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Dispersion of small particles into operating rooms due to door openings

A measurement study performed at Sahlgrenska University Hospital in Göteborg

Master of Science Thesis in the Master´s Programme Structural Engineering and Building Performance Design

NIKLAS GUSTAVSSON

Department of Energy and Environment
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CHALMERS UNIVERSITY OF TECHNOLOGY
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Master´s thesis in the field of safety ventilation. A cooperation between the division Building Services Engineering at Chalmers University of Technology and at the Royal Institute of Technology.

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Examiner: Jan Gustén

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ABSTRACT

There is a connection between postoperative wound infections and the number of bacteria-carrying particles in an operating room. Normally operating rooms are designed with a positive pressure to ensure that airborne contaminants are not transferred from spaces with a higher particle concentration. When a door is opened between an operating room and adjoining corridor, the pressure difference between the two spaces becomes equal to zero. Air with a higher particle concentration is thereby given an opportunity to be transferred into the operating room. Only a few papers have been found concerning a door openings impact on the particle concentration in an operating room. A surgical ward at Sahlgrenska University Hospital in Göteborg has been used as a reference object to perform different kinds of measurements to investigate this further. A pre study of door usage was done at the surgical ward and also participation during operations to better understand the conditions given by the activity. Measurements of the prerequisites for the air exchange driving forces through a door opening were made and also measurements of the particle concentration in corridor and in an operating room during surgery.

Measurements show that the investigated operating room had a positive pressure of 3 Pa towards the corridor, despite a big air gap between the doors and the floor. No air density difference was noticed. The particle concentration in the operating room was increased near the door due to vortices created by the door swing. This indicates that air from the corridor is transferred even when there is a positive pressure in the operating room and no temperature difference between the room and the corridor.

Keywords: operating room, door opening, particle dispersion, particle concentration.

Contents

Preface

This master´s thesis is within the field of Civil Engineering and the master´s programme Structural Engineering and Building Performance Design at Chalmers University of Technology in Göteborg.

The measurements have been performed at Sahlgrenska University Hospital in Göteborg. Hopefully, this real case study can help the ongoing discussion on how door openings could affect the conditions in operating rooms.

I would like to thank some involved people who have made this measurement study possible. My supervisors Jan Gustén, Bengt Ljungqvist and Berit Reinmüller for discussions and guidance throughout the project. Christina Ekroth who has been my contact at Sahlgrenska University Hospital and helped planning the measurement occasions. Research Engineer Håkan Larsson and technician Marek Machowski, at Chalmers University of Technology, for supplying measurement equipment and helping to test these.

Niklas Gustavsson

Göteborg, November 2010

Notations

C_d	Discharge coefficient (-)
g	Gravitational acceleration (m/s^2)
H	Door opening height (m)
Q_d	Flow rate through door opening (m^3/s)
T_0	Reference temperature (K)
T_1	Temperature (K)
ΔT	Temperature difference (°C, K)
v_p	Forced air flow (m/s)
W	Door opening width (m)
ρ_{0m}	Mean density (kg/m^3)
$\Delta\rho_0$	Density difference (kg/m^3)

1 Introduction

The primary task of the ventilation system in an operating room is to provide a good indoor climate for patients and personnel. To achieve a good climate, odours and anaesthetic gases has to be removed. The ventilation system should also ensure that the air contains as few viable particles as possible to lower the infection risk, since there is a correlation between postoperative wound infections and the number of bacteria-carrying particles. These are also called Colony Forming Units, CFU. Infectious bacteria, such as streptococci and staphylococci, are carried by particles, Abel & Elmroth (2007).

The limit for an operating room is 100 CFU/m^3 air throughout the operation in the presence of up to 10 people, which is managed with so-called conventional ventilation. In operating rooms with high hygiene requirements, advanced ventilation systems are used to keep bacteria-carrying particles below 10 CFU/m^3 during surgery. In such operating rooms implant surgery is performed within orthopaedic, thorax and vascular. An example of such advanced ventilation system is air supplied unidirectional from the ceiling, so-called Laminar Air Flow ceiling (LAF). Hambraeus & Tammelin (2010) and Hammarsten (1998).

The question on how door openings between operating rooms and adjoining corridor affects the dispersion of airborne contaminants into the room has been investigated to some extent. When a door opens it creates vortices that can result in transferred air from the corridor, with a higher concentration level of CFU, into the operating room. A high concentration level of CFU increases the infection risk during operation.

1.1 Aim

The aim with this master´s thesis is to investigate door openings between operating rooms and adjoining corridor, and how it affects the air flow characteristic. It is interesting to see how well the predicted results coincide with the measured.

1.2 Delimitations

The measurements are performed at the surgical ward Operation Norr at Sahlgrenska University Hospital in Göteborg. The focus in this report is on the usage of doors into operating rooms and if air from the corridor is transferred into operating rooms due to door openings.

1.3 Method

A pre study of the door usage into four operating rooms during surgery was done. Also participation during an operation was done to understand the activity better and get familiar with the procedure. The impact of door openings in one operating room with its specific prerequisites was then investigated further. The instant influence of a door opening is difficult to detect when measuring CFU. The air flow characteristic was thereby investigated instead since particles follow the air stream. The air flow characteristic was measured with particle counters to investigate if it is possible for air from the corridor to be transferred into the operating room due to vortices created by a door swing. This could be done since the particle concentration is higher in a corridor than in an operating room.

The prerequisite for air density difference and pressure difference between the corridor and one operating room were investigated and also the particle concentration in the corridor and in the operating room during surgery.

1.4 Report structure

The setup of the report is to at first give some general knowledge about the driving forces for air. In Chapter 3 the reference object is described and the prerequisites for the surgical ward. Chapter 4 is about the pre study performed to get familiar with the activity. The approach for all measurements is found in Chapter 5 and its result in Chapter 6. A summary of the project is presented in Chapter 7 and a discussion in Chapter 8.

2 Theory

Airborne contaminants in operating rooms are one of the causes to infections when surgery is performed. The greatest source of infection in healthcare is the human being. Patients with an open wound are obviously more exposed to an infection. Bacteria can be spread in a number of different ways. Infections are mainly transferred by contact, directly or indirectly, by droplet or by air, SFVH (2003). A droplet infection is a type of infection where there is no contact between the source of infection and the receiver. When a person talks, coughs or sneezes a number of particles are released as small liquid drops that could cause infection.

Airborne contaminants are often divided into gaseous and particle contaminants. In operating rooms it is important to keep the particle concentration as low as possible. This is done by filters, different solutions to supply air into the room, protective clothing etc. The air supplied to the room is more or less free from particles. It is not possible to segregate gaseous contaminants from the air with filters and the solutions are too expensive and thereby not used to treat air supplied to operating rooms. Sundbeck & Värmsjö (2005)

Particles fall towards the floor with different velocities dependent on their size. For small particles it takes time which leads to that they will very much follow the air flow characteristic. On their way towards the floor it is possible for them to come in contact with instruments, lamps or even the patient. Disturbances in the air flow can cause movements for particles, for an example on particles located on a lamp, to come near the patient area. Therefore is it important to avoid sudden movements in operating room and unnecessary door openings. Sundbeck & Värmsjö (2005)

It is of great importance to understand that a good ventilation rate in an operating room is not enough to secure the patients from infections. In most cases there are well established directions to handle instruments and material to prevent spreading of bacteria. Precautions have to be made for clothing, human activity and activity routines.

In the following chapter the importance of barriers and when these are needed explained. Also the different driving mechanism for air exchange through a door opening is clarified.

2.1 Barriers

Activities that could be hazardous for personal and environment, or activities that requires high demands to not jeopardize the product or process, needs some kind of barrier to surrounding spaces. A barrier means boundary which airborne contaminants cannot pass. The barriers can be divided into two groups:

1. Primary barriers which delimits a product or process from the room.
2. Secondary barriers which delimits a room or a part of the building to the remaining building.

Primary boundaries are safety equipment which isolates the source of pollution to prevent dispersion to the surroundings. Local exhaust ventilation of diathermy smoke during surgery is one example.

Secondary barriers can be a physical boundary or a change of activity, like change of clothes. Door openings into an operating room can also be found under secondary boundaries. Akademiska Hus AB (2000)

If the air flow characteristic under stable conditions is disturbed, it is possible for the contamination to leak to unwanted places. This happens when either the pressure difference, air flow or air velocity is changed. Situations when the flow characteristic is disturbed and contaminations are spread over the barrier are when:

1. Persons are passing through the barrier.
2. Material and supplies are passing through the barrier.
3. Air flow over the barrier.
4. Waste water and decay products are passing the barrier.

Contaminations could thereby pass the barrier attached to a surface or with a flowingly medium.

A need for barriers is when

1. Dispersion of hazardous contaminants from a source must be prevented, for example in chemical laboratories.
2. There are high demands on the cleanliness in the room so that infusion from the surrounding rooms must be prevented, for example in clean room and operating room.
3. There is a combination of both above, for example experimental laboratory.

Schulz (2001)

2.2 Driving mechanisms for air flow

Since the dispersion of airborne contaminants is strongly connected to the air flow characteristic, it is of great interest to understand the air flow driving mechanisms. The driving mechanisms for air flows are typically a combination of density differences, mechanical ventilation and air vortices created by for an example motion of a person through the door opening and the motion of the door itself. The different driving forces can act at the same time, but usually one driving mechanism is dominating so the other ones can be more or less neglected. Ljungqvist et al (2009)

2.2.1 Air density difference

If a door between two rooms with different temperatures opens, an air exchange will occur since the air have different density. Cold air has a higher density and will thereby enter the other room at the lower part of the door opening. Warm air with a lower density passes the door opening in the upper part instead, see Figure 2.1. Schulz (2001)

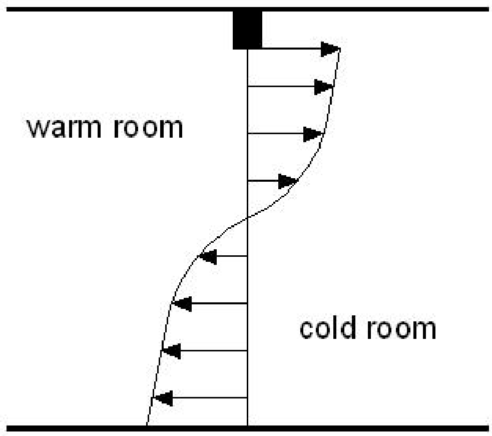

Figure 2.1 Air flow through a door opening caused by differences in density.

The air flow through the door opening in each direction due to differences in density can according to Ljungqvist et al (2009) be calculated as

$$Q_d = C_d \frac{WH^{\frac{3}{2}}}{3} \left(g \frac{\Delta\rho_0}{\rho_{0m}}\right)^{\frac{1}{2}} \tag{1}$$

Q_d = flow rate through door opening in each direction (m^3/s)
C_d = discharge coefficient (-)
W = door opening width (m)
H = door opening height (m)
g = gravitational acceleration (m/s^2)
$\Delta\rho_0$ = density difference (kg/m^3)
ρ_{0m} = mean density (kg/m^3)

$$\frac{\Delta\rho_0}{\rho_{0m}} = \frac{2\Delta T}{(T_1+T_0)} \tag{2}$$

ΔT = temperature difference (°C, K)
T_1 = temperature (K)
T_0 = reference temperature (K)

The air exchange through the door increases thereby with a higher temperature difference.

