OPTIMUS

AIROLIGHT

Industrial Design
AD:MT AAU
MSc04-ID16
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Preface

Master Thesis - Process report

Title:	Optimus
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Appendix:	17 (A-Q)
Pages Process:	153
Pages Presentation:	23
Technical drawings:	8
CDs:	6
Prints:	6

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Synopsis EN

The master thesis project takes its starting point in a collaboration with DTU, but diverged into an individual project.

The focus has from the beginning been to reduce the prevalence of hospital acquired infections. A new modular hospital bed platform and a novel ventilation module for the platform were developed.

The modular bed platform, Optimus, is able to have new modules easily installed and seamlessly integrated into its user interface. This allows the hospital staff to tailor the bed's functionality to each patient.

One of the module that can be installed on the Optimus bed platform is the AiroLight ventilation unit. It is designed to reduce hospital acquired infections by providing an "open" isolation of potentially infectious patients, while also directly supplying the patients with cleaned air.

To increase the comfort and reassurance of the patient, steps have been taken to make the Optimus bed and the modules appear clean, professional and sturdy. While also embedding a dynamic lighting solution into the AiroLight module.

Synopsis DA

Dette kandidatspeciale tager udgangspunkt i et samarbejde med DTU, men måtte dog adskille sig til et individuelt projekt.

Hovedfokuset har fra starten af været at reducere prævalensen af hospitals erhverved infektioner. En ny modulær hospitalssenge platform og et nyt ventilations modul til denne platform blev udviklet.

Den modulære platform, Optimus, er istand til let at få nye moduler installeret og integrere problemfrit ind i brugerinterfacet. Dette gør det muligt for personalet at skræddersy senges funktionalitet til hver enkelte patient.

En af de moduler der kan installeres på Optimus senge platformen er AiroLight ventilationsenheden. Den er designet til at reducere hospitalserhvervede infektioner, ved at lave en "åben" isolation af potentielt smitsomme patienter, mens det også leverer frisk luft direkte til patienten.

For at øge patientens komfort og tryghed, blev der taget tiltag til at gøre Optimus sengen og modulerne renlige, professionelle og robust. Samtidig med at et dynamisk lys system er indbygget i AiroLight modulet.

Terminology

- **HAI -** Hospital acquired infection, any infection that occurs during or up to 48 hours after a hospitalization
- **HCW -** Health Care Worker, e.g., doctors and nurses
- **Somatic -** Something relating to the body as opposed to psychiatric
- **Epidemiology -** The science that studies the patterns and causes of infections and diseases
- **Pathogen -** Any disease causing agent e.g., virus, bacteria, mold or pryon
- **Opportunistic pathogen -** An infection that does not harm its host until the host's resistance is low
- **Opportunistic infection -** Infections that usually does not cause disease in a healthy host
- **Immunodeficiency -** A state in which the immune system's ability to illht infectious diseases is compromised or entirely absent
- **Aerosol -** A colloid of fine solid particles or liquid droplets, in air or another gas
- **Re-aerosolization -** A nuclei from an evaporated settled droplet
- **Trendelenburg tilt -** Tilting the head-end of the bed down
- **CPR -** Cardiopulmonary resuscitation, emergency chest compressions done in order to preserve blood circulation
- **Laminar airflow -** Air moving coherently and with little variation in pressure and velocity
- **Turbulent airflow -** Air moving chaotically and with rapid variation in pressure and velocity
- **Coandă effect -** Airflow's tendency to be attracted to nearby walls or objects along its path
- **FEA -** Finite element analysis, a computational strength analysis
- **CFD -** Computational fluid dynamics, used to analyze and validate airflows.

Table of content

Partners and experts

This project involves a lot of stakeholders that all needs to be considered, as well as a extensive scientific evaluation of concepts. To achieve the knowledge required to accommodate all these facets, many experts were consulted and stakeholders were interviewed, shadowed and analyzed. Several references in this report is based on interviews with some of these people.

Below is the acknowledgment to the people that helped the design team to define and execute this project.

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Initial research

ill. 8a

An initial research was initiated to discover, explore and validate different problem statements.

It will form the basis for the entire project through the "Problem statement"

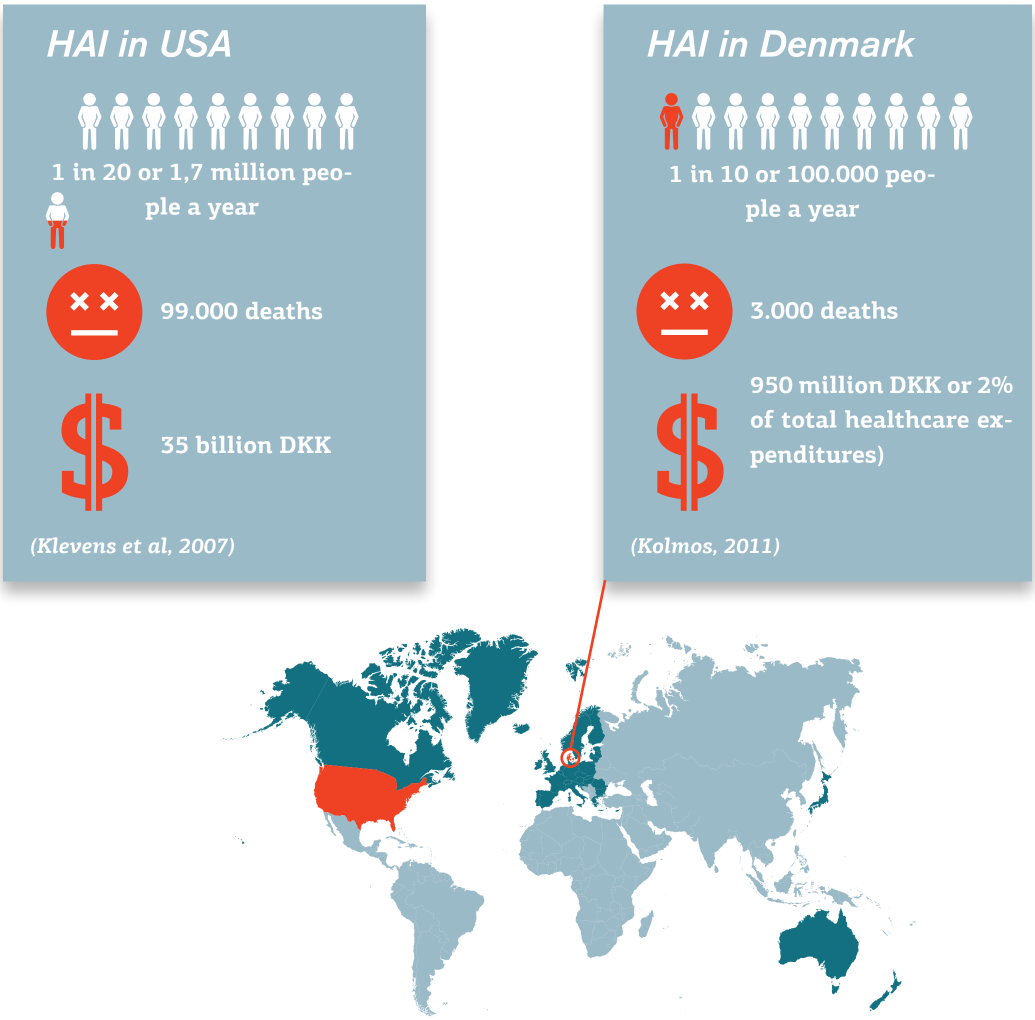
Problem

Originally the intent of this project was to have a close collaboration with DTU as they are developing an air based solution for reducing a very serious problem: hospital acquired infections. However this collaboration did not work out, and the design team chose to use the DTU project as a basis for the initial problem statement.

One of the great problems in even the most modern hospitals is that a significant number of patients during hospitalization acquires infections they would otherwise not be exposed to. This is called a nosocomial infection or hospital-acquired infections (HAI will be used as an abbreviation in this report), and is a great burden for the patient, the families, the health care workers (HCW) and society. It can prolong the hospitalization for patients who acquire such infections by 14 days on average ***(Pedersen and Kolmos, 2007)***.

In Denmark, as in most other developed countries (EU, North America & Japan) it is also noted that HAIs causes more deaths than breast cancer ***(Kræftens Bekæmpelse, 2013)***, car accidents and diabetes combined ***(SSI, 2011)***.

It is obvious that the stated costs to hospitals of HAIs is significant. However, the cost to our societies are even higher as the costs of sick leaves, disabilities and even deaths will have to be added to the direct costs of the hospitals.



Initial problem statement

How do we reduce the number of Hospital-Aquired Infections (HAIs)?

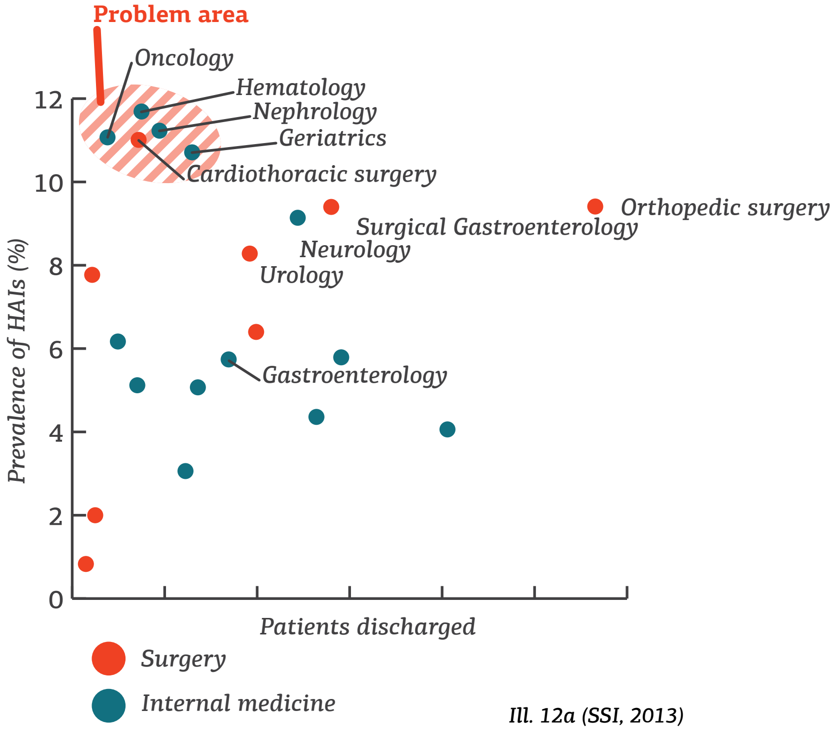
Hospital-acquired infections

In order to develop a solution to the identified problem, a thorough research phase, based on desktop research and interviews was initiated. The following section describes how the design team investigated the scope of the problem and defined a limited area where an effort could potentially make a contribution towards reduction of the problem.

Types of Hospital-acquired infections

There is not a big difference between the infections acquired in hospitals and the infections acquired in the "wild". The major difference is the density of infectious pathogens and the susceptibility of the people exposed to these pathogens.

There are different types of HAIs that affects different types of patients in different somatic departments.



Ill. 12a (SSI, 2013)

When examining the prevalence of the different departments according to Staten's Serum Institute's national prevalence survey ***(SSI, 2013)***, a group of departments pops out with a high prevalence (note that anesthesiology and intensive care have been omitted as these departments are significantly different from the rest of the departments)

Categories

The types of infections acquired in hospitals are usually divided into four or more groups. These groups are defined not by the type of pathogen, but by the location in which they are contracted. This makes it easier to categorize and define effective ways to combat HAIs.

There is typically two different ways to acquire a HAI; endogenous and exogenous. Endogenous is when bacteria or viruses are transmitted from one part of the body to another. The patients are infecting themselves. This could be something like e.coli bacteria from a patient's colon entering a surgical site.

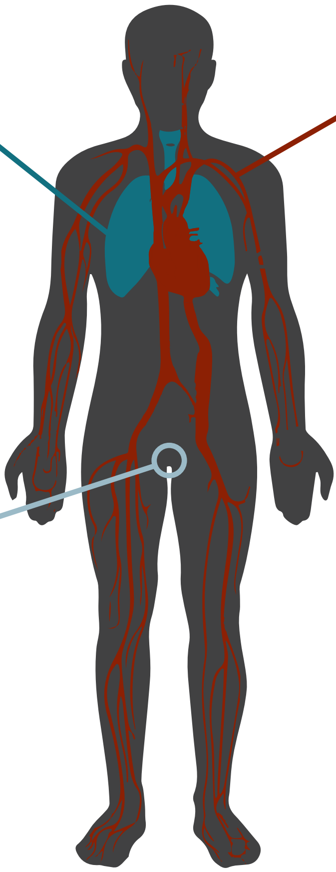
Exogenous infections occurs when a pathogen from the environment enters patients and infects them.

Pneumonia

is often acquired from inhalation of airborne pathogens or by using infected respiratory equipment. It lengthens the hospitalization with **12.5 days**. ***(Pedersen and Kolmos, 2007)***

Bloodstream

can be caused by many things such as surgery or intravenous injections. But it can also be endogenous from e.g. an endoscopy. It lengthens a hospitalization with **1.9 days.** ***(Pedersen and Kolmos, 2007)***



Urinary tract

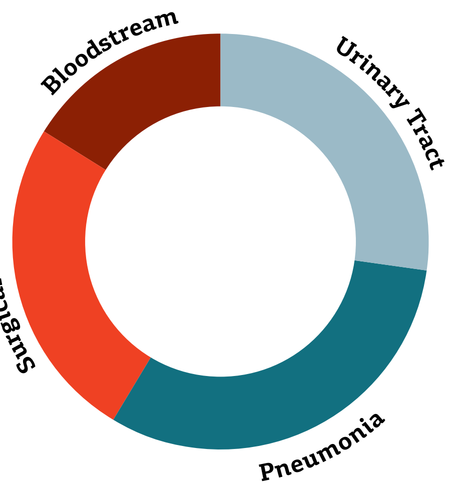
is the most common HAI and is often attributed to the use of catheters. It lengthens a hospitalization with **5.1 days**. ***(Pedersen and Kolmos, 2007)***

Surgical site

After surgery, the wound can very easily be infected from either airborne pathogens or by direct contact with HCW. It lengthens a hospitalization with **6.5 days.** ***(Pedersen and Kolmos, 2007)***

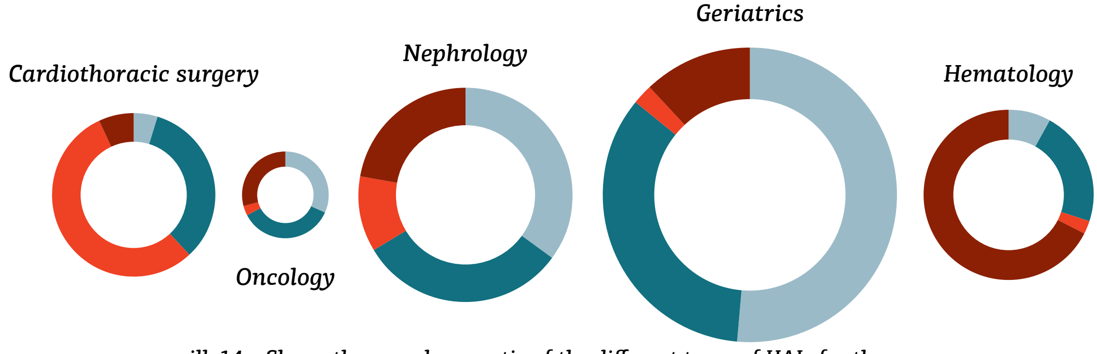
Note that the hospitalization days are for a single type of infection. Patients who acquire a HAI will often acquire more than one HAI. When multiple HAIs occur the average hospitalization increases by **29 days** ***(Pedersen and Kolmos, 2007)***.

Statistics from the Danish "Statens Serum Institute" ***(2013)*** show that the prevalence of urinary tract infection and pneumonia is the most common. These numbers are not uncommon and correlate with those observed both in the rest of EU ***(ECDC, 2013)***, and in the US ***(Kowalski, 2007).***



ill. 14a: Shows the prevalence ratio of the different types of HAIs (SSI, 2013)

Looking at the prevalence of the departments in the problem area as shown in "Ill. a (SSI, 2013)" on page 12, it is obvious that the HAIs that are troublesome are very different in each department, and usually relate to the treatment or organs relating to that department. This information can be used to illure out exactly where a potential solution would have the biggest effect.



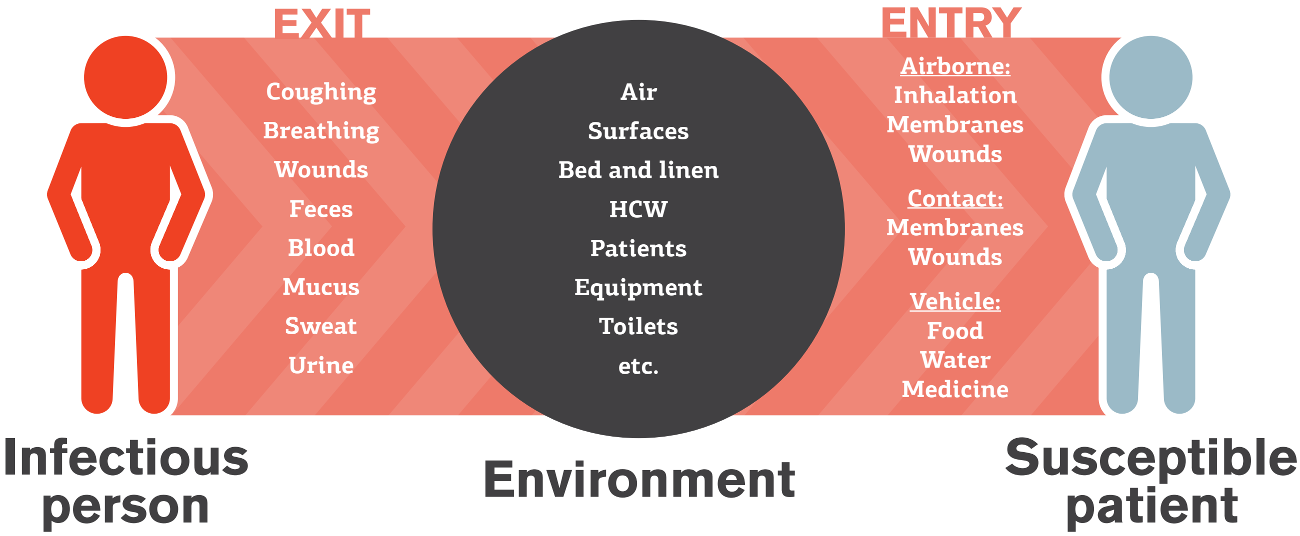
ill. 14a: Shows the prevalence ratio of the different types of HAIs for the problem area shown in "Ill. a (SSI, 2013)" on page 12 (SSI, 2013)

Modes of infection

In hospitals there are many ways for infections to spread. For an infection to occur, certain conditions have to be met. The chain of infection is often used to analyze the spread of infections in hospitals as well as to develop tools to combat the spread of infection ***(Kolmos, 2007).***

Below is a simplified version of the chain of infection that shows how an exogenous infection occurs. The infections requires at least one parameter in each link in order to occur.

A typical scenario could be an infectious patient coughing, resulting in a small droplet landing on some equipment or an exposed surface. The HCW can then, even after they sanitize their hands between seeing each patient, touch the contaminated equipment or surface, and afterwards infect a susceptible patient when addressing their needs.



The chain starts with an infectious person. Note that this person does not necessarily have any symptoms, e.g. 20% of the population are permanent carriers of S. aureus. The infectious person can then either directly transmit the disease to another person or contaminate the environment. It is possible to contaminate the environment in many different ways, and different opportunistic pathogens have different characteristics that will make it possible for them to infect other people.

A contaminated environment includes the air and all the surfaces. The droplets from a cough from an infected person can either hit a susceptible patient or it can land on a surface, dry out and then re-aerosolize and infect another susceptible patient. The same droplet can also land on some equipment where the droplet nuclei is transmitted to a susceptible patient by the HCW.

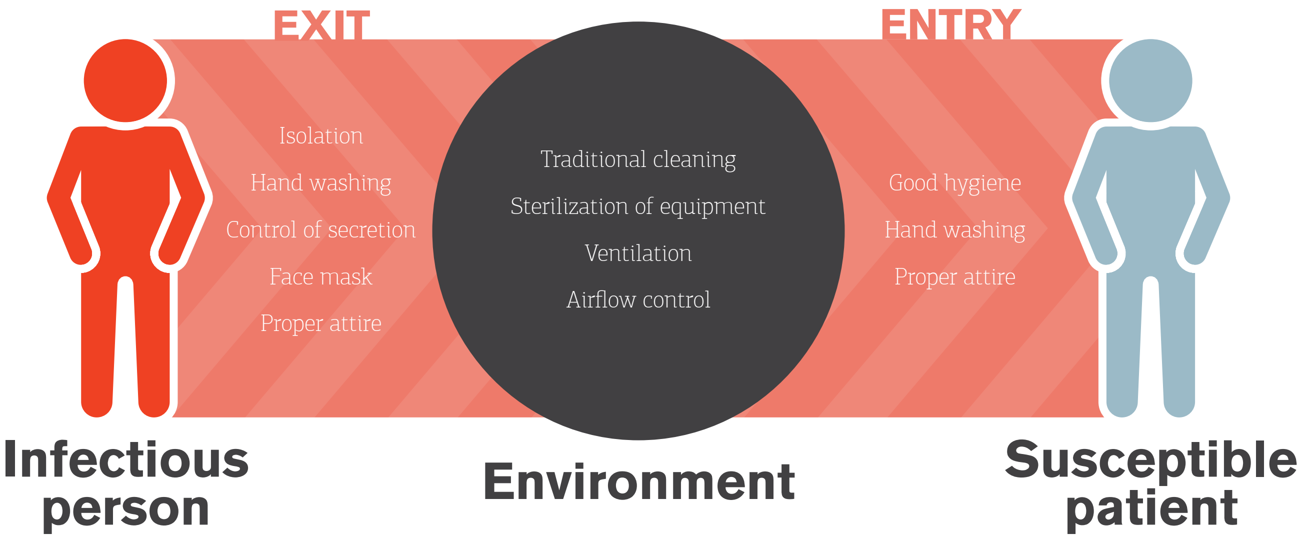
This is why it can be extremely difficult to determine the epidemiology of hospital-acquired infections. Describing a route of transmission as either: direct-contact, indirect-contact, airborne or droplet transmissions is completely inadequate to describe the epidemiology. In fact it shows that the majority of common pathogens associated with hospital-acquired infections might have a potential airborne route in their transmission process ***"the tendency has been to dismiss the airborne route as unimportant except for well-known exceptions like tuberculosis (TB)"*** *(Kowalski, 2012: 1).*

Preventive measures

Currently if there is no special precautions, the procedures for infection control is:

- Proper hand washing (between each patient visit)
- Conventional cleaning (with special focus on all contact surfaces)
- Sterilization of equipment
- Cleaning of beds between each patient, but not while in use
- Proper handling of organic material and waste (blood, secretion, excretion)

In special circumstances such as suspicion of an infectious pathogen, extra precautions will be taken to isolate the patient in a single-bed room and special precautions are taken at each visit. Some hospitals also have negative pressure rooms when dealing with highly infectious diseases such as SARS and H1N1.***(SSI, 2010)***



When relating the hospital's standard procedures to the chain of infection, it becomes apparent that most of their efforts are very conventional, and relate mostly to cleaning the environment and preventing pathogens from entering susceptible patients. It is only in special circumstances that their procedures prevent pathogens at their point of source.

Levels of infection control

- **Standard Precautions** Standard precautions are at the basic level of infection control and should be used in the care of all patients in all settings to reduce the risk of transmission of organisms that are both recognized and unrecognized.
- **Contact Precautions** Contact precautions should be utilized when direct or indirect contact with contaminated body fluids, equipment or the environment is anticipated
- **Droplet Precautions** Droplet precautions should be utilized when working within 3 feet of a patient who is coughing or sneezing, or during procedures that result in dispelling droplets into the air.
- **Airborne Precautions** Airborne precautions should be utilized when exposure to microorganisms transmitted via the airborne route is anticipated – including procedures such as nebulizing, suctioning and intubation.
- **Full Barrier Precautions** Full barrier precautions should be utilized for diseases such as Severe Acute Respiratory Syndrome (SARS), hemorrhagic disease, and all known and suspect avian and pandemic influenza patients.

(Siegel et al, 2007)

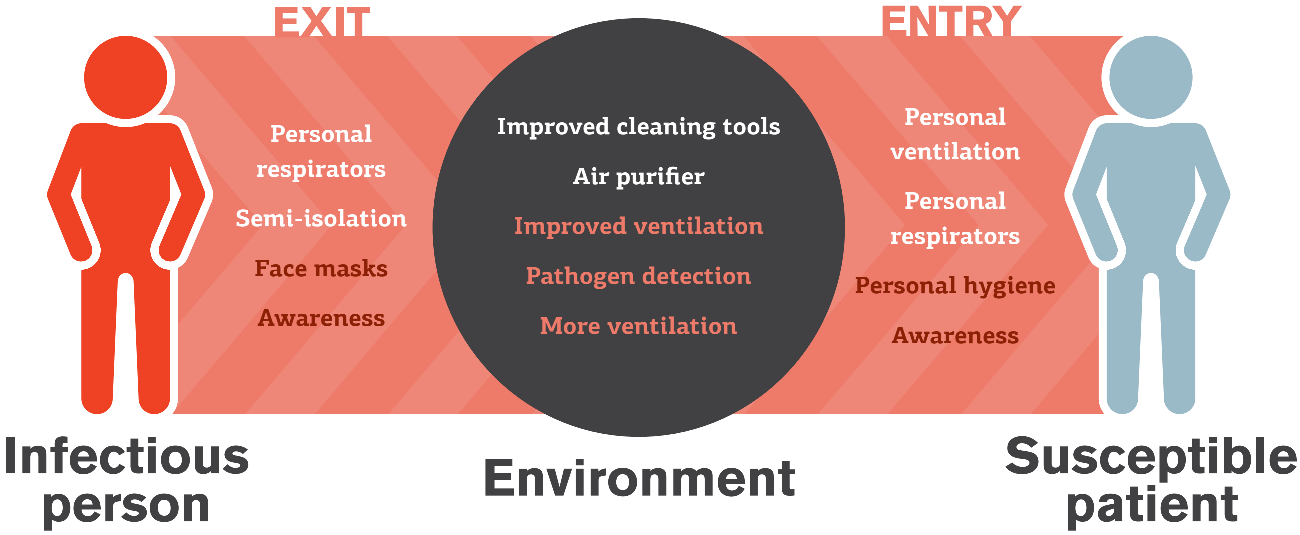
Output

The research conducted clearly shows that HAIs are a huge problem in modern medicine. Many initiatives are taken to prevent HAI's but there is a tendency to underestimate the importance that the airborne route often plays in the chain of infection. It's important that the solution being developed not only focus on minimizing the risk of a susceptible patient getting infected but also reduce the contamination at the source.

Potential solution space

Based on the initial problem statement and the knowledge gained from the research on HAIs, brainstorming and sketching sessions were carried out. These focused on how an engineering solution can be used for reducing airborne hospital acquired infections.

The brainstorming and sketching sessions resulted in a catalog of ideas, which was subsequently sorted after potential. The ideas which the group found the most promising was plotted according to where in the infection chain they would be most effective and given pros and cons for easy evaluation.



Cleaning device

A device that enables the cleaning staff to improve cleaning effectiveness and quality. Or a device for controlling whether the area has been cleaned properly or not. Such a device should not increase the workload of the cleaning staff or the HCWs.

- ✚ Possibly save resources by cleaning more effectively
- ✚ A cleaner environment
- ✖ Doesn't prevent exit or entry of pathogens

Personal respirators

A personal respirator will completely block both the point of entry and the point of exit for the airborne or droplet based pathogens. It should be worn whenever patients or HCWs are exposed to an infectious risk. Itøs important that the solution doesn't make the patient look sick and allow them to eat and talk without any difficulties.

- ✚ Extremely effective
- ✚ Also removes smells
- ✖ Dehumanizes patients and HCWs
- ✖ Great difficulty doing every day operations

Personal ventilation

Is a system that is designed to provide filtered ventilation not for the whole room, but just for one person. This allows a susceptible patient to inhale cleaned air. It is important that such a device is located as close to the patient's mouth as possible during the majority of the time they are exposed to an infection.

- ✚ Possible to remove bad smell
- ✚ When using a personal ventilation the central ventilation can be reduced.
- ✖ Effectiveness limited to inhaled pathogens

Semi-isolation

Isolating patients is a great way to reduce an infection at it's source. However when an infection is confirmed, other patients have most likely already been infected. The solution should creating a form of isolation around each patient either by a physical barrier such as glass or plastic dividers or by using jets of high velocity air to create an air-curtain between patients.

- ✚ Limits contaminated area
- ✖ Big and cumbersome solution
- ✖ Can obstruct visual contact with patients

Air purifier

A mobile air purifier that can effectively reduce airborne infections or re-aerosolized droplets. Potentially by automatically moving around the room to improve ventilation effectiveness. Either like a robotic vacuum cleaner or along the aluminum rails on the wall.

- ✚ Slowly and effectively cleans some of the environment
- ✚ Also removes smells
- ✖ Saturated market

Output

Based on the brainstorming session as well as the initial research on airborne infections, it was decided to focus on developing an engineering solution that uses air for reducing HAIs caused by airborne pathogens.

Several of the ideas could potentially be combined to create a solution that is more effective. The solution should reduce the contamination at the source like semi-isolation, clean the environment like the air purifier and prevent patients from being infected like personal ventilation.

Ventilation in hospitals

Because the solution being developed relies on air for reducing HAIs the team found it important to investigate how the ventilation systems at hospitals works as this might affect the performance or the design of the solution.

There are many different concepts for ventilating hospital rooms, but there are two overall principles that most types of ventilation will fall under: displacement and mixing ventilation.

A ventilation system will usually consist of a fan, air-treatment (heating, cooling, humidity, filter), a series of ducts and inlets and Outlets in the ventilated rooms.

In larger buildings it is common to control both the airflow into the building and the airflow out of the building. This is done by having a system to perform each of these tasks and is the norm in most existing and planned hospitals today ***(Skytte)***.

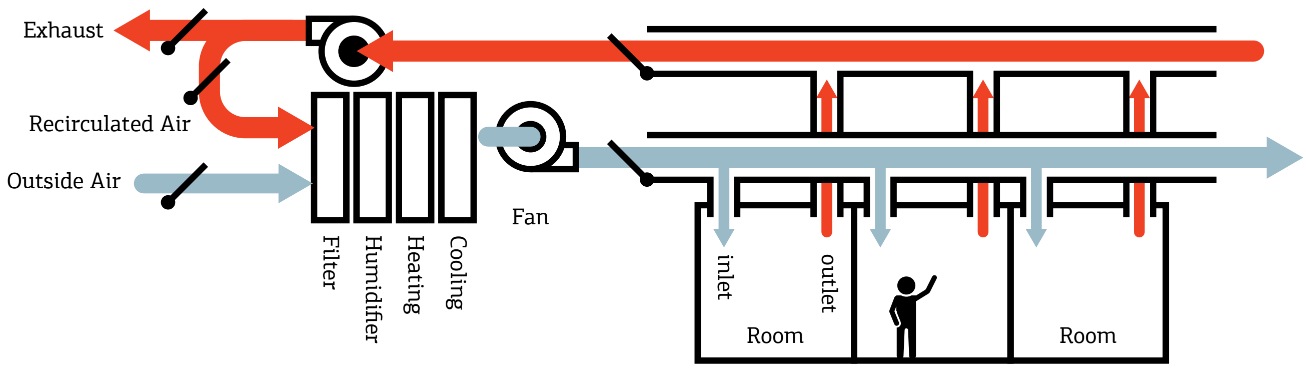
To improve the efficiency of such systems it is normal to either recirculate air with 15-25 % outside air ***(Kowalski, 2007)*** and use a heat-exchange to avoid unnecessary heat waste. However, in hospitals this can sometimes cause infections to spread. It is not uncommon that a contamination can spread from one room to a neighboring room through the ventilation system.

There are currently no standards regarding both the use of recirculated air, or how airflows should work in hospitals.

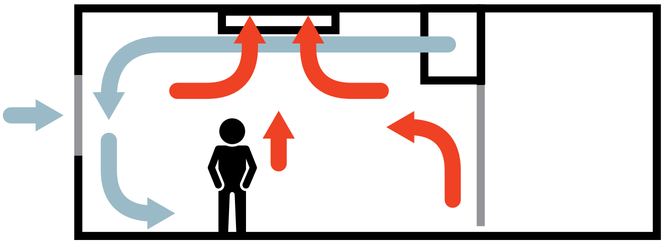
However there is recommendations that hospitals should have high air change rates as ventilation is still the most effective way to reduce airborne transmissions. In general areas the AC/H (Air change pr hour) should be 4x - 7x and 12 AC/H for ORs (operating rooms) ***(Kowalski, 2007)***. There is research that shows that increasing the air change rate above 6 AC/H only has a limited effect ***(Beggs, n.d.)***.

There is a lot of research being conducted on how size and placement of inlets and Outlets affect the spread of contamination in patient room. However, the efficiency of novel ventilation systems are extremely vulnerable to small variables such as the direction of patient exhalation or distance between patients.

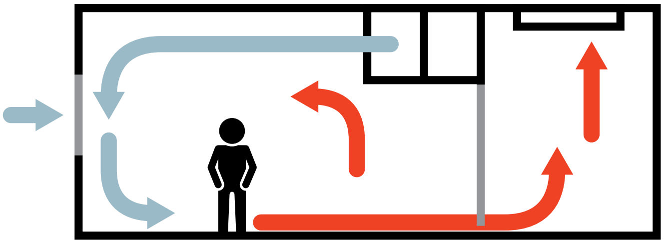
One of the reasons that novel ventilation systems only show improvement in limited situations, is because the distance between the contaminant and the ventilation system is too great. No matter how well the airflow is designed in a room, there will always be situations where they won't work ***(Nielsen, 2012)***.



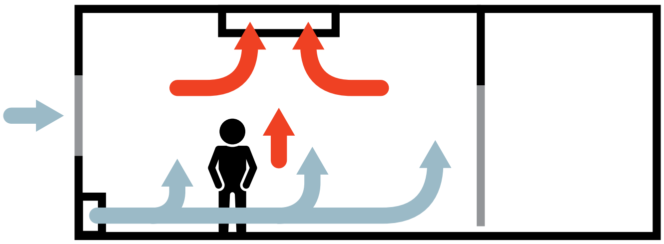
ill. 20a: A typical mixing ventilation, with recirculated air, used in many hospitals



ill. 21a: A typical mixing ventilation system with inlet and Outlet in the ceiling



ill. 21b: A typical mixing ventilation system, with inlet in the room and Outlet in the hallway



ill. 21c: A typical displacement ventilation principle

Mixing ventilation

Mixing ventilation works with the principle that there is no specific guided airflow in a building. The clean Inlet air is pushed into a room and mixes with the air in that room and the mixed air is then slowly sucked out through the Outlet or pushed out through natural exits, such as doors, windows and vents. In larger buildings such as hospitals it is also necessary to actively exhaust the air out of the rooms to both ensure a proper air change rate, but also to ensure there are no pressure drops. ***(Nielsen, 1997)***.

The advantage of a mixing ventilation system is a greater freedom to place inlets and Outlets, as it dictates no specific direction for the airflow.

Displacement ventilation

Convection ventilation works by blowing clean cold air into the room either through the floor or by an Inlet close to the floor. The cold air will then through convection slowly rise through the room and will be sucked out through an Outlet in the ceiling ***(ill. 21c)***.

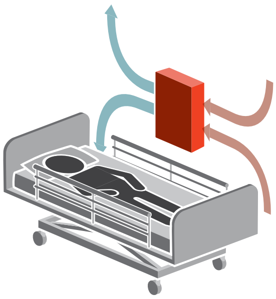
The advantage of such a system is that it is very energy efficient, and the air quality is greatly improved, since the inhaled air has not been mixed with contaminated air. However, the main disadvantage of this system is that it requires a lot of space between the breathing zone and the Outlet height as the air in the top of the room can be saturated with warm contaminated air. This means that contaminated air exhaled from one person will remain stagnant in a breathing zone height for a long time ***(Nielsen, 1997)***. For this reason it is not recommended that this type of ventilation is used in hospitals ***(Nielsen)***.

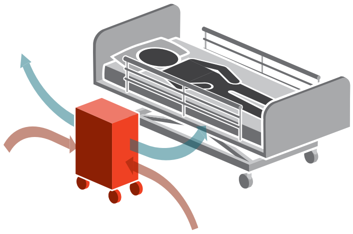
Output

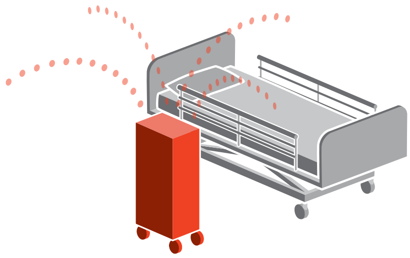
When designing a solution that might interact with the airflow in the room, there can be no assumptions as to how the ventilation system is designed in any particular hospital. Hospitals will most often use a mixing ventilation principle, but the inlets and Outlets for the airflow can be placed anywhere in the room. A potential solution for a hospital setting should accommodate all types of ventilation it may encounter.

Current solutions

There are already several solutions on the market that are designed to reduce HAIs. These were divided into three categories and assessed on how they function and to what extent they are able to prevent airborne infections from spreading.







Wall-Mounted Air Purifiers

These units are mobile and can be placed anywhere in the room and used while the patients are in the room. They are typically equipped with a fan that draws in contaminated air from the room and passes it through a HEPA or ULPA filter. Often this is combined with a UVGI disinfection lamp that irradiates and destroys airborne viruses, bacteria and other micro-organisms. The cleaned air is recirculated into the room.

Mobile Air Purifiers

Just like the mobile air purifiers these units use a fan to draw in contaminated air, which is sterilized within the unit and then recirculated into the room. Some use a combination of filters and UVGI lamps to sterilize the air, while others use a dielectric barrier of discharge plasma ***(Novaerus, 2014)*** or nano covered catalytic tubules ***(Airocide, 2014).***

Decontamination Systems

Most decontamination systems work by filling the room with a vapor form of hydrogen peroxide that effectively decontaminates the room ***(Glosair, 2014)***. Others, such as the Meditrox 100 combines water and oxygen to generate a dry ozone vapor that spreads throughout the room and destroys pathogenic cells. ***(PD+1, 2011)***. Both solutions are harmful for humans so the room needs to be empty and all gaps sealed when the system is running. It takes a couple of hours to decontaminate the room so this solution is primarily used to disinfect rooms after they have been used for isolation.

Wall-Mounted Air Purifiers

ill. 23a: Novaerus

ill. 23b: Airocide

ill. 23c: NQ 400

Mobile Air Purifiers

ill. 23d: IQ Air

ill. 23e: NQ 500

ill. 23f: Airvention

Decontamination Systems

ill. 23g: Glosair 400

ill. 23h: Meditrox 100

ill. 23i: Bioquell Q-10:

Output

All of these solutions try to lower the possibility of infections spreading in hospital departments by creating an overall cleaner environment for patients and HCWs. Decontamination units make sure that the room is cleaned between patients but have no effect while the patients are in the room and air purifiers relies on collecting and cleaning the contaminated air. But none of these solutions focus on stopping the infections at the source or at the susceptible patient, which is where the design team sees great potential for improvement.

Deconstruction

Current airflow principles has been studied and used as a reference for defining how the solution being designed should manipulate air to achieve the intended effect.

Personal ventilation

Personal ventilation is an area, where only a few commercial solutions are available but many examples and studies showing the effectiveness and application potential of a personal ventilation system.

AAU have tested a principle that distributes clean air through a pillow to a patient lying in a bed. The results showed a great efficiency of about 90 % with a 10 l/s flow. This test also showed an improved evacuation of exhaled contaminations when the patient exhales upwards ***(Nielsen, 2008)***.

ill. 24a: The exhausto personal ventilation system

Air curtain

Commercial air curtains are primarily used at the entrance of buildings to create a barrier that keeps out dust, insects wind etc.

The principle can also be used to contain an infection to the infectious host by separating the host from the surrounding environment with a curtain of air. This principle has been tested at the Danish Technical University, where air curtains were mounted on both sides of a bed. A tracer gas from the patient was discharged and then measured 0.55m away from the bed in breathing height. The experiment showed a huge improvement in the evacuation efficiency with such a device attached ***(Melikov, 2011)***.


ill. 24b: A commercial air curtain

Air purifier

When working with ventilation systems whether it is to create an air-curtain or personal ventilation, it is important to clean the air.

Using the room's air to supply such devices will not only help where they are applied locally, but will also help clean the air in the environment.

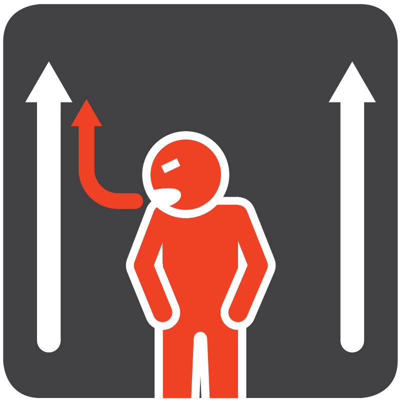
The principle for cleaning the air can be compared to conventional air purifiers that draw in air from the surrounding environment and cleans it before it is blown out into the room again.

ill. 24c: Airocide air purifier

Functional criteria

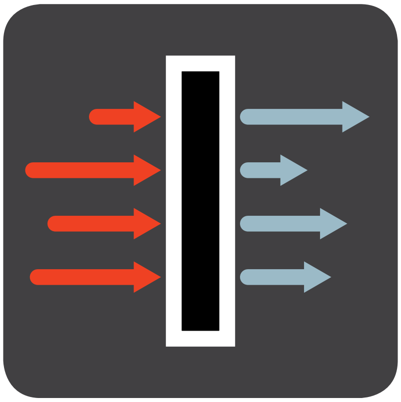
As shown in the "Solution Space", the best solution is something that will break the chain of infection in several places. It should protect the environment from an infectious host and protect susceptible patients from the contaminated environment, while also cleaning the environment.

