside of the LAF. For both 04.03 and 11.03 the highest level of CFU outside the laminar airflow is measured during the first surgery.

Inside the laminar airflow the sterile table with the highest CFU level was position I3 top followed by the O2 bottom position. For both 04.03 and 11.03 the sterile table with the highest CFU level was placed in the top area of the OR, close to the windows. The highest measurement for the sterile table were also during the second surgery for both measurement days. Similarly to 04.03, the overall highest CFU level inside the LAF was measured at the top instrument table (PPT) during the second surgery.

4.2.3 Results from passive samplers 18.03.22

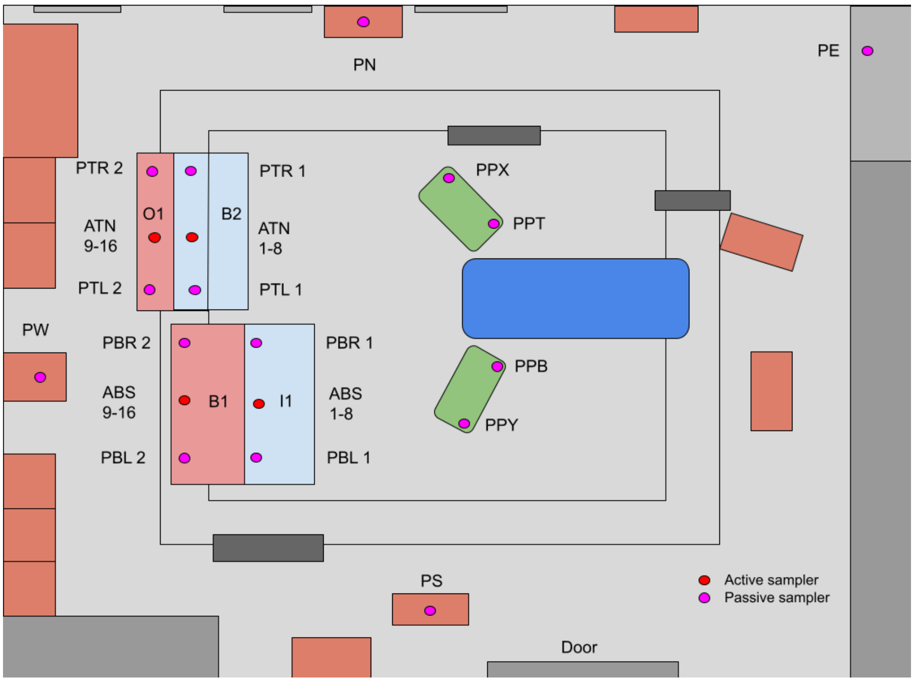


Figure 55: Positioning of active and passive samplers 18.03.22

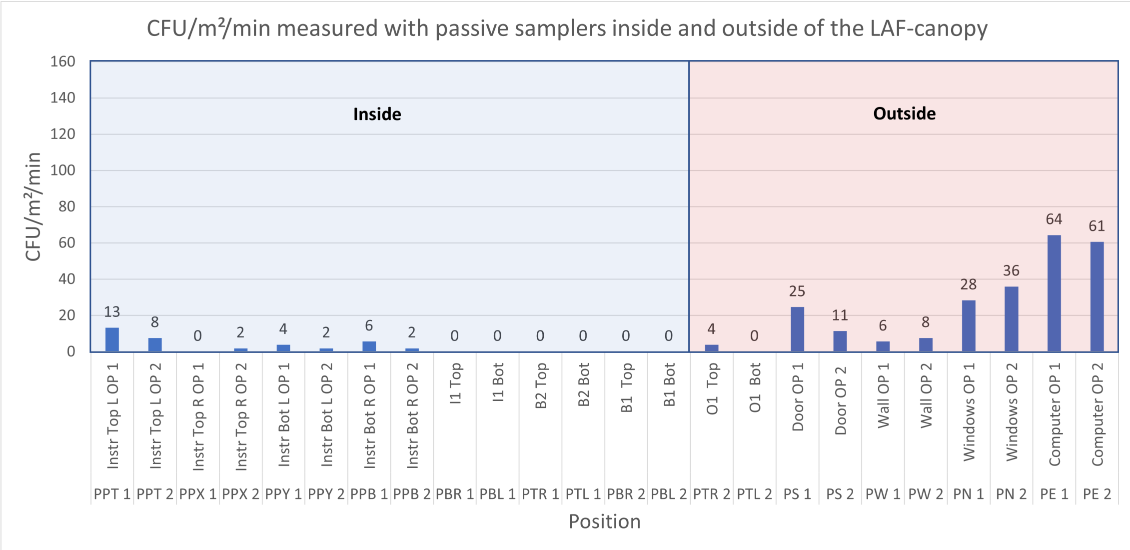


Figure 56: Results from CFU measurements with passive samplers 18.03.22

In order to get a more accurate understanding of the CFU level on the instrument tables, a second passive sampler were placed on both instrument tables. This was done due to the two previous measurement days showing a higher CFU level for the passive samplers placed on the instrument tables, close to the surgeons. As these were heavily affected by the surgeons activity, the passive samplers PPX and PPY were added.

On the 18.03 the results differ from the two previous measurement days. Here the highest level of CFU outside the LAF is measured at the position PE, at the computer table. The second highest level was measured at position PN, close to the windows. There is still a trend of a higher CFU level measured in the top right corner of the operating room. Similar to the other measurement days, the lowest CFU level was measured at the sterile table position outside of the LAF. On this measurement day, this was the only sterile table position were any CFU was measured.

Inside the laminar airflow the highest CFU level was measured at the top instrument table (PPT), similar to both previous measurement days. The new passive sampler PPX, placed on the same instrument table as PPT, show a similar low CFU level as the other passive samplers inside the LAF. Similarly to the two previous measurement days, the highest CFU level for the sterile tables are during the second surgery and the position with the highest CFU level is placed in top of the operating room, close to the windows.

4.2.4 Results from passive samplers 25.03.22

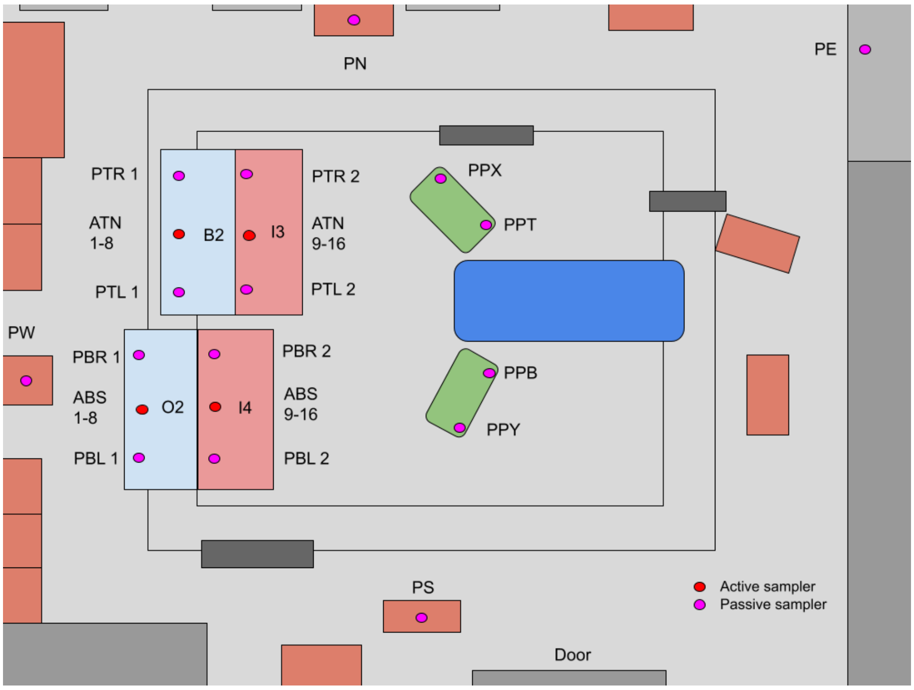


Figure 57: Positioning of active and passive samplers 25.03.22

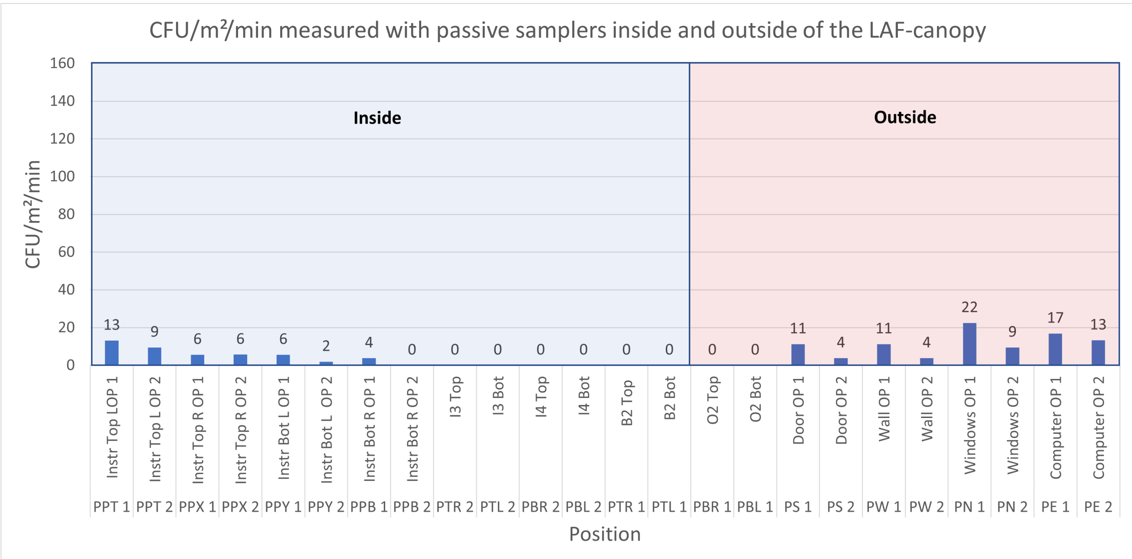


Figure 58: Results from CFU measurements with passive samplers 25.03.22

A trend for each measurement day is that the general CFU level measured by the passive samplers decrease for each measurement day, especially outside the LAF. This becomes very clear in the results from 25.03 were the CFU level outside of the LAF becomes more similar to the CFU level measured inside the LAF.

Similar to the measurement days on 04.03 and 11.03, the highest CFU level outside the LAF is measured at PN, the position close to the windows. The second highest CFU level was also measured at position PE, on the computer table. Also similarly to 04.03 and 11.03, the highest CFU level for all position was measured during the first surgery. Similar to all measurement days is that the sterile table position measured the lowest CFU level of the passive samplers outside of the LAF.

Inside the LAF the highest level was measured at position PPT, similar to all previous measurement days. Similar to 18.03, no CFU was measured by the passive samplers on the sterile tables placed inside the LAF.

4.3 Results from particle measurements

In the results from the Aerotrak particles sampler, only the results from Aerotrak 1 and 2 positioned at the sterile tables are included. The results from Aerotrak 3 and 4, positioned at the patient and computer table, did not provide any significant data for the conclusion of this study. The results from Aerotrak 3 and 4 are therefore included in Appendix G.

As only particles with size of $\geq$ PM5.0 μm are likely to carry bacteria (Hansen et al., 2005)(Memarzadeh and Manning, 2004), Figure 60, 62, 64 and 66 only focus on particles of size PM5.0 and PM10.0 μm. The result from the Aerotrak particle samplers are accumulated to the same ten minute period as the active samplers measures. This means that M1 in Figure 60 is the same measurement period as M1 in Figure 44. As the Aerotrak has a sampling rate is 2.83 L/min, the number of particles have been scaled by 35.3356 in order to show the results of 100 L/min, similar to the active sampler. This way, the number of particles/m^3 and CFU/m^3 could be compared in Section 4.4.

A Excel sheet analyzing every peak in the Figure 60, 62, 64 and 66, is shown in Appendix H.

The results from the Aerotrak are presented similarly to the results from the active and passive samplers, with a figure showing the sterile table positions followed by the measurement results.

4.3.1 Results from Aerotrak particle counter 04.03.22

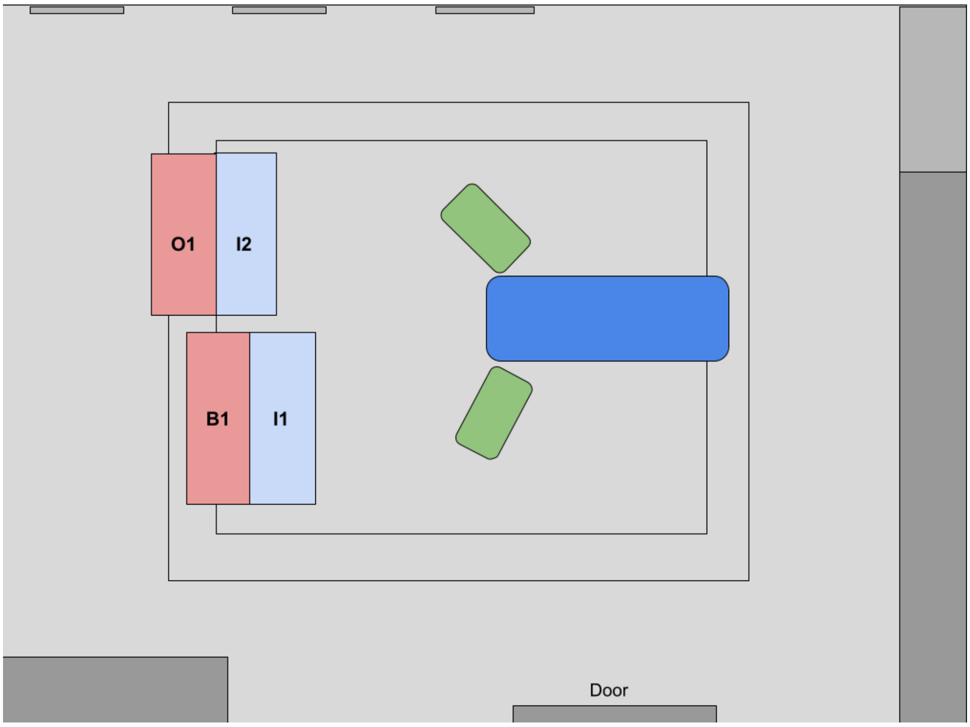


Figure 59: Position of sterile tables 04.03.22

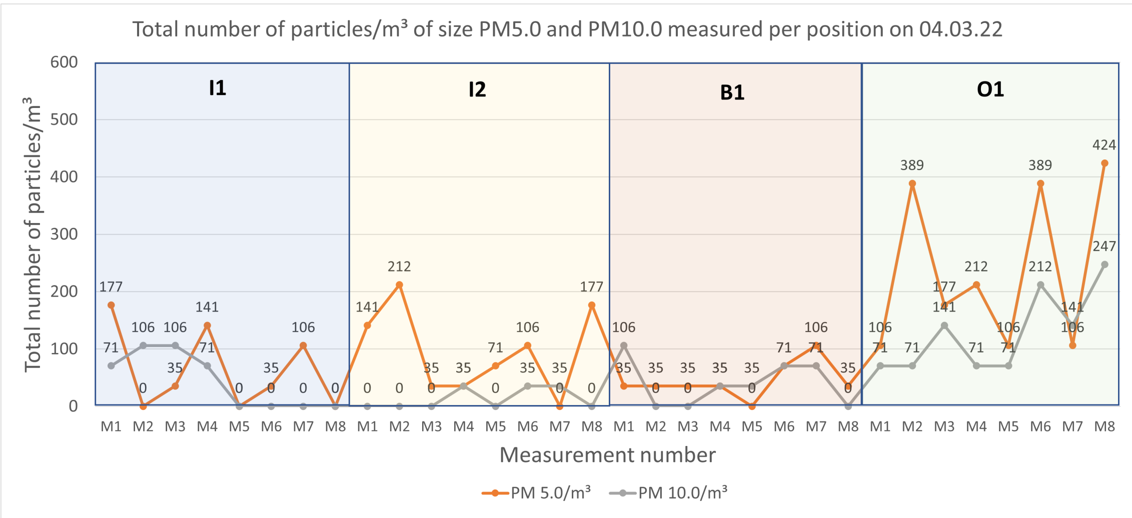


Figure 60: Total number of particles/m^3 of size PM5.0 and PM10.0 μm measured per measurement with the active samplers 04.03.22

Figure 60 shows a higher level of particles measure outside the LAF at position O1. The lowest level of PM5.0 μm was in the boundary area at position B1, while the lowest level of PM10.0 μm was measured at position I2.

4.3.2 Results from Aerotrak particle counter 11.03.22

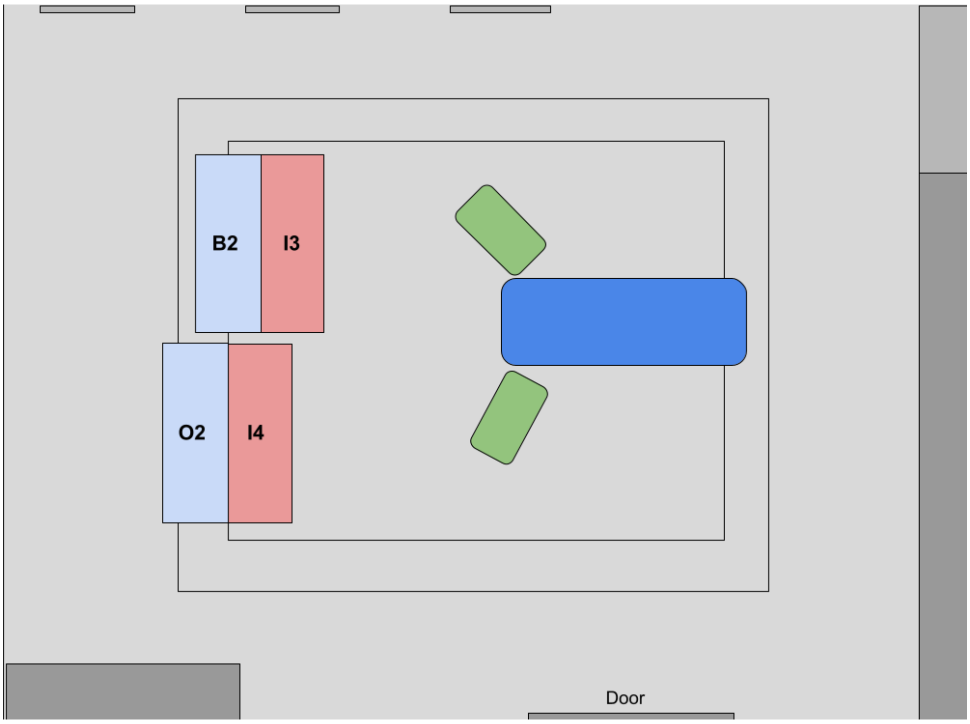


Figure 61: Position of sterile tables 11.03.22

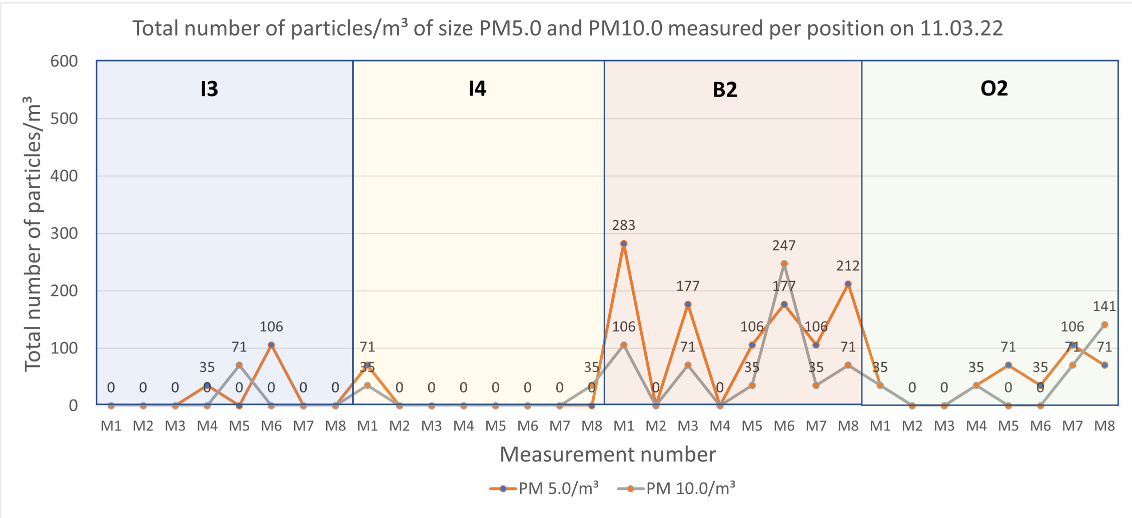


Figure 62: Total number of particles/m^3 of size PM5.0 and PM10.0 μm measured per measurement with the active samplers 11.03.22

Figure 62 shows a higher level of particles of both sizes in the boundary area at position B2, followed by position O2 outside of the LAF. The lowest number of particles was measured at position I4. Similarly to 04.03 the highest particles level was measured in the top left corner of the OR and the lowest PM10.0 μm level at the position inside the LAF, closest to the boundary.

4.3.3 Results from Aerotrak particle counter 18.03.22

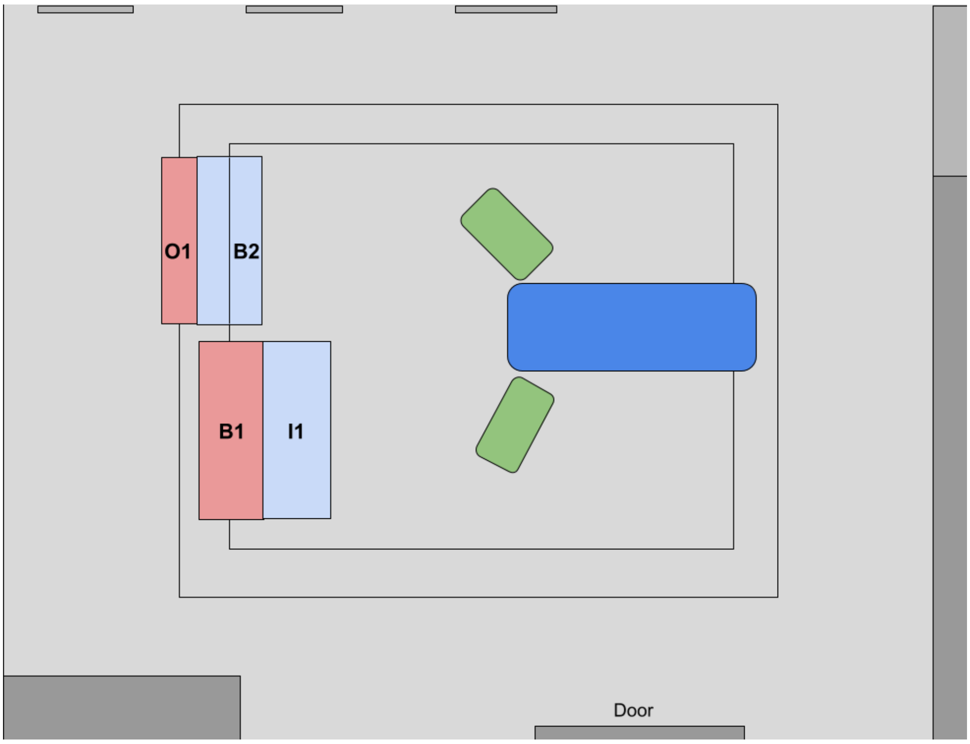


Figure 63: Position of sterile tables 18.03.22

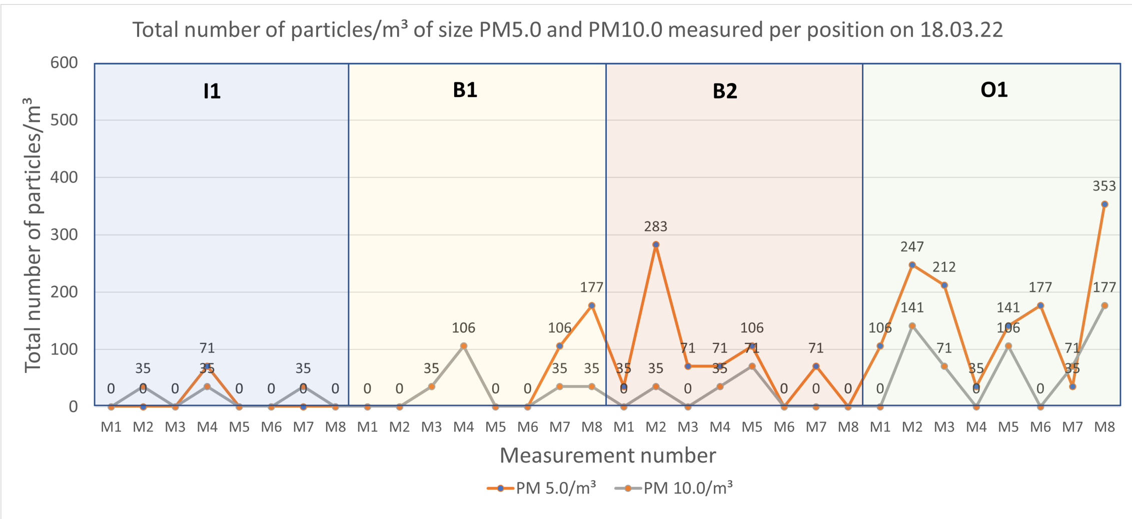


Figure 64: Total number of particles/m^3 of size PM5.0 and PM10.0 μm measured per measurement with the active samplers 18.03.22

Figure 64 shows the highest level of particles at position O1 outside the LAF, followed by B2 in the boundary area. The lowest particle level was measured inside the LAF at position I1. Similarly to 04.03 and 11.03, the highest particle level is measured in the top area of the OR.

4.3.4 Results from Aerotrak particle counter 25.03.22

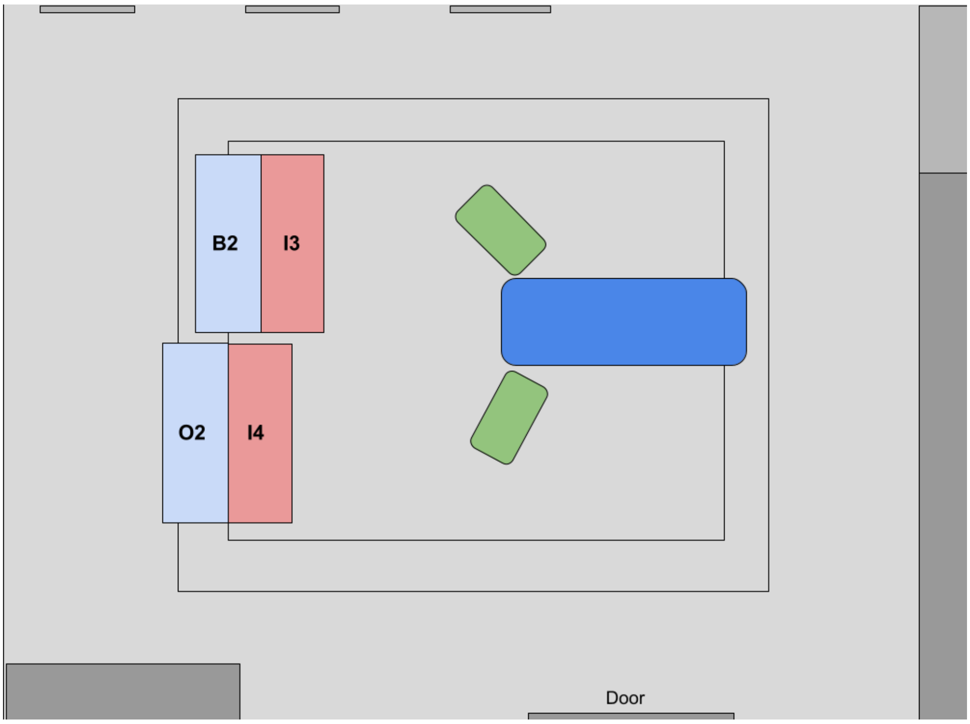


Figure 65: Position of sterile tables 25.03.22

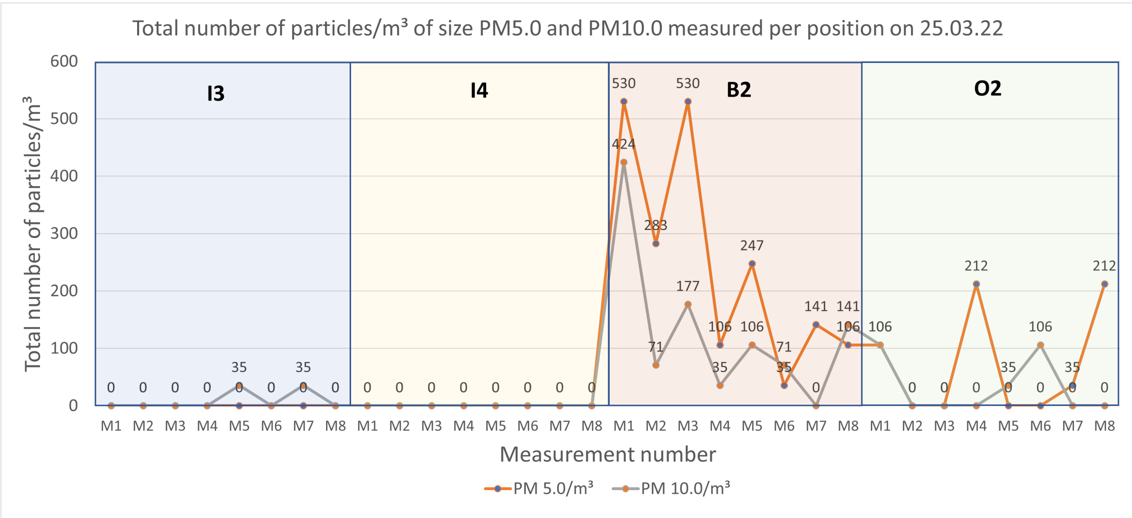


Figure 66: Total number of particles/m^3 of size PM5.0 and PM10.0 μm measured per measurement with the active samplers 25.03.22

Figure 66 shows the highest particle value in the boundary area at position B1, followed by outside the LAF at position O2. The lowest level of particles is at position I4 with no particles measured. Common for all measurement days is that the highest particle level is measured at the position in the top area of the OR.

4.4 CFU/m^3 and particle/m^3 comparison

The following graphs compares CFU/m^3 and particles/m^3 for each position for every measurement day. The graphs show the sterile table positions moving from the position inside the laminar airflow (left) to the outside (right). As in previous graphs, M1 to M8 indicate the measurement number for each active sampling.

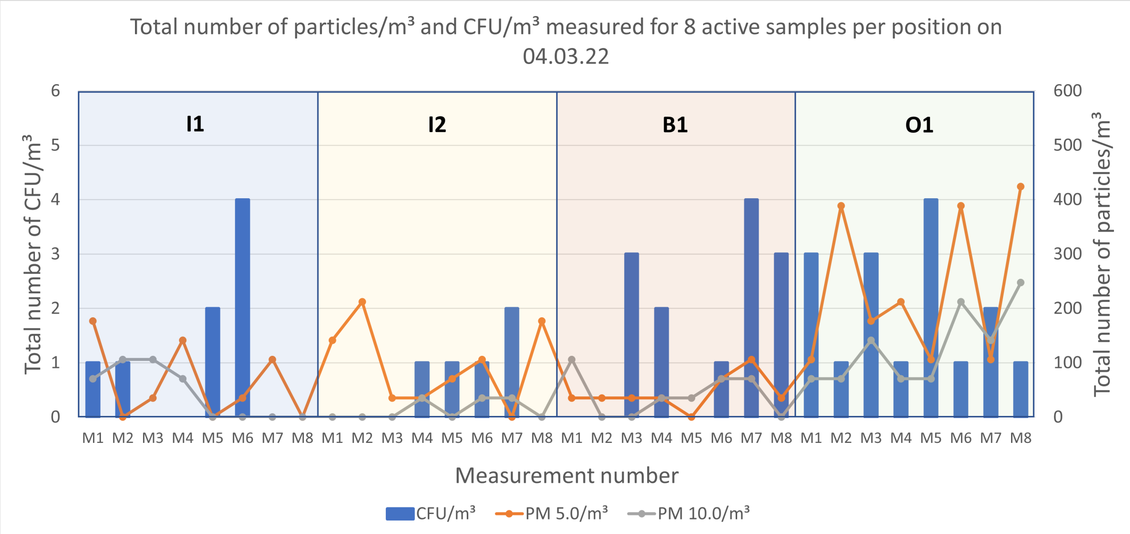


Figure 67: Total number of CFU/m^3 and particles/m^3 of size PM5.0 and PM10.0 μm measured 04.03.22

The similarities between the results on 04.03 from the active samplers and particle samplers are that the highest level of CFU and particles of size PM5.0 and PM10.0 μm was measured on position O1. The CFU results and particles results for size PM10.0 μm show the lowest level measured on position I2. The lowest particle level of size PM5.0 μm was measured on position B1.

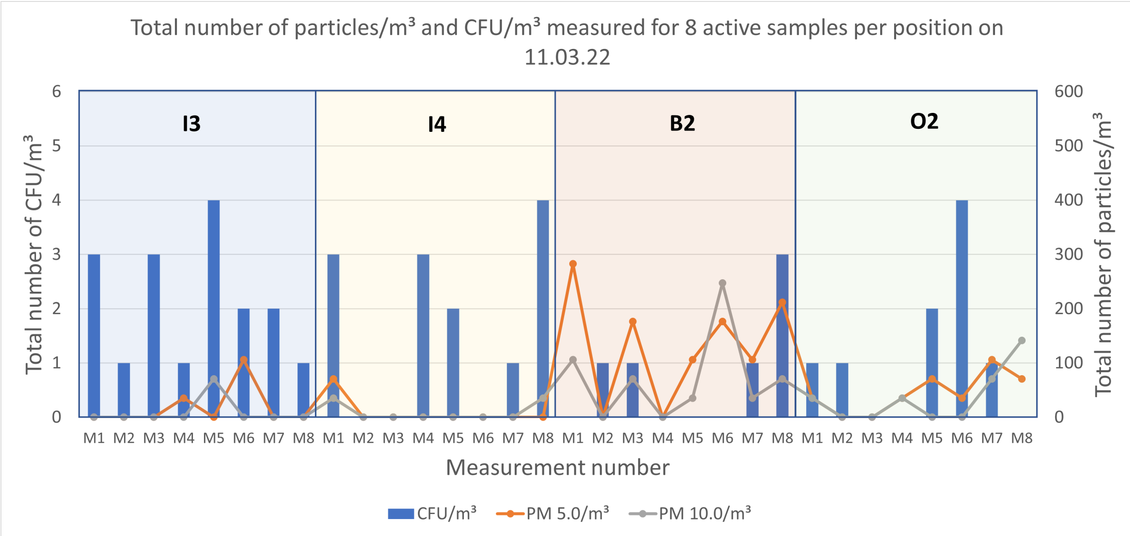


Figure 68: Total number of CFU/m^3 and particles/m^3 of size PM5.0 and PM10.0 μm measured 11.03.22

Figure 68 show that the highest particle level of size PM5.0 and PM10.0 μm was measured at position B2, while the lowest particle level for both sizes were measured at position I4. For the CFU results from the active sampler, the position B2 showed the lowest CFU level and position I3 showed the highest CFU level. Here the particle results and the CFU result are close to opposites.

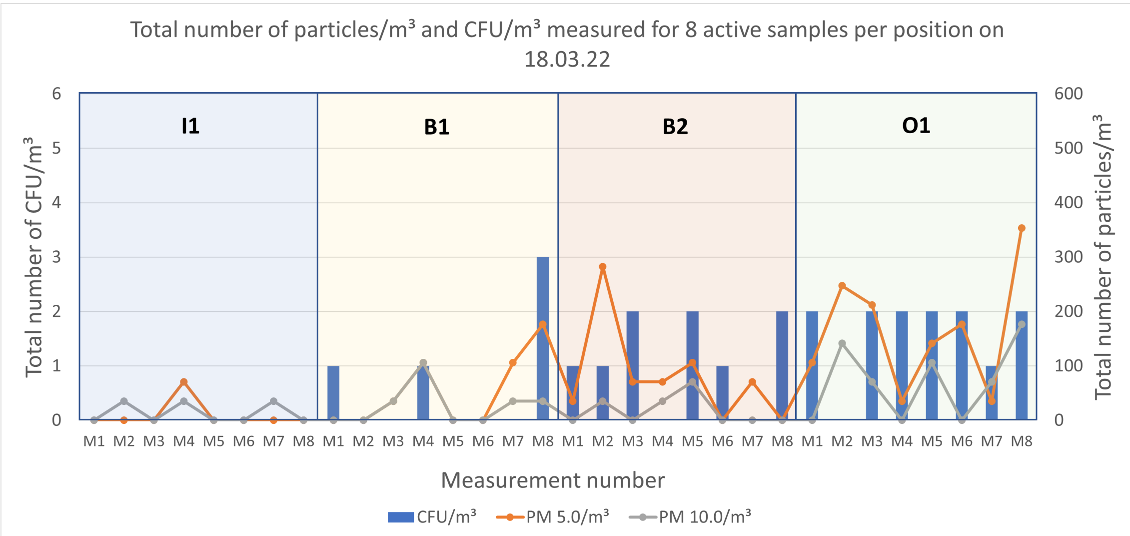


Figure 69: Total number of CFU/m^3 and particles/m^3 of size PM5.0 and PM10.0 μm measured 18.03.22

On the measurement day 18.03, both the particle results and the CFU results showed the highest level measured at position O1, similarly to measurement day 04.03. The lowest level of both particles and CFU was measured at position I1.

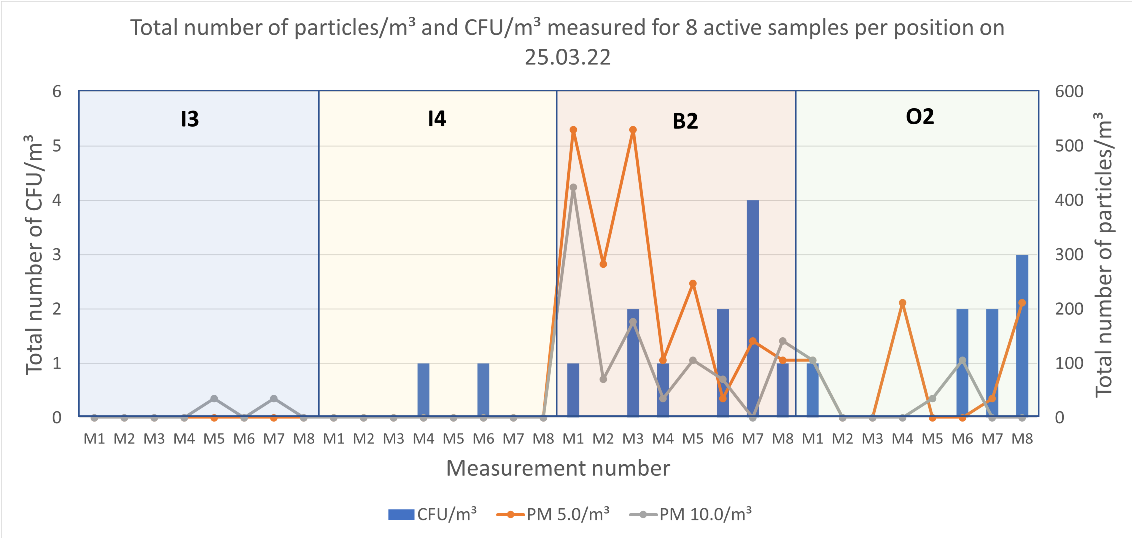


Figure 70: Total number of CFU/m^3 and particles/m^3 of size PM5.0 and PM10.0 μm measured 25.03.22

Figure 70 show that both the particles results and CFU result measured the highest level on position B2. The lowest level for both particles and CFU was measured on position I4.

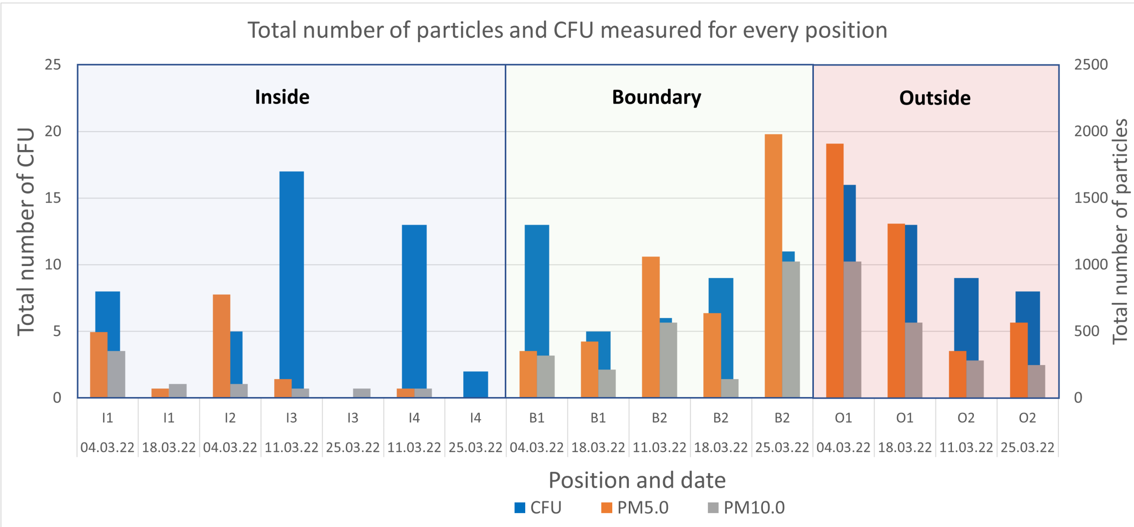


Figure 71: Total number of CFU and particles measured for each sterile table position for all mock surgeries

Figure 71 shows the total number of particles of PM5.0 and PM10.0 μm measured with the Aerotrak particle counter and CFU measured with the active sampler summarized for every position for all measurement days. Similarly to previous graphs, the graph moves from inside the LAF (left) to the outside of the LAF (right). The figure shows that position B2 had the highest number of particles of size PM5.0μm, followed by position O1. The highest number of particles of size PM10.0μm was sheared between position O1 and B2. The highest CFU level is measured at position I3, followed by position O1. The positions I2, I3, B2 and O1 are all placed in top area of the operating room, close to the windows.

4.5 Relative humidity results from TinyTag sensors

The AirThings sensors measured air temperature, relative humidity, absolute pressure and CO_2. The TinyTag sensors measured air temperature and relative humidity. Out of these four parameters, relative humidity was the only result of interest. The measured air temperature and CO_2 level were very similar during all mock surgeries, and the relatively small differences in atmospheric pressure was presumed not have an effect on the conclusion of this study. The results from these parameters are therefore added in Appendix C and D. The following graphs from the TinyTag sensors include the measurement of relative humidity on the sterile tables and the computer table for each measurement day between 09:00 - 13:30. This is due to the mock surgeries being started at different times as shown in Table 9.

Table 9: Start and finish for all mock surgeries

Date	**Start of the first mock surgery**	**End of the first mock surgery**	**Start of the last mock surgery**	**End of the last mock surgery**
04.03.22	09:02:46	10:34:19	12:02:20	13:24:30
11.03.22	09:00:56	10:26:41	11:34:15	12:56:18
18.03.22	09:02:59	10:24:38	11:40:38	13:02:13
25.03.22	09:02:13	10:23:47	11:40:42	13:02:44

Table 9 shows that the second mock surgery of 04.03 started later than the other surgeries in the following measurement days. This was due to the anemometer being set up and prepared in the OR after the first surgery on the 04.03, causing the lunch break and second surgery to start a half hour later than planned. During the following measurement days, the anemometer was prepared after the second surgery.