The discharge coefficient C_d is dependent on the temperature difference between the rooms. For a door opening a discharge coefficient of 0.65 has been used by various sources and is in the range with theoretical considerations and experimental results. Ljungqvist et al (2009)

2.2.2 Mechanical ventilation

The mechanical ventilation to supply the room with clean air is another driving mechanism that affects the air flow. In operating rooms it is often desirably to have a positive pressure compared to the adjoining corridor to secure different contaminants from enter. Because of this pressure difference between the two spaces, an air leakage flow will occur from the operating room towards the corridor by eventual leaks in the barrier. This air flow direction is wanted since the corridor has a higher concentration of CFU that could increase the infection risk to the patient if the air flow had the opposite direction instead. The mechanical ventilation creates a forced air movement towards the corridor so that the air flow is unidirectional, see Figure 2.2. Schulz (2001)

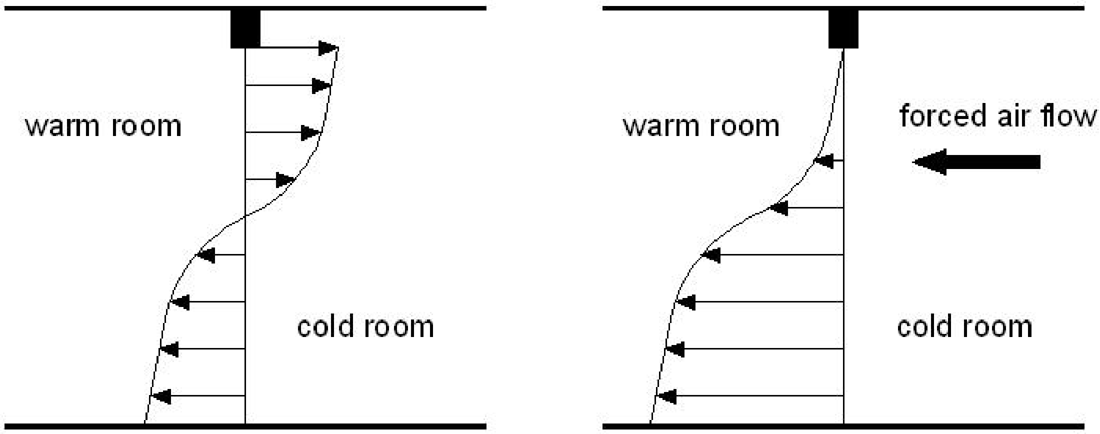

Figure 2.2 Air flow through a door opening without a forced air movement and with a forced air movement.

The air flow through the door opening with a forced air movement can be calculated according to Shaw & Whyte (1974) as

$$Q_d = C_d \frac{W}{3} \frac{1}{g\left(\frac{\Delta\rho_0}{\rho_{0m}}\right)} \left(g \frac{\Delta\rho_0}{\rho_{0m}} H - v_p\right)^{\frac{3}{2}} \tag{3}$$

v_p = forced air flow (m/s)

Sometimes a negative pressure in the operating room is actually wanted. This is when a patient has a very contagious disease, like tuberculosis. In that way it is easier to isolate the person infected and minimize the risk of infection.

2.2.3 Air vortices

Another driving force is forced air movements caused by object moving. An example is when the door to an operating room is opened and closed. These air vortices' characteristic caused by a door is difficult to predict. The effect of the air vortices is short lasting but can result in dispersion of particles from one room to another.

Schulz (2001) has illustrated the characteristic of the air when a door is opened and closed. These figures are also used here; see Figure 2.3 and Figure 2.4.

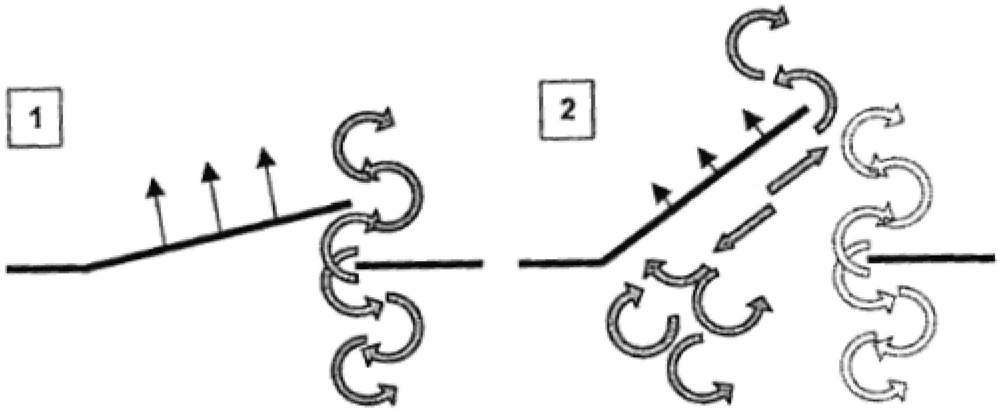

Figure 2.3 Appearance of air vortices created when a door is opened in two different steps. Schulz (2001)

When a door is opened, vortices are created and moves close to the door-frame (1) to both of the two rooms, see Figure 2.3. When the speed of the door blade reduces and finally stops (2), more vortices are created and enter the rooms. Some seconds after the door is opened all vortices have dissolved.

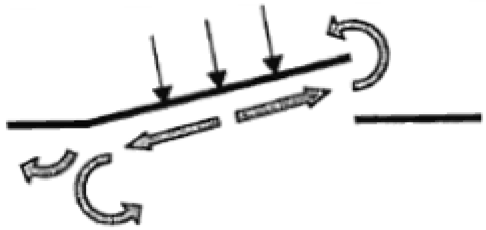

Figure 2.4 Appearance of air vortices when a door is closed. Schulz (2001)

According to Schulz´s (2001) experiment, the movement of the air vortices is not as clear when a door is closed as when it is opened, see Figure 2.4. It means that the effect of closing a door has a smaller risk of disperse airborne contaminants than when opening a door.

Sansone & Keimig (1987) made a conclusion that the air leakage is smaller if the door is opened in the same direction as the eventually main flow through the door opening and also that it is smaller if the door is opened slowly.

3 Reference object

A surgical ward at Sahlgrenska University Hospital is used as a reference object for all measurements in this report.

3.1 Location

Sahlgrenska University Hospital is located in central Göteborg. The location of the five storey building with the surgical ward can be seen in Figure 3.1. The surgical ward is titled Operation Norr and is situated on the fourth floor with the address Gröna Stråket 2.

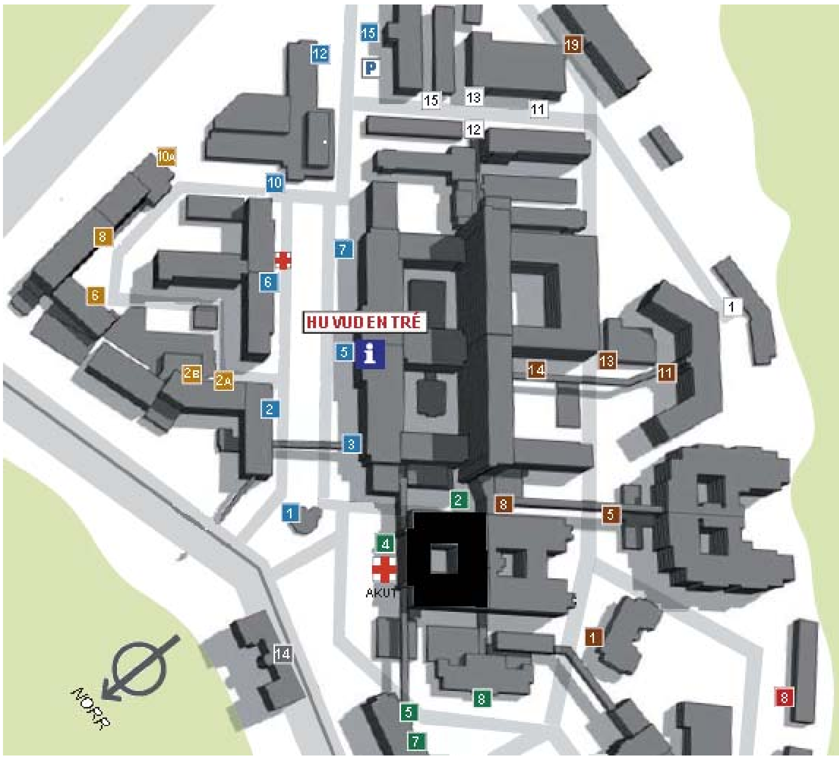

Figure 3.1 Image over Sahlgrenska University Hospital where the building marked with black is showing the location of the surgical ward Operation Norr.

3.2 Plan arrangement

The activity for the ward of interest is divided into three different spaces here named pre operation space, corridor and operating room (OR 5-OR 8). See Figure 3.2 for an overview. The activity for the different spaces is described in Section 3.2.1-3.1.3 together with some observations.

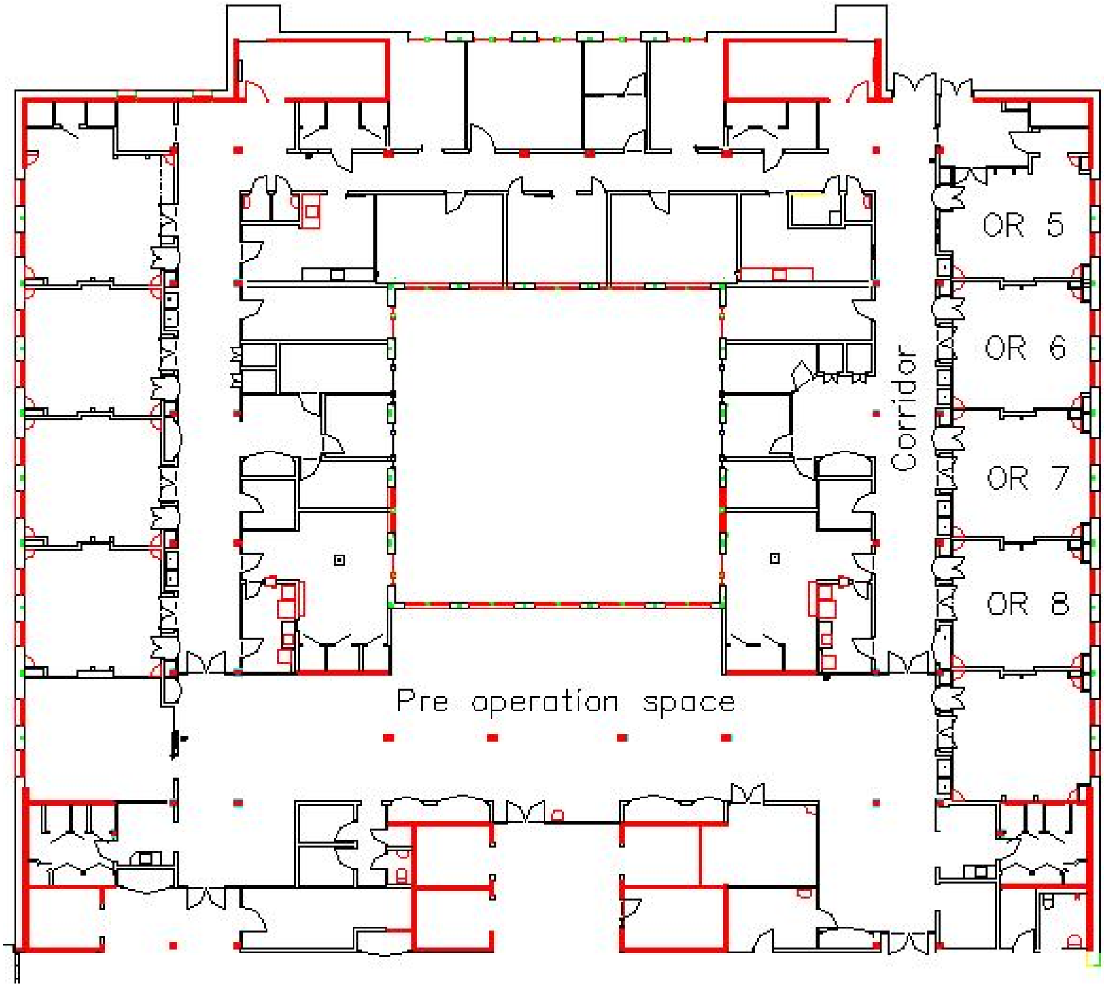

Figure 3.2 Plan drawing of the fourth floor with the pre operation space, corridor and the operating rooms 5-8 marked.