The exposure time, meaning the time that the patient is in direct contact with an airborne pathogen, is a very important factor to consider, as it relates directly to the risk of getting infected by the pathogen ***(Nielsen).*** As the patients spend the majority of their time in the patient room, this is where they are most likely to get infected. This means that it's critical for the success of the solution that it works optimally inside the patient room. To guide the development process three functional criteria have been defined for the solution. These will be used actively throughout the development process to assess the potential of different concepts.



Contain

The solution should contain the infection to the infectious host. This should be achieved by creating a barrier between the patient and the surrounding area that works in similar way as a conventional air curtain.



Clean

The solution should Clean the surrounding environment. By doing so the risk of airborne infections spreading is reduced. This is the same principle used in air purifiers

Supply

The solution should supply fresh air to the patient. Supplying cleaned air directly to a susceptible patient will greatly reduce the chance of contracting an airborne infection. A personal clean air supply will also help remove unwanted odors.

Output

The solution being designed should be assessed on three key critereias, which is it's ability to Contain, Clean and Supply. Furtermore it's important that it works optimally in a patinet room as this is where the patinet is most at risk of getting a HAI.

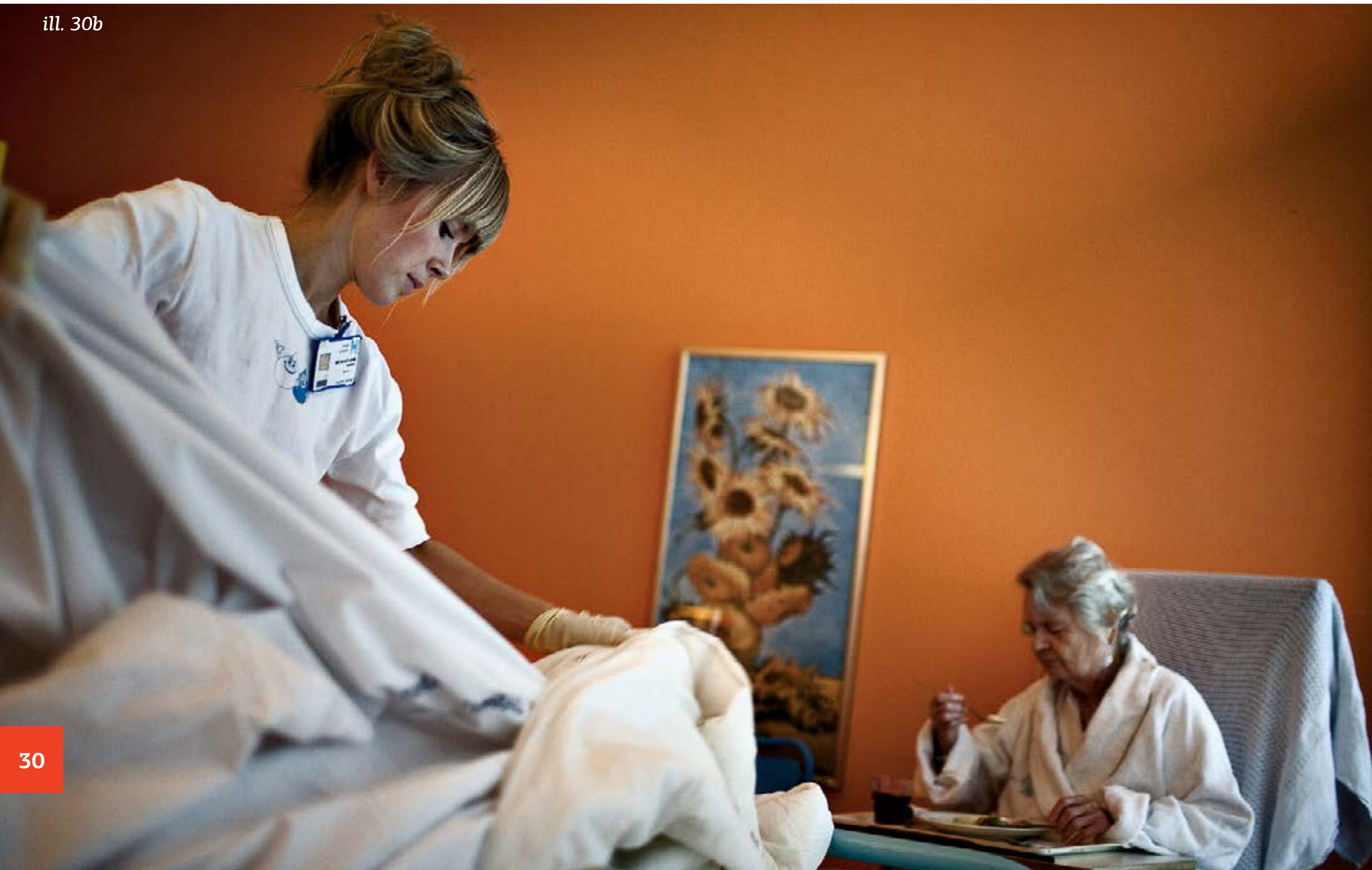
Problem statement

How to use air as an "open" isolation and personal ventilation to reduce HAIs

Analysis

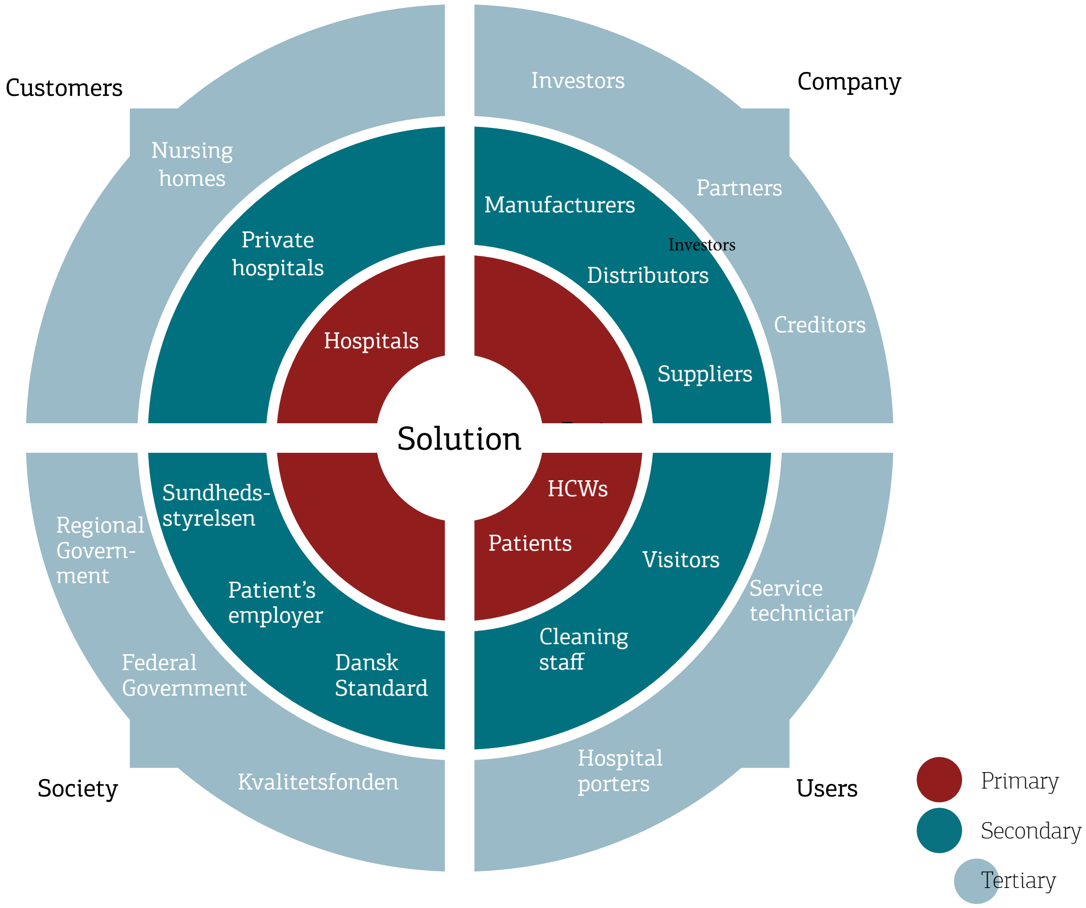
ill. 30a

ill. 30b



Stakeholders

To get a better understanding of the people, institutions and companies that can affect and be affected by the project a stakeholder map has been generated. The stakeholders have been divided into primary, secondary and tertiary according to their perceived importance.



Mapping the stakeholders helped prioritize which stakeholders to focus on. The solution being developed, revolves around its primary users, and its success relies heavily on how well the needs of the users are met. As a result it was decided to focus primarily on the users of the solution and to prioritize patients and HCWs the highest as these are the users that will interact with the solution on a daily basis.

Output

The stakeholder map proved helpful in establishing the priority between the different stakeholders. It was decided to primarily focus on the users. The analysis phase will be used for defining the needs of the users through interviews, observations and analysis of the context.

User insight

To identify the patient's needs, several semi-structured interviews have been carried out. Below is an excerpt of the two most diverse interviews; a young self-reliant woman and a retired engineer.

Julie Navntoft

Urological department, Frederiksberg Hospital

Hospitalized for removal of a kidney stone

25 years old

Student at CBS

Julie has been hospitalized 7 times. Most recently at the Urological Department at Frederiksberg Hospital where she was operated for kidney stones. She was in a two-bed room, but she was the only patient there most of the time. She prefers to be alone when hospitalized.

"When you are feeling sick you just want to have your privacy"

The curtains between each patient provided some privacy, which she appreciated. But she felt it was really uncomfortable that she could hear everything. Especially when the neighbor was really sick or even dying. She wasn't scared herself of getting a HAI because she is young and have a healthy immune system, but as she says:

"It's a bit uncomfortable when the neighboring patient is coughing a lot and seems really ill."

At the Urological Department a lot of the patients have some rather intimate diseases. Due to this she didn't feel comfortable discussing the details of her disease with other patients.

During the night the door to her room was open, resulting in light from the hallway flooding the room. This, combined with the many noises from the hallway and other patients made it very difficult for her to sleep properly.

The nurses recommended that the patients go to the common room to eat so they get a bit of exercise, but she was feeling quite weak from the operation so she preferred staying in bed as well as eating her meals in the bed.

It's very important for her that it looks white and clean.

"I would much rather prefer that the room looks sterile than homely".

The cleaning staff came every morning and mopped the floor and wiped the surfaces clean. The bedding wasn't changed during the 2 nights she was hospitalized, but in general she thought the cleaning staff did a good job.

Torben Mejnertsen

Cardiology department, Hillerød Hospital

Hospitalized for troubled breathing

66 years old

Retired

Torben was hospitalized because he had great trouble breathing and was admitted to the cardiology department because of previous history of heart problems.

He was administered to a night under intensive care. He was then submitted to normal care in the cardiology department where he was placed in the hallway for half a day due to lack of room space. He was later admitted to a two-person room, where he spent two nights and then a four-person room where he spent his final night.

His wife stayed with him during his stay in the intensive care providing much appreciated assistance. Since the weather was great during his stay, the door to the balcony was open most of the time, to allow fresh air to enter the room.

"When you are coughing, you are afraid you might infect other people"

He was checked by a doctor every day during their rounds, as well as his nurses checking in at least 3-4 times a day.

Since Torben was admitted to a cardiology department, a lot of the other patients were connected with electrodes as they were closely monitored by the HCWs. Each patient was assigned to one specific nurse (HCW). This was often frustrating as you could not easily approach the team of nurses but had to wait until your nurse was available.

"There were only one TV for every two beds, so I just read my book"

He describes the bed rooms as noisy due to the other patients, as well as their conditions meant only limited socialization occurred.

"Feeling safe and under professional supervision is the most important thing for me"

Most of his daily activities were centered around his bed, such as eating, medical treatment etc. Also when x-rayed he was transported in his bed to the x-ray department.

"A clean and professional atmosphere is much more important to me than having a homely atmosphere"

Output

A commonality of all the interviews was a feeling of having little control over their own situations, bad air quality, and the perception that the HCWs were not on top of things.

The most important thing for the interviewed patients was being in safe hands and having a clean and proffesional atmosphere.

Context analysis

The design team carried out field research at Bispebjerg Hospital and Rigshospitalet to get a better understanding of the context the solution needs to be designed for. The analysis is based on observations as well as interviews with nurses at both hospitals.

01: Toilet / bathroom: Some rooms have their own bathroom, but in many cases there is a bathroom in the hallway, which is shared between multiple rooms.

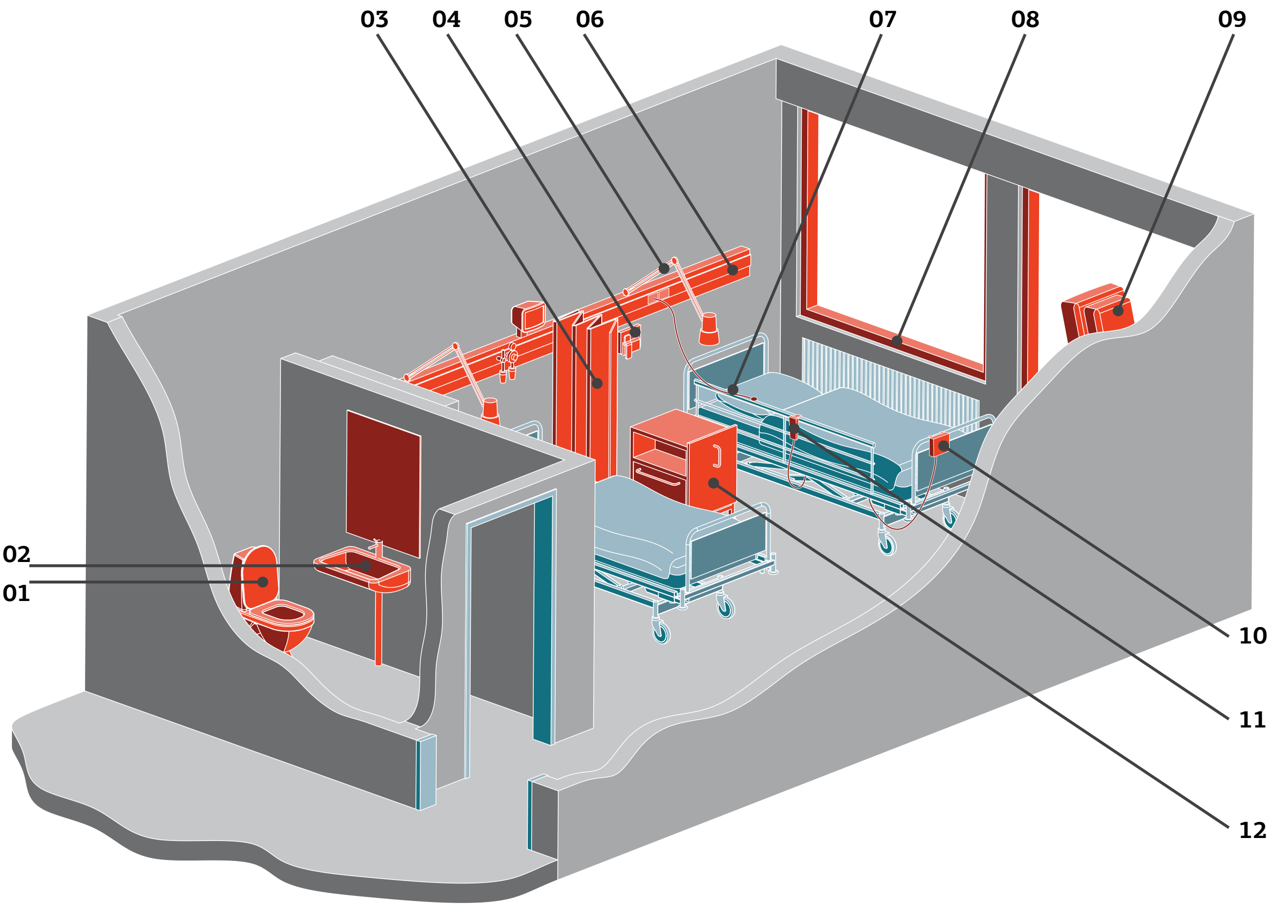
02: Sink: The hospitals are very focused on hand sanitization. There is a sink in every room and alcohol for disinfecting hands, which the HCWs use between each patient.

03: Cubicle curtains: Curtains are used to give each patient some privacy. These can be textile curtains or hard screens. The latter has the advantage of being easily cleaned and they do not collect spores as textile curtains do.

04: Remote / phone: Each patient has a remote control that can be used for operating the TV or contacting the HCWs. When docked it's hanging on the wall, out of reach for the patient, so normally it's lying in the bed beside the patient.

05: Bedside lamp: Each patient has a bedside lamp. It's often mounted on the head panel, which makes it difficult for the patient to reach it.

06: Hospital Bed Head Panel: All rooms have an aluminum panel mounted on the wall behind the beds. These are used for the mounting of power supply, patient alarm, air and medical gas supplies and patient entertainment.



07: Windows: All rooms have windows allowing sunlight to enter the room and making it possible for the patient to look out.

08: Pull cord: At each bed there is a pull cord, which enables the patient to call for HCWs if they need help. When the cord is pulled it makes a noise which can be heard in the hallway.

09: TV: There is a TV for each patient. The TV is controlled via a remote /phone. The TV's are on mute and so the patient has to use headphones connected to the remote.

10: Attendant control: An additional controller, which is only for the HCW, hangs on the footboard. Besides the regular adjustments it also includes Trendelenburg tilt (Feet up and head down) as well as the ability to lock functions on the patient handset.

11: Hand control: The hand control for adjusting height of the bed as well as angles of backrest, leg- and thigh sections, can be used both by the HCWs and the patients. The handset normally hangs on the side rail.

12: Trolley: Each bed comes with a small trolley where the patient can keep his/her belongings. The trolley is equipped with a fold out table, which can be used when the patient is in bed.

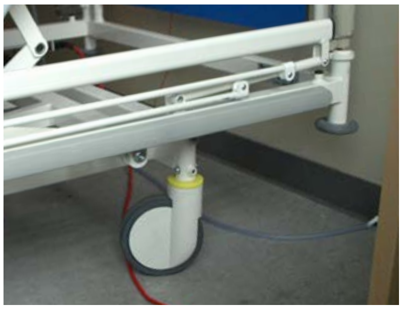
Department of Endocrinology Gastroenterology

Bispebjerg Hospital

20 beds

Single, double and quadruple rooms

Diabetes patients and patients with disorders of the stomach, intestine, pancreas or liver.



Single rooms:

Single rooms are used for patients that require extra attention, who are delusional or dying. Furthermore, the single rooms are used to isolate patients that have an infectious disease. Anyone entering the isolation room is required to wear personal protective equipment such as mask, gloves and gown.

Double Rooms

These are the most common rooms and are used for all kinds of patients. The rooms are divided by gender, but not by age or level of sickness. Cubicle curtains are used when the HCWs examines the patient to provide some privacy.

Cleaning

Every morning the floors are mopped and surfaces are wiped with a cloth. The beds are only cleaned between patients or if they are visually dirty. There are many devices in the rooms and cables on the floor thus making it difficult for the cleaning staff to clean properly.

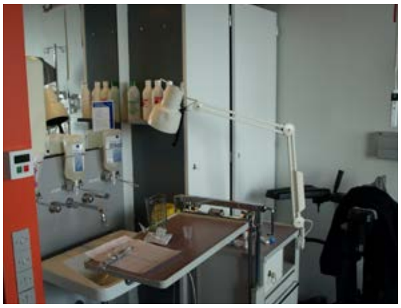
Department of Nephrology

Rigshospitalet

24 beds

Single and Double rooms

Patients with acute and chronic kidney diseases and kidney failure. Performs all aspects of dialysis.



Hand sanitization

Hand sanitization is a key priority. Posters on the wall reminds HCWs and visitors to clean their hands properly. HCWs routinely use alcohol based hand sanitizers between each patient to properly disinfect their hands. Hand sanitizers as well as gloves are hanging on the walls in every room.

Working environment

The rooms are small resulting in minimal space for the HCWs to work. This is especially an issue in the toilets where lack of space often makes it impossible to use a wheelchair thus forcing the HCWs to manually handle the patients. Doors and hallways are narrow and maneuvering the hospital beds is difficult.

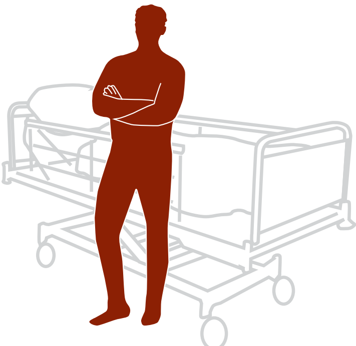
Equipment

Various different monitoring equipment and drainage bags are hung on the side of the bed, on the side rail or mounted on the footboard. Besides taking up space and occasionally being in the way for HCWs and patients they also make the patient look more sick.

Patient categorization

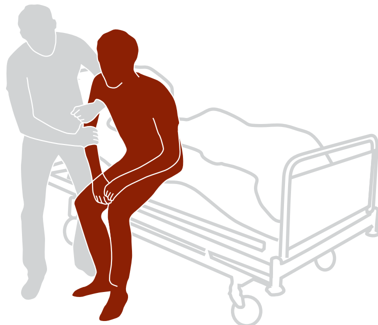
Patients' needs and demands vary greatly and designing a solution that fits all patients is simply impossible. It is important to be able to roughly divide patients into categories to define which category the solution should be designed for.

There is currently no standardized categorization of patients. The following categories are based on an interview with Hanne Schmidt from the Department of Nephrology at Sydvestjysk Sygehus in Esbjerg. This department is currently involved in a project that aims at defining a Danish Standard for the level of dependency of the patient. Four categories are actively used at the Department of Nephrology. These categories help the HCW assess each patient's needs and provide help accordingly.



1: Self-reliant - Patients that can take care of themselves

They can walk by themselves, but might need help washing their back when taking a shower e.g., They eat all their meals in the common area and only spend time in bed when watching TV or sleeping.



2: Semi-dependent - Patients that need a helping hand

They often needs a bit of support when going to the toilet or shower. They are only in bed during their midday nap and in the night.

3: Dependent - Patients that need help for most things

Spends up to 75% of their time in bed. Some are transferred to a shower chair and showered in the bathroom, while others get washed in bed. They often take their meal in bed or on the side of the bed. Meals are served by HCWs.

4: Highly dependent - Patients that need help with everything

Spends more than 80% of their time in bed. They also often get washed in bed because they are two difficult to move to the shower. Many are highly immunocompromised, meaning that they are more susceptible to infectious diseases.

A day in the life of a highly-dependent patient

07.00 Waking up
Nurse wakes up patient and helps with brushing teeth.

07.15 Getting weighed
Ceiling hoist or chair with integrated scale is used.

07.30 Heart rate and blood pressure is checked
This is done routinely by the nurses every day.

08.00 Eating breakfast
The patient sits up in the bed or on the side of the bed while eating.

08.15 Shower
The patient is washed in bed or transfered to a shower chair and helped to the bathroom for a shower

08.30 Toilet
Some patients use the toilet, others sit in a shower chair with a tray. Some are given laxative to stimulate peristaltic actions.

10.00 Treatment
The patient is transported in his/her own bed to x-ray or dialysis department.

11.00 Training
A physiotherapist comes to help patient to do exercises in own bed. If patient is able to he/she is taken out of bed and a walker is used.

12.00 Lunch
The patient eats in bed.

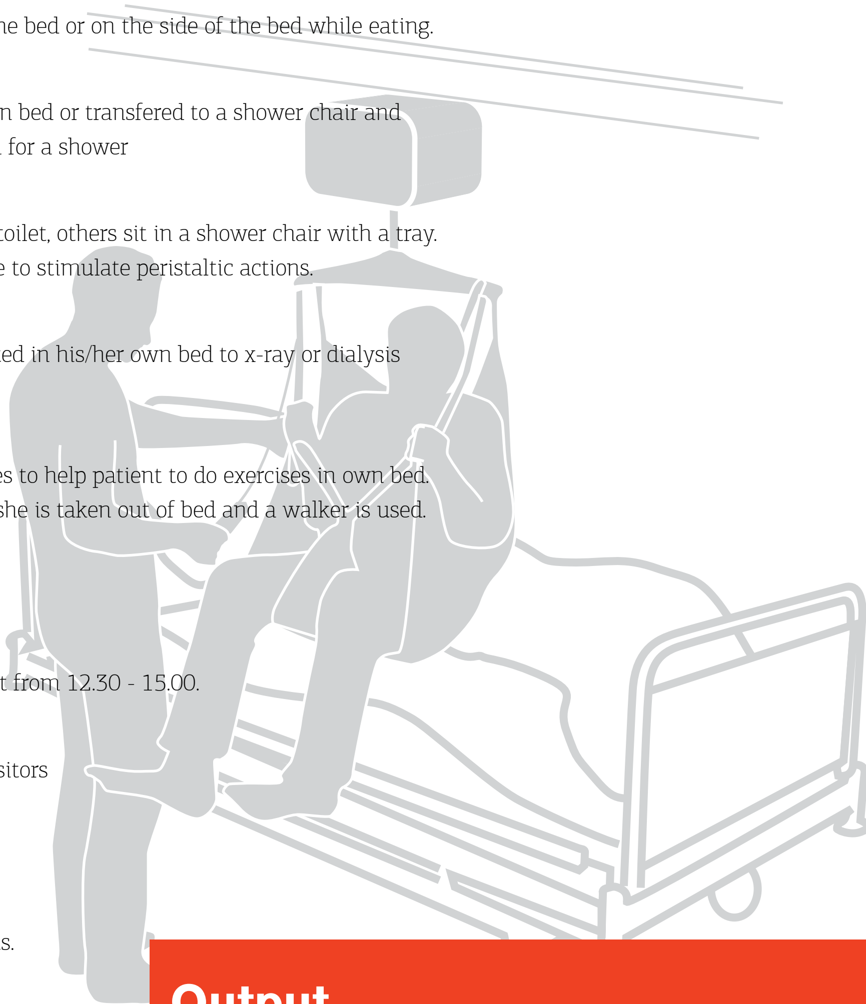
12.30 Midday nap
The whole ward is quiet from 12.30 - 15.00.

15.00 Visitors
The ward is open for visitors

17.30 Dinner
The patient eats in bed.

20.00 Hygienic check
Washing of private parts.

20.30 Go to sleep
Patients are often given sleeping pills to improve sleep.

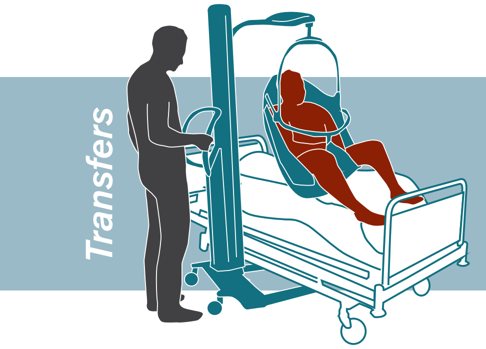


Output

This project will focus on patient group 3 and 4. These patients are often immunocompromised, which makes them particularly vulnerable to opportunistic infections.

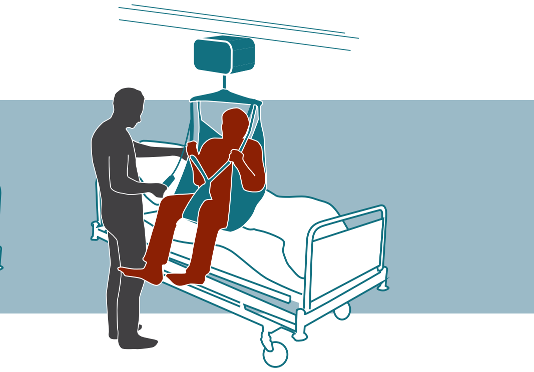
Patient scenarios

While visiting the Nephrological department at Rigshospitalet a series of scenarios was carried out together with Mette Marie Morsing, who is a nurse at the hospital. Mette was asked to go through all the steps of handling a patient that the HCWs perform every day as well as any infrequent activities such as CPR. A member of the design team played the role of a patient in order to better feel and understand what it is like to be a patient.

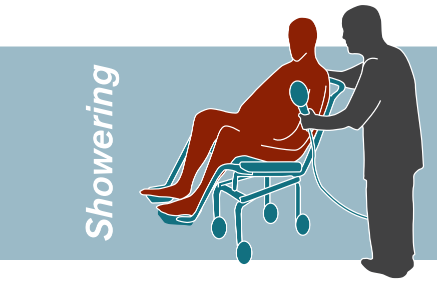


Personal hoists are often used for transferring highly dependent patients

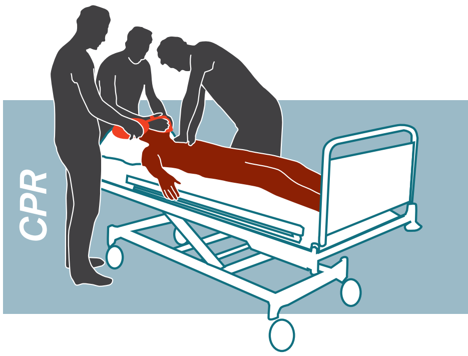
Assistive aids such as transferring discs are used when the patient has a low level of mobility.



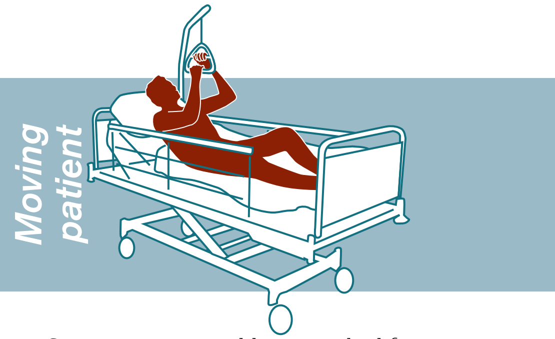
For highly dependent patients ceiling hoists are used for both transferring and for weighing the patient



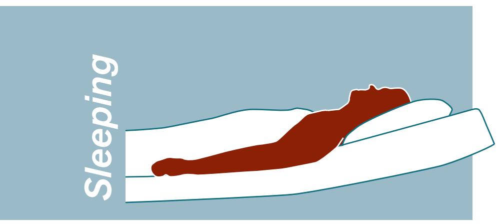
Patients who cannot stand upright by themselves are often seated in a shower chair while a HCW washes them.



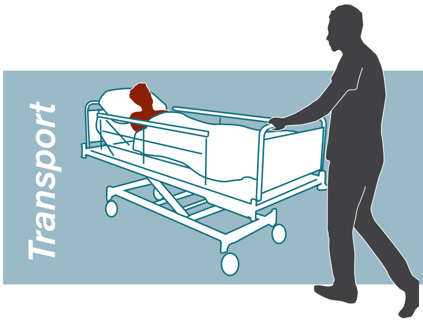
If the patient needs CPR the HCWs quickly fold down the side rails and remove the head board to get access.



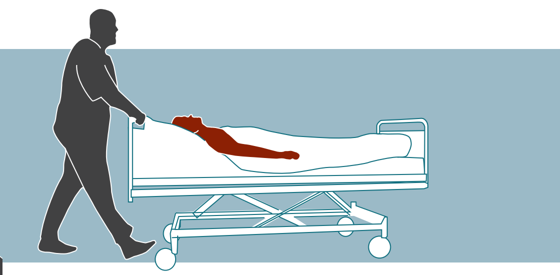
Some patients are able to use the lifting pole to move themselves around in the bed if needed.



Many patients have a midday nap



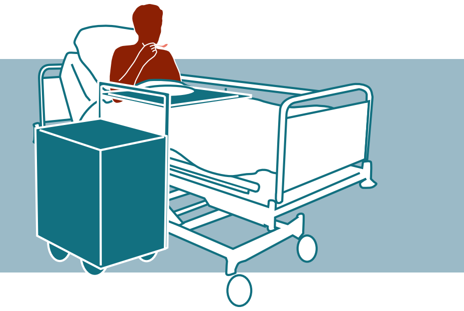
The patients are transported between departments in their own bed with the side rails up.



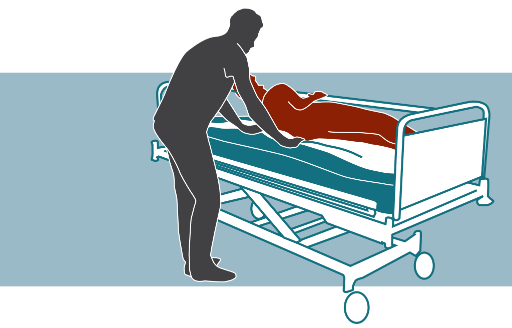
Sometimes transfer systems are used for transporting beds.

Patients that are more self-reliant are only given a bit of support when getting in and out of bed.

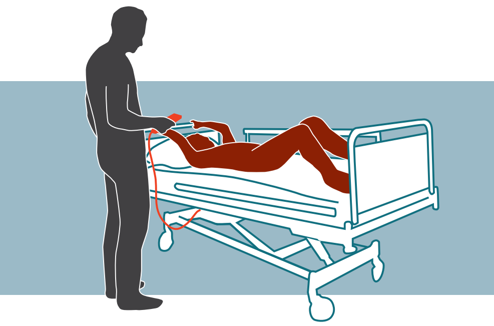
Many patients sit at the side of the bed and use the trolley when eating all their meals.



Patients who can't sit upright themselves sit in the bed with the backrest up while eating.

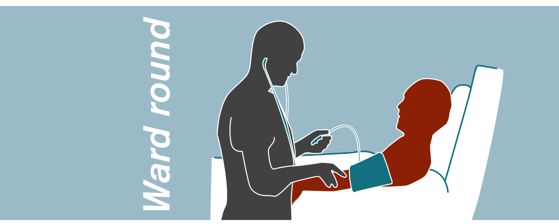


When changing the bedding the patient is rolled over to the side and asked to grab the side rail.

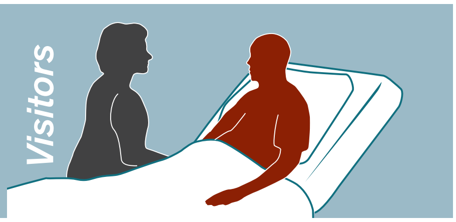


Patients tend to move down to the foot end. If they are able to, the HCWs ask them to pull themselves up

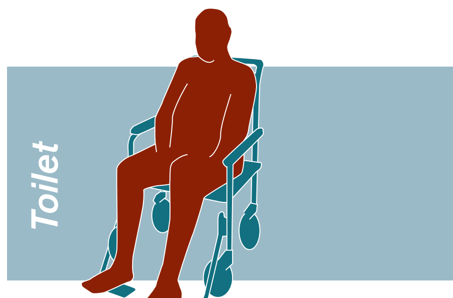
If the patient doesn't have sufficient mobility, two HCWs will manually pull the patient up to the head end.



Heart rate and blood pressure is checked routinely while the patient is in bed



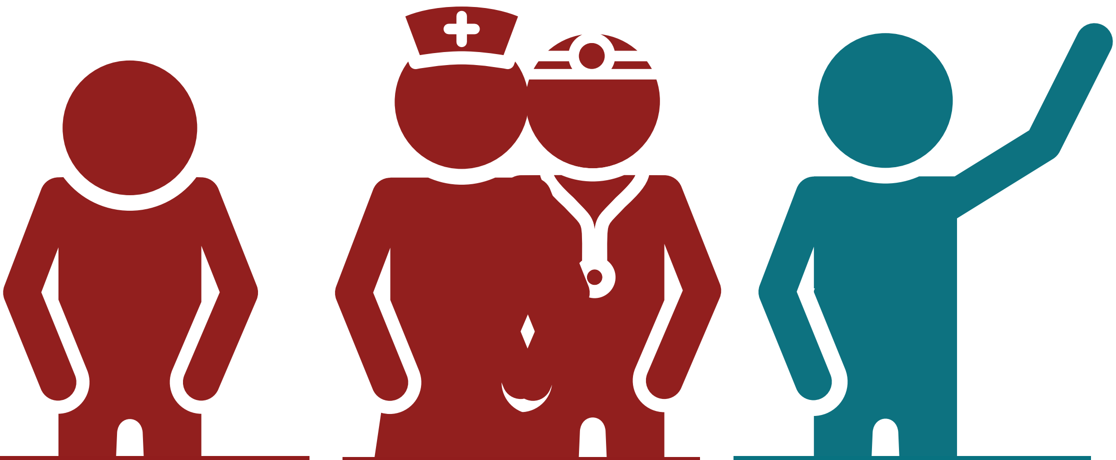
Visitors often sit on the side of the bed or in a chair next to the bed.



Some patients use a shower chair with a tray as a toilet.

User needs

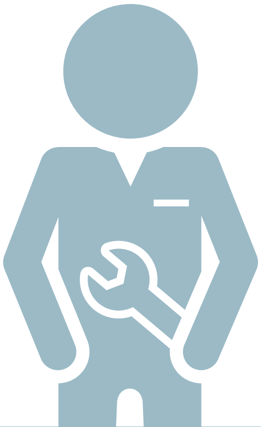
The table below sums up the needs for all the primary, secondary and tertiary users defined in the stakeholder analysis, in relation to the solution being developed The needs have been identified throughout the analysis phase via interviews, observations, scenario play and workshops. The main focus has been on the primary users and several interviews of both patients and HCWs has been conducted. Furthermore, one porter and one cleaning lady have been interviewed.



	Patient	HCW	Visitors
Needs	• Feeling safe	• Good air quality	• Good access to patient
	• Good air quality	• Intuitive interaction	• Visually appealing
	• Lying comfortably	• Fast and easy to operate	• Intuitive interaction
	• Being as self reliant as possible	• Good ergonomics	• Feeling safe when visiting patient
	• Low noise level	• Reduction of smells	• Assurance that patient is safe
	• Feeling of control	• Good access to patient	
	• Reduction of smells	• Good workflow	
	• Comfortable temperature	• Easy handling of patient	
	• Cleanliness		
	• Good light quality		
	• Privacy		
	• Social interaction		
	• Entertainment		

Cleaning staff

- Large smooth surfaces that are easy to clean
- Visual inspection of level of cleanliness.



Service Technician

- Good access to service parts
- Indication of when service is necessary

Porter

- Compact
- Easy to maneuveur
- Good ergonomy

Primary

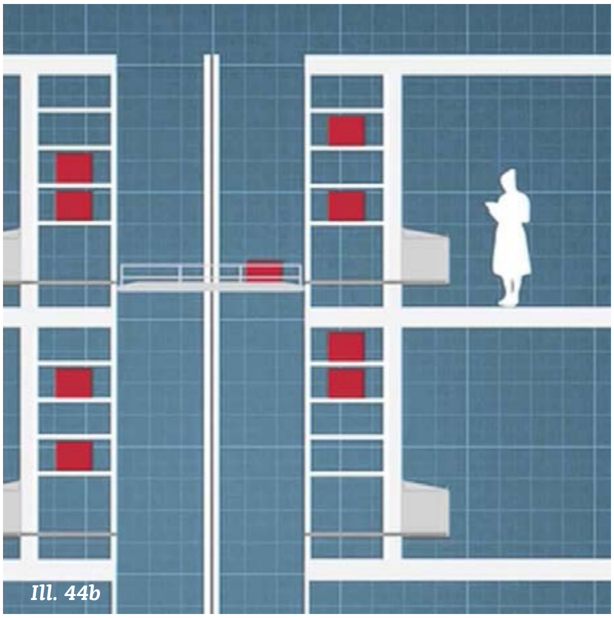
Secondary

Tertiary

Trends

It is important to know the current trends in the heath-care industry so it is possible to evaluate which solutions will be most advantageous as well as guiding the project to conform to the future values of the health-care industry.

Ill. 44a



Ill. 44b

Less hospitalization

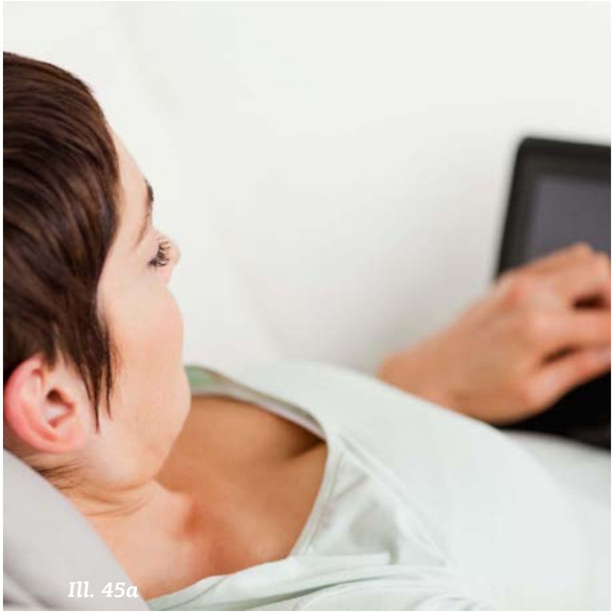
There is a consensus that hospitalizations should only occur when absolutely necessary. This is not only a way to combat the increasing cost of health-care, but also because most modern surgeries require less invasive procedures than previously. Another reason is also that patients are more comfortable recovering in familiar settings, which will usually also lead to a faster recovery.