The included graphs for relative humidity are only for the sterile table positions and the computer table measured with the TinyTag sensors. The remaining position for the TinyTags are included in Appendix D.2 and all positions for the AirThings sensors are included in Appendix C.2. This is because the same trend is seen at all positions for every mock surgery and the effect on the results on the sterile tables are the main interest. The measurements from the computer table is included to compare the relative humidity level inside and outside of the LAF. The AirThings sensors and TinyTag sensors measured the same relative humidity level at all positions. Only the TinyTag results are included as the TinyTag sensor has a higher sampling rate compared to the AirThings sensor.

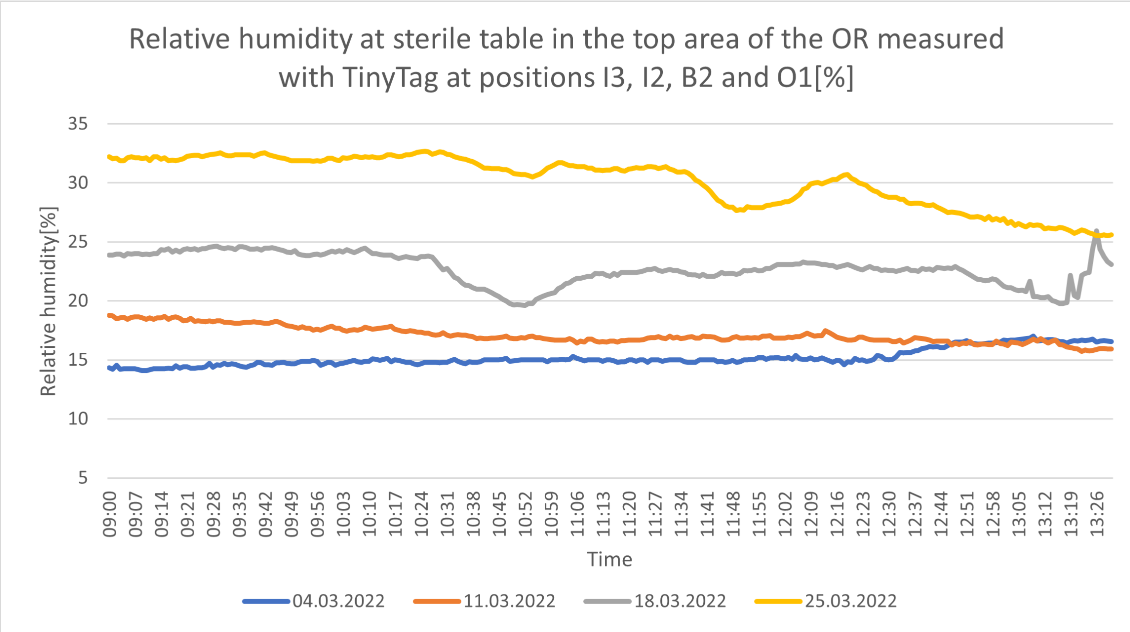


Figure 72: Relative humidity at sterile table in the top area of the OR measured with TinyTag at positions I3, I2, B2 and O1

In Figure 72 the relative humidity increases every measurement day. The relative humidity measured on the 25.03 is twice as high as the relative humidity measured on 04.03. When comparing the measurement days it becomes apparent that by the end of the second mock surgery, the relative humidity levels are more similar than at the start of the first mock surgery for all measurement days.

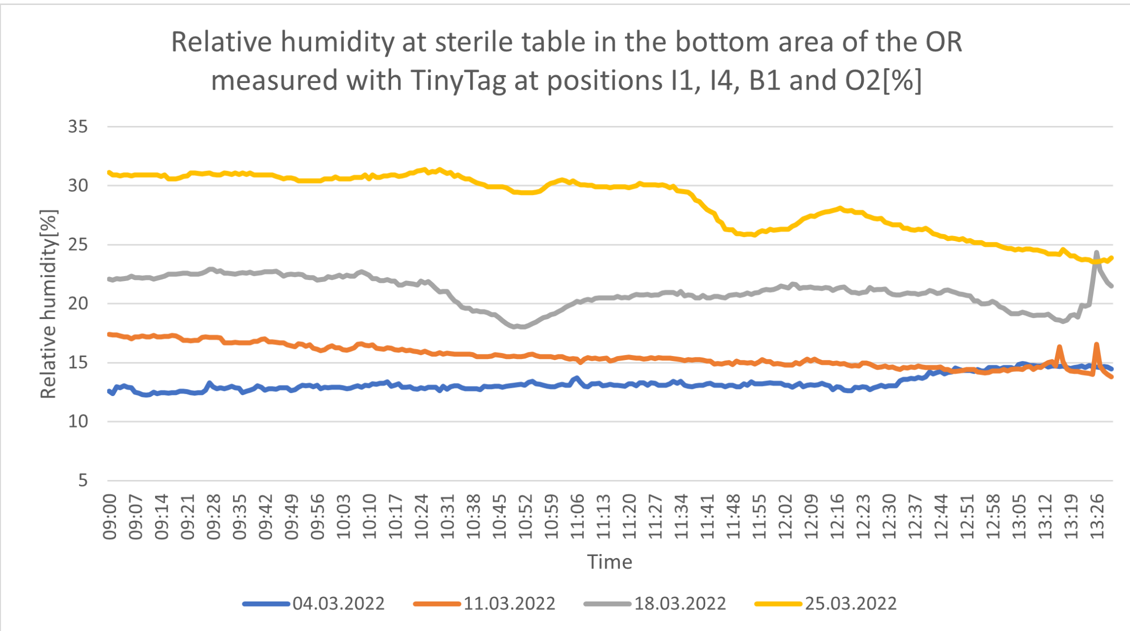


Figure 73: Relative humidity at sterile table in the bottom area of the OR measured with TinyTag at positions I1, I4, B1 and O2

Figure 73 shows a very similar results with the same trend as in Figure 72, showing an increasing relative humidity for every measurement day.

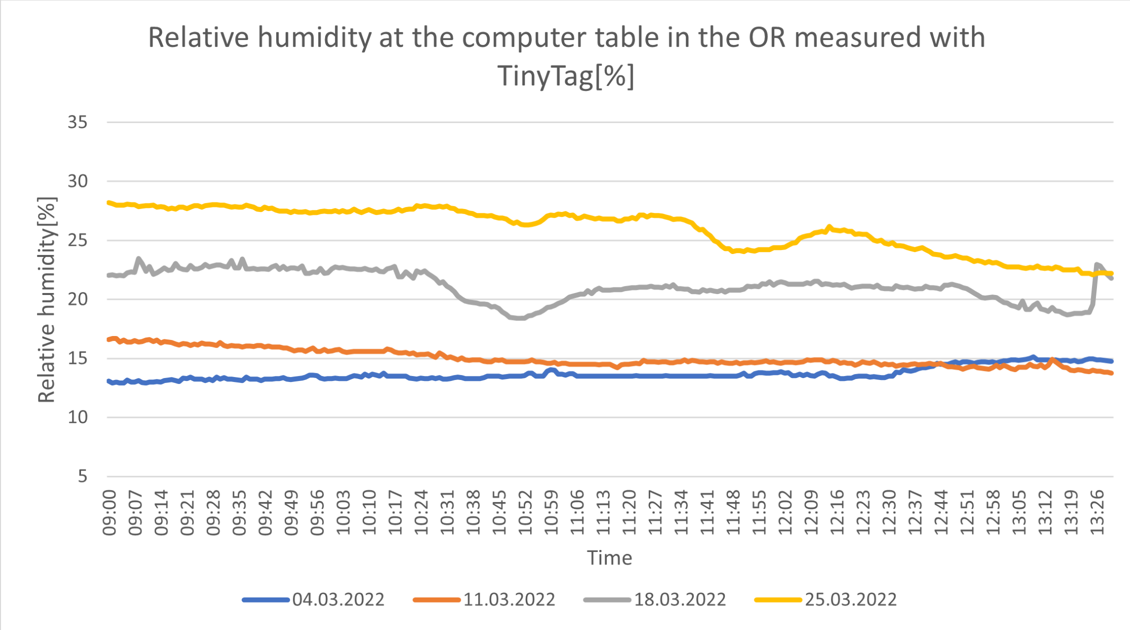


Figure 74: Relative humidity at the computer table for all measurement days

The relative humidity level at the computer table outside of the LAF is very similar to the measurements in side the LAF at the sterile tables and show the same trend.

5 Discussion

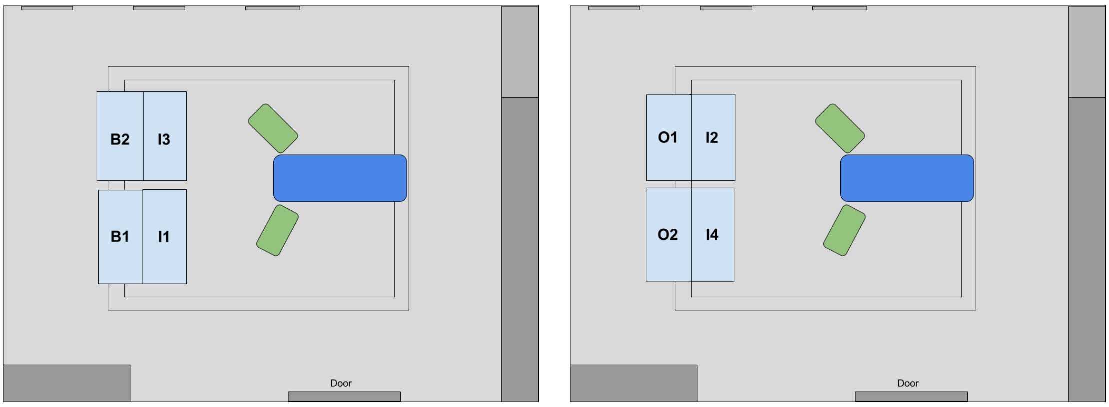
The discussion section presents a summery of the results from active samplers, the passive samplers, the particle measurements, the relative humidity measurements, as well as summery of the particle and CFU comparison. How the results connect to the presented theory and research question is discussed in each summary. Lastly, improvements and recommendation for further research is presented.

Research question was formulated as: *Does the air contamination and number of bacteria on and around the sterile tables increase when the sterile tables are placed in the boundary area or outside of the vertical laminar airflow, compared to being placed inside the vertical laminar airflow?.*

The original hypothesis for this thesis was that the CFU level and particle level would be higher outside and in the boundary area of the laminar airflow, compared to the inside of the laminar airflow for all mock surgeries. Based on this hypothesis the CFU level and particle level at the sterile table positions should gradually increase as the tables are moved from the inside of the LAF canopy to the outside.

5.1 Summary of results from the active samplers

The following chapter summarizes and comment the result from the active air sampler placed on the sterile tables. Figures 75a and 75b are included as a reminder for the position investigated in this thesis.



(a) Sterile table positions I1, I2, B1, B2

(b) Sterile table positions I2, I4, O1, and O2

Figure 75: Illustration of all sterile table positions investigated in this thesis

Table 10: Overview of the results from the active samplers for all sterile table positions for all measurement days

Date	# CFU	Lowest	2. lowest	2. highest	Highest
04.03.22	42	I2	I1	B1	O1
11.03.22	45	B2	O2	I4	I3
18.03.22	27	I1	B1	B2	O1
25.03.22	21	I3	I4	O2	B2

Table 10 summarizes the results from the active samplers. The total number of CFU measured for all positions for the sterile tables are summarized in the column "# CFU". The following columns show the sterile table positions ranging from the lowest measured number of CFU/m^3 to the highest number of CFU/m^3 measured. The table summarizes the results presented in Figure 43, 45, 47 and 49.

Table 10 shows that there's is no result that is reoccurring for all four measurement days. On three out of four measurement days (04.03, 18.03 and 25.03), the positions inside the laminar airflow had the lowest CFU level. Alas, on the 11.03 the boundary position measured the lowest CFU level with the highest CFU level being measured for both positions inside the laminar airflow.

The results show that the measurement of CFU in the air around the sterile table does not entirely concur with the original hypothesis as the CFU does not gradually increase as sterile tables are moved from the inside to the outside of the laminar airflow. The result does on the other hand indicate that CFU level is lower inside the laminar airflow compared to the boundary area and the outside of the laminar airflow. The results from 11.03 did on the other hand show that a lower CFU level inside the laminar airflow is not a certainty as a lower CFU level was measured outside and in the boundary area of the laminar airflow.

On the measurement days 04.03, 11.03 and 18.03, the highest total CFU level was measured during the second mock surgery of the day. During the measurement day 25.03 on the other hand, the highest level was measured during the first mock surgery of the day. "Total CFU level" refers to the sum of the CFU measured by both active samplers placed on the sterile tables each mock surgery. During the measurement days 04.03 and 18.03, the sterile tables are moved further outside the LAF during the mock second surgery. On the measurement days 11.03 and 25.03, the sterile tables are moved further inside the LAF during the second mock surgery. Based on the original hypothesis, the CFU level was expected to increase as the sterile tables were moved more outside the LAF, and decrease as the sterile tables were moved inside the LAF. This is believed to explain why the highest level is measured during the second mock surgery on measurement day 04.03 and 18.03, while the highest CFU level was measured during the first mock surgery on 25.03. Still it is difficult to explain why the results from 11.03 deviate from the other results.

In order to confirm that there were no clear differences between the measurement days and how the mock surgeries were completed, recorded video of all measurement days were reviewed. No clear difference were found between the measurement days, indicating some variation in the CFU level and behaviour of the CFU in the operating room. After reviewing the recordings from all the mock surgeries from each measurement day, no explanation was found to why the measurements on 11.03 were so dissimilar from the other measurements. The result was also verified multiple times to control for human error.

Table 10 shows that the highest CFU levels were measured at positions I3, B2 and O1. These positions, along with position I2, are all position in the top area of the room, close to the windows. This indicates a higher CFU level in the top area of the OR. The lowest CFU level have on the other hand been measured on position I2, I3 and B2 showing a significant variation in the CFU level in this area of the OR.

When comparing the total number of CFU, the CFU level on the 25.03 is half of the total CFU level on the 04.03. It is not known why the total CFU level is lower on 18.03 and 25.03 compared to 04.03 and 11.03. Based on studies from Taylor and Hugentobler (2016), it is theorized that the increasing relative humidity may have had an effect on the CFU level. With the exception of the results from 11.03, the CFU level decrease each measurement day, while the relative humidity level increase each measurement day. The relative humidity level on 25.03 was twice as high as on the 04.03, while the CFU level on 25.03 was half of the CFU level on 04.03. The result may therefore indicate that there is a connection which will be further discussed Section 5.4.

Added in Appendix I is an Excel sheet showing which activity was performed during each measurement with the active samplers. Based on this overview, it is the activities which involve hand movements or moving of surgical instruments close to the active sampler which causes the highest CFU levels. This includes activity 2, 3, 6, 8 and 9 shown in the Acting plan in Table 8. This relationship is on the other hand not consistent, as an increase in CFU is not observed for every time these activities were performed. On some occasions, no CFU are measured in a period where all of these activities were been performed. As the active sampler has a measuring period of ten minutes, it is difficult to pin point what exactly causes the registered level of CFU. Due to this, there are multiple measurements where no obvious explanation for the CFU level was found.

Another activity believed to have caused a higher CFU level, particularly on the positions O2 and B2, is activity 1 and 5 where the distribution nurse walks between the computer table and the surgical cabinets. The distribution nurse seem to pass these table positions relatively close which may have caused some of the registered CFU.

5.2 Summary of results from passive samplers

The summary of the passive samplers first presents the result from the sterile tables, followed by the results from the passive samplers placed inside the LAF and then the passive samplers placed outside the LAF.

Table 11: Overview of the results from the passive samplers for all sterile table positions for all measurement days

Date	**# CFU**	**Lowest**	**2. lowest**	**2. highest**	**Highest**
04.03.22	8	I2	B1	I1	O1
11.03.22	10	B2	I4	O2	I3
18.03.22	2	I1/B1/B2			O1
25.03.22	0	I3/I4/B2/O2			

In Table 11 the total number of CFU measured by the eight passive samplers placed on the sterile tables for each measurement day is shown in the column "# CFU". The following columns show the position which measured the lowest to highest number of CFU.

The total number of CFU measured follows the same trend as the active samplers, with an increase on 11.03 compared to 04.03, followed by a decreasing total number of particles on measurement days 18.03 and 25.03. On the measurement day of 25.03, no CFU was measured on the sterile tables by any of the passive samplers. On measurement day 18.03, only two CFU was measured on position O1 and zero on all other positions.

On the measurement day 04.03 and 11.03, the active samplers and passive samplers showed similar results with the lowest CFU level being measured on sterile table position I2 on 04.03 and B2 on 11.03, as well as the highest number of CFU being measured at position O1 on 04.03 and I3 on 11.03. Position O1 also measured the highest number of CFU for both the active samplers and the passive samplers on 18.03.

Table 12: Summary of results from passive samplers placed inside of the LAF

Date	**# CFU**	**Lowest**	**2. lowest**	**2. highest**	**Highest**
04.03.22 MS 1	4	I1 bot I2 top I2 bot Instr table bot right			I1 top Instr table top left
04.03.22 MS 2	16	B1 bot		B1 top Instr table bot right	Instr table top left
11.03.22 MS 1	6	B2 top B2 bot Instr table bot right			Instr table top left
11.03.22 MS 2	18	I3 bot I4 bot	Instr table bot right	I3 top	Instr table top left
18.03.22 MS 1	12	I1 top I1 bot B2 top B2 bot Instr table top right	Instr bot left	Instr table bot right	Instr table top left
18.03.22 MS 2	9	B1 top B1 bot Instr table top right		Instr table top right Instr table bot right Instr table bot left	Instr table top left
25.03.22 MS 1	15	B2 top B2 bot	Instr table bot right	Instr table top right Instr table bot left	Instr table top left
25.03.22 MS 2	9	I3 top I3 bot I4 top I4 bot Instr table bot right	Instr table bot left	Instr table top right	Inst table top left

Table 12 summarizes the CFU measured with passive samplers inside the laminar airflow. In the column "Date" the measurement day is shown with the text "MS 1" or "MS 2", which refers to mock surgery 1 or 2 that measurement day. The words "Bottom" and "Instrument" have been reduced to "Bot" and Instr" respectively. The table summarizes the results from Figure 52, 54, 56 and 58. The purpose of the table is to show repeating tendencies between the measurement days.

As zero CFU was measured for several positions inside the laminar airflow, multiple position are included in the column "Lowest" in Table 12. For every measurement day, the position on the instrument table, closest to the main surgeon, was always the passive sampler with the highest CFU level of all the passive samplers inside the LAF. On measurement day 04.03, position I1 top measured the same amount of CFU as the main surgeons instrument table, with 2 CFU measured on both positions.

Figure 76: Picture of passive samplers on the instrument tables

The reason why the CFU level is higher on the instrument tables is due the surgeons standing very close to the passive samplers when performing their activities. This can be seen in Figure 76 where the passive sampler positions "Instrument table top left" and "Instrument table bottom right" are visible. Every time the surgeons would pick up an instrument or perform activities described in Table 8, their hand moved closed to or directly over the passive sampler.

Table 13: Summary of results from passive samplers placed outside of the LAF

Date	**# CFU**	**Lowest**	**2. lowest**	**2. highest**	**Highest**
04.03.22 MS 1	163	Door	East wall	Computer table	Windows
04.03.22 MS 2	79	O1 Bot	Door	Windows	Computer table
11.03.22 MS 1	146	O2 Top	East wall O2 Bot	Computer table	Windows
11.03.22 MS 2	76	East wall	Door	Windows	Computer table
18.03.22 MS 1	65	East wall	Door	Windows	Computer table
18.03.22 MS 2	61	O1 Bot	O1 Top	Windows	Computer table
25.03.22 MS 1	33	O2 Top O2 Bot	East wall Door	Computer table	Windows
25.03.22 MS 2	16	East wall Door		Windows	Computer table

From Table 13 it is evident that the highest CFU level measured by the passive samplers is in the top, right area of the OR. During five out of eight mock surgeries, the highest CFU level was measured at the computer table, with the window position showing the highest CFU level for the remaining mock surgeries. The reason for this is believed to be due to this being the main area for the distribution nurses activities which is the only participant performing activities outside of the LAF. The base position for the distribution nurse is right next to the computer table and the distribution nurse would sometimes take notes on a piece of paper close to the passive sampler. The distribution nurse would also walk back and forth between the computer table and the cabinet on the other side of the OR. The distribution would then always pass the passive sampler by the window at a relatively close distance.

The lowest CFU level outside of the LAF was commonly measured on the sterile table positions O1 or O2 for the mock surgeries when the sterile table were positioned outside of the laminar airflow. It is believed that this is due to the sterile table positions being closest to the laminar airflow, compared to the other passive sampler positions outside of the laminar airflow area. The sterile table positions O1 and O2 were likely positively affected by the laminar airflow's washing effect, resulting in a lower CFU level. A low CFU level is also measured at the east wall, the position directly behind the sterile tables. This might indicate that this is an area with low air contamination due to the two exhaust vents in the ceiling right above these positions, as well as the two exhaust vents in the north-east corner of the OR. It is likely that the air contamination is lower in this area compared to the remaining OR as more exhaust vents remove more of the dirty air.

During the measurement days 04.03, 11.03 and 25.03, the highest CFU level outside the laminar airflow was measured during the first mock surgery of the day. On 18.03, two position measured a higher CFU level during the second surgery with all other positions measuring higher during the first mock surgery. This result is close to opposite of the results from the active samplers where the highest CFU level was measured during the second mock surgery for three out of four measurement days.

Before the first mock surgery of each measurement day, the OR had not been used for minimum of thirteen hours with the ventilation system set to resting mode. As there was a low ventilation rate and no activity during these hours, particles and CFU would likely have settled on surfaces in the OR. The theory for why the CFU level measured by the passive sampler outside of the laminar airflow is higher during the first surgery is that when the participant arrive and start doing activities, the particles and CFU on surfaces will aerosolize. The particles and CFU will then move around the OR and land on the passive sampler during the first mock surgery. As the ventilation system is set to surgery mode before the first mock surgery, providing a higher ventilation rate, more and more of the aerosolized air contamination will be removed from the OR air. This means that less and less particles and CFU will aerosolize from surfaces, causing the

CFU level to be lower during the second mock surgery.

Interestingly the passive sampler close to the door had a generally low CFU level for all measurement days, indicating that the three door openings during each mock surgeries did not significantly effect the CFU level in the OR.

Table 14: Summary for total number of CFU measured with passive samplers

Date	**# CFU inside the LAF**	**# CFU outside the LAF**
04.03.22	20	242
11.03.22	24	222
18.03.22	21	126
25.03.22	24	49

From Table 18 it is apparent that the high CFU level outside the LAF decrease every measurement day, making the CFU level inside and outside of the LAF more similar during the last measurement day on 25.03. The CFU level on the 25.03 is the lowest measured CFU level outside the LAF, but is still over twice as high as the CFU level measured inside the LAF for all measurement days.

The results clearly demonstrate that the laminar airflow canopy provide a significantly lower CFU level inside the defined laminar airflow area. The results support the evidence that the laminar airflow mainly provide protection inside the laminar airflow. This supports the evidence found by Traversari, Heumen, and Hoksbergen (2019)Smith et al. (2013)McHugh, Hill, and Humphreys (2015)Taylor and Bannister (1993) who all found a significantly higher bacteria count outside of the laminar airflow. The results did not confirm the finding of (Kirschbaum et al., 2020) who found that the laminar airflow provide a low CFU level in the entire OR.

The results also strengthens the argument that the laminar airflow canopy should be large enough for sterile equipment to be placed inside the laminar airflow. This further supports a requirement for a minimum size for laminar airflow canopies.

5.3 Summary of Aerotrak particle measurements and comparison with CFU measurements for all measurement days

The following tables presents the results from the particle measurement from the Aerotrak. The results are divided into particle size PM0.5 μm and PM10.0 μm.

Table 15: Summary of results from Aerotrak particle counters for PM5.0 μm

Date	# particles	Lowest	2. lowest	2. highest	Highest
04.03.22	3534	B1	I1	I2	O1
11.03.22	1625	I4	I3	O2	B2
18.03.22	2438	I1	B1	B2	O1
25.03.22	2544	I3/I4		O2	B2

Table 16: Summary of results from Aerotrak particle counters for PM10.0 μm

Date	# particles	Lowest	2. lowest	2. highest	Highest
04.03.22	1802	I2	B1	I1	O1
11.03.22	989	I3/I4		O2	B2
18.03.22	1025	I1	B2	B1	O1
25.03.22	1343	I4	I3	O2	B2

Table 15 and 16 summarizes the result from Figure 60, 62, 64 and 66. Here the total number of particles for each sterile table position are summarized in the column "# particles" for each measurement day. Following columns shows the sterile positions ranked form lowest measured number of particles/m^3 to the highest.

On the 25.03 position I3 and I4 had the same number of particles/m^3 of size PM5.0 μm and is therefore both listed as "Lowest". The same occurred on 11.03 where the same number of particles/m^3 of size PM10.0 μm was measured at I3 and I4.

Position O1 and B2 measured the highest number of particles of size PM0.5 μm and PM10.0 μm. for all measurement days. Both position are in the top area of the OR. When both O1 and B2 was measured on 18.03, the highest particle level was measured at position O1. This indicates that the highest particle level is in the top area of the OR, outside of the laminar airflow.

For three out of four measurement days (11.03, 18.03 and 25.03) the lowest number of particles/m^3 of size PM5.0 μm is measured inside the laminar airflow. On 04.03, the lowest level was measured in the boundary area of the LAF at position B1. For particles/m^3 of size PM10.0 μm, the lowest level was measured inside the LAF for all measurement days.

The lowest total number of particles/m^3 for both particle size PM5.0 μm and PM10.0 μm was measured on the measurement day 11.03, and the highest number of particles/m^3 for both size PM5.0 μm and PM10.0 μm was measured 04.03. The total number of particles of size PM5.0 μm were 2.2 times higher on 04.03 compared to 11.03. The total number of particles of size PM10.0 μm were 1.8 times higher on 04.03 compared to 11.03. The reason behind the decrease in particles/m^3 on 11.03 is unknown.

The total number of particles has the opposite trend as the active and passive sampler placed on the sterile tables, where the highest total number of CFU was measured on the measurement day 11.03.

In Figure 71, the CFU level and particle level are compared. From this figure there seem to be a trend of higher particle and CFU level when moving across the boundary of the LAF in the top area of the operating room. The exception is position I3 and I4 which have a high CFU level, and positions I1 and I2 which has a moderate particle level. It should be noted that position I4 and I1 both are position in the bottom part of the room, meaning that they don't fit with the aforementioned trend.

Based on theory presented in Section 2.1.1, the expected result in Figure 71 would be a higher number of particles of size PM5.0μm, followed by PM10.0μm, and lastly CFU/m^3 with the lowest total number. This is based on there likely being more smaller particles and the fact that only around 10% of particles carry bacteria (Aganovic, 2019). The expected trend can be seen at 6 out 16 positions, with the remaining measurement not following this trend. This compared with the results from Figure 67, 68, 69 and 70 show a very weak connection between the CFU/m^3 results from the active sampler and the particle/m^3 results from the Aerotrak placed on the sterile tables.

5.4 Summary of relative humidity results

As seen in the Figures 72 and 73, the relative humidity level in the OR increases each measurement day. A likely reason for the changing relative humidity in the operating room is the changing temperature and relative humidity in the outdoor air. Weather data for Trondheim on all measurement days was gathered from a weather station placed approximately 2.6 km from St. Olavs hospital, shown in Table 17.

Table 17: Comparison of the results from the active sampler, passive samplers, particle measurements and relative humidity

Date	**Average temperature outside** [$°C$]	**Average relative humidity outside** [%]	**Average relative humidity inside** [%]	**# CFU Active**	**# CFU Passive**	**# Particles PM5.0** μ**m**	**# Particles PM10.0** μ**m**
04.03.22	-0.9	61.3	14.3	42	8	1802	3534
11.03.22	8.1	41.4	16.2	45	10	989	1625
18.03.22	5.7	60.6	21.8	27	2	1025	2438
25.03.22	6.9	73.8	29.1	21	0	1343	2544

Table 17 summarizes the key parameters measured during the mock surgeries, focusing on the sterile tables. The columns "Average temperature outside" and "Average relative humidity outside" shows the average temperature and average relative humidity outside in Trondheim reported by Trondheim Havn IKS (2022) between 09:00 and 14:00 each measurement day. The column "Average relative humidity inside" shows the average relative humidity measured by the TinyTag sensors placed on the sterile tables inside the OR. Following is the total number of CFU measured by the active samplers, total number of CFU measured with passive samplers inside the LAF and total number of particle measured with the Aerotrak inside the LAF.

From Table 17 it appears that the relative humidity might have an affect on the CFU and particle level measured in the OR. With the exception the results from the measurement day 11.03, CFU decrease as the relative humidity increase for all measurement days. The average relative humidity measured outside of the hospital, follow the inverted trend of the CFU for all measurement day. Here the relative humidity decrease on the 11.03, while the CFU increase. The total number of particles follows the trend of the outside average relative humidity as it decreases on 11.03, before increase the 18.03 and 25.03. The relationship between average relative humidity, CFU and particles is difficult to confirm. The measurement station from Trondheim Havn IKS (2022) is placed approximately 2.6 km from St. Olavs hospital, meaning that this is not necessarily the same relative humidity as outside St. Olavs hospital. The fact that the average relative humidity level measured inside the OR does not decrease on 11.03 shows that the connection between relative humidity outside and CFU is fragile as the relative humidity level inside is the representative relative humidity level for the sterile tables.

Table 18: Relative humidity compared with results from passive samplers placed outside of the LAF

Date	Average relative humidity outside the LAF[%]	# CFU outside the LAF
04.03.22	13.8	242
11.03.22	14.9	222
18.03.22	21.2	126
25.03.22	25.7	49

Interestingly, the CFU level measured outside the laminar airflow decrease every measurement day while the average relative humidity level increase. Here the average relative humidity from 09:00-14:00 measured by the TinyTag placed at the computer table is shown. This again indicates that there might be a relationship.

5.5 Limitations, errors and possible improvements for this study

Even though the mock surgeries where planned in detail, some errors and possible improvements were discovered during the measurement period. These errors and improvements, as well some limitations for this thesis are listed below:

During the first mock surgery there was more talking compared to the later mock surgeries as this was the first time performing the mock surgery for all participants. The extra talking was in the form of explaining and giving directions during simulated surgery. The extra amount of talking was still limited as much as possible and the extra time used was not substantial. This is therefore not believed to have affect the results significantly.

The first measurement day there were also problems with one of the active samplers with the sampler turning off right after a new measurement started. This resulted in a delay between the two active sampler and increased the duration the mock surgeries this measurement day. The delay have not affected the results in any capacity.

As mentioned in Section 3.5.6, the distribution nurse did not wear sterile gloves during the mock surgeries. As the distribution nurse performed hand movements directly over the active sampler, it may have caused the CFU measurements from the active sampler to be higher than what can be expected during a real surgery were the distribution nurse wear sterile gloves.

The results from the AirDistSys 5000 could not be included in the results due inconstancy in the measuring method and sensor errors. The air velocity and air turbulence results from this equipment could have made it possible to understand the observed difference between the measurement days. With these results, the laminar airflow could have been visualized providing more information about the movement of air contamination in operating room used in the mock surgeries.

Based on the comparison between the particle results and the CFU results, it seems that several of the peaks in particle measurement happens when there is no peak in CFU and vise versa. This might due to the Aerotrak measuring tube being very close to the active sampler. This means that the Aerotrak only measured the particles not inhaled by the active sampler. These sensors should have been placed further apart to ensure that the didn't affect each other.

On the measurement day 18.03, one of the positions for the sterile tables was changed in order to confirm a higher CFU level in the top, boundary area of the laminar airflow. This change did confirm a higher CFU level in this area but this also meant that the positions were not repeated equally to the measurement day 04.03. This meant that position I2 was only measured once while position B2 was measured three times. This resulted in a lower credibility in the results for position I2 as this position was only measured once.

When reviewing the recording of the mock surgeries, it was discovered that several of the peaks in the Aerotrak 1 and 2 was caused by the sterile nurse touching paper positioned close to the Aerotrak. The paper was used to take notes such as the start time for the active samplers. The peaks were mainly in particles of size PM0.3, PM0.5, PM1.0 and PM3.0, but caused some peaks in PM5.0 and PM10.0. This was noted in Appendix H.

The measurements for this study was performed in march of 2022, a time where the COVID-19 pandemic was still ongoing. Restrictions, sickness and other COVID related complications lead to a reduced number of available participants and the mock surgeries being postponed a week. As less participants were present during the mock surgeries, compared to a real surgery, the CFU and particle level in the measurements are lower than what can be expected during a real surgery.

Even though all mock surgeries were recorded, the task of analysing peaks and abnormalities in the results turned out to be very challenging. With the various equipment having different sampling rate, it was difficult to pin point the cause for the peaks and variations in the measurements. As the active sampler had a sampling time of ten minutes it was difficult to confirm the origin of the measured CFU as various activities were being performed during the ten minute period.

Weather data from Trondheim was gathered from a weather station 2.6 km from St. Olavs hospital. It would have been beneficial for this study if the relative humidity was measured outside the hospital, providing information of the humidity entering the OR through the ventilation system.

5.6 Further work

The objective of this thesis was to observe the influence of the position of sterile tables under vertical laminar airflow on bacteria and particles on and around the sterile tables. As the CFU and particle results gathered from the mock surgeries varied between each measurement day, the mock surgeries should be repeated multiple times in order to confirm the observed tendencies.

Following is some recommendations for further research related to the topic of this thesis:

- As this thesis observed contradicting results for the CFU measurement with one measurement day showing an opposite result of both the hypothesis and the other measurement days, more mock surgeries should be performed under similar conditions. By performing more similar mock surgeries, it is possible to confirm that positioning the sterile tables inside the laminar airflow result in a lower bacterial contamination compared to the sterile table being placed in boundary area or outside the laminar airflow.
- The relationship between relative humidity, CFU and particles should be further researched in order to confirm the relationship indicated in this study. If the relationship can be confirmed, it suggests that surgical environments should keep a stable relative humidity level in the air by adding or removing moisture the supply air in order to reduce CFU in the air. By measuring CFU and relative humidity in a vertical laminar airflow environment were the relative humidity can be controlled, the relative humidity level can be adjusted to observe the effect on CFU level inside and outside the laminar airflow.

Following are suggested improvements for future measurements if the method in this study were to be repeated:

- An anemometer should be used in order to measure the air velocity and air turbulence each mock surgery or measurement day in order to use these parameters to understand variations in the CFU results.
- The distribution nurse should wear gloves during the entire mock surgeries as the hand movements are performed inside the LAF, over the sterile tables. The distribution nurse wearing gloves is more similar to a real surgery.
- The time between the mock surgeries should be increased to ensure that the air contamination and indoor environment is more similar for each mock surgery.
- The relative humidity should be observed in order to confirm the observed trends in this study. New studies were the relative humidity is controlled is recommended.
- All sterile table positions should be measured the same day in order to account for difference between the measurement days.
- Touching of paper close to the Aerotrak particle counter should be avoided as it affected the particle measurements.
- More participants should be present during the mock surgeries in order to have a more similar surgical environment as during a real knee arthroplasty surgery.

6 Conclusion

This master thesis investigated CFU and particle contamination based on the positioning of sterile tables in a vertical laminar airflow OR environment. Through the use of eight mock surgeries performed in an operating room at St. Olavs hospital in Trondheim, eight different positions for the sterile tables where investigated. Of these positions, four positions were inside the laminar airflow, two positions in the boundary area and two positions outside the laminar airflow. Though the use of two air samplers and multiple blood agar plates, CFU was measured in the air around the sterile tables, as well as on the sterile table surfaces.

The thesis tried to answer the following research question: *Does the air contamination and number of bacteria on and around the sterile tables increase when the sterile tables are placed in the boundary area or outside of the vertical laminar airflow, compared to being placed inside the vertical laminar airflow?*.

The original hypothesis for this thesis was that the CFU level and particle level would be higher outside and in the boundary area of the laminar airflow, compared to the inside of the laminar airflow for all mock surgeries. Based on this hypothesis the CFU level and particle level at the sterile table positions should gradually increase as the tables are moved from the inside of the LAF canopy to the outside.

The results from the air sampling showed the highest CFU level on the sterile tables placed outside of the laminar airflow, and the lowest CFU level inside the laminar airflow for three out of four measurement days. For these three measurement days, the CFU level increased every time a sterile table was moved further outside the laminar airflow, and the CFU decreased every time the sterile tables were moved further inside the laminar airflow. The CFU did on the other hand not gradually increase for every position moving from the inside the LAF to the outside.

The exception from these result were on one measurement day, showing the highest CFU level inside the laminar airflow and the lowest in the boundary area. During this measurement day, the CFU level increased when the sterile tables were moved inside the laminar airflow. After reviewing recording of all mock surgeries, the reason for the deviating results are unknown.

The results from the blood agar plates showed that the total number of CFU landing on all surfaces was between ten times higher and two times higher outside of the laminar airflow compared to inside the laminar airflow. The blood agar plates placed outside the laminar also showed that the number of CFU landing surfaces was noticeably higher in some areas of the OR. This is believed to be due to the surfaces position in regards to the OR's exhaust vents. The blood agar plates placed outside of the OR did not show a higher CFU level close to the door, despite there being three door openings per mock surgery.

Interestingly, the relative humidity results indicated that relative humidity might influence the number of CFU landing on surfaces outside of the laminar airflow. The number of CFU measured with blood agar plates outside of the laminar airflow decreased for every measurement day, as the relative humidity increased every measurement day. The number of CFU measured with blood agar plates inside the laminar airflow did not follow this trend as the CFU level was very similar each measurement day.

Regarding the research questions, this thesis did confirm that the position of the sterile tables does matter in regards to bacterial and particle contamination. The results from the air sampler confirmed that the CFU level in the air is likely to be higher just outside of the laminar air or in the boundary area of the laminar airflow, compared to inside the laminar airflow. The result did on the other hand show that other factors can have a stronger affect on the CFU level in the air, as one measurement day showed a higher total CFU level inside the laminar airflow compared to outside and in the boundary of the laminar airflow. The blood agar plates placed on the sterile tables did not confirm the same trend as the air samplers as only a few CFU was measured by multiple blood agar plates. The particles measurements showed that highest particle level was measured at sterile table positions outside or in the boundary area of the laminar airflow every measurement day, while the lowest particle level was measured inside the laminar airflow every measurement day.

The thesis was intended to show the necessity of having vertical laminar airflow systems large enough to ensure that all sterile equipment is placed inside the laminar airflow. The result does indicate that placing sterile tables inside the laminar airflow does result in a positive effect as it decreased the number of CFU and particles measured on and around the sterile tables. This means that ensuring that sterile tables and equipment are placed inside the boundaries of the laminar can be a preventive measure against SSIs. More research is needed to confirm the results from this thesis as it only found indications and trends that must be confirmed through further research.

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Appendix

A SketchUp reference list

1. **Item title:** Anasthesia Machine Mayo
   Creator username: MJThiele
   Link: https://3dwarehouse.sketchup.com/model/88b93ee3-0178-49b7-a928-283d90e7041f/Anasthesia-Machine-Mayo
2. **Item title:** Anesthesia Supply Cart Mayo
   Creator username: MJThiele
   Link: https://3dwarehouse.sketchup.com/model/05f7c967-09f9-4775-b022-558921b1dcf0/Anesthesia-Supply-Cart-Mayo
3. **Item title:** Doctor 02
   Creator username: Katarzyna M.
   Link: https://3dwarehouse.sketchup.com/model/0ffdcde5-a9aa-496f-a9f9-6db8b2a47193/DOCTOR-02
4. **Item title:** Doctor 03
   Creator username: Katarzyna M
   Link: https://3dwarehouse.sketchup.com/model/9624b8f4-c50c-4e78-beb8-8863a6ae8e46/DOCTOR-03
5. **Item title:** Doctor 04
   Creator username: Katarzyna M
   Link: https://3dwarehouse.sketchup.com/model/1ba6e6bc-a3ed-4995-9cad-05c60833396e/DOCTOR-04
6. **Item title:** Doctor 05
   Creator username: Katarzyna M
   Link: https://3dwarehouse.sketchup.com/model/32d90b13-817d-474d-b0b0-3890f2346377/DOCTOR-05
7. **Item title:** Doctor 07
   Creator username: Katarzyna M
   Link: https://3dwarehouse.sketchup.com/model/a3b02c49-7366-42c7-92b8-f99ceef267d9/DOCTOR-07
8. **Item title:** Surgical Table
   Creator username: Spudz
   Link: https://3dwarehouse.sketchup.com/model/3f69820797eab9a1d3d16e22a491eab8/Surgical-Table

9. **Item title:** Computer

   Creator username: AJ E

   Link: `https://3dwarehouse.sketchup.com/model/029c3d31-d17f-47b1-be24-b1d1653d1392/Computer`

10. **Item title:** Hanging Shelf Ceiling Mounted

    Creator username: Vanessa B.

    Link: `https://3dwarehouse.sketchup.com/model/193d70d6-0c40-4a07-89fb-e8c49f21db3b/Hanging-Shelf-Ceiling-Mounted`

11. **Item title:** Instrument Table Test

    Creator username: Chris G.

    Link: `https://3dwarehouse.sketchup.com/model/fd1e08cb-bbe5-4a95-a068-9bb44ba2e753/Instrument-Table-Test`

12. **Item title:** Medical Table

    Creator username: Modelfundgrube

    Link: `https://3dwarehouse.sketchup.com/model/e27b5f3a-9f12-4412-bd6a-cd7e70c1e0be/Medical-Table`

13. **Item title:** M7490 - Light, Surg, Ceiling Mtd, Dual, Unequal Dia Head

    Creator username: MILSTD 1691 Medical Equipment SEPS2BIM

    Link: `https://3dwarehouse.sketchup.com/model/u8c95222e-f29d-4dc3-af31-51345de59fc9/M7490-Light-Surg-Ceiling-Mtd-Dual-Unequal-Dia-Heads`

14. **Item title:** Sliding Door

    Creator username: Carolineruss

    Link: `https://3dwarehouse.sketchup.com/model/ca42f940-0602-4b4c-9982-2307ed04b507/Sliding-Door`

15. **Item title:** Trash Can

    Creator username: Neon

    Link: `https://3dwarehouse.sketchup.com/model/d97a6917-82b8-49a6-858c-41eba3e7f1e0/Trash-can`

16. **Item title:** Grille Ventilation

    Creator username: Pat P.

    Link: `https://3dwarehouse.sketchup.com/model/udad3e92c-f4b8-4a53-bab2-6c903342ed3c/Grille-Ventilation`

17. **Item title:** Tall Windows

    Creator username: Thomas U. Fosseli

    Link: `https://3dwarehouse.sketchup.com/model/df299a45-16dd-4805-82ed-3153698dfd47/Tall-Window-120x60`

18. **Item title:** Diffuser

    Creator username: hamada A.

    Link: https://3dwarehouse.sketchup.com/model/41cd5721b6dd0321b8bd9e719292218c/Diffuser

19. **Item title:** Table d'instrumentation

    Creator username: Albin L.