3.2.1 Pre operation space

When entering the surgical ward from the public corridor, you step right into the pre operation space. No demands on special clothing exist in this space. Here is an information counter and a waiting room for patients and also a small locker room for visitors. Patients that are next up to operation are lying in beds and personnel are preparing as much as possible before the patient is brought to the operating room.

3.2.2 Corridor

Before entering the corridor from the pre operation space, safety clothing must be put on. The safety clothing is clean top and trousers, clean shoes and hairnet provided by the hospital. The corridor is connected to some office rooms and rooms where operation equipment is stored and sterilized. The corridor is also connected to four different operating rooms. Two of these are for scheduled operations and two are intended for more immediate operations.

From the corridor it is possible for the operating personnel to set the temperature in the operating rooms. Dependent on the kind of operation that are being performed, different temperatures are desirable.

3.2.3 Operating room

All four operating rooms at this surgical ward are almost identical. The only thing that varies is the volume of the rooms. The opening between the corridor and the operating rooms consist of a double door with windows, see Figure 3.3. The doors are opened inwards to the operating room. This would according to Sansone & Keimig (1987) increase the air exchange when a door is opened if a positive pressure is assumed in the operating room. In the left door, seen from the corridor, it is possible to open a small window if it for instance is necessary to have a conversation between the personnel in the corridor and those who are located in the operating room.

Figure 3.3 Door into the operating room seen from the corridor.

Notice the gap between the doors and also the gap between the floor and doors. The gap between the doors is approximately 5 mm and between door and floor about 20 mm.

3.3 Ventilation principle

Operating rooms have one of the highest demands of cleanliness in order to minimize the infection risk to the patients. The HEPA-filter (High Efficiency Particulate Air) is a Sofilair, which according to EN1822, fulfils the demands for filter class H14. It has a separation range of 0.3 µm particles better than 99.995 %. The efficiency of filters is measured by their ability to separate particles with a size of 0.3 µm since it is most difficult. The distribution system for supply and exhaust air can have a number of different appearance to secure the process. All four operating rooms at Operation Norr have a displacement ventilation system. For information of other ventilation principles, see Nordenadler (2008). Air with a temperature lower than the room temperature is supplied from every corner slightly above floor level. Four exhaust devices are placed in the middle of the ceiling above the operating table, see Figure 3.4. Supplied air is heated by the activity in the room and thereby moving upwards due to the density difference. The air is exhausted at the ceiling taking contaminations in the room with itself.

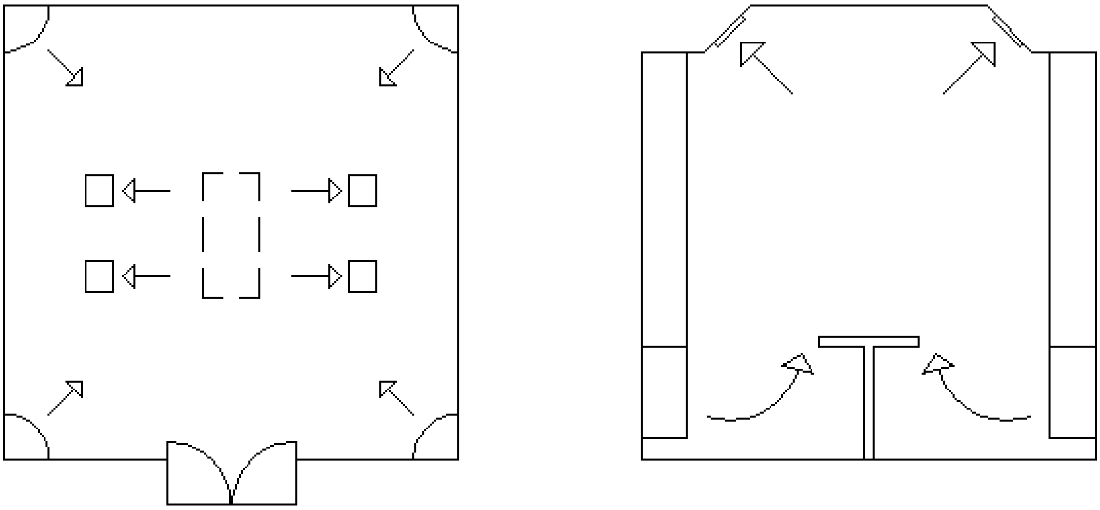

Figure 3.4 Distribution systems for supply and exhaust air in the operating rooms. A plan view for an operating room to the left and a section view to the right. Arrows indicate the direction of the air.

The system is a two-speed Constant Air Volume, CAV, system. There is a presence detector in every operating room to decide which air flow that should be supplied. This CAV system has one normal speed when personnel are using the room. If the detector does not notice any movements in the room during a half an hour, the fan speed will decrease.

4 Pre study of activity and door openings

In the article “Contamination Risks due to Door Openings in Operating Rooms” by Ljungqvist et al (2009), the speed of a 90° door opening were divided into fast, average and slow. The total times were 6, 9 and 16 seconds respectively. The opening time, closing time and hold time of the door were here included.

In this pre-study, door openings to operating rooms is observed both from the corridor and inside the operating room during surgery to see if the total door opening time is the same at this surgical ward. The investigation from the corridor focuses on how many times the door is opened and also the total door opening time for every occasion.

In order to understand the activity at the surgical ward better, participation during an operation procedure was done. From the preparations before the patient was brought into the operating room to the cleaning after the operation.

4.1 Door opening observation

Four different operating rooms were investigated to see how frequent and during how long time doors to operating rooms were opened in each case. Also to what extent the door was open were noticed. As mentioned in Section 3.2.3, the left door to the operating room has a small window. The usage of the window was not included in this investigation. Every door opening was timed with a stopwatch and the door opening type was divided to either 45° or 90°.

4.2 Participation during an operation

Before an operation begins, many preparations must be done. Much is already made in the pre operation space before the patient is moved to the operating room. When the patient is brought to the operating room, nurses make the final preparations before the operation starts.

The author attended a vessel operation. At first the anaesthetist put the patient into sleep and a surgery nurse cleaned the operation area. The surgery nurse did also put out protective clothing to only make the area of interest visible. The anaesthetist with belonging equipment was located near the door which means that the patient´s head was positioned in a direction against the door. Protective clothing was placed like a cover so the anaesthetist did not have to see the operation and thereby not use an operating mask to avoid droplet infection. When the surgeon and the assistant surgeon arrived and all safety measures were made, minute´s of silence were held. The surgeon described the patient’s situation and the operation procedure. During this time, all persons attending the operation presented themselves and their task in the operation. A total of seven persons attended this operation. Then the operation began.

The underlying reason with these minutes of silence is to give the ventilation system a cleanup period to remove the temporary increased particle concentration caused by preparations for the operation.

The operation lasted for about three hours. The temperature when the operation started was 24.1 °C and when it was finished 23.5 °C. The temperature was found within this interval during the whole operation.

4.3 Result

After two days and observation of door usage of totally eight operations, it came clear that there was not any particular way the doors were opened dependent on kind of operation. The only thing that differs was how many times personnel was entering and leaving the room. The number of times the doors were opened varied a lot and also the time for the different operations. When personnel were passing through the door the angle was approximately 45° and a total door opening time varied mainly between 3.5 and 5 seconds. The total time for just opening and closing the door with an angle of 45° was around 4 seconds, and for a door opening with the angle 90° around 6 seconds.

Examples in observation of door openings during two operations can be seen in Appendix B. The reason the total door opening time sometimes was less than 4 seconds was because of a smaller door opening degree than 45°.

The impression from the observations is that personnel often use the door instead of the small window on the door if they have to talk to someone in the operating room. Maybe some door openings can be avoided if personnel are aware of the problem with particle transportation.

Like in earlier conclusions, most of the door openings during the operation occur when personnel are passing through the barrier. A common reason is when it is time for the nurses' break and other personnel must fill in for them temporarily. Before surgery, a surgery nurse try to make sure that equipment needed for the operation is in the room. Sometimes something is missing and the nurse at floor, assisting the operating team, must then go and get it and thereby pass the secondary barrier.

When participating in this operation the author did not get the impression that there were many unnecessary door openings. When the investigation of door openings were made in the corridor it seemed that the doors were opened at more occasions. Probably when participating in an operation you know the real reason behind why personnel are entering and leaving the room which not makes it seem unnecessary.

5 Measurement approach

The major focus is on how the usage of door openings affects the particle concentration in the operating room. Since there are many factors that affect the air flow and thereby the dispersion of airborne contaminants, some measurements on all of the driving mechanism presented in Chapter 2 is performed. Information about the surveying equipment used is presented in Appendix A.

To get a reference value of the particle concentration at the surgical ward Operation Norr, measurements were made at the corridor and in an operating room during surgery. All particle measurements were made with P-TRAK Ultrafine Particle Counter Model 8525. The equipment measures particles with the size range 0.02 – 1 µm. A high concentration of particles increases the probability of CFU.

The equipment used for measuring temperature is SwemaAir 300 with the accessory sensor SWA 31. A Differential Pressure Transmitter Model 332 together with a Datascan 7320 and the software program DasyLAB 6.0 is used to test the pressure difference between one operating room and corridor. The Differential Pressure Transmitter Model 332 has a sensibility range of 0 – 25 Pa.

The results for all measurements are presented in Chapter 6.

5.1 Particle concentration in corridor

The P-TRAK was placed at the information counter next to a column in the corridor, see Figure 5.1. This place was chosen because of not disturbing the activity and also because of its location in the middle of the corridor. The measurements were going on for two days during 08:00-15:00. Since the activity in the corridor is largest during these hours, this range was chosen to receive a reliable result.

Figure 5.1 Blue P-TRAK Ultrafine Particle Counter Model 8525 placed near a column in the corridor to measure the particle concentration.

5.2 Particle concentration during operation

The particle concentration was measured during two operations using two P-TRAK devices denoted as P-Trak 1 and P-Trak 2. To be able to compare the particle concentration at different positions in the room, P-Trak 1 was placed as close to the operation area as possible and P-Trak 2 in the outer range. The both devices should, if possible, not be exposed to vortices in the room caused by the activity to receive a non fluctuating result.