Technologies are already being tested to aid and monitor the recovery of patients in their own homes. This is commonly know as tele-medicine and is predicted to free up much needed bed space in hospitals.

The consequences of this is that the patients that are hospitalized will require more care than previously. This could also lead to an artificial increase in HAIs as there are less "healthy" patients.

Flexible hospitals

The majority of our current hospitals are logistically very old fashioned and require a lot of manual labor. Whenever new equipment is needed, that the department doesn't have space for in their small local storage room, they have to manually retrieve it from the central storage. As a way to reduce the amount of man-hours spent on logistics, an Intelligent Hospital Logistics (IHL) system is being tested at Hvidovre Hospital. The system works by having a central robotic storage room, that can send boxes of goods and equipment directly to the different department ***(Intelligent Systems, 2013)***.



Ill. 45a

Ill. 45b

Smarter equipment

A tendency among hospital equipment manufacturers is to make the equipment smarter. Hospital equipment should communicate with each other and aim to make the HCW's job as easy as possible.

A good example is the Danish company Linak that creates linear actuators for hospital beds and their control units. Their new control unit, OpenBus, is no longer a simple button based interface to do predefined operations. Now it is possible to add or remove features from their systems or interface third party products. This makes hospital beds that use OpenBus much more flexible and can be used in a wider scope as it can cover more patients ***(Linak, 2014)***.

Focus on comfort

A factor that has always been important is the comfort and mental health of the patients. Hospitals have always strived to make hospitalizations as pleasant as possible, however recently hospital equipment manufacturers have included patient comfort and satisfaction as a point of sale.

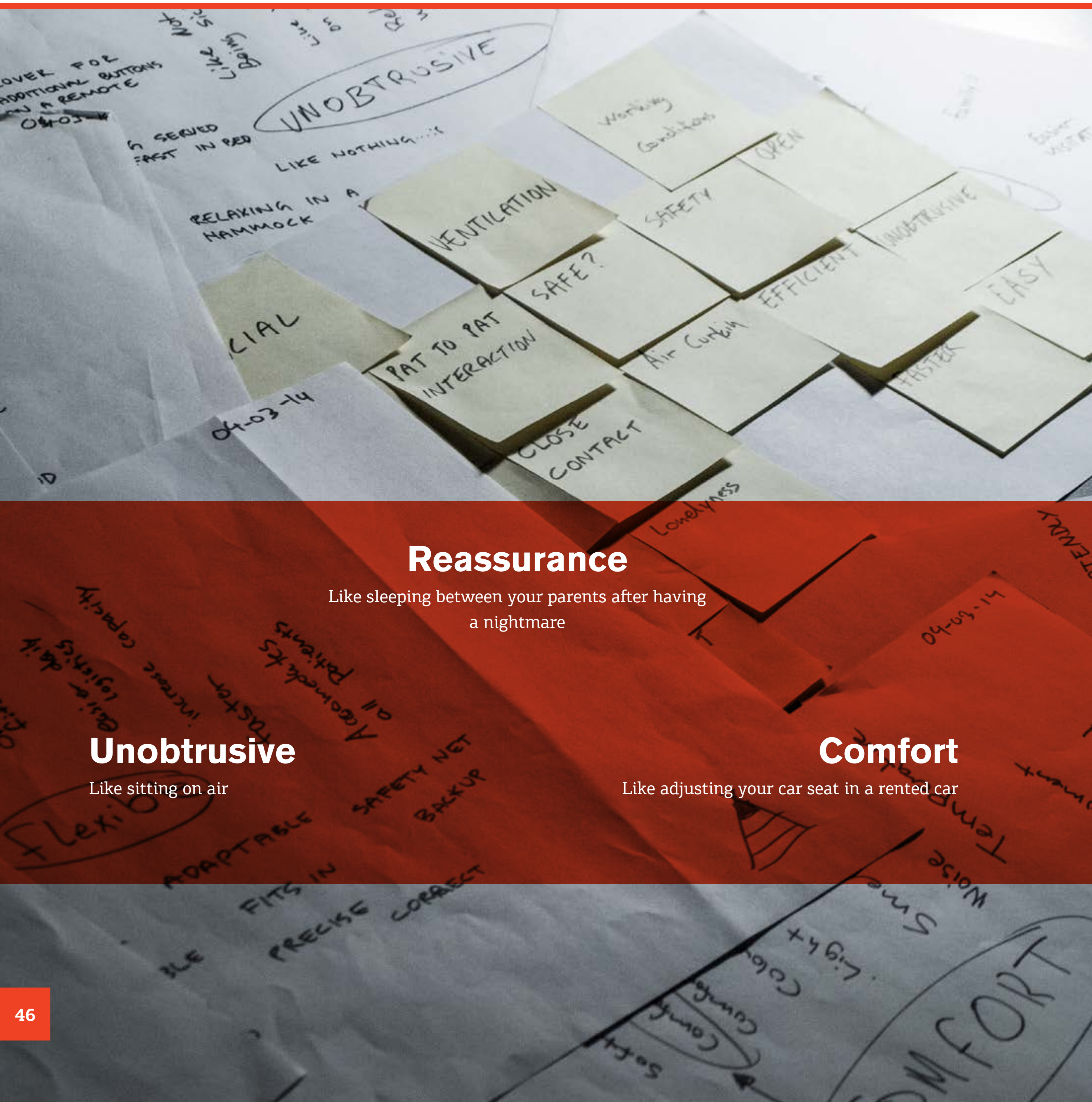
Output

The future of the health-care sector is uncertain, but tendencies like fewer but more serious hospitalizations and more walk-in patients seem quite clear.

It is also important that a future solution fits into the hospital environments' well run automated logistics. It should offer management a great level of flexibility by using the same solution in many different situations while also focusing on the comfort of the patients.

Value mission

Based on interviews with patients and observations of both the context and current trends, a value mission for the solution has been defined through a series of associative mind maps and metaphors. This value mission should work as an abstract guiding star through out the concept and detailing phase. It provides the team members with a common understanding of the qualities the solution should exude.



Reassurance

Like sleeping between your parents after having a nightmare

Unobtrusive

Like sitting on air

Comfort

Like adjusting your car seat in a rented car

Interaction vision

Using the principles from Tangible Interaction it has been defined how the user should interact with the solution and how the user can read the solution to ensure it is used properly.

Feedforward

Feedforward describes the way the user reads the solution before they interact with it. It is a very important factor to ensure both confidence and correct operation of the solution. It can be divided into three sub-categories: functional, inherent and augmented.

Functional feedforward

The functional feedforward relates to the user's mental model of the solution and how they understand it's functions. It should be clear to both patients and the HCWs what the main function of the solution is and how it should work.

Inherent feedforward

Inherent feedforward informs the users of what is possible to manipulate and what type of interaction is required to do so. This could present a challenge because some features might need to be hidden or unavailable for the patient as they are only intended for the HCW, while others might need to be accessible for all users.

However it should be clearly understood by all users which objects they are "allowed" to manipulate in order to achieve the wanted function.

Augmented feedforward

Augmented feedforward is the information that is added on top of the readable geometric information. This means graphical overlays or computer screens embedded to aid the interaction with the solution.

It is very important that such information is easily understood and navigable for all users. The patients might be confused and disorientated but should still be able to manipulate the most basic functionality of the solution. The HCW might be stressed and has to deal with many similar solutions, so it should be fast and fool-proof for the HCW to manipulate the features.

Feedback

Feedback is the solutions reaction to the users manipulation. Feedback can also be divided into three sub-categories.

Functional feedback

The functional feedback of the solution is very important, as the functional reaction should correlate with the intent of the users. This means that if a user manipulates the solution it should behave as the user would expect it to do.

Inherent feedback

Inherent feedback signals if an action has been performed correctly. This could be a subtle sound when the solution is manipulated correctly, which is especially important if the result of the action is not visible as might easily be the case when working with air.

Augmented feedback

Augmented feedback can be used to help enforce the functional feedback. Since it can be hard to detect the details of airflows, using augmented feedback, such as a screen or LED's might be a efficient way to ensure confidence in the user's actions.

Criteria

The following list sums up the criteria defined for the solution being developed. The criteria are based on the analysis of the users as well as the Value Mission and Interaction Vision. These criteria will be taken into account when developing concepts and actively used for assessing and comparing different concepts.

The solution should..

Qualitative	***Quantitative***
Be unobtrusive	Provide patient with clean air
Make the patient feel safe	Improve the overall air quality of the room
Be intuitive to operate for both patients and HCW	Effectively isolate the patient
Be visually appealing	Be comfortable for the patient
Not make the patient seem more ill	Be simple to install and service
Allow for social activity	Be easy to clean
Provide patient with privacy when needed	Accommodate all types of patients

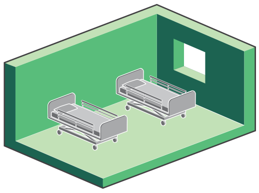
Concept Development

The following section will describe the process of expanding and developing the solution to a concrete and refined concept. It takes a starting point in exploring different scales of implementation, and then based on that choice, further investigations are conducted to create a better platform to develop and refine the concept.

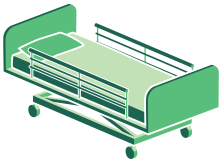
Implementation

To determine what type of solution an “open” isolation should be, brainstorms were conducted on different implementation scales as well as whether it should be a flexible solution or a permanently fixed solution.

The outcome of the brainstorm was then evaluated.



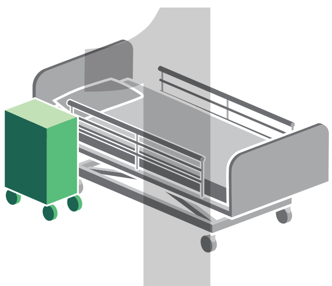
ROOM



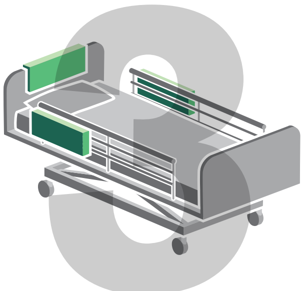
BED

PATIENT

FLEXIBLE



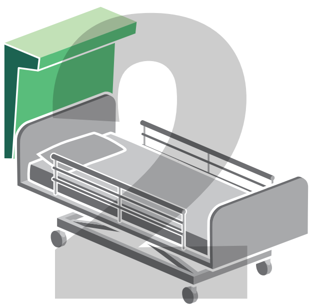
A mobile solution that can be placed in each room, much like today’s trolleys, is a great flexible solution. It will however take up a lot of space in a cramped working environment.



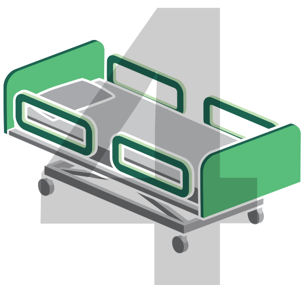
A solution that can easily be mounted on existing beds will offer great flexibility at an affordable initial investment. However, it can easily be a great nuisance for the HCW,.

Designing a wearable solution that the patients will wear all the time is a great way to ensure the patients are protected all the time. However there are some concerns regarding both component size, battery life and the comfort when wearing it 24 hours a day.

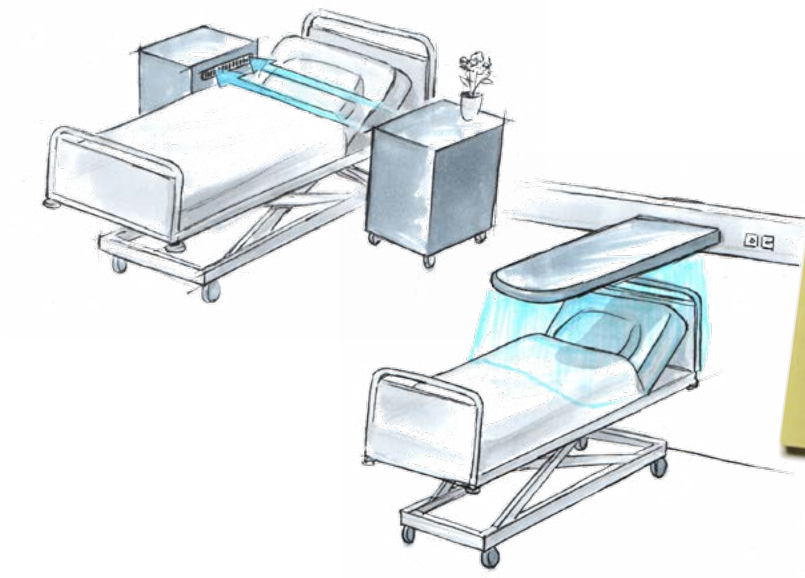
FIXED



Integrating the solution into the room permanently will allow the solution to be well integrated into the context. However it will be a larger investment for the hospitals and be less flexible.



Designing a new bed with integrated ventilation, is a great way to thoroughly implement the new features, but it will also require a large initial investment, and will not offer a lot of flexibility



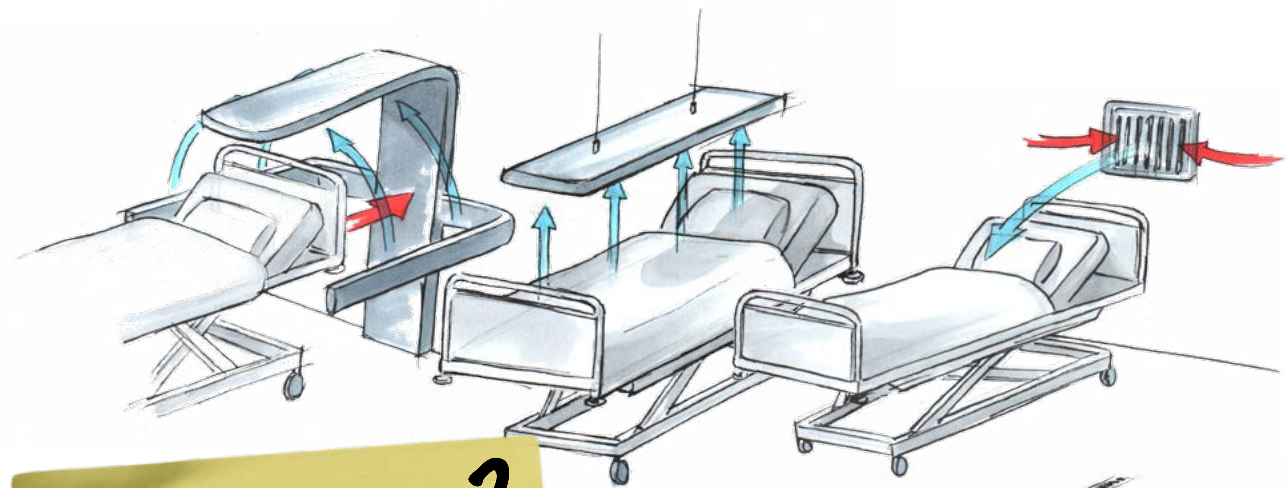
1

Pros

Always connected to power
Fits everything
Install when needed
Less restricted with components size

Cons

Clutter
Not active during transport
Difficult to fit aesthetically to different beds
Works only when patient is in bed
Difficult to fit to different beds



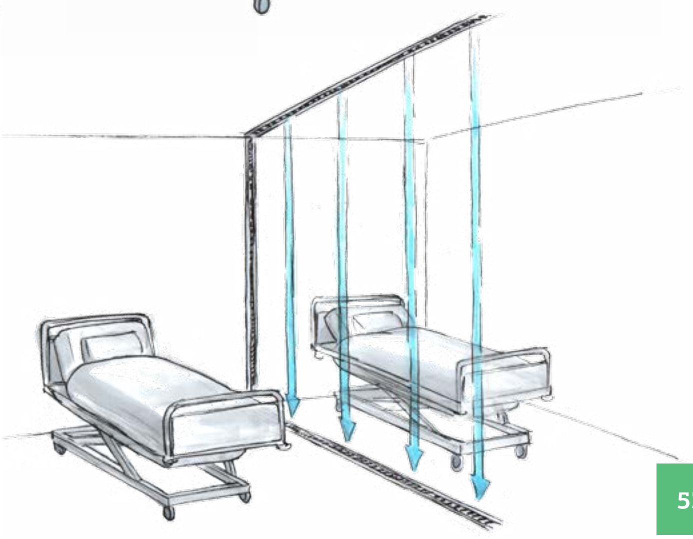
2

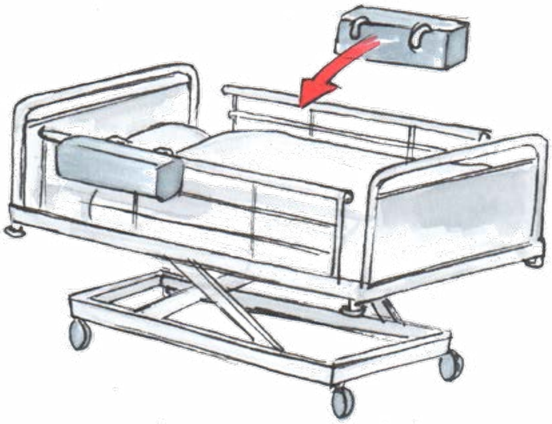
Pros

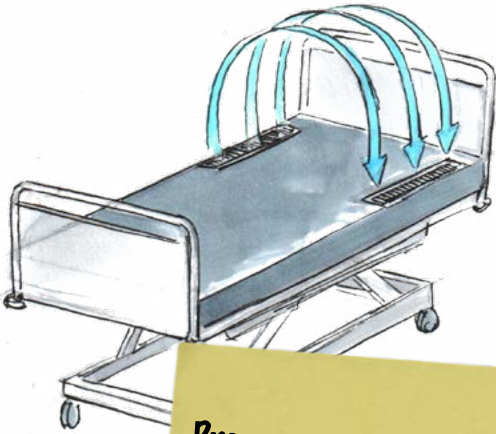
Possible to hide in the wall
Well integrated into the room
Less restricted with component sizes

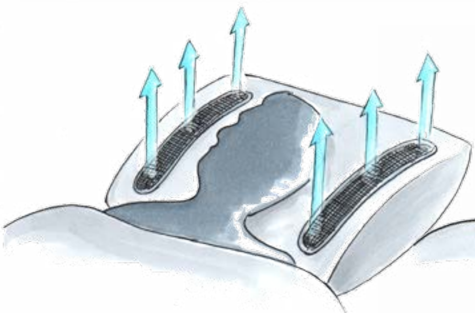
Cons

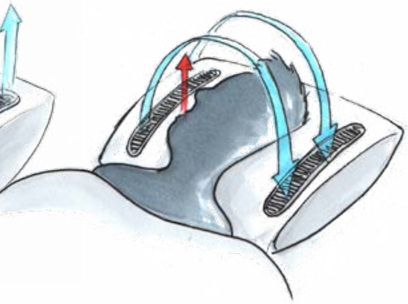
Requires mounting
Not active during transport
Precise placement of bed required
Works only when patient is in bed
Difficult to fit aesthetically to different beds











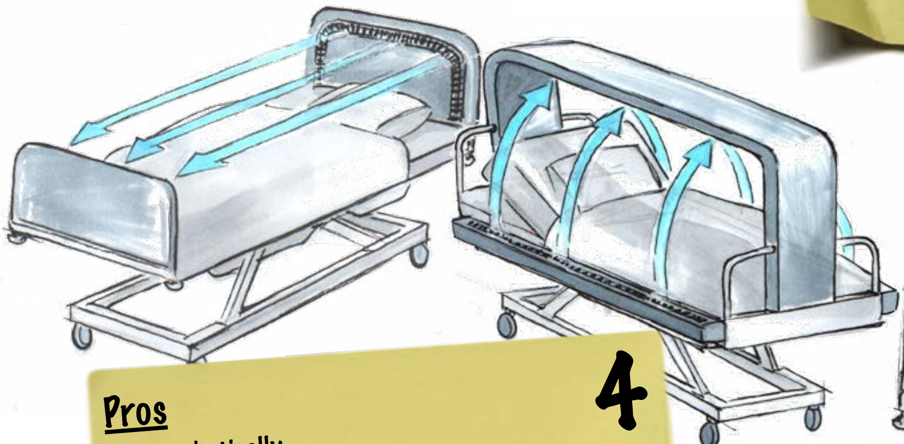
3

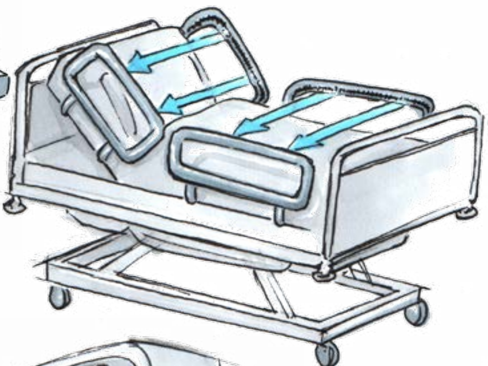
Pros

Fits to existing beds
Install when needed
Cheap for hospitals to buy

Cons

Requires more models to fit all/most beds
Not so well integrated
Difficult to fit aesthetically to different beds
Works only in bed





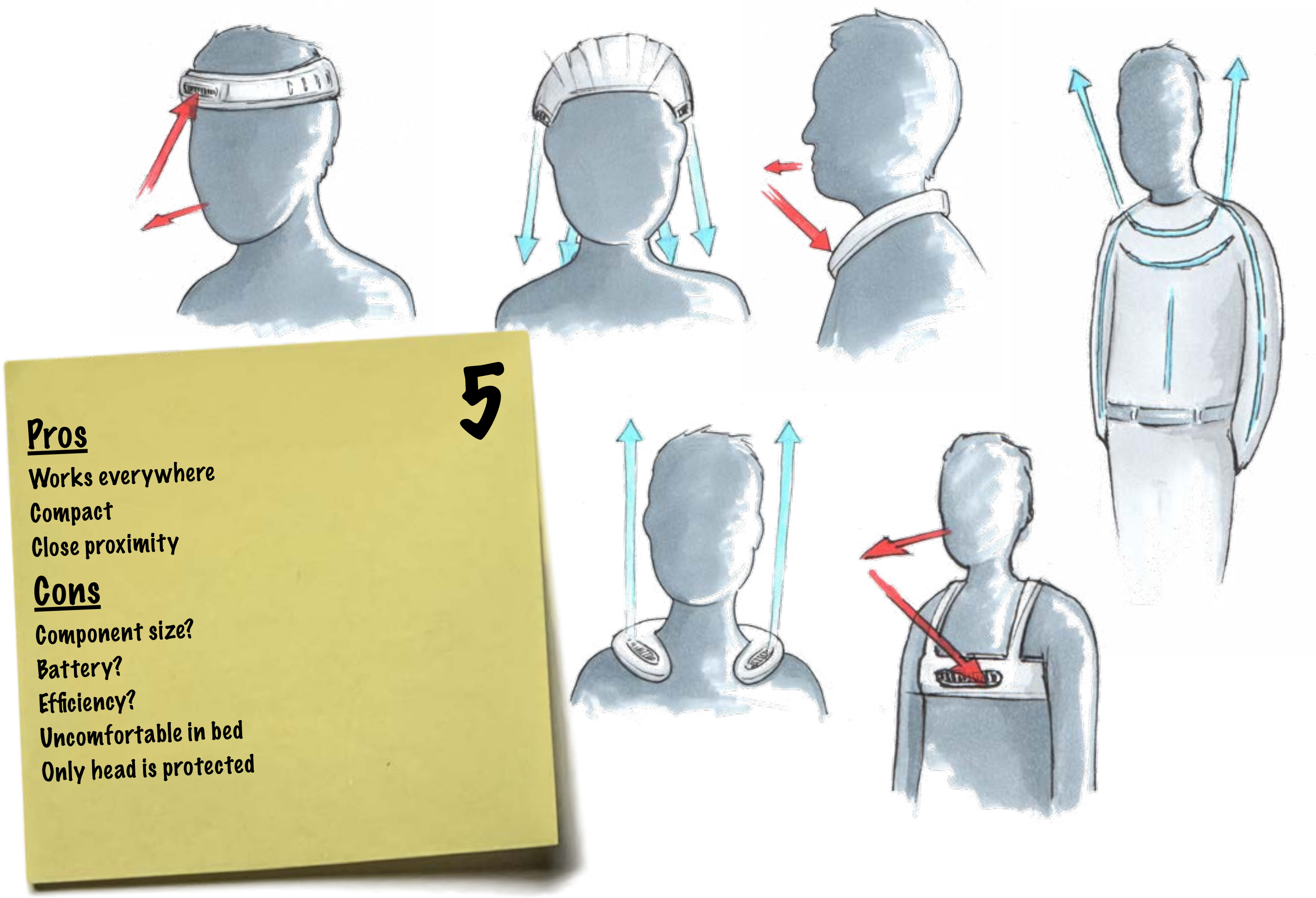
4

Pros

Fits aesthetically
Combines features
Well integrated
Uses battery / power from bed
Combined and simplified controls

Cons

Expensive acquisition
All or nothing (Not flexible)
Hospital has to buy new beds
Has to fit to bed manufacturer's brand
Whole bed has to go to service if system doesn't work
Only works in bed



Output

Of the 5 different implementation concepts, a mixture of number 3 and 4 was chosen. Implementation 3 is really great in its ability to provide flexibility to the staff, as they can now add or remove modules to the bed according to their need. It will also mean that the required initial investment will be smaller compared to implementation 1, 2 and 4. However implementation 3 greatly lacks the opportunity to properly integrate both the functions and the interaction into the existing beds. Implementation of concept 4 is great in the way that the feature can be directly integrated into a new bed, however this means that hospitals will have to invest a lot money in an unproven concept.

The best solution will be to create a new modular bed platform as flexibility is an important factor for modern hospitals as shown in “Trends” on page 44.

Invacare A/S

When deciding to develop a new modular bed the design team investigated what types of beds that are currently available on the market (See"Appendix J" on page 141). Based on this it was decided to focus on ward beds as this type of bed is the most commonly used in Danish hospitals. After researching the Danish market for hospital beds, a meeting with Product manager Ninna Lund from Invacare was arranged.

The company

Invacare Danmark is part of the Invacare Corporation, which is a global leader in home and long-term care medical equipment industries. The corporation is present in more than 80 countries worldwide and have more than 6.000 employees ***(Invacare, 2014).*** The Danish sales subsidiary used to be called Scandinavian Mobility, before it was taken over by Invacare in 1999. Invacare Danmark is the only part of the corporation that sells hospital beds.

Invacare is by far the biggest manufacturer of hospital beds in Denmark. According to Ninna Lund, more than 80% of the hospital beds used in Danish hospitals are from Invacare. The product range consists of 8 different beds, where only Scanbed 900, Scanbed 910 and Staccata are suitable for hospitals.

The bed

It was decided that the new modular bed being developed should bee an upgrade of the popular Scanbed 910, which is currently responsible for the majority of Invacare's sales. The bed is very popular but hasn't been updated for many years. It has all the basic functions needed for a hospital bed and has proven very reliable over the years, but according to Invacare it is slowly getting outdated. The design team sees a great potential in reusing the elements that works well from the Scanbed 910 and updating the rest of the bed so it is ready by year 2020, where the new hospitals currently being build are due to be finished. ***(danishhospitalconstruction, 2014).***

Part of the reason for choosing the Scanbed 910 was that most hospitals are currently using this bed, which made it possible to study how the bed was being used in it's actual context and get input from several user of the bed. Furthermore, it was possible to borrow a Scanbed 910 from Rigshospitalet.

01 Footboard: The porter uses the frame as a handle when transporting the patient. A name tag is often placed on the panel

02 Side rails: These prevent the patient from falling out or trying to get out by themselves. Some cover the full length of the bed, while others are divided into two units that can be folded down separately. They can be both molded plastic parts or steel tubes.

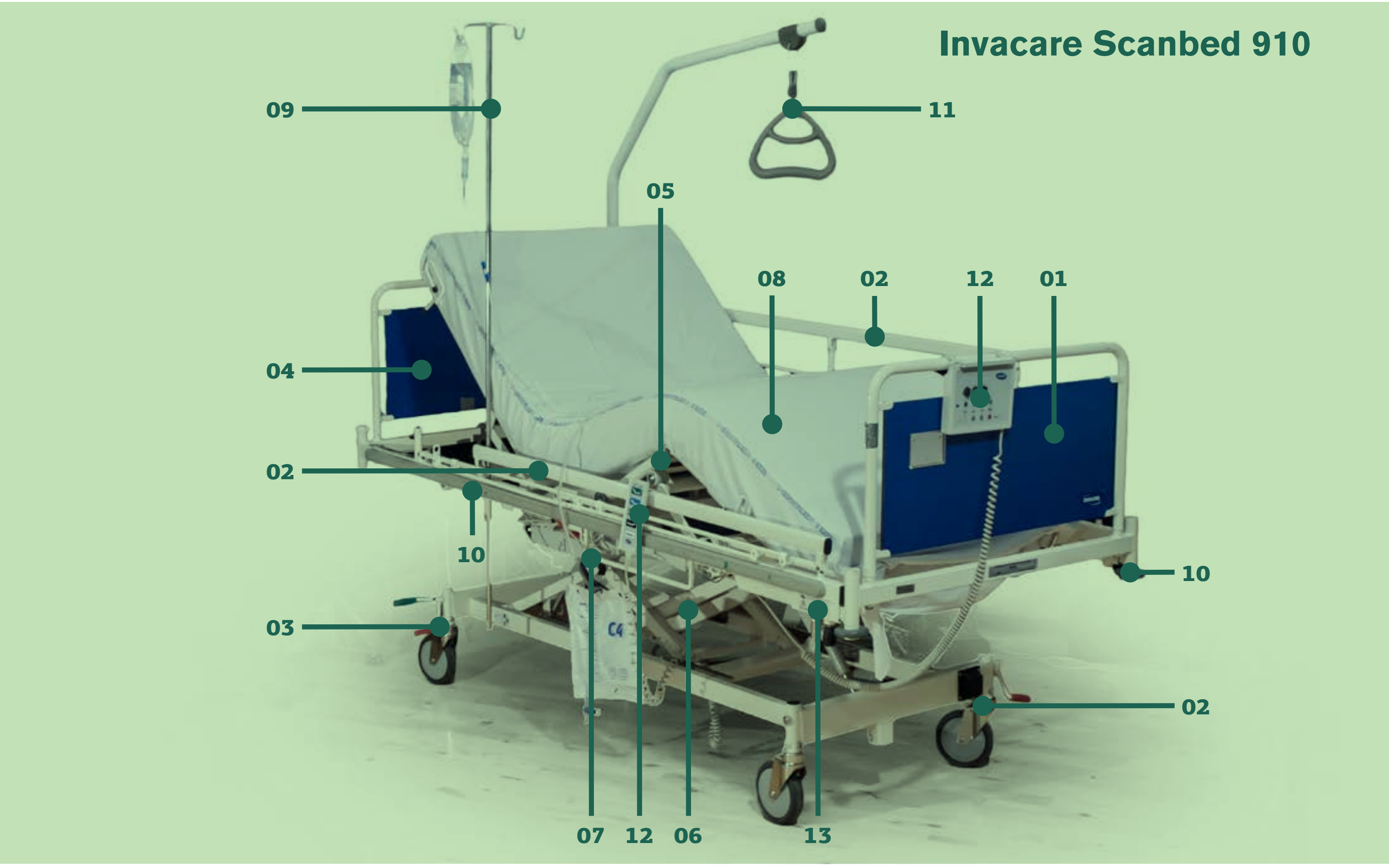
03 Casters with foot pedal: By pressing the pedal the staff can switch between locked, free to move and straight forward movement.

04 Headboard: The headboard is used when moving the bed. Furthermore, the patients can use the frame as a handle to reposition themselves. The headboard needs to be removable when performing CPR

05 Mattress platform The most common platform consists of four sections where one is fixed and the others are adjustable.

06 Lifting mechanism: Most hospital beds are height adjustable and able to tilt. Some beds are hydraulic, some electric and some manual

07 Drainage rail: It is important that the patient's drainage, such as urine and fecal, has a firm mounting position.



08 Mattress: These come in different sizes and with various different specifications. E.g. an air mattress is used for patients that are at risk of getting pressure ulcers (bedsores).

09 IV pole: The IV pole is often removable but can also be fixed. They are often placed beside the headboard, but many beds have additional options for placing the poles.

10 Bumpers There is a bumper in each corner of the bed and some have a bumper along the side. If the bed accidentally hits an obstacle during transport the impact is softened.

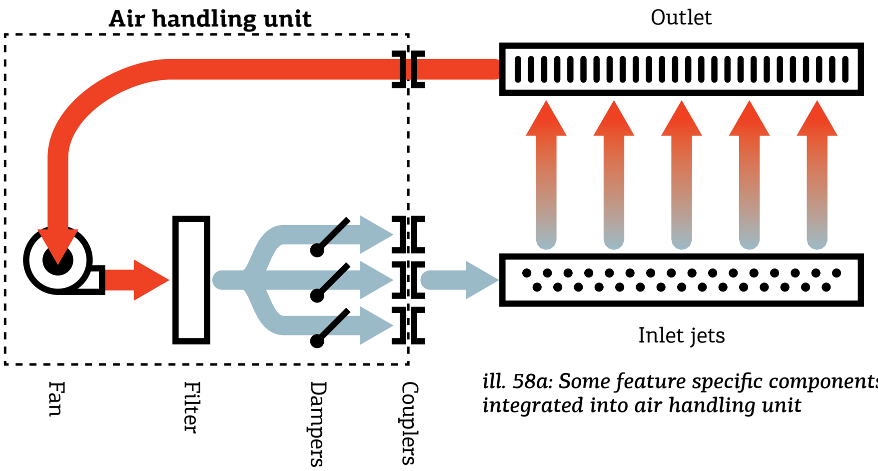
11 Lifting pole: Lifting poles are extra equipment that can be fitted onto the bed. They are used by the patient to move around in the bed. They are commonly placed beside the headboard.

12 Controllers: Hospital beds have two controls for adjusting the bed's position. One for the patient, and one for the HCW which can have extra features such as Trendelenburg and feature locks.

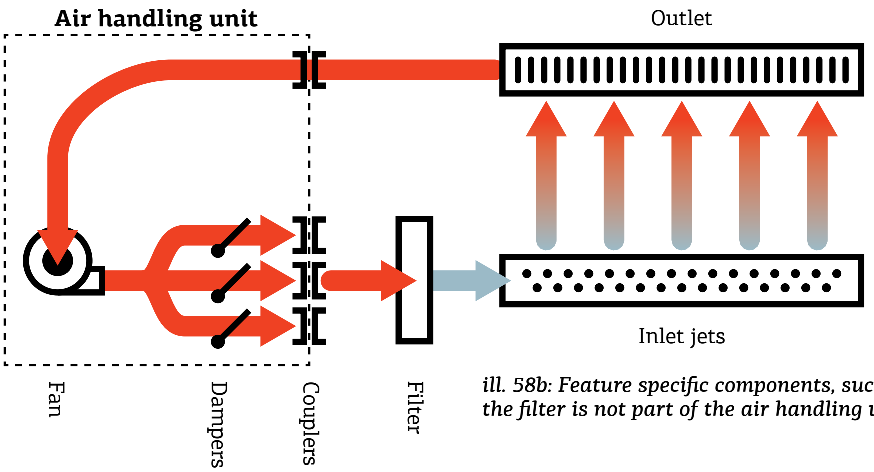
13 Bed extension: Most beds have the option to increase the overall length of the bed in case the patient is tall. This is often done by sliding the footbord back and adding an additional mattress piece

Components

To illure out how the concepts should be refined, it is necessary to understand how they work. Illuring out the different components required, their functions, their size and how they relate to each other will provide a better foundation to evaluate the feasibility of different concepts



ill. 58a: Some feature specific components integrated into air handling unit



ill. 58b: Feature specific components, such as the filter is not part of the air handling unit

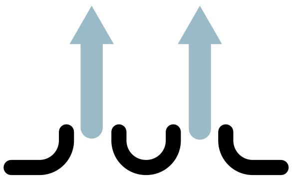
To generate the wanted effect of an air curtain and personal ventilation, certain components are required to perform different functions. Such a system is similar to most air purifiers used today, as well as most HVAC systems.

A fan is used to generate an airflow by pulling air in through an Outlet, passing it through a filter to clean the air, and out through an inlet. The inlets in this system are designed to jet air at a high speed to create the aforementioned air curtain.

As mentioned earlier, this system is part of a modular platform and therefore the air handling unit should also accommodate this modular philosophy. The air units should be universal and be usable not just with the open ventilation concept, but also with other modules that require an airflow. Such devices as alternating pressure mattresses that require an external air pump today, could benefit from having an on-board air supply.

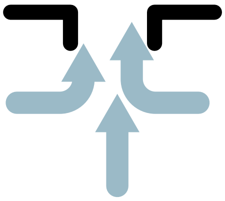
To accommodate all these features, universal air couplers should be available to install different devices. Each of these should also have independently controlled dampers to control the flow and pressure for each connected device.

To lower the cost and size of the unit, feature-specific components, such as the filter, could be made part of the modules instead. This would however also mean an increase in price and complexity of the module. ***(ill. 58a vs b).***



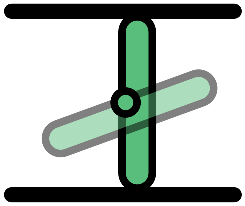
Nozzles

The nozzles are the inlets into the room, and must be able to create a powerful laminar air curtain to suppress the routes of airborne contaminations.



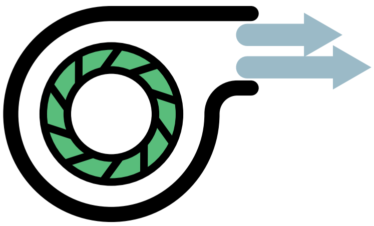
Outlet

Outlets are very simple as all that is required is an opening to allow the unit to pull in air. Certain considerations should be taken to ensure that only air enters the system such as having a grill. Installing a rough pre-filter on the inlets is a perfect solution to minimize the required cleaning of the entire system.



Dampers

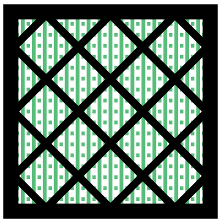
The function of the dampers is to either restrict the airflow through certain channels or to completely shut them off. The low pressure of the system means they are relatively easy to produce, and off the shelf solutions are available for HVAC.



Fan

There are many different kinds of fans that offer different properties. The important properties that define different fans characteristics are airflow under different static pressures, as well as the power consumption and noise level. See “Appendix B” on page 126 for evaluation of different types of fans.

To ensure that the device works with not just the ventilation system, but also with other components, a backward curved centrifugal fan is preferred for its ability to deliver a high flow rate with a compact form factor.

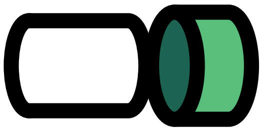


Filter

The filter’s main function is to clean the air of contaminants. The contaminants includes small particles, bacteria, viruses and smells. There are many different kinds of filters with different characteristics. Please see “Appendix C” on page 127 for evaluation of different filter technologies.

To achieve the wanted air quality the filter should be a combination of a HEPA filter and a UV-GI light. This will be a very efficient system where the HEPA filters out all the particles >0,3μm and the UV-GI kills all small bacteria and viruses.

An active carbon filter can be used to remove unwanted smells. For the sake of maintenance, the filters should be easy to change.



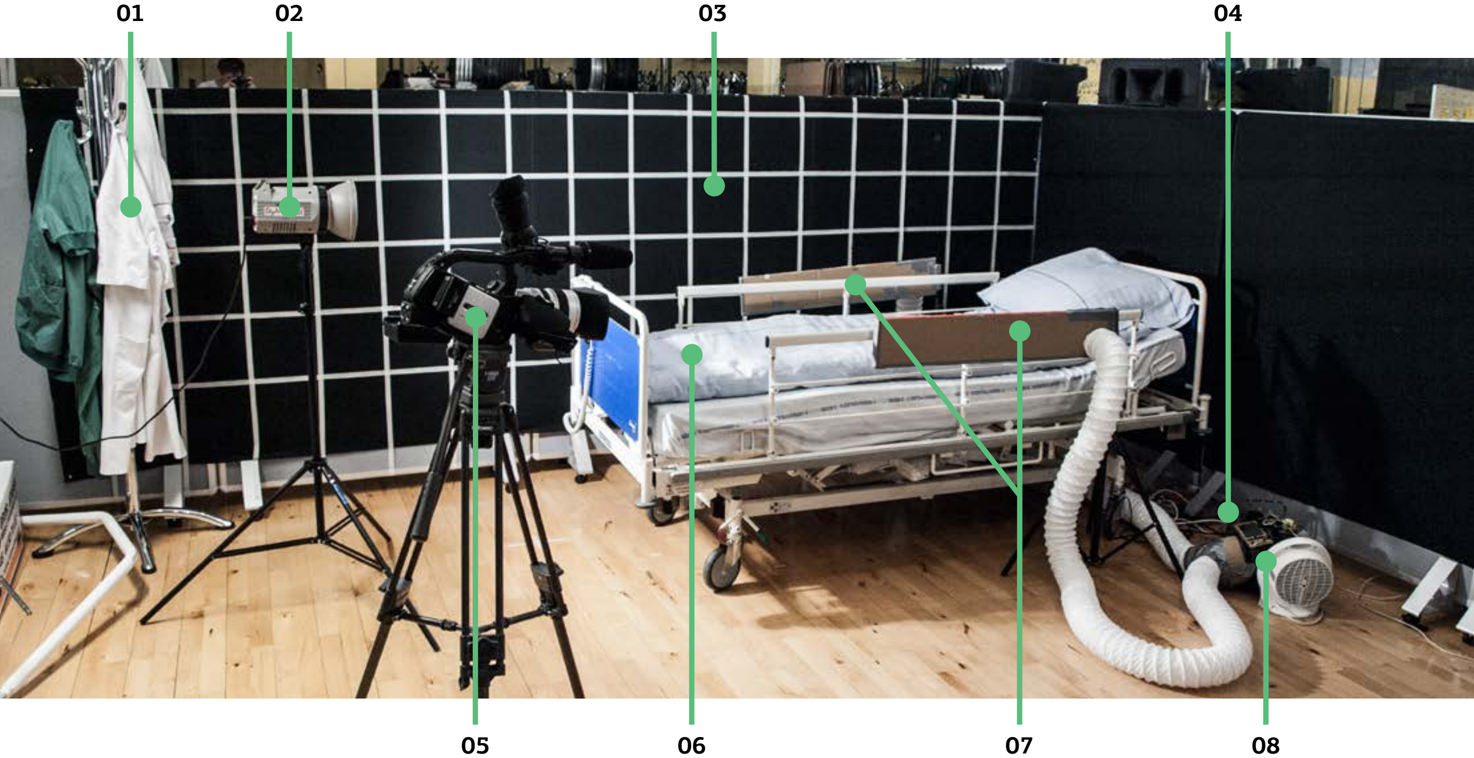
Couplers

When something is coupled to the system, it is important that it is locked in airtight, and that the system can register new connections. There are many examples of airtight high pressure couplers. However there are currently no standards for low pressure solutions as the low pressure reduces the need for a tight seal.