    Link: https://3dwarehouse.sketchup.com/model/6fab84300095765e8b90ca5a8d93018c/Table-dinstrumentation

20. **Item title:** medical table

    Creator username: gromoff

    Link: https://3dwarehouse.sketchup.com/model/ucf59bcc0-e672-430b-a194-e8976c5cd033/medical-table

21. **Item title:** Metal Cabinet 1

    Creator username: Fritz R.

    Link: https://3dwarehouse.sketchup.com/model/uc04e51ba-34a5-4e8f-b0f8-12b452f78a73/Metal-Cabinet-1

22. **Item title:** Herman Miller Healthcare L-Cart

    Creator username: Lindsey D.

    Link: https://3dwarehouse.sketchup.com/model/4fb55fe0-f625-4c64-a51f-f4553ff78662/Herman-Miller-Healthcare-L-Cart

23. **Item title:** Computer chair

    Creator username: Zeta

    Link: https://3dwarehouse.sketchup.com/model/edd530c7-0fc5-4a7a-8cb1-5b104113cbe0/Computer-chair

24. **Item title:** M1800 - Computer, Microprocessing, W CRT Monitor

    Creator username: MILSTD 1691 Medical Equipment SEPS2BIM

    Link: https://3dwarehouse.sketchup.com/model/u48a8cf21-87f5-4187-bd1d-7a7e67df52c9/M1800-Computer-Microprocessing-W-CRT-Monitor

25. **Item title:** Bakery Trolley

    Creator username: Abdul Yazid l.

    Link: https://3dwarehouse.sketchup.com/model/6a2f39fb30c4b7c5e2e6aa5366c8ffc3/Bakery-Trolley

B Description of equipment and measurement accuracy

The following sections provides a description of the equipment AirThings view Plus and AirDystSys 5000 with an overview of the sensor data provided by the manufacturers.

B.1 AirThings View Plus

Figure 77: Picture of AirThings View Plus monitor

During the mock surgeries, six AirThings sensors were placed in operating room in order to monitor the indoor environment. The AirThings sensors can measure air temperature, relative humidity, particle matter of size PM2.5 μm, CO_2, VOC and air pressure (Airthings ASA, 2022). Particle matter was not measured during the mock surgeries.

Table 19: Sensor specification for AirThings View Plus (Airthings ASA, 2022)

Parameter	**Sensor interval**	**Sensor accuracy**	**Measurement range**
Temperature	5 min	$\pm 0.5°C$	NA
Relative humidity	5 min	$\pm 3\%$	NA
Air pressure	5 min	$\pm$0.6 hPa	NA
PM2.5	10 min or 60 min	Below 150 $\mu g/m^3$ $\pm 5 \mu g/m^3$ + 15% Above 150 $\mu g/m^3$ $\pm 5 \mu g/m^3$ + 20%	0 - 500 $\mu g/m^3$
CO_2	5 min	$\pm$50 ppm	400 - 5000 ppm
VOC	5 min		0 - 10 000

NA = Not Available

B.2 AirDistSys 5000

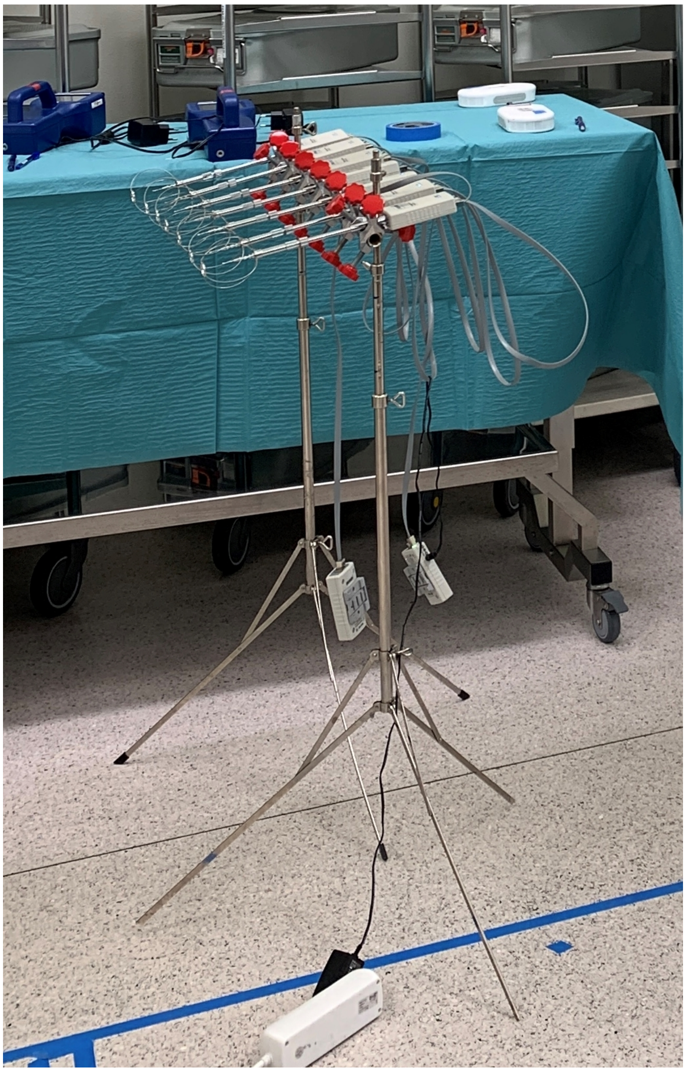


Figure 78: Picture of the AirDistSys 5000

AirDistSys 5000 consist of seven individual sensors connected via cable. The sensors then communicated with a computer via Bluetooth. The sensors was mounted on a tripod with the sensors 700 mm above the ground, the same as the height of the sterile tables. The results from AirDistSys 5000 could be used to describe how the velocity and turbulence intensity changes from the inside of the LAF to the outside of the LAF.

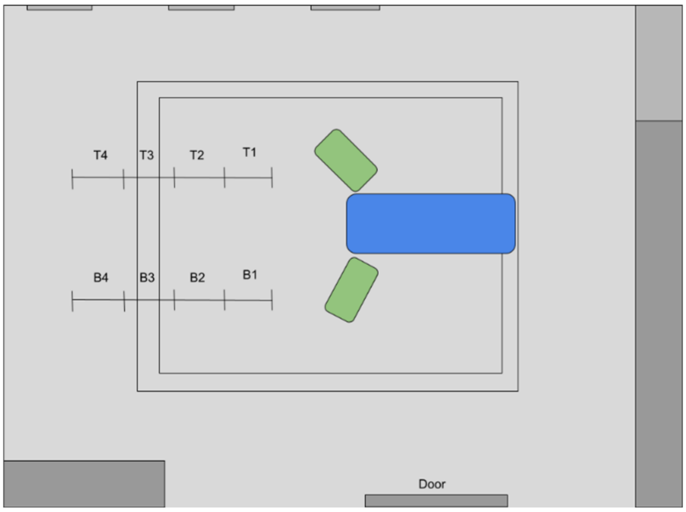


Figure 79: Measuring points for AirDistSys 5000

Figure 121 shows the measuring point used for the AirDistSys 5000 on the measurement day 25.03. By measuring one line from the inside of the LAF to the outside, the full development of the airflow can be visualized. The line moves across the center of the sterile tables positions, providing a description of the air velocity, turbulence intensity and temperature at all studied positions.

On the measurement days 04.03 and 11.03, the AirDistSys 5000 was positioned on the same positions as the sterile tables investigated on the measurement day. The individual sensors were positioned moving from west to south similarly to 25.03.

Table 20: Sensor specification for AirDistSys 5000

(Sensor Electronic, 2014)

Parameter	**Sensor interval**	**Sensor accuracy**	**Measurement range**
Temperature	2 s	0.2 $°C$	-10 - +50 $°C$
Air velocity	2 s	±0.2 m/s	0.05 - 5 m/s

C Results from AirThings View Plus sensor

The following sections describe the results from AirThings View Plus sensors including air temperature, atmospheric pressure and CO_2.

C.1 Temperature results from AirThings sensor

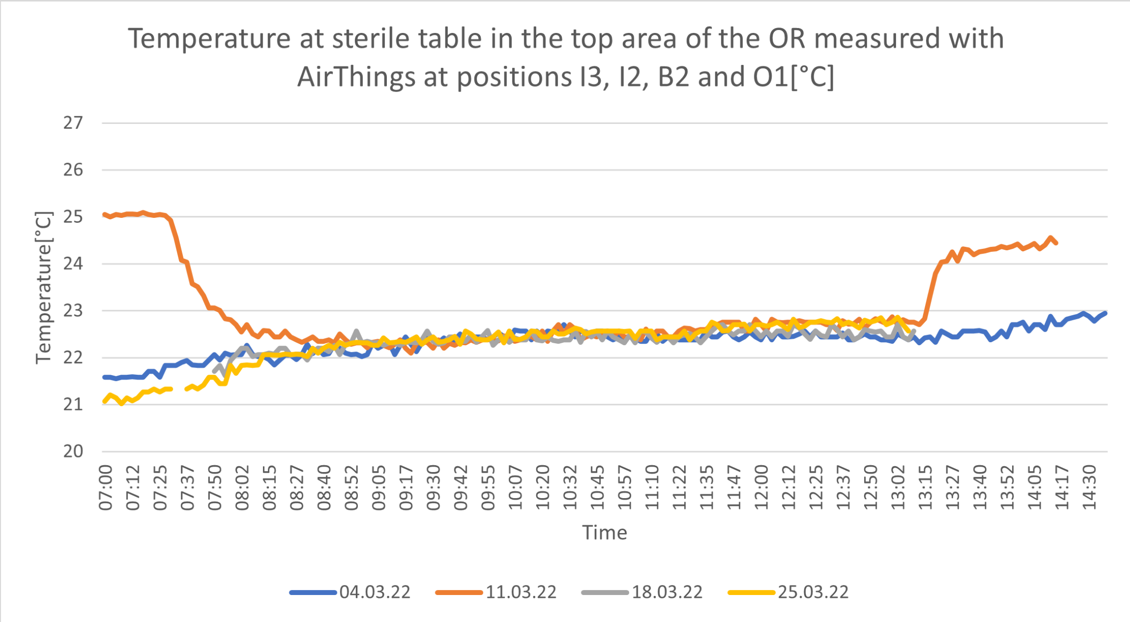


Figure 80: Temperature at sterile table in the top area of the OR measured with AirThings at positions I3, I2, B2 and O1

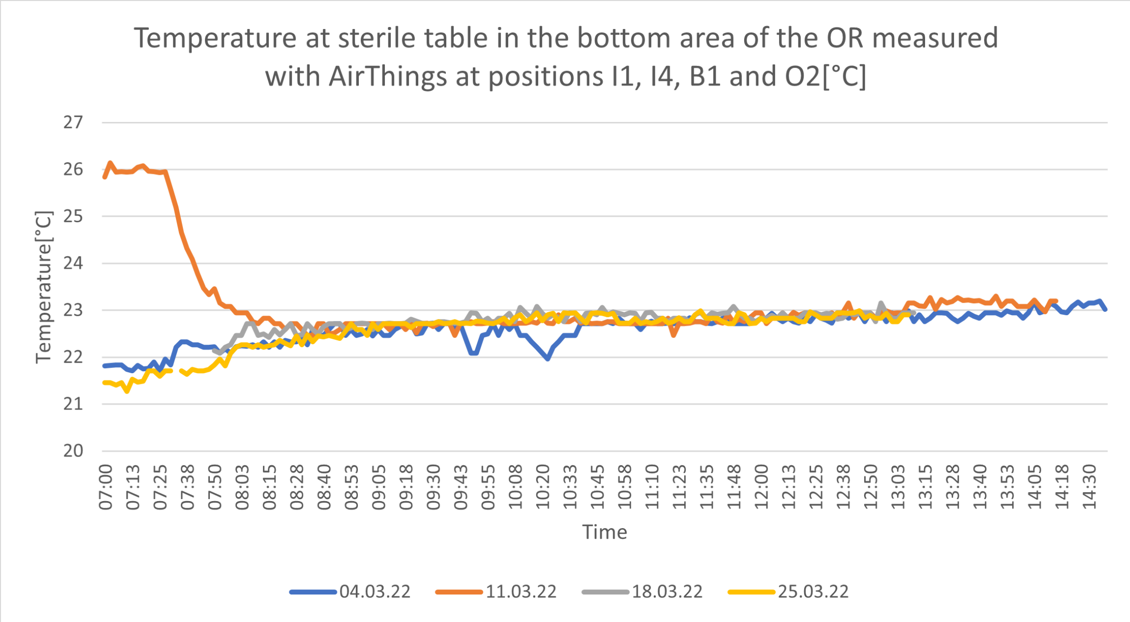


Figure 81: Temperature at sterile table in the bottom area of the OR measured with AirThings at positions I1, I4, B1 and O2

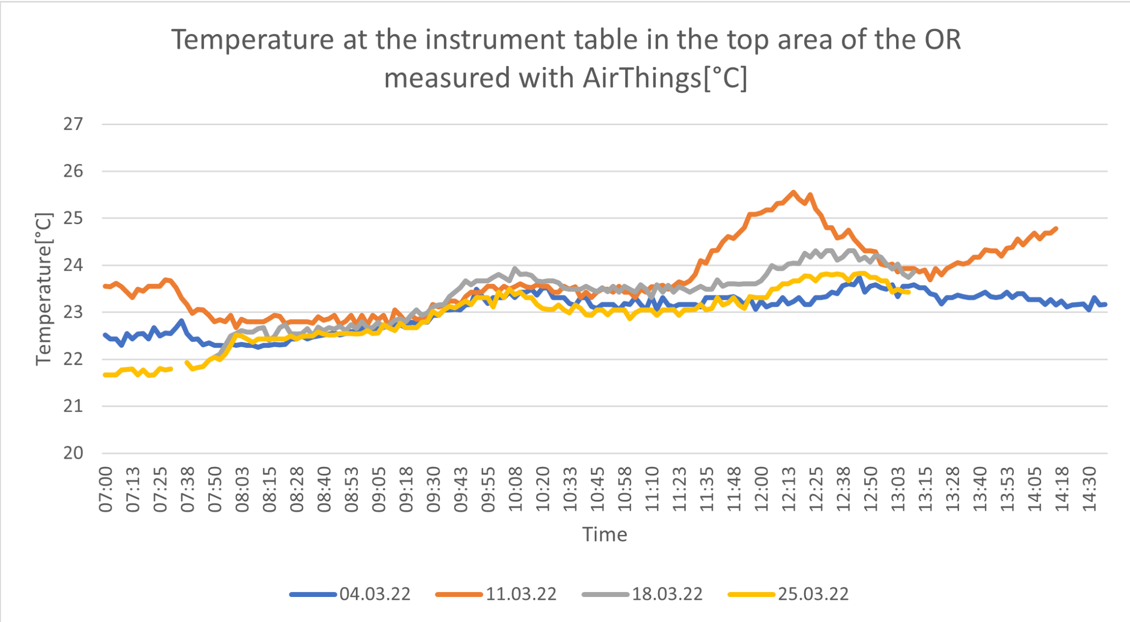


Figure 82: Temperature at the instrument table in the top area of the OR measured with AirThings

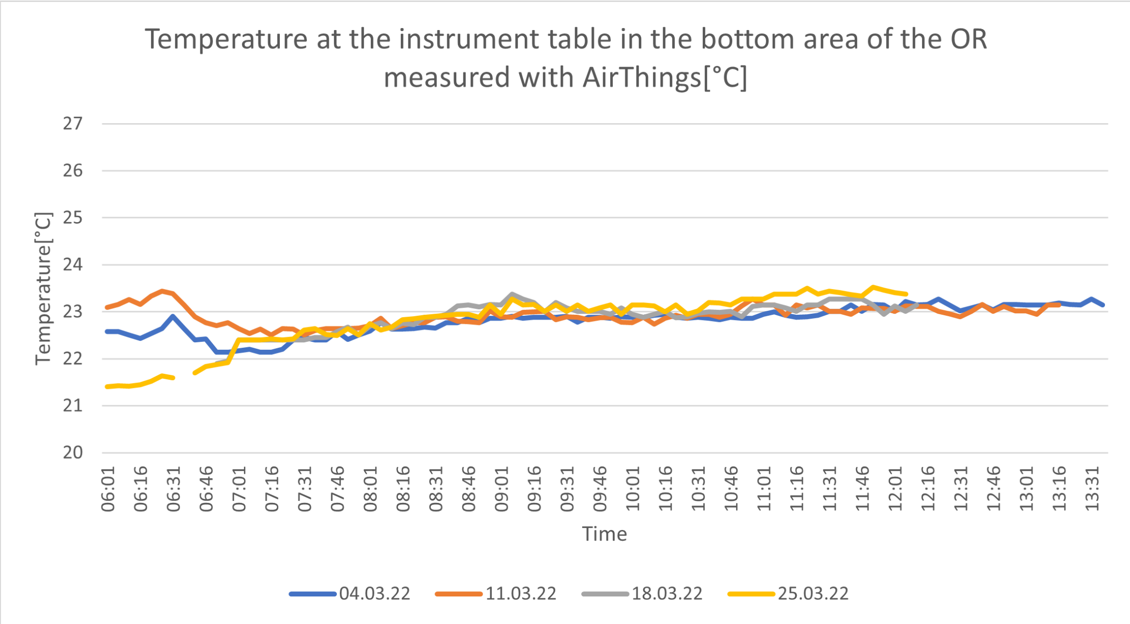


Figure 83: Temperature at the instrument table in the bottom area of the OR measured with AirThings

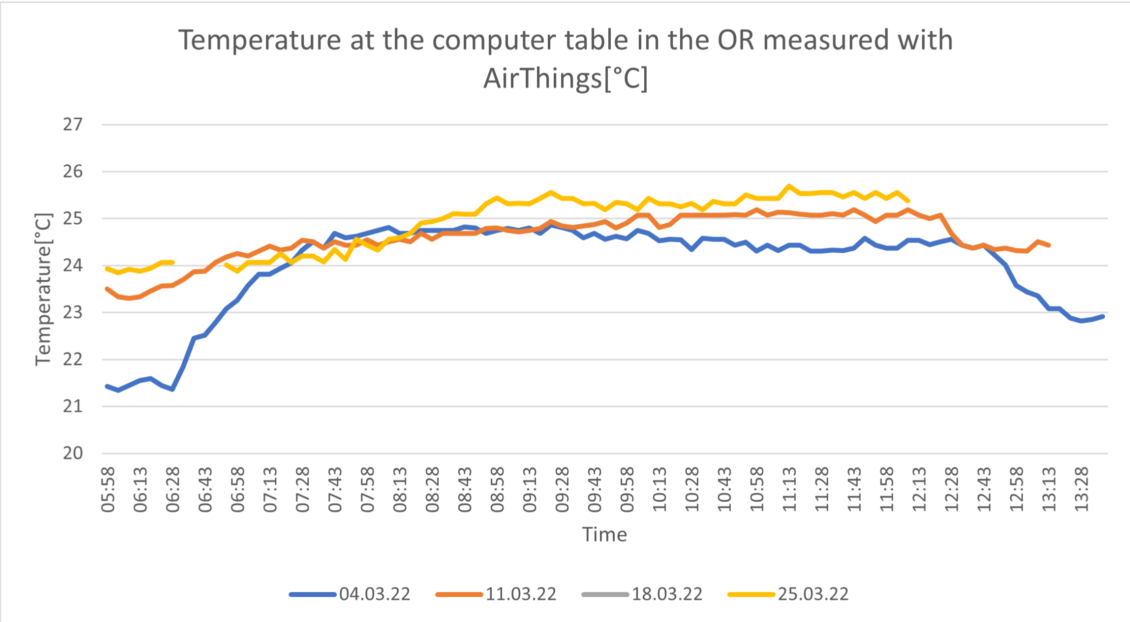


Figure 84: Temperature at the computer table in the OR measured with AirThings

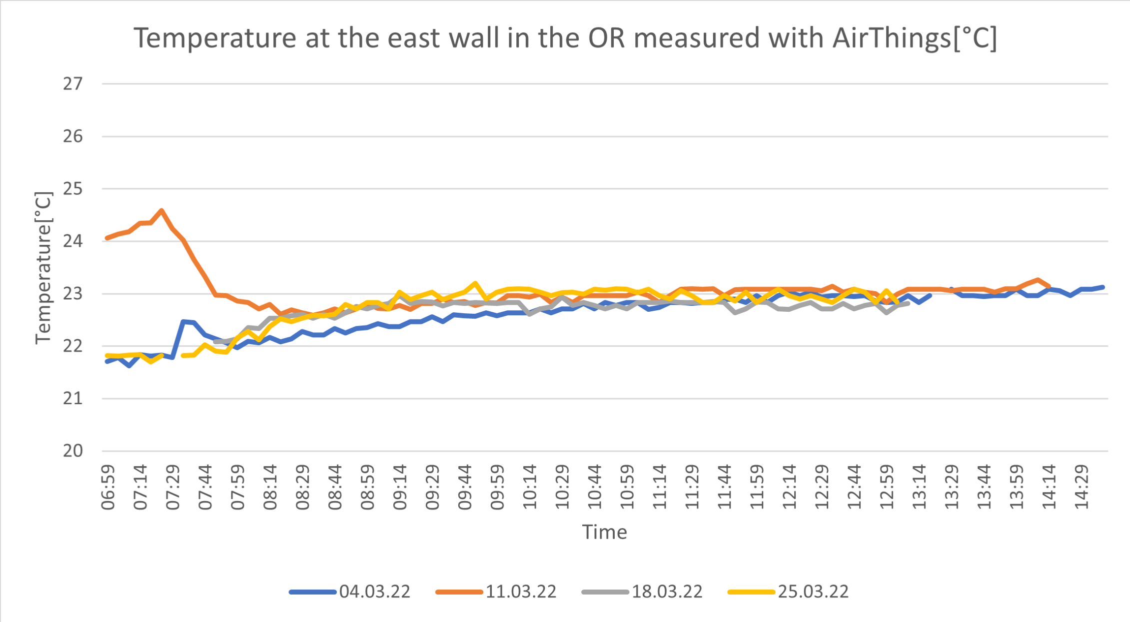


Figure 85: Temperature at the east wall in the OR measured with AirThings

C.2 Relative humidity results from the AirThings sensors

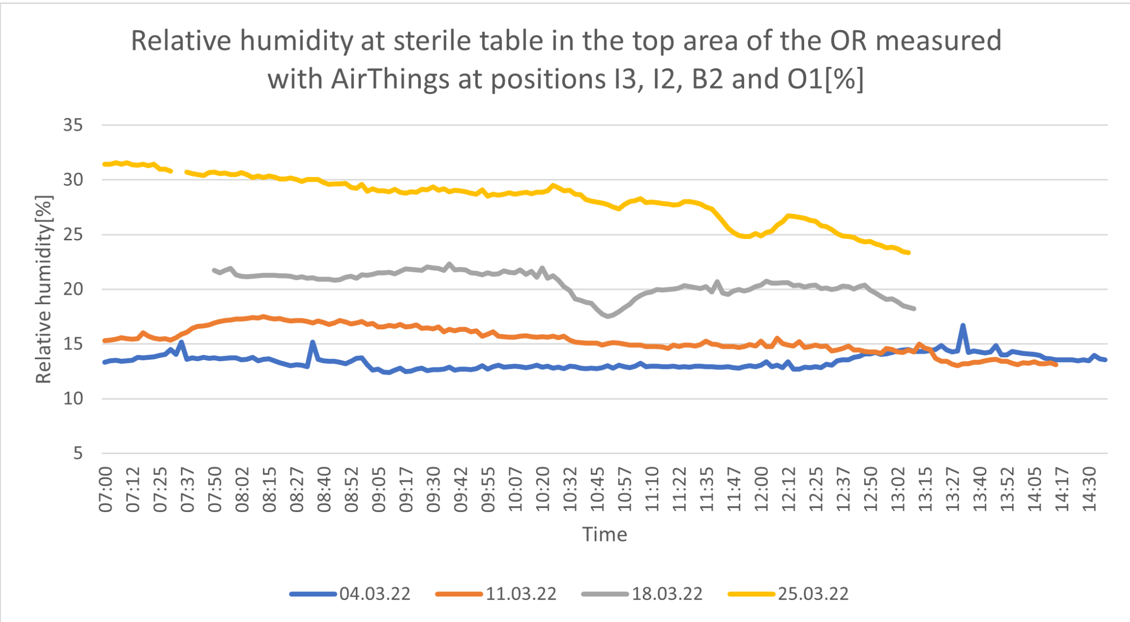


Figure 86: Relative humidity at sterile table in the top area of the OR measured with AirThings at positions I3, I2, B2 and O1

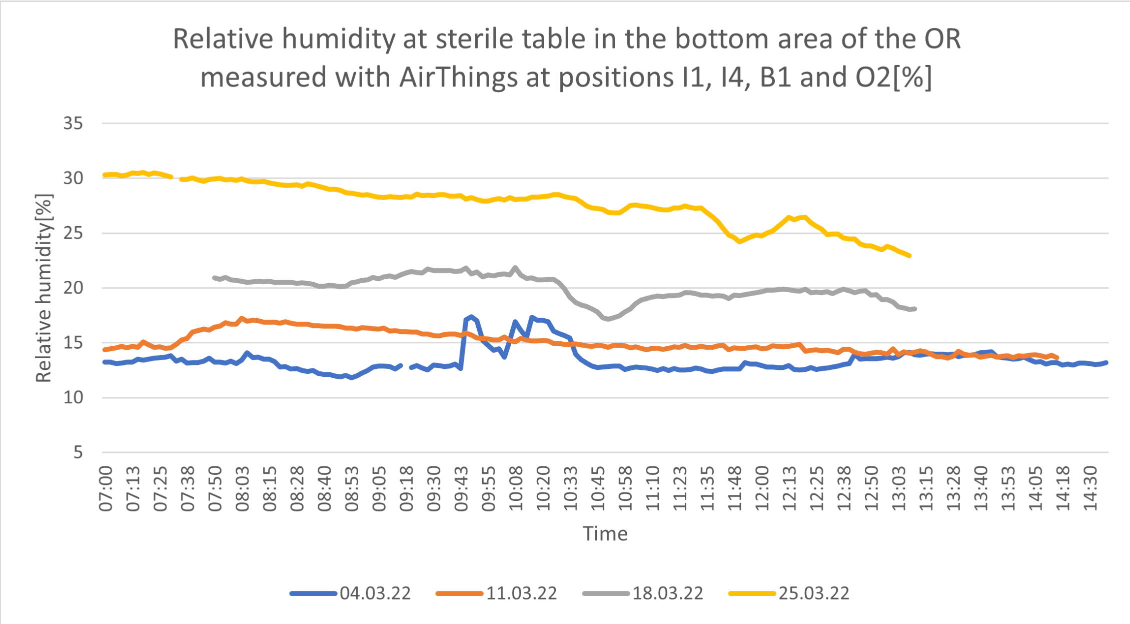


Figure 87: Relative humidity at sterile table in the bottom area of the OR measured with AirThings at positions I1, I4, B1 and O2

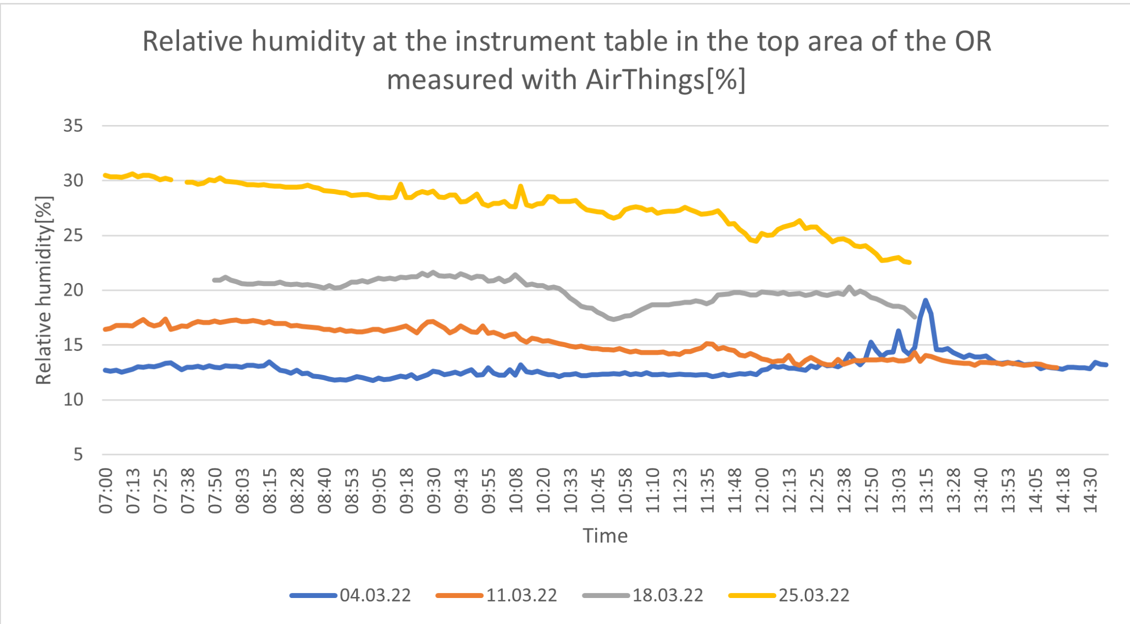


Figure 88: Relative humidity at the instrument table in the top area of the OR measured with AirThings

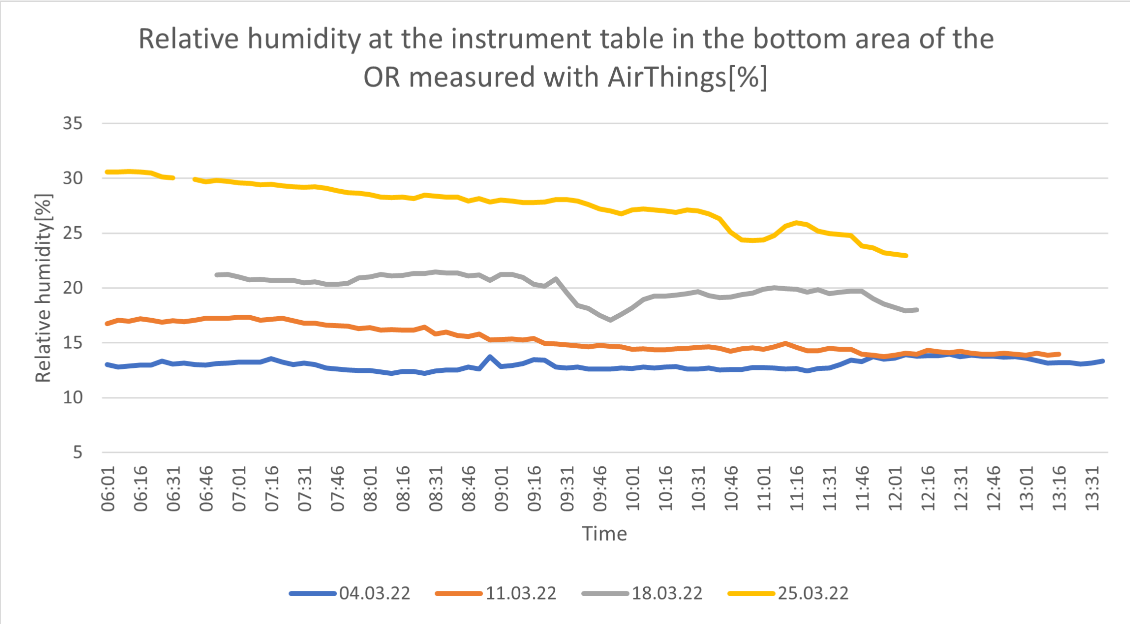


Figure 89: Relative humidity at the instrument table in the bottom area of the OR measured with AirThings

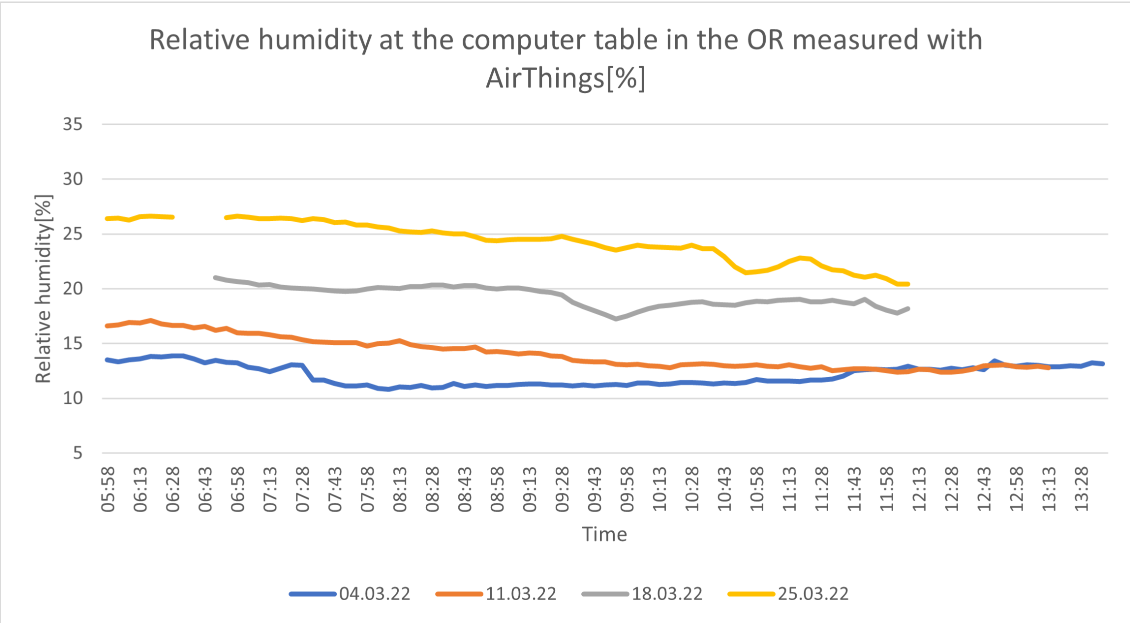


Figure 90: Relative humidity at the computer table in the OR measured with AirThings

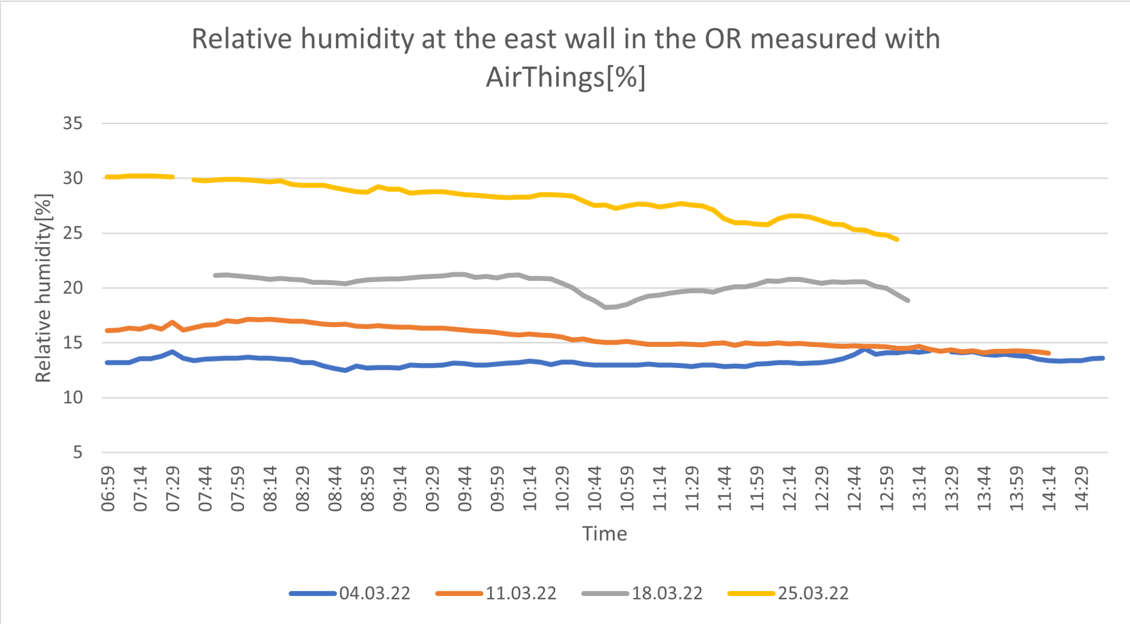


Figure 91: Relative humidity at the east wall in the OR measured with AirThings

C.3 Atmospheric pressure results from AirThings sensor

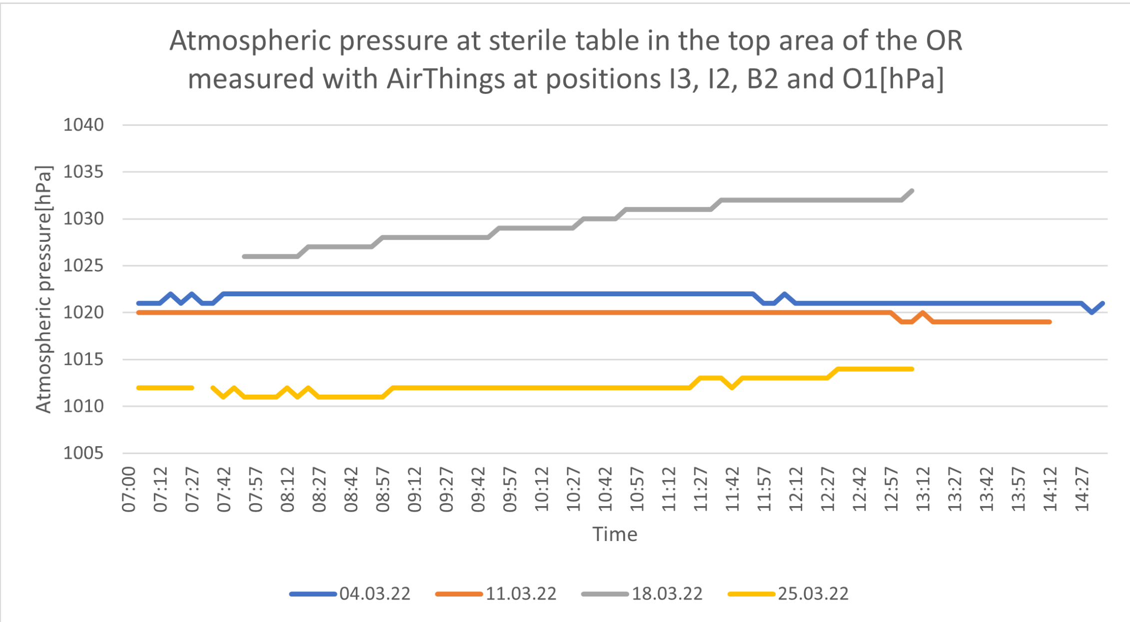


Figure 92: Atmospheric pressure at sterile table in the top area of the OR measured with AirThings at positions I3, I2, B2 and O1

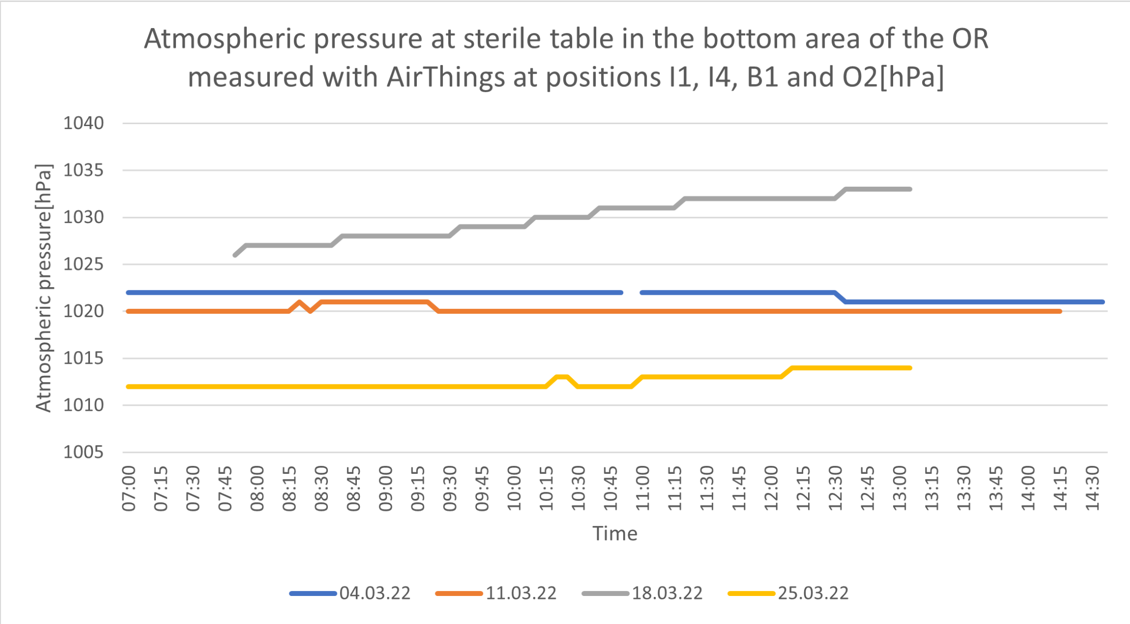


Figure 93: Atmospheric pressure at sterile table in the bottom area of the OR measured with AirThings at positions I1, I4, B1 and O2

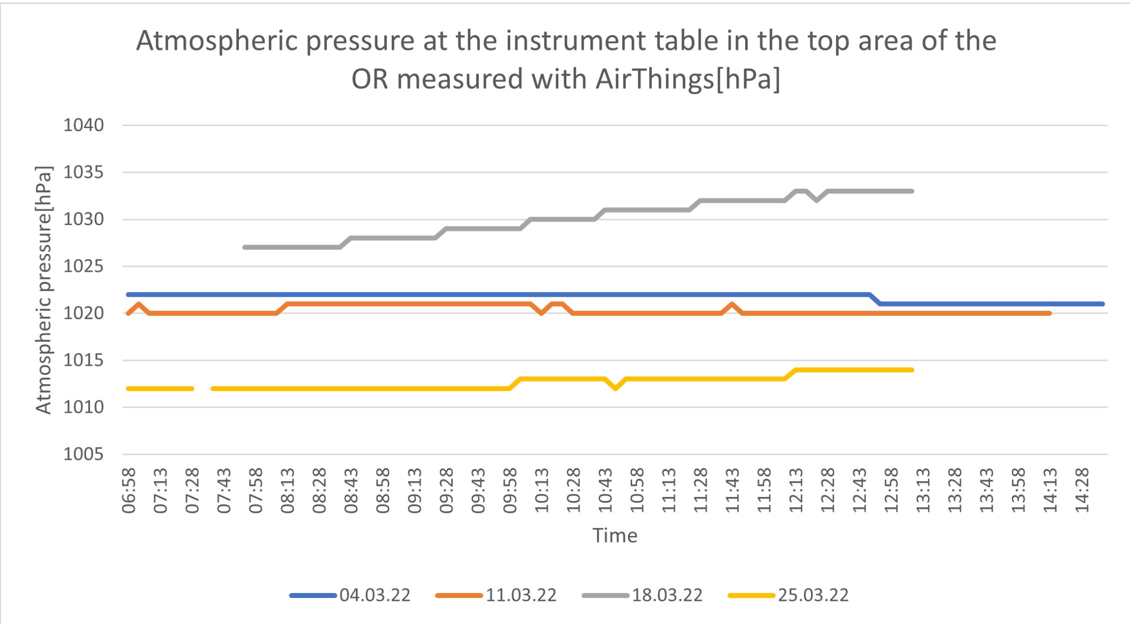


Figure 94: Atmospheric pressure at the instrument table in the top area of the OR measured with AirThings