During the first operation the placement of the equipment can be seen in Figure 5.2. P-Trak 1 was placed near the surgeon in the operation area approximately 1.6 m above the floor. P-Trak 2 was placed on a table 1.0 m above the floor.

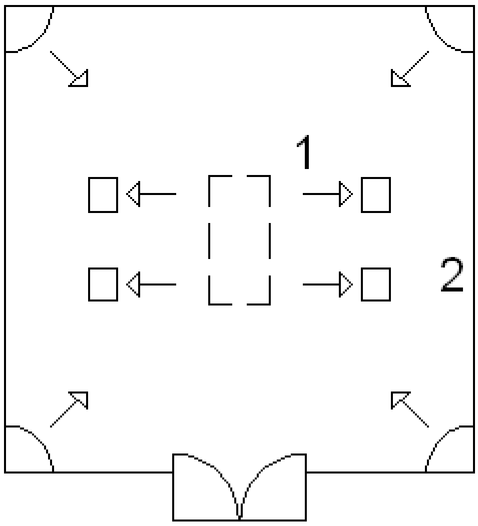

Figure 5.2 Locations for P-Trak 1 and P-Trak 2 during the first measured operation.

In the second operation the placement for P-Trak 1 was the same as in the first operation, but P-Trak 2 was now positioned near the wall opposite the door entrance instead, see Figure 5.3. The space for P-Trak 2 used in the first operation was not available during the second operation so it had to be moved.

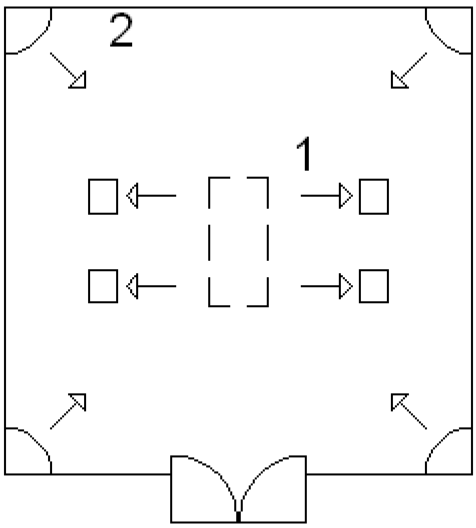

Figure 5.3 Locations for P-Trak 1 and P-Trak 2 during the second measured operation.

5.3 Particles transferred due to door openings

In this chapter an investigation is performed on what happens with the particle concentration in the operating room when a door between the operating room and corridor is opened. The air exchange and thereby the particle amount transferred is dependent on the magnitude of the three different driving forces. The prerequisites and measurement procedure for the driving forces temperature and pressure difference are explained in Section 5.3.1 and 5.3.2. The method for measuring transferred particles through the door is explained in Section 5.3.3. All practical measurements are performed in operating room 6 and the projected ventilation airflows are presented in Table 5.1. The air flows has earlier been measured and controlled.

Table 5.1 Projected supply and exhaust air flows for OR 6. The numbers for air supply etcetera are for the two-speed CAV system. The first number is for normal use and the second number when no activity in the operating room has been detected. Room volume has been measured on site to be able to calculate the specific air flow rate.

Area	Supply [l/s]	Exhaust [l/s]	Difference [l/s]	Volume [m^3]	Specific airflow [1/h]
OR 6	560/280	410/205	150/75	100	20.2/10.1

5.3.1 Temperature difference

As described earlier in this report, the operating personnel can set a suitable temperature in the operating room dependent on the kind of operation. In order to register the temperature during 08:00-15:00, when the most operations are performed, the temperature were logged in OR 5-OR 8 for three days.

At the same time as the particle concentration in an operating room was measured, measurements if the temperature did vary vertically near the door were made. These measurements were done at six points several times, both in the operating room and in the corridor approximately 0.5 m and 1.0 m from the door. The measure points vertically were at the top at the door, in the middle of the door and 0.1 m above the floor. See Figure 5.4 for further understanding. This was to investigate if any air density driving force existed.

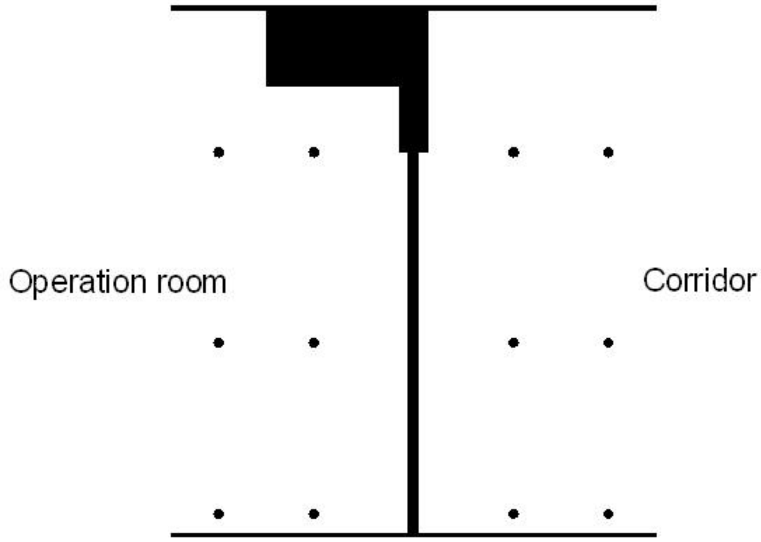

Figure 5.4 Black dots in the figure illustrate temperature measure points to investigate if there was an air density difference driving force between the two spaces.

5.3.2 Pressure difference

All operating rooms at this surgical ward are supposed to have a positive pressure in the operating room compared to the corridor. To make sure the investigated operating room had a positive pressure, the pressure difference between the operating room and the corridor was measured.

A Differential Pressure Transmitter Model 332 together with a Datascan 7320 and a computer with the software program DasyLAB 6.0 was placed in the operating room, see Figure 5.5. Two plastic tubes were connected to the Differential Pressure Transmitter. One end of a tube was positioned in the middle of the room to avoid air vortices caused by the air supply devices as far as possible. Since the gap between the door and floor was approximately 20 mm, it was possible to put the second plastic tube through this gap to the corridor, see Figure 5.6. The end of the second tube was placed in a box on a wagon, see Figure 5.7. The box was used to avoid air vortices created by movements in the corridor that would affect the outcome.

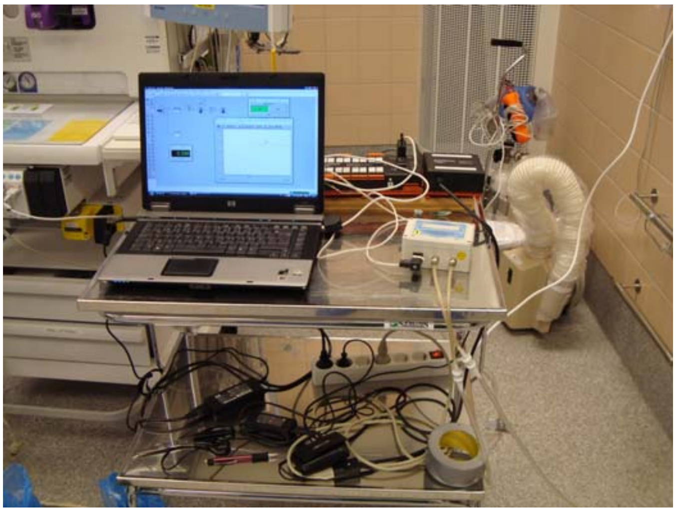

Figure 5.5 Setup of the Differential Pressure Transmitter Model 332, Datascan 7320 and a computer with the software programme DasyLAB 6.0 inside OR 6.

Figure 5.6 The second plastic tube connected to the Differential Pressure Transmitter passes the secondary barrier under the door to the corridor.

Figure 5.7 End of second tube placed in a box in the corridor to avoid vortices created by movements that would affect the outcome.

Since the big air gap between the doors and floor was so big, it seemed interesting to investigate the consequences it causes. To demonstrate what a rubber spline attached to the doors could result in the gap was blocked with duct tape, see Figure 5.8, and the pressure difference was measured.

Figure 5.8 Air gap between doors and floor blocked with duct tape to investigate the gap´s consequences on the pressure difference.

5.3.3 Particle measurements

To measure the increased particle concentration in the operating room caused by a door opening, a P-TRAK was placed on a table in the operating room perpendicularly to the door approximately 1.0 m above floor level, see Figure 5.9.

Figure 5.9 P-TRAK placed on a table in the operating room to measure the increase of particles due to door openings. The device was located at varied distances from the door.

Particle concentration measurements were made with a varied distance between the door and P-TRAK. The distances were set to 0.5, 1.0, 1.5 and 2.0 m between the door and P-TRAK. In order to see if the P-TRAK would notice any difference of the amount particles transferred into the room dependent on door opening angle, measurements were done with door openings of 45° and 90°. Every measurement lasted for 5 minutes each and the door was opened with an interval of 30 seconds. No person entered the door at that time, which means that the increased particle concentration was all because of the door swing. The goal was to as far as possible open the door with the same speed every time. The interval of 30 seconds was chosen to let the ventilation system have a cleanup period so that the starting particle concentration was approximately the same.

The doors were opened into the operating room that according to Section 2.2.3 and Sansone & Keimig (1987) should increase the impact of dispersion of airborne contaminants compared to if it was opened in the other direction instead.

6 Result

The results are presented under similar subtitles as in Chapter 5.

6.1 Particle concentration in corridor

As can be seen in Figure 6.1, the particle concentration is highest in the early hours to later decrease to a more stable concentration. This due to preparations in operating rooms before the operations begins at approximately 09:00-10:00, when there are many persons moving back and forth in the corridor. When the activity in the corridor later stabilizes the particle concentration is approximately 400 particles/cm^3.

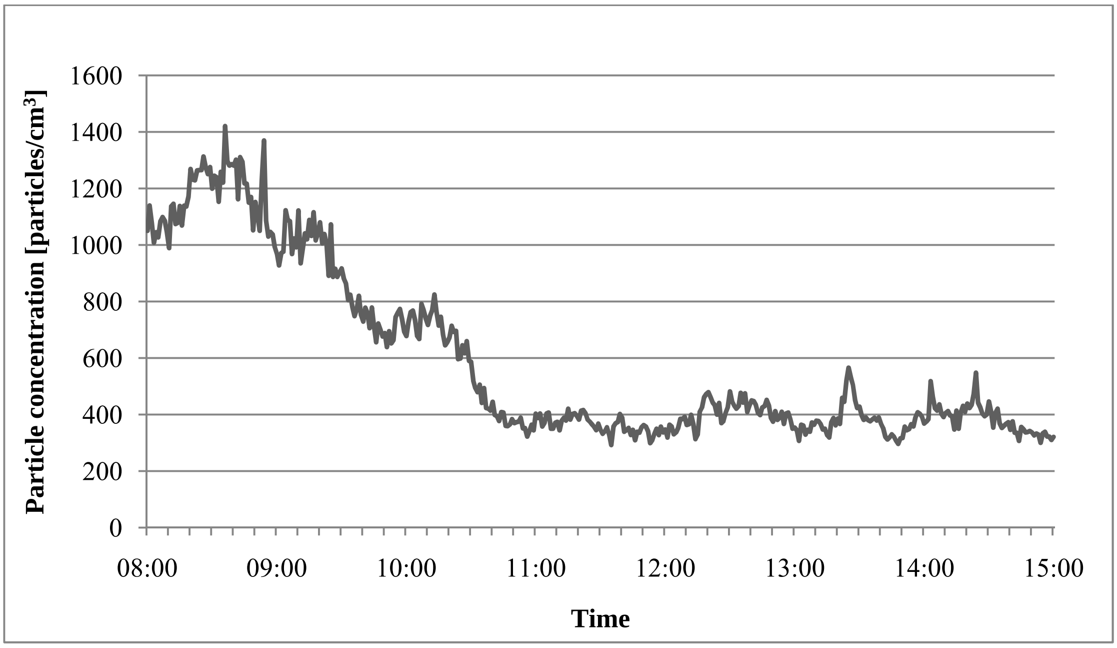

Figure 6.1 The particle concentration in the corridor Tuesday April 13th 2010.