“The Lab”

As many of the factors that determine the effectiveness of different concepts are very complicated and hard to understand, it was necessary to construct a lab where it was possible to quickly test and visualize airflows.

“The Lab” was designed in such a way that it allowed the design team to quickly build and test different concepts in a realistic hospital environment. With the collaboration of Rigshospitalet it was possible to construct a 2-bed patient room at AAU Sydhavnen. The Lab was designed to allow the design team to: test airflows as well as how the different concepts are perceived by the patients.



01 Costumes: As part of the user tests and workshops, costumes such as a surgeon, doctor and patient, were used to improve the immersion

02 Lighting: When using smoke to visualize airflow, powerful projectors was used to highligt the smoke.

03 Reference background: Made it easier to calculate air speeds and sizes of airflows, as well as track movement during user scenarios

04 Fog Machine: It can either be connected directly to the air supply to visualize the airflow, or it can be used to fill smoke squirters to visualize cough’s evacuation efficiency

05 Recording: To record both airflow tests, exit velocities and user tests, different devices were used, such as high-speed cameras, DSLRs and video cameras

06 Scanbed 910: A hospital bed borrowed from Rigshospitalet.

07 Air distribution: To test different airflows, simple air jets were constructed with an universal “duct tape” mounting system.

08 Air Supply: An adjustable powerful 240W centrifugal fan was used as the main fan. A heating unit was used to test comfort.

Output

The lab proved to an incredibly useful tool for quickly testing and validating concepts. Not just usability but also for efficiency.

“Flow-cepts”

With the lab established, the design team was able to go through many fast paced concept iterations where different flow concepts were quickly tested.

A matrix combining different locations for the inlet nozzles and the Outlet was created to systematicly generate and verify new concepts. The different concepts were rated according to the following parameters:

- Fresh air to patient
- Ability to clean environment
- Isolation of patient
- Practicality
- Comfort

Out of these tests, three concepts were chosen to continue to evaluate for HCW usability, patient experience and flow efficiency (for a complete list of the different concepts and their evaluation, please see “Appendix A” on page 122).

Output

Concept 1: Downwards

To create a downward airflow to isolate the patient, a panel above the bed with jet nozzles must be connected to the bed. Such a panel could easily be quite big so it’s important that it’s designed in such a way that it doesn’t obstruct the HCW’s workflow. The outlet for the system could easily be tucked away under the mattress platform.

Concept 2: Horizontal

An airflow running from the patient‘s head to the footboard. This means that the patient is almost completely isolated and the coandă effect will effectively move contaminants to the outlet at the footboard. To achieve this the nozzles have to be integrated into the headboard, which means that the headboard itself might have to be height adjustable to accomodate all bed positions.

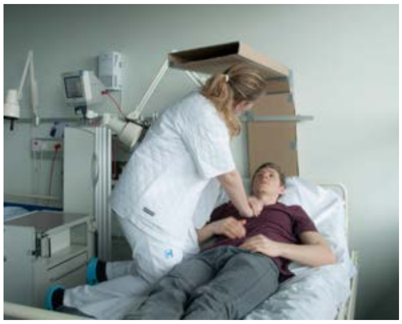
Concept 3: Upwards

Jet nozzles could easily be installed on the sides in either the side rails or in the bed frame to create an upward airflow.

Such a system should either complement the existing room ventilation system or include an Outlet installed above the bed to contain the contaminants.

HCW usability

Simple mock-ups of the three concepts were made and brought to the Department of Nephrology at Rigshospitalet. Mette Marie Morsing who is a nurse at this department was asked to comment on the potential of each concept seen from a HCWs perspective. Furthermore, everyday scenarios were acted out to see if the concepts would fulfill the needs of both HCWs and patients. A list of pros and cons of the different concepts can be seen in “Appendix D” on page 128.



Concept 1

The overhanging unit is not in the way while attending the patient but it is too long for ceiling hoists to clear it. At the Department of Nephrology they currently only have 3 rooms with ceiling hoists, but it might be more frequently used in future hospitals. If the nurse needs to perform CPR he/she will often jump in the bed so there must be free space above the patient. Furthermore, an additional nurse assisting with the CPR will often stand in the head-end and ventilate the patient, in which case the unit might also be in the way. For this concept to work in practice Mette suggested that the unit should be able to fold away when necessary.

Concept 2

The frame of the headboard is currently used by the patients to reposition themselves in the bed and for porters while transporting the bed. If the nozzles are integrated into the headboard it is important that they do not interfere with these functions.

The headboard needs to be height adjustable so it is higher when the patient is sitting up and lower when the patient is lying down and during transport. Furthermore, it must be detachable in case the nurse needs to perform CPR. There should be room for a sign on the footboard with patient name so the porter can easily identify the patient.

Concept 3

The side rail needs to be designed so patients do not get their head, legs or other body parts stuck in the side rail. It must be very easy to clean and made in a way so it doesn't collide with drainage bags that are normally hanging on the side of the bed. If the patient has a heart attack the side rails should be very easy and quick to fold down.

Some patients would benefit from being able to fold down the side rails themselves, while others might get hurt when trying to get out. Mette thought that it would be most safe if the side rails could only be operated by the HCWs.

Mette was a bit concerned that it would be uncomfortable to grab the side rails if the nozzles are integrated into it. She preferred the long foldable side rail they currently have apposed to the two separate solid side rails. If the side rail follows the backrest it is not in the way when the patient needs to reach for the bedside table and it also limits the patient's vision.

Output

- **There are a lot of confused patients that can not handle adjusting temperature and airflow. They might potentially put the system on a setting that could be harmful for themselves**
- **A lot of patients are complaining about temperature, draft etc. Both in summer and winter.**
- **If there is a risk of the patient getting pressure ulcers they are provided with a special air mattress**
- **The bed is normally placed at a low height when the patient is sleeping or resting**
- **The bed is lifted to an ergonomically correct position when the HCWs need to handle the patient**
- **The HCW can be standing beside the patient for up to an hour. So it is important that they won't catch a cold from standing in a constant draft**
- **It is important that the bed doesn't get wider or longer. Current beds can only just get through the doors and barely make a turn in the corridors**

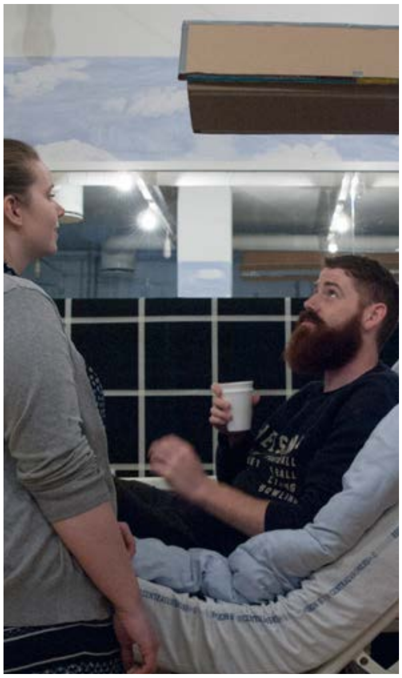
Patient experience

To get some input on the experience of the different concepts seen from a patient's and a visitor's point of view, 6 students were invited to a creative workshop. They were paired in groups of two and asked to act out predefined scenarios, while commenting on the usability of these. Simple cardboard mock-ups were used and the air distribution was controlled via a fan. Afterwards they were asked to sketch possible improvements for each concept. A list of the pros and cons defined by the participants can be found in "Appendix E" on page 129.

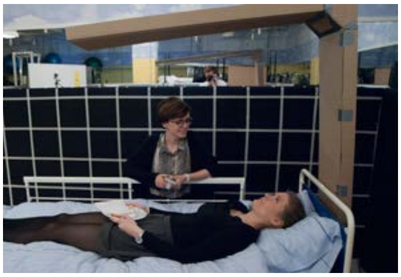
Concept 1

The participants liked the fact that this solution is well integrated into the bed and it visually indicates that the patient is safe. Furthermore, they saw great potential in integrating features such as reading light and a screen. It is very import that the overhanging unit is high enough and not too wide.

If the visitor leans through the air curtain it feels less intrusive than the other solutions because the air comes from above and hits the hair rather than the skin.



"By adding additional functionality the unit would be a positive addition to the bed rather than something that makes you feel more sick"



Concept 2

The participants didn't see it as a problem that the headboard is bigger because it is against the wall, but stressed the fact that it should have handles to use during transport.

Some participants liked that the air unit was less visible, while others thought it would be confusing for visitors not to be able to see where the air is coming from.

"I like that I can keep the side rail up when I want some privacy and fold it down if I want to talk with the neighboring patient or have visitors"

Concept 3

The participants liked that this concept offered both privacy and social interaction and thought it would be nice if the patient could fold down the side rail themselves.

Some participants were worried that it might be uncomfortable to sit on the side of the bed with air blowing upwards and that patients might get their head stuck in the side rail.

Another concern was if the system would function properly if the side rails were down or the duvet covers the nozzles.

Output

Some participants expressed that having an air curtain might create the impression that the patient is in a "bacteria zone" and were uncertain if they would feel safe approaching the patient. This will be less evident if all the beds were equipped with the system. Several participants suggested integrating features such as light, TV, radio and mirror in the bed. This is perceived as added comfort for the user and removes the perception of the patient being extra sick.

Several participant highlighted the importance of the system being as silent as possible to make it comfortable for the patient. There was mixed opinions on whether or not the patients should be able to adjust airflow and temperature themselves. Many patients would benefit from being able to cdo so, while others wouldn't be able to handle it and could potentially make adjustments that would be harmful for themselves.

It was discussed whether or not the air curtain needed to be reduced or turned off when the patient has visitors or is handled by the HCWs. Most participants stated that turning off the air curtain should be an option and some suggested that this was done automatically with sensors.

All participants thought it was significantly more comfortable going through the air curtain when the air was heated.

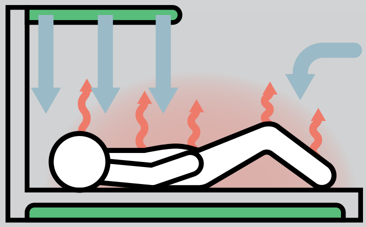
All the participants stated that they would prefer cleanliness to homeliness. Hospitals are high-tech so it's fine that the solution is also perceived as high-tech.

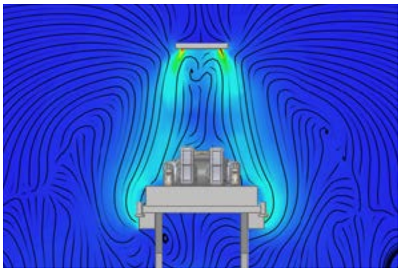
Flow efficiency

To thoroughly verify the feasibility of each concept, it is important to do more comprehensive flow evaluation tests. These tests involves doing many scenarios with smoke to visualize the airflow and interact with it ***(“Appendix F” on page 130)***, CFD (computational fluid dynamics) analysis to verify and quantify the effectiveness ***(“Appendix G” on page 132)***. Lastly indoor-environment expert Peter V. Nielsen and research assistant Siamak R. Ardkapan assisted with helpful input to evaluate and improve the CFD analysis and smoke tests.

Concept 1

This proved to be the most effective of the three concepts in regards of preventing pathogens exhaled by the patient from spreading to the environment. It also performs well when it comes to supplying the patient with clean air. The angle of which the air is discharged is critical for the effectiveness of the system. If it’s too wide the air will spread to the room, resulting in poor protection of the patient. If it’s too narrow the patient will feel an uncomfortable draft.

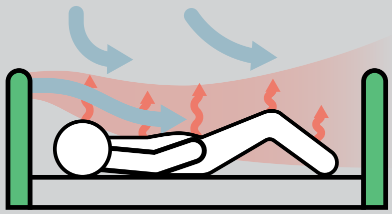


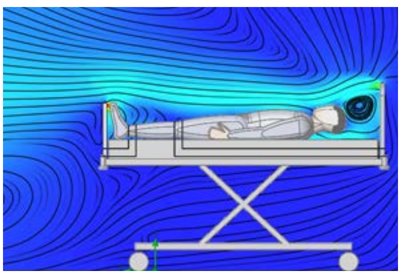


“The heat convection of the patient will create an upwards stream of warm air, which will probably draw in cleaned air from the air curtain at the breathing zone of the patient.”

Concept 2

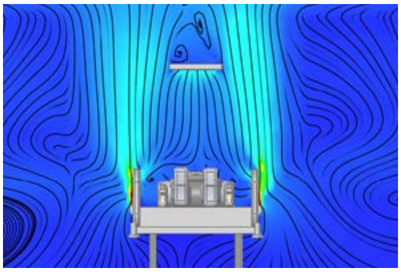
This concept is the most effective in regards of supplying fresh air to the patient as it discharges air directly into the breathing zone. But this also creates a draft which is potentially uncomfortable or even harmful for the patient. Furthermore, a large fraction of the air discharged will blow over the footboard and out into the room, thus potentially increasing the spread of pathogens.





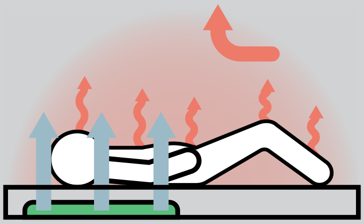
“The horizontal stream of air will most likely stick to the nearby surface of the patient due to the Coandă effect. This will supply the patient with clean air, but also cause draft.”

“The air discharged from the system won’t reach the patient so additional air supply to the patient will probably be necessary.”



Concept 3

The airflows in the same direction as the heat convection of the patient. As a result the patient won’t feel a draft, as might be the case of the two other concepts. But this also means that the patient won’t be supplied properly with clean air. The CFD analysis also indicated that the Outlet only has little effect and that most of the potentially contaminated air will be blown out into the environment.



Output

To validate the effectiveness of the flow of the different concepts three factors were considered, visual smoke tests, CFD analysis and expert evaluation. All three concepts behaved very differently and exhibited very different advantages and weaknesses. All the concepts had varying degrees of capturing the contaminated air in the Outlet and clean it, but there was a great difference in where the air that didn’t get captured ended. Concept 2 performed very poorly as the contaminated airflow would be blown directly to a breathing zone at the end of the bed, concept 1 performed well as all the non-captured air crawled along the floor. It was expected that concept 3 would do this very well and would in some case not require a well placed Outlet to capture the contaminated airflow, as it was evacuated to the ceiling and then slowly evacuated by the hospital ventilation system. However relying on the hospital ventilation means the effect of the system can not be guaranteed as it is not an independent system.

Concept selection

To choose the best concept to proceed with, the HCW usability, patient experience and flow efficiency, are taken into consideration as well as a general evaluation done by the design team based on their own observations.

Below is a non exhaustive list of pros and cons which highlight the differences between the concepts, and the challenges that will have to be overcomed for each concept.

Concept 1

- ✚ Downward stream will also provide clean air to patient
- ✖ Inlet counters natural convection stream
- ✖ Inlet panel obstructs HCW's work and CPR
- ✖ Possibility for draft

Concept 2

- ✚ The coandă effect will provide clean air to patient
- ✖ Contaminants are blown towards visitors and HCW
- ✖ Headboard will have to follow backrest and increase in height to be effective in all positions
- ✖ Possibility for draft

Concept 3

- ✚ Inlet follows and aids the natural contaminated convection stream from patient
- ✖ Separate device is needed for clean air to patient
- ✖ Nozzles could be very exposed to dirt, fluids and droplets from patients
- ✖ Requires an overhead outlet in some ventilation scenarios
- ✖ Airflow is easily disrupted by duvet

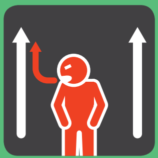
Output

Concept 2 was eliminated as the design team saw huge difficulties in supplying the right airflow in all situations and inevitable problems with draft as well as issues with air exiting horizontally out into the room.

To better understand the limits and the possibilities of both the remaining concepts, continued refinements was conducted on both. The refinement would break down the issues detected in the previous tests and thus trying to solve them, as well as exploring different ways the solution could materialize, how it would affect these issues and how they would relate to the experience and the value mission.

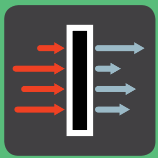
Concept 1 was chosen because of it's superior performance in the CFD analysis as it's potential for integrating value adding features. Please see “Appendix H” on page 138 to see some of the refinements generated for concept 3.

The final concept was also assessed on how well it performed according to the three criteria defined in “Functional criteria” on page 25.



Contain

Particle studies showed that concept 1 was the best at containing the particles to the infectious host



Clean

The concept will help clean the environment as air from the room is sucked in and cleaned.

Supply

The concept performed well on supplying the patient with clean air without creating a draft.

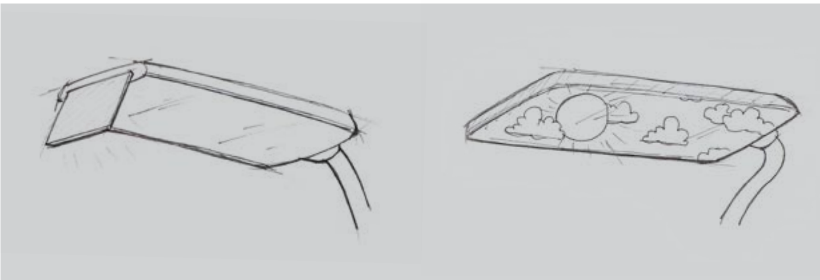
Concept refinement

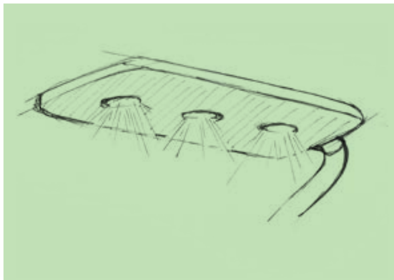
The potential of concept 1 was explored through a systematic refinement process. The problems discovered throughout the concept phase was examined and potential solutions for eliminating these was generated.

Additional features

Several of the participants who took part in the workshop described in "Patient experience" on page 64 expressed that adding functionality to the overhead inlet would make the unit a positive addition to the bed rather than something that makes the patient feel more sick. One solution could be to add a fold down screen and sound system in the overhead unit. Currently most patients have their own TV, which is often mounted on the opposite wall and controlled by a separate remote. By integrating a screen into the bed the patient could watch TV without disturbing the neighboring patient and the close proximity of the screen could be beneficial for patients with poor eyesight Alternatively the whole bottom surface of the inlet could be used for projecting calming images or videos that the patients could customize themselves.

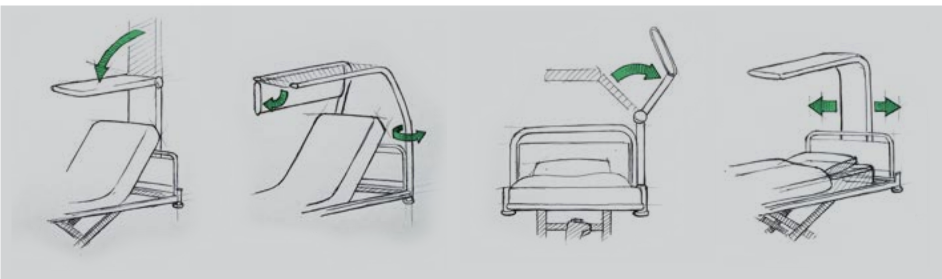
Another issue in many hospitals is the lack of proper lighting, which can affect parameters like sleep, mood, depression and even lengthen the patients hospitalization ***(Philips, 2014)***. By using dynamic lighting to mimic the varying patterns of natural daylight it would be possible to create an automated day-rhythm. This will help to reinforce the reassurance and comfort values stated in "Value mission" on page 46. Other lighting settings such as reading light and examination light could also be added to increase patient comfort and the HCWs working conditions. Based on this the design team sees the biggest potential in integrating lighting into the unit and will focus on detailing this solution.





Inlet removal

As described in "HCW usability" on page 62, it's important that the HCWs are able to quickly and easily remove the overhead inlet when performing CPR or transferring the patient with a ceiling hoist. This could be achieved by sliding the unit sideways, folding it up or swinging it to the side. It was decided to focus on the swinging mechanism as this solution offers the best access to the patient from all sides, while still being easy and fast to move away and unobtrusive to the staff. The unit needs to have a mechanism for locking the unit into place while in use as well as a release function when swinging it away.

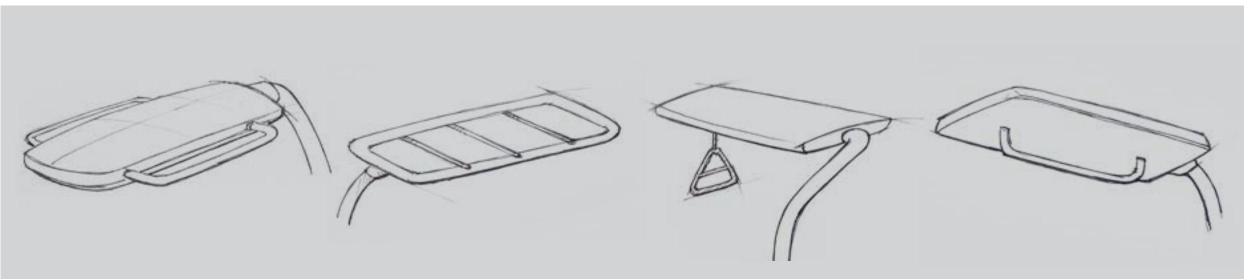


Inlet structure

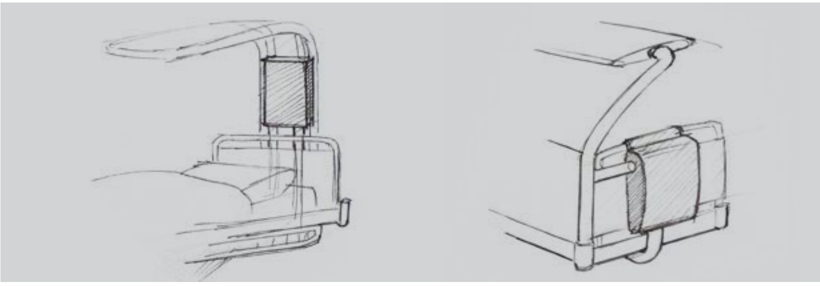
The goal is to seamlessly integrate the overhead inlet into the structure of the bed. It should be perceived as a positive addition rather than making the patient look more sick or feel claustrophobic. Giving the unit a solid structure allows for easy integration, but limits the access to the patient from the head-end and makes the unit look heavy, thus stealing focus from the bed. Furthermore, "Appendix J" on page 141 illustrates how a solid structure completely obstructs the view for the porter during transportation. Using tubes instead creates a lighter look that seems less obtrusive and makes the bed accessible from all sides. By supporting the overhead inlet with two tubes a strong and rigid structure is achieved, but by doing so the unit will be difficult to remove quickly if needed. Instead an asymmetric design is chosen where one tube mounted in the corner of the frame supports the overhead inlet. This allows for easy access to the patient and quick removal if needed.

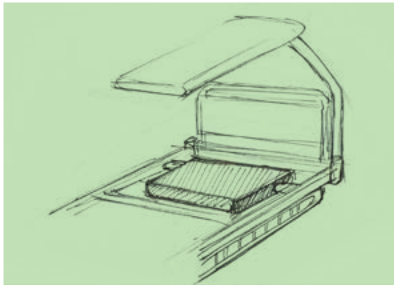
Handles for patient repositioning

Some hospital beds has a lifting pole mounted in the corner of the bed frame that patients can use to repositioning themselves. According to a tender from the Central Denmark Region, 60 out of 150 beds will be equipped with a lifting pole ***(regionmidtjylland 2014)***. This shows that the hospitals are still requesting lifting poles even though our research from Rigshospitalet and interviews with Invacare indicates that they are rarely used. To accommodate the hospitals requirements the option of mounting handles onto the unit has been explored. The design team worked with both patient and HCW handles, but unfortunately none of the generated solutions could be smoothly integrated into the unit without significant compromises in functionality and aesthetics. It was therefore decided that if a lifting pole is needed then it would have to be mounted separately in the unused mounting hole in the head-end.



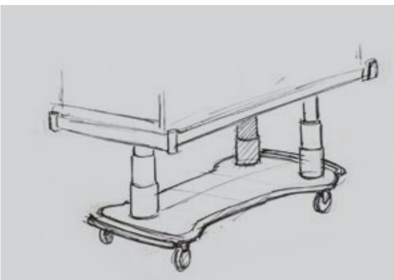
Air handling unit

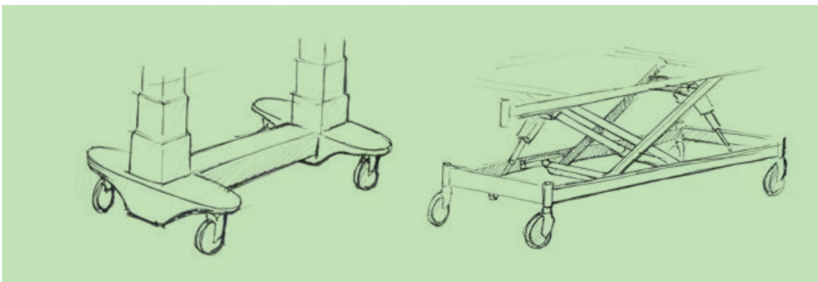




The placement of the air handling unit, which contains the fan, filter and UV lamp, is key for the modularity of the bed. One option is that each module that needs air has it's own air handling unit. This would simplify the bed, but would require a separate unit for each module and make the bed less modular. The air handing unit could also be externally mounted onto the bed, thus allowing for easy retrofitting. The disadvantage with this solution is that it takes up space and is in the way when the HCWs need to access the patient from the head-end. A third option would be to integrate the unit into the bed frame. This solution was chosen because it is well hidden and allows for additional modules to be connected to the same air handling unit thus complementing the modularity of the bed.

Height adjustment

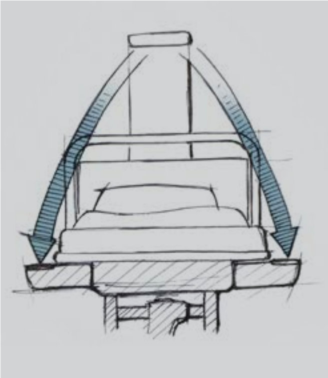


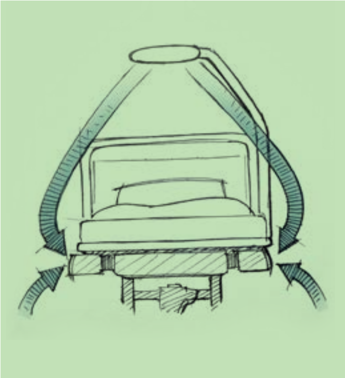


The Scanbed 910 uses a scissor lift for height adjustment. The benefits are a rigid and reliable structure with a long life time and low servicing costs. Furthermore, a minimum height of 380 mm can be achieved, which is impressive compared to beds with lifting columns, which typically can't go below 450mm. Lifting columns on the other hand are significantly easier to install and to keep clean and offers a more clean look, which isn't cluttered by numerous tubes and actuators like the scissor lift has. It's been decided to focus on the scissor lift but the modularity of the bed should allow for mounting lifting columns instead if the customer prefers these. Three and four column designs have been opted out as these are expensive and primarily are used in special cases where lateral tilting of the patient is needed.

Outlet orientation

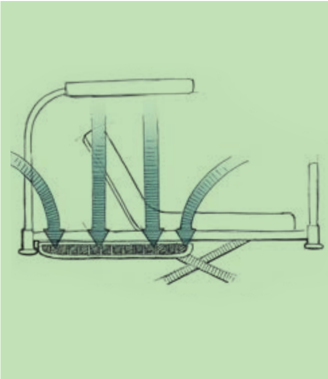
By having a vertically oriented Outlet a larger fraction of the air discharged will be recirculated into the system compared to a horizontal Outlet. But having a vertically oriented Outlet will increase the overall width of the bed and be in the way when the patient is getting in and out of bed and when the HCW is working with the patient or maneuvering the bed. Furthermore, a vertical orientation will increase the risk of blood, urine and other substances dripping into the Outlet. A horizontal orientation on the other hand will allow for a neat unobtrusive integration into the bed frame and keep the overall width of the bed at a minimum.

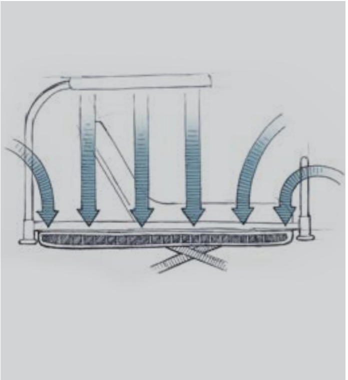




Outlet dimensions

If assumed that the amount of air discharged by the system is equal to the amount it sucks in, then increasing the length of the Outlet won't affect the volume drawn into the system. Having a unit that covers the whole length of the bed will result in more air, from the surrounding environment, getting drawn into the system compared to a shorter unit with similar length as the inlet. Although it's an advantage that the additional air from the surrounding environment gets cleaned it's preferable to recirculate as much of the discharged air as possible thus capturing more of the potentially contaminated air exhaled by the patient. Therefore it's been decided to focus on an Outlet that matches the inlet in length.





Output

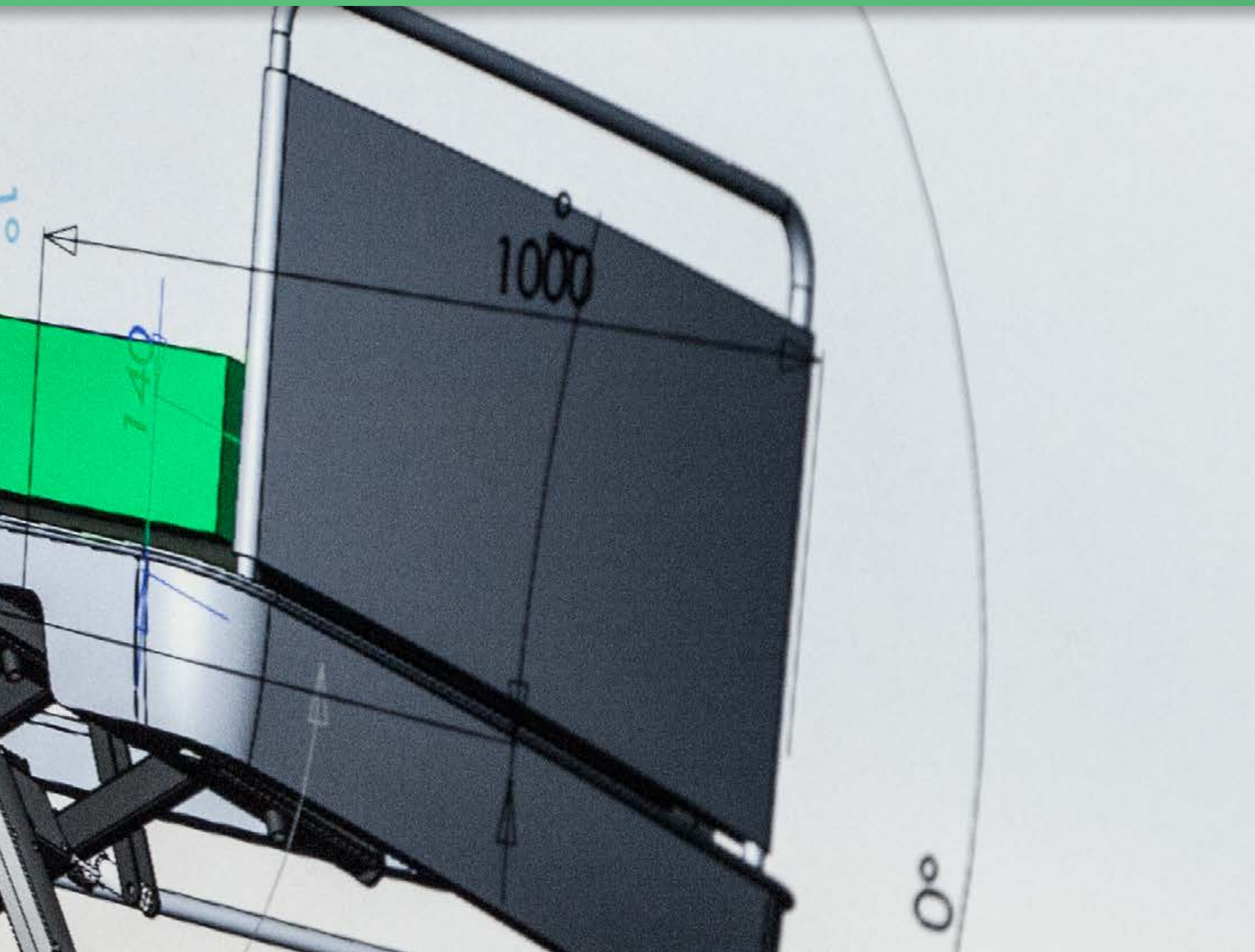
This project will focus on the design of a modular ward bed with an integrated inlet above the patient that can be swung away if needed. The inlet is fitted with dynamic lighting and is asymmetrically mounted in the rear corner of the bed. The Outlet has similar length as the inlet, is mounted on the side of the bed and sucks in air horizontally. The inlet and Outlet are connected via a air handling unit, which is integrated into the frame of the bed and can be used for connecting other air modules as well.

Detailing

The following section contains the detailing describing the process and thought behind developing the concept to a solution.

It is divided into five sections showing the detailing for each device as well as aesthetic considerations and an economy section:

- *Aesthetics*
- *Modular bed platform*
- *Air handling unit*
- *Open isolation unit*
- *Economy*



ill. 76a

Moodboard

This moodboard was created as a tool to guide the detailing of the solution.

It is a collection of pictures and valuedriven words that works as an aesthetical translation of the values stated in the "Value mission" on page 46


ill. 76b

Cleanliness **Quality** **Professionalism**

ill. 76c

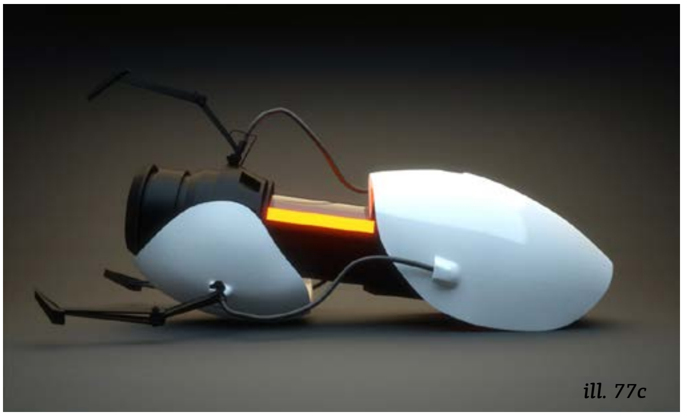
ill. 76d


ill. 77a


ill. 77b

Structure vs. Surface

Geometric


ill. 77c


ill. 77d


ill. 77e

OPTIMUS

MODULAR HOSPITAL BED PLATFORM

The system calls for a new type of bed that can support not only the open isolation unit, but also future modules. To do this it is necessary to rethink how to mount and install different modules as well as how they work with the bed. As mentioned earlier, the starting point will be an update of the Invacare Scanbed 910 as used in most hospitals in Denmark presently. The modular bed platform has been named “Optimus” as its ability to change its features will make it optimal in most situations. This modularity also applies to the manufacturing as the modular bed platforms also can be optimized to different countries with different demands.

Scope

- Parts that contain known or modified solutions will not be thoroughly detailed
- Parts will only be detailed to the point where their construction and functions are justified
- Mounting system will only be tested with the ventilation module
- Assembly and transportation will not be thoroughly considered

Making it modular

Like most hospital beds, the Scanbed 910’s modularity only extends to a few predetermined accessories such as a lifting pole, IV pole, and a small washing table. All other equipment will either stand on the floor or be hooked to some rail, and if it’s an electric accessory it requires more cables and its own interface mounted somewhere.

To create a modular universal bed it must include:

- Universal mounting rail for small equipment
- Heavy-duty mounting holes
- Mounting space below bed frame
- Easily accessible control unit
- Modular controllers (both patient and attendant controllers)

Colors and materials

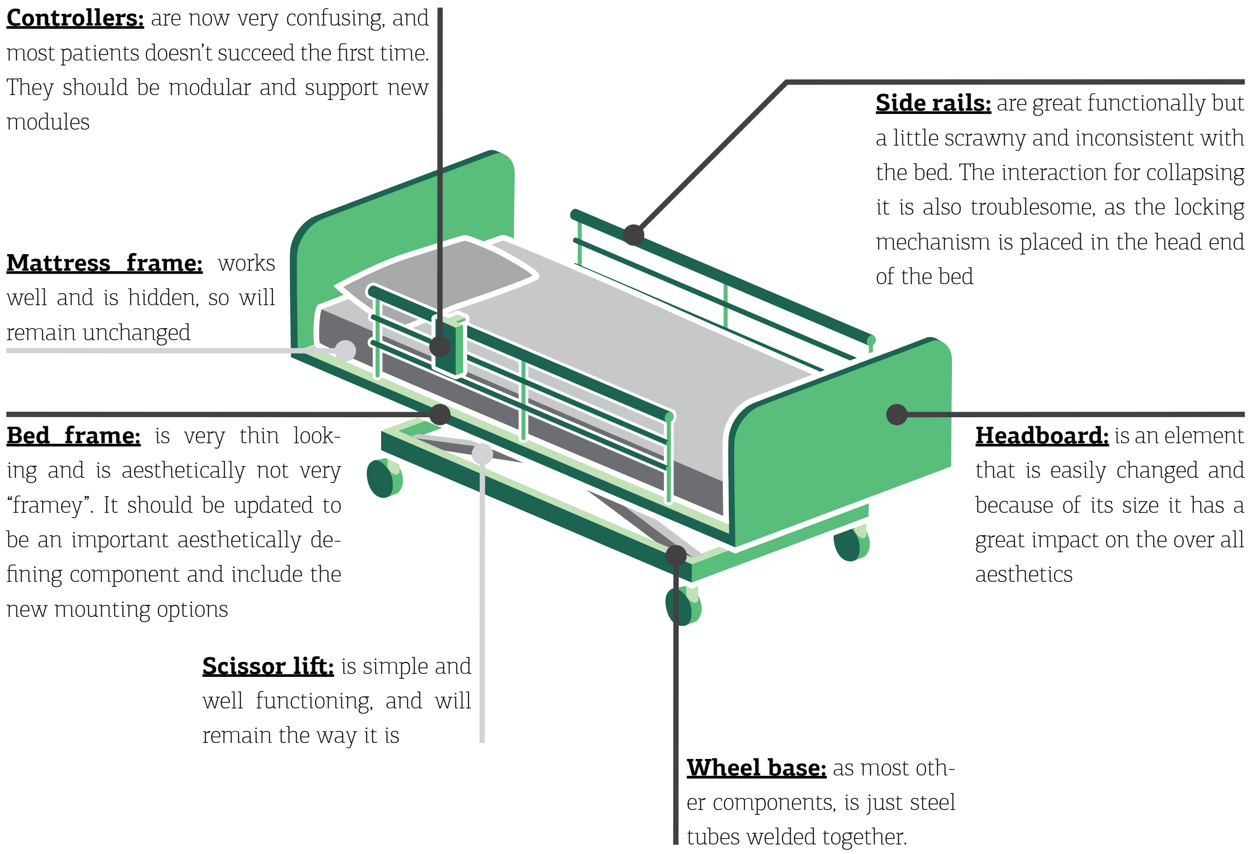
To make the features and functions of the bed more transparent, the colors and finishes of different materials should reflect their function. The “Interaction vision” on page 47 was used to define the inherent feedback of the bed. As a result all points on the bed that has an interaction will be marked with either an accent color or a function specific color, whether it be a button or just a flange for mounting. Larger interaction surfaces, such as the grip on the headboard or the gripping part of the side rail will be in anodized aluminum. The remaining part of the bed will be powder coated in a white or gray color. The important framing parts, such as the wheel base and bed frame will be coated in a white color, while all the complex mechanical parts will have a darker coat. This will make the important parts stand out and ensure they define the aesthetics of the bed.

Updating a success

The Scanbed 910 was developed over a long period of time with many small incremental changes and updates. The bed is very sturdy, but has very little thought as to aesthetics and design consistency.

