Degree Project in Technology

First cycle, 15 credits

Automated Hermetically Sealed vs. Conventional Waste Management Systems in Hospitals

A Comparative Study of Microbial Presence

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Automatiserade hermetiskt slutna jämfört med konventionella avfallshanteringssystem på sjukhus

En jämförande studie av mikrobiell närvaro

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Degree project in medical engineering
First cycle, 15 credits
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2024

Abstract

This study assesses the effectiveness of automated hermetically sealed waste management systems compared to conventional waste disposal methods in reducing microbial loads in hospitals. A comparative analysis was conducted between Södersjukhuset, which utilizes the automated system, and Östra Sjukhuset, which employs a conventional system. Microbial presence was quantified through colony forming units (CFUs). Results demonstrate that Södersjukhuset experienced a 49.3% reduction in mean CFU count and a 6.10% reduction in median CFU count compared to Östra Sjukhuset. Statistical analysis using the Mann-Whitney U test produced a p-value of 0.055, slightly above the significance threshold of 0.05, providing limited statistical support of the difference in microbial load between the hospitals. Hence, the findings suggest that there may be a potential for automated waste management systems to improve hospital sanitation and patient safety.

Keywords: Automated Waste Management Systems, Hospital Sanitation, Microbial Load, Colony Forming Units (CFUs), Patient Safety

Sammanfattning

Denna studie undersöker effektiviteten av automatiserade hermetiskt slutna avfallshanteringssystem jämfört med konventionella avfallshanteringsmetoder på sjukhus, med fokus på deras påverkan på mikrobiell närvaro. Genom en jämförande analys mellan Södersjukhuset, utrustat specifikt med Envacs automatiserade system, och Östra Sjukhuset som använder den konventionella metoden, kvantifierar studien bakteriekontamineringsnivåer genom kolonibildande enheter (CFU). Resultaten visade ett 49,3% lägre genomsnittligt CFU-antal och ett 6,10% lägre median CFU-antal på Södersjukhuset jämfört