The result of the second day´s measurements does not have alike appearance as the first, see Figure 6.2. The particle concentration is slowly declining during the whole day. A particle concentration of 600 particles/cm^3 is a suitable value to describe the situation during this day.

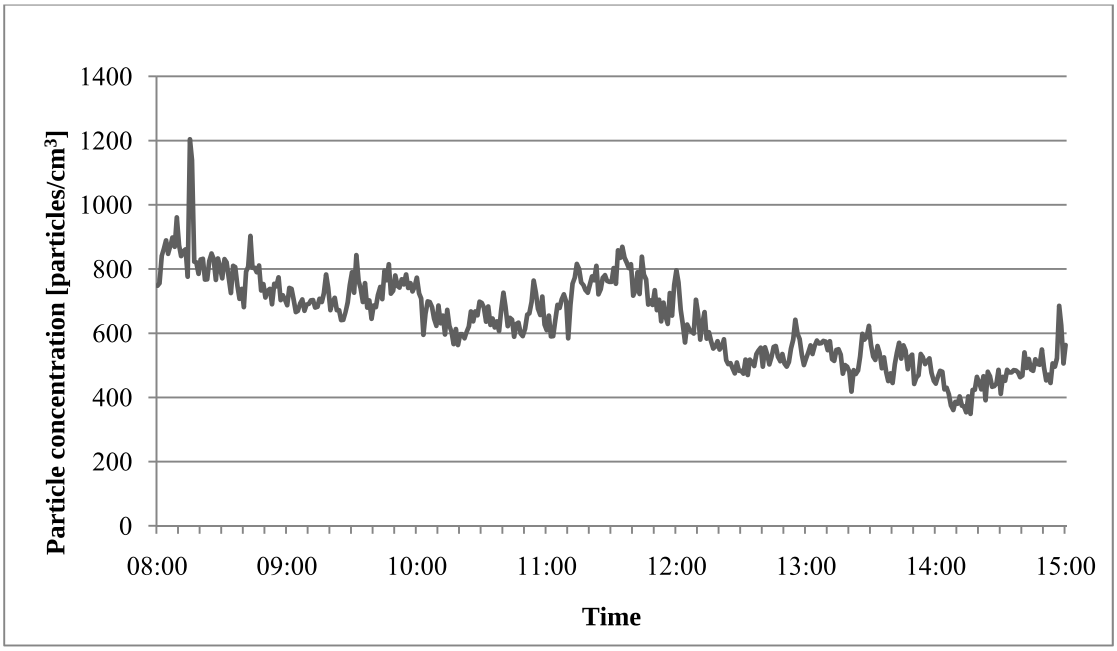

Figure 6.2 The particle concentration in the corridor Wednesday April 14th 2010.

From these two diagrams it can be seen that the particle concentration varies much during the day. The particle concentration is highest in the morning to slowly decrease during the day. As said before, this can partly be explained by a higher activity in the corridor before operations begin. Compared with the first particle measurements it seems that the second measurements were more exposed to disturbance according to the look of the diagrams. The location of the P-TRAK at the nurses' information desk was chosen to not disturb the activity but also to receive a good reference value because of its position near the middle of the corridor. Since a lot of personnel are moving in this area due to the information desk and offices, it can be assumed that the received result is slightly higher than the mean particle concentration in the corridor. Human beings are as mentioned in Chapter 2 the greatest source of infection in healthcare. The positioned chosen for the P-TRAK in the corridor is still regarded as the most suitable location due to the prerequisites.

6.2 Particle concentration during operation

The particle concentration varies as expected dependent on the area in the operating room. P-Trak 1 positioned closest to the surgeon reached a peak of 20211 particles/cm^3 around 11:00 AM. The peak of P-Trak 2 with 3545 particles/cm^3 was reached soon after. Notice the time delay between both particle counters in Figure 6.3. Except from these peaks, the concentrations were less than 1 particles/cm^3 during the whole operation.

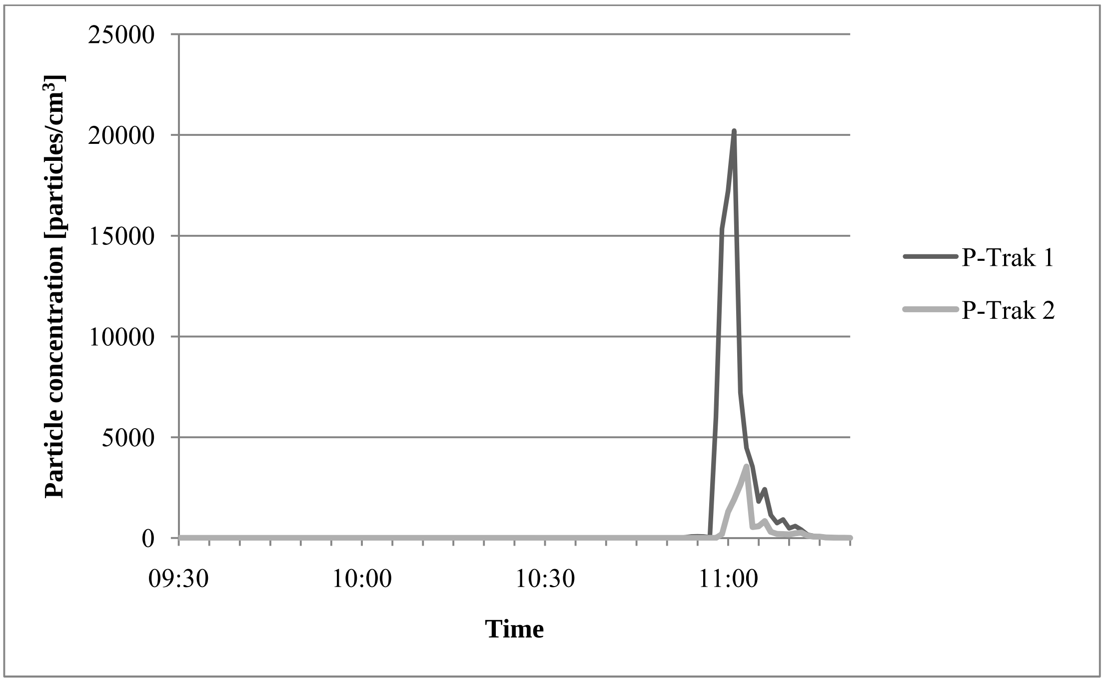

Figure 6.3 Particle concentration during the first operation measured. P-Trak 1 located closer to the particle source had as expected a much higher concentration. Notice the time delay between the devices peak´s. The particle concentrations were less than 1 particles/cm^3 during the whole operation besides these peaks.

The particle concentration during the second operation was not near the same amount compared to the first operation, see Figure 6.4. P-Trak 1 detected two peaks in particle concentration during this time. Also during this operation the peaks for P-Trak 2 occurred with a small time delay compared to P-Trak 1. The particle concentration was much smaller as expected since it was located near an air supply device. During the rest of the operation the concentrations were less than 1 particles/cm^3.

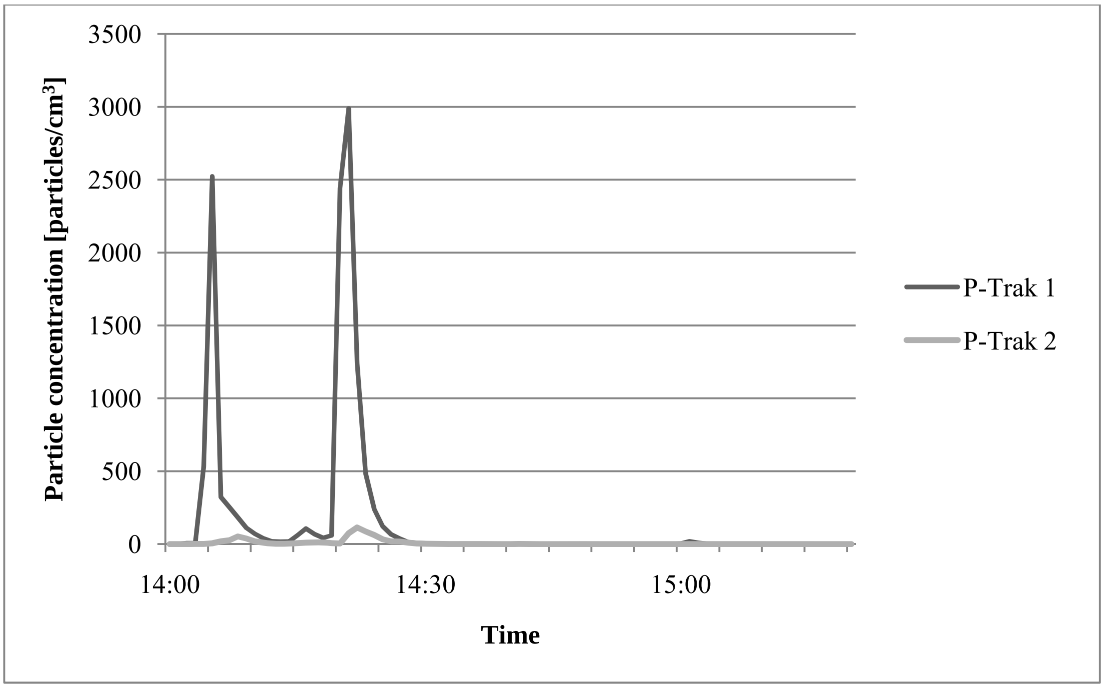

Figure 6.4 Particle concentration during the second operation measured. Two peaks were detected by P-Trak 1 but not near the range of particle concentration as in the first operation. The particle concentration was close to zero particles during the whole operation besides these peaks.

6.3 Particles transferred due to door openings

The second stage of measuring with the particle counters was to investigate the influence of a door opening on the airflow. From the beginning it was meant to be done directly after an operation. The idea was that the particle concentration would be approximately the same as during an operation. This would have to be done at several times in order to investigate all the different door openings. But since the appearance of Figure 6.3 and Figure 6.4 shows that the particle concentration during the entire operations is less than 1 particle/cm^3, except some few peaks, it was not necessary to interfere with the cleaning scheme. Instead the measurements of how a door opening affects the particle concentration in the room were done in an empty operating room.

The result of the measurements on temperature and pressure are presented in Section 6.3.1-6.3.2. Measurements of the particle concentration caused by door openings are presented in Section 6.3.3.

6.3.1 Temperature difference

The temperature was measured during two operations. The temperature difference between the corridor and the operating room was less than or equal to 0.5°C during both operations. This means that the temperature difference as a driving force for air flows can hereby be neglected.

The registered temperature mean values for the four operating rooms during three days between 08:00-15:00 were 24.4°C. The maximum and minimum temperatures were 25.2°C and 23.5°C respectively.