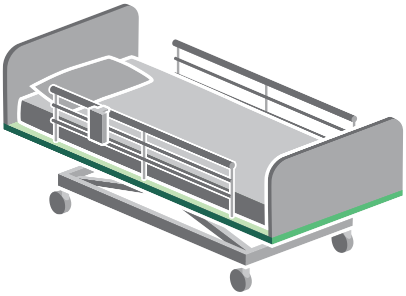
There are however a few things that this bed does, that virtually no other hospital bed does. The side rail looks and feels scrawny, however when it is collapsed it takes up very little space. This is something that is very useful not only when cleaning the patient-room, but also if there is something mounted below the frame. Another thing this bed has, is a bumper on the sides to protect the bed and the walls. These features should remain as they are an important part of what made the bed successful.

The design team will focus on updating the parts that will add to an aesthetic focus and purpose to the bed, as well as integrating the features mentioned in "Making it modular".



Bed frame

The bed frame contains most of the features associated with the modularity of the bed platform. This makes it an important structural par, which should be reflected aesthetically.



The bed frame must..

- Be able to extend the total length by 20 cm
- Have a pole for drainage bags
- Have a locked mounting solution for heavy duty modules
- Have a universal mounting solution for lighter modules
- Be perceived as sturdy
- Be the aesthetic base of the whole bed
- Have a bumper to avoid injury and damage

To make the bed frame an important and identity defining part of the bed, it is designed as one continuous loop. Making it larger means that the frame will distinguish itself from the rest of the bed, such as the scissor lifting mechanism.

To make the bed more inviting to the patients, the frame will have a soft curve at both ends as well as slightly curving inwards. The frame's height will greatly decrease at the sides to allow external modules to be mounted so that they reinforces the overall aesthetics.

The frame will consist of four parts; an extruded profile on each side with a mounting groove, a drainage pole, an extendable foot-end, and a head-end which will contain the heavy-duty mounting holes.

Universal mounting groove

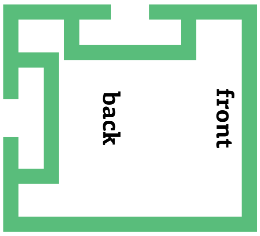
The steel tubes that surround the bed have been exchanged with an aluminum extrusion instead. In this extrusion it is possible to create a simple groove to mount modules in. With such a groove it is possible to have "easy quick release" modules mounted securely on the side of the bed. Modules that need a more secure or permanent fitting can have a small threaded plate inserted into the groove and then bolted onto the module.

This will not only allow modules to be easily mounted, but also the assembly of the bed can be completed through these grooves and the open ends of the extrusion. This will make it easier to repair and allow for a more agile production.

Below are two different ways such grooves could be included into the design of the frame. The first groove on the top of each profile will be for everything that can be top mounted, such as the side rails. The second groove will be for mounting most other things, such as IV pole, washing table etc.

Of the two extrusion, #2 was chosen as it's second groove is less susceptible to dirt than the one on extrusion #1, which is far more exposed. To cover the visibility of the mounting points, a small lip was added to the front of the profile. This lip will also help ensure the mounts doesn't rotate out of their position.

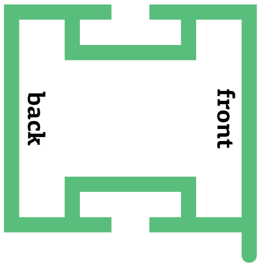
Extrusion #1



✚ Easy mounting for internal parts

✖ 2nd groove susceptible dirt

Extrusion #2



✚ Good transmission of forces

✚ 2nd groove not as susceptible to dirt

✖ Shorter distance between internal horizontal surfaces means inserts will be thinner and more fragile

✖ Mounted parts more visible

Bumper

To close the top groove the rubber bumper was made to completely cover the top of the whole frame. This will protect the frame from bumps and scratches while also hiding all of the top side of the assembly,

The bumper is also an important aesthetic element as it will run as a continuous loop and emphasize the contour of the frame.

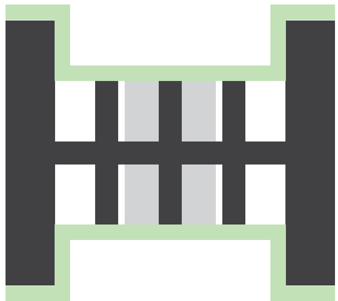
Extendable foot-end

The foot-end is constructed just like the head-end and will contain most of the same features. However there is no heavy-duty mounting holes, and the arms that connect to the extruded side profiles are designed differently.

Like most hospital beds, it is important to be able to extend the total length of the bed to accommodate very tall patients. Therefore the arm that connects the foot-end to the rest of the bed needs to be longer to accommodate at least an 200 mm extension. This means that the arm must be designed to be a lot tougher and durable, while also being able to slide in and out effortlessly of the extruded side profile.

To ensures the arm is strong enough an iterative design process was conducted to test and verify different designs through finite element (FE) analysis. Please see “Appendix K” on page 142.

The analysis showed that it was necessary to make the arm as strong as possible and make a nylon glider that covers both top and bottom of the arm.



Cross-section (1:1)

Nylon gliders
Mounting boss
Arm

Expansion bay

There will be many different modules that require larger functional parts, that does not require any access or interaction, such as a fan and filter. These parts should be installed where they are not visible when the bed is in use, but still be accessible to the HCW and service technicians.

Currently there is a rather large empty volume below the backrest that is not utilized for anything. This will be a perfect location to be able to install new components. Permanently existing components, such as the control unit will also be installed in this space. This will limit the service area to a single position to make repairs and adjustments easier. The control unit will be a Linak CB14 OpenBus, as it currently supports 3rd party accessories, communicates with nursing systems, can be controlled from a smart device, logs all data from devices, and can communicate with electronic patient journals.

The space behind the backrest measures approximately 900 x 390 mm, and when the control unit is installed, there will be 630 mm left for new modules.

Head-end

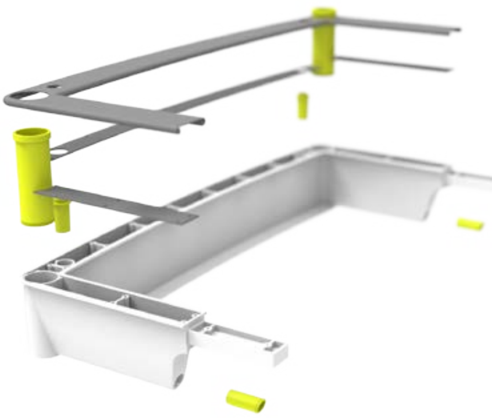
To achieve the desired space below the sides of the bed frame while still having a visually high frame, the head-end will have to transition from high to low.

The head-end will include the corners of the frame, which are double curved. To meet all these demands to geometry, the part will be die-cast in aluminum and have a lid screwed in on top of it, to close it.

The part will be connected to the extruded side profiles, and the headboard and the drainage pole will also be connected to this part. The two corners will be used for the heavy-duty mounting.

The heavy-duty mounting hole goes all the way through the head-end part so that there is an easy connection point below it. This connection will be well hidden below the frame, and provide easy access to the control unit for either power, data, air or future modules.

The dimensions for the heavy-duty mounting holse is based on FE analysis on a overhanging pole. Please see "Appendix M" on page 145



ill 83a: Three different variations of how a heavy-duty mounting point meets the curved frame

Drainage pole

The drainage pole is an important and simple mounting space that most hospital beds have. It is just a tube or pole that runs on the side of the bed, and offers HCW the ability to hang drainage bags for urine, feces, etc.

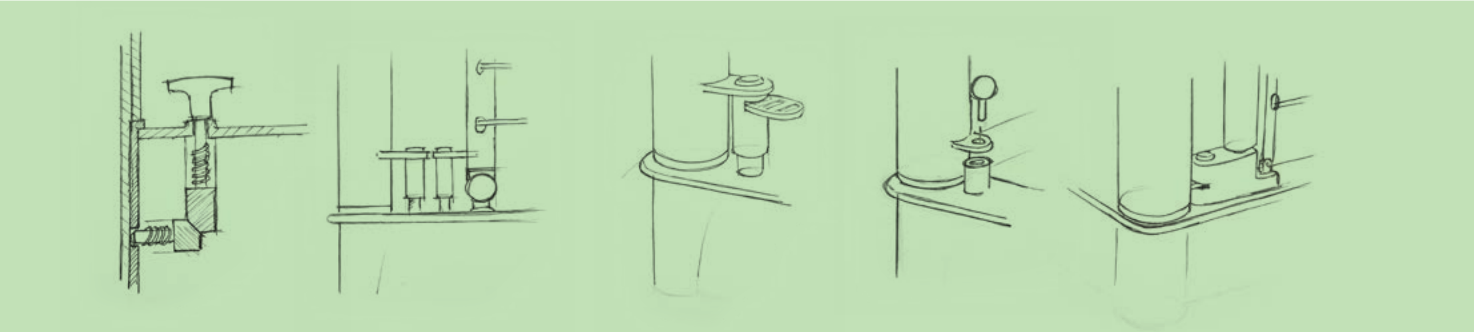
On the new bed the drainage pole is used to finish the lines that were drawn by the head-end and foot-end pieces. It runs almost the entire length of the bed and merges into the both aluminum ends of the bed. This also means that the foot-end will have to have room for the drainage pole when extended and collapsed.

Interactions

Heavy-duty release

Everything mounted in the heavy-duty hole will need a lock to prevent it from rotating. The interaction vision was taken into considerations when designing this mechanism. The lock is a simple spring loaded rod that makes a subtle mechanical clicking sound when it is rotated to the right degree, thus providing the user with an inherent feedback that the action has been performed correctly.

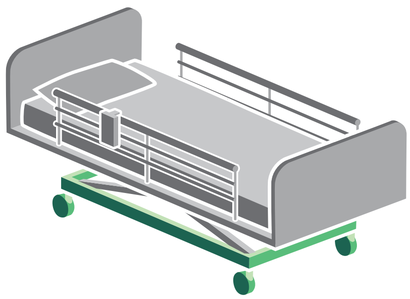
A small lever can be pushed down to release the module. This locking mechanism is very close to the mounting point for the side rail, so combining it into one part will clean up the appearance.



Locking the extender

The bed extension is locked by a small threaded steel rod that is inserted into the extruded profile groove. When turning it, the rod applies a lot of friction to the nylon covered extender arm, which locks it into place.

Wheelbase



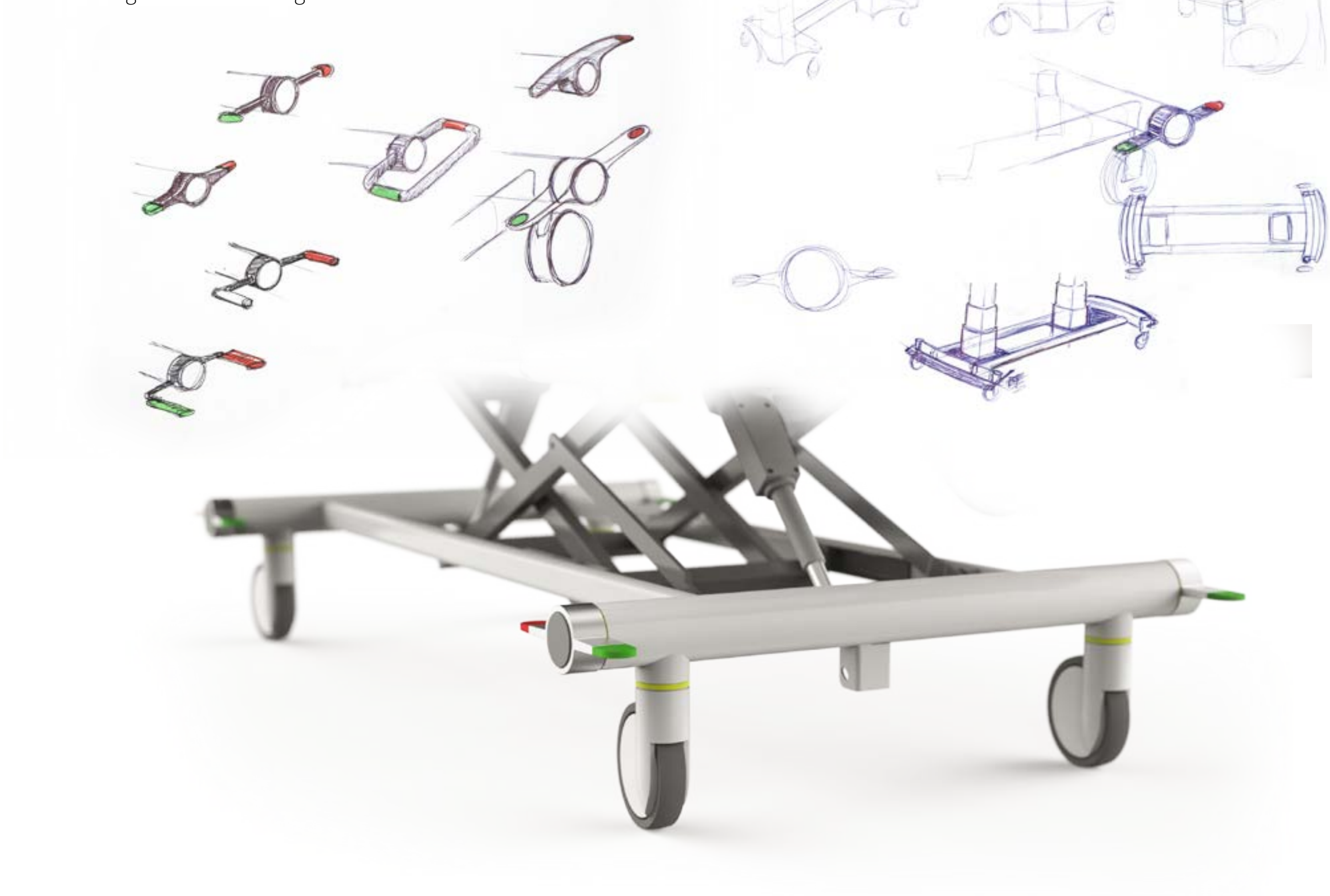
The wheelbase is a large but very simple construction that, like the bed frame, has a big impact on the perceived aesthetics and quality of the bed.

The wheelbase must..

- Lock on all four wheels
- Lock rotation on two front wheels
- Fit on transporters

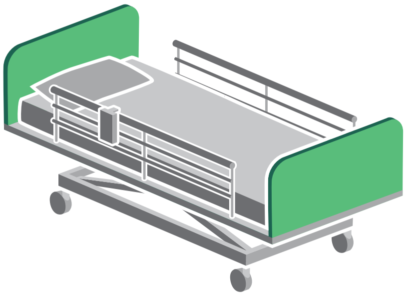
The simple construction and size of the wheelbase remain the same, however the tubing is changed. Currently it consists of square and rectangular steel tubes welded together, and this is just changed to a large round tube and a flat oval tube to create a simple and very geometric looking base. The increased size of the round tube allows more of the locking mechanism of the wheels to be hidden inside the tube.

The casters was changed to a standard Tente medical caster and the wheel locks were redesigned to be consistent with the rest of the bed.



Headboard

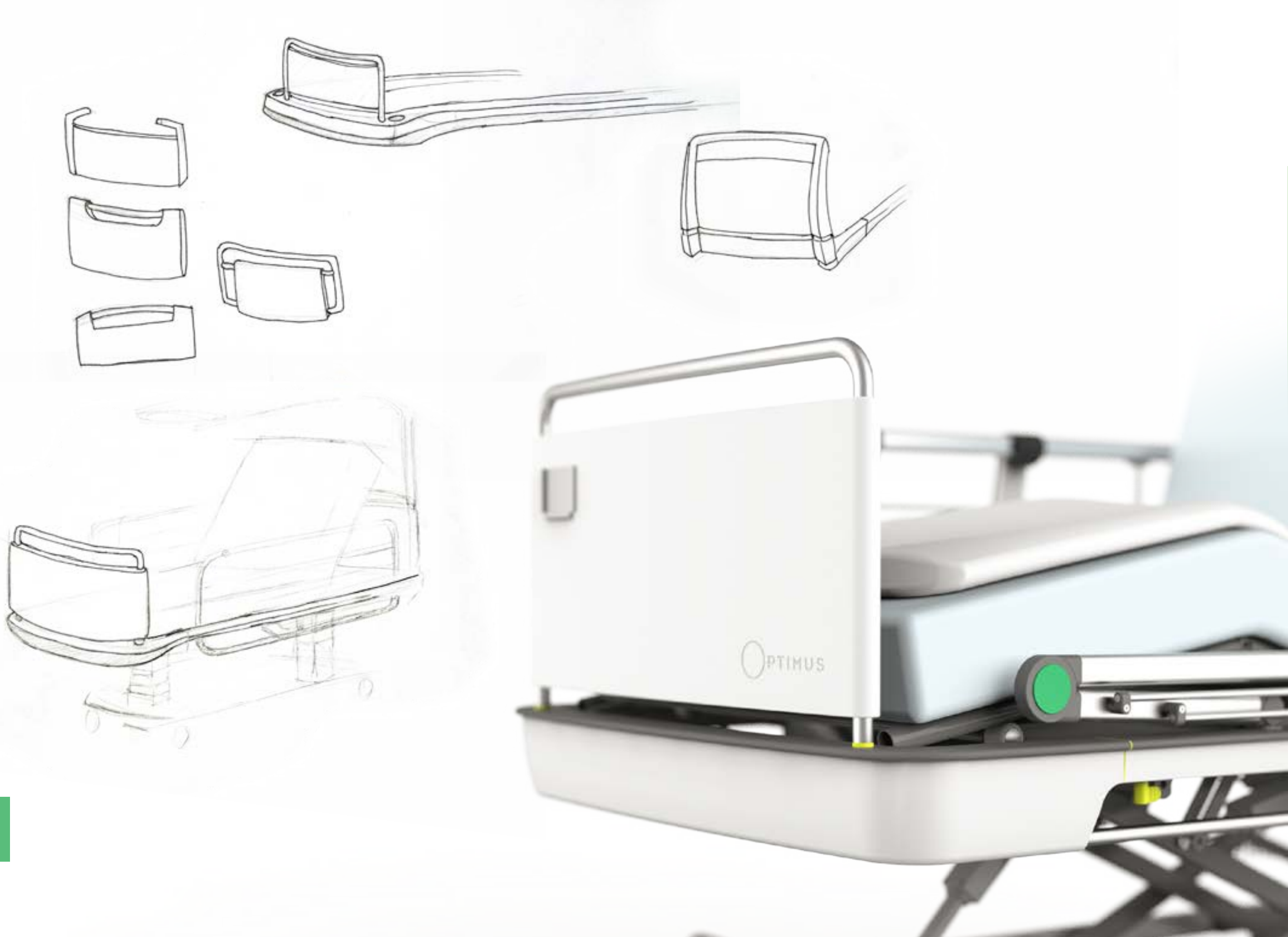
The headboard is a very simple component for which the only requirements are that it should keep the patient from falling out of the bed, while also containing handles so the patients can pull themselves up and the staff can push the bed.



The headboard must..

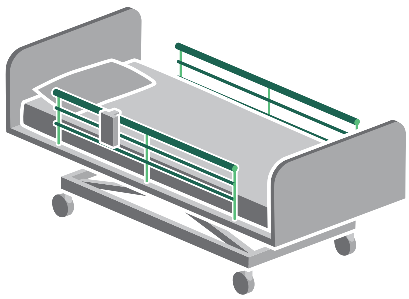
- Be detachable
- Function as a transport handle
- Suitable for patient repositioning

The headboard consists of a simple bend anodized aluminum tube, much like it is today. However the top will have a slight curve to match the bed frame below. The large plastic surface is a rotational molded PE shell with PUR foam sprayed inside the cavity. This is a common production method often used by other bed manufacturer to make side rails and headboards. Despite its name, the headboard is used in both ends of the bed.



Side rail

The side rails main function is to make the patient feel secure and prevent the patient from falling out of the bed.



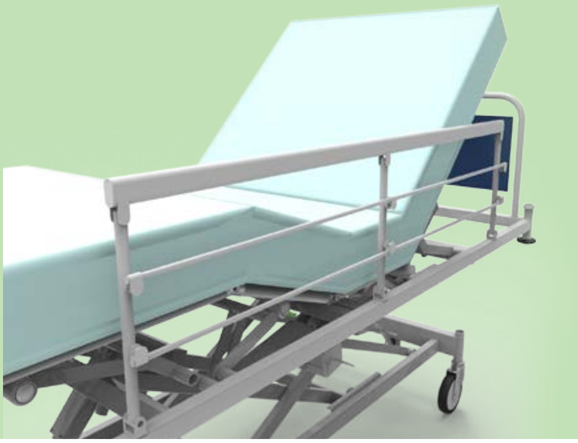
The side rail must..

- Collapse to the bed frame
- Contain a locking mechanism
- Comply with IEC 60601-2-52
- Be perceived as sturdy

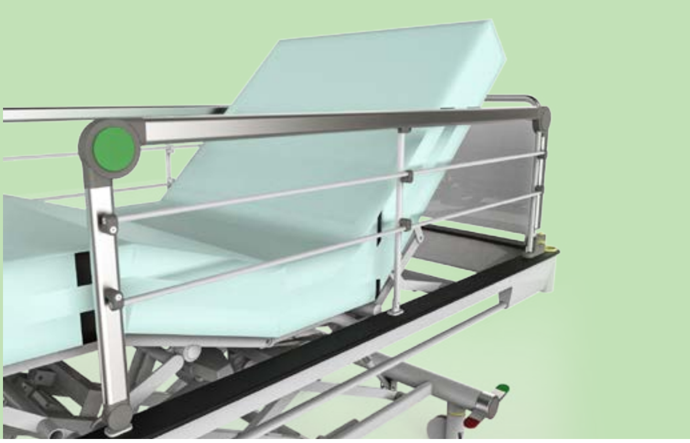
The side rails currently used work as a parallelogram where the horizontal and the vertical beams are in two different planes. This allows the side rail to fold down to a very small size. However it also makes it looks very unsturdy. The top beam is currently the only element of the side rail that has some mass. In the new design the top beam is also used for the vertical members in each end of the side rail. This will give the top rail a continuous profile from the bottom to the top. Large solid looking joints are added in each end to emphasize the sturdiness of the side rail. By lifting the mounting position of the vertical member in the head end of the side rail, the side rail will appear completely horizontal when collapsed.

To be compliant with new standards, the side rail has also been moved closer to the head end of the bed. This is a new standard that all new bed will have to comply with.

ill 87a: The original Scanbed 910 side rail



ill 87b: A new and sturdier side rail



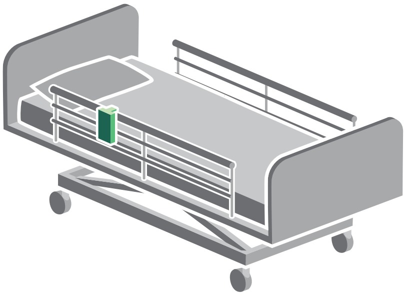
Interaction

The new side rail avoids the problem of having the release button in the wrong end, as it is now placed directly on the side rail. The round joint at the foot end functions as a large button to release the side rail locks. This will allow a smooth one-handed operation to collapse the side rail, unlike before.

To avoid the side rail from collapsing too hard, a gas spring is included in the tube at the head end of the side rail. This means that the side rail no longer slams loudly against the frame when collapsed. It's important that the correct resistance of the gas spring is found, so it collapses smoothly, but still is fast to fold down.

Controllers

The controllers are a very important touch-point for almost all the users; the patient, visitors, HCW, porters and technicians. They should always be available and easy to use for all the users.



The controllers must..

- Be separate for patients and HCWs
- Work on both sides of the bed
- Be able to deactivate patient's functions
- Be easy to use
- Be operable with one hand
- Accommodate new modules

HCW controller

The HCW controller should, like it is now, be a larger controller with more features. Currently it is sitting on the headboard at the footboard of the bed so that patients, that are confused cannot change any of the settings.

The HCW controller is meant to be primarily used by the HCWs and can therefore be a little more complex in its interaction and functions,

Functions

- Bed positions
- Trendelenburg and reverse-trendelenburg (special bed tilt positions)
- Lock patient's features
- Control 3rd party devices (such as pressure alternating mattress and weighing)
- Turn off air curtain
- Read patient's status and medical journal
- Control lighting

Patient controller

The patient controller is a smaller and more handy controller. It is normally sitting on the side rail, but patients can put it anywhere they want.

HCWs will often also use this controller as it is smaller, they can maintain their focus on the patient while adjusting the bed position.

When designing an interface where the main goal is ease of use and flexibility, it is important to know what the primary functions should be.

Primary functions

- Bed positions
- Turn off air curtain
- Call nurse

Secondary functions

- TV (small speakers and/or audio jack)
- Reading lights
- Control lighting
- Phone function

HCW controller

The HCW controller is the larger controller used by the HCW to modify any specific settings for the patients. Having a larger device to control modules such as an alternating pressure mattress will also help ensure that the HCWs use these modules correctly. Currently such modules' controls are obscure and correct use of the controls can be hard to remember for the HCWs as they give very little feedback.

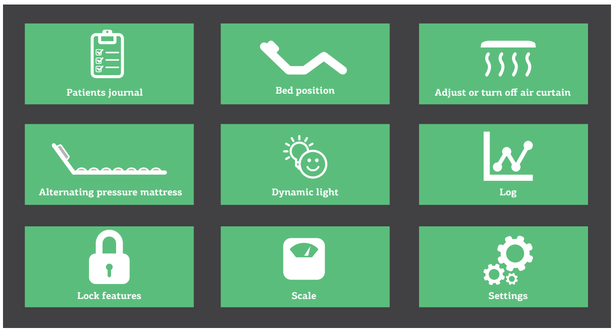
Different hardware possibilities were explored, please see "Appendix L" on page 144, to illure out what the basis for the controller should be. For the HCW controller a large durable tablet-like device is perfect. The large touchscreen ensures a great overview of the available functions and enables new features such as viewing the patient's journal.

Patient controller

Currently the patient controller is only used to control the bed position. Since it is just a film of physical buttons, it is very easy to use and understand and used often by both the patient and the HCW. This simplicity is the benchmark for the controller. To find out how such a new controller should be created, an exploration into different types of controllers were made. Please see "Appendix L" on page 144 This exploration showed that it is important that the controller has a large touch screen for the flexibility of supporting different modules, preferably with some kind of tactile feedback included (such as a Tactus panel ***(Tactus, 2014)***).

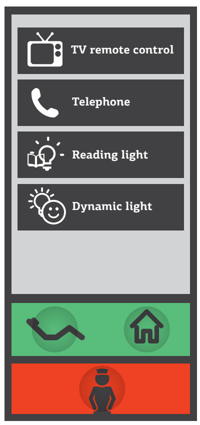
To ensure that the primary functions are always fast and easily accessed the controller is divided into two systems with a physical button for each of these systems, as well as a button to call a nurse. The two systems are: the bed position and a simple modular system to control all other functions.

It is important that both devices are extremely durable and easy to clean. To ensure this, the physical buttons and the touchscreen are part of one film, similar to how the buttons are now. To avoid accidental presses, the buttons should require about 5 N to be activated, similar to the current controllers.



ill 89b: the large HCW controller allows fine adjust of many features and modules

ill 89b: the patient controller in the bed position interface



ill 89c: the patient controller in the modular interface

The ventilation system consists of two Outlets that are installed under the bed and a overhead inlet. The overhead inlet also contains a lighting solution to increase the comfort and recovery of the patient

Overhead inlet

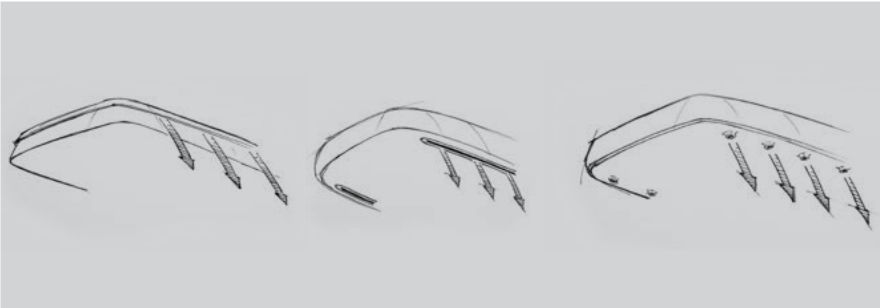
In the concept phase the decision was made to design an overhead unit mounted asymmetrically on a tube in the corner of the bed. The inlet is supplied with cleaned air from an air handling unit that is placed in the bed frame and sucking in air through two side Outlets.

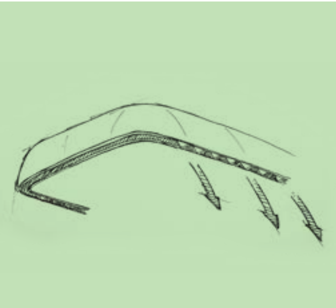
The overhead inlet must.

- Be lockable in position over bed
- Be removable when HCWs need to perform CPR or transfer patient with hoist
- Not obstruct view for porters when transporting bed
- Protect the patient from airborne pathogens
- Supply the patient with clean air
- Be easy to clean
- Be easy to service
- Incorporate user customizable lighting
- Be energy efficient
- Have an acceptable noise level
- Not create draft around patient
- Provide easy access to basic functions
- Withstand the load of a person hanging in the unit

Nozzle design

Throughout the detailing phase several nozzle designs was generated and evaluated. The design team saw the biggest potential in using ribs to guide the airflow as lower pressures were required compared to having a thin opening. Furthermore, this solution is easily integrated into the unit and easy to produce as no additional tool for nozzles is needed. It also offers a clean look from beneath as no visual slots are necessary on the bottom cover for discharging the air.



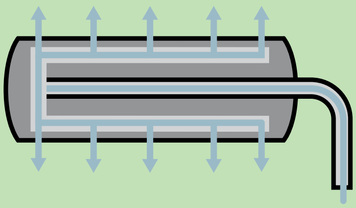


Optimizing airflow

CFD (Computational fluid dynamics) analysis in Solidworks has been used actively to define the internal design of the overhead inlet. None of the members of the design team are flow experts or have previous experience with flow simulation so the results were only used as an indication of the actual potential of each concept. A systematic iterative approach was taken where each design was modeled in Solidworks, tested for flow efficiency and then evaluated. The knowledge acquired from each iteration was used to improve the next iteration. The concepts were assessed by their ability to distribute the air equally amongst the nozzles, the direction and velocity of the discharged air as well as the overall pressure drop throughout the system. This approach proved to be a fast and effective way to gain valuable insight into how air behaves in a closed system.

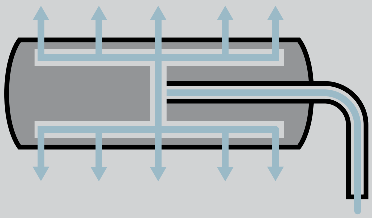
Flow concepts

All the designs tested were variations of the two overall designs shown in illustration 91a - b, which also point out the pros and cons for each design. In the first concept, the tube mounted on the bed frame, which channels the air to the overhead unit, goes halfway into the unit and then integrated channels spread the air to both sides. The only difference in the other concept is that the tube goes all the way to the end of the unit before it spreads into two channels. A total of 12 iterations were run before the final design was found. "Appendix N" on page 146 shows a direct comparison of all the iterations performed.



- ✚ Good distribution of air along the length of the unit
- ✚ Supports the unit all the way to the end.
- ✖ Large pressure loss
- ✖ High turbulence intensity

Ill. 91a: design where tube goes to the end of he unit



- ✚ Low pressure loss
- ✖ High turbulence intensity
- ✖ Poor distribution of air
- ✖ Doesn't support the unit in the end

Ill. 91b: design where tube goes to the middle of he unit

Result

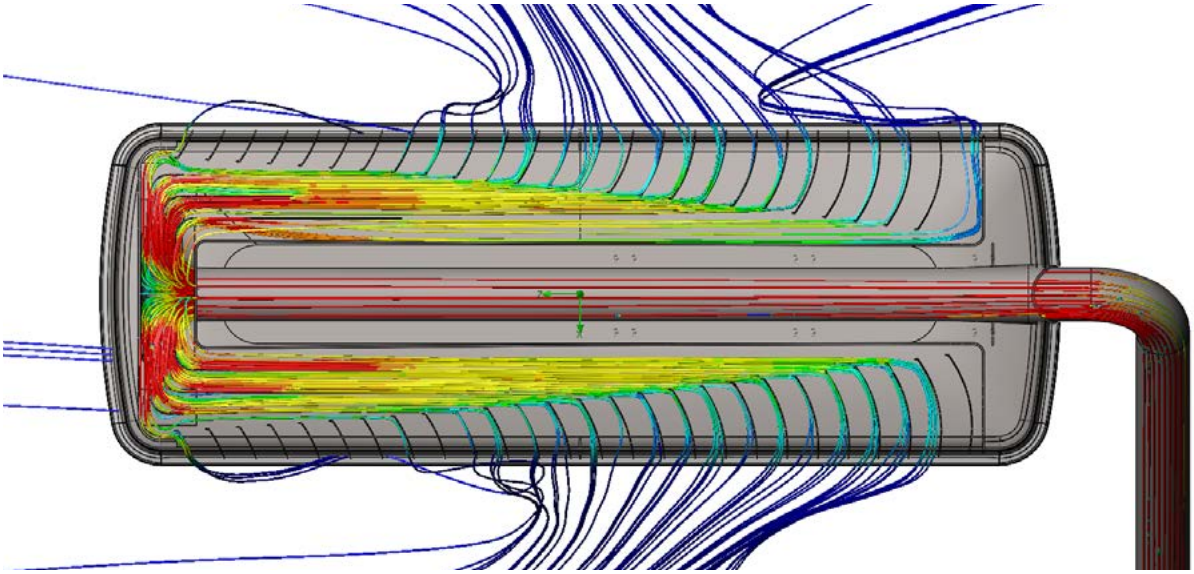
The CFD simulations clearly indicated that the air will exit the unit at one single point, rather than spreading over the whole opening, if it isn't guided properly.

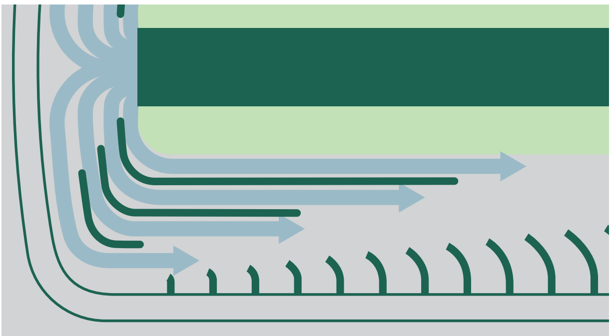
Having the tube only going to the middle of the main body and then splitting up into two channels proved to be ineffective in regards to directing the air properly. By adding additional guiding ribs the air distribution was improved, but still not to an acceptable level.

Extending the tube all the way to the end of the unit resulted in a much more even air distribution but also an increase in pressure loss of approx a factor of three. Besides from improving the flow, having a longer tube also has the clear advantage that the unit is much better supported. Based on this it was decided to focus on the concept with a tube all the way to the end.

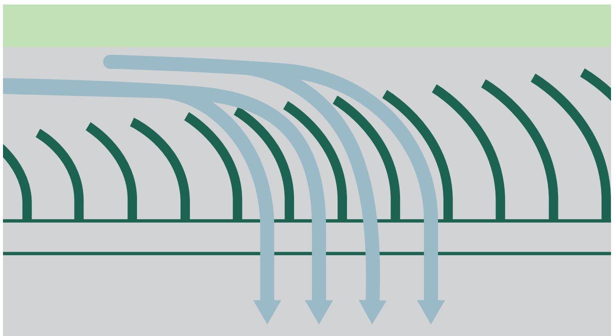
Internal design

The final design of the internal airflow consists of a supply tube that channels the cleaned air from the air handling unit to the internal cavity of the unit. When the air exits the tube it is divided into two channels by small ribs. These ribs ensure that the air is send straight down the length of the unit where it is collected by a series of ribs that increase in length the further away they are from the opening of the tube. These ribs have been given a curvature, which helps to reduce turbulence and guide the air so it leaves the unit with a more straight trajectory.





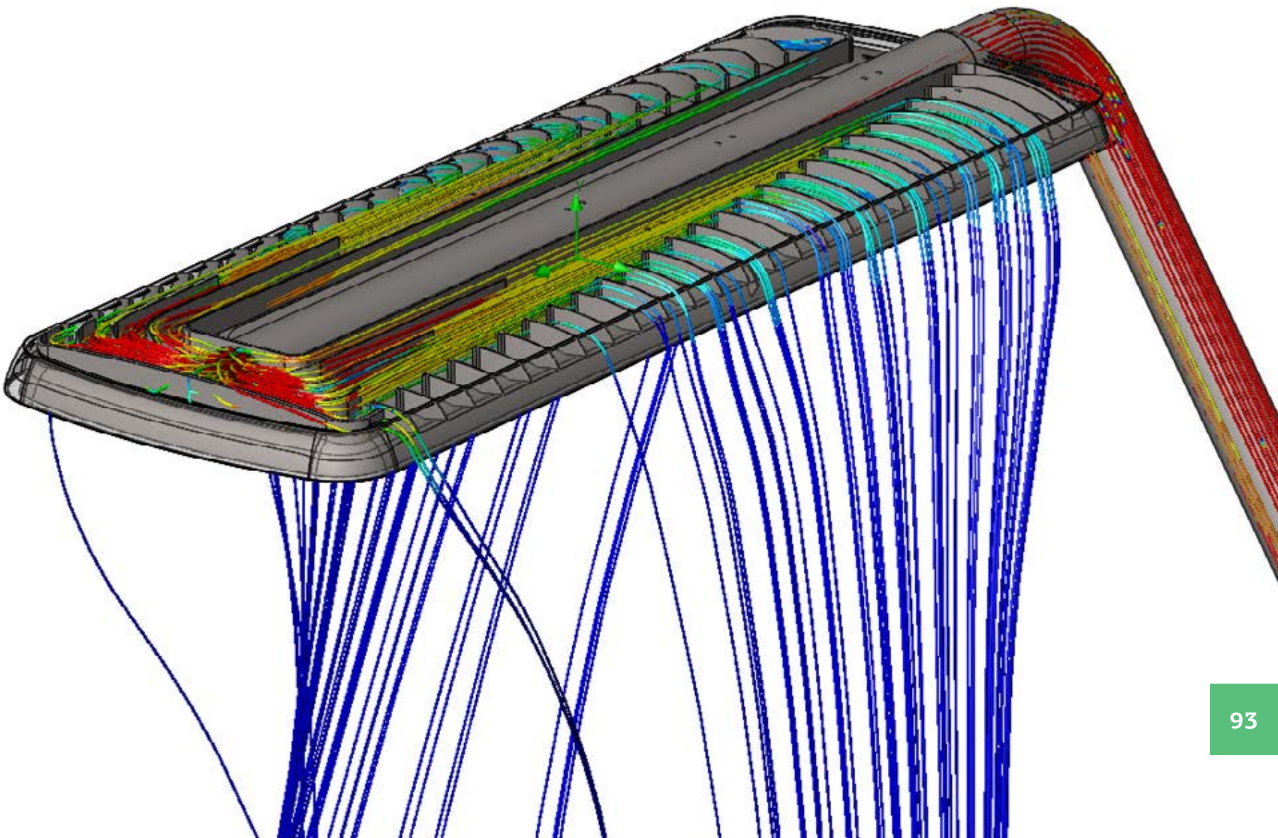
The ribs placed on both sides of the tube opening helps to guide the air so it gets evenly distributed amongst the nozzles. Without these ribs the air would just exit the unit at the first opening.



The curved ribs have been given a sharp edge to slice the air so it is separated more easily and turbulence is reduced. The air that doesn't get collected by the first rib will continue in a straight line without getting obstructed by the rib. This leads to a more even distribution of air between the nozzles.

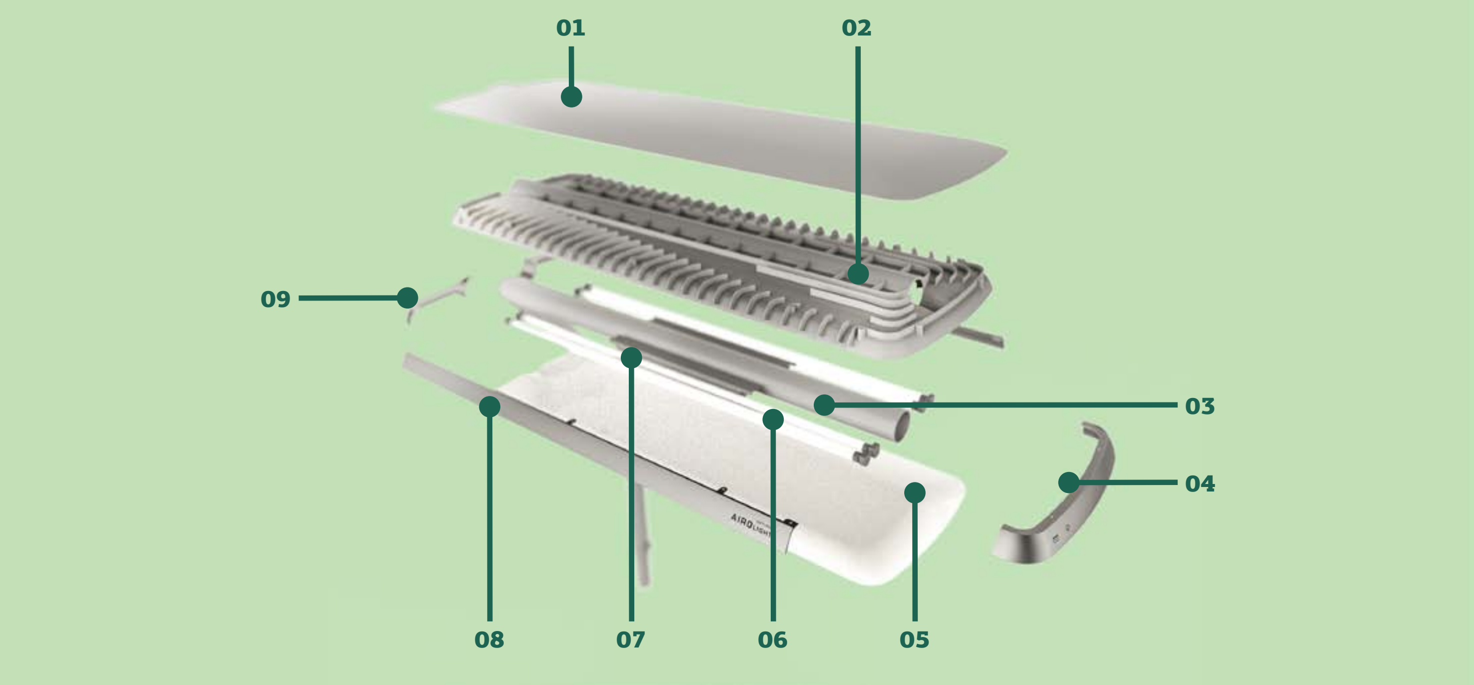
Air curtain

The success of the system relies on it's ability to create a protective air curtain on both sides of the patient. Some of the main factors that affect the quality of the air curtain is the volume flow and how evenly the air is distributed. Also the angle at which the air is exiting the unit is key. If the angle is too small the air will blow directly at the patient thus creating an uncomfortable draft that can be directly harmful for the patient. If the angle is too big on the other hand, the air discharged from the unit will get blown out into the room without getting collected by the Outlet. The angle of the exiting air is directly derived from the inside angle of the side guide. By running a few simulations with different angles it was possible to find an appropriate angle.