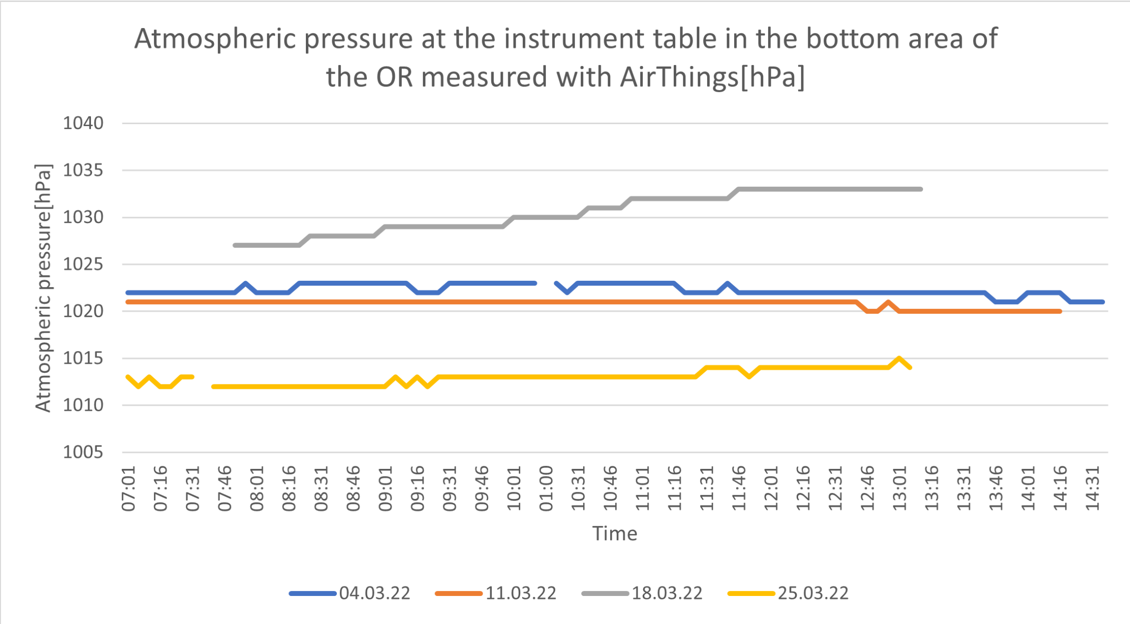


Figure 95: Atmospheric pressure at the instrument table in the bottom area of the OR measured with AirThings

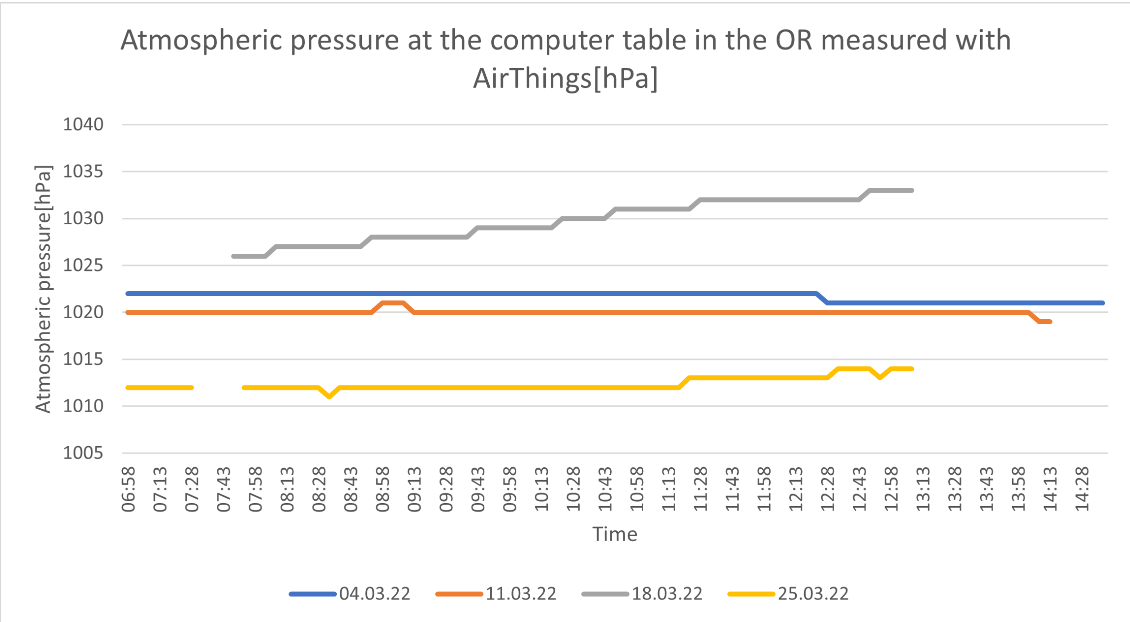


Figure 96: Atmospheric pressure at the computer table in the OR measured with AirThings

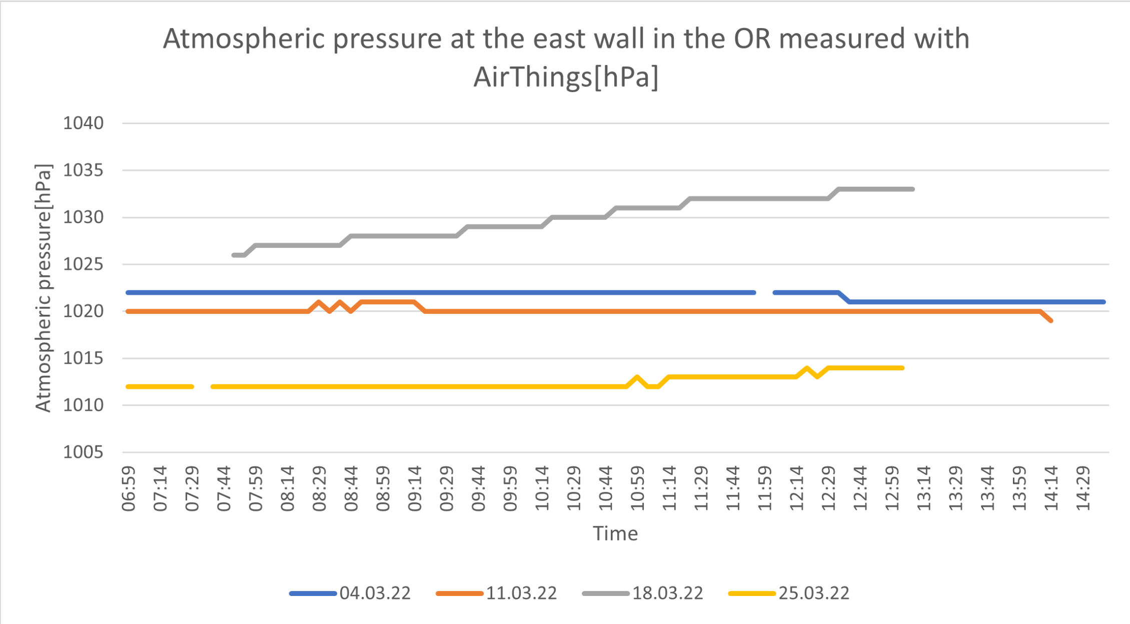


Figure 97: Atmospheric pressure at the east wall in the OR measured with AirThings

C.4 CO2 results from the AirThings sensors

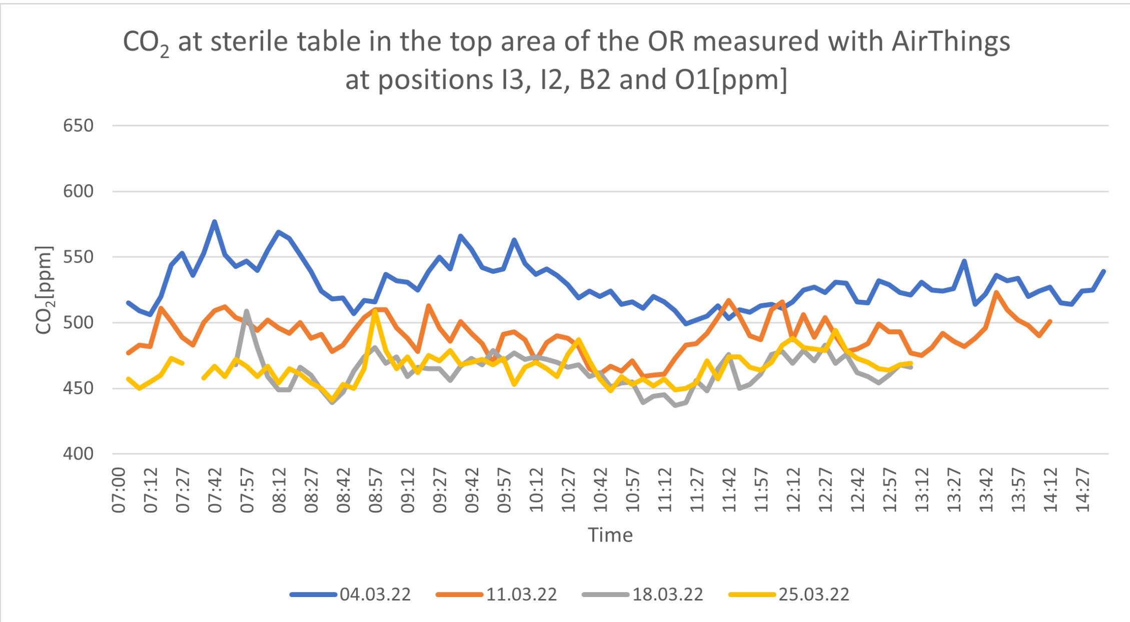


Figure 98: CO_2 at sterile table in the top area of the OR measured with AirThings at positions I3, I2, B2 and O1

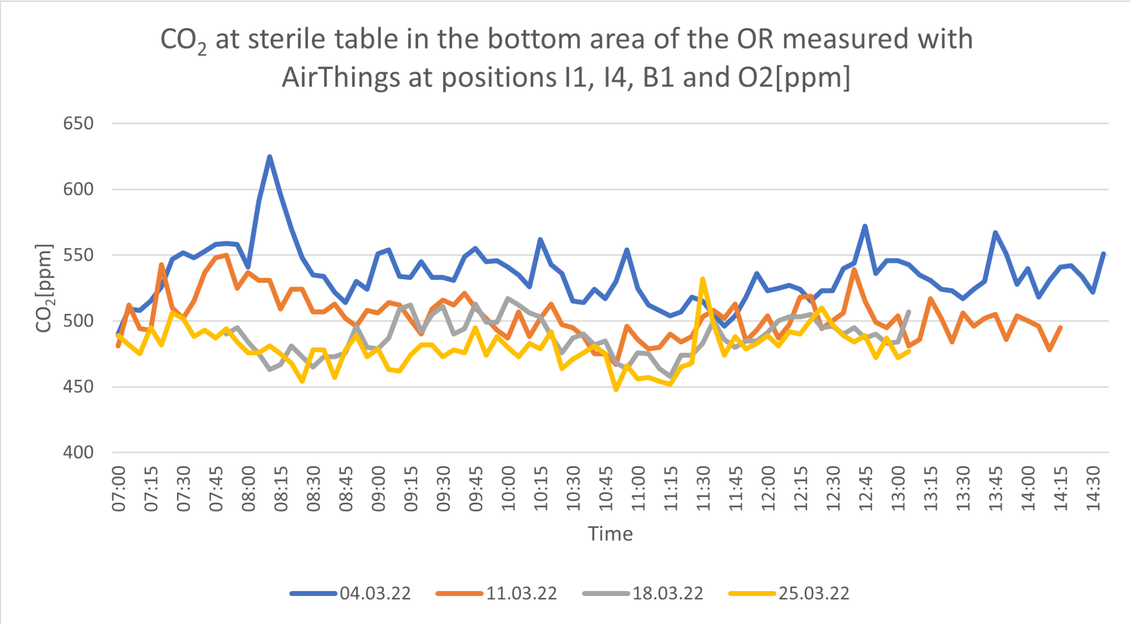


Figure 99: CO_2 at sterile table in the bottom area of the OR measured with AirThings at positions I1, I4, B1 and O2

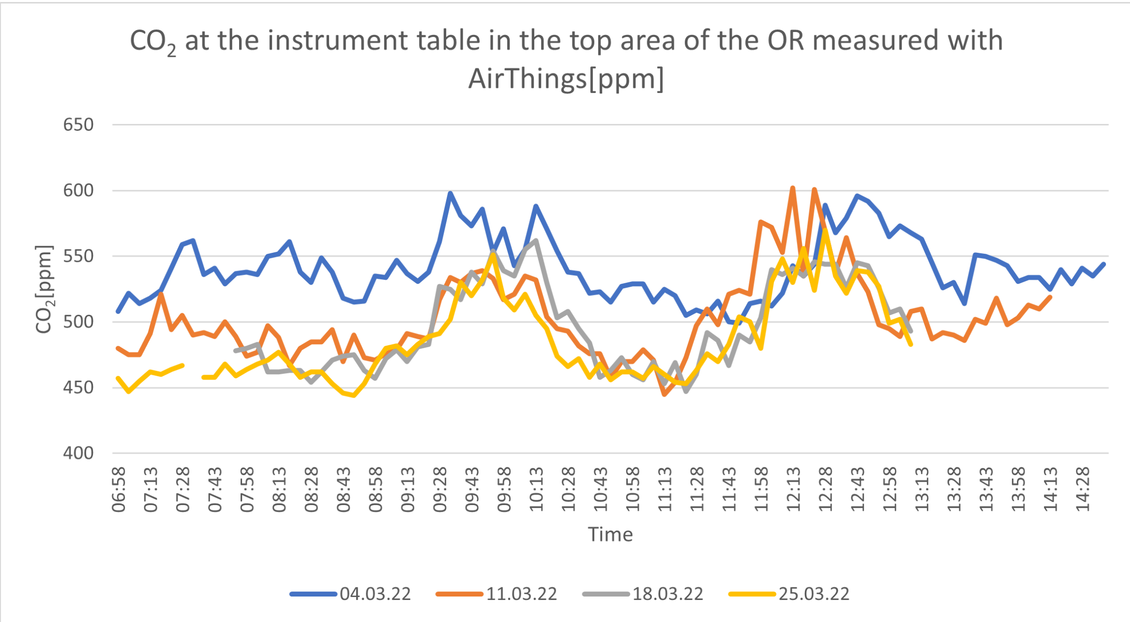


Figure 100: CO_2 at the instrument table in the top area of the OR measured with AirThings

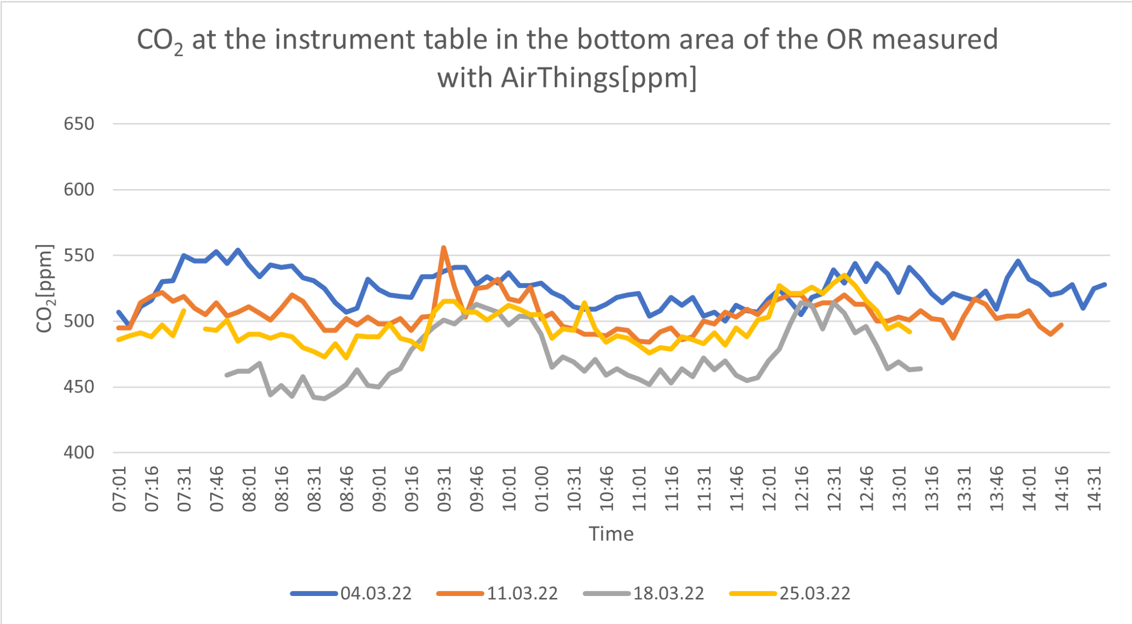


Figure 101: CO_2 at the instrument table in the bottom area of the OR measured with AirThings

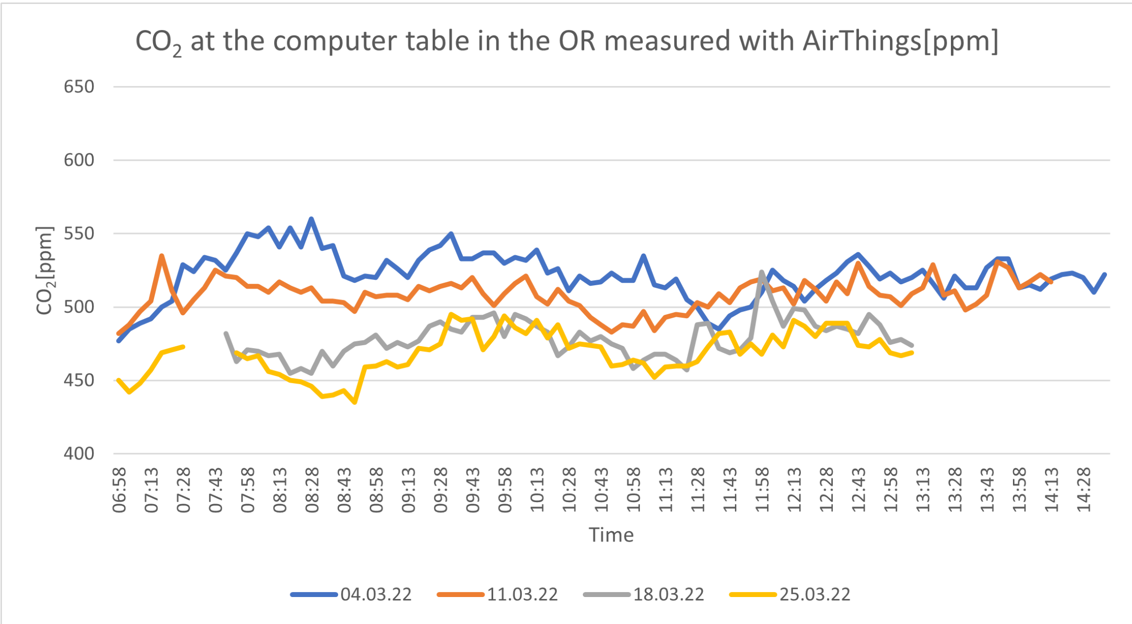


Figure 102: CO_2 at the computer table in the OR measured with AirThings

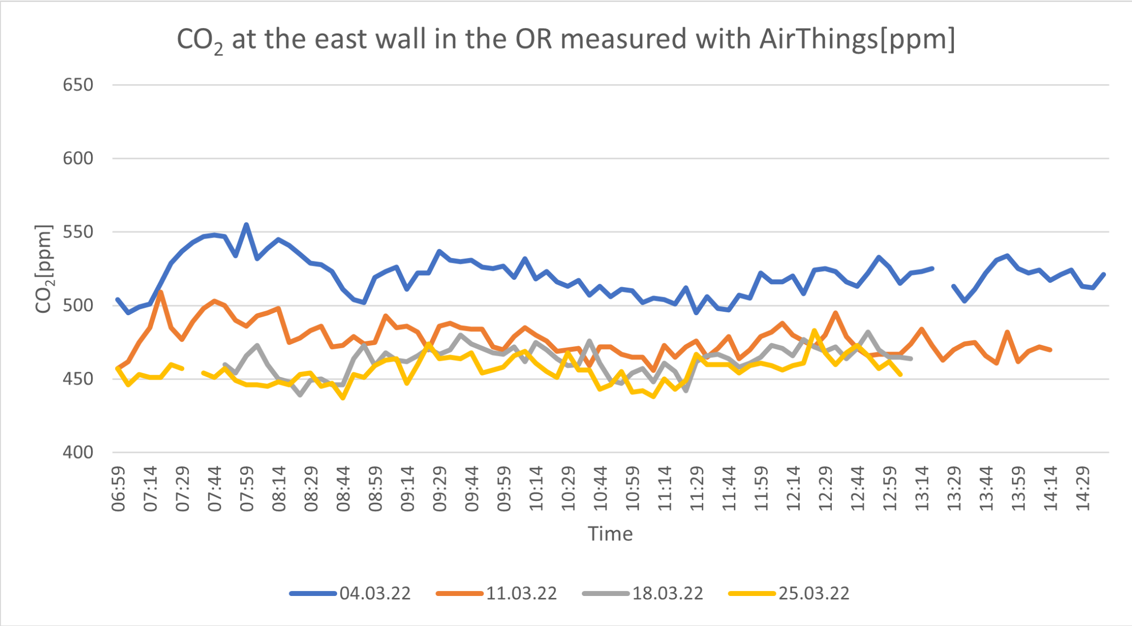


Figure 103: CO_2 at the east wall in the OR measured with AirThings

D Results from the Gemini TinyTag TGP-4500 sensor

The following sections describe the results from the Gemini TinyTag TGP-4500 sensors for air temperature and relative humidity.

D.1 Temperature results from TinyTag

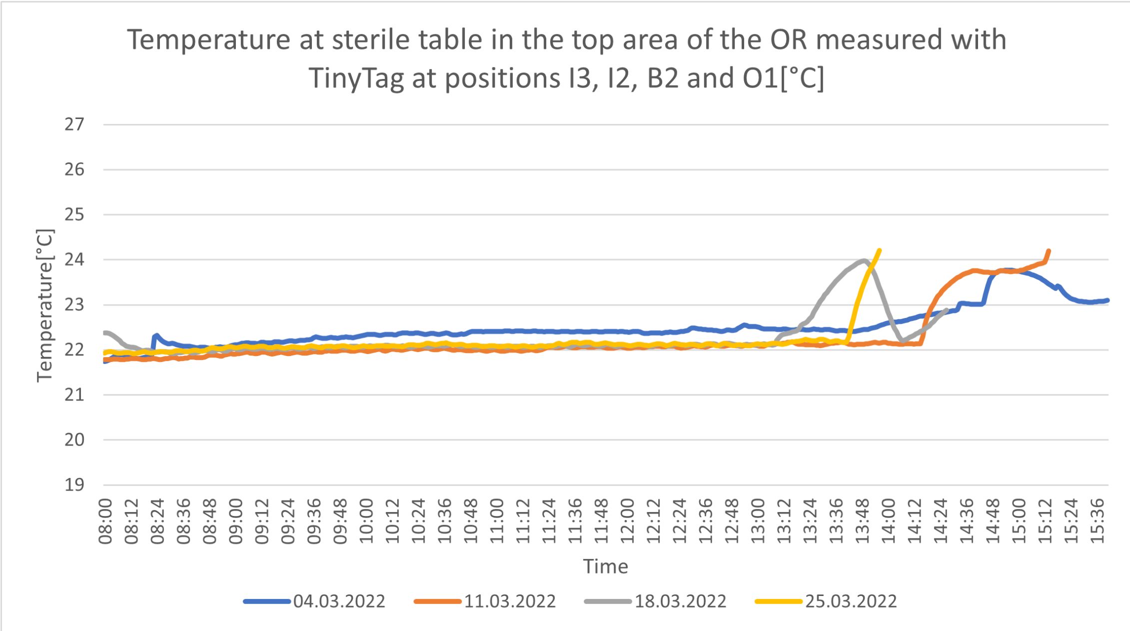


Figure 104: Temperature at sterile table in the top area of the OR measured with TinyTag at positions I3, I2, B2 and O1

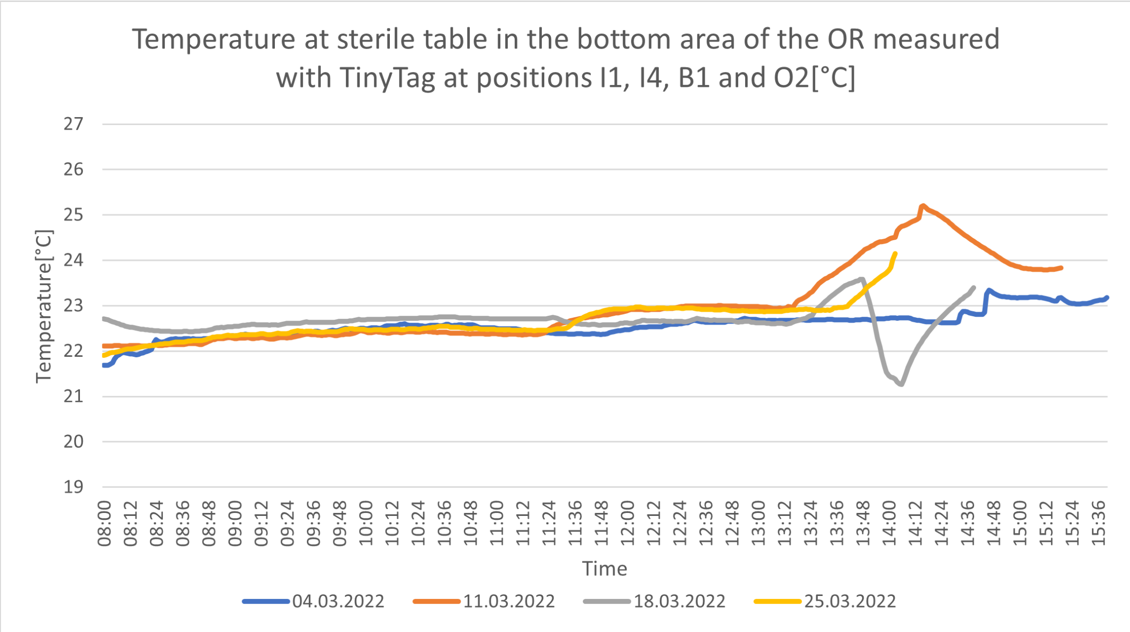


Figure 105: Temperature at sterile table in the bottom area of the OR measured with TinyTag at positions I1, I4, B1 and O2

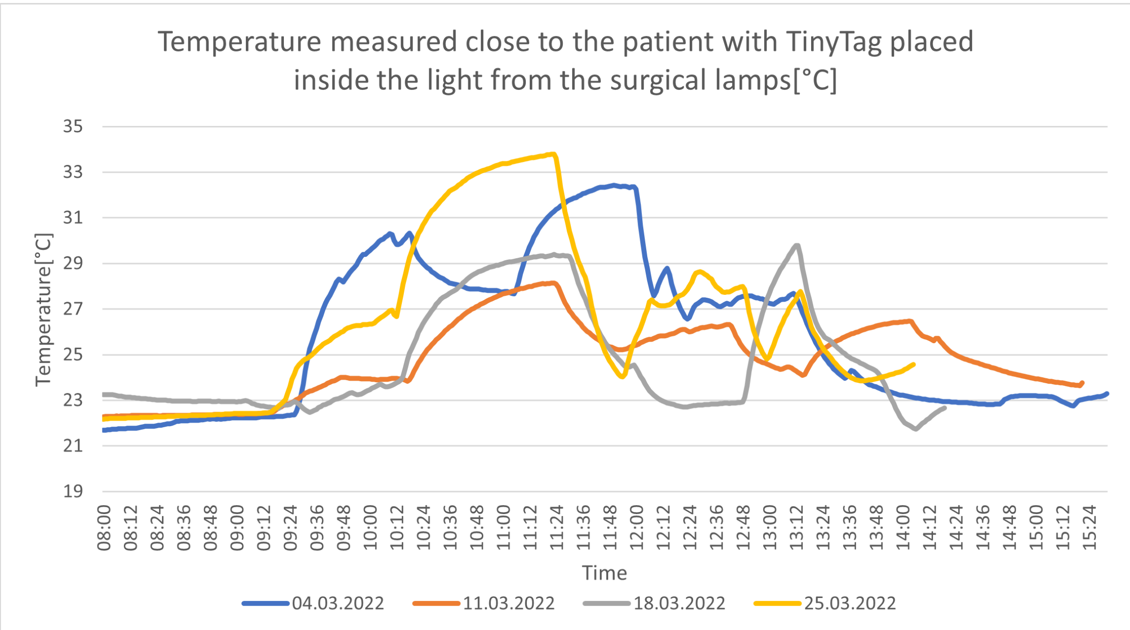


Figure 106: Temperature measured close to the patient with TinyTag placed inside the light from the surgical lamps

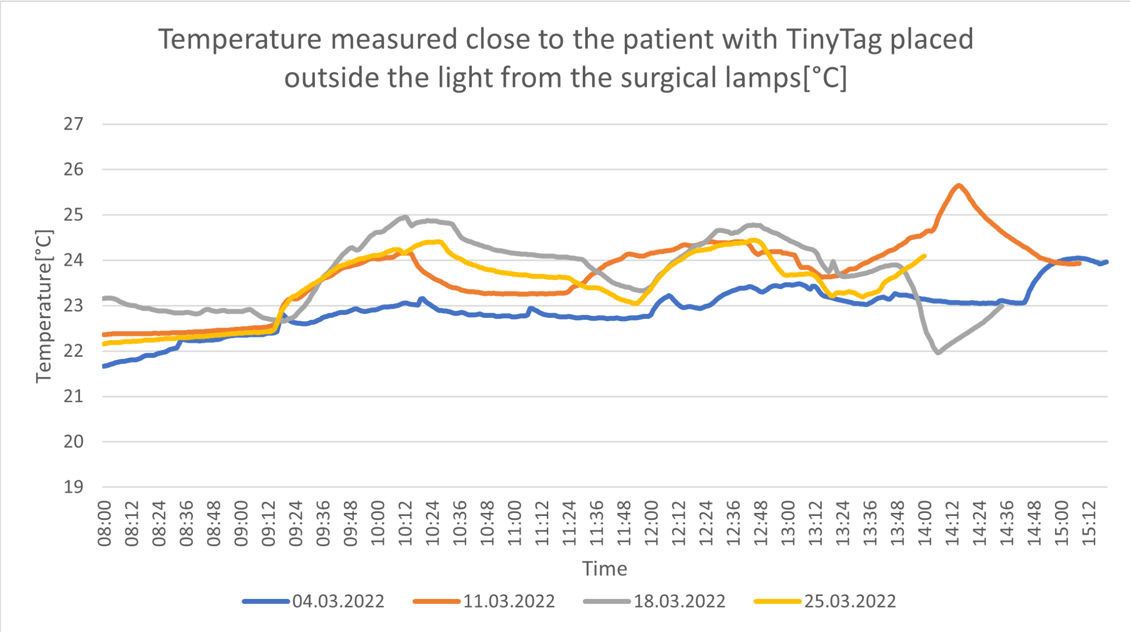


Figure 107: Temperature measured close to the patient with TinyTag placed outside the light from the surgical lamps

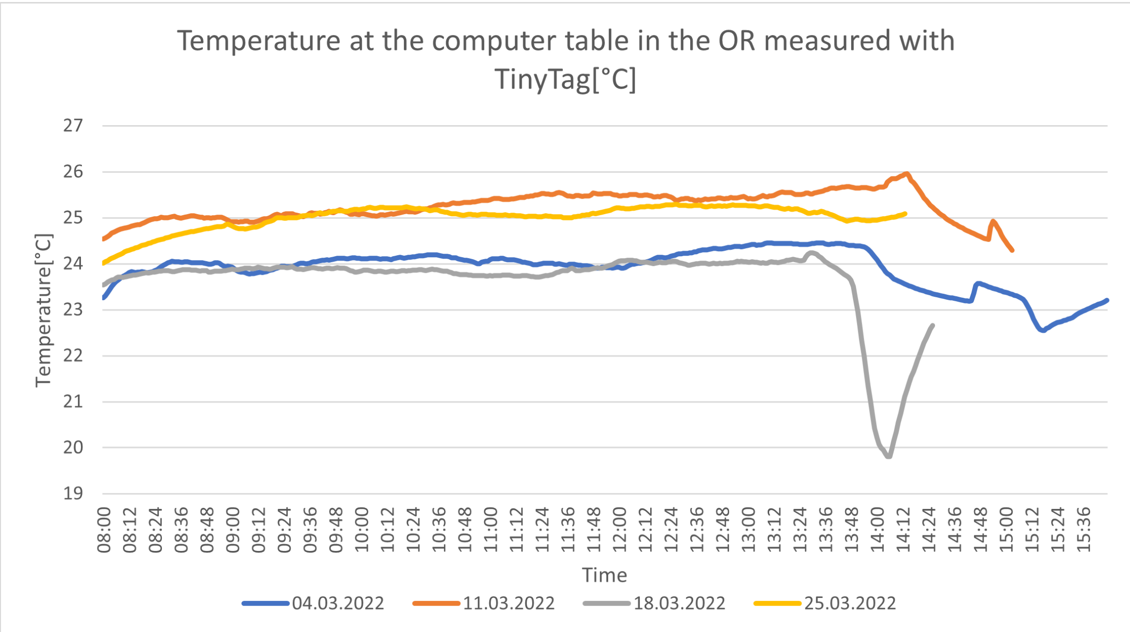


Figure 108: Temperature at the computer table in the OR measured with TinyTag

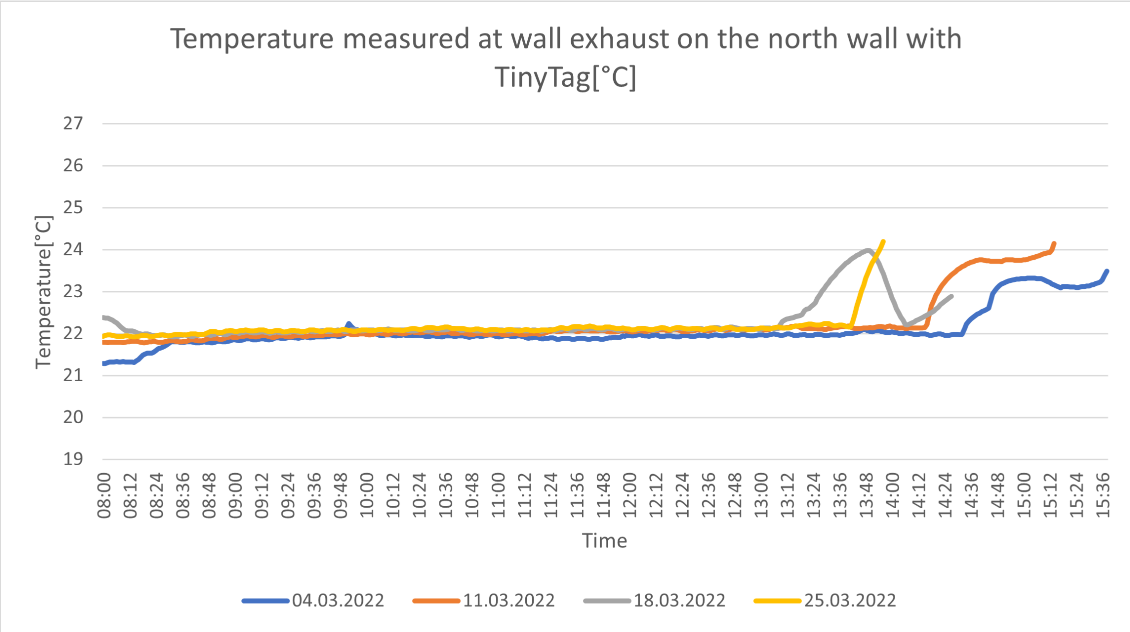


Figure 109: Temperature measured at wall exhaust on the north wall with TinyTag

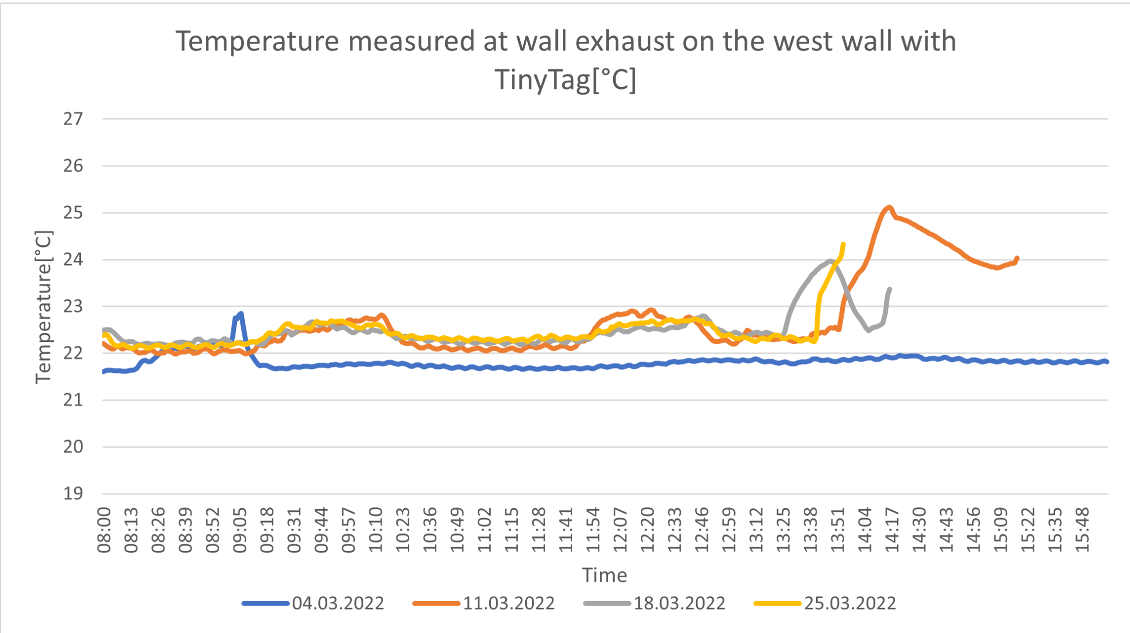


Figure 110: Temperature measured at wall exhaust on the west wall with TinyTag

D.2 Relative humidity results from TinyTag

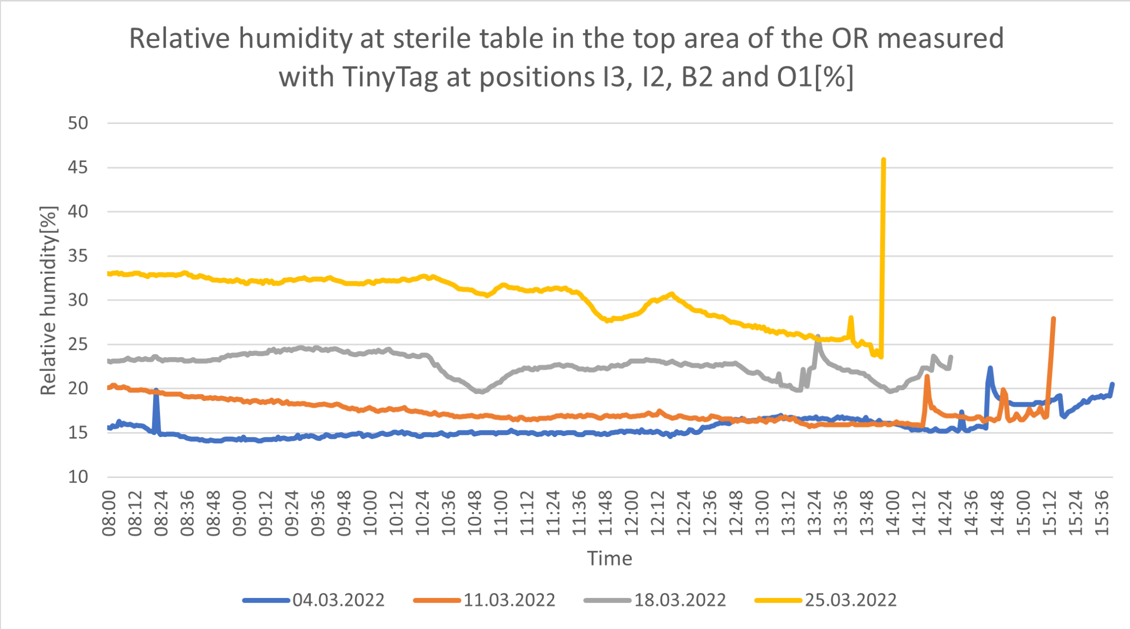


Figure 111: Relative humidity at sterile table in the top area of the OR measured with AirThings at positions I3, I2, B2 and O1

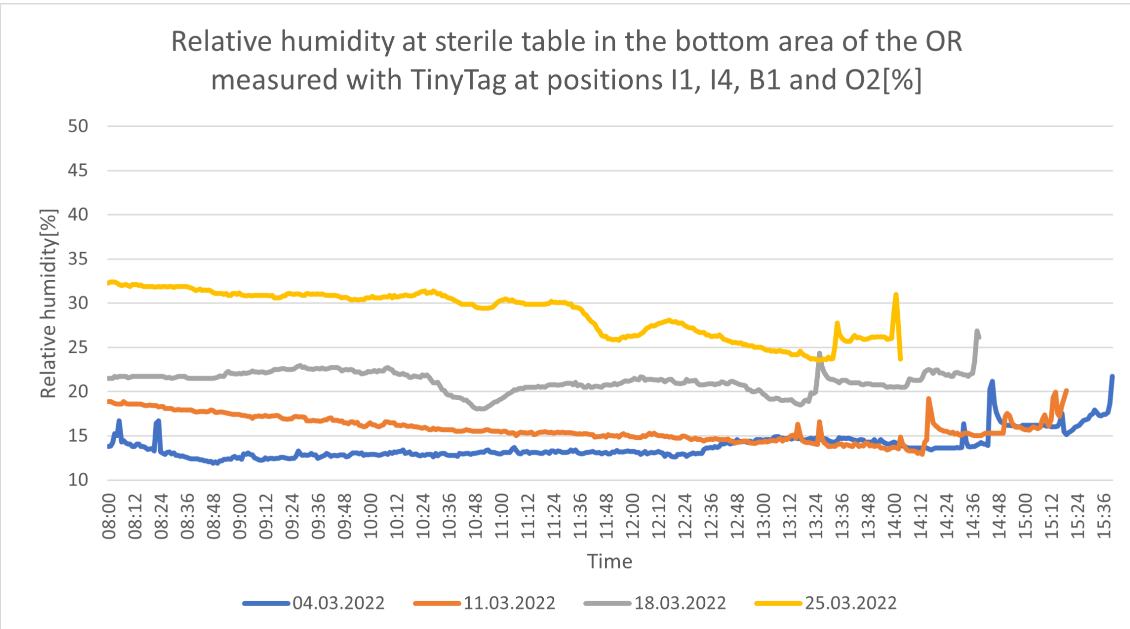


Figure 112: Relative humidity at sterile table in the bottom area of the OR measured with AirThings at positions I1, I4, B1 and O2