6.3.2 Pressure difference

All pressure measurements performed used a sample rate of 2 values per second.

The result of the pressure difference between operating room and corridor is presented in Figure 6.5. The measurement was done for an interval of 10 minutes. It can be seen that the operating room had a positive pressure compared to the corridor of approximately 3 Pa the whole time except from some disturbance from the activity in the corridor.

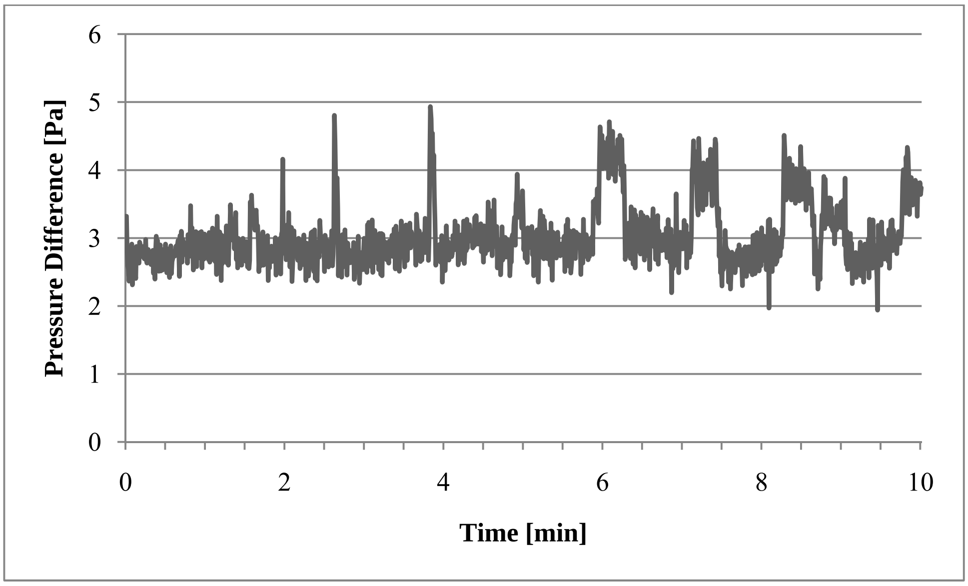

Figure 6.5 The pressure difference between OR 6 and corridor. The pressure difference fluctuated probably caused by disturbances in the corridor.

A positive pressure difference was consequently obtained despite big air gaps by the door. As mentioned earlier, the gap between the doors and the floor was blocked with duct tape to investigate the consequences it creates. The result is presented in Figure 6.6. Just by improving the tightness by the doors resulted in a pressure difference between the two spaces of almost 6 Pa instead of 3 Pa. The pressure difference would therefore be doubled if the gap was sealed with a rubber spline.

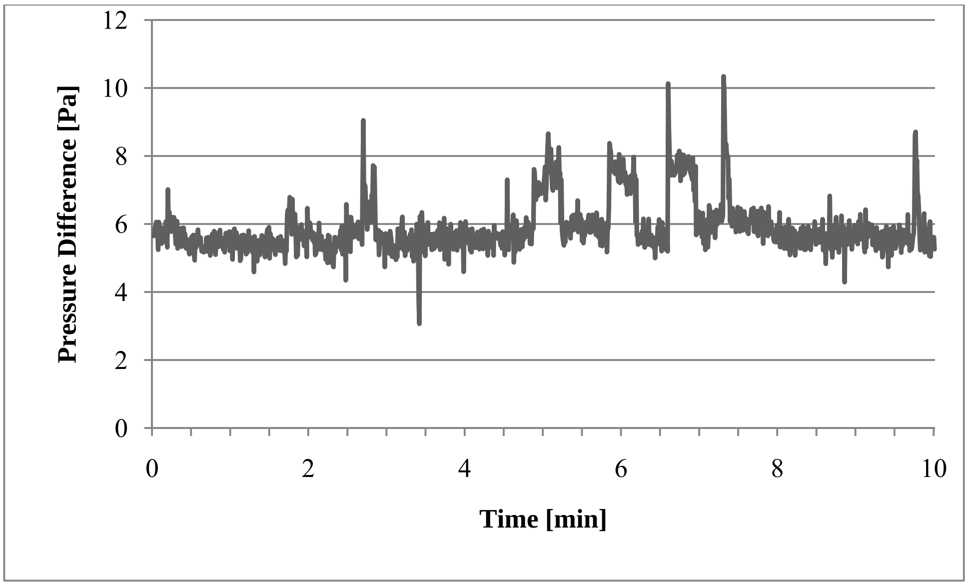

Figure 6.6 The pressure difference between OR 6 and corridor when the gap between the doors and the floor was blocked with duct tape.

The result from the pre-study indicated that the most common door opening type at the surgical ward is 45°. The look of what happens with the pressure difference between operating room and corridor when one door is opened at either 45° or 90° is presented in Figure 6.7 and Figure 6.8. The total time of a door opening of 45° takes around 4 seconds and the total time for a 90° door opening around 6 seconds.

From Figure 6.7 with a door opening time of 4 seconds, it can be seen that the pressure difference more or less instantly disappears. The great peaks when opening the door rapidly is probably because of air suction since the differential pressure tube in the corridor was located near the door.

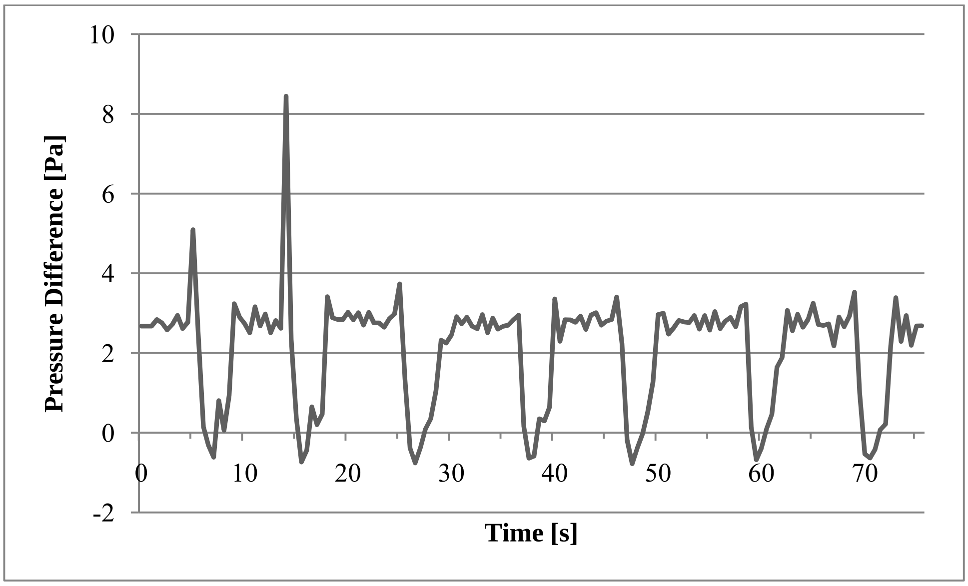

Figure 6.7 Pressure difference between OR 6 and corridor when a door is opened 45°. The pressure difference is more or less equal to zero when the door is opened and almost instantly rebuilt when the door once again is shut.

The appearance of the pressure difference when the door is opened 90° and thereby 6 seconds shows in principle the same result, see Figure 6.8. The pressure difference disappears almost direct when the door is opened and is rebuilt soon after the door is closed. The explanation for the peaks is the same as for the previous measurement.

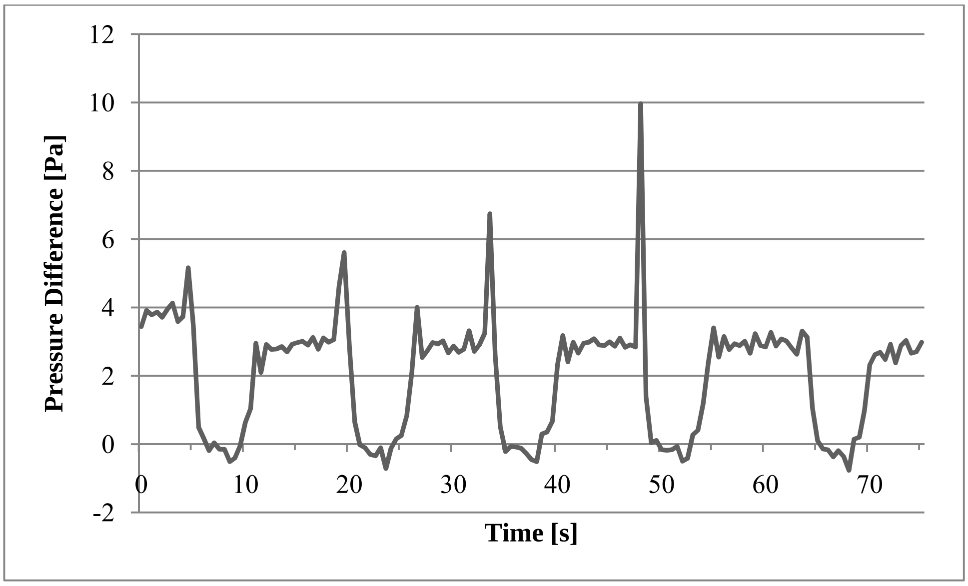

Figure 6.8 Pressure difference between OR 6 and corridor when a door is opened 90°. The pressure difference is more or less equal to zero when the door is opened and almost instantly rebuilt when the door once again is shut, as in Figure 6.7. Only the door opening time is changed.

Like mentioned in Chapter 2, there is usually one dominating driving force so that the others can be more or less neglected. In this case the pressure difference is far more dominating than the temperature difference.

6.3.3 Particle measurements

The increase of particle concentration in the operating room caused by a door opening was measured at the distance 0.5, 1.0, 1.5 and 2.0 meters in the room. Measurements were performed with door openings of 45° and 90° to be able to compare the impact of them both. The door was opened with an interval of 30 seconds for a total time of 5 minutes.

In Figure 6.9-6.12 the affect of a 45° door opening is tested at the chosen four distances vertically from the door.