Components overview

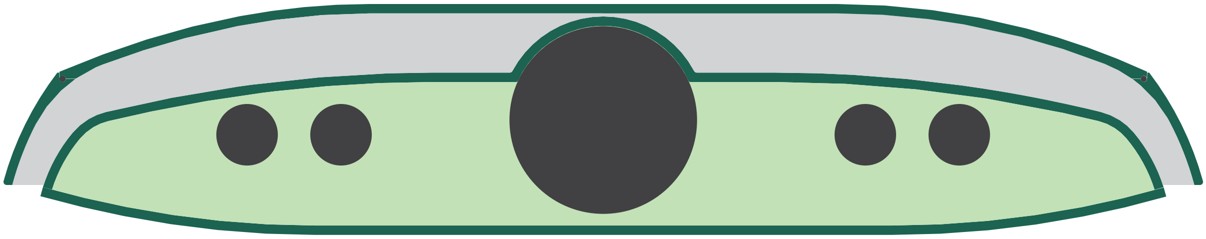
The overhead inlet consists of a main body in die casted aluminum onto which a top plastic lid is mounted as well as side guards on all sides. On the bottom of the unit the dynamic lighting solution is mounted as well as an opal diffuser, which also acts as a bottom cover.



- 01: Lid - Injection molded in ABS
- 02: Main body - Die casted in Aluminum
- 03: Tube - Powder coated steel tube
- 04: Front guide - Anodize die casted aluminum
- 05: Diffuser - Vacuumformed PMMA, Opal
- 06: Fluorescent Lamp - Philips MASTER TL5
- 07: Fluorescent Dimming Gear - Philips HF-Regulator
- 08: Side guide - Anodized extruded profile
- 09: Rear guide - Anodized die casted aluminum

Assembly and servicing

The unit can be divided into two sections. The bottom section of the unit is where the fluorescent lamps and the HF-regulators are mounted. This area should be accessible for the end users so lamps and regulators can be changed if necessary. The top section of the unit consists of channels where the airflows and where an airtight seal is required. This section of the unit shouldn't be accessible for the end-user, as they might accidentally damage the seal, thus reducing the effect of the inlet. To attain a natural partition of the unit it has been decided to mount the top lid from underneath so there are no visible screws on top. To achieve this the top lid is equipped with threaded brass inserts that have been placed into the molding cavity during the injection molding process, which means that they are completely encapsulated. The top lid, the side guards and the main body are then fastened together by bolts inserted from below. If the lamps or regulators needs to be changed only the bottom cover has to be removed, whereas the unit will have to get send back to Invacare for servicing if there is something wrong in the top section of the unit.



Cleaning

To make it easier for the cleaning staff to keep dust and grease off the overhead unit, all surfaces have been made large and smooth. Furthermore, the top lid is completely without visible screws as it is fastened from below, which means that there are less cracks where grease can accumulate.

The buttons in the front of the unit for quickly switching on and off light and air curtain are touch buttons. These touch buttons make the front significantly easier to keep clean compared to regular push buttons where grease can gather in the small gap between the button and the material around it.

It might be difficult for the cleaning staff to reach on top of the unit to wipe it off if the bed is in a high position. To make it easier to clean the inlet panel, the bed can be lowered or the panel can be swung to the side so leaning over the bed is avoided.

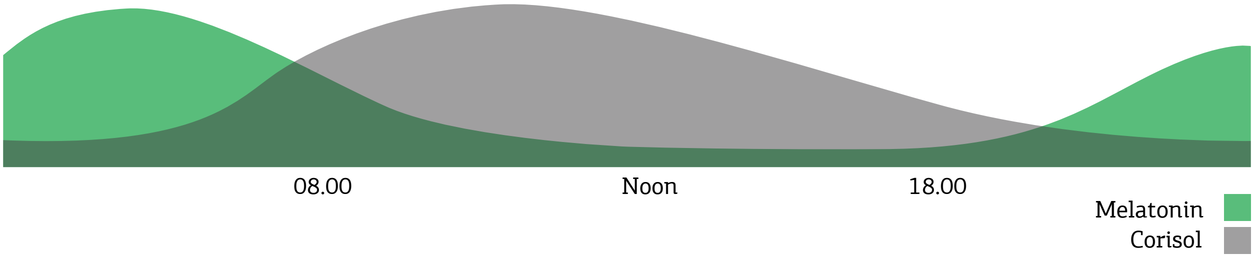
Cleaning routines vary from hospital to hospital. According to the cleaning staff interviewed at the Department of Nephrology at Rigshospitalet during the concept phase, beds are only properly cleaned between each patient. In many hospitals the same will most likely be the case for the overhead inlet, which means that cleaning staff won't have to clean the unit while a patient is in the bed that often.

Lighting

A dynamic lighting solution has been developed as an integrated part of the overhead inlet. Hospital lighting specialist Anne Marie Lund from Philips lighting has been consulted regarding component specification and selection as well as expert advice on lighting design.

The biological clock

Light and darkness influences our health and well-being and the cycles of night and day actively regulates our biological clock as our hormone levels rise and fall with these light cycles ***(Healwell, 2014).*** The illustration below shows how cortisol production increases with morning light and decreases throughout the day. Melatonin levels on the other hand increase as darkness sets in and decrease as morning approaches. Because patients spend most of their time indoors they are particularly at risk of getting insufficient light during the day to set their biological clock properly ***(Healwell, 2014).***



Night

Low light level to achieve an undisturbed good night's sleep

Dawn

Cool increasing levels to raise the energy level

Day

Cool to warm light with decreased light levels to provide a break and refresh

Dusk

Warm light levels to relax and start melatonin production

Dynamic lighting

Dynamic lighting is a term commonly used in lighting design. According to Philips, ***"Dynamic lighting is an advanced solution that brings the dynamics of daylight indoors. It creates a stimulating, 'natural' light that enhances people's sense of well-being."*** *(Philips, 2014).*

A study performed by Clinical Trial Centre Maastricht and Maastricht University showed how the use of dynamic lighting that mimics the natural daylight cycle can be used to improve patient and staff satisfaction. Compared to conventional lighting the patients experienced longer sleep durations and shorter time to fall asleep as well as enhanced mood ***(Healwell, 2014).*** The design team sees great potential in incorporating a dynamic lighting solution into the overhead unit. The positive effect on patients' well being combined with the protective air curtain helps to create a safe healing environment for the patient.

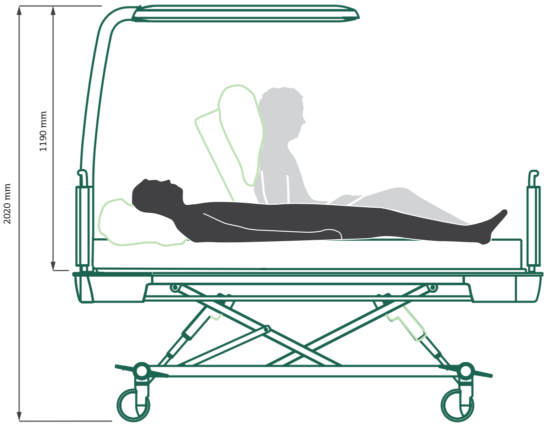
Lighting design

The lighting solution for the overhead inlet builds on the principle of dynamic lighting. The solution consists of two 14W TL5 fluorescent lamps with a warm color temperature of 2600 K and two 14 W TL5 lamps with a cold light temperature of 6500 K. These are controlled by two Philips DALI HF-Regulators that can alter the light output of the lamps, thus making it possible to vary the color temperature seamlessly between the two values. The reason why four lamps is used instead of just two is to achieve a more smooth blending of the color temperatures. Only using two lamps would most likely result in a noticeable difference in color temperature from one side of the unit to the other. The DALI HF-Regulator can be programmed to follow a time schedule which makes it possible to make predefined programs that mimic the natural daylight cycle. It's also possible to have predefined settings for examination light, reading light, night light etc, that can be activated via the patient or HCW controllers.

Diffuser

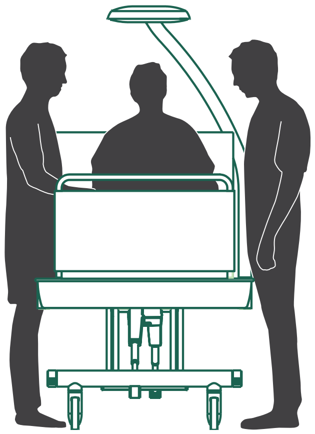
It's important that the light is sufficiently diffused to avoid uncomfortable glare and achieve a smooth blending of the different color temperatures of the lamps. This is achieved by passing the light through a translucent vacuum formed PMMA cover. Both Acrylic Satine and anti-reflective Acrylic Opal are suitable for lighting fixtures because of their good optical properties. Acrylic Satine is more than twice as expensive so test samples and data sheets need to be collected and compared to define the correct material. One thing that might prove to be a problem with the current design is the limited distance from the diffuser to the fluorescent lamps and the center tube. If the distance is too small the outline of the fluorescent lamps might be visible through the cover and a shadow from the tube might be present in th middle of the diffuser. According to Anne Marie Lund from Philips Lighting there is not a defined guideline for choosing an appropriate distance, instead tests are often used.

Usability



Dimensions

The workshop described in “Patient experience” on page 64 showed that if the unit is too low or two wide it might feel a bit claustrophobic for the patient. Especially if the patient is sitting up as the distance to the overhead inlet is decreased. The proper dimensions of the unit were established based on the input from the participants from the workshop, own tests with different heights as well as practical considerations. One of the practicalities that limits the height is that it should be possible to pass through a door with the bed at its maximum height without the unit hitting the door frame. This resulted in a height of 1190 mm over the bed frame and a total height of 2020mm.



Asymmetric design

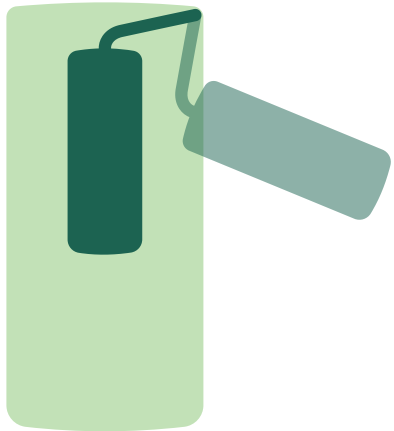
The heavy-duty holes in the corners of the bed frame are used for mounting the overhead inlet. This creates an asymmetric design, which is desirable for a number of reasons. First of all it significantly improves the view for the porter compared to a centrally mounted solution (See “Appendix J” on page 141). Secondly it enables the HCWs to access the patient from all sides and makes it easy to swing away the unit if needed. This is especially important if the HCWs have to perform CPR.

CPR

The procedure for performing CPR is folding down the side rails and backrest and removing the headboard so there is sufficient access from all sides. One HCW will get up into the bed to perform CPR or stand on the side if the bed is low enough. If there is other HCWs present they will stand on the opposite side of the bed and at the head-end and help ventilate the patient. This clearly emphasizes the importance of being able to easily swivel the inlet to the side so proper working conditions can be achieved.

Swinging and locking mechanism

The overhead unit takes up additional space when it is swiveled to the side. Some patient rooms have limited space on the side of the bed, which would limit the range of motion of the unit. The current solution can't be mounted on the opposite side of the bed so it would most likely be necessary to offer a mirrored version. This is not a very flexible solution so it would be relevant to investigate if other methods for removing the unit can solve this issue.



Noise

It's very important that the noise generated by the system is kept at an acceptable level. If the unit is too noisy it will be uncomfortable for the patient and the system won't be used. Unfortunately completely removing noise is impossible as moving air creates noise and the higher the velocity of the air the higher the noise. There is currently no way of directly predicting noise levels using CFD analysis and making physical tests doesn't give a proper indication of the noise level unless the correct materials, components and geometry is used. Indoor-environment expert Peter V. Nielsen and research assistant Siamak R. Ardkapan have been consulted and they confirm that a certain amount of noise is inevitable, but can't give any indication of how much. This means that the noise level is still unknown and one of the critical elements that have to be properly investigated. To ensure the unit can run without causing a nuisance to the patient, a noise level of 40 dB is the goal to strive towards.

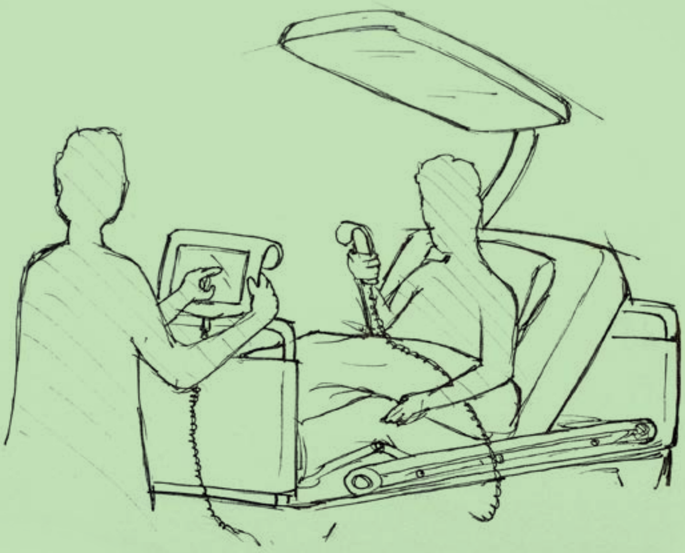
Trendelenburg tilt

Scanbed 910 allows for a 12^0 trendelenburg tilt, which the new bed should also be able to perform. If the bed is standing against the wall there is a small risk of the overhead inlet tube hitting the wall. But in all the hospital rooms that have been visited during the research phase the beds have been placed at a distance from the wall. This is partly because of the aluminum profile mounted on the wall behind the bed and partly to get better access to the patient. Furthermore, the tube doesn't take up more space than the lifting pole currently used on some beds, so accidentally hitting the wall is not seen as a problem. Adding a small bumper on the tube could be an easy way of preventing the tube from making visible makrs on the wall in case it actually hits the wall.

Interaction

HCW controller

The HCW controller can be used to adjust both light and the air curtain. The HCW can activate predefined dynamic light programs as well as adjust basic settings for the air curtain such as setting a timer. The HCW has full access to all controls of the bed and also has the option to lock specific functions on the patient controller, which can be necessary if the patient is not capable of handling certain functions.



Patient controller

By default the patient has access to all light and air settings. The intention is to enable the patient to create their own atmosphere and as a result feel more in control of his/her environment. Settings include dynamic lighting that mimics daylight, reading light and custom adjustment of light level and color temperature. The patient is also able to turn on and off the air curtain unless the HCW locks this function.

Quick adjustments

The aluminum profile in the front of the unit has been equipped with touch buttons where the HCW or a visitor can manually override the current settings. There is only two options, which is turning examination light on and off and turning the air curtain on and off. This makes it possible for the HCW to quickly switch off the air curtain and turn on the examination light without having to find the settings on the controller. There is a small light indicator beneath the icon for the air curtain to give a visible indication whether or not the air curtain is activated. This enables the HCW to see if the inlet is on or off from a distance without having to walk over and feel for themselves.

Details

Tube

To obtain a smooth transition where the circular tube meets the rounded rear face of the unit, the aluminum guide opens up and encircles the tube, thus creating a visible outline around the tube. Furthermore, both the top lid and the bottom cover has a small curvature that meets the circular tube and highlights the joint.

Side guide

The side guide, which covers all sides of the unit consists of several individual parts. Instead of trying to hide where these parts meet the joint has been highlighted by introducing a small gap, which also help to hide any minor inaccuracies. The logo for the AiroLight system has been added for easy identification of the system as well as an aesthetic element.

Diffuser

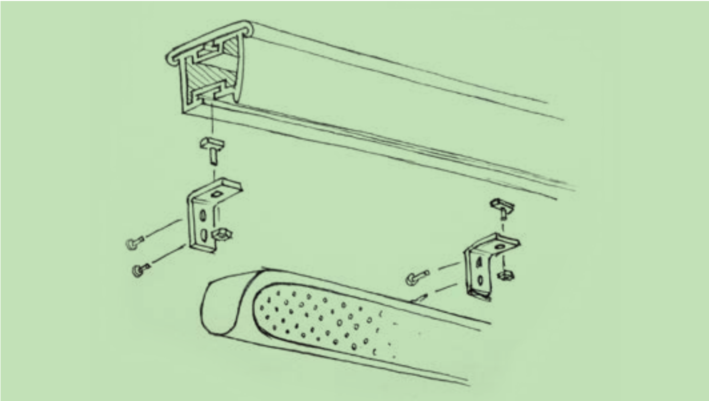
The gap created by the opening where the air exits the overhanging inlet creates a visual distinction between the diffuser and the rest of the unit. By continuing the gap all the way around the unit the opal translucent surface gets a dark outline which makes it stand out.

Under bed Outlet

The under bed Outlet must.

- Effectively suck in a large fraction of the discharged air from the overhead inlet
- Be easy to mount and remove
- Be easy to keep clean
- Include a pre-filter for removing larger particles
- Be designed for autoclaving
- Be unobtrusive

Mounting



The Outlet is part of the modular platform and should consequently be easy to mount on the bed and connect to the air handling unit. The aluminum profile, which is part of the top frame of the bed, has a T-slot where a T-bolt can easily be inserted. Subsequently the brackets are screwed onto the profile and then the Outlet itself. If the Outlet needs to be removed the sequence is simply reversed. The rib on the aluminum profile effectively covers the joint so a clean look is obtained from the front.

Dimension

In the concept refinement it was decided to give the Outlet unit similar length as the inlet. This was done to ensure that as much air as possible discharged by the overhead inlet is recirculated into the system. Increasing the length of the unit wouldn't change the amount of air sucked in, but only reduce the fraction of air coming from the inlet. The hight of the Outlet was defined based on smoke tests as well as the available space in the bed frame. To properly define the most effective hight, additional CFD analysis and more refined physical tests have to be performed.

Production and material selection

The main body of the Outlet is rotational molded in PE. This plastic molding technique allows for complex hollow shapes with integrated features. Four threaded brass inserts used for mounting the unit are placed into the mold cavity as well as one threaded connection tube in PE. The inserts are encapsulated by the plastic during the molding process thus creating a permanent bond. The front of the unit is afterwards milled in a machining center to create an opening for the air to pass through and a flange for mounting the front cover.

The front cover is made from a laser cut aluminum sheet, which has been given a slight curvature in a sheet metal roller. Subsequently the cover is anodized to increase its corrosion resistance while still keeping the raw aluminum look. The anodized aluminum can stand up to repeated autoclave sterilization.

Cleaning

Designing an easily cleanable Outlet is rather difficult as the air needs to be guided into the Outlet thus inevitably dividing the surface into smaller sections where grease can gather. The goal in this case is to minimize this effect as much as possible and allow for an easy way to remove trapped grease. To achieve this a single cover is used rather than having individual ribs. For the daily cleaning the cover can be wiped off with a cloth. This will keep the surface clean but won't remove grease trapped in the holes, so between each patient a more thorough cleaning is required. The front cover has been equipped with a sliding lock mechanism that holds the cover in place and allows for easy removal. This makes it possible to remove the cover and put it in an autoclave to completely sterilize it.

Pre-filter

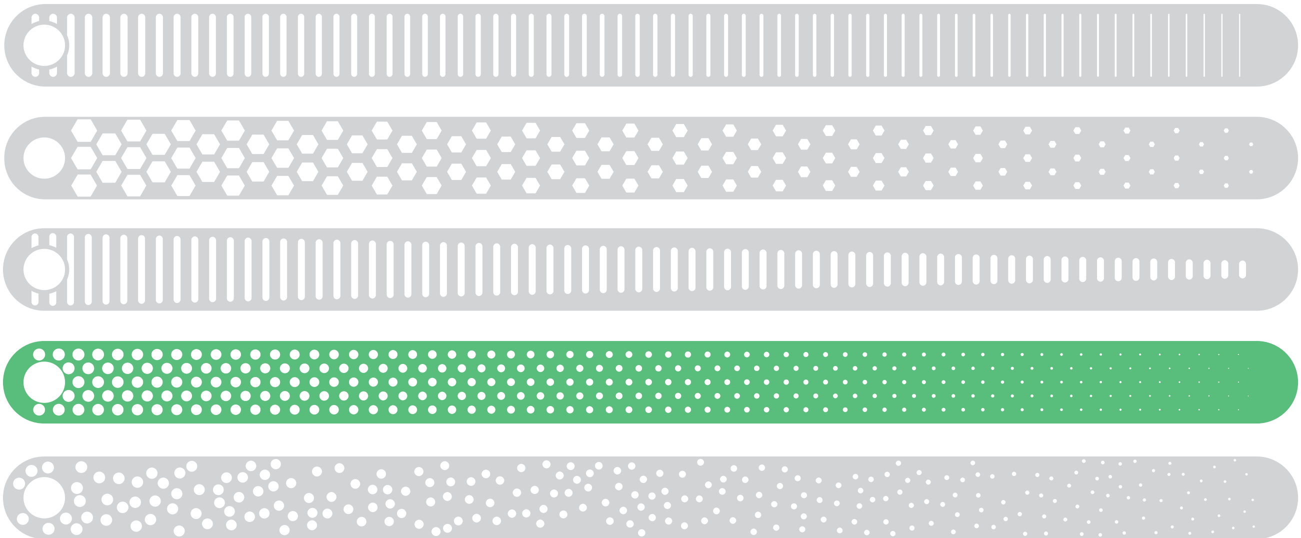
The pre-filter is clicked onto the back of the front plate. The main purpose of the filter is to prevent larger particles and dust from entering the air handling unit. This is common practice for increasing the lifetime of the HEPA-filter. The filter can easily be detached from the front plate without any tools and then emptied by sucking the dust off with a regular vacuum cleaner.

Effectiveness

The Outlet has been designed to suck evenly along the length of the surface. Normal Outlet designs doesn't bother to create an even suction because the volume of air it sucks in will remain the same no matter how evenly it is distributed. But in this case it is beneficial to target the air discharged from the overhead inlet to recirculate as much air as possible.

If the holes had the same size and was evenly distributed over the surface it would mean that the fraction of air entering the Outlet would be significantly higher at the head-end where the tube is connected to the Outlet. To avoid this the surface area at the head-end is made small and then gradually increases along the length of the Outlet.

Various different patterns have been generated. It was decided to go with a simple pattern with round holes as this matched the overall aesthetics of the bed the best.

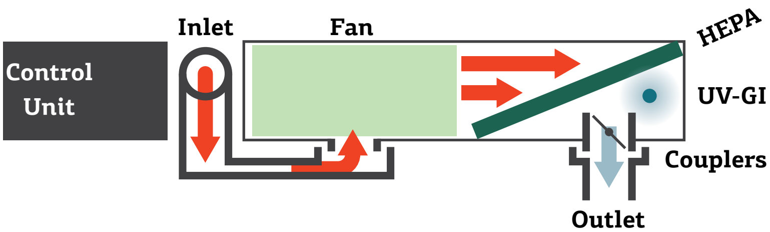


OPTIMUS MULTIAIR

The air handling unit is meant to be installed in the expansion bay in the bed frame and act as a device that will be used to accommodate many different modules, hence the name “MultiAir”.

The air handling unit must..

- Have two Outlet couplers
- Have one inlet coupler
- Support and run different modules simultaneously
- Automatically maintain required static pressure for each Outlet
- Contain powerful fan
- Contain air purification (HEPA + Carbon filter + UV-GI)
- Be quiet



Components

As mentioned in “Components” on page 58 the components that are necessary to the air handling unit is: a fan, a filter, dampers and coupler. All of these components must fit into the expansion bay which only measures 630 x 367 mm while the couplers should be accessible and not interfere with any of the bed's mechanical parts.

The fan

The fan must be powerful as it should be able to run both the Optimus AiroLight and other modules such as a pressure altering mattress.

The Optimus AiroLight module requires 40 l/s at XXX Pa of static pressure. Besides the pressure loss in the inlet module, there is also a pressure loss in the HEPA filter and tubing. While the additional pressure drop is not calculated it is estimated to be less than 100 Pa. The chosen fan is a backwards curved centrifugal fan K2E 225-RA92-01 from EBM-Papst, as it can supply 215 l/s at 300 Pa with a noise level of 65 dB, please see "Appendix O" on page 150 for a comparison of different fan models.

Filtering

The filtering process consists of a HEPA filter, a carbon filter and a UV-GI light. Since HEPA filters are easily produced in any shape and size, it is designed to have as large of an area as possible, while still being able to fit into the unit. The filter is placed diagonally to make the area, the air passes, as large as possible. On the outside of the HEPA filter there is included a thin carbon filter to reduce most of the smells normally associated with a hospital.

The UV-GI light is a 25 W bulb that is positioned right next to the Outlet dampers as it is important for the efficiency of the UV lights that as much air as possible passes by it. Since UV-GI is as harmful to human skin as it is to germs, some precautions must be taken ***(Kristensen)***. There must be a breaker switch that is automatically activated when the top lid is off to avoid accidental exposure. When something is disconnected from the couplers, the UV must also shut off until the damper has sealed the air handling unit again.

Couplers

The Outlet couplers (the ones the inlet module connects to) must have dampers, pressure measurements and electric connectors. The dampers must be able to create a good seal when closed to maintain the static pressure while adjusting the flow through the Outlet to compensate for the requirements of different connected modules. The electric connectors are an important part of the Outlet connectors as some connected modules, such as the AiroLight module, can require both power and a data link to the OpenBus control unit.

Optimized for noise

To reduce the noise as much as possible in air systems, three tings can be done: reduce vibrations, absorb noises and avoid turbulence. To reduce the vibrations, which are mainly caused by the fan, the fan is installed in a vibration reduced housing by the OEM manufacturer. To isolate and absorb the noises, the air handling unit has a case within a case construction, where the cavity between the cases are filled with a noise reducing polyurethane foam. Lastly to avoid turbulence all connections will be done with rigid tubing instead of flexible hoses.

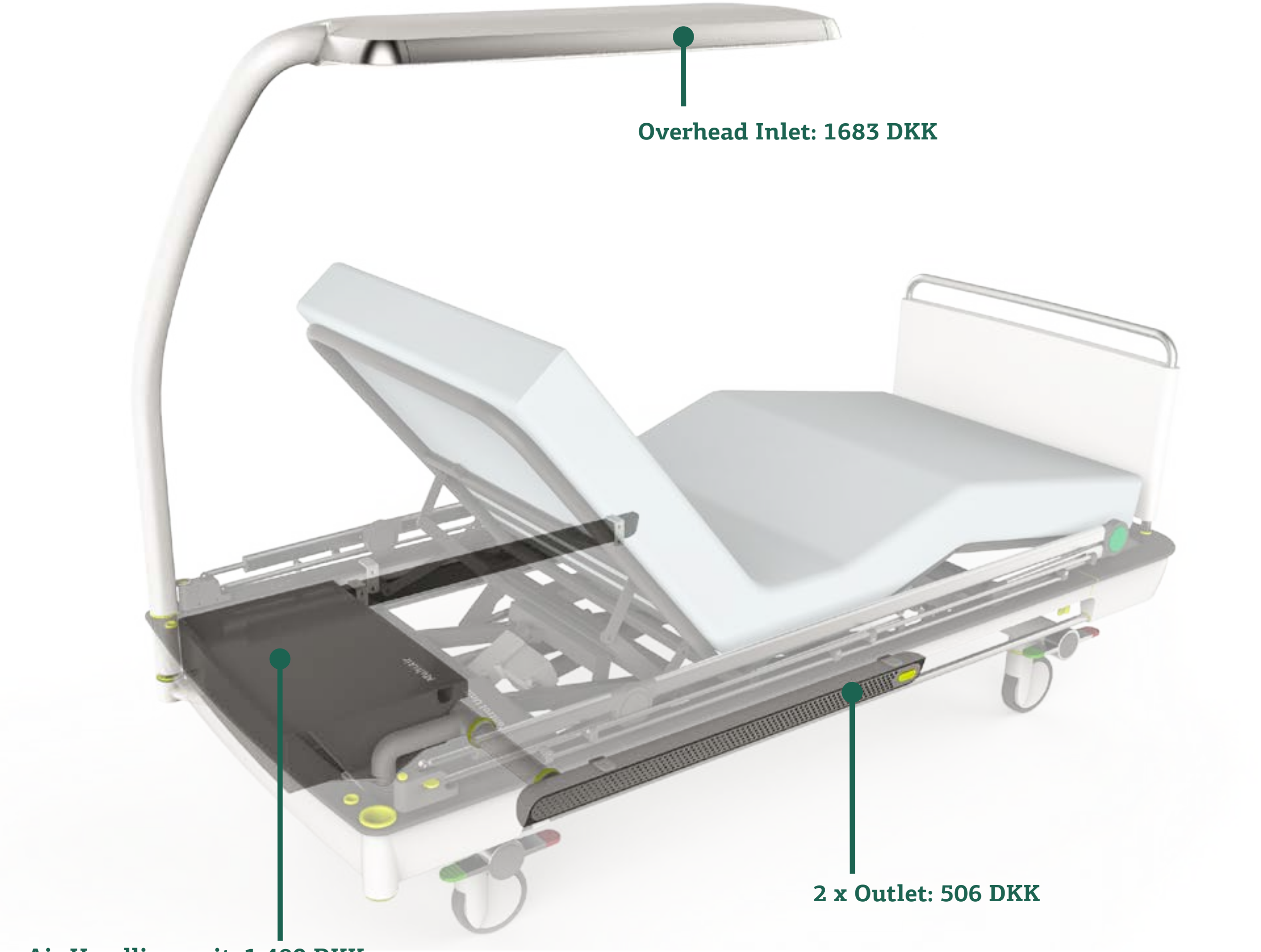
Servicing

The air handling unit contains two components which require periodic changing. The HEPA filter and the UV light will have to be changed about every two years of constant use. The top lid is screwed on with finger screws to make this servicing easier. When the lid is taken off, the technician will have access to all of the components.

Since most of the components are not the correct IP class to allow the device to go into a bed washer. Either the unit will have to be removed if a washer is used, or the inlets and Outlets will have to be sealed.

Economy

It was decided not to calculate the cost price of the bed itself as it would take too much time and instead focus on calculating a realistic cost price of the ventilation system.



A cost price for the ventilation system has been calculated and a detailed version can be found in "Appendix Q" on page 152. Actual price quotes from manufacturers represents 68% of the total cost price calculated, whereas the rest is based on rough estimates. To account for the inaccuracy of the estimation, 10% was added to the price.

The selling price should relate to the amount of money that can be saved by reducing HAIs, staff sick days and hospitalization time. Furthermore, the running costs of the system should be accounted for. For obvious reasons the design team haven't been able assess the impact, the ventilation system potentially has on these parameters, which makes it difficult to define an appropriate sales price.

Key illures

Total cost price: 4.150 DKK (10 % insecurity)

Tool investments: 580 t.DKK

Best case

Sales price: 12.000 DKK (incl. VAT)

Sales price: 9.600 DKK (excl. VAT)

Cost price 4.150 DKK

Gross margin: 5.450 DKK

Margin: 57 %

Worst case

Sales price: 8.000 DKK (incl. VAT)

Sales price: 6.400 DKK (excl. VAT)

Cost price 4.150 DKK

Gross margin: 2.255 DKK

Margin: 35 %

Buyer behavior

Based on an interview with Medical Specialist Leif P. Andersen, who is responsible for testing and implementing solutions for reducing infections at Rigshospitalet, a maximum acceptable price of approx. 8.000 - 12.000 DKK was defined. This offers a profit margin of 35 - 57 %, without taking depreciation of tools and development budget into considerations.

According to Leif P. Andersen hospitals are rater conservative when it comes to implementing new solutions. As an example the department of Nephrology at Rigshospitalet are currently running a 6 months test on a new air purifier from Novaerus to assess whether or not the health benefits outweigh the costs of implementing the system. This is very important to take into consideration as it clearly illustrates that the hospitals are very focused on being able to validate the potential of a new solution before they invest in it.

Another important factor is that hospitals normally send out request for tenders when they are to buy new hospital beds. These are often very specific and focused on price, which means that adding 8.000 - 12.000 DKK on top of the bed's price might make it uncompetitive.

To accommodate the hospitals need for validation and low initial investments a business model including a leasing system has been developed. The leasing system takes advantage of the bed's modularity by offering a standard bed that lives up to the specifications in the tenders and should be comparable with competitors in regards of price. The AiroLight and the MuliAir systems, as well as other modules can then be leased by the hospital afterwards. This allows the hospital to lease the modules they need when they need them. Furthermore, it provides the hospital with an ideal opportunity to test the system properly without any large initial investments. The Business model can be seen on page 110.

Output

A rough cost price has been calculated for the ventilation system as well as a worst and best case for the gross margin. The price of the ventilation module would significantly increase the total price of the system, which as a result would lower it's competitiveness in tenders. As a result it was decided to separate the sales into direct sales of the Optimus modular bed and leasing for the range of modules offered for the bed.

Business model

A business model has been generated for the Optimus Modular bed, which relies on Invacare selling a standard modular bed by itself and then offering leasing agreements of the modules.

Key Partners

Sub suppliers

ebmpapst

PHILIPS

LINAK

External manufacturers

sapa:

HekaDanmark

Key Activities

Production

Marketing and sales

Logistics

Continuos development of the Optimus platform

Key Resources

Human
Sales, Customer service and Development

Physical
Production facilities

Value propositions

Optimus Modular bed

Customizable to meet specific needs

Low initial investment and risk

MultiAir and AiroLight

Reduction in HAIs

Reduction in length of hospitalization

Customer Relationships

Dedicated personal assistance

There is a sales person for each client, thus offering dedicated personal assistance

Channels

Outreach (Visit, call)

Network and reputation

Website

Customer segments

Business to business

Primary segment is Hospitals and secondary is private hospitals

Cost Structure

Fixed costs
Production, administration, rent of facilities, heating, electricity etc.

Variable costs
Development, Internal and external salaries

Revenue Streams

Optimus modular bed
Direct sales

MultiAir, AiroLight and other modules
Leasing and direct sales

Leasing

The business model is based on business to businees sales of the Optimus bed directly to hospitals, primarily through tenders. As a secondary revenue stream, modules for the Optimus platform are leased to hospitals.

Various different leasing agreements can be made to fit the specific customer's needs. Modules like the AiroLight would make sense to lease on a monthly or yearly basis whereas modules such as pressure alternating mattresses, which can be plugged into the MultiAir unit, might be leased on a daily or weekly basis. Companies such as Arjohuntleigh already offers leasing of pressure alternating mattresses, which cost in the price range of 100-180 DKK a day ***(Arjohuntleigh, 2014)***. As a reference the microAir mattresses from Invacare costs 43.000 DKK. By using the MultiAir unit for both the ventilation system and for a pressure alternating mattress a reduction in leasing price could potentially be achieved. This would make the system more competitive and act as an additional unique selling point for choosing the Optimus modular platform.

Leasing the modules rather than selling them allows for continuous updating of the system as well as the option to easily add new modules or remove modules that aren't successful. In the long run it would be cheaper to buy the system rather than leasing it, so an option would be to offer a reduction in price if the hospital decides to buy modules that they have been leasing. This makes it possible for hospitals to test a module for a while and then buy it afterwards, if it has been a success.

Market potential

To assess the potential of the new system it's important to know what the market size is and estimate what market share can be expected.

As stated by a report from the Central Denmark Region an estimated total of 3132 beds is needed for the entire region when the new hospitals, that are to be build by 2020, are finished ***(Regionmidtjylland, 2014)***.

If it's assumed that the same amount of beds per citizen is needed in the other 4 Danish regions, this adds up to 14.921 or approx. 15.000 beds in total in Denmark. The report doesn't state how many of these bed are new and how many are reused. But if an average lifetime of approx 15 years per bed can be expected this would mean that 1.000 new beds is needed in Denmark every year.

According to Product Manager Ninna Lund from Invacare, more than 80% of the hospital beds on the Danish market today are from Invacare. If Invacare is able to keep this market share it would lead to a yearly sales of approx. 800 beds.

This is off course a simplified calculation of the market potential but it gives an indication of the size of the market and what the potential is. The intention is that the new Optimus modular bed should be able to completely replace the old Scanbed 910. In practice it would properly be necessary to gradually make the switch to the new bed thus selling both Scanbed 910 and Optimus for a period of time, until the bed is completely implemented.

The design team also sees great potential in expanding to other European countries. Assuming that the other European countries has the same hospital bed to population ratio it would mean that a total of 1.3 million beds is required in Europe or approx. 90.000 beds per year, if an average lifetime of 15 years is assumed. Again this is just a very rough estimate but it serves as an indication. Invacare currently only focus on the Danish market in regards of hospital beds, but is present in over 80 countries with their range of home and long-term care medical products. This means that it's already a well established global brand, which makes it easier to expand the line of hospital beds to other countries. A strategy could be to start with Norway and Sweden, which have more similar requirements for hospital beds than is the case with countries south of the border.

Denmark

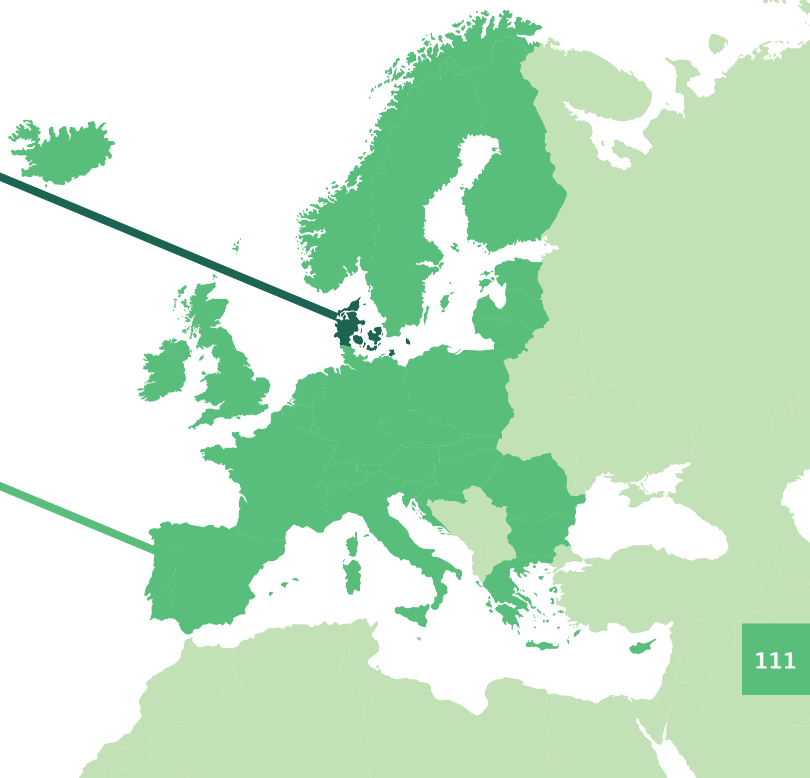
15.000 beds in total

1.000 new beds needed per year

Europe

1,3 million beds in total

90.000 new beds needed per year



Summary

Conclusion

This conclusion will follow up on the problem statement: ***"How to use air as an "open" isolation and personal ventilation to reduce hospital acquired infections"***, the value mission and interaction vision in relation to the ventilation system and the modular bed.

The primary focus of the project has been on the ventilation system, which consists of an inlet, an Outlet and an air handling unit. The air handling unit is equipped with a centrifugal fan that draws air into the system and passes it through a HEPA filter, a UV lamp and an active carbon filter, which in combination cleans the air of contaminants and removes unwanted smells. The cleaned air is channeled to the overhead inlet where it is discharged through a set of nozzles thus creating a protective air curtain on both side of the patient.

To support the ventilation system and to create a platform that makes it possible to expand the concept, a modular bed has been designed. The new bed is an upgrade of the Scanbed 910. The scissor lift principle and the mattress frame have been reused, but the rest of the bed has been updated to add modularity to the bed. The modularity is achieved by using aluminum profiles for the bed frame where different modules can quickly be mounted as well as having an expansion bay where modules that require larger functional parts can be installed.