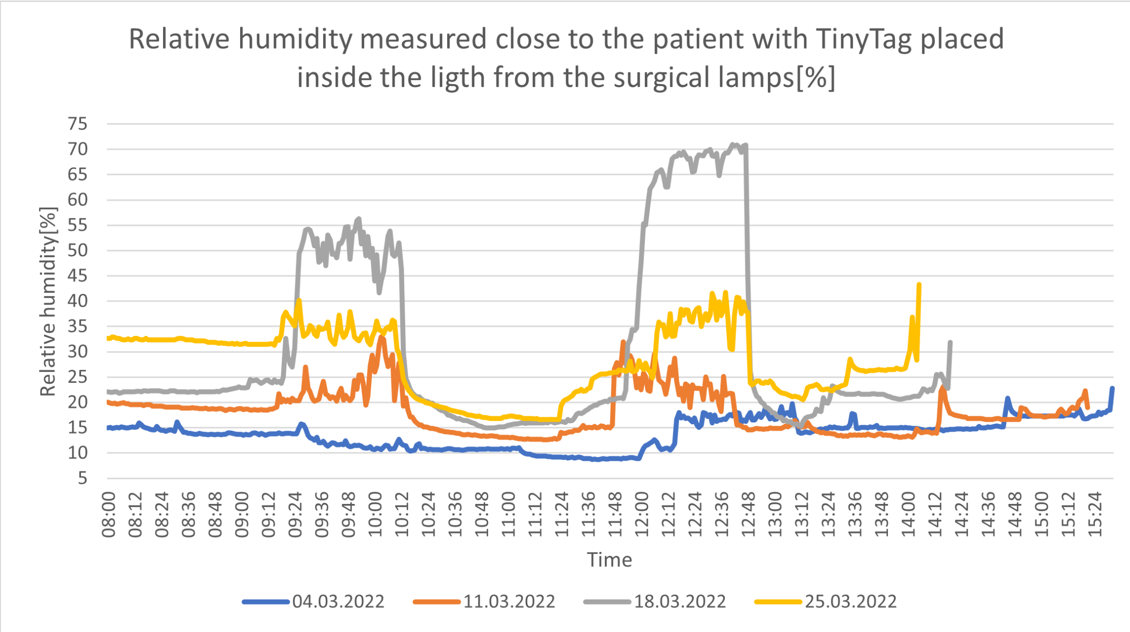


Figure 113: Relative humidity measured close to the patient with TinyTag placed inside the light from the surgical lamps

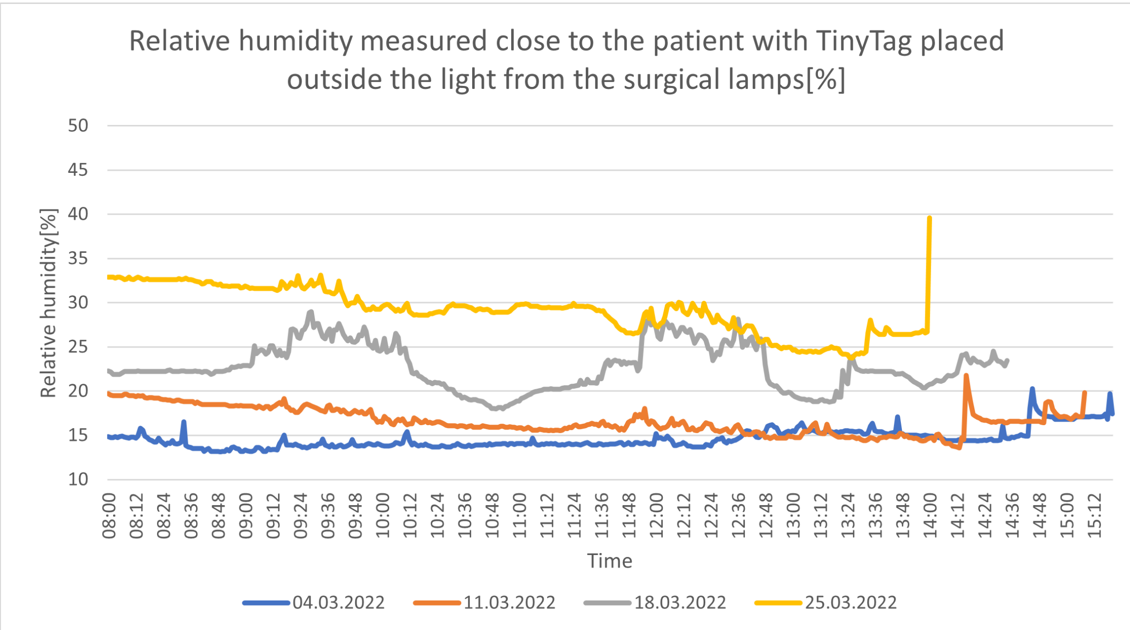


Figure 114: Relative humidity measured close to the patient with TinyTag placed outside of the light from the surgical lamps

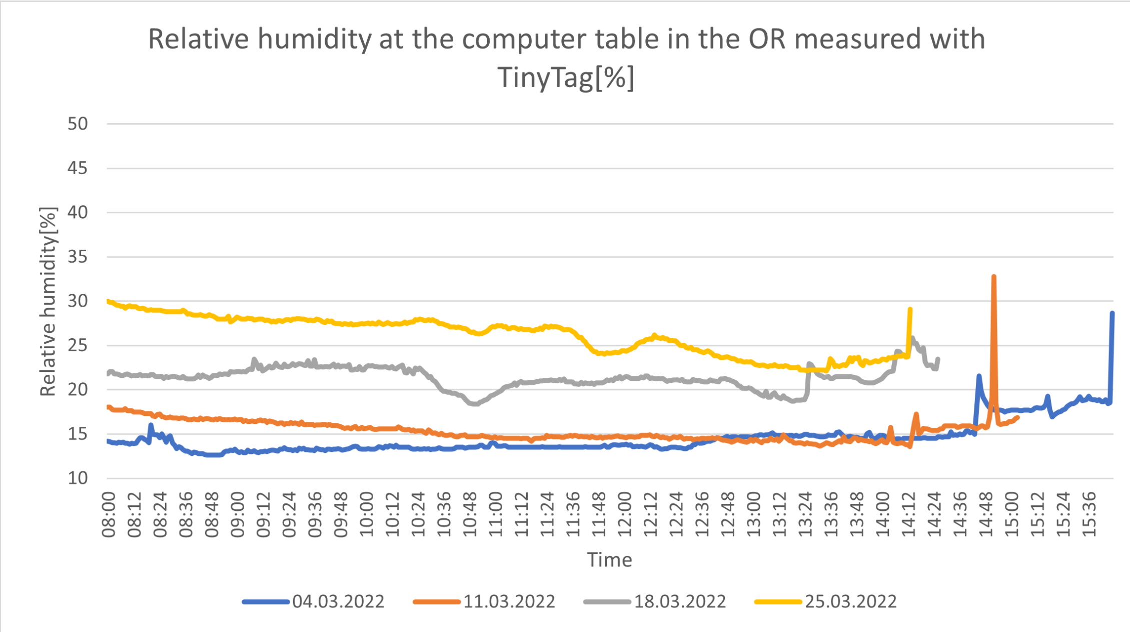


Figure 115: Relative humidity at the computer table in the OR measured with TinyTag

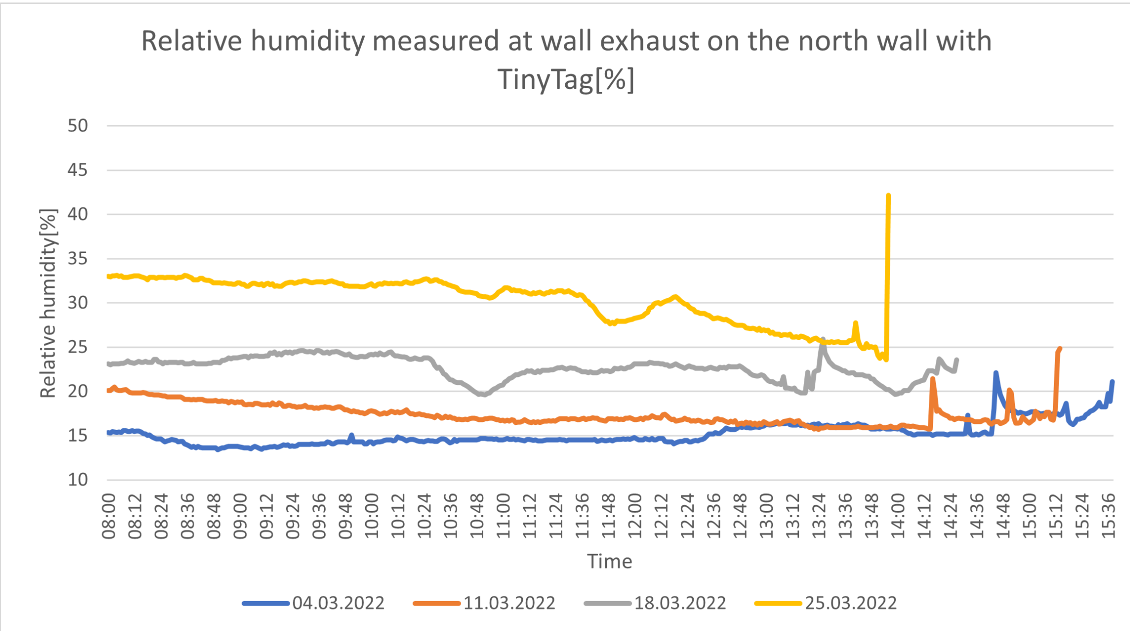


Figure 116: Relative humidity measured at wall exhaust on the north wall with TinyTag

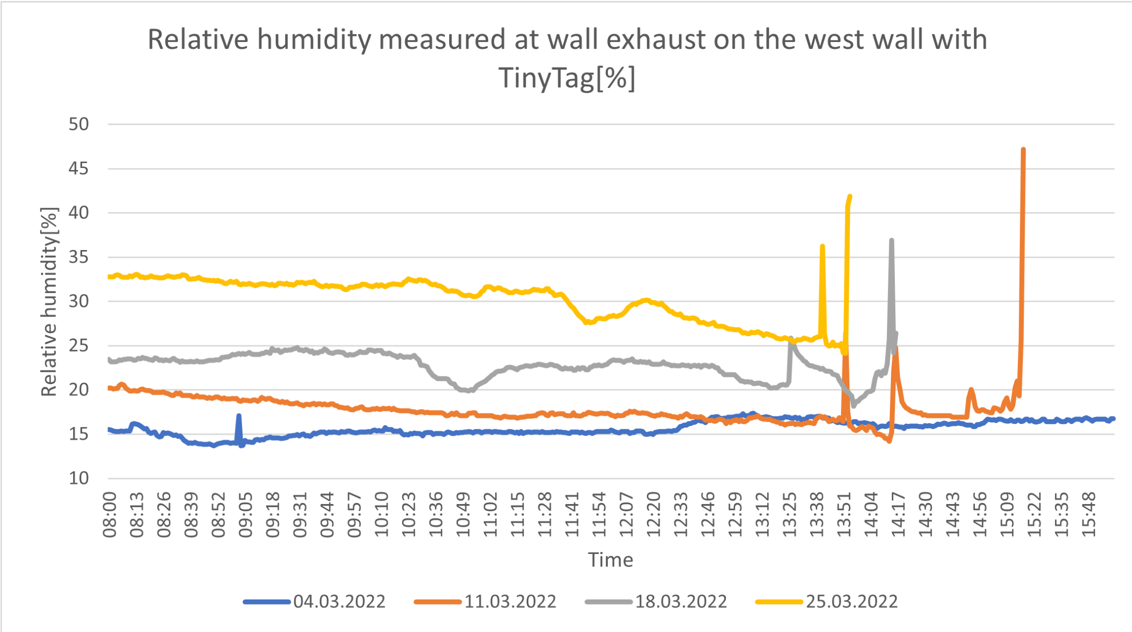


Figure 117: Relative humidity measured at wall exhaust on the west wall with TinyTag

E Results from AirDistSys 5000

The AirDistSys 5000 was mounted on a tripod wit had seven senors placed horizontally with approximately 10cm between each sensor. The tripod was always positioned moving west to east so that it measured in a straight line with senors P1 closest to the center of the laminar airflow and sensor P8 or P10 furthest from the center of the laminar airflow. On measurement days 04.03 and 11.03. the AirDistSys was placed on the same positions as the sterile tables with sensor P4 being position in the center of where the sterile table was positioned. The sensor where positioned at the same height as the sterile tables, 700 mm above the ground. There were no measurement of air velocity and air turbulence on the measurement day of 18.03 due to time limitations this measurement day. This is a part of the reason why the results were not included in the thesis.

E.1 Air velocity measurements

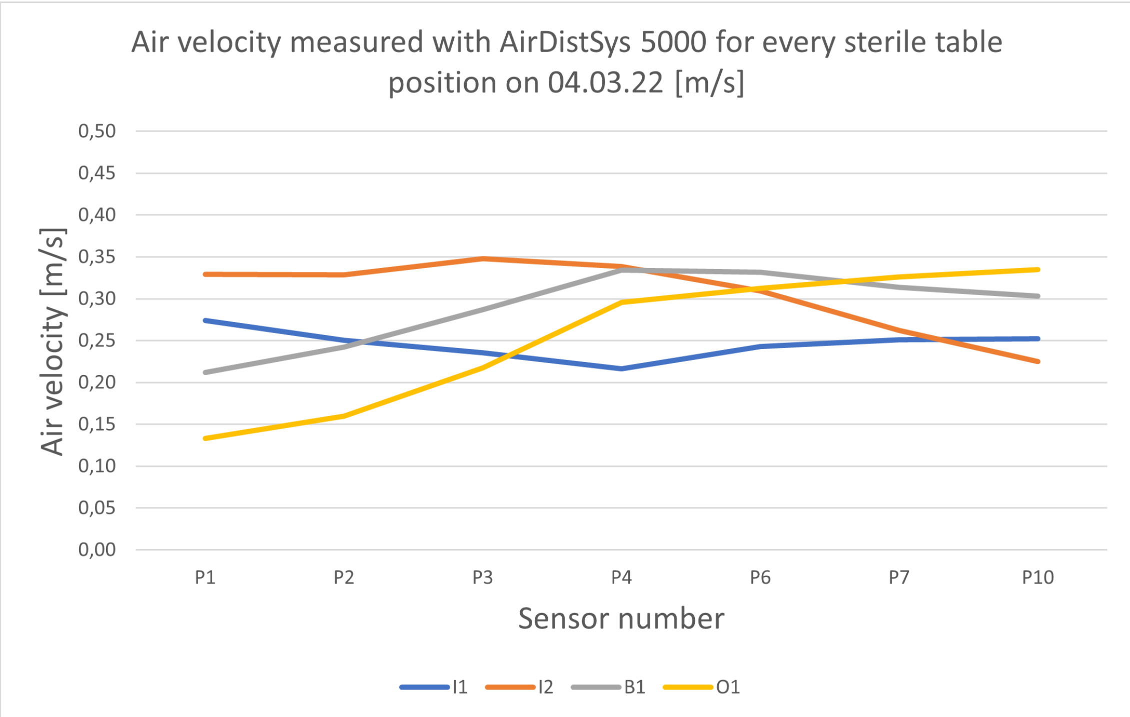


Figure 118: Air velocity measured on the sterile tables on 04.03.22

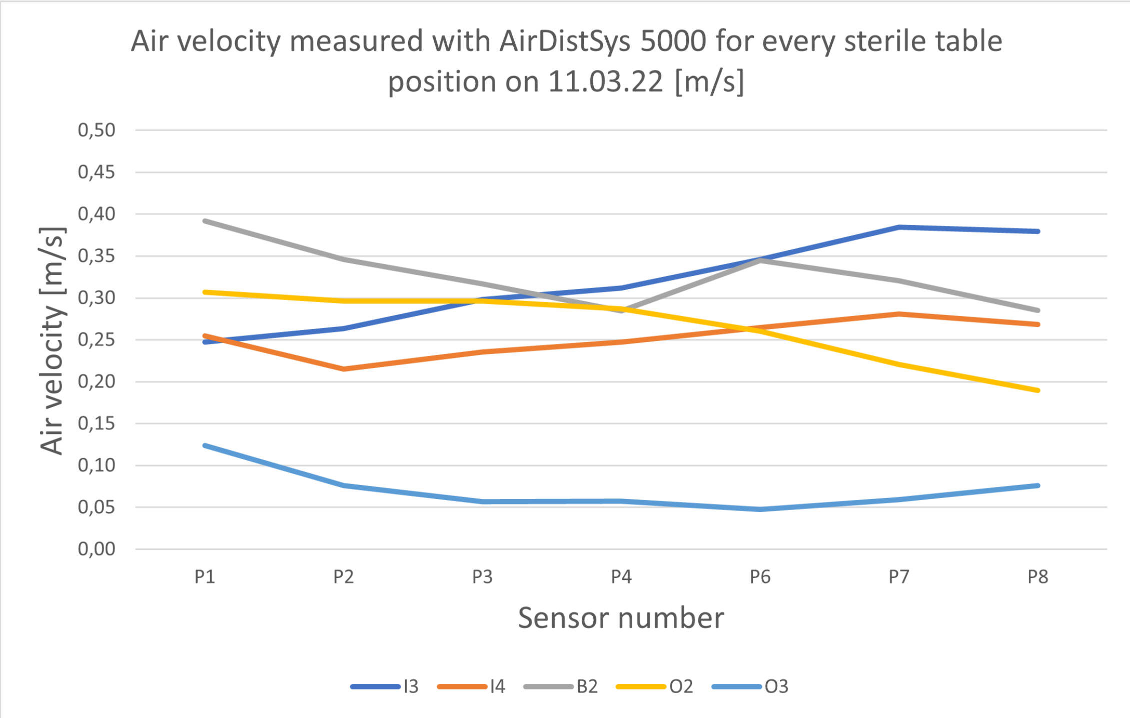


Figure 119: Air velocity measured on the sterile tables on 11.03.22

On the 11.03, a second position was measured outside of the laminar airflow named O3. This position followed the same line as position O2, but was placed further outside the laminar airflow. Here senors P1 on position O3 was 10 cm from position P8 on position O2.

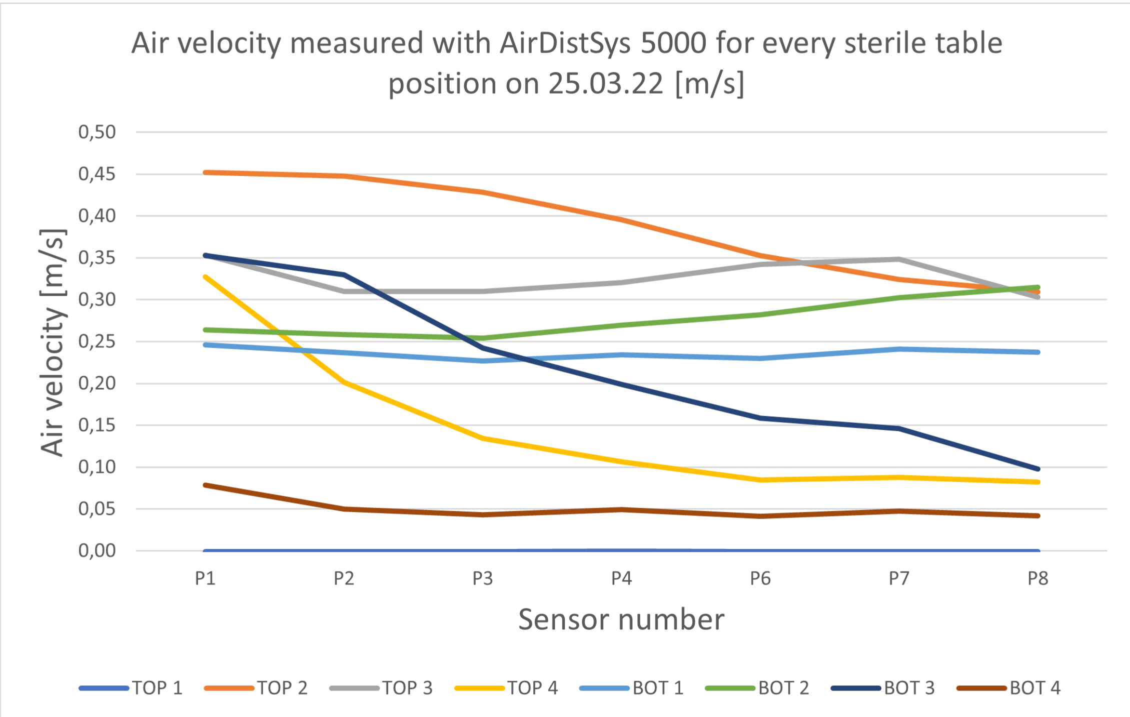


Figure 120: Air velocity measured on the sterile tables on 25.03.22

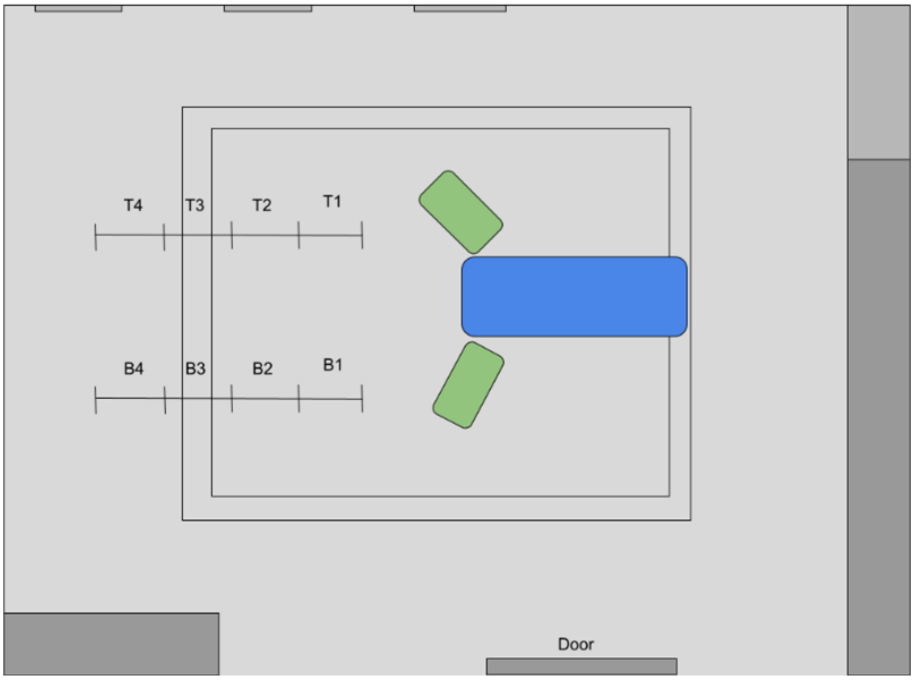


Figure 121: Measuring points for AirDistSys 5000

Figure 121 shows the position of the AirDistSys during the measurements on the 25.03. This is the position that should have been used during all measurement days.

Figure 120 shows that there was a sensor error for position TOP 1 where no values were measured. This is a part of the reason why the results were not included in the thesis.

E.2 Air turbulence measurements

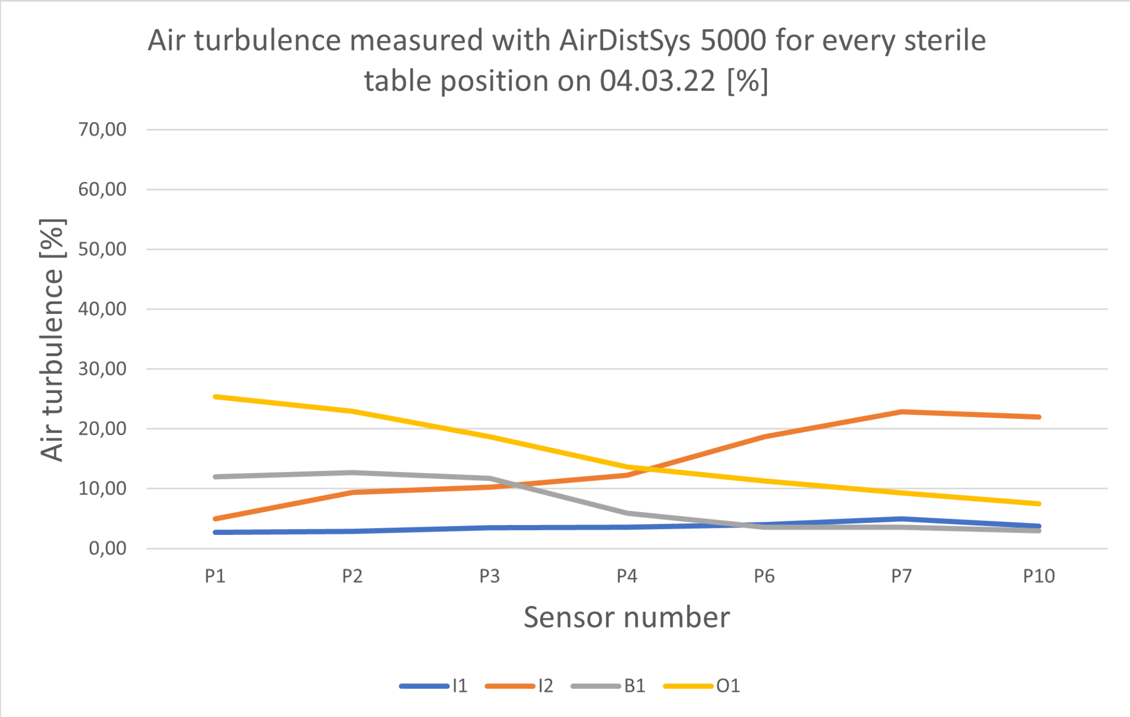


Figure 122: Air turbulence measured on the sterile tables on 04.03.22

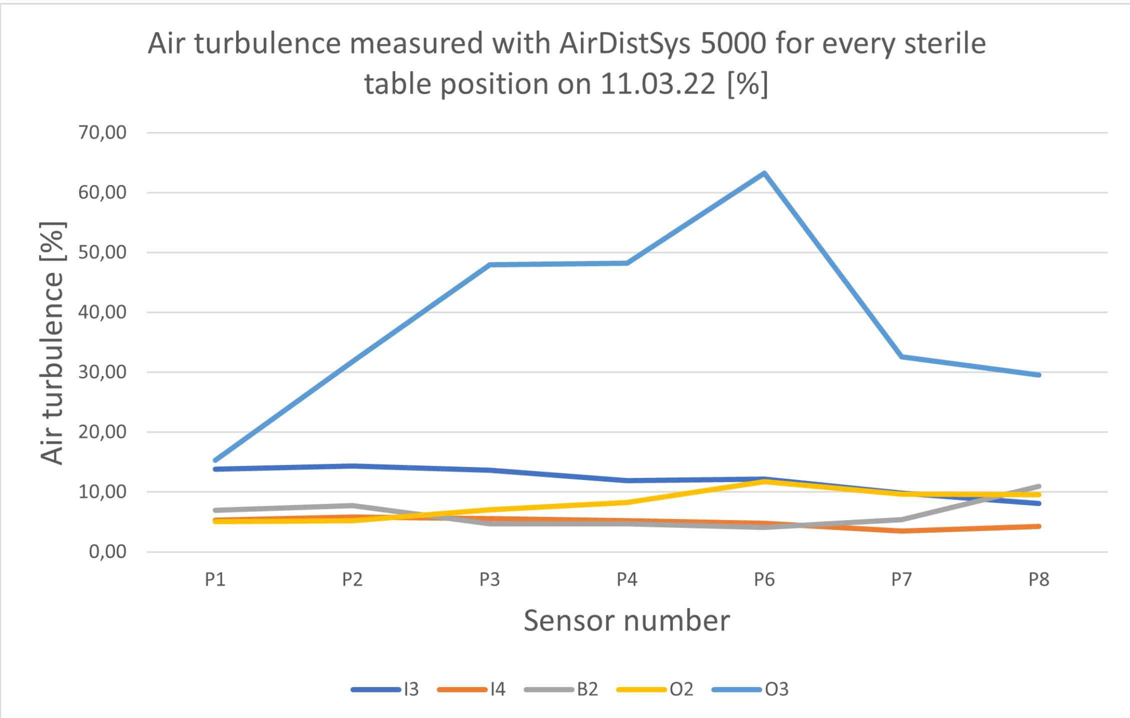


Figure 123: Air turbulence measured on the sterile tables on 11.03.22

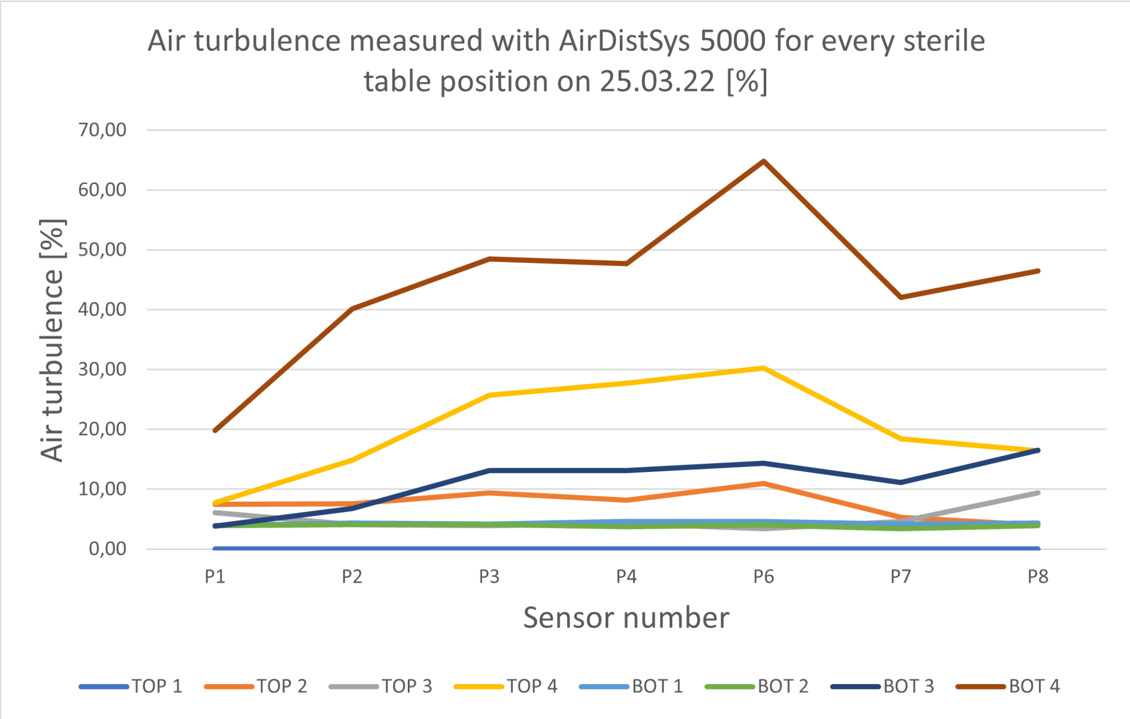


Figure 124: Air turbulence measured on the sterile tables on 25.03.22

Briefly summarized, the result from the air velocity and air turbulence show that the air velocity decrease outside of the laminar airflow while the air turbulence increase outside of the airflow. There was not a significant increase or decrease in air velocity and air turbulence in the boundary area.

F Results from sensors at St.Olavs

The following results was provided by St.Olavs hospital and consist of data gathered from sensors installed in the ventilation system for operating room 8. The results show the different airflow rates and temperatures in airflow.

F.1 Airflow rates in the OR's ventilation system

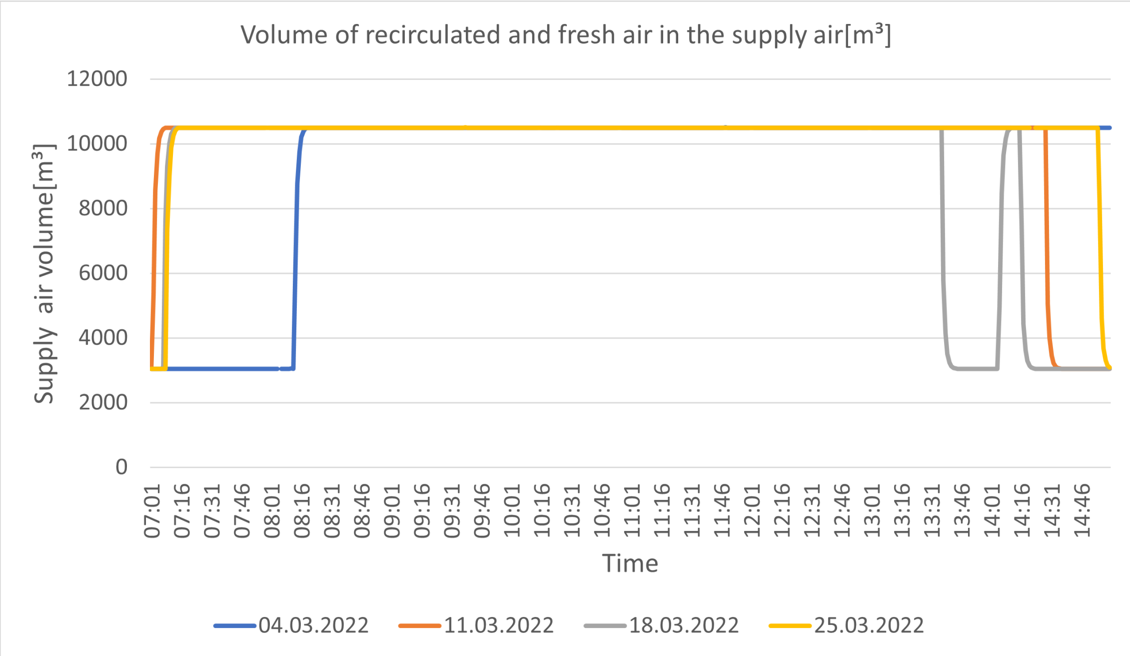


Figure 125: Volume of recirculated and fresh air in the supply air

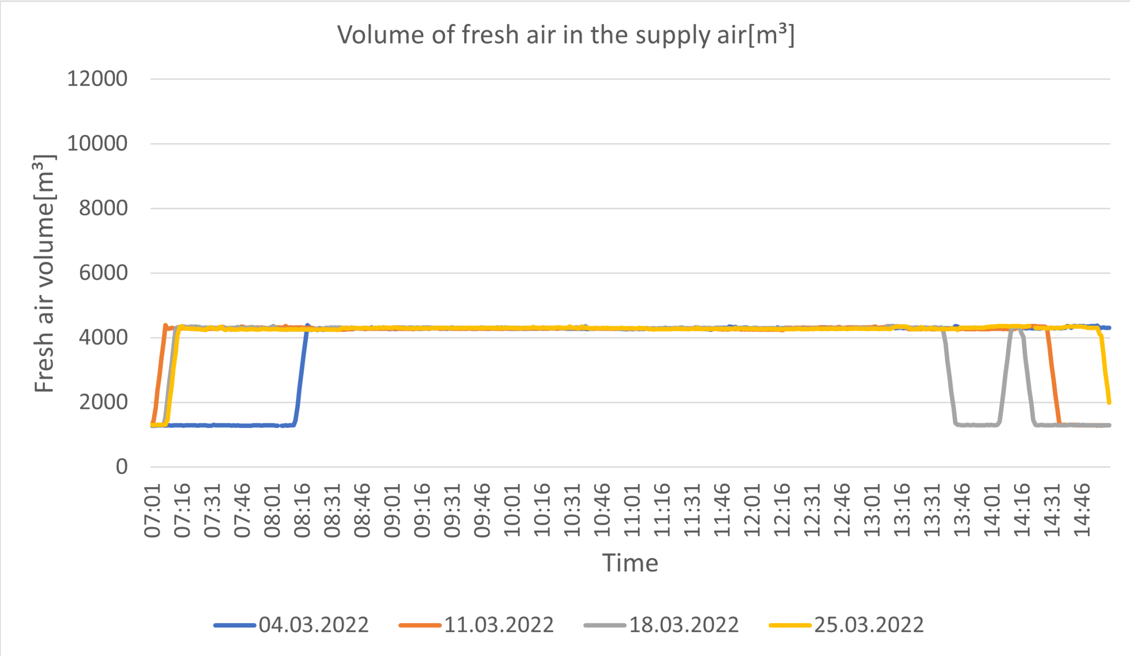


Figure 126: Volume of fresh air in the supply air

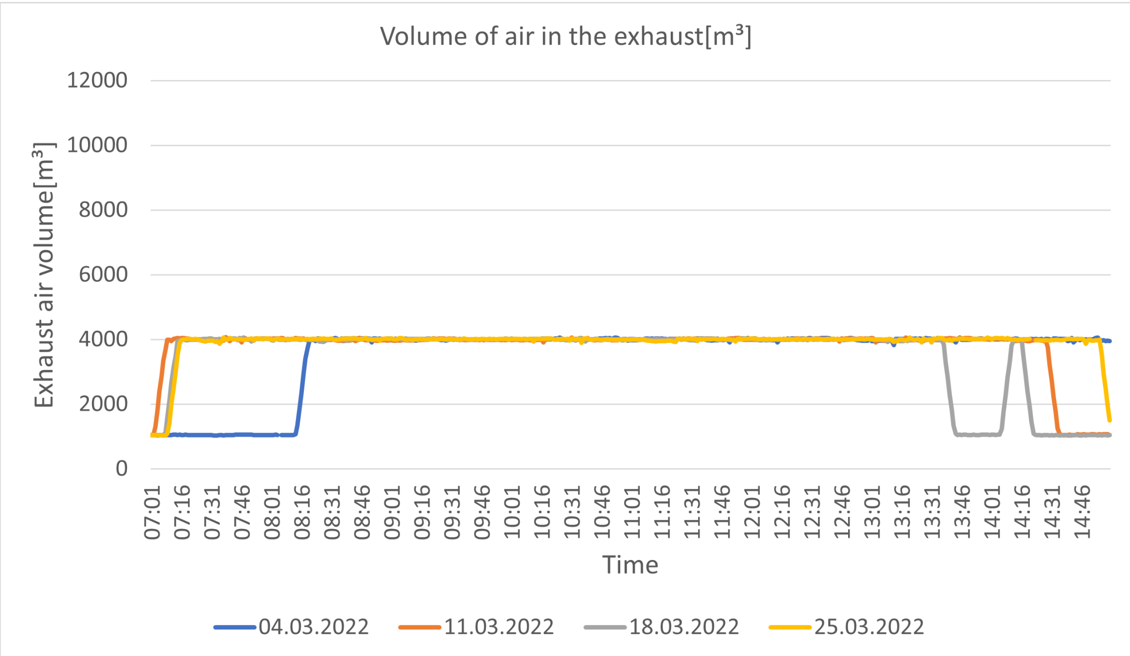


Figure 127: Volume of air in the exhaust

F.2 Temperatures in the OR's ventilation system

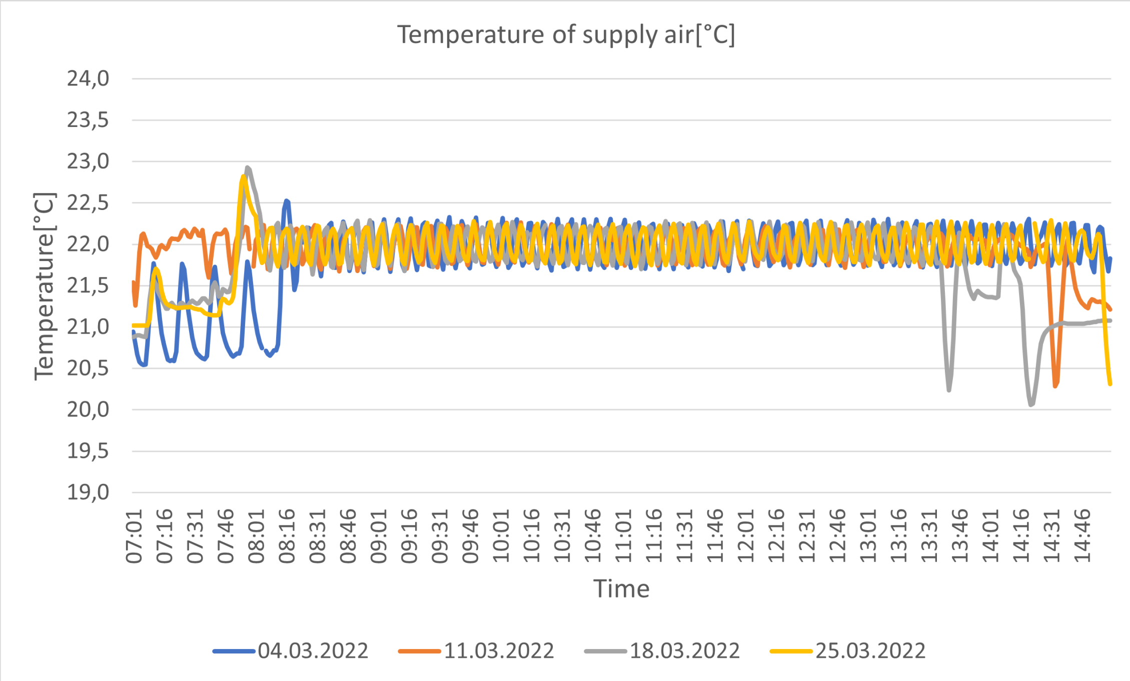


Figure 128: Temperature of supply air

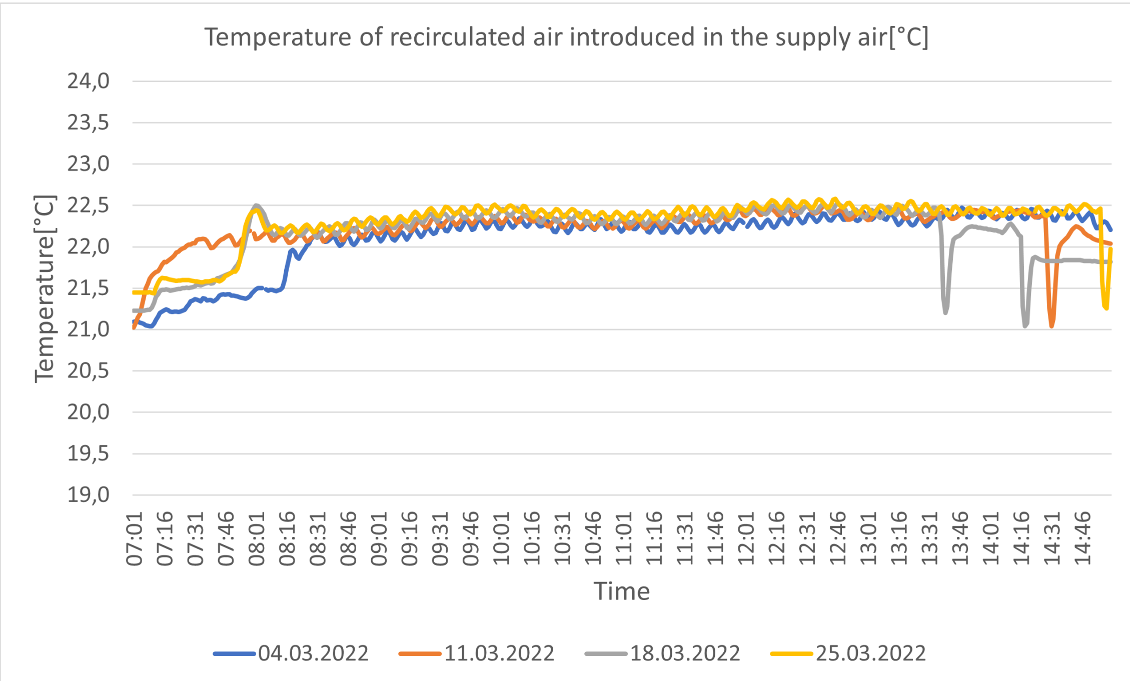


Figure 129: Temperature of recirculated air introduced in the supply air

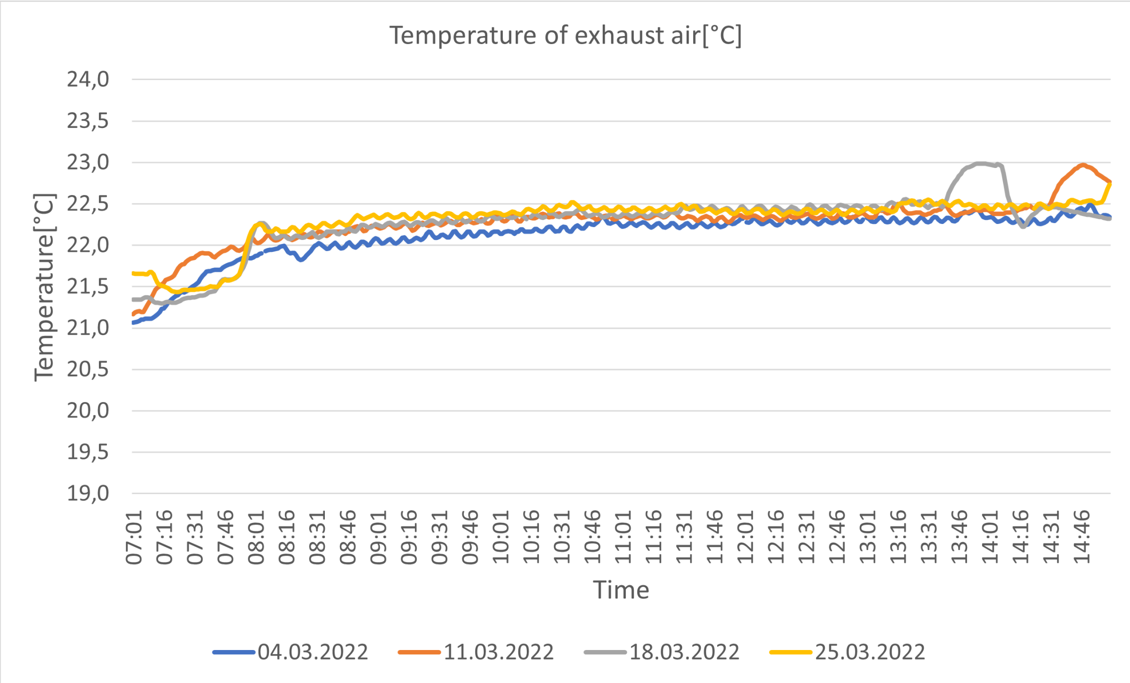


Figure 130: Temperature of exhaust air

G Results from the TSI Aerotrak 9306-04 sensors positioned by the patient on the operating table, and on the computer table

The following results are the results are gathered from the Aerotraks positioned by the patient and the computer table.