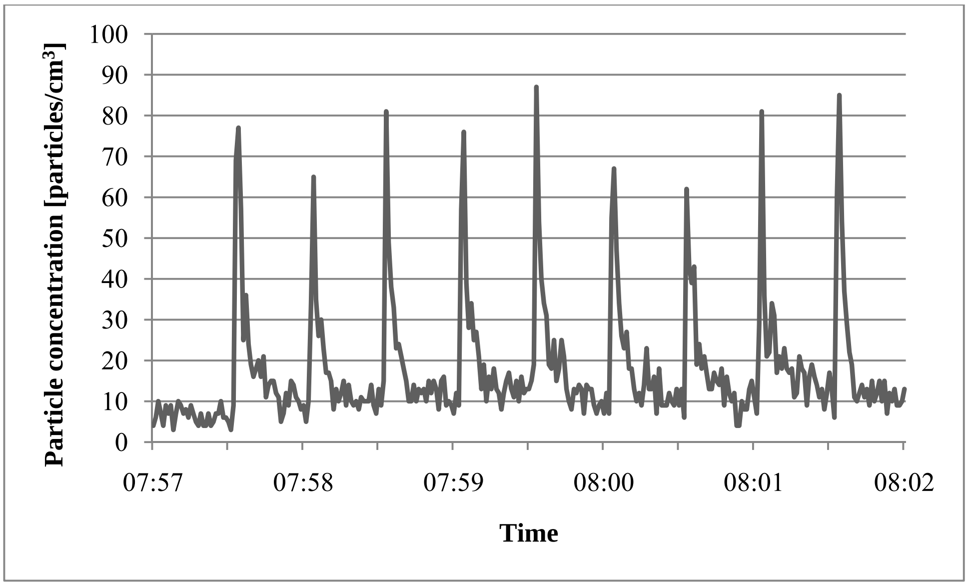

Figure 6.9 *Changes in particle concentration in the operating room 0.5 m from the door due to door openings of 45°.*

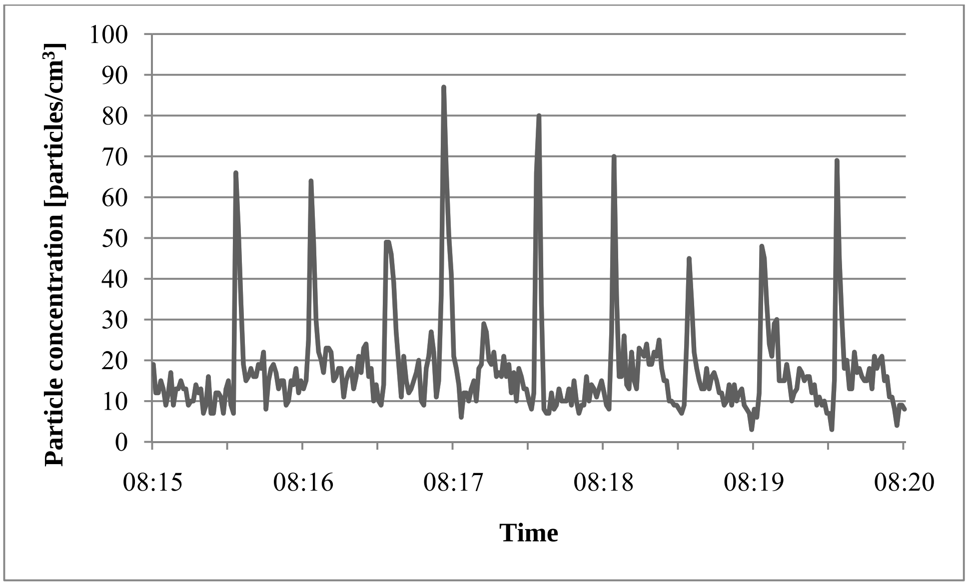

Figure 6.10 *Changes in particle concentration in the operating room 1.0 m from the door due to door openings of 45°.*

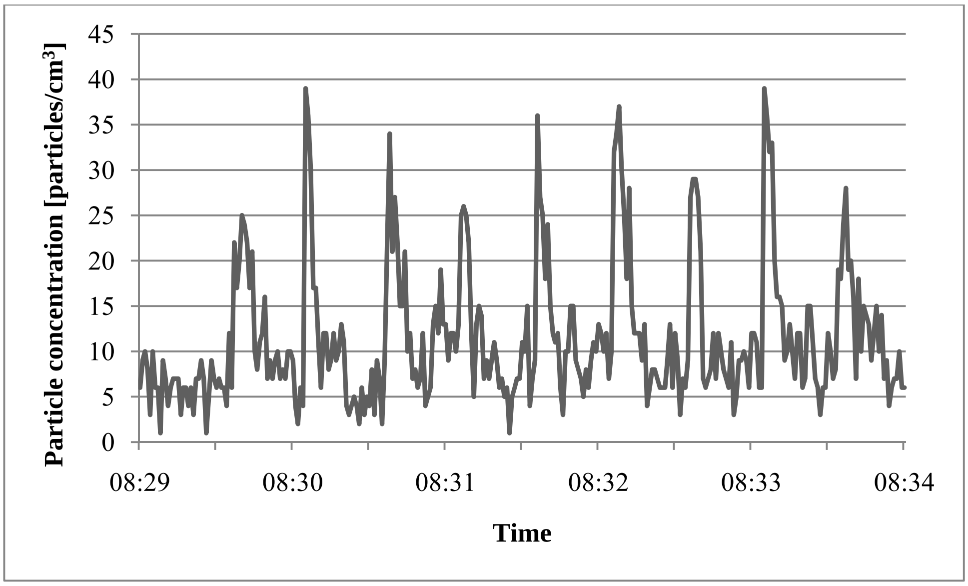

Figure 6.11 Changes in particle concentration in the operating room 1.5 m from the door due to door openings of 45°.

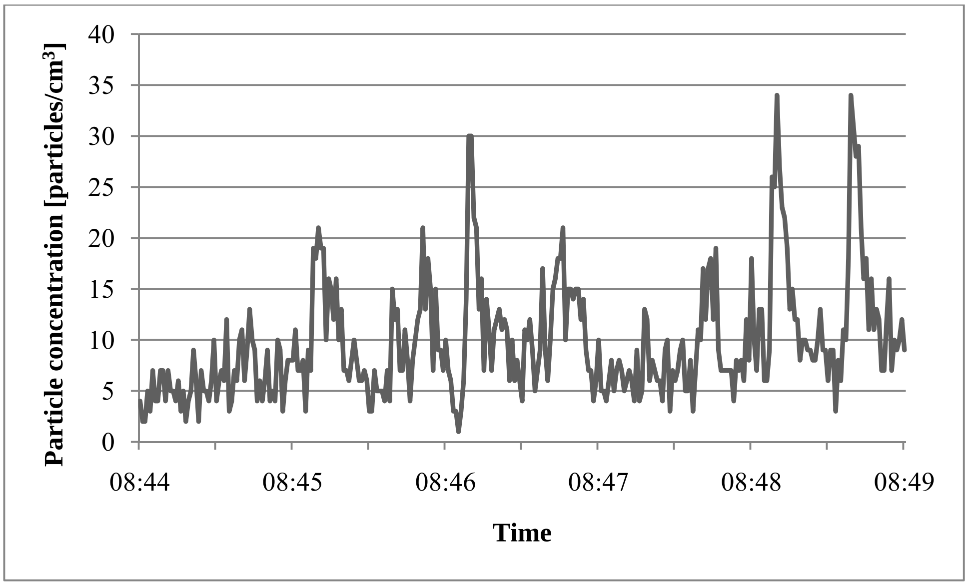

Figure 6.12 Changes in particle concentration in the operating room 2.0 m from the door due to door openings of 45°.

An increase of particles is obtained due to air vortices created by the door swing. The influence of the door swing is noticeably greatest near the door. Particle concentration peaks when a door is opened is pretty clear in Figure 6.9-6.11, but in Figure 6.12 the door openings is difficult to distinguish.

In Figure 6.13-6.16 the affect of a 90° door opening is tested at the chosen four distances vertically from the door.

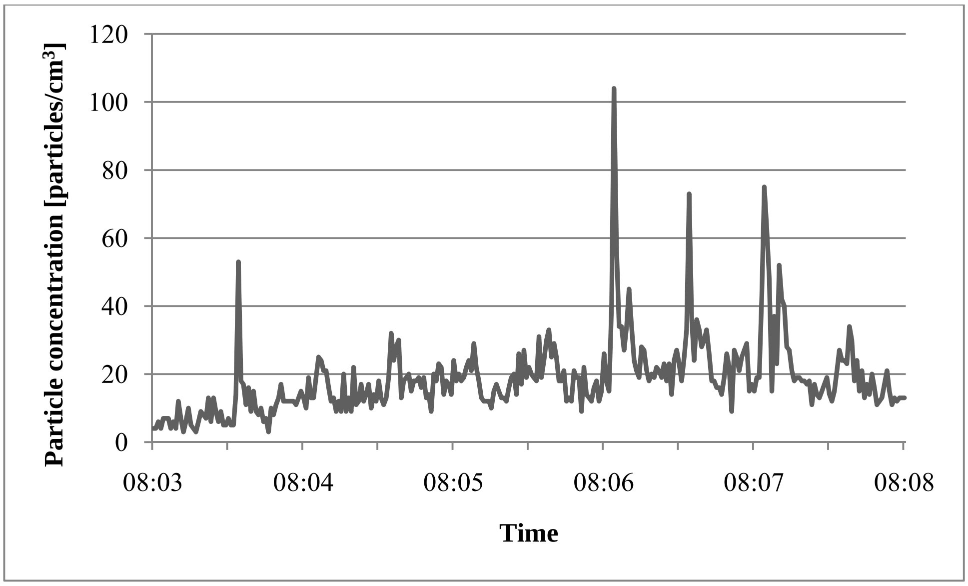

Figure 6.13 Changes in particle concentration in the operating room 0.5 m from the door due to door openings of 90°.

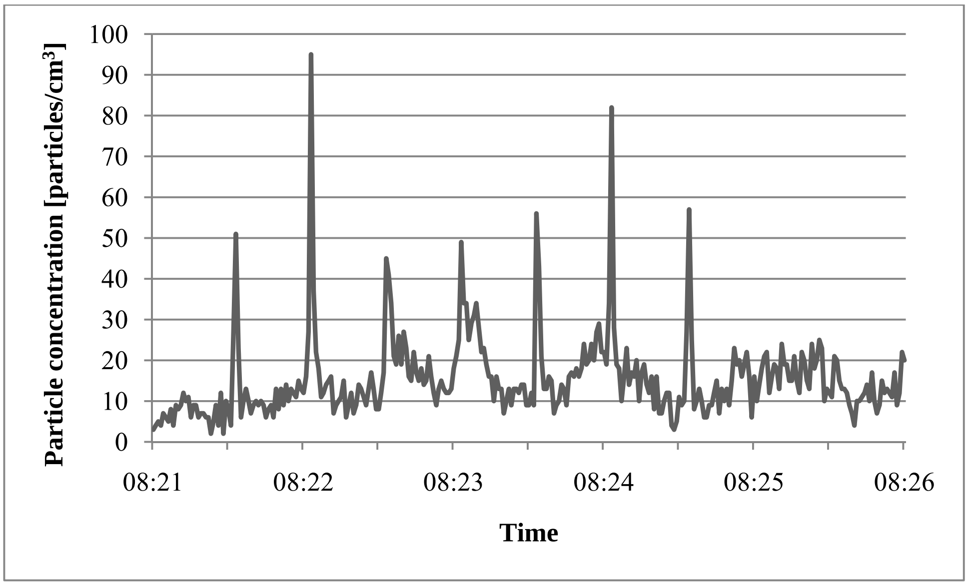

Figure 6.14 Changes in particle concentration in the operating room 1.0 m from the door due to door openings of 90°.