Value mission

A value mission consisting of three descriptive words with associated metaphors has been used actively through the project as a guiding star for the design process:

- Unobtrusive
- Reassurance
- Comfort

The design goal for the overhead inlet was to create a visual element that would make the patient feel protected. At the same time it needed to be unobtrusive in the sense that it shouldn't be in the way for the HCW and even more importantly the patient shouldn't feel a draft from the air curtain or get affected by noise from the system. These parameters helped to choose the final concept, as both CFDs and usability tests indicated that having the air curtain coming from above was the least obtrusive of the potential solutions. The final design ended up being asymmetric to give staff access to the bed from all sides and swingable so it can easily be swiveled away if the additional space is needed.

Comfort, especially for the patient, has also been a main concern affecting the design. This is reflected in the design of the dynamic lighting solution, which has been integrated in the overhead inlet. Via the controller the patient has full control over the lighting thus enabling them to create their own atmosphere and as a result feel more comfortable and in control of their environment.

Interaction vision

Special attention has been given to providing HCWs with inherent feedforward that clearly indicates which parts of the bed that can be manipulated and what kind of interaction is needed for doing so. This is achieved by highlighting all the areas on the bed that has an interaction with a yellow accent color as well as using buttons that clearly indicates if they are to be pushed, pulled or slided.

Attention has also been given to areas where the user needs an inherent feedback, that an action has been performed correctly. An example is the locking mechanism for the overhead inlet tube, which is designed to provide the user with a confirming clicking sound as it is returned to it's position over the bed.

Implementation

Hospitals are rather conservative when it comes to implementing new solutions and products are often thoroughly tested before they are purchased. The ventilation system would present a large initial investment, which might scare off many hospitals. To avoid this issue a business model focusing on a leasing service has been generated. The modular bed is sold to the hospital and then a large range of additional modules, including the ventilation system can be leased. This model was inspired by alternating pressure mattresses that hospitals currently often lease as they are too expensive to buy. This business model complements the modular platform well and allows for easy updates and continuous improvements.

It can be concluded that the ventilation system and the modular bed fulfill the demands of the problem statement as well as the defined value mission and interaction vision.

Reflection

The following section will be a reflection on the cooperation with the design team and DTU, as well as the design process and how it all relates to the original problem statement.

Originally the intention was to partner up with a project team at DTU, which is currently developing a personal ventilation unit that can be mounted on a regular hospital bed. But after waiting more than two months for DTU to write an official contract it was decided to continue independently without the assistance from DTU. The reason being that the project at this point had moved in another direction than the original concept from DTU. Furthermore, the contract demanded that the project would be confidential and that DTU had all the rights, which the design team wouldn't accept.

Inspired by the project at DTU the initial problem statement was defined as ***"How do we reduce the number of Hospital-Acquired Infections (HAIs)?"*** Based on this a thorough research was initiated. The purpose was to investigate the scope of the problem, analyze current solutions and gain insight into the different types of HAIs (Hospital-acquired infections) and how they spread.

Based on the initial research the problem statement was updated to ***"How to use air as an "open" isolation and personal ventilation to reduce HAIs".***

The problem statement were deconstructed into three different aspects, that the solutions should be able to perform. The system should.

- Contain the infection to the infectious host
- Clean the surrounding environment
- Supply fresh clean air to the patient

Subsequently numerous concepts with different implementation scales were generated, categorized and evaluated based on the value mission and an interaction vision for the solution. The design team saw the biggest potential in designing a new modular bed with an integrated ventilation system. After a meeting with Invacare, the leading manufacturer of hospital beds in Denmark, it was decided that the new bed should be an update of the Scanbed 910. This bed was chosen because it's the most commonly used bed in Danish Hospitals, thus presenting a large market potential and furthermore, it made it possible to observe the bed in use at several departments and even borrow one for testing.

To test the three most promising concepts within the defined focus area a test lab was built at Aalborg University Copenhagen. The lab consisted of a 1:1 patient room, including a Scanbed 910 borrowed from Rigshospitalet as well as fans and a smoke machine. This enabled the design team to perform physical smoke tests, usability workshops with simple mock-ups and invite experts for validating the results. Combined with CFD (Computational Fluid Dynamics) the physical tests helped narrowing down the concepts to only one final concept:

A modular bed with a side mounted Outlet, an air handling unit for cleaning the air and an overhead inlet for creating an air curtain on both sides of the patient and supplying the patient with fresh air.

Throughout the detailing phase the different elements of the bed was systematically optimized for production and assembly, while taken both usability and aesthetical considerations into account.

All the elements have been detailed to a level that allows for proper assessment of the overall concept's potential. Developing a complete hospital bed including a comprehensive ventilation system proved to be an enormous task and as a result certain areas of the project have been given a lower priority than intended. Especially the economical aspects of the project would have been appropriate to investigate more thoroughly as this defines whether or not the project is profitable.

Future perspectives

Reduce noise

It's inevitable that noise will be generated by the system. Unfortunately it hasn't been possible to properly assess the noise level as this would require sophisticated physical tests with the correct materials and components. It's essential that the system is optimized for noise reduction so an acceptable level is achieved

Improve airflow

The physical tests carried out during the project as well as the CFD analysis have been heavily simplified to allow for quick iterations. They have been used for getting insight into how airflows and to compare the potential of different concepts rather than as a verification tool. More precise testing in a controlled lab environment, with thermal manikins and proper measuring equipment will be necessary for optimizing the airflow.

Production optimization

The hospital bed and the ventilation system has been detailed to a level that makes it possible to make a qualified assessment of the different components' manufacturability and calculate precise tool and unit prices. All components require additional optimization before they are completely ready for production. Furthermore, it should be decided what to produce in-house and what should be outsourced.

Explore business potential

A simplified business model for a leasing concept has been made, but to get a proper indication of the business potential a qualified cost price and profitability calculations should be made and the potential for expanding the concept to other European countries should be investigated.

Software development

The software required for controlling the system via the patient and HCW controllers has to be developed and tested before implementation.

Electronic development

The electronic solutions for the bed haven't been a focus for this project, so additional detailing is required. of the detailed in this project.

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Appendix A

Flow concept evaluation

To explore different possible solution, a matrix of different inlet and Outlet positions were created. The result of the cross matrix flow based concept testing and evaluation.

Outlet

Inlet	Headboard	Footboard	Side	No Outlet	Above bed
Headboard		Concept B		Concept D	
Footboard	Concept A			Concept E	
Side				Concept F	Concept H
Above bed			Concept C	Concept G	

Concept A:

Outlet headboard / Inlet footboard

Pros:

- ✚ Linear flow over pat
- ✚ Not in the way for hcw
- ✚ Easy installation
- ✚ Can be fitted onto current beds
- ✚ Patient completely isolated
- ✚ Doesn't blow hcw in the face
- ✚ Doesn't limit patient's side view
- ✚ Air curtain also works as fresh air for patient

Cons:

- ✖ Blows patient in the face
- ✖ Footboard limits patient's front view
- ✖ Headboard limits porter's view

Comments:

- Headboard should be height adjustable
- Easier when transporting the bed
- Can the air from the air curtain be used for the patient?
- Bystanders potentially get blown in the face
- Headboard can be lowered if Outlet is on top and sucks vertically

Concept B:

Inlet headboard / Outlet footboard

Pros:

- ✚ Linear flow over patient
- ✚ Not in the way for HCW
- ✚ Easy installation
- ✚ Can be fitted onto current beds
- ✚ Patient completely isolated
- ✚ Doesn't limit patient's side view
- ✚ Nothing in the way for ceiling hoist

Cons:

- ✖ Blows HCW sideways in the face
- ✖ Footboard limits patient's view
- ✖ Headboard limits porter's view
- ✖ Headboard needs to be very high to blow air over patient when sitting upright
- ✖ No direct air Inlet near patient's head
- ✖ Bystanders potentially get blown on

Comments:

- Headboard could be height adjustable
- Easier when transporting the bed
- Only up when needed
- Possible to place intlet on top of footboard and suck vertically - reduce height of footboard
- Height of headboard = 1120mm when backrest is up
- Can the air from the air curtain be used for the patient?
- Change tilting mechanism so headboard is always just behind the backrest?

Concept C:

Inlet above bed / Outlet side

Pros:

- ✚ Good airflow
- ✚ Fresh air for patient from above
- ✚ Possible to add multiple functions - Monitor, lifting pole, light, hoist
- ✚ Good isolation of patient
- ✚ Recirculating air
- ✚ The amount of unclean air to the room is reduced
- ✚ There is no need for HEPA and UV in several units
- ✚ HEPA-filters and other large components are easily integrated into the bed
- ✚ By placing the Outlet under the bed the overall width of the bed is kept at a minimum
- ✚ Not in the way for HCW
- ✚ Good sideview for patient
- ✚ Modular architecture

Cons:

- ✖ Re-aerosolization of particles, which has settled on the floor
- ✖ Big unit
- ✖ In the way of ceiling hoists
- ✖ Minimum clearance under the bed is reduced
- ✖ In the way when transporting the patient

Comments:

- Inlet needs to be high enough not to be in the way for the HCWs
- Bump their head into it
- Look at HCW on the other side
- Should potentially be height adjustable
- Should the Outlet be in the full length of the bed if the Inlet is not?
- Does it only cover the head and the upper body?
- If it's the full length it potentially captures particles from shaking bed linen
- Can supply the patient with fresh air when transporting (battery)

Concept D:

Inlet headboard / No Outlet

Pros:

- ✚ Linear flow over patient
- ✚ Not in the way for HCW
- ✚ Easy installation
- ✚ Can be fitted onto current beds
- ✚ Patient completely isolated
- ✚ Doesn't blow HCW in the face
- ✚ Doesn't limit patient's side view

Cons:

- ✖ Headboard limits porter's view
- ✖ Headboard needs to be very high to blow air over patient

Comments:

- Headboard could be height adjustable
- Easier when transporting the bed
- Height of headboard = 1120mm when backrest is up
- Can the air from the air curtain be used for the patient?
- Bystanders potentially get blown in the face

Concept E:

Inlet footboard / no Outlet

Pros:

- ✚ Linear flow over patient
- ✚ Not in the way for HCW
- ✚ Easy installation
- ✚ Can be fitted onto current beds
- ✚ Patient completely isolated
- ✚ Doesn't limit patient's sideview
- ✚ Air curtain also works as fresh air for patient

Cons:

- ✖ Blows patient in the face
- ✖ Footboard limits patient's front view
- ✖ Blows HCWs in the face

Comments:

- Can the air from the air curtain be used for the patient?
- Bystanders potentially get blown in the face

Concept F:

Inlet side / No Outlet

Pros:

- ✚ Good for supplying fresh air to patient when side rail is up
- ✚ Helps circulate clean air in the room
- ✚ Good isolation of patient

Cons

- ✖ When side rail is down the patient doesn't get any clean air
- ✖ Side rail limits patient's side view when up
- ✖ Nozzles are easily covered
- ✖ HCWs get air blown in their face when leaning over bed
- ✖ Might function as a fountain, spreading coughed particles to the room
- ✖ Relying on current exhaust system in the room

Comments

- Nozzles for fresh air for patient shouldn't be too close to Inlet for air curtain
- Shouldn't add to the width of the bed

Concept G:

Inlet above bed / No Outlet

Pros:

- ✚ Good airflow
- ✚ Fresh air for patient from above
- ✚ Possible to add multiple functions - monitor, lifting pole, light
- ✚ Good isolation of patient

Cons:

- ✖ Re-aerosolized particles landed on the floor
- ✖ Big unit

Comments:

- Inlet needs to be high enough not to be in the way for the HCWs
- Bump their head into it
- Look at HCW on the other side
- Should potentially be height adjustable

Concept H:

Inlet in side rail / Outlet above bed

Pros:

- ✚ Good airflow
- ✚ Fresh air for patient from the side
- ✚ Possible to add multiple functions - monitor, lifting pole, light, hoist
- ✚ Good isolation of patient
- ✚ Recirculating air
- ✚ The amount of unclean air to the room is reduced
- ✚ There is no need for HEPA and UV in several units
- ✚ Modular architecture
- ✚ Possible to remove the top unit if there is a sufficient exhaust system in the room
- ✚ Not in the way of ceiling hoists

Cons:

- ✖ Mechanical complexity
- ✖ Reduced sideview for patient
- ✖ HEPA-filters and other large components are difficult to integrate into the bed
- ✖ Side rails moves up and down making it difficult to recirculate the air
- ✖ Limited space inside the side rails for components
- ✖ In the way when transporting the patient
- ✖ If side rail is down it's difficult to provide patient with fresh air
- ✖ If side rail is down it easily gets covered by the duvet

Comments:

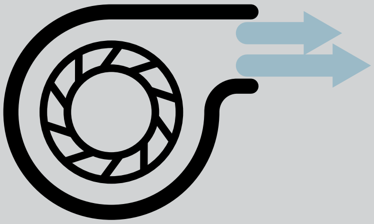
- Outlet needs to be high enough not to be in the way for the HCWs
- Bump their head into it
- Look at HCW on the other side
- Should potentially be height adjustable
- Should the Inlet be in the full length
- Does it only cover the head and the upper body?
- If it's the full length it potentially captures particles from shaking bed linen
- Can supply the patient with fresh air when transporting (battery)

Appendix B
Fans

Evaluation of different types of fans

Axial fan

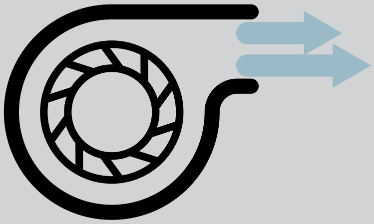
- ✚ Good power consumption
- ✚ Compact form factor
- ✚ High airflow
- ✖ No airflow at low static pressure



Centrifugal fan

Forward curved blade

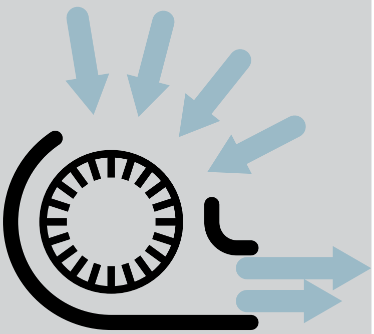
- ✚ Low noise (low rpm)
- ✚ Most efficient at high pressure and low flow
- ✖ Sensitive to particulates



Centrifugal fan

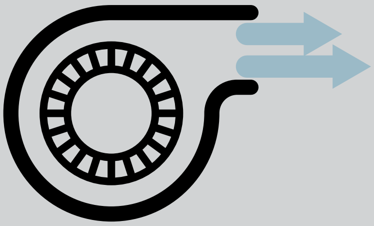
Backward curved blade

- ✚ Doesn't require housing
- ✚ Energy efficient
- ✚ Self cleaning
- ✖ Inefficient at high pressures



Tangential fan

- ✚ Quite
- ✚ Scalable form factor
- ✚ Good pressure coefficient
- ✖ Bad power consumption



Centrifugal fan

Straight blade

- ✚ Self cleaning
- ✚ Very good to particulates
- ✖ Bad power consumption

(EBM-Papst, 2007)

Appendix C

Filters

Evaluation of different types of filters

HEPA

- ● Lasts 3 - 5 years
- ✚ Good flow
- ✚ Removes particles >0,3µm
- ✚ Cheap
- ✚ 99,97% effective
- ✖ Not effective against volatile organic compounds (VOC), such as bacteria or viruses

ULPA

- ● Lasts 1 - 1.5 years
- ✚ 99,999% effective
- ✚ Removes particles >0,1µm
- ✖ Restrictive airflow (20-50% less air than HEPA)

Active carbon

- ● Lasts 1 - 1.5 years
- ✚ Removes VOC
- ✚ Removes smells
- ✖ Expensive
- ✖ No effect on larger particles

Passive

UV-GI

- ● 10.000 - 50.000 houres
- ✚ Destroys pathogen's DNA
- ✖ Particles makes shadows for the pathogens
- ✖ Does not penetrate larger particles
- ✖ Does not filter particles

Ionizer

- ✚ No airflow required
- ✚ Works with VOC
- ✖ Produces ozone
- ✖ Low flow efficiency
- ✖ Needs a passive filter
- ✖ Does not filter particles

Photocatalytic Oxidation

- ✚ No airflow required
- ✚ Efficient
- ✖ Expensive
- ✖ Does not filter particles

Polarized-Media

- ● Pads lasts 3-4 months
- ✚ No airflow required
- ✚ Works with VOC
- ✖ Low flow efficiency
- ✖ Does not filter particles

(Penn State U, 2008)

Active

	HEPA	Activated Carbon	Ionizer	UV-GI
Dust mites				
Pollen				
Mold				
Bacteria				
Viruses				
VOCs				
Odors				
Smoke				
May release ozone				

Appendix D
Workshop with HCW

The results of the workshop with HCW at the Department of Nephrology at Rigshospitalet.

- ✚ Integration of light, radio, monitor, trapez etc.

- ✖ In the way of ceiling hoist
- ✖ Will potentially hit the wall if the bed is performing a trendelenburg tilt (Head-end down)
- ✖ In the way if the patient is having a heart attack. (HCW will jump in the bed and the headboard will be removed)

- ✚

- ✖ If the headboard is too high it will potentially hit the wall if the bed is performing a trendelenburg tilt (Head-end down)
- ✖ Difficult to remove the headboard quickly if the patient gets a heart attack

- ✚ Privacy when side rail is up
- ✚ Social interaction and view out the window when the side rail is down

- ✖ Drainage bags, urine bags, feces bags etc. is hung on the side rail

Appendix E
Workshop with patients

The results of the workshop with patients.

- ✚ Bed is more open than the other concepts
- ✚ The least noticeable of the three concepts
- ✚ The patients view is not limited

- ✖ Horizontal air curtain is more annoying for visitors than a vertical air curtain
- ✖ Headboard needs to be height adjustable to be effective both while sitting and lying
- ✖ If the patient is reading a paper the wind might blow the pages

- ✚ Visually indicates that patient is protected
- ✚ Well integrated into the bed
- ✚ Can be used outside the room while transporting the patient
- ✚ Possible to integrate light, monitor, lifting pole

- ✖ Might be in the way for instruments hanging on the wall-mounted profile
- ✖ Doesn't cover the whole length of the bed
- ✖ Inlet unit limits the porters view
- ✖ The patient looks more sick.

- ✚ Side rail can provide patients with a feeling of privacy
- ✚ Can be moved down if patient wants to socialize with the neighboring patient
- ✚ Possible to add features in side rail

- ✖ Side rail is in the way when visitor hugs or hold hands with patient.
- ✖ Side rail is blocking the view for the patient
- ✖ The duvet can potentially block the airflow
- ✖ Air curtain might be uncomfortable for the thighs when sitting on the side of the bed

Appendix F

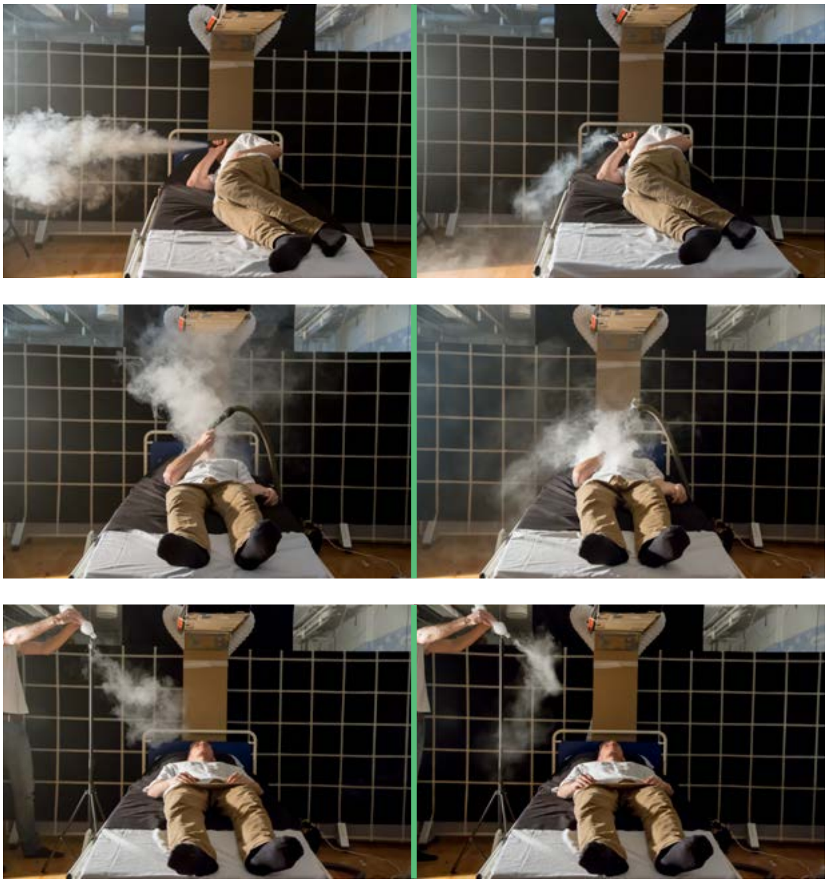
Visual smoke testing

To evaluate the flow movement and the evacuation efficiency of the different concepts, extensive testing with a fog machine to visualize the movement, were conducted. Below is a sample of the scenarios that were conducted. The three scenarios below simulates evacuation of horizontal breathing (1), isolation of patient air (2) and external high velocity cough (3) Note that most test were conducted without an Outlet.

System off

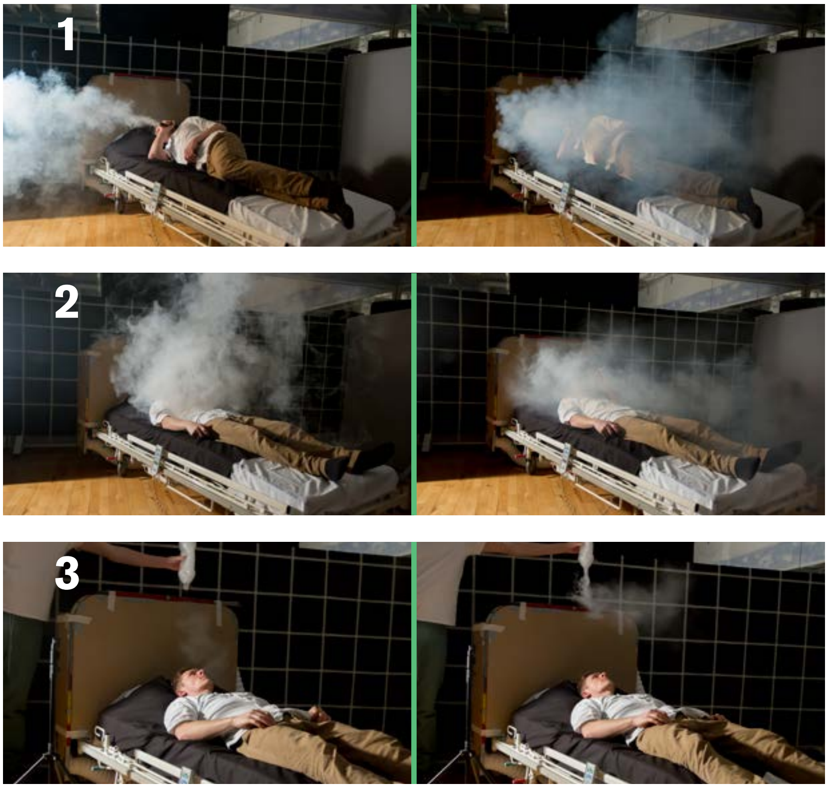
System on

Concept 1



- ✚ Flow leads directly to Outlet position
- ✖ Possible draft

System off | System on | Concept 2



- ✚ The coandă effect limits airflow to room
- ✚ Air curtain on all sides
- ✖ Airflow goes towards HCW, visitors etc
- ✖ Possible draft

System off | System on | Concept 3

- ✚ The coanda effect limits airflow to room
- ✚ Air not cought by Outlet, is not in a breathing zone
- ✖ Duvet easily obstruct airflow
- ✖ Exposed nozzles
- ✖ No fresh air to patient

Appendix G
CFD analysis

To compare the flow dynamics of the 3 concepts a simplified CFD (Computational fluid dynamics) of each concept have been run. To be able to make a direct comparison, the same input parameters have been used for all simulations. The parameters were defined based on Bolashikov et al, ***(2012)*** as well as numerous test simulations. To make it easier to compare each concept the room ventilation haven't been taken into account.

Input parameters

Volume flow from inlet: 80 l/s

Volume flow through Outlet: 80 l/s

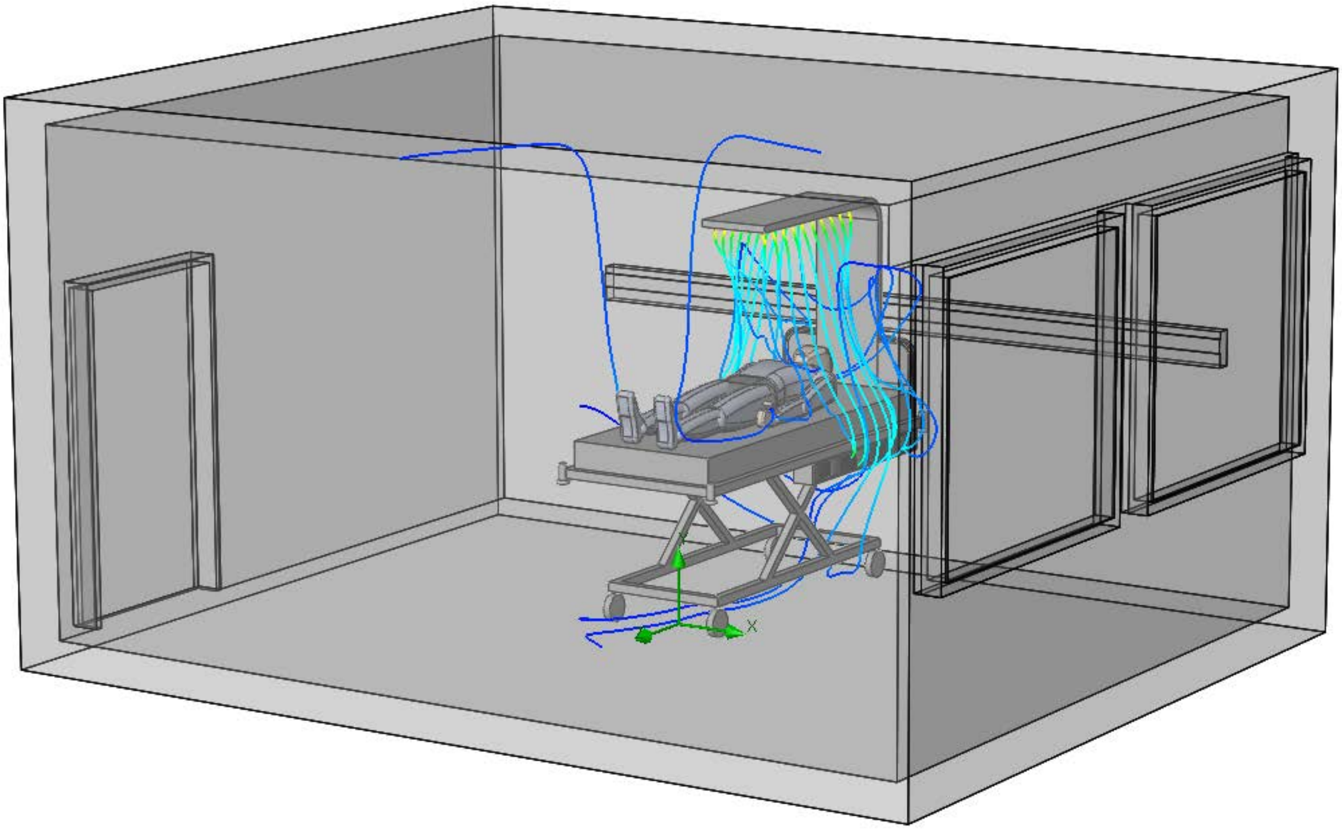
Room dimensions (W x L x H): 5140 x 4200 x 2800 mm

Patient height: 1,8 m

Metabolic rate of patient: 80 W/m^2.

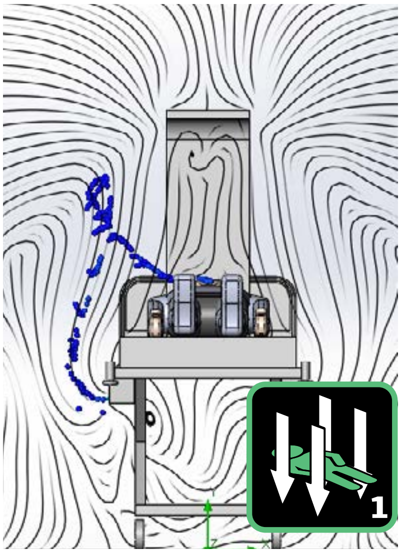
Simulation time 60 s.

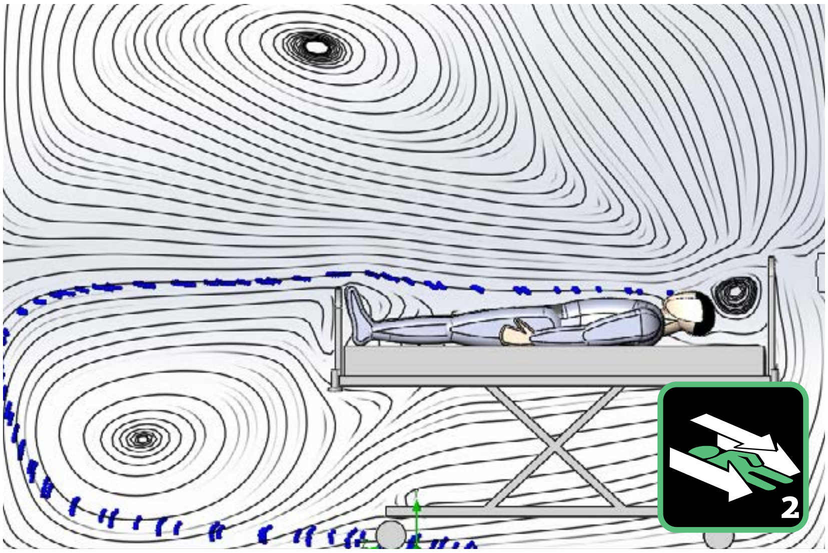
Inlet dimensions (W x L): 10 x 1000 mm

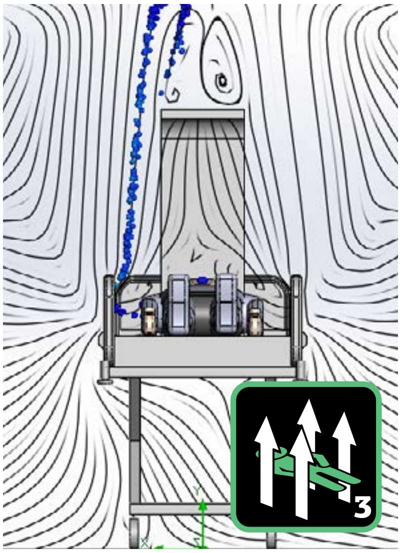


Isolation effectiveness

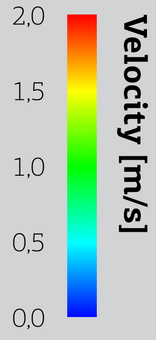
To examine the different concepts' ability to confine a sneeze, particle studies were performed. Particles with a size of 10 µm and with an initial velocity of 20 m/s ***(Bolashikov et al, 2012)*** were injected at the mouth of a patient lying on his back.





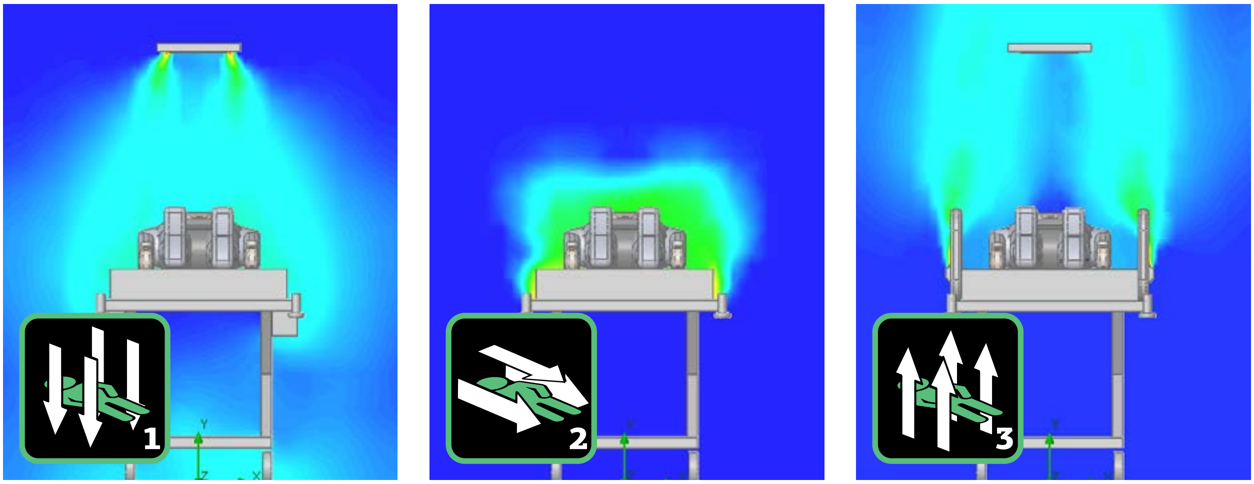


Concept 2 and 3 are not able to block the sneeze, which means that pathogens will potentially spread to the surrounding environment. Concept 1 on the other hand effectively captures the particles in its air curtain and draws it into the Outlet under the bed.

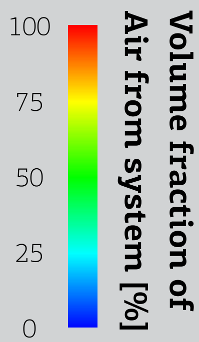


Clean air distribution

To examine the different concepts ability to supply the patient with clean air a cut plot is used. The plot displays the volume fraction of air discharged by the system. The larger the fraction of air from the system at the breathing zone of the patient, the better.



In concept 1 and 2 the patient primarily breathe s in cleaned air from the system while in concept 3 the inhaled air is primarily coming from the surrounding environment. A lot of the clean air discharged from the system in concept 3 will also mix with the surrounding air, thus improving the overall air quality. But if an infected person sneezes directly into the air curtain it might act as a fountain and spread the pathogens into the room.

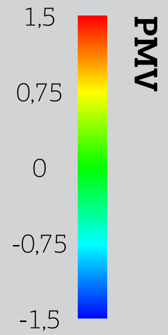


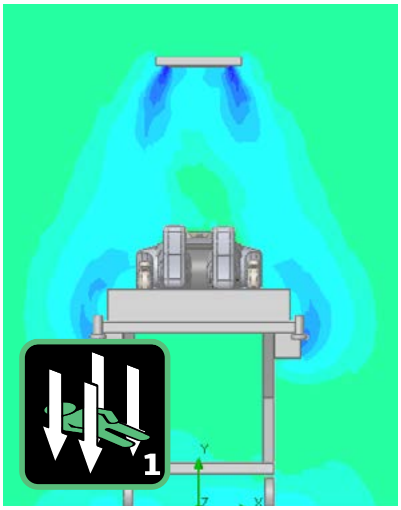
Thermal comfort

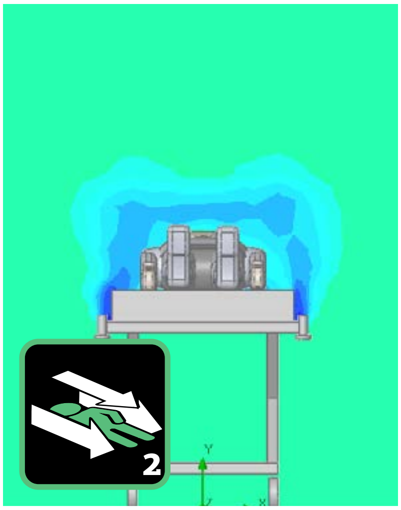
Maintaining an acceptable level of thermal comfort for the patient is one of the most important parameters to consider when designing a ventilation system. The integrated HVAC module in SolidWorks Flow Simulation uses the Predicted Mean Vote (PMV) model to assess the thermal comfort of ventilation systems. The PMV model has been developed using principles of heat balance and experimental data collected in a controlled climate chamber under steady state conditions. ***(Parsons, 2013).***

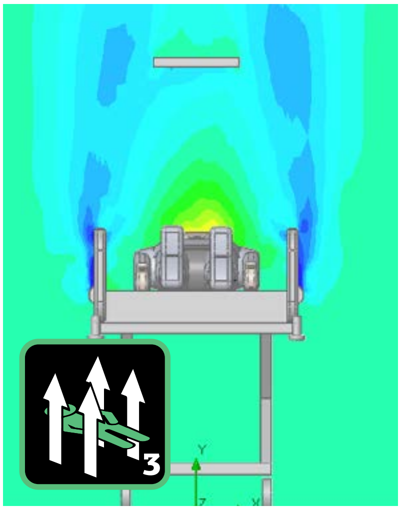
The PMV index predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale. ***(Parsons, 2013)***

-3	-2	-1	0	+1	+2	+3
cold	cool	slightly cool	neutral	slightly warm	warm	hot





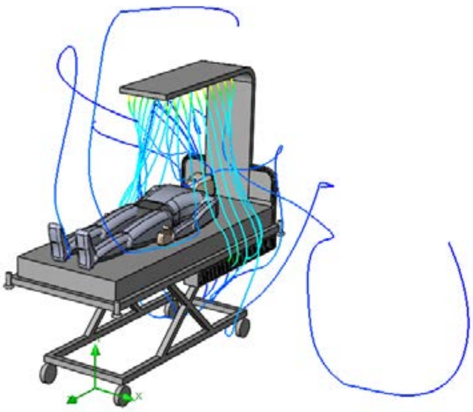




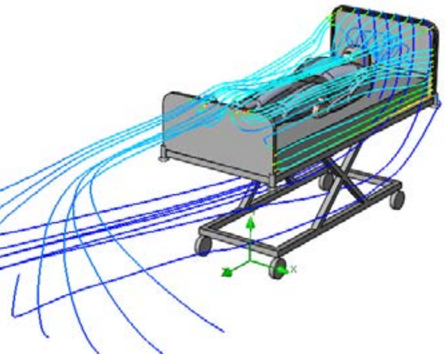
Concept 3 performs the best in regards of thermal comfort. By pointing the inlet upwards there is only limited amount of air from the system passing the patient, thus reducing draft. But this also means that the patient won't be supplied with the same amount of fresh air as the two other concepts. Both Concept 1 and 2 has a negative PMV rating, which means that there is a risk that the patient might feel a bit cold.

Flow effectiveness

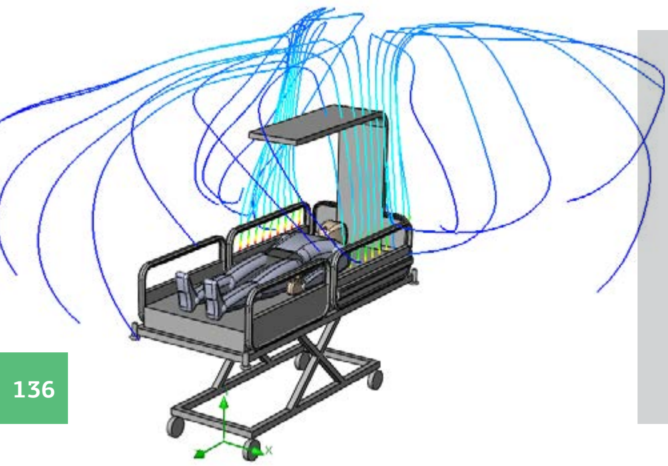
By using flow trajectories it's possible to visualize the flow streamlines from the inlet. This provides a good image of the 3D fluid flow, which makes it possible to assess the effectiveness of each system.



Concept 1 is the most effective of the 3 concepts. Most of the discharged air is recirculated back into the system through the Outlet under the bed. Furthermore, the flow creates a straight air curtain on both sides of the patient that prevents air from the outside environment from getting into the patient.



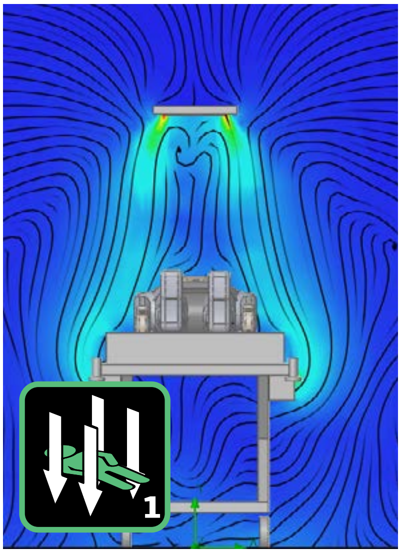
As the air is blown out horizontally over the patient the stream of air sticks to the nearby surface of the patient due to the Coandă effect ***(Nielsen)***. Some of the discharged air is collected at the foot-end but a noticeable amount of air continues horizontally over the footboard and out into the room. This means that a person standing at the foot-end might feel a draft and that pathogens from the patient might be spread out into the room.