G.1 Aerotrak 3 position patient

The results from the Aerotrak positioned at the patient was heavily influenced by two activities. When the main surgeons cut in the pork loin(the wound), the peak in particles increased substantially. The same happened when the sterile nurse wiped imaginary blood of the wound with a bandage cloth and moved his hand over the particles sampler. The hand and bandage cloth which moved over the Aerotrak after touching the pork loin, caused substantial peaks.

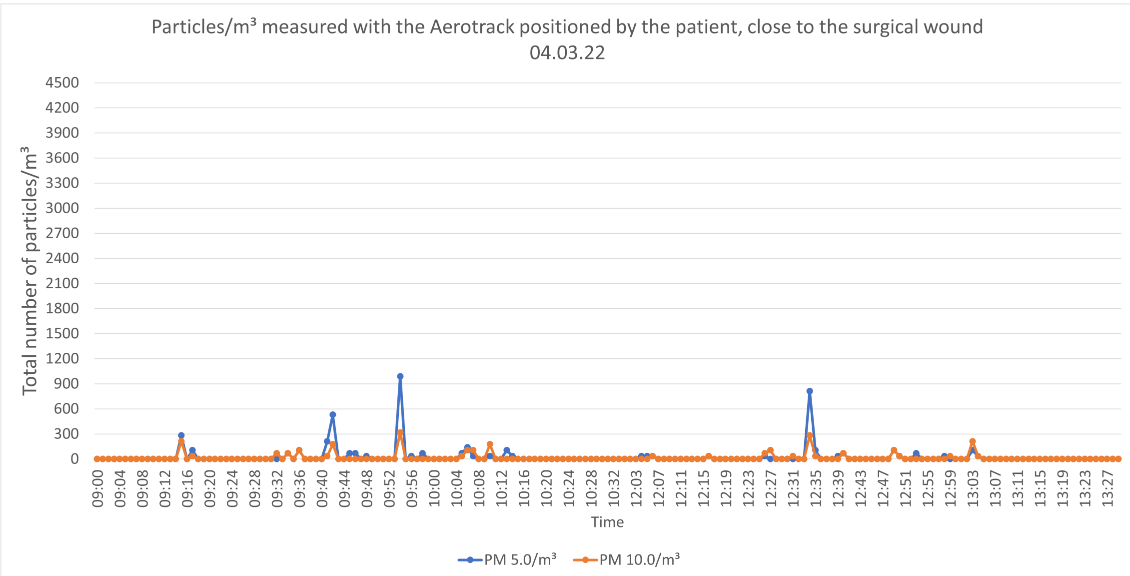


Figure 131: Particles/m³ measured with the Aerotrak positioned by the patient, close to the surgical wound 04.03.22

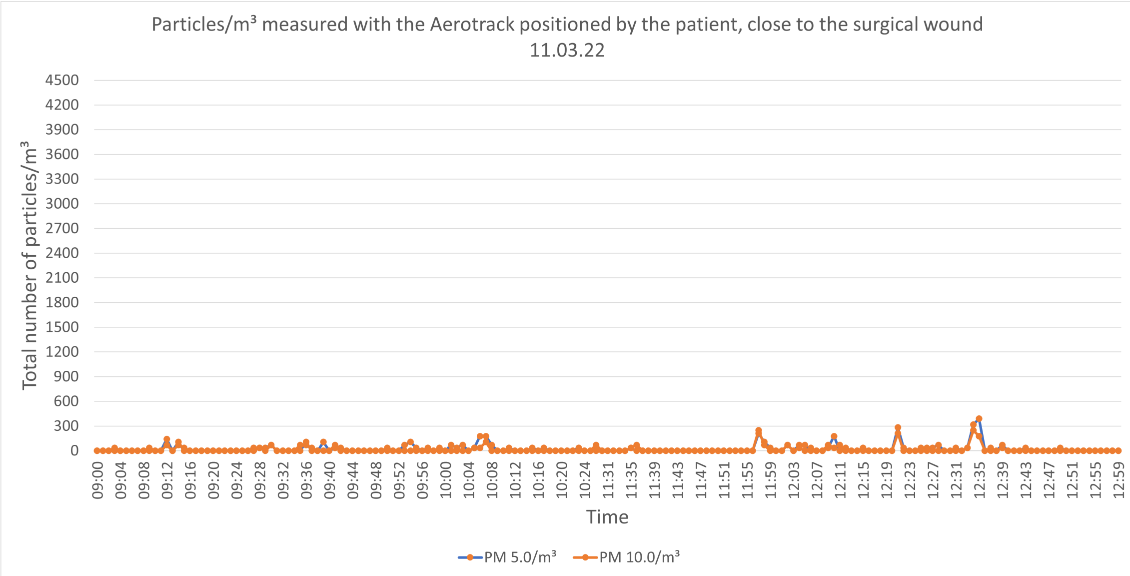


Figure 132: Particles/m³ measured with the Aerotrak positioned by the patient, close to the surgical wound 11.03.22

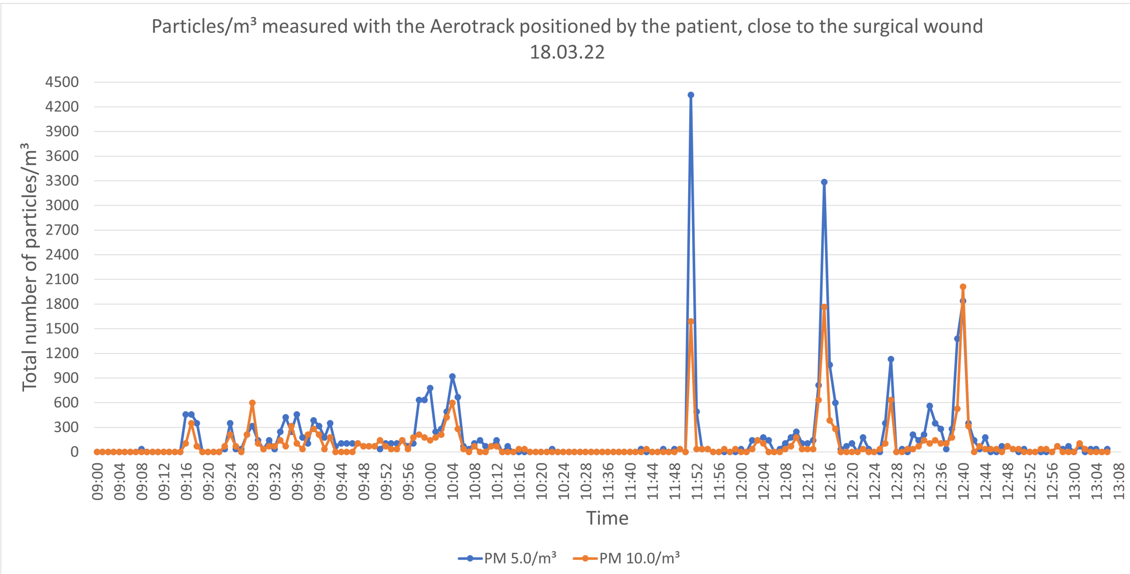


Figure 133: Particles/m³ measured with the Aerotrak positioned by the patient, close to the surgical wound 18.03.22

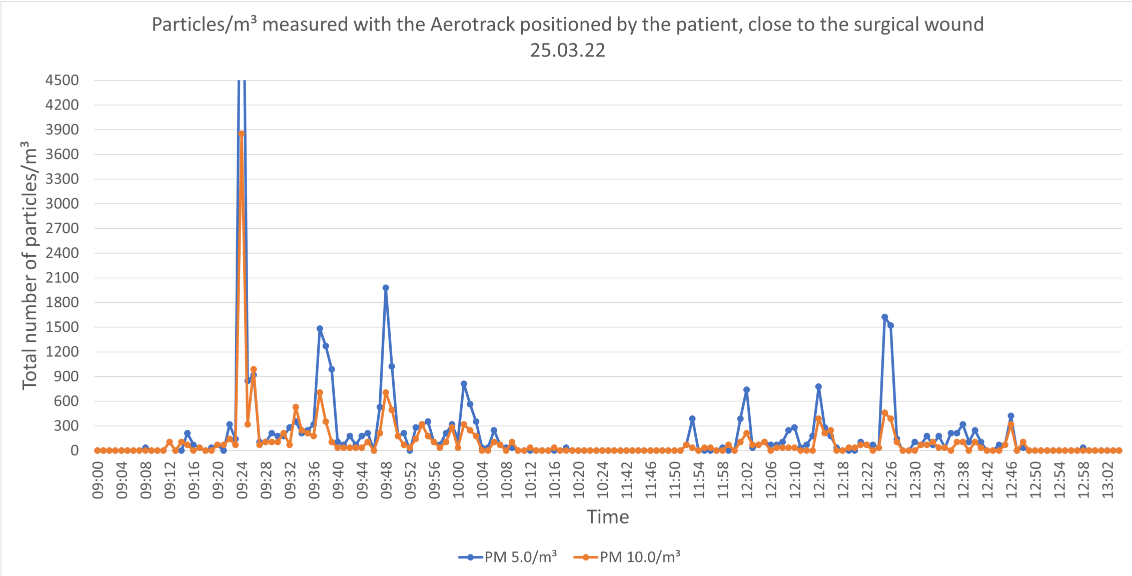


Figure 134: Particles/m³ up to 4500 measured with the Aerotrak positioned by the patient, close to the surgical wound 25.03.22

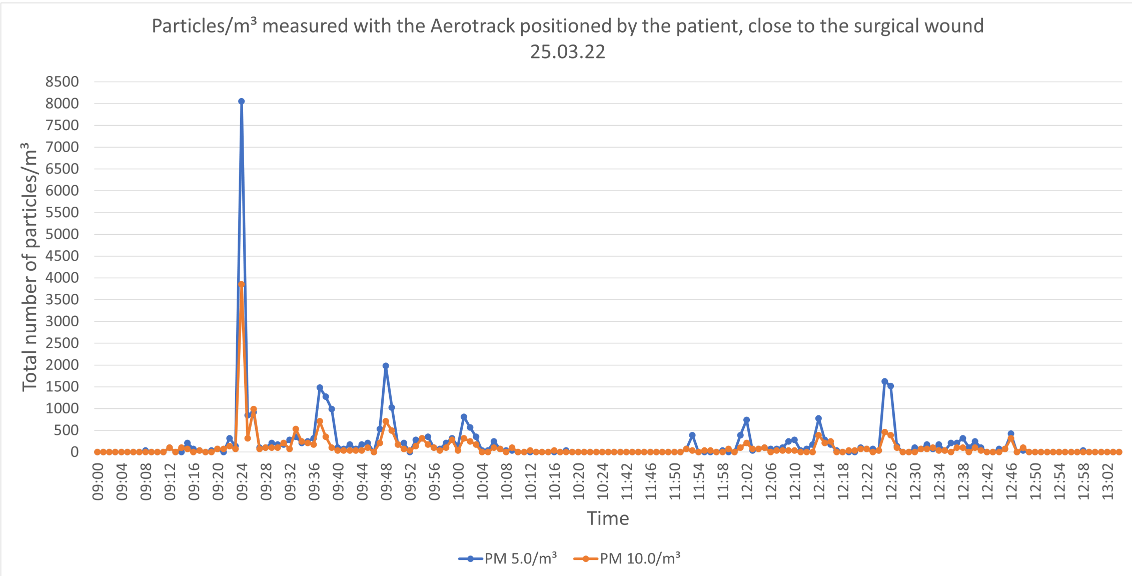


Figure 135: Particles/m³ up to 8500 measured with the Aerotrak positioned by the patient, close to the surgical wound 25.03.22

Two figures from the 25.03 is included. This is the same graph with different y axis. Figure 135 is included to show the highest peak on 25.03.

G.2 Aerotrak 4 position computer table

The Aerotrak positioned at the computer table was mainly influenced by the distribution nurse standing close to the Aerotrak. No other participants were near the computer table.

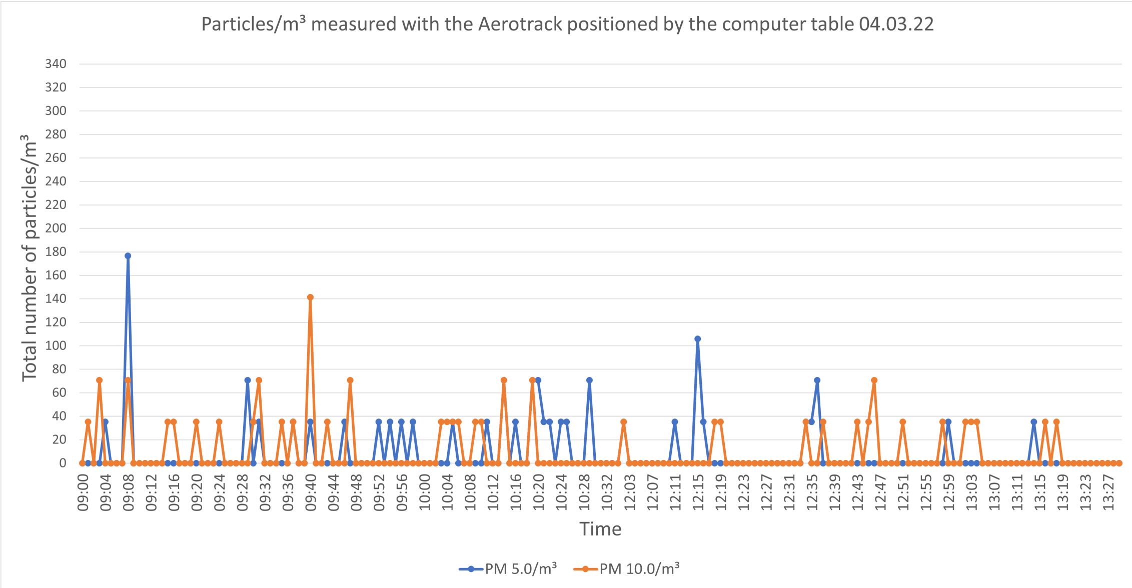


Figure 136: Particles/m³ measured with the Aerotrak positioned by the computer table 04.03.22

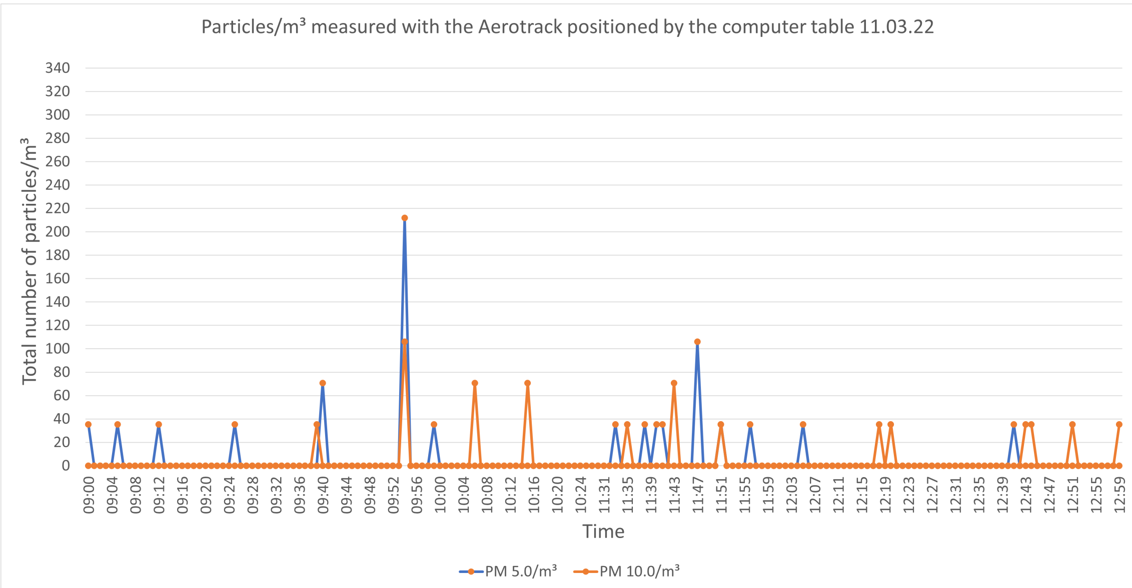


Figure 137: Particles/m³ measured with the Aerotrak positioned by the computer table 11.03.22

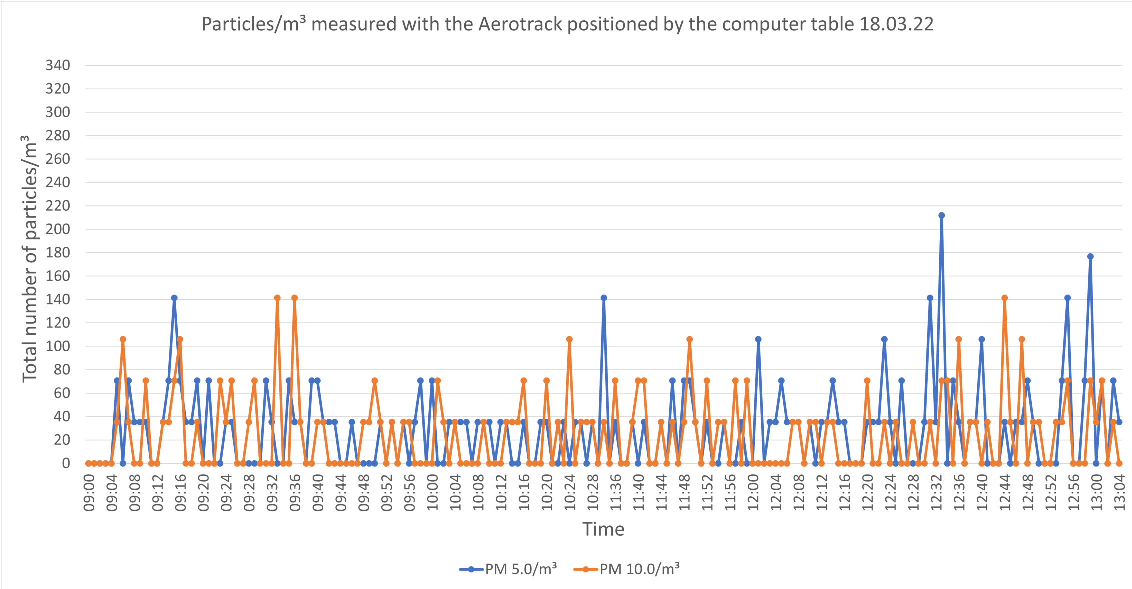


Figure 138: Particles/m³ measured with the Aerotrak positioned by the computer table 18.03.22

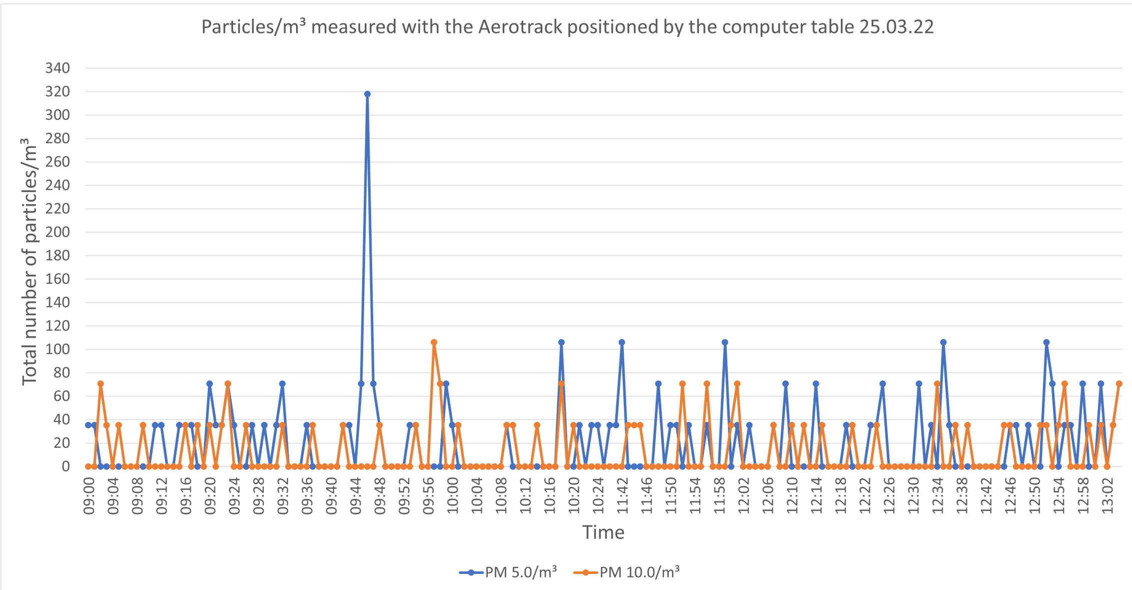


Figure 139: Particles/m³ measured with the Aerotrak positioned by the computer table 25.03.22

H Analysis of particle results from Aerotrak 1 and 2 at sterile tables for all measurement days

Following is the analysis of all registered particles of size PM5.0 and PM10.0 μm presented in Excel tables. The results from the Aerotrak sensors placed on the sterile tables are here compared with the events recorded by the GOPro camera during all mock surgeries. When the Aerotrak measured a particle of size PM5.0 or PM10.0 μm, the timestamp was noted. The timestamp was then reviewed in the video recording from the mock surgery, and the activity was noted in the column "What" in the table. The lines in light blue color show the start of each active sampling. On the left, the sterile table position is shown. The color of this column changes between grey and white only to show which row belongs which column.

H.1 Analysis of particle results from Aerotrak at sterile tables 04.03.22

04.03.2022 Aerotrack 1					
Position	When	What	PM5.0	PM10.0	Comment
I2	09:02:46	1. measurement active sampler 1			
	09:12:12	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	09:13:22	Sterile nurse changes active sampler. Sterile nurse changes the blood agar in the active sampler. Touches plastic packing for the blood agar and active sampler filter.	3		
	09:13:40	2. measurement active sampler 1			
	09:16:52	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	3		
	09:17:52	Sterile nurse pick up paper close to the Aerotrack. Sterile nurse is standing very close.	2		
	09:23:42	Sterile nurse is helping surgeons putting on sterile clothing.	1		
	09:24:25	3. measurement active sampler 1			
	09:32:02	Distribution nurse perform hand movement over the Active sampler.	1		
	09:35:17	4. measurement active sampler 1			
	09:42:42	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Distribution nurse walk past the table a few seconds later.		1	
	09:44:32	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Distribution nurse touches plastic packing on the other table.	1		
	09:46:02	5. measurement active sampler 1			
	09:50:52	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Distribution nurse walks past.	1		
	09:56:32	Sterile nurse changes the blood agar in the active sampler.	1		
	09:56:53	6. measurement active sampler 1			
	10:01:22	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	10:01:32	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:01:42	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		

	10:02:32	Sterile nurse move surgical instrument and paper close to Aerotrack.	1		
	10:07:37	7. measurement active sampler 1			
	10:14:22	Distribution nurse walk past the Aerotrack.		1	
	10:18:22	8. measurement active sampler 1			
	10:19:52	Sterile nurse walks up to the table with the Aerotrack.	3		
	10:20:02	Sterile nurse walking away from the Aerotrack.	2		
	10:29:00	Active sampler 1 finished			
O1	12:02:26	9. measurement active sampler 1			
	12:02:45	Sterile nurse walks to and from the table. Places blood agar on the table.	1	1	All measurements have a +15-30 second delay.
	12:04:15	Sterile nurse puts on sterile clothing relatively close to the Aerotrack.	1		
	12:08:15	Sterile nurse take bloodagar out of plastic packing.		1	
	12:12:15	Sterile nurse changes active sampler.	1		
	12:12:46	10. measurement active sampler 1			
	12:16:35	Sterile nurse helps surgeons put on surgical clothing.	1		
	12:16:45	Sterile nurse helps surgeons put on surgical clothing.	1		
	12:17:55	Sterile nurse helps surgeons put on surgical clothing.	1	1	
	12:18:45	Sterile nurse helps surgeons put on surgical clothing.	1		
	12:19:25	Sterile nurse helps surgeons put on surgical clothing.	1		
	12:19:45	Sterile nurse helps surgeons put on surgical clothing.	1	1	
	12:20:25	Sterile nurse helps surgeons put on surgical clothing.	1		
	12:22:15	Sterile nurse walks back and forth to the table and writes on paper.	1		
	12:22:45	Sterile nurse changes active sampler.	2		
	12:22:55	Sterile nurse writes on paper clsoe to the Aerotrack.	1		
	12:23:03	11. measurement active sampler 1			

	12:26:05	Sterile nurse throws away plastic wrapping for sterile gloves. Sterile nurse writes on paper close to the Aerotrack.	1		
	12:26:35	Sterile nurse and distribution nurse performs hand movements over the Aerotrack.		1	
	12:26:55	Sterile nurse and distribution nurse performs hand movements over the Aerotrack.		2	
	12:27:05	Sterile nurse and distribution nurse performs hand movements over the Aerotrack.	2	1	
	12:27:45	Sterile nurse and distribution nurse performs hand movements over the Aerotrack.	1		
	12:28:55	Sterile nurse writes on paper close to the Aerotrack.	1		
	12:33:18	12. measurement active sampler 1			
	12:33:25	Sterile nurse walks back and forth to the table.	1		
	12:33:35	Distribution nurse walk past the Aerotrack. Unknown reason for peak.	1	1	
	12:37:55	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:38:55	Sterile nurse walk to and away from the table. Distribution nurse walks past the table.	1		
	12:39:25	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse performs hand movements over the other table.	1		
	12:39:55	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse performs hand movements over the other table.	1		
	12:40:05	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse performs hand movements over the other table.		1	
	12:43:32	13. measurement active sampler 1			
	12:44:15	Distribution nurse walk past the Aerotrack. Unknown reason for peak.	1		
	12:50:25	Sterile nurse and distribution nurse performs hand movements over the Aerotrack.		1	
	12:50:45	Sterile nurse and distribution nurse performs hand movements over the Aerotrack.	1		
	12:51:05	Sterile nurse and distribution nurse performs hand movements over the Aerotrack.		1	
	12:52:15	Sterile nurse writes on paper close to the Aerotrack.	1		

	12:52:45	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:53:25	Sterile nurse changes active sampler.	1	1	
	12:53:48	14. measurement active sampler 1			
	12:54:55	Distribution nurse walk past the Aerotrack. Unknown reason for peak.	2	3	
	12:55:05	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:57:15	Distribution nurse perform hand movement over the Active sampler.	2		
	12:58:25	Distribution nurse perform hand movement over the Active sampler.		1	
	12:58:45	Distribution nurse perform hand movement over the Active sampler.	1	1	
	13:01:15	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	13:02:05	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse performs hand movements over the other table.	1		
	13:03:15	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse performs hand movements over the other table.	1		
	13:04:05	15. measurement active sampler 1			
	13:05:45	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2	2	
	13:05:55	Sterile nurse marking blood agar close to the Aerotrack.		1	
	13:06:35	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	13:11:45	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	13:14:15	16. measurement active sampler 1			
	13:14:25	Sterile nurse move surgical instrument close to Aerotrack.	1		
	13:14:45	Distribution nurse walks past some seconds before. Unknow what causes the peak.		1	

	13:16:25	Sterile nurse move surgical instrument close to Aerotrack.	1	1	
	13:16:55	Sterile nurse move surgical instrument close to Aerotrack.		1	
	13:17:05	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	13:19:05	Sterile nurse move surgical instrument close to Aerotrack.		1	
	13:19:25	Distribution nurse walk past the Aerotrack. Unknown reason for peak.	1		
	13:21:25	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse had walked close to the table a few seconds before.	1	2	
	13:21:35	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1	1	
	13:21:45	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		
	13:23:25	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		
	13:23:45	Distribution nurse walk past the Aerotrack. Unknown reason for peak.	1		
	13:24:15	Sterile nurse changes active sampler.	1		
	13:24:30	Active sampler 1 finished			
04.03.2022 Aerotrack 2					
Position	When	What	PM5.0	PM10.0	Comment
I1	09:03:10	1. measurement active sampler 2			
	09:03:28	Sterile nurse walks close to the Aerotrack and picks up paper placed in the middle of both Aerotracks.	1		
	09:06:08	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		

	09:06:18	Sterile nurse walks close to the Aerotrack and picks up paper placed in the middle of both Aerotracks.		1	
	09:06:28	Sterile nurse stands close to the table and moves things around on the table.		1	
	09:06:38	Sterile nurse performing hand movements over the Aerotrack.	1		
	09:07:08	Sterile nurse performing hand movements over the Aerotrack.	1		
	09:14:07	2. measurement active sampler 2			
	09:18:08	Sterile nurse places paper on the table in the middle of the Aerotracks.		1	
	09:18:18	Sterile nurse walks relatively close to the Aerotrack. Unclear what causes the peak.		2	
	09:24:46	3. measurement active sampler 2			Problems occured with the sampler showing the error "Last sampling not completed". The measurement restarted 09:28:17
	09:27:28	Sterile nurse changes active sampler.		1	
	09:34:48	Sterile nurse walks up to the table and performs hand movements over the Aerotrack.		1	
	09:38:18	Sterile nurse stands relatively close to the Aerotrack and walks between instrument tables.	1		
	09:38:28	Sterile nurse changes active sampler.		1	
	09:38:41	4. measurement active sampler 2			Trouble with active sampler again with the same error. New measurement started 09:40:24
	09:42:38	Sterile nurse stands close to the table and picks up bandage close to the Aerotrack.		1	
	09:43:28	Distribution nurse moves the active sampler and surgical instruments close to the Aerotrack.	3		
	09:47:08	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:50:48	Sterile nurse changes active sampler.	1		
	09:51:07	5. measurement active sampler 2			Same error. New measurement 09:52:33
	10:03:03	6. measurement active sampler 2			
	10:08:28	Sterile nurse walks relatively close to the Aerotrack. Distribution nurse performs hand movements cover the Aerotrack.	1		

	10:13:27	7. measurement active sampler 2			
	10:20:58	Sterile nurse picks up and moves paper in between the Aerotracks.	3		
	10:23:54	8. measurement active sampler 2			
	10:34:19	Active sampler 2 finished			
B1	12:02:20	9. measurement active sampler 2			
	12:05:13	Sterile nurse walks relatively close to the Aerotrack. Unknown reason for peak in particles.	1		10 second delay in the video for all measurements.
	12:06:33	Unknown reason for peak in particles. Sterile nurse puts on sterile clothing on the other table.		1	
	12:11:33	Unknown reason for peak in particles. Sterile nurse stands close to the other Aerotracks 8 seconds before. Distribution nurse passes 3 seconds before.		1	
	12:12:03	Sterile nurse changes active sampler.		1	
	12:12:25	10. measurement active sampler 2			
	12:13:03	Sterile nurse touches paper in the middle of the Aerotracks.	1		
	12:22:25	11. measurement active sampler 2			
	12:27:43	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse performs hand movements over the other table.	1		
	12:32:26	12. measurement active sampler 2			
	12:41:33	Sterile nurse picks up needle close to the Aerotrack.	1		
	12:42:03	Sterile nurse change active sampler.		1	
	12:42:25	13. measurement active sampler 2			
	12:43:43	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse writing on paper on the other table.		1	
	12:52:28	14. measurement active sampler 2			
	12:54:43	Sterile nurse writes on blood agar close to the Aerotrack.		1	
	12:54:53	Sterile nurse writes on blood agar close to the Aerotrack.	1		
	12:56:03	Sterile nurse moving surgical instruments close to the Aerotrack.	1		
	12:58:23	Distribution nurse perform hand movement over the Active sampler.		1	
	13:02:27	15. measurement active sampler 2			
	13:04:43	Sterile nurse moving surgical instruments close to the Aerotrack.	1		
	13:06:23	Sterile nurse moving surgical instruments close to the Aerotrack.	1	1	
	13:06:43	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	13:07:13	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	13:12:28	16. measurement active sampler 2			
	13:22:03	Sterile nurse changes active sampler.	1		
	13:22:25	Active sampler 2 finished			

H.2 Analysis of particle results from Aerotrak at sterile tables 11.03.22

11.03.2022 Aerotrack 1					
Position	When	What	PM5.0	PM10.0	Comment
B2	09:00:56	1. measurement active sampler 1			
	09:01:33	Sterile nurse writes on paper close to the Aerotrack. Distribution nurse walks past the table.		1	
	09:01:43	Sterile nurse writes on paper close to the Aerotrack.	3		
	09:04:13	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse and distribution nurse walk away a few seconds earlier.	2		
	09:04:23	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:07:03	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walk up to the other table.	1		
	09:07:33	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse moves surgical instruments on the other table.	1	1	
	09:08:43	Sterile nurse move surgical instruments and paper close to the Aerotrack.	1		
	09:11:24	2. measurement active sampler 1			
	09:21:53	3. measurement active sampler 1			
	09:22:03	Sterile nurse writing on paper next to the Aerotrack.	1		
	09:26:23	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:27:03	Distribution nurse walks past the table.	1		
	09:29:43	Distribution nurse perform hand movements over the active sampler.	1		
	09:30:13	Distribution nurse perform hand movements over the active sampler.		1	
	09:30:43	Sterile nurse and distribution nurse perform hand movements over the active sampler.		1	
	09:31:03	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:32:14	4. measurement active sampler 1			
	09:42:56	5. measurement active sampler 1			
	09:47:23	Unknown reason for peak in particles. No participants are close to the Aerotrack and no	1		

		activity close to the Aerotrack. Sterile nurse walks between instrument tables.			
	09:48:13	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:51:53	Distribution nurse walks past the table.	1		
	09:52:03	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:53:20	6. measurement active sampler 1			
	09:54:33	Distribution nurse perform hand movements over the active sampler.	1		
	09:56:33	Sterile nurse and distribution nurse perform hand movements over the active sampler.		1	
	09:56:43	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:59:53	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks between instrument tables.		2	
	10:00:03	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks between instrument tables.	1	1	
	10:01:53	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse performs hand movements over the other table.	1	2	
	10:02:43	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks between instrument tables.	1	1	
	10:03:50	7. measurement active sampler 1			
	10:06:13	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks between instrument tables. Distribution nurse walked past a few seconds before.	1		
	10:12:13	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks between instrument tables.		1	
	10:12:33	Sterile nurse move surgical instruments close to the Aerotrack.	1		
	10:13:13	Unknown reason for peak in particles. No participants are close to the Aerotrack and no	1		

		activity close to the Aerotrack. Sterile nurse walks up to the other table.			
	10:14:19	8. measurement active sampler 1			
	10:14:53	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:16:33	Sterile nurse writes on paper close to the Aerotrack.		1	
	10:18:13	Sterile nurse puts down pen next to the Aerotrack and walks to another table.	1		
	10:20:33	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks between instrument tables.	1		
	10:22:53	Distribution nurse walks past the table. Sterile nurse performs hand movement over another table.	2		
	10:23:03	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:24:33	Sterile nurse changes active sampler.		1	
	10:24:43	Active sampler 1 finished			
I3	11:34:15	9. measurement active sampler 1			
	11:44:20	10. measurement active sampler 1			
	11:54:28	11. measurement active sampler 1			
	12:04:24	12. measurement active sampler 1			
	12:13:52	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:14:36	13. measurement active sampler 1			
	12:17:22	Distribution nurse walks past the table.		1	
	12:22:22	Sterile nurse and distribution nurse perform hand movements over the active sampler.		1	
	12:24:38	14. measurement active sampler 1			
	12:30:32	Distribution nurse performs hand movements over the active sampler.	1		
	12:33:02	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		
	12:34:38	15. measurement active sampler 1			
	12:44:40	16. measurement active sampler 1			

Position	When	What	PM5.0	PM10.0	Comment
	12:54:30	Active sampler 1 finished			
11.03.2022 Aerotrack 2					
Position	When	What	PM5.0	PM10.0	Comment
O2	09:01:17	1. measurement active sampler 2			
	09:01:53	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile writes on paper on other table.	1		10-20 second delay in the video for all measurements.
	09:10:23	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:12:02	2. measurement active sampler 2			
	09:22:43	3. measurement active sampler 2			
	09:33:18	4. measurement active sampler 2			
	09:43:33	Sterile nurse changes active sampler.		1	
	09:43:53	Sterile nurse changes active sampler. hand movements from distribution nurse and sterile nurse writing on blood agar.	1		
	09:43:59	5. measurement active sampler 2			
	09:46:33	Sterile nurse moves surgical instruments on the table.	1		
	09:47:43	Sterile nurse moves surgical instruments on the table.	1		
	09:54:39	6. measurement active sampler 2			
	10:02:43	Sterile nurse moves surgical instruments on the table.	1		
	10:05:14	7. measurement active sampler 2			
	10:05:33	Distribution nurse performs hand movements over the active sampler.		1	
	10:09:23	Sterile nurse and distribution nurse performs hand movements over the active sampler.	1		
	10:11:33	Sterile nurse moves surgical instruments on the table.		1	
	10:15:43	Sterile nurse changes active sampler.	1		
	10:15:53	Sterile nurse changes active sampler.	1		
	10:16:08	8. measurement active sampler 2			
	10:18:13	Sterile nurse moves surgical instruments on the table.		1	

	10:19:33	Sterile nurse moves surgical instruments on the table.		1	
	10:19:53	Sterile nurse moves surgical instruments on the table.	1		
	10:20:03	Sterile nurse moves surgical instruments on the table. Distribution nurse walks past the table.	1		
	10:22:03	Sterile nurse performs hand movements over the Aerotrack.		1	
	10:24:33	Sterile nurse performs hand movements over the Aerotrack.		1	
	10:26:41	Active sampler 2 finished			
I4	11:34:32	9. measurement active sampler 2			
	11:42:28	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse moves surgical instruments on the other table.		1	
	11:43:08	Sterile nurse moves surgical instrument close to the Aerotrack.	1		
	11:43:18	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse stand relatively close to the Aerotrack.	1		
	11:44:54	10. measurement active sampler 2			
	11:55:02	11. measurement active sampler 2			
	12:05:40	12. measurement active sampler 2			
	12:15:48	13. measurement active sampler 2			
	12:26:01	14. measurement active sampler 2			
	12:36:10	15. measurement active sampler 2			
	12:46:17	16. measurement active sampler 2			
	12:54:28	Sterile nurse changes the active sampler.		1	
	12:56:18	Active sampler 2 finished			

H.3 Analysis of particle results from Aerotrak at sterile tables 18.03.22

18.03.2022					
Position	When	What	PM5.0	PM10.0	Comment
B2	09:02:59	1. measurement active sampler 1			
	09:08:55	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:13:10	2. measurement active sampler 1			
	09:19:15	Sterile nurse helps surgeons put on sterile clothing.	6		
	09:19:25	Sterile nurse helps surgeons put on sterile clothing.	2		
	09:20:45	Sterile nurse helps surgeons put on sterile clothing.		1	
	09:22:25	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:23:20	3. measurement active sampler 1			
	09:28:45	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:33:33	4. measurement active sampler 1			
	09:36:25	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		
	09:36:55	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:43:44	5. measurement active sampler 1			
	09:44:55	Distribution nurse walks past the sampler.	3	2	
	09:53:58	6. measurement active sampler 1			
	10:04:07	7. measurement active sampler 1			
	10:04:45	Sterile nurse walking away from the table after moving a blood agar on the table. Distribution nurse walks past the table.	1		
	10:09:45	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:14:17	8. measurement active sampler 1			
	10:24:25	Active sampler 1 finished			
O1	11:40:38	9. measurement active sampler 1			
	11:42:01	Sterile nurse putting on sterile clothing relatively close to the Aerotrack.	1		
	11:42:21	Sterile nurse putting on sterile clothing relatively close to the Aerotrack. Distribution nurse walking past the table.	1		
	11:48:01	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the	1		

		Aerotrack. Distribution nurse walks past a few seconds later.			
	11:50:49	10. measurement active sampler 1			
	11:53:51	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	3	1	
	11:54:11	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	11:55:01	Sterile nurse helps surgeons put on sterile clothing.	1	1	
	11:55:21	Sterile nurse helps surgeons put on sterile clothing.	1		
	11:55:51	Sterile nurse helps surgeons put on sterile clothing.	1		
	11:56:31	Sterile nurse helps surgeons put on sterile clothing.		1	
	11:57:31	Sterile nurse helps surgeons put on sterile clothing. Touching of plastic wrapping for gloves close to the Aerotrack.		1	
	12:01:03	11. measurement active sampler 1			
	12:04:01	Distribution nurse walks past the sampler.	1		
	12:04:21	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	12:04:51	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	12:05:01	Sterile nurse and distribution nurse perform hand movements over the active sampler.	2	1	
	12:05:21	Sterile nurse and distribution nurse perform hand movements over the active sampler.		1	
	12:09:01	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:11:12	12. measurement active sampler 1			
	12:21:11	Sterile nurse changes active sampler.	1		
	12:21:21	13. measurement active sampler 1			
	12:21:51	Sterile nurse drops pen on paper next to the Aerotrack and walks away from the table.		1	
	12:25:41	Distribution nurse performs hand movements over the active sampler.	1		
	12:28:01	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	12:28:41	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	12:29:01	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		