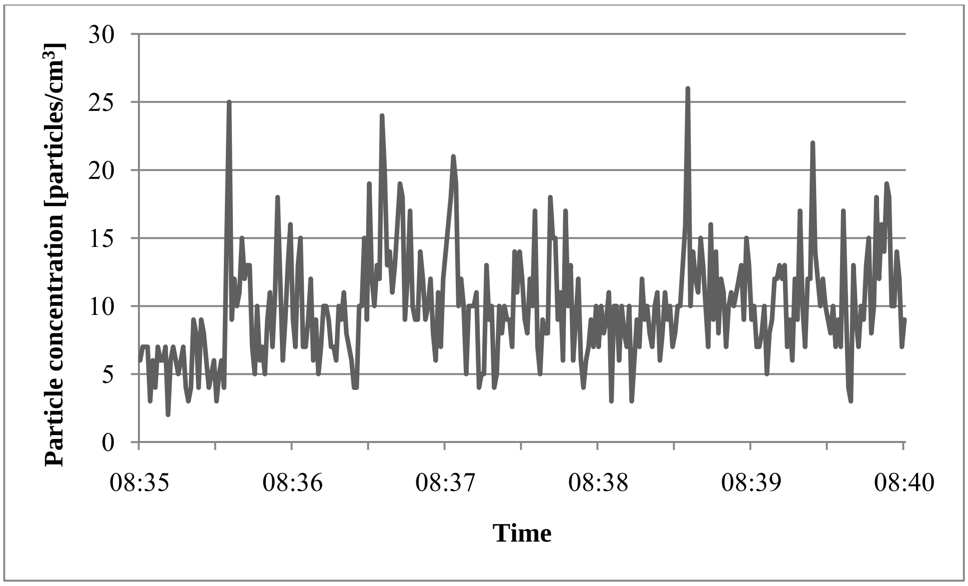

Figure 6.15 Changes in particle concentration in the operating room 1.5 m from the door due to door openings of 90°.

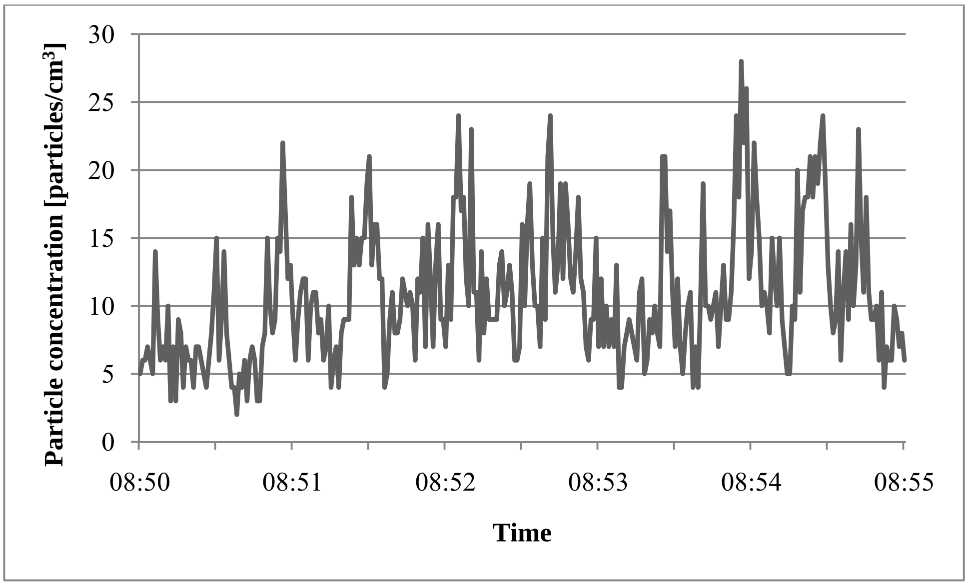

Figure 6.16 Changes in particle concentration in the operating room 2.0 m from the door due to door openings of 90°.

In Figure 6.13-6.14 it is possible to distinguish a door opening, while in Figure 6.15-6.16 it is more difficult. A door opening in these figures causes just a disturbance and the particle concentration is here significantly less.

Figure 6.9-6.16 show that a door opening every 30 second result in an increased particle concentration in the operating room. Despite no difference in air temperature and a positive pressure in the operating room, the measurements performed prove that air from the corridor were transferred into the operating room.

While doing these measurements it came clear that the increase of particle concentration caused by a door swing is very much dependent on the speed the door is opened. This coincides with the earlier mentioned conclusion made by Sansone & Keimig (1987) in Chapter 2. Of course a natural door opening and speed were tried to be obtained.

7 Summary

From the investigation of door usage during operation it came clear that doors were mainly opened when there was a need to get surgical equipment or when it was time for the personnel´s break. The most common door opening angle in this investigation was approximately 45° with a total door opening time between 3.5-5 seconds.

No air density difference between the operating room and corridor was noticed during the two operations investigated. The result of the temperature measurement can be confirmed with the logged temperatures in the operating room to conclude that there was a small or no air density driving force at all. Thereby was the pressure difference the dominating driving force in this case.

Pressure difference measurements showed a positive pressure in the operating room of 3 Pa towards the corridor, despite big air gaps between the doors and the floor. With these gaps sealed a positive pressure of 6 Pa was obtained instead.

The particle concentration in the corridor varied during the day. In the morning when there was a lot of activity in the corridor to prepare operations, the particle concentration was high. When the operations began, the particle concentration in the corridor declined. The measured particle concentration was approximately 500-600 particles/cm^3 in the corridor when the conditions had stabled. The location of the P-TRAK on the counter near a lot of activity has to be considered. A more accurate particle concentration would probably be 400 particles/cm^3, which was obtained during the first day. The P-TRAK measured particles in size range 0.02-1 µm.

During the operation, the particle concentration was most of the time less than 1 particle/cm^3. At some occasions the concentration was increased considerably. The highest peak measured during these two operations investigated was 20211 particles/cm^3 and it was detected by the P-Trak closest to the surgical area. The P-Trak located near the wall had a smaller peak with a small time delay.

Measurements show that door openings disturb the air flow in the operating room. Even with a positive pressure in the operating room and no temperature difference between the two spaces, air from the corridor was still transferred due to vortices created by the door swing.

8 Discussion

It is important to understand the conditions and the routines for the activity when designing operating rooms. If the solution with a door directly connected between a corridor and an operating room is chosen, it is important to be aware of the consequences frequently door openings during operation can have on the conditions in the room.

The results from this master´s thesis show that air from the corridor is transferred into the operating room despite a positive pressure and no temperature difference. Door openings would probably cause a larger impact on the air exchange between the two spaces if the pressure difference was lower or a temperature difference actually existed. Parameters such as door opening angle, door opening time and door opening speed would maybe influence the amount of air transferred even more in that case. Personnel have to be informed about the issue to reduce the number of door openings during operation. At the surgical ward Operation Norr, every operating room has an open able window on one of the doors. If an open able window exists, personnel in the corridor and personnel in the operating room shall use it if they need to communicate with each other during an operation.

The ventilation system for supply and exhaust air affects probably also the outcome of the measurements. The operating rooms investigated at Operation Norr all uses displacement ventilation. Most air transferred from the corridor into the operating room due to a door opening is pushed back towards the corridor because of the forced ventilation. But there is a possibility that some corridor air is transferred further into the operating room and thereby extracted in the ceiling above the operating space instead. In that case, it gives the less clean air an opportunity to come near the operating area. Measurement of the air flow characteristic with smoke would have been interesting to see if the assumption is correct. By using a LAF-ceiling instead of a displacement ventilation system, the air stream from the supplied air device would work in the same direction as the forced air movement. The impact of door openings into operating rooms with a LAF-system is still to be investigated. Another option is to build an airlock to avoid this issue. An airlock demands space and that costs money, but a more foreseeable condition is achieved.

The contaminations created during surgery, for instance diathermy smoke, are extracted with the ventilation system in the room. The contaminations from the operating room are also transferred to the corridor due to the pressure difference. The question if the contaminations have a negative effect on the people in the corridor still remains.

There are many questions in this field and it needs more research. Maybe postoperative infections are connected with air transferred due to door openings, but any certain conclusions cannot be drawn yet so the possibility has to be investigated further.

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APPENDICES

Appendix A Instrument data

A.1 P-TRAK Ultrafine Particle Counter

Manufacturer	TSI Incorporated
Model	P-TRAK Ultrafine Particle Counter Model 8525
Concentration range	0 to $5*10^5$ particles/cm^3
Particle size range:	0.02 to 1 µm
Temperature operation range	0 to 38°C

A.2 SwemaAir 300

Manufacturer		Swema
Model		SwemaAir 300 with air velocity sensor SWA 31
Measuring range velocity		0.1…30 m/s by - 10…+ 45°C
Accuracy	By 20°C	0.10…1.33 m/s = 0.04 m/s
		1.33…30 m/s = 3 % of read value
	Else	0.10…1.10 m/s = 0.05 m/s
		1.10…30 m/s = 4.5 % of read value
Measuring range temperature		- 20…+ 80°C
Accuracy		±0.3°C by 20°C
		±1.0°C by -20…+80°C

A.3 Differential Pressure Transmitter

Manufacturer	Furness Controls Limited
Model	Differential Pressure Transmitter Model 332
Minimum step response	100ms
Temperature limits working	-10 - 60°C
Maximum static working pressure	-1 to +1bar Gauge
	Used model 1 with the measure range 0 – 25 Pa

Software DasyLAB 6.0
Datascan 7320

Appendix B Example door openings during operation

Date	March 2nd 2010
Type of operation	Umbilical hernia
Operating room	6
Operation started	08:10 AM
Operation ended	10:25 AM
Personnel attending	5

Hour	Door angle	Door opening time (s)	Hour	Door angle	Door opening time (s)	Hour	Door angle	Door opening time (s)
08:10	45°	5.4		45°	3.5		45°	3.9
	45°	3.4		45°	4.1		45°	6.2
	45°	8.5	09:00	45°	5.9	09:50	45°	45.0
08:20	45°	4.4		45°	3.7		45°	4.0
	45°	5.0		45°	8.4		45°	4.2
	45°	11.9		45°	5.0	10:00	45°	3.2
	45°	5.5	09:10	45°	4.2		45°	3.4
	45°	5.2		45°	3.8		45°	5.9
	45°	4.0	09:20	45°	4.9	10:10	45°	13.8
	45°	4.4		45°	4.3		90°	11.7
08:30	45°	4.3		45°	3.8		45°	3.9
	45°	4.4		45°	3.5	10:20	45°	3.7
	45°	7.7		45°	3.1		45°	3.8
08:40	45°	4.4		45°	3.4		45°	3.7
08:45-08:55	No observation		09:30	45°	4.4	10:25		
08:55	45°	3.1	09:40	45°	3.9			

Appendix B Example door openings during operation

Date	March 2nd 2010
Type of operation	Embolectomy left arm/exploration
Operating room	8
Operation started	10:00 AM
Operation observation ended	11:40 AM
Personnel attending	6-7

Hour	Door angle (radians)	Door opening time (s)	Hour	Door angle (radians)	Door opening time (s)	Hour	Door angle (radians)	Door opening time (s)
10:00	45°	7.0		45°	5.4		45°	4.8
	45°	9.1		45°	3.8		45°	5.0
	45°	6.5		45°	5.4	11:10	90°	5.8
	45°	4.3		45°	4.3		90°	8.5
10:10	45°	5.0		45°	4.0		45°	4.8
	45°	5.7		45°	4.6		45°	7.4
	45°	4.8		45°	7.3		45°	4.2
	45°	3.7	10:40	45°	4.5	11:20		
	45°	7.0		45°	5.8	11:30	45°	3.9
10:20	45°	3.9		45°	4.8		45°	8.8
	45°	3.4		45°	4.3		45°	5.0
	45°	3.8	10:50	45°	4.7		45°	3.0
	45°	4.9		45°	3.0		90°	7.3
	45°	4.1		45°	5.2		45°	4.4
	45°	6.7		45°	5.1		45°	3.5
10:30	45°	3.3	11:00	45°	5.6	11:40		