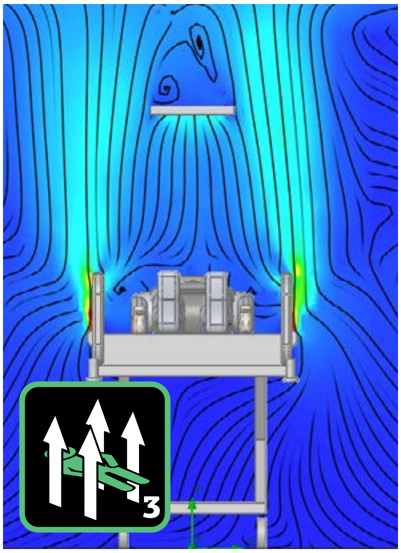


Concept 3 is the least effective of the three concepts. The upwards flowing stream of air acts as an air curtain on both sides of the patient, but most of the discharged air passes by the overhanging Outlet. If the room has displacement ventilation the over-head Outlet might not be necessary as the air often is extracted at ceiling height.

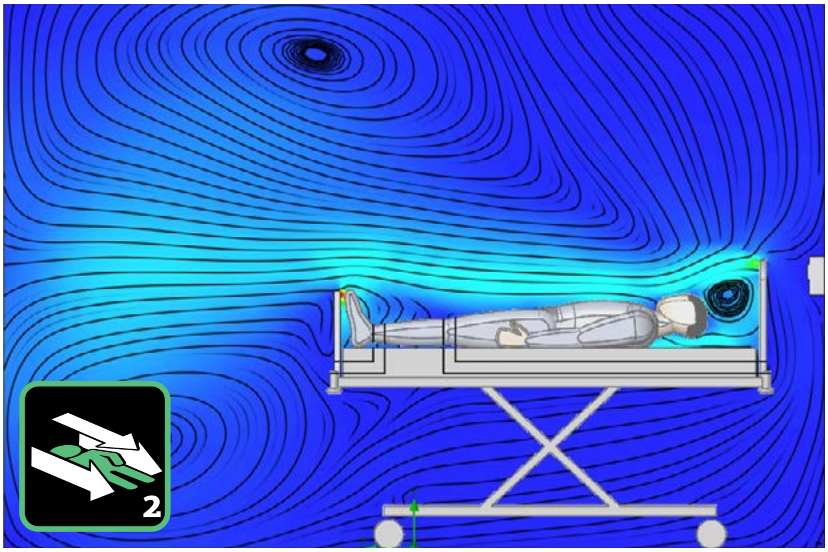
Airflow

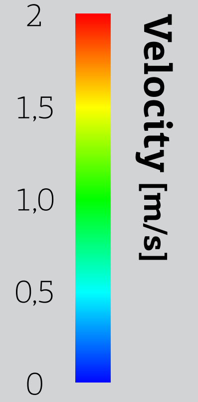
The following simulations have been performed to assess the flow of the 3 different concepts and how it affects the surrounding air. Cut plots have been used to display the air distribution and velocity.





Just as the flow trajectories, these cut plots give an indication of how effectively the different concepts collect the discharged air. Furthermore, they illustrate how the stream of air from the system drags along air from the surrounding environment. The more air that is dragged along, the more air will be drawn into the Outlet. This effect should be taken into consideration when dimensioning the system.

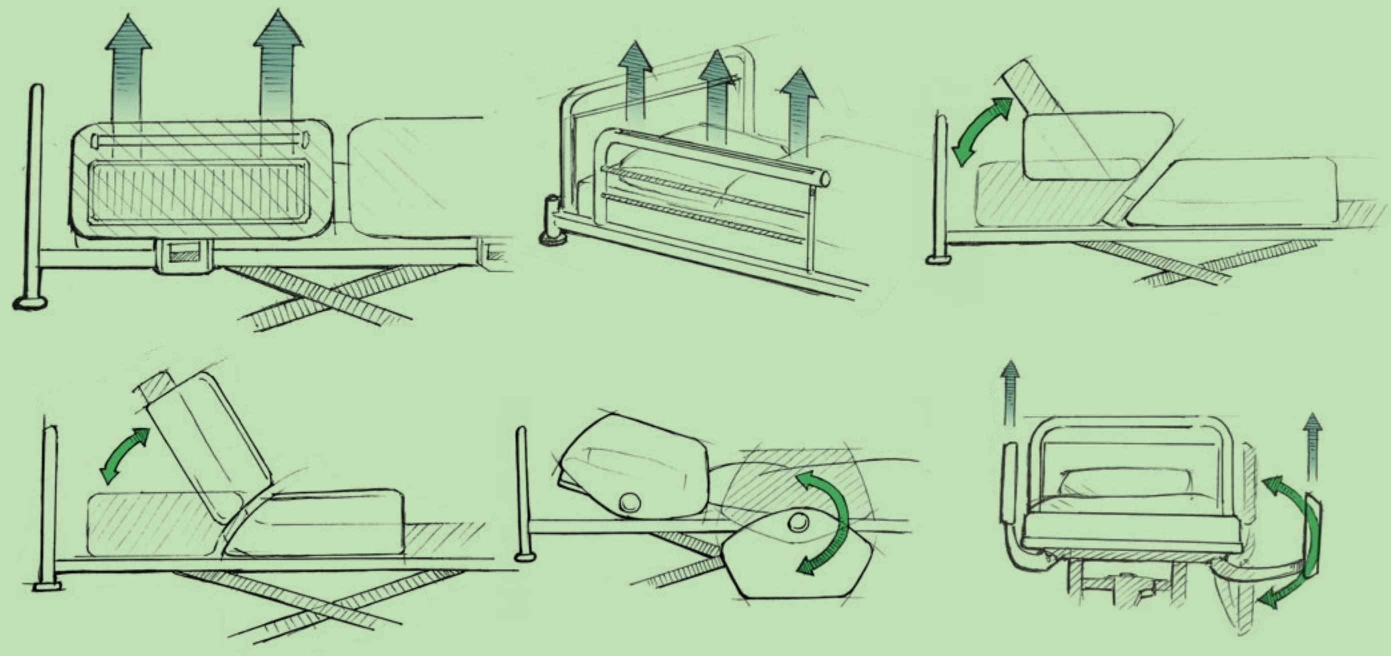




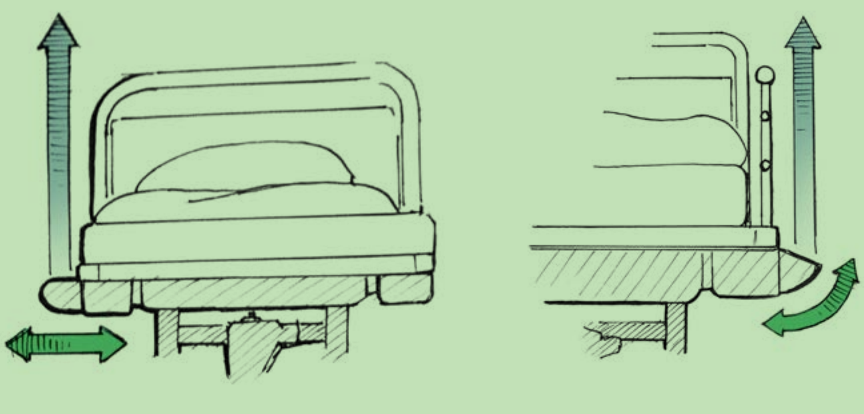
Appendix H
Concept 3 refinements

Both concept 1 and 3 was chosen to be explored and refined to optimize the solution. See "Concept refinement" on page 70 to see the refinement for concept 1.

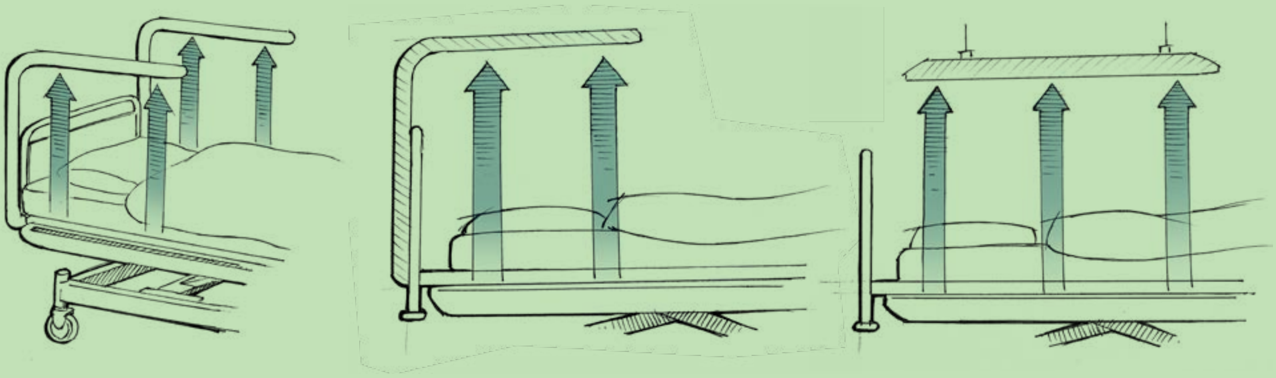
Side rail



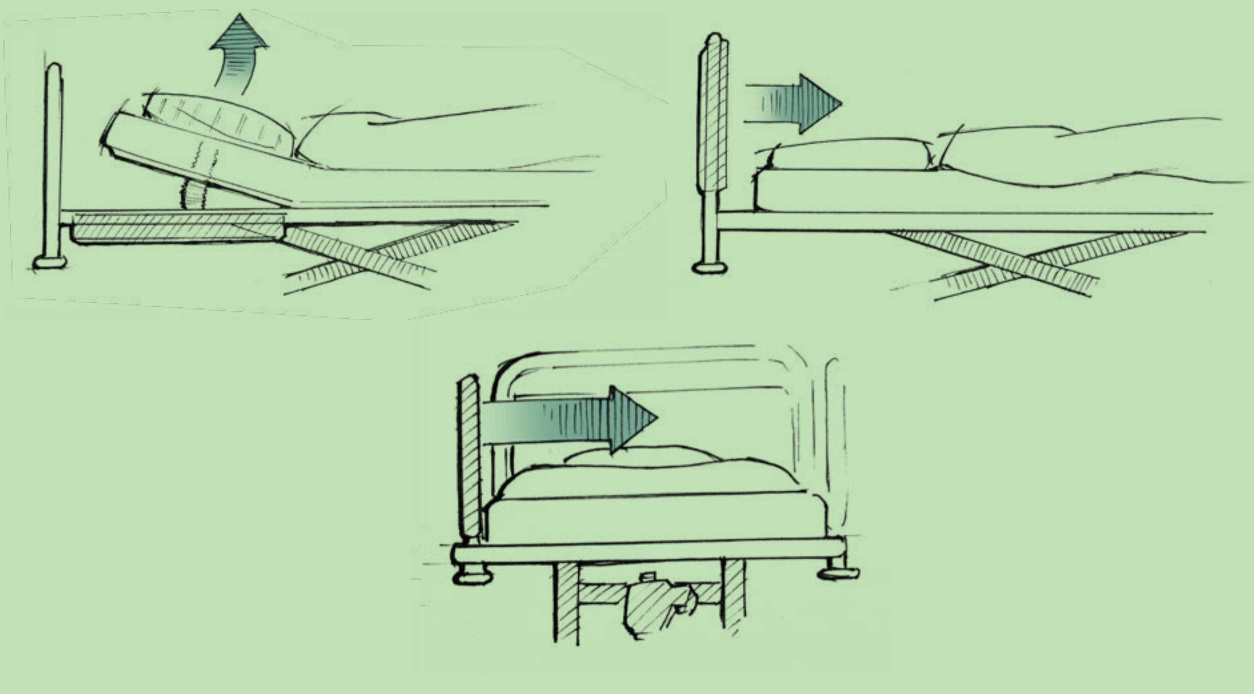
Pop-out of bed frame



Overhead outlet



Personal ventilation



Appendix I

Bed types

There is a wide variety of beds used within the healthcare sector. These can roughly be categorized into the 6 different types as shown below. Each category of beds has its own specific application area and is designed to accommodate the needs of patients and staff within this area of use.

Pediatric bed: Pediatric beds are designed for children. They are smaller than regular ward beds and often more colorful. The side rails cover the whole length of the bed and the gaps are narrow to prevent entrapment.

ICU bed: These beds are used in intensive care units and optimized to treat patients with severe and life-threatening illnesses and injuries, that require constant, close monitoring and support. They often have advanced features such as lateral rotation therapy, vibration therapy and microclimate management.

Ward bed: Ward beds are often just referred to as hospital beds. They are height adjustable, can tilt and adjust the mattress platform. They are equipped with side rails, a lifting pole, IV poles and both patient handset and attendant controls.

Birthing bed: Birthing beds are specifically designed for women in labour. They are equipped with footrests, support handles and some also have massage functions.

Home Care bed: These beds are primarily used in residential homes, nursing homes and private hospitals. They only have basic features and often have wooden frames to create a home-like environment.

Bariatric bed: These beds are designed for immobile bariatric patients that can weighing up to 400 kg. They often have therapeutic surfaces that help prevent and treat pressure ulcers.

Appendix J
Porter's view

It is very important that the bed can be easily transported without obstructing the view.

Overhead panel is connected to the bed by a slim tube on one side only.

Overhead panel is connected to the bed with a tower of the same cross section as the overhead panel

Appendix K

Foot-end frame FEA

Since the foot-end frame will have to be length adjustable, it will pose a risk for high stress and displacement in the arm that slide into the long side extrusions. A comparative finite element analysis (FEA) was done to test different designs.

Input parameters

Force: 1000 N

Fixed length: 10 cm

Extended length: 20 cm

Material: AA380

Cross-section (1:1)

Nylon gliders

Screw tower

Arm

Displacement [mm]

Safety factor (Yield strength)

Design 01

Arm height: 19 mm

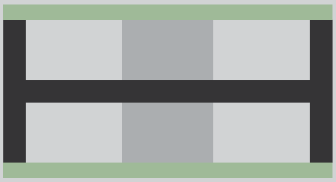
No ribs

Δmass: 0 g

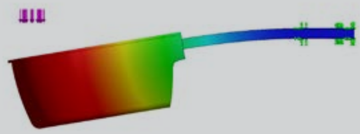
Max displacement: 73 mm

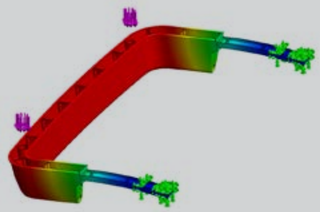
Max stress: 653 MPa

Cross-section

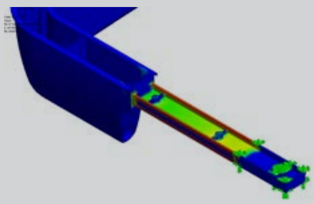


Displacement [mm]





Safety factor



Design 02

Arm height: 19 mm

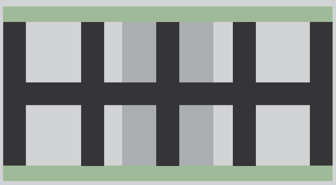
3 ribs

Δmass: 185 g

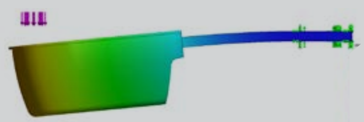
Max displacement: 43 mm

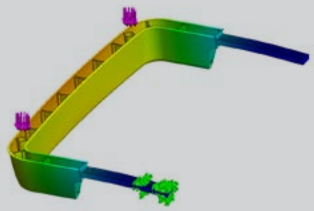
Max stress: 641 MPa

Cross-section

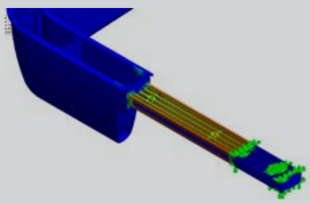


Displacement [mm]





Safety factor



Design 03

Arm height: 27 mm

Side extrusion redesigned

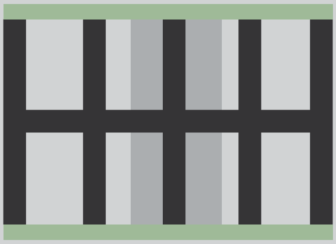
3 ribs

Δmass: 450 g

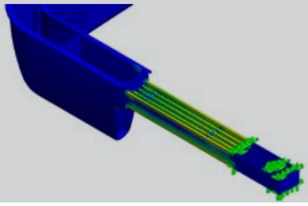
Max displacement: 12 mm

Max stress: 172 MPa

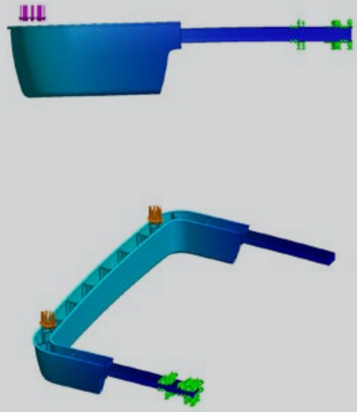
Cross-section



Safety factor



Displacement [mm]



Design 04

Arm height: 35 mm

H-profile

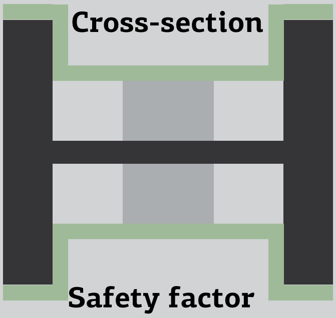
No ribs

Δmass: 678 g

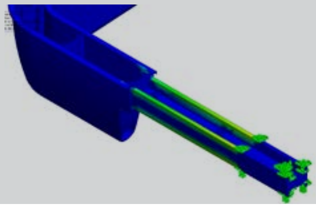
Max displacement: 6,8 mm

Max stress: 129 MPa

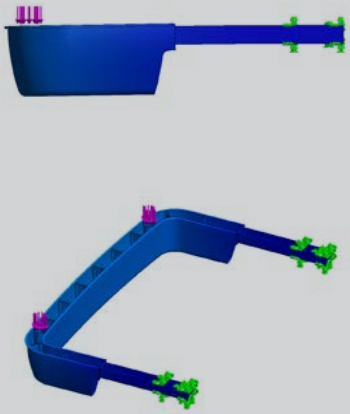
Cross-section



Safety factor



Displacement [mm]



Design 05

Arm height: 35 mm

H-profile

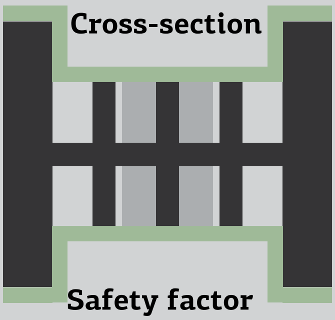
3 ribs

Δmass: 715 g

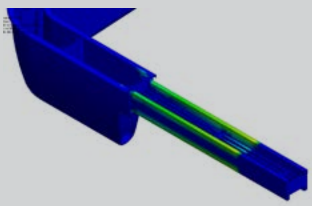
Max displacement: 6,2 mm

Max stress: 117 MPa

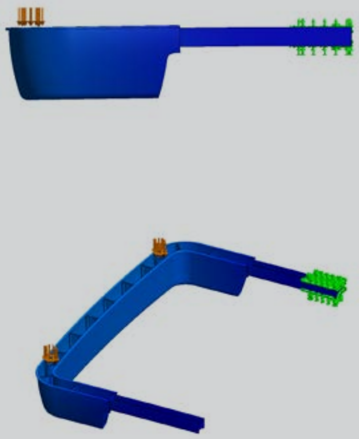
Cross-section



Safety factor



Displacement [mm]



Appendix L
Controller types

To get an overview of the pros and cons connected to the different controller types, a table is created rating how possible it is to do or integrate different functions into the controller types.

	Touch Screen	Physical buttons	Combination
Easy to clean	No problems	Not optimal	Not optimal
Easy to use in the dark	No problems	Not optimal	No problems
Patient can use own device	No problems	Problematic	Problematic
Possible to add new features/functions	No problems	Not optimal	No problems
Vibration can be added	No problems	No problems	No problems
Sound can be added	No problems	No problems	No problems
Possibility to connect to a headset	No problems	No problems	No problems
One-handed interaction	No problems	No problems	No problems
Tactile feedback	Problematic	No problems	No problems
Possible to add braille	Problematic	No problems	No problems
Rugged	Problematic	No problems	Not optimal
Power efficient	Not optimal	No problems	Not optimal
Wireless/transportable	No problems	No problems	No problems
Can be used as a phone	No problems	No problems	No problems
Integrated speaker for television	No problems	No problems	No problems
Possibility to play games	No problems	Not optimal	No problems
Possible to read files/books	No problems	Problematic	No problems

No problems

Not optimal

Problematic

The table gives an estimate on which of the different controller types there would be most suitable as a controller for this project.

One of the downsides of touch screen is it lack of tactile feedback. As a result it demands more attention from the user, which have to look at the controller when using it. If the user do not look at the controller, he can not know for certain if he hits a button. The lack of tactile feedback can be compensated by the use of vibrations, but it is still not the same as "real buttons". Furthermore, touch screen is very fragile. If a user drops the controller, it can easily be broken.

Unlike the touch screen, physical buttons, can give the user tactile feedback. However, it is hard to add new features to this kind of controller. If the controller is a touch controller, new software can easily be written and added. Whereas adding new hardware to a controller with physical buttons can have a negative impact on the ergonomics of the controller, and also on how easy it is to interact with.

A combination of both touch and physical buttons would be the optimal solution. In this way the positive sides for both controller types can be used.

Emerging technologies such as the Tactus Panel ***(Tactus, 2014)*** shows a great potential to unite the tactile befits of physical buttons with the versatility of touch screens.

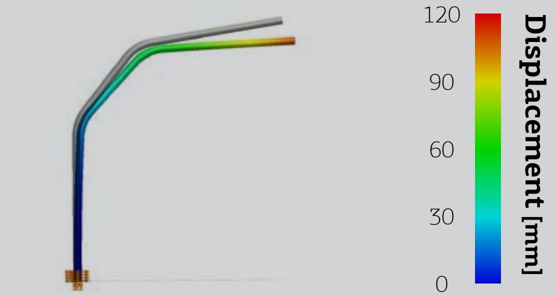
Appendix M

Overhead panel tube FEA

The overhead panel is situated in a position where it can very easily experience a lot of force, and being only fixed in one point, it will need to be very strong. As a reference the lifting pole used today was seen as being sufficiently strong, and its deflection was not perceived as fragile. The current lifting pole was modeled and a FEA was conducted as a benchmark, that the tube for the overhead panel should not exceed.

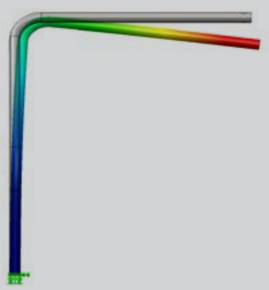
Reference part

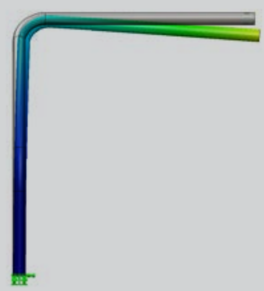
As a reference the lifting pole from Invacare was found to have amble strength, flexibility and a deflection that made it trustworthy.



Reference part

- **Tube:** Ø32x4
- **Deflection:** 109 mm
- **Weight:** 6,3 kg
- **Force:** 1000 N
- **Material:** AISI 304



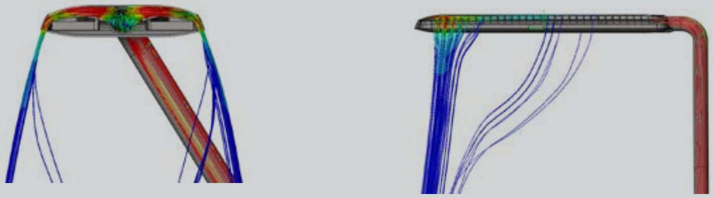


	Ø50x2	Ø50x2,5	Ø50x3	Ø50x4	Ø60x2	Ø60x2,5	Ø60x3	Ø60x4
Deflection	159	139	115	91	108	85	70	53
Weight	5,9	7,3	8,6	11,3	7,1	8,8	10,5	13,7

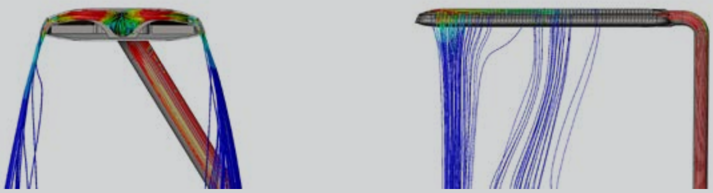
Appendix N
Inlet Panel CFD

CFD analysis was used iteratively to optimize the inside channels of the Inlet panel. The output of each simulation was analyzed and used for optimizing the next simulation. The goal was to distribute the air evenly. The following images show the flow trajectories of the different iterations from different angles. All simulations were run until a steady state was achieved and with the same input parameters.

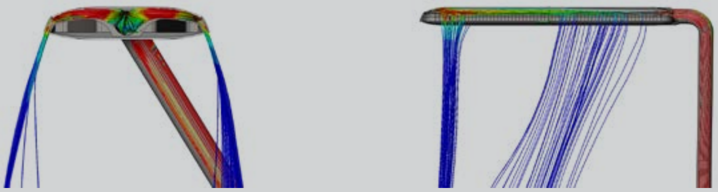
Iteration 01
Long tube



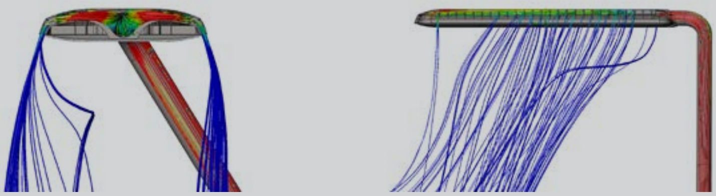
Iteration 02
Long tube



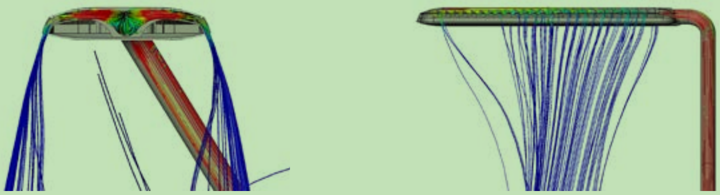
Iteration 03
Long tube

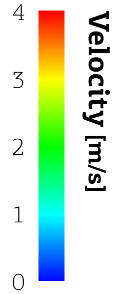


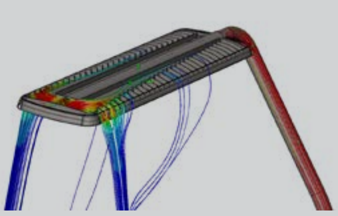
Iteration 04
Long tube

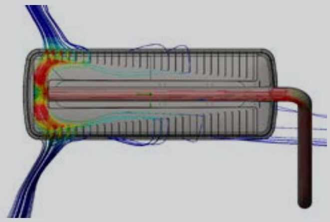


Iteration 05
Long tube

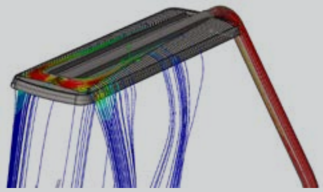


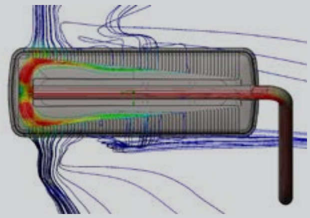




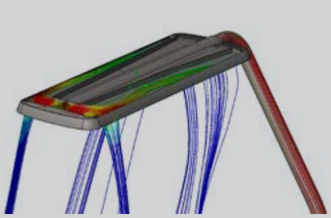


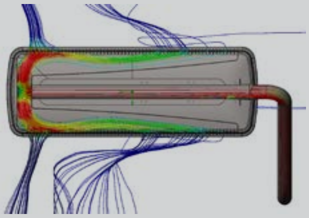
The guide ribs increase in length the further back into the unit they are placed, but the air exits at the easiest point which is right at the beginning.



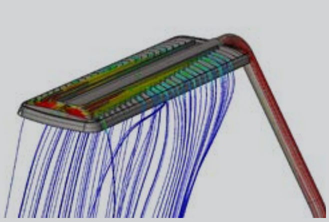


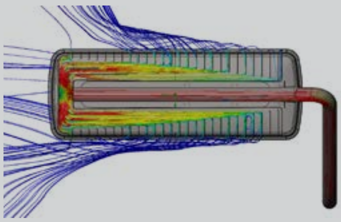
This concept builds on the same principle, but the distance between the ribs has been reduced. A bit more air is channeled to the opening further back but most air still exits right away.



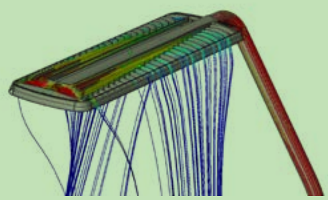


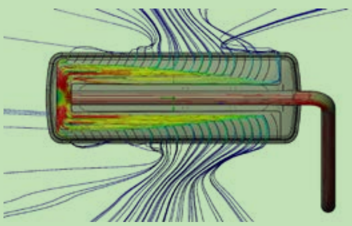
Instead of increasing the length of the ribs along the length of the unit a guiding curve is used that narrows along the length of the unit. The result is that most of the air exits in the beginning and the rest bounces of the first ribs and moves further down into the unit and exits at a narrow stretch.





In this concept, ribs with varying length were tried again, but this time several guiding ribs were added where the air exits and around the first bend. This significantly improved the spread of air along the length as the air was properly guided. But the air exiting the unit had an unwanted forward angle.

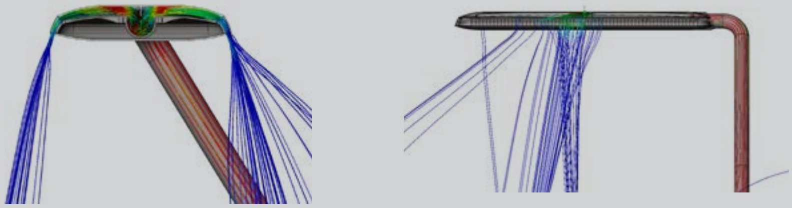




This concept was based on the same principle as the last but instead of having straight ribs the ribs had a slight curvature. This helped to guide the air so it was distributed more evenly over the nozzles and exiting in a more straight angle. There was still openings where the air didn't exit.

Iteration 01

Short tube

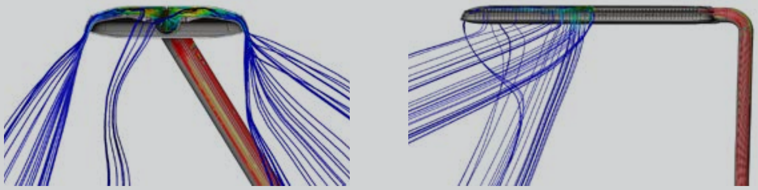


Iteration 02

Short tube

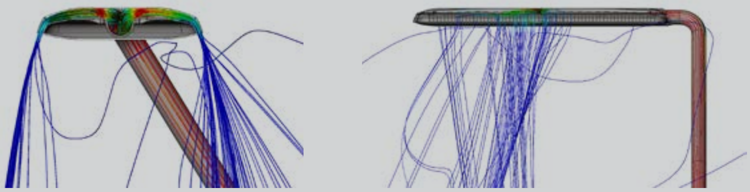
Iteration 03

Short tube



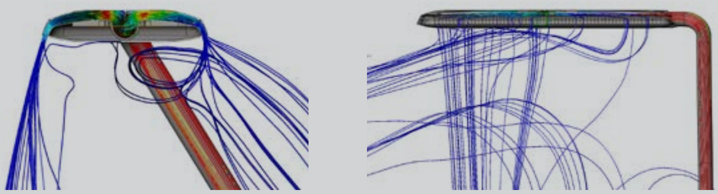
Iteration 04

Short tube



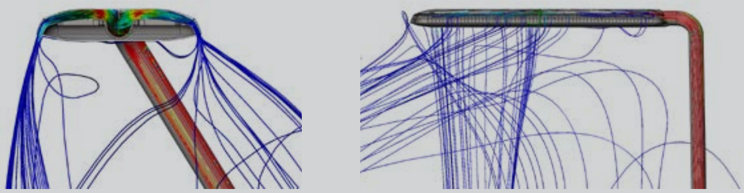
Iteration 05

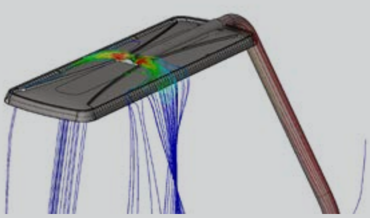
Short tube

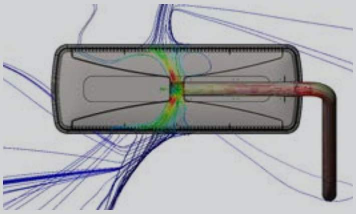


Iteration 06

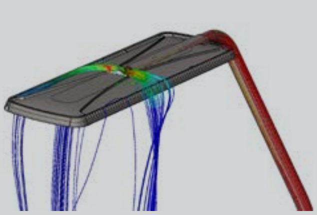
Short tube

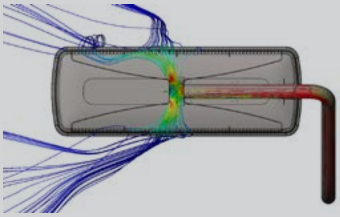




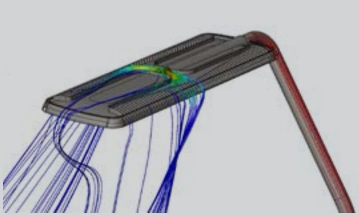


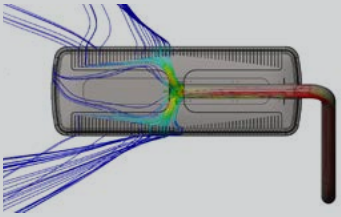
In this concept the air exits the tube in the middle of the unit where it hits a slope that sends the air upwards and to the side. On each side the chnanel opens up and the air is free to spread over the length of the unit. But instead of spreading most of the air exits in on a narrow stretch in the middle.



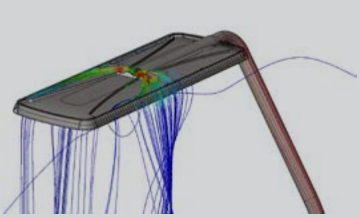


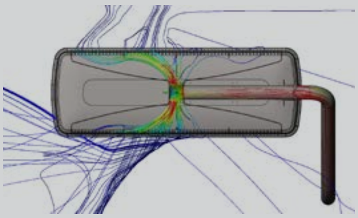
This concept is identical to the previous besides from a change in the radius between the upwards slope at the end of the tube and the open cavity. This allows for a more smooth curve but doesn't prevent the air from simply exiting in the middle of the unit.



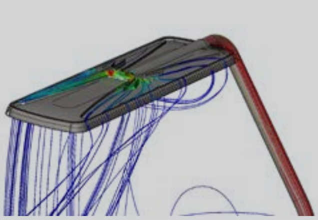


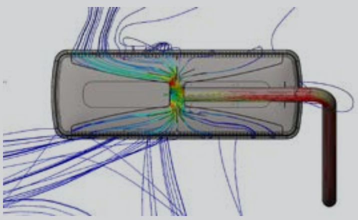
This concept uses ribs that increase in length the further away from the middle they are placed. But this concept has the same problem as the previous two that the air finds the easiest point to exit, which is right in the middle.



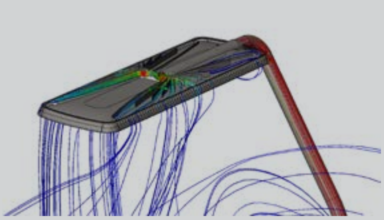


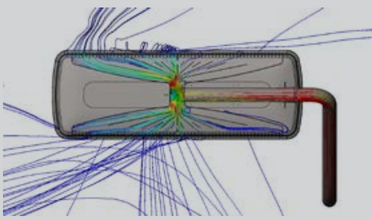
To prevent the air from exiting only in the middle, three guiding ribs are added on both sides that have a slight outwards curve. This helps to spread the air somewhat, but most of the air is pushed to the front of the unit because of the direction that it enters the open cavity.





Just as the previous concept guiding curves are added on both sides. But to avoid that the air only exits in the front the number of ribs is increased to 7 on both sides and the length of these have been increased. This helps to spread the air more evenly.





In this concept the ribs have been made even longer and additional ribs have been added. Of the 6 designs where the tube goes to the middle this one performs the best, but the air distribution is still not as good as the concept where the tube goes all the way to the end of the unit.

Appendix O
Fan selection

The right fan for the MultiAir unit should be able to deliver at least 40 l/s at XXX Pa while also possibly supplying a second module and a HEPA and carbon filter.

Fan 01

K2E 225-RA92-01

Backward curved centrifugal

2500 rpm

155 W

63 dB

Fan 02

RG-160-28/18 2NTDHHP

Backward curved centrifugal

6000 rpm

159 W

85 dB

Fan 03

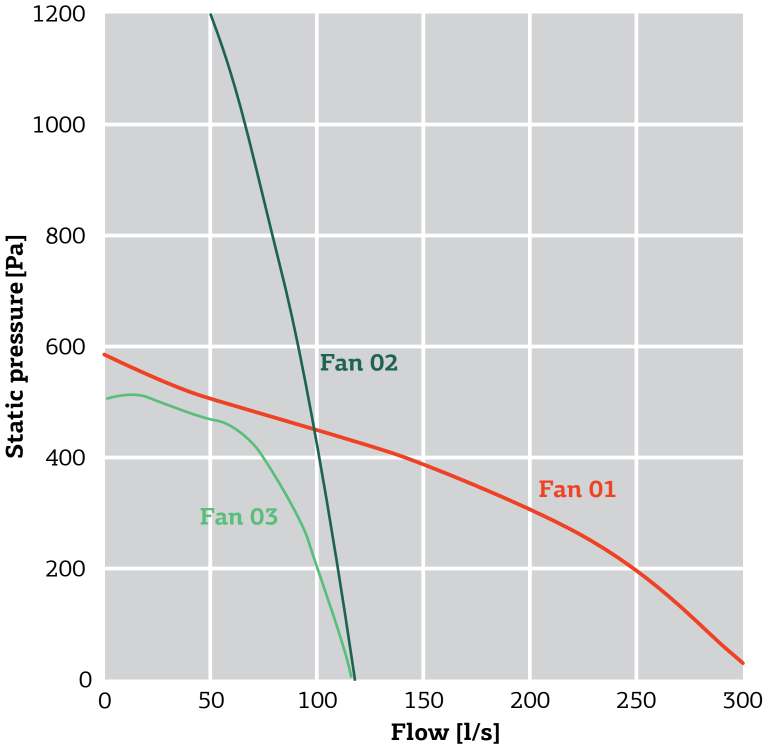
G2E 140 NS38 01

Forward curved centrifugal

2150 rpm

155 W

64 dB



Appendix P
Investment

This appendix shows an estimate for the investment required in tooling for the production to begin.

INVESTMENTS		Price (t.DKK)	Source
The ventilation system			
Main body	Die casting	200	Heka Danmark
Side guide	Extrusion	20	Heka Danmark
Rear guide	Die casting	110	Heka Danmark
Front guide	Die casting	110	Heka Danmark
Top lid	Injection molding	80	Heka Danmark
Bottom cover/diffuser	Vacuum forming	15	Gibo Plast A/S
Outlet body	Rotational molding	45	Dan Hill A/S
Total		**580**	

Appendix Q
Cost price

The cost price was created based on acquiring prices from manufacturers for major parts, and then guess the prices for all the smaller parts

Component	Processing	Quantity	Material price DKK/kg	Material	Weight kg
Overhead Inlet					
Main body	Die casting	1	**55**	Aluminum	4,045
Side guide	Extrusion, anodization	2	**35**	EN AW 6060 T6	0,644
Rear guide	Die casting, anodization	2	55	Aluminum	0,226
Front guide	Die casting, anodization	1	**55**	Aluminum	0,178
Top lid	Injection molding	1		ABS	1,136
Bottom cover/diffuser	Vacuum formning	1		PMMA, Opal	1,347
Seal		1		Rubber	
Overhead inlet tube	Bended steel tube	1		60x2 steel tube	
Fluorescent lamp		4			
HF+Regulator		2			
Socket		8			
Outlet		2			
Outlet body	Rotational molded, milled	1		PE	
Bracket	Laser cut and bended	2			
Front cover	Laser cut and rolled	1			
Pre-filter	Injection molded	1			
Air handling unit					
Housing	Laser cut, bended and welded and foamed	1			
Tubes		1			
Connector	Vacuum formed	1			
Couplers		2			
Papst centrifugal fan		1			
HEPA filter	Standard	1			
UVGI Lamp w. Transformer	Standard	1			
	Standard	1			
Assembly					
Total cost price					
insecurity of costprice				10%	
Total cost price incl. Insecurity margin					

Profit (Best case)		
Sales price incl VAT	12.000	DKK
VAT	2400	DKK
Sales price excl VAT	9.600	DKK
Cost price	4146,1255	DKK
gross margin	5.454	DKK
margin (%)	56,81119271	%

Profit (Worst case)	
Sales price incl VA	8.000
VAT	1600
Sales price excl V/	6.400
Cost price	4146,1255
gross margin	2.254
margin (%)	35,21678906

Cost price	Accumulated	Tool pricing	Uncertainty on costprice	Source
DKK	DKK			
	1683,205			
222,475		200.000		HEKA Danmark
45,08		20.000		HEKA Danmark
24,86		110.000		HEKA Danmark
9,79		110.000		HEKA Danmark
100		80.000		HEKA Danmark
175		15.000		Gibo Plast A/S
10				
60				
186				Philips
800				Philips
50				
	506			
173		45.000		Dan Hill A/S
10				
60				
10				
	1480			
350				
30				
50				
350				
470				Ebm Papst
100				
130				Philips
	100			
	3769,205			
	376,9205			
	4146,1255			

Guess - very insecure

Concrete offer/price

DKK
DKK
DKK
DKK
DKK
%