	12:29:11	Sterile nurse and distribution nurse perform hand movements over the active sampler.		1	
	12:30:01	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	12:31:34	14. measurement active sampler 1			
	12:32:11	Sterile nurse drops pen on paper next to the Aerotrack and walks away from the table.	1		
	12:33:51	Sterile nurse walked away from the table a few seconds before. Distribution nurse walked past the table a few seconds before.	1		
	12:34:41	Distribution nurse walks past the sampler.	1		
	12:35:31	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		
	12:41:45	15. measurement active sampler 1			
	12:44:21	Sterile nurse walks up to the table.		1	
	12:44:31	Sterile nurse moves surgical instruments close to the Aerotrack.		1	
	12:50:11	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:51:53	16. measurement active sampler 1			
	12:53:31	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:54:31	Sterile nurse moves surgical instruments close to the Aerotrack.	4	1	
	12:56:11	Distribution nurse walks past the sampler.		1	
	12:56:31	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	12:57:01	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	12:58:31	Sterile nurse moves surgical instruments close to the Aerotrack.		1	
	13:00:31	Sterile nurse moves surgical instruments close to the Aerotrack.	2	1	
	13:00:41	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	13:00:51	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	13:02:03	Active sampler 1 finished			

18.03.2022					
Position	When	What	PM5.0	PM10.0	Comment
I1	09:03:27	1. measurement active sampler 2			
	09:13:34	2. measurement active sampler 2			
	09:16:48	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:24:01	3. measurement active sampler 2			
	09:34:00	4. measurement active sampler 2			
	09:34:18	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse writing on paper on the other table.	1		
	09:41:28	Sterile nurse and distribution nurse performs hand movements over the active sampler.	1		
	09:43:18	Sterile nurse walks past the table relatively close to the Aerotrack.		1	
	09:44:11	5. measurement active sampler 2			
	09:54:18	6. measurement active sampler 2			
	10:04:23	7. measurement active sampler 2			
	10:06:38	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse writing on paper on the other table. Sterile nurse moving surgical instruments on the other table.		1	
	10:14:33	8. measurement active sampler 2			
	10:24:38	Active sampler 2 finished			
B1	11:40:59	9. measurement active sampler 2			
	11:51:02	10. measurement active sampler 2			
	12:01:21	11. measurement active sampler 2			
	12:10:27	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks away from other table.	1	1	
	12:11:17	Sterile nurse changes active sampler.		1	
	12:11:24	12. measurement active sampler 2			
	12:12:07	Distribution nurse performs hand movements over the active sampler.	2	1	
	12:18:27	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	12:19:07	Sterile nurse and distribution nurse perform hand movements over the active sampler.		1	

	12:21:34	13. measurement active sampler 2			
	12:31:47	14. measurement active sampler 2			
	12:41:57	15. measurement active sampler 2			
	12:42:37	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walking between instrument tables.	1		
	12:42:57	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walked away from the table a few seconds before.	1		
	12:44:47	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:46:07	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	12:52:05	16. measurement active sampler 2			
	12:56:57	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	12:58:57	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walking between instrument tables.	1		
	12:59:07	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	12:59:27	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walking between instrument tables.	1		
	13:01:27	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walking between instrument tables.	2		
	13:02:13	Active sampler 2 finished			

H.4 Analysis of particle results from Aerotrak at sterile tables 25.03.22

25.03.2022					
Position	When	What	PM5.0	PM10.0	Comment
B2	09:02:13	1. measurement active sampler 1			
	09:04:24	Sterile nurse putting on gloves and placing plastic wrapping from gloves close to the Aerotrack.	1	1	
	09:04:34	Sterile nurse putting on gloves and placing plastic wrapping from gloves close to the Aerotrack.		1	
	09:04:44	Sterile nurse putting on gloves close to the Aerotrack.		1	
	09:07:04	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:07:14	Distribution nurse walks past the table.		1	
	09:07:24	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	5	1	
	09:09:04	Sterile nurse moves surgical instruments close to the Aerotrack. Distribution nurse walks past the table.	1	2	
	09:09:14	Sterile nurse moves surgical instruments close to the Aerotrack.	4		
	09:09:24	Sterile nurse moves surgical instruments close to the Aerotrack.	2	3	
	09:09:34	Sterile nurse walks away from the table.	1		
	09:10:04	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Distribution nurse walked past a few seconds before.		1	
	09:11:14	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	09:12:13	2. measurement active sampler 1			
	09:16:54	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:17:14	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:17:34	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:18:14	Sterile nurse helps surgeons put on sterile clothing.		1	
	09:18:54	Sterile nurse helps surgeons put on sterile clothing.	1		
	09:19:24	Sterile nurse helps surgeons put on sterile clothing.		1	
	09:20:34	Sterile nurse helps surgeons put on sterile clothing.	1		
	09:20:44	Sterile nurse helps surgeons put on sterile clothing.	3		

	09:21:34	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:22:11	3. measurement active sampler 1			
	09:22:34	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:25:54	Distribution nurse performs hand movements over the active sampler.	1	1	
	09:26:04	Distribution nurse performs hand movements over the active sampler.	2		
	09:26:24	Distribution nurse performs hand movements over the active sampler.	1		
	09:26:34	Distribution nurse performs hand movements over the active sampler.	1		
	09:26:44	Distribution walks away from the table after performing hand movements over the active sampler.	1	1	
	09:26:54	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:27:04	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:27:14	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:27:44	Sterile nurse and distribution nurse perform hand movements over the active sampler.		2	
	09:27:54	Sterile nurse and distribution nurse perform hand movements over the active sampler.	2		
	09:28:14	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:31:04	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1	1	
	09:32:12	4. measurement active sampler 1			
	09:32:54	Distribution nurse walks past the table.	2	1	
	09:41:24	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:42:10	5. measurement active sampler 1			
	09:42:44	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1	1	
	09:42:54	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		

	09:49:44	Distribution walks away from the table after performing hand movements over the active sampler.		1	
	09:50:24	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:50:44	Sterile nurse and distribution nurse perform hand movements over the active sampler.		1	
	09:51:14	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:51:24	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:51:44	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:52:08	6. measurement active sampler 1			
	09:53:24	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks towards the table.		1	
	09:55:14	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	09:56:44	Sterile nurse moves surgical instruments close to the Aerotrack.		1	
	10:02:09	7. measurement active sampler 1			
	10:02:14	Sterile nurse walks away from the table after writing on paper close to the Aerotrack.	1		
	10:06:14	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:06:54	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	2		
	10:12:06	8. measurement active sampler 1			
	10:14:54	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:19:04	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:20:34	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	10:20:44	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	10:20:54	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		2	

	10:21:04	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	10:22:02	Active sampler 1 finished			
I3	11:40:42	9. measurement active sampler 1			
	11:50:40	10. measurement active sampler 1			
	12:00:38	11. measurement active sampler 1			
	12:10:35	12. measurement active sampler 1			
	12:20:32	13. measurement active sampler 1			
	12:20:35	Sterile nurse writes on paper close to the Aerotrack.		1	
	12:30:33	14. measurement active sampler 1			
	12:40:32	15. measurement active sampler 1			
	12:41:35	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	12:50:29	16. measurement active sampler 1			
	13:00:23	Active sampler 1 finished			
25.03.2022					
Position	When	What	PM5.0	PM10.0	Comment
O2	09:02:37	1. measurement active sampler 2			
	09:07:53	Distribution nurse walks past the table.		1	10 second delay in all measurements.
	09:08:03	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1	1	
	09:09:43	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.	1		
	09:09:53	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Distribution nurse walked past a few seconds before.	1		
	09:10:03	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack.		1	
	09:12:45	2. measurement active sampler 2			
	09:22:58	3. measurement active sampler 2			
	09:33:03	Sterile nurse changes active sampler.	1		
	09:33:06	4. measurement active sampler 2			
	09:40:03	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		

	09:40:23	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:41:13	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:41:53	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	09:42:03	Distribution nurse performs hand movements over the active sampler.	1		
	09:43:13	5. measurement active sampler 2			
	09:45:13	Distribution nurse walks past the table.		1	
	09:53:23	6. measurement active sampler 2			
	09:54:23	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Sterile nurse walks between instrument table.		1	
	09:56:03	Unknown reason for peak in particles. No participants are close to the Aerotrack and no activity close to the Aerotrack. Distribution nurse walked past a few seconds before.		1	
	09:57:43	Distribution nurse performs hand movements over the active sampler.		1	
	10:03:30	7. measurement active sampler 2			
	10:04:03	Sterile nurse and distribution nurse perform hand movements over the active sampler.	1		
	10:13:42	8. measurement active sampler 2			
	10:15:03	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	10:17:03	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	10:19:23	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	10:21:23	Sterile nurse moves surgical instruments close to the Aerotrack.	1		
	10:23:43	Sterile nurse walks away from the table a few seconds before.	2		
	10:23:47	Active sampler 2 finished			
I4	11:41:30	9. measurement active sampler 2			
	11:51:41	10. measurement active sampler 2			
	12:01:50	11. measurement active sampler 2			
	12:12:00	12. measurement active sampler 2			
	12:22:09	13. measurement active sampler 2			
	12:32:19	14. measurement active sampler 2			
	12:42:27	15. measurement active sampler 2			
	12:52:36	16. measurement active sampler 2			
	13:02:44	Active sampler 2 finished			

I Analysis of CFU results from active sampler for all measurement days

Following is the analysis of all registered CFU results presented in Excel tables. The results from the active samplers placed on the sterile tables are here compared with the events recorded by the GOPro camera during all mock surgeries. During all measurement days, the time was recorded every time a new measurement was started with the active sampler. After the mock surgeries were finished, all recordings where reviewed. The activities performed during each measurement with the active sampler was then recorded in the following Excel tables.

The surgical activities shown in the tables are the activities described in Appendix K. In the following tables, each measurement with the active sampler is shown grey color with the name of the position of the sterile tables and the measurement number. Light blue rows shown when a mock surgery start or stop. A blank, green row separate the two surgeries for each measurement day. In the column "What" follows the activities performed after the measurement with the active sampler started. Some activities are colored red, green, orange and blue. Red rows indicate an activity where hand movements are performed over the active sampler, either by only the distribution nurse, or by the distribution nurse and the sterile nurse. The green rows are the activities where the sterile nurse walk back and forth between the cabinets and the computer table. Orange is when the sterile nurse move surgical instruments close to the active sampler.

In column marked "CFU", the number of CFU recorded during the specific measurement is shown. If the measured number of CFU is believed to be caused by a specific activity, the "CFU" row and the "What" row with the activity will have the same color. As an example, during measurements day 04.03 the measurement number M6 at position I1 resulted in 4 CFU. During this measurement, activity 6 and 8 was performed where both activities included hand movements over the active sampler. After reviewing the recording from 04.03, these activities were presumed to be the reason for the recorded CFU level. If no explanation for the CFU level is found, the CFU row have a light grey color indicating a CFU level of 0 or 1, dark grey indicating 2 CFU, and yellow indicating 3 or 4 CFU recorded. The sterile nurse's last activity includes moving surgical instruments close to the active sampler, which is why some of the CFU rows after the surgery has ended has an orange color.

I.1 Analysis of CFU results from active sampler at sterile tables 04.03.22

04.03.2022		
When	What	CFU
09:02:46	I2 M1	0
09:03:10	I1 M1	1
09:03:25	First ABC	
09:03:42	Sterile nurse puts on sterile clothing	
09:06:39	Sterile nurse starts first activity	
09:13:40	I2 M2	0
09:14:07	I1 M2	2
09:14:21	Door opens. Patient and anesthesia nurse enters	
09:17:30	Patient ready for surgery	
09:20:19	Door opens. Surgeons enter	
09:24:25	I2 M3	0
09:24:46	I1 M3	0
09:25:26	Surgeons finished dressed	
09:28:59	Start of surgery and 1. surgical activity	
09:31:39	2. surgical activity	
09:34:19	3. surgical activity	
09:35:17	I2 M4	1
09:36:59	4. surgical activity	
09:38:41	I1 M4	0
09:39:39	5. surgical activity	
09:42:19	6. surgical activity	
09:45:00	7. surgical activity	
09:46:02	I2 M5	1
09:47:40	8. surgical activity	
09:50:19	9. surgical activity	
09:51:07	I1 M5	2
09:52:59	1. surgical activity	
09:55:40	2. surgical activity	
09:56:53	I2 M6	1
09:58:20	3. surgical activity	
10:01:00	4. surgical activity	
10:03:03	I1 M6	4
10:03:40	5. surgical activity	
10:06:20	6. surgical activity	
10:07:37	I2 M7	2
10:09:00	7. surgical activity	
10:11:40	8. surgical activity	
10:13:27	I1 M7	0
10:14:20	9. surgical activity	
10:17:31	Surgery finished	
10:18:22	I2 M8	0
10:19:00 - 10:19:48	Removing cover from the patient	

10:21:09	Door opens and surgeons and anesthesia nurse leaves the OR	
10:21:24	Door opens. Patient leaves	
10:21:25	Last activity started	
10:23:54	I1 M8	0
10:29:00	Active sampler 1 finished	
10:34:19	Active sampler 2 finished	
12:02:20	B1 M1	3
12:02:26	O1 M1	0
12:03:00	Distribution nurse starts first activity	
12:03:21	Sterile nurse puts on sterile clothing	
12:05:32	Sterile nurse starts first activity and first ABC	
12:12:25	B1 M2	0
12:12:46	O1 M2	0
12:12:04	Door opens. Anesthesia nurse and patient enters	
12:14:50	Patient ready for surgery	
12:16:36	Door opens. Surgeons enter	
12:20:38	Surgeons finished dressed	
12:20:48	Start of surgery and 1. surgical activity	
12:22:25	B1 M3	0
12:23:03	O1 M3	3
12:23:23	2. surgical activity	
12:25:56	3. surgical activity	
12:28:30	4. surgical activity	
12:31:03	5. surgical activity	
12:32:26	B1 M4	3
12:33:18	O1 M4	2
12:33:37	6. surgical activity	
12:36:09	7. surgical activity	
12:38:44	8. surgical activity	
12:41:16	9. surgical activity	
12:42:25	B1 M5	2
12:43:32	O1 M5	0
12:43:51	1. surgical activity	
12:46:24	2. surgical activity	
12:48:57	3. surgical activity	
12:51:31	4. surgical activity	
12:52:28	B1 M6	0
12:53:48	O1 M6	1
12:54:05	5. surgical activity	
12:56:39	6. surgical activity	
12:59:11	7. surgical activity	
13:01:45	8. surgical activity	
13:02:27	B1 M7	1
13:04:05	O1 M7	4

13:04:19	9. surgical activity	
13:06:58	Surgery finished.	
13:08:37	Door opens and surgeons, patient and anesthesia nurse leaves the OR	
13:12:28	B1 M8	4
13:12:28	Last activity started for distribution nurse	
13:13:22	Last activity started for sterile nurse	
13:14:15	O1 M8	3
13:15:24	ABC started	
13:22:25	Active sampler 2 finished	
13:24:30	Active sampler 1 finished	

I.2 Analysis of CFU results from active sampler at sterile tables 11.03.22

11.03.2022		
When	What	CFU
09:00:56	B2 M1	0
09:01:17	O2 M1	1
08:59:40	Distribution nurse starts first activity	
09:04:01	Sterile nurse starts first activity. Start of first ABC	
09:11:24	B2 M2	0
09:12:02	O2 M2	1
09:12:14	Door opens. Patient and anesthesia nurse enters	
09:15:50	Patient ready for surgery	
09:19:26	Door opens. Surgeons enter	
09:21:53	B2 M3	0
09:22:43	O2 M3	0
09:23:55	Surgeons finished dressed	
09:24:55	Start of surgery and 1. surgical activity	
09:27:36	2. surgical activity	
09:30:15	3. surgical activity	
09:32:14	B2 M4	1
09:32:55	4. surgical activity	
09:33:18	O2 M4	0
09:35:36	5. surgical activity	
09:38:15	6. surgical activity	
09:40:56	7. surgical activity	
09:42:56	B2 M5	1
09:43:37	8. surgical activity	
09:43:59	O2 M5	2
09:46:16	9. surgical activity	
09:50:08	1. surgical activity	
09:52:46	2. surgical activity	
09:53:20	B2 M6	1
09:54:39	O2 M6	4
09:55:27	3. surgical activity	
09:58:07	4. surgical activity	
10:00:46	5. surgical activity	
10:03:28	6. surgical activity	
10:03:50	B2 M7	3
10:05:14	O2 M7	1
10:06:09	7. surgical activity	
10:08:47	8. surgical activity	
10:11:26	9. surgical activity	
10:14:11	Surgery finished	
10:14:19	B2 M8	0
10:15:06 - 10:16:09	Removing cover from the patient	
10:16:08	O2 M8	0

10:16:46	Door opens and surgeons, patient and anesthesia nurse leaves the OR	
10:17:02	Last activity started	
10:24:43	Active sampler 1 finished	
10:26:41	Active sampler 2 finished	
11:34:15	I3 M1	3
11:34:32	I4 M1	3
11:35:00	Sterile nurs puts on sterile clothing	
11:37:20	Sterile nurse starts first activity	
11:37:22	Start of first ABC	
11:44:20	I3 M2	1
11:44:54	I4 M2	0
11:45:05	Door opens. Anesthesia nurse and patient enters	
11:46:56	Patient ready for surgery	
11:49:14	Surgeons enter	
11:52:26	Surgeons finished dressed	
11:52:37	Start of surgery and 1. surgical activity	
11:54:28	I3 M3	3
11:55:02	I4 M3	0
11:55:15	2. surgical activity	
11:57:43	3. surgical activity	
12:00:18	4. surgical activity	
12:02:52	5. surgical activity	
12:04:24	I3 M4	1
12:05:33	6. surgical activity	
12:05:40	I4 M4	3
12:07:59	7. surgical activity	
12:10:32	8. surgical activity	
12:13:04	9. surgical activity	
12:14:36	I3 M5	4
12:15:40	1. surgical activity	
12:15:48	I4 M5	2
12:18:14	2. surgical activity	
12:20:47	3. surgical activity	
12:23:18	4. surgical activity	
12:24:38	I3 M6	2
12:25:26	5. surgical activity	
12:26:01	I4 M6	0
12:28:25	6. surgical activity	
12:31:00	7. surgical activity	
12:33:33	8. surgical activity	
12:34:38	I3 M7	2
12:36:07	9. surgical activity	
12:36:10	I4 M7	1
12:38:48	Surgery finished.	

12:41:20	Door opens and surgeons, patient and anesthesia nurse leaves the OR	
12:41:44	Last activity started	
12:44:40	I3 M8	1
12:46:17	I4 M8	4
12:54:30	Active sampler 1 finished	
12:56:18	Active sampler 2 finished	

I.3 Analysis of CFU results from active sampler at sterile tables 18.03.22

18.03.2022		
When	What	CFU
09:02:59	B2 M1	1
09:03:27	I1 M1	0
09:03:45	Sterile nurse puts on sterile clothing	
09:03:40	Sterile nurse starts first activity. Start of first ABC	
09:13:10	B2 M2	0
09:13:34	I1 M2	0
09:14:18	Door opens. Patient and anesthesia nurse enters	
09:16:28	Patient ready for surgery	
09:17:46	Door opens. Surgeons enter	
09:20:52	Surgeons finished dressed	
09:21:08	Start of surgery and 1. surgical activity	
09:23:20	B2 M3	2
09:23:43	2. surgical activity	
09:24:01	I1 M3	0
09:26:15	3. surgical activity	
09:28:49	4. surgical activity	
09:31:24	5. surgical activity	
09:33:33	B2 M4	0
09:33:57	6. surgical activity	
09:34:00	I1 M4	0
09:36:30	7. surgical activity	
09:39:04	8. surgical activity	
09:41:36	9. surgical activity	
09:43:44	B2 M5	4
09:44:10	1. surgical activity	
09:44:11	I1 M5	0
09:46:44	2. surgical activity	
09:49:17	3. surgical activity	
09:51:50	4. surgical activity	
09:53:58	B2 M6	2
09:54:18	I1 M6	0
09:54:26	5. surgical activity	
09:56:57	6. surgical activity	
09:59:31	7. surgical activity	
10:02:04	8. surgical activity	
10:04:07	B2 M7	1
10:04:23	I1 M7	0
10:04:39	9. surgical activity	
10:07:22	Surgery finished	
10:07:59	Removing cover from the patient	
10:08:49	Door opens and surgeons, patient and anesthesia nurse leaves the OR	
10:14:17	B2 M8	1

10:14:20	Distribution nurse starts last activity	
10:14:33	I1 M8	0
10:15:17	Sterile nurse start last activity and ABC	
10:24:25	Active sampler 1 finished	
10:24:38	Active sampler 2 finished	
11:40:38	O1 M1	2
11:40:59	B1 M1	1
11:41:15	Sterile nurs puts on sterile clothing	
11:43:16	Sterile nurse starts first activity and ABC	
11:50:49	O1 M2	0
11:51:02	B1 M2	0
11:51:25	Door opens. Anesthesia nurse and patient enters	
11:52:47	Patient ready for surgery	
11:54:21	Surgeons enter	
11:57:55	Surgeons finished dressed	
11:58:23	Start of surgery and 1. surgical activity	
12:01:03	O1 M3	2
12:01:21	B1 M3	0
12:01:25	2. surgical activity	
12:03:58	3. surgical activity	
12:06:31	4. surgical activity	
12:09:04	5. surgical activity	
12:11:12	O1 M4	2
12:11:24	B1 M4	1
12:11:38	6. surgical activity	
12:14:11	7. surgical activity	
12:16:45	8. surgical activity	
12:19:18	9. surgical activity	
12:21:21	O1 M5	2
12:21:34	B1 M5	0
12:21:52	1. surgical activity	
12:24:25	2. surgical activity	
12:26:59	3. surgical activity	
12:29:33	4. surgical activity	
12:31:34	O1 M6	2
12:31:47	B1 M6	0
12:32:06	5. surgical activity	
12:34:39	6. surgical activity	
12:37:13	7. surgical activity	
12:39:46	8. surgical activity	
12:41:45	O1 M7	1
12:41:57	B1 M7	0
12:42:20	9. surgical activity	
12:44:55	Surgery finished.	

12:46:08	Door opens and surgeons, patient and anesthesia nurse leaves the OR	
12:51:46	Distribution nurse starts last activity	
12:51:53	O1 M8	2
12:52:05	B1 M8	3
12:52:52	Sterile nurse starts last activity and ABC	
13:02:03	Active sampler 1 finished	
13:02:13	Active sampler 2 finished	

I.4 Analysis of CFU results from active sampler at sterile tables 25.03.22

25.03.2022		
When	What	CFU
09:02:13	B2 M1	1
09:02:37	O2 M1	1
09:02:54	Sterile nurse puts on sterile clothing	
09:05:00	Sterile nurse starts first activity. Start of first ABC	
09:12:13	B2 M2	0
09:12:45	O2 M2	0
09:13:32	Door opens. Patient and anesthesia nurse enters	
09:15:57	Patient ready for surgery	
09:17:00	Surgical lights turned on	
09:18:00	Door opens. Surgeons enter	
09:21:01	Surgeons finished dressed	
09:21:36	Start of surgery and 1. surgical activity	
09:22:11	B2 M3	2
09:22:58	O2 M3	0
09:24:10	2. surgical activity	
09:26:44	3. surgical activity	
09:29:17	4. surgical activity	
09:31:49	5. surgical activity	
09:32:12	B2 M4	1
09:33:06	O2 M4	0
09:34:24	6. surgical activity	
09:36:58	7. surgical activity	
09:39:30	8. surgical activity	
09:42:02	9. surgical activity	
09:42:10	B2 M5	0
09:43:13	O2 M5	0
09:44:38	1. surgical activity	
09:47:10	2. surgical activity	
09:49:45	3. surgical activity	
09:52:08	B2 M6	2
09:52:19	4. surgical activity	
09:53:23	O2 M6	2
09:54:51	5. surgical activity	
09:57:27	6. surgical activity	
09:59:59	7. surgical activity	
10:02:09	B2 M7	4
10:02:35	8. surgical activity	
10:03:30	O2 M7	2
10:05:05	9. surgical activity	
10:07:45	Surgery finished	
10:08:00 - 10:09:07	Removing cover from the patient	
10:09:31	Door opens and surgeons, patient and anesthesia nurse leaves the OR	

10:12:06	B2 M8	1
10:12:21	Start last activity	
10:13:42	O2 M8	3
10:22:02	Active sampler 1 finished	
10:23:47	Active sampler 2 finished	
11:40:42	I3 M1	0
11:41:20	Distribution nurse starts first activity	
11:41:30	I4 M1	0
11:41:55	Sterile nurs puts on sterile clothing	
11:43:32	Sterile nurse starts first activity and first ABC	
11:50:40	I3 M2	0
11:51:41	I4 M2	0
11:52:06	Door opens. Anesthesia nurse and patient enters	
11:53:53	Patient ready for surgery	
11:54:49	Surgeons enter	
11:57:45	Surgeons finished dressed	
11:58:09	Start of surgery and 1. surgical activity	
12:00:38	I3 M3	0
12:00:43	2. surgical activity	
12:01:50	I4 M3	0
12:03:16	3. surgical activity	
12:05:50	4. surgical activity	
12:08:23	5. surgical activity	
12:10:35	I3 M4	0
12:10:57	6. surgical activity	
12:12:00	I4 M4	1
12:13:30	7. surgical activity	
12:16:03	8. surgical activity	
12:18:37	9. surgical activity	
12:20:32	I3 M5	0
12:21:10	1. surgical activity	
12:22:09	I4 M5	0
12:23:44	2. surgical activity	
12:26:17	3. surgical activity	
12:28:51	4. surgical activity	
12:30:33	I3 M6	0
12:31:24	5. surgical activity	
12:32:19	I4 M6	1
12:33:57	6. surgical activity	
12:36:31	7. surgical activity	
12:39:05	8. surgical activity	
12:40:32	I3 M7	0
12:41:39	9. surgical activity	
12:42:27	I4 M7	0

12:44:17	Surgery finished.	
12:47:03	Door opens and surgeons, patient and anesthesia nurse leaves the OR	
12:59:25	Last activity started for distribution nurse	
12:50:29	I3 M8	0
12:50:48	Last activity started for sterile nurse	
12:52:36	I4 M8	0
13:00:23	Active sampler 1 finished	
13:02:44	Active sampler 2 finished	

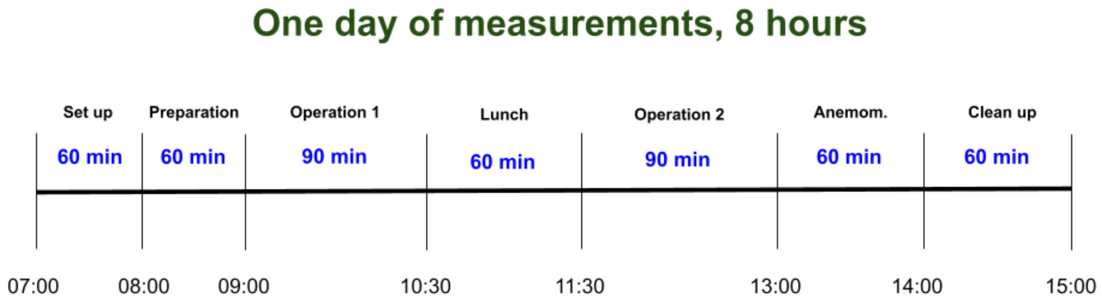
J Measurement Plan

What:			
CFU-measurements on and around sterile surgical tables in an operating room with laminar airflow ventilation.			
Purpose:			
Study the change in CFU-levels and bacterial contamination on surgical instruments based on the different placement of sterile surgical tables under a laminar airflow canopy. The goal is to determine if there is a significant difference in the number of bacteria on and around the instrument table if it is placed outside or in the boundary area of the laminar airflow. This will be compared to the instrument table being placed inside the laminar airflow.			
When:			
Friday 04.03.22 Kl.07.00 - 15:00	Friday 11.03.22 Kl.07.00 - 15:00	Friday 18.03 Kl.07.00 - 15:00	Friday 25.03 Kl.07.00 - 15:00
Where:			
St.Olavs Hospital, Bevegelsessenteret, Operasjonsstue 08			
Who:			
Runar	Yang	Tomas	Tina
Liv-Inger	Sara	Mathilde	Lisa
Øystein			
Equipment:			
TinyTag	AirThings	AirDistSys 5000	Thermal camera
Aerotrak 9306	Decentlab	PC	Active and passive sampler
Tape	Extension cord	Pen and paper	
Description:			
Friday 04.03, 11.03, 18.03 and 25.03 will consist of the main measurements and will be performed using simulated surgery and repeated measurements for different positions for the sterile surgical tables. All of these Fridays will consist of the same experiment and will therefore be similar with the same measurements. A detailed description of the mock-up surgery is described in the “Acting plan”.			

To-do-list:

Measurements
Before the measurements: ● Transport necessary equipment to St. Olavs. ● Check the indoor climate in the operating room. ● Charge necessary equipment. ● Get blood agar and the measuring machine at 08:30. ● Covering surfaces with sterile cover. ● Place equipment in their correct position. ● Mark the floor of the operating room where the LAF-area ends. ● Set up camera. ● Hang up a sign on the door. ● Review of the acting plan. ● Adjust the surgical lamp. **During the measurements:** ● The measurements and mock-up surgery will be performed according to the acting plan. **After the measurements:** ● Turn off the surgical lamp and measure the placement of the lamp. ● Take a picture of the surgical team in surgical clothing. ● Take pictures of the surgical set up with everyone in position. ● Take pictures of the different equipment and placement. ● Measure the placement of tables and equipment. ● Return blood agar and measuring instrument before 15:00. ● Clean and notify the cleaning crew. ● Transport necessary equipment back to NTNU.

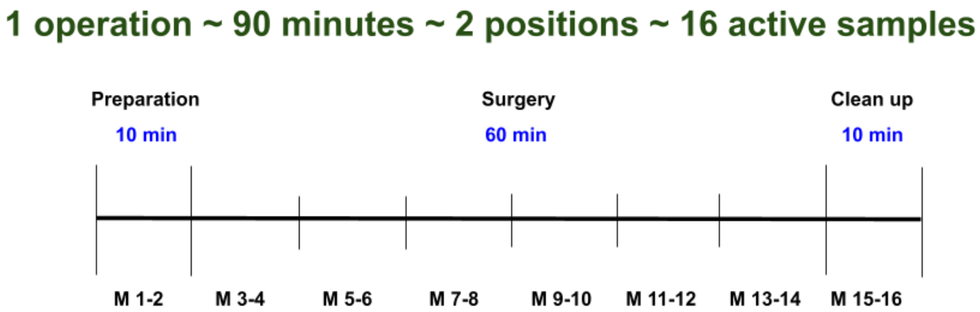
Time schedule one day:
Total of 2 operations with 4 positions for the instrument table, 8 measurements each position.



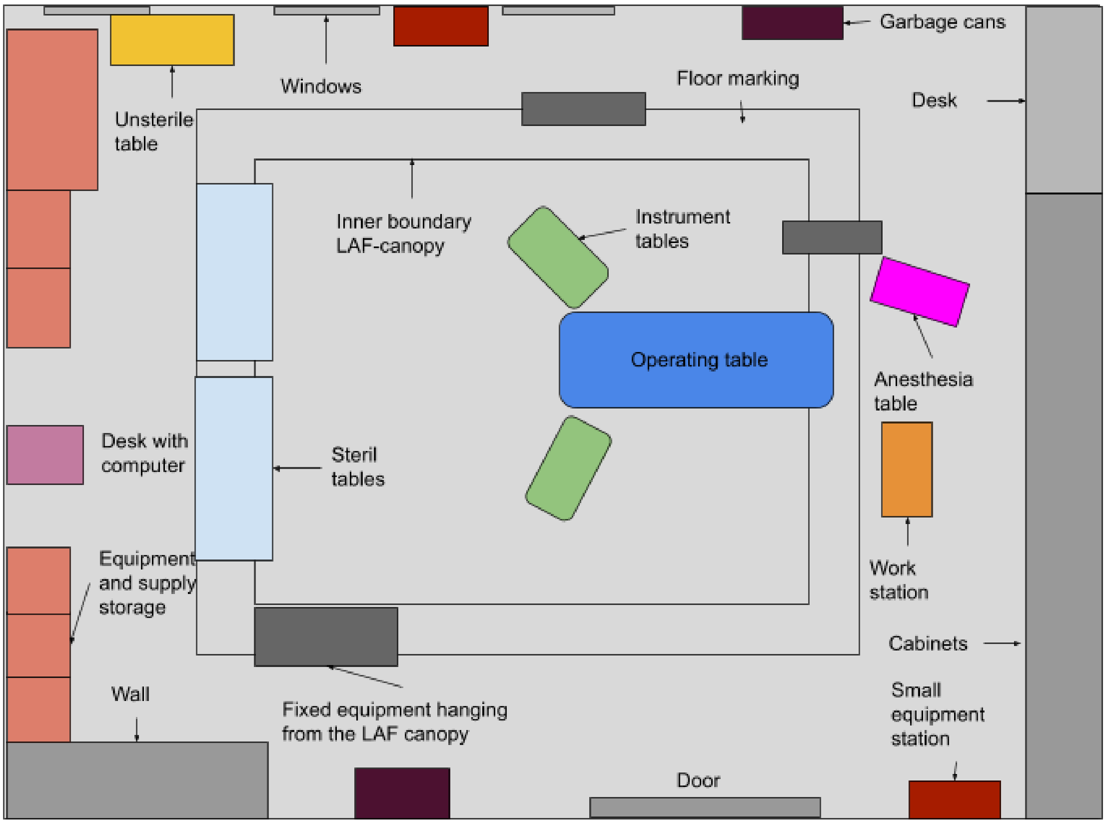
* Anemom. = Anemometer which refers to air velocity measurements.

- **07:00 Runar and Tomas arrives.**
- **08:00 All other participants arrive at the operating room and prepare.**
- **08:30 Pick up the active sampler and blood agar.**
- **09:00 First measurements start. All participants should be dressed and ready.**
- **10:30 Lunch**
- **11:30 Start of the second measurement. All participants should be dressed and ready before this.**
- **14:30 Return active sampler and blood agar**

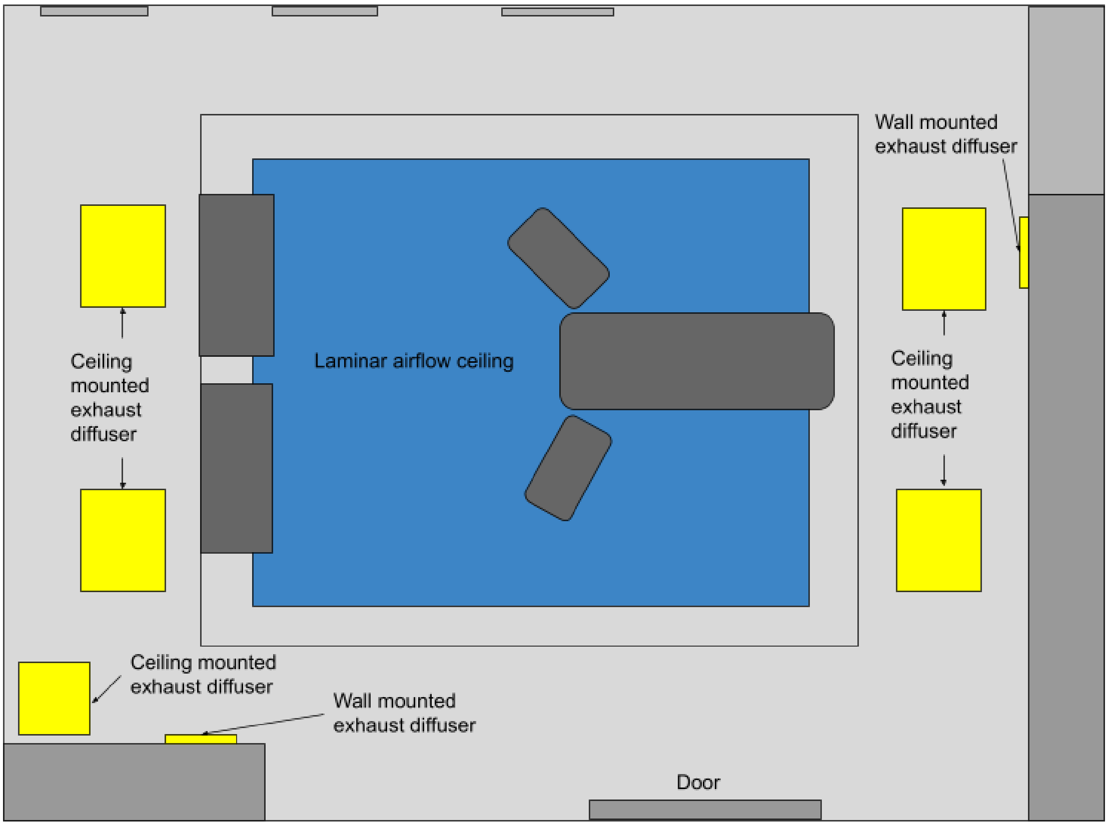
Time schedule per operation:
A total of 8 measurements per position of the instrument table. Schedule for 1 operation with 2 positions:

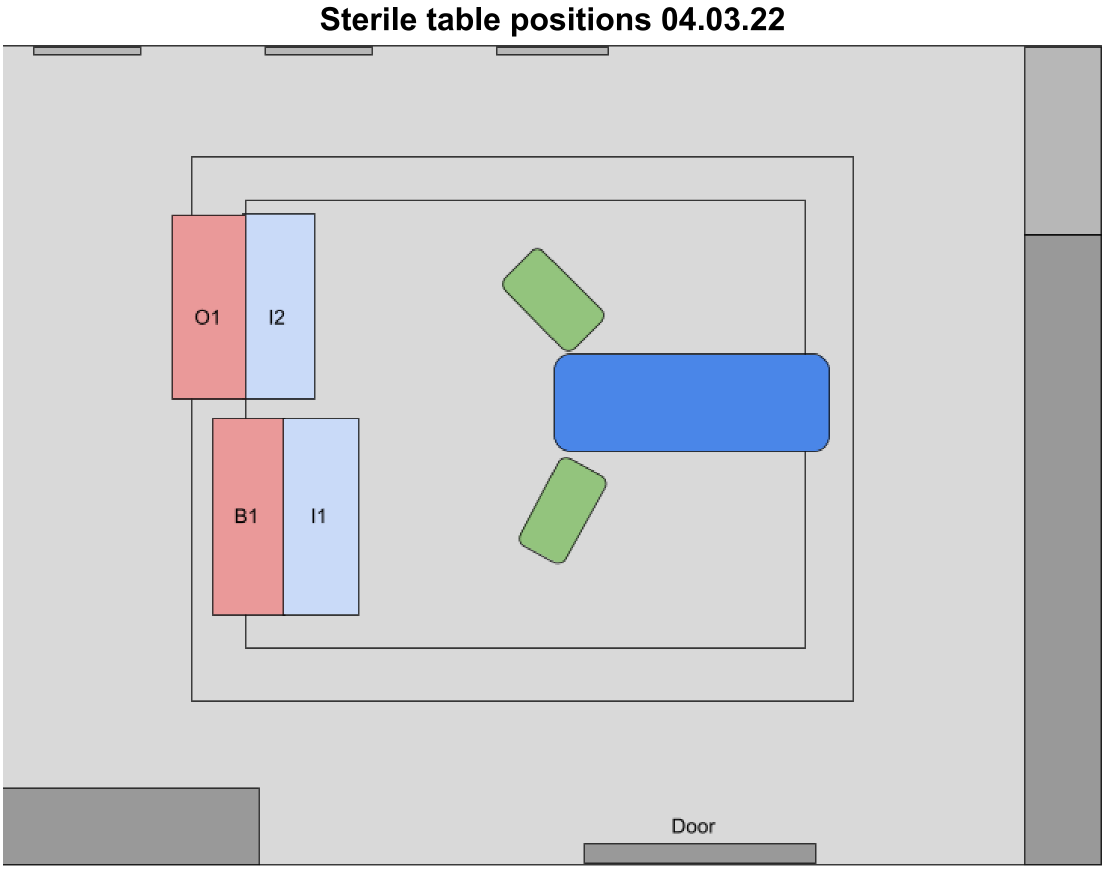


OR with all interior:



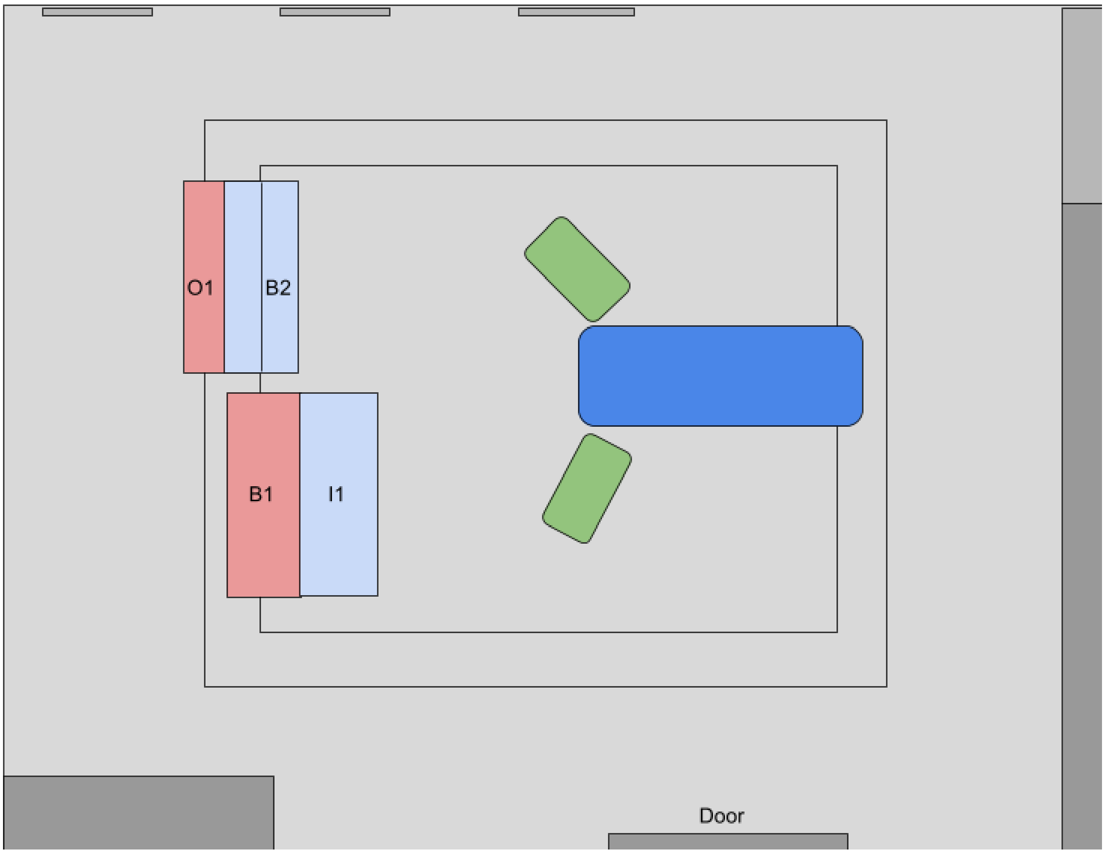
Supply and exhaust diffusers

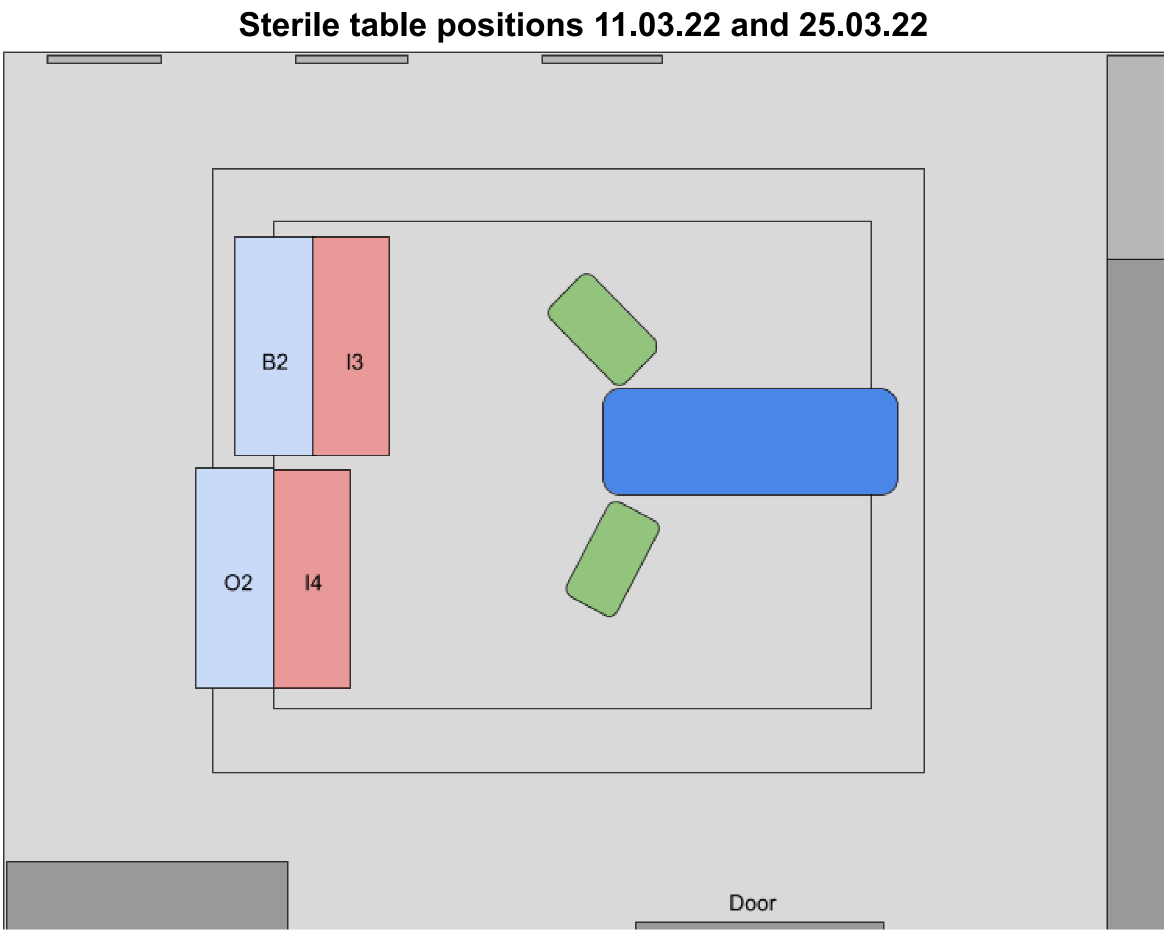


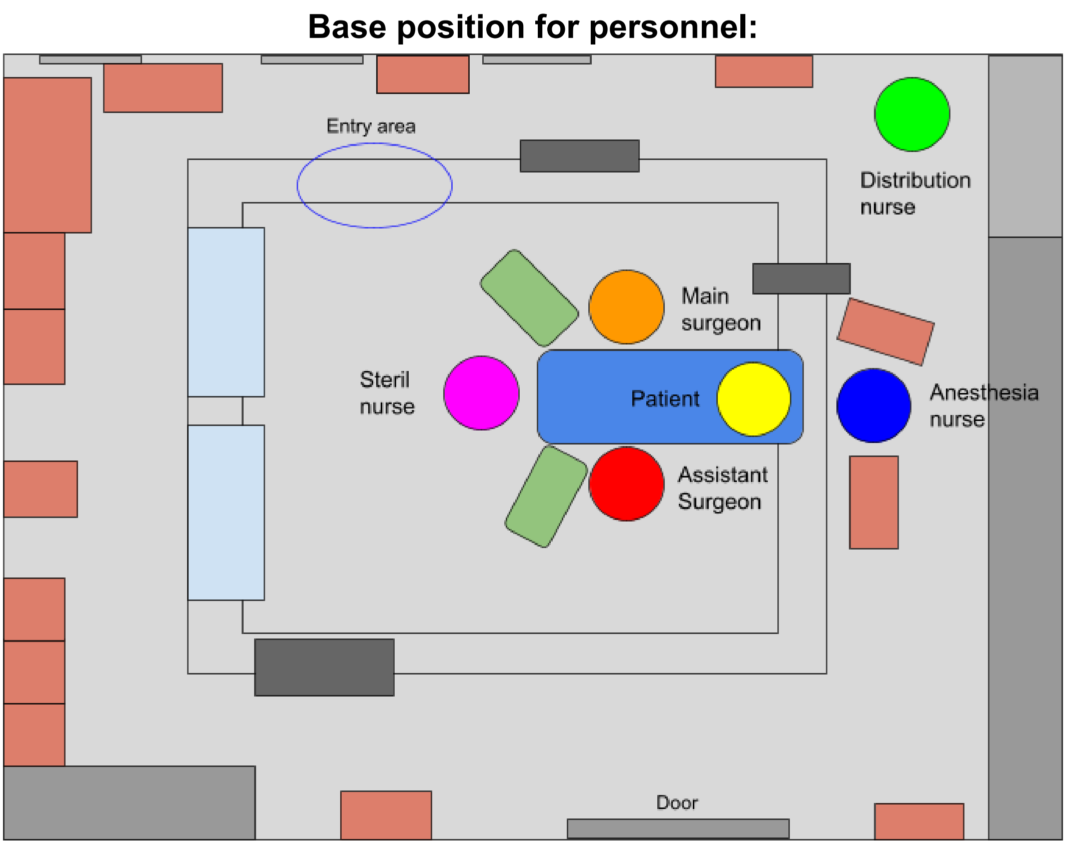


Blue tables = first surgery, Red tables = second surgery

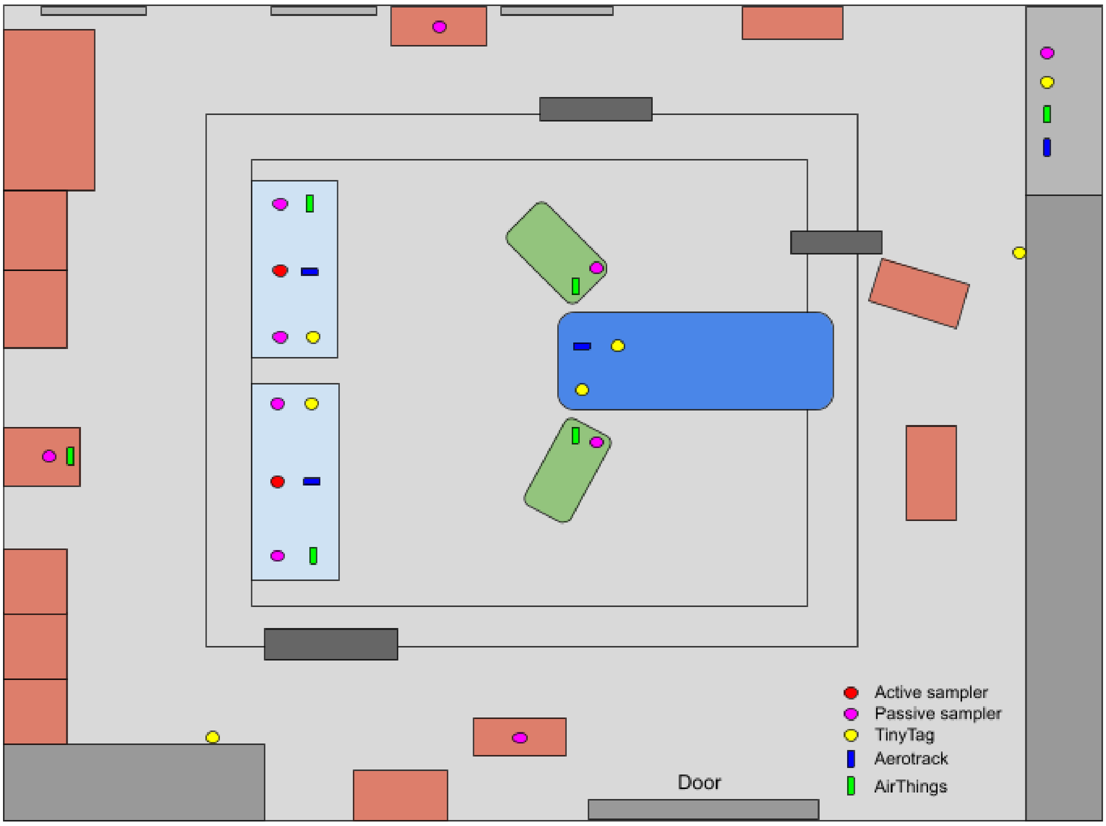
Sterile table positions 18.03.22



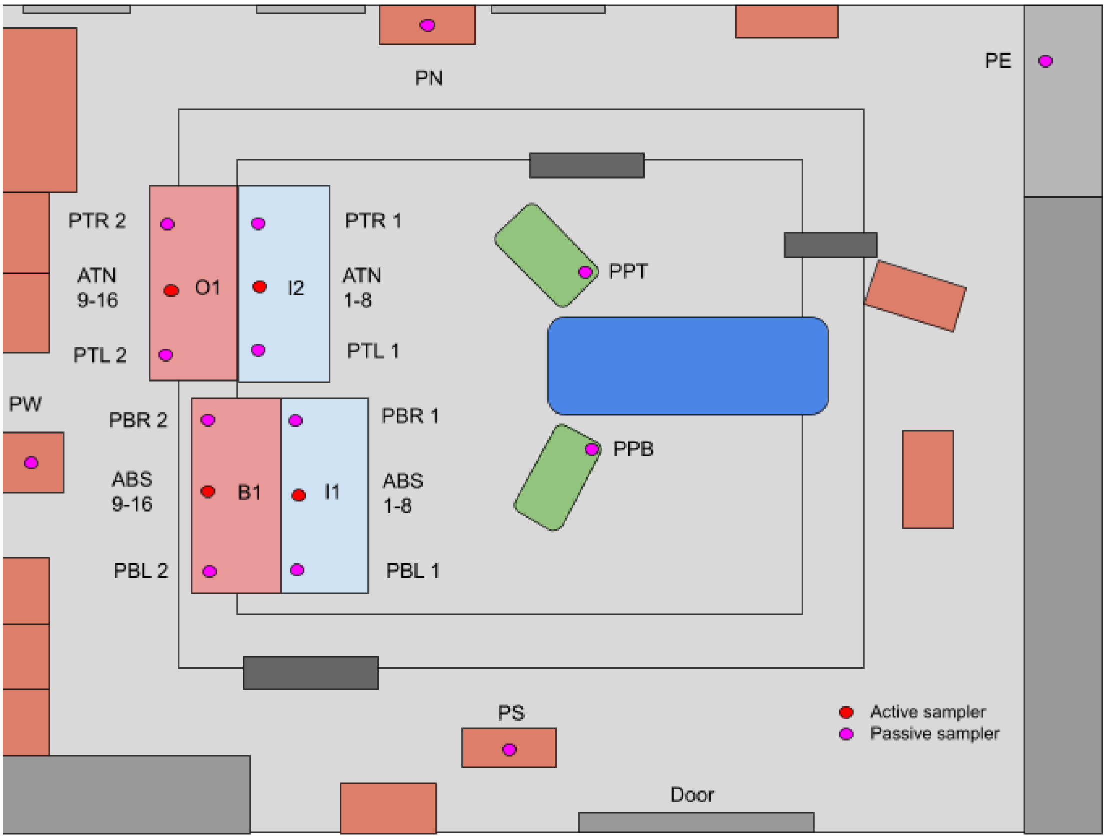

Sterile table positions 11.03.22 and 25.03.22
B2
I3
O2
I4
Door


Base position for personnel:
Entry area
Distribution nurse
Main surgeon
Steril nurse
Patient
Anesthesia nurse
Assistant Surgeon
Door

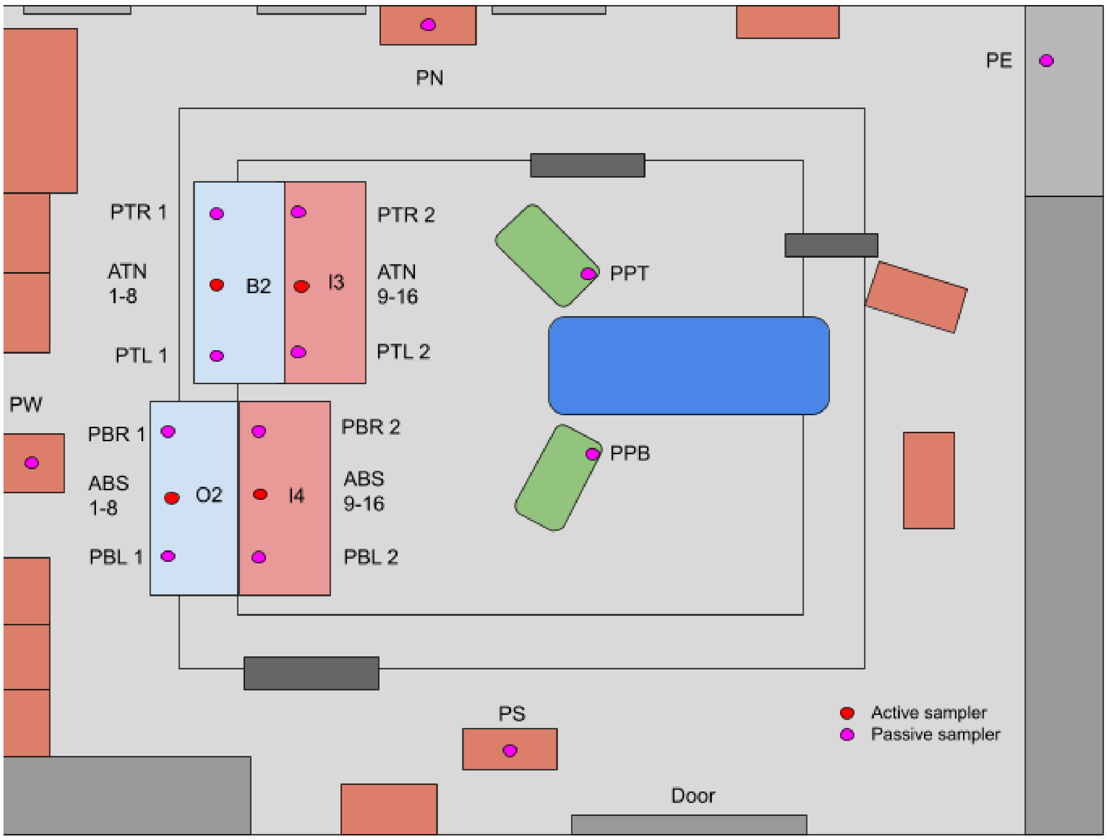
Positioning of equipment:



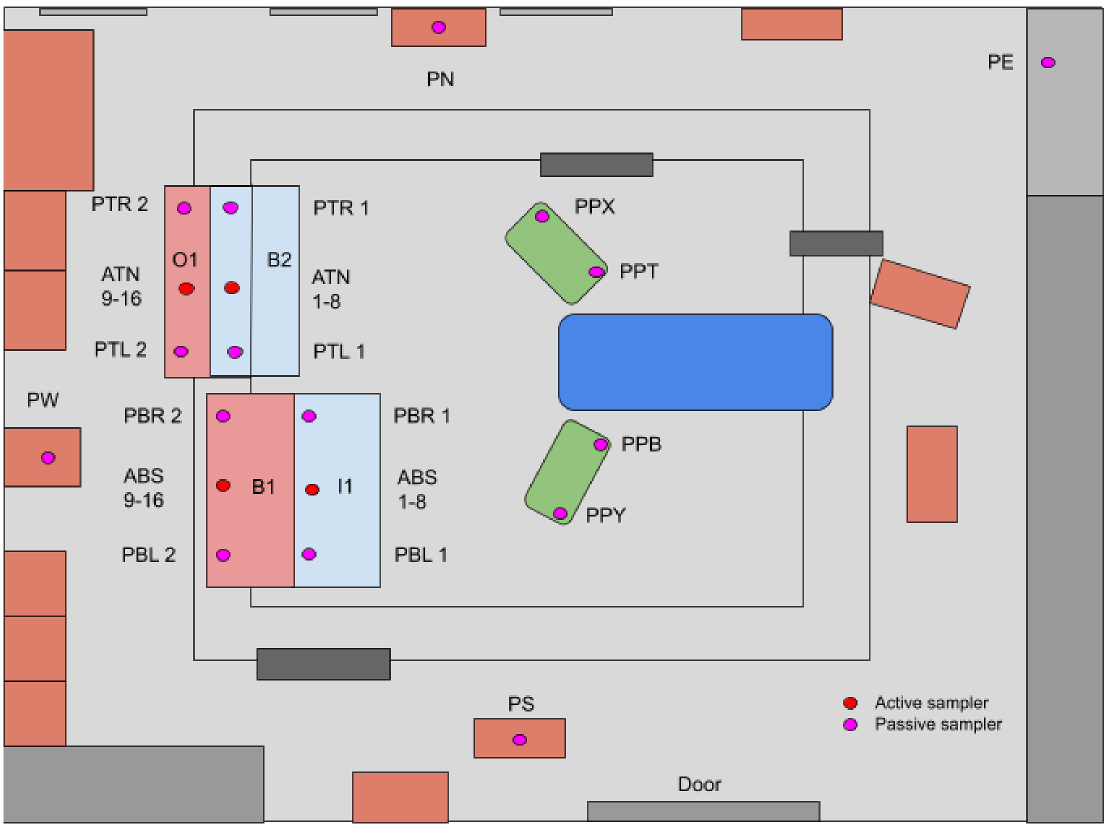
Marking on blood agar 04.03



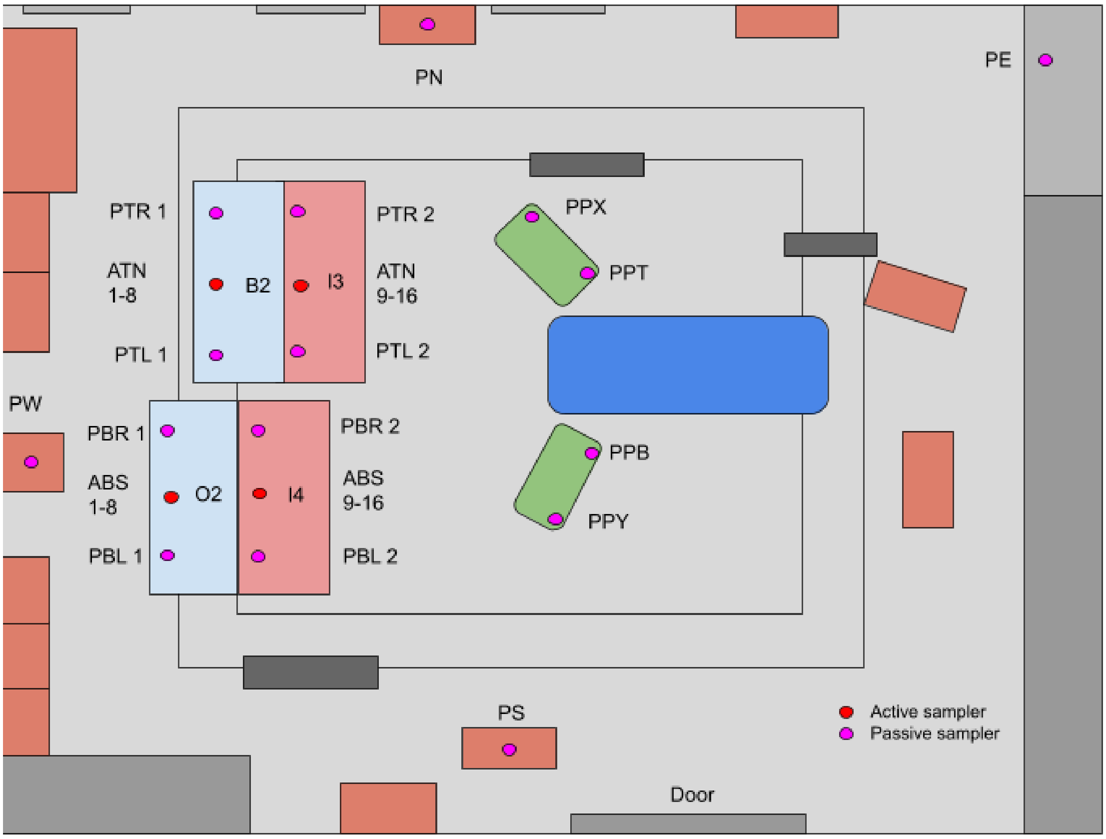
Marking on blood agar 11.03



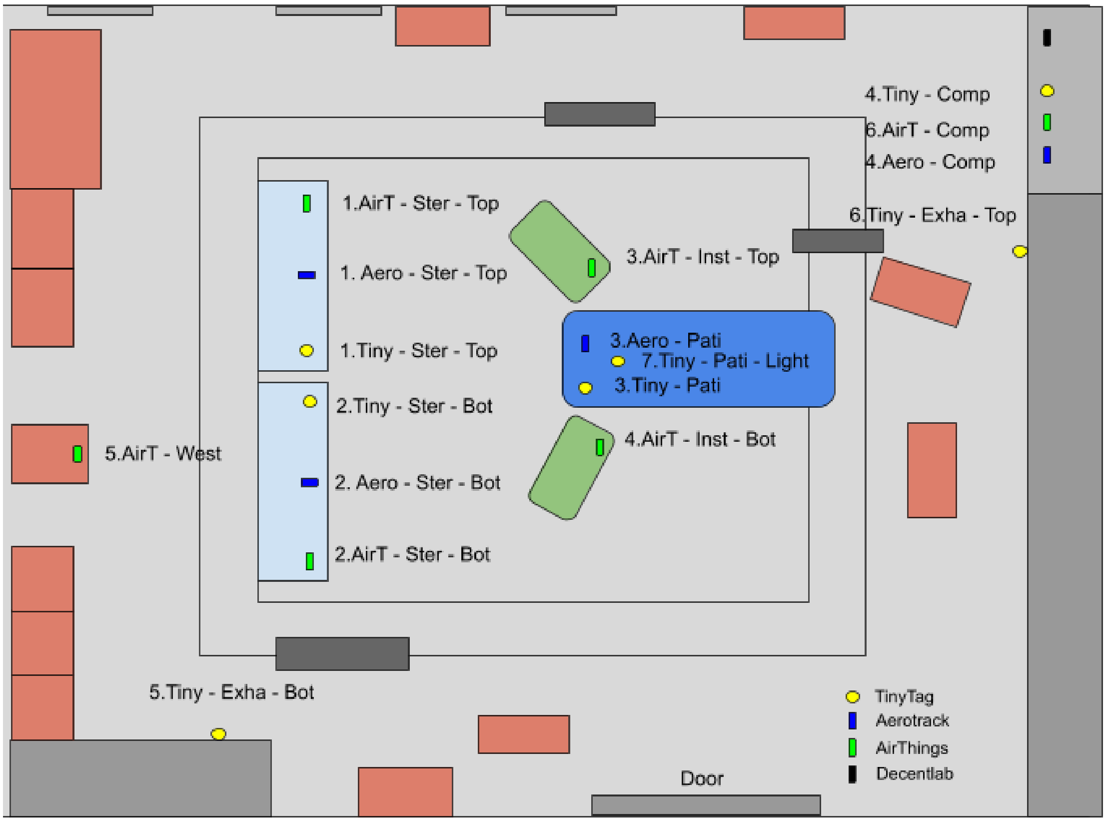
Marking on blood agar 18.03



Marking on blood agar 25.03



Equipment names



K Acting Plan

- We will simulate real surgery during each measurement and will therefore act according to what can be presumed as normal behavior during a surgical procedure.

- The operating room will be prepared as for a normal procedure and the indoor climate will be set to standard values for a normal procedure. Equipment, machines and personnel will be placed as during a standard procedure.

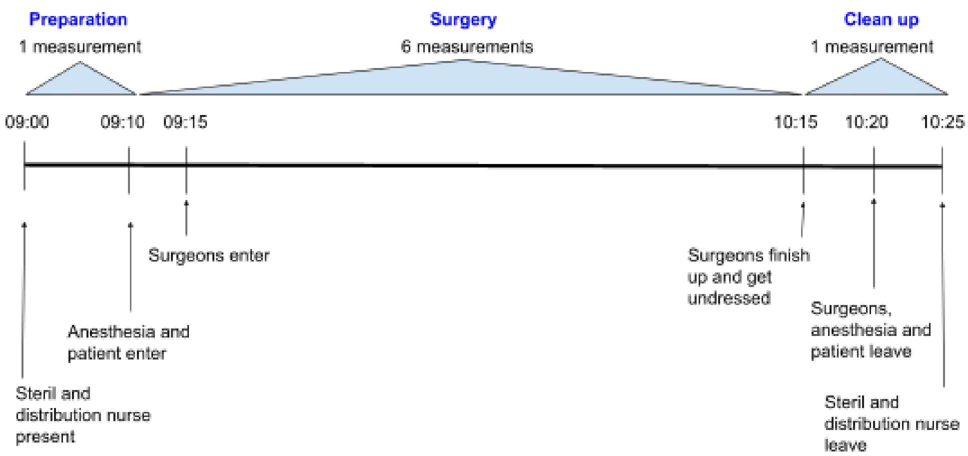
- Talking will be regulated during all measurements, meaning there will be a script for when you can talk and what to say. All talking outside the script should be avoided, but participants can ask questions and communicate with each other as long as it is kept short and quiet.

- It is important that the measurements on each Friday are performed as similarly as possible. Therefore try to remember what you did, when you did it and how many times you did it. This is to create consistency in the measurement.

- The roles inside the LAF-canopy will wear sterile clothing, roles outside the canopy will wear normal scrubs. The exception is the patient who will wear normal scrubs with a sterile cover placed on top when on the operating table. The sterile participants should try to keep their hands steril during the experiment.

- If you are not sure about something or not sure what to do, just ask anytime. If you are finished with your task before everyone else, just return to base position and stand still.

- As in a somewhat normal procedure the steril and distribution nurse will arrive first to prepare the room. Then the anesthesiologist and the patient arrive. Lastly the surgeons arrive. The surgeons, anesthesiologist and the patient will leave at the same time. Last to leave is the steril and distribution nurse. This will be done for every measurement.



Anesthesiologist

General:

- Outside of the LAF-canopy at all times.
- Will dress in normal scrubs.
- Will be sitting during all measurements.
- Sits close to the patient's head during the procedure.

Timeline:

09:00 - 09:10 / 11:30 - 11:40 (First measurement - before the surgery)

1. Wait outside the operating room.

09:10 - 09:15 / 11:40 - 11:45 (During the surgery)

2. Enter the operating room with the patient and cover the patient with the sterile cover.
3. Turn on the surgical lamp and position the light on the knee.
4. Walk to the base position and help the steril nurse hang the dividing cover between the anesthesia and the surgeons.
5. Sit down on the chair next to the patient's head.

09:15 - 10:15 / 11:45 - 12:45 (During surgery)

6. Sit still while the surgeons operate.

10:15 / 12:45 (Last measurement - After the surgery)

7. Help remove the dividing cover.
8. Turn off the surgical lamp.
9. After all equipment is removed from the patient, leave the operating room together with the patient on the surgical table.
10. When the patient is placed outside of the operating room and the surgeons have left the operating room, close the door to the operating room as soon as possible.

Tasks:

- Will bring surgical instruments.
- Will help make sure that all participants are dressed correctly and following the rules of the hospital.

Distribution nurse

General:
- Outside LAF-canopy at all times.
- Will dress in normal scrubs.
- Will be standing and moving around.

Timeline:

08:50 - 09:00 / 11:20 - 11:30 (Before the first measurement)
1. Enter the operating room and walk outside of the LAF to the computer table.
2. Check that the computer is turned on and that all AirThings outside the LAF are positioned correctly and are measuring.
3. Check that the Decentlab is connected and is measuring.
4. Check that the Aerotrack placed outside of the LAF is positioned correctly and is measuring.
5. Check that the TinyTags are placed correctly outside LAF and measuring.
6. Check that pen and paper is available to take notes if anything unexpected happens.
7. Place 4 passive samplers outside the LAF area and around 08:59 open them. Remember to mark the lids.
8. If finished before 09:00, wait in a standing position at the base position.

09:00 - 09:10 / 11:30 - 11:40 (First measurement - before the surgery)

9. Starting from the base position, walk around the LAF-area to the cabinets. Stand by the cabinets for 30 seconds. Return to base position and wait 30 seconds. Repeat.

09:10 - 10:15 / 11:40 - 12:45 (During the surgery)

10. Follow the Powerpoint which will specify all the activities to perform during the surgery.

10:15 - 10:25 / 12:45 - 12:55 (Last measurement - After the surgery)

11. Starting from the base position, walk around the LAF-area to the cabinets. Stand by the cabinets for 30 seconds. Return to base position and wait 30 seconds. Repeat.

10:25 / 12:55 (After the measurements)

12. Gather and put the cap on all passive samplers outside of the LAF.
13. If necessary: save the measurement on the Aerotrack and charge it.
14. Exit the operating room with the sterile nurse.

Tasks:
- Will take notes of the time if anything unexpected happens.

Steril nurse

General:

- Will be inside the LAF canopy at all times.
- Will wear sterile clothing.
- Will be standing at all times.

Timeline:

07:00 - 08:00

1. Check the indoor conditions and write them down.
2. Help place the sterile covers on the surfaces.
3. Arrange the room as planned with the sterile table in the correct position.
4. Place equipment on their correct placement.
5. Set up the computer with AirThings and powerpoint ready.
6. Connect cables and charge necessary equipment.
7. Mark the floor with tape at the edge of the LAF area.
8. Place the sterile clothing on the sterile tables.
9. Place the coller with the rib inside the LAF.
10. Turn off any unnecessary equipment.

08:00 - 08:50

11. Meet the others and bring them to the operating room.
12. Go through the day and the planned activities.
13. Make sure that the active sampler and blodagar is picked up.

08:50 - 09:00 / 11:20 - 11:30 (Before the first measurement)

14. Enter the operating room and walk outside of the LAF to the entry area.
15. Put on sterile clothing.
16. Check that the Aerotrack placed inside of the LAF is positioned correctly and is measuring.
17. Check that the TinyTags are placed correctly inside of the LAF and measuring.
18. Check that the AirThings are placed correctly inside of the LAF and measuring.
19. Check that the active samplers are positioned, marked and ready.
20. Check that the passive samplers are positioned, marked and ready.
21. Place the instruments on the instrument table and sterile table.
22. If finished before 09:00, wait in a standing position at the base position.

09:00 - 09:10 / 11:30 - 11:40 (First measurement - before the surgery)

23. Open up the passive samplers.
24. Turn on the active samplers.
25. Walk to the instrument tables and stand by the instrument table for 30 seconds. Do hand movements over the instrument table. Return to the sterile table and stand there for 30 seconds, performing hand movements over the table. Repeat.

09:10 - 09:15 / 11:40 - 11:45 (During the surgery)

26. Move the instrument table out of the way when the patient arrives and move it back when the patient is placed correctly.
27. Help hang the cover between the patient and surgeons.
28. Place the measuring devices on the patient.
29. Place the rib on the patient.
30. Place the computer close to the patient so all can see.
31. Stand still at base position.

09:15 - 10:15 / 11:45 - 12:45(During the surgery)

32. Help the surgeons get dressed.
33. When everyone is ready press start on the Powerpoint.
34. Follow the Powerpoint which will specify all the activities to perform during the surgery.

10:15 - 10:25 / 12:45 - 12:55 (Last measurement - After the surgery)

35. Move the instrument table out of the way.
36. Remove the rib and place it back in the cooler.
37. Remove the measuring devices on the patient and place it on the instrument table.
38. Walk to the instrument tables and stand by the instrument table for 30 seconds. Do hand movements over the instrument table. Return to the sterile table and stand there for 30 seconds, performing hand movements over the table. Repeat.

10:25 / 12:55 (After the measurements)

39. Gather and put the cap on all passive samplers outside of the LAF.
40. If necessary: save the measurement on the Aerotrack and charge it.
41. Take off sterile clothing and exit through the entry area.
42. Exit the operating room with the distribution nurse.

Tasks:

- Will control the active sampler and all passive samplers inside the LAF.
- Will control that all equipment inside the LAF-canopy is turned on before and after the measurements.

Main surgeon

General:

- Inside the LAF at all times.
- Will dress in steril clothing.
- Will be standing during all measurements.
- Will try to keep hands and clothing sterile during the measurements.

Timetable:

09:15 - 09:20 / 11:45 - 11:50 (During surgery)

1. Enter the operating room and walk to the left on the outside of the LAF to the entry area.
2. Get dressed with sterile clothing inside the LAF-canopy. Steril nurse will help with the steril clothing.
3. Stand on the left side of the operating table when ready.

09:20 - 10:15 / 11:50 - 12:45 (During surgery)

4. Follow the Powerpoint which will specify all the activities to perform during the surgery.

10:15 - 10:20 / 12:45 - 12:50 (Last measurement - After the surgery)

5. Walk out of the LAF-canopy and remove the sterile clothing and throw it in the trash.
6. Leave the room with the assistant surgeon, anesthesia nurse and patient.

Tasks:

- Will bring a GoPro and a GoPro-holder.
- Start the GoPro at the start of the day and stop it during break. Turn it back on after the break and turn it off at the end of the day-

Assistant surgeon

General:

- Inside the LAF at all times.
- Will dress in steril clothing.
- Will be standing during all measurements.
- Will try to keep hands and clothing sterile during the measurements.

Timetable:

09:15 - 09:20 / 11:45 - 11:50 (During surgery)

1. Enter the operating room and walk to the left on the outside of the LAF to the entry area.
2. Get dressed with sterile clothing inside the LAF-canopy. Steril nurse will help with the steril clothing.
3. Stand on the right side of the operating table when ready.

09:20 - 10:15 / 11:50 - 12:45 (During surgery)

4. Start the Powerpoint.
5. Follow the Powerpoint which will specify all the activities to perform during the surgery.

10:15 - 10:20 / 12:45 - 12:50 (Last measurement - After the surgery)

6. Walk out of the LAF-canopy and remove the sterile clothing and throw it in the trash.
7. Leave the room with the main surgeon, anesthesia nurse and patient.

Tasks:

- Pick up the blood agar and active sampler before the measurements.
- Return the active sampler after the measurements.

Patient

General:

- Inside the LAF-canopy at all times.
- Will dress in normal scrubs.
- Will be laying down for all the measurements.

Timeline:

09:00 - 09:10 / 11:30 - 11:40 (First measurement - Before the surgery)

1. Wait outside the operating room.

09:10 - 10:15 / 11:40 - 12:45 (During the surgery)

2. Enter the operating room with the anesthesia nurse.
3. Walk to the operating table and lay down.
4. Lie still during the measurements

10:15 / 12:45 (Last measurement - After the surgery)

5. Wait for the sterile nurse to remove the equipment and covering on top of you.
6. Stand up and leave the room together with the anesthesia nurse and the surgeons.

Tasks:

- None.

Observed activity from videos

Activity	Main surgeon	Assistant surgeon	Steril nurse	Distribution nurse
1	Receiving instruments and material from the sterile nurse. Returns used instruments and material to sterile nurse.	Picking up instruments and equipment, used to assist the main surgeon, from the instrument table.	Delivering instruments to the main surgeon. Throws used material in the trash.	Gathering equipment and material from cabinets.
2	Surgical activity inside the wound. Using a scalpel for cutting and a peang for removing tissue.	Using a suctioning device to remove blood. Using a tool to hold the wound open.	Receiving pieces of tissue using a tray and disposing of the tissue. Wipes of blood in the wound area.	Unpacking supplies at the sterile table.
3	Using a diathermy pen.	Using a suctioning device to remove blood. Using a tool to hold the wound open.	Deliver and receive supplies to and from the distribution nurse.	Deliver and receive supplies to and from sterile nurse.
4	Using a surgical drill.	Using a tool to hold the wound open and the knee in the correct position.	Cleaning instruments.	Resting position.
5	Using surgical hammer and mazel	Using a tool to hold the wound open and the knee in the correct position.	Moves equipment to and from the sterile table to and from the instrument tables. Cleaning and organizing equipment on the sterile table.	Gathering equipment and material from cabinets.
6	Using surgical saw	Using a tool to hold the wound open and the knee in the correct position.	Cleaning instruments.	Unpacking supplies at the sterile table.
7	Using a long peang to pull out larger pieces of tissue	Using a suctioning device to remove blood. Using a tool to hold the wound open.	Receiving pieces of tissue using a tray and disposing of the tissue. Wipes of blood in the wound area.	Resting position.
8	Using a large syringe.	Using a tool to hold the wound open and the knee in the correct position.	Deliver and receive supplies to and from the distribution nurse.	Deliver and receive supplies to and from sterile nurse.
9	Sewing the wound shut.	Resting position.	Moving equipment from the instrument table to the sterile table. Cleaning and organizing equipment on the sterile table.	Resting position.

Mock-up surgery

Activity	Main surgeon	Assistant surgeon	Steril nurse	Distribution nurse
1	Body rotations between the patient's knee and sterile nurse. Receive instruments from the nurse and place them close to the operating area. Pick up the instruments and return them to the sterile nurse.	Body rotations between the patient's knee and instrument table. Pick up instruments and place them close to the operating area. Pick the instruments back up and place them back on the instrument table.	Body rotations between the instrument table and the main surgeon. Pick up equipment from the instrument table and hand it to the main surgeon. Receive instruments from the main surgeon and place them on the instrument table.	Walking back and forth. Walk from base position, around the laminar area to a cabinet. Stand therefore for 10 seconds and then return to the base position.
2	Small and precise hand movements close to the wound. Receive scalpel and peang from the sterile nurse. Make an incision in the rib. Cut out pieces of the rib from the inside of the incision. Use the peang to pick out pieces and place them in the tray.	Hand movements close to the wound. Pretend to use the suction tool close to the wound while the main surgeon makes the incision. Move the suctioning tool back and forth over the wound. When the incision is finished, pick up an instrument from the instrument table and use it to hold the wound open while the main surgeon removes tissue. At the same time, pretend to use the suction tool close to the wound by moving it back and forth over the wound every time the main surgeon removes tissue.	Hand movements towards and away from the main surgeon. Hand movements towards and away from the wound. Hold up the tray when the main surgeon removes tissue. Wipe of the rib close to the incision.	Hand movements over the sterile table. Walk from base position to sterile table. Pretend to open up multiple pieces of equipment and drop it on the table.
3	Small and precise hand movements close to the wound. Body rotations. Pretend to use the diathermia tool inside the wound. Changes position often by rotating the body to access the wound from a different angle.	Hand movements close to the wound. Pretend to use the suction tool close to the wound by moving it back and forth over the wound. Pick up an instrument from the instrument table and use it to hold the wound open while the main surgeon removes tissue.	Hand movements over the sterile table, towards and away from the distribution nurse. Move to the sterile table. Pretend to receive equipment from the distribution nurse and place them on the sterile table.	Hand movements over the sterile table, towards and away from the sterile nurse. Move to the sterile table. Pretend to receive equipment from the sterile nurse and place them on the sterile table.

4	Firm hand movements towards and away from the wound. Body rotations. Using both hands, pretend to drill holes in the open wound 3 times. Changes position after 3 times by rotating the body to access the wound from a different angle. Repeat.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Hand movements over the instrument tables. Pick up equipment from the instrument tables and pretend to wipe them down.	Resting position. Stand still at the base position.
5	Firm hand movements towards and away from the wound. Body rotations. Pretend to use a hammer and mazel on the wound. Hold the mazel close to the wound and pretend to strike the mazel 3 times with the hammer. Changes position after 3 times by rotating the body to access the wound from a different angle. Repeat.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Walking back and forth. Hand movement over tables. Pick up instruments from the instrument table and walk to the sterile table. Put the instruments down. Wait 5 seconds and pick them back up and walk back to the instrument table.	Walking back and forth. Walk from base position, around the laminar area to a cabinet. Stand therefore for 10 seconds and then return to the base position.
6	Firm hand movements towards and away from the wound. Body rotations. Pretend to use a surgical saw inside the wound. Move both hands back and forth towards the wound 3 times. Changes position after 3 times by rotating the body to access the wound from a different angle. Repeat.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Hand movements over the instrument tables. Pick up equipment from the instrument tables and pretend to wipe them down.	Hand movements over the sterile table. Walk from base position to sterile table. Pretend to open up multiple pieces of equipment and drop it on the table.

7	Aggressive hand movements towards and away from the wound. Using a large peang, pretend to grab 3 pieces inside the wound and pull them out by force and place them in the tray. Changes position after 3 times by rotating the body to access the wound from a different angle. Repeat.	Hand movements close to the wound. Pretend to use the suction tool close to the wound by moving it back and forth over the wound. Pick up an instrument from the instrument table and use it to hold the wound open while the main surgeon removes tissue.	Hand movements towards and away from the main surgeon. Hand movements towards and away from the wound. Hold up the tray when the main surgeon removes tissue. Wipe of the rib close to the incision.	Resting position. Stand still at the base position.
8	Firm hand movements towards and away from the wound. Body rotations. Pretend to use a large syringe and add substance into the wound 3 times. Do this by placing the syringe close to the wound and pretending to push the substance out of the syringe. Changes position after 3 times by rotating the body to access the wound from a different angle. Repeat.	Steady hand placement close to the wound. Small hand movements. Pick up 2 instruments from the instrument table and use them to hold the wound open while the main surgeon operates.	Hand movements over the sterile table, towards and away from the distribution nurse. Move to the sterile table. Pretend to receive equipment from the distribution nurse and place them on the sterile table.	Hand movements over the sterile table, towards and away from the sterile nurse. Move to the sterile table. Pretend to receive equipment from the sterile nurse and place them on the sterile table.
9	Small and precise hand movements close to the wound. Body rotations. Using needle and thread to sew close the incision in the rib.	Resting position. Stand still in the base position.	Walking back and forth. Hand movement over tables. Pick up instruments from the instrument table and walk to the sterile table. Put the instruments down. Wait 5 seconds and pick them back up and walk back to the instrument table.	Resting position. Stand still at the base position.

- Every action for 2 minutes and 40 seconds each x2 = 48 minutes.
- After every action give back the equipment to the person you received it from og place it back where you picked it up.
- If the same action is repeated back to back, put down or return the equipment, and then pick it up or recieve back.
- After the surgeon had closed most of the wound, the assistant surgeon left the LAF and got undressed.
- When the wound was closed, the main surgeon got undressed and the steril nurse cleaned the wound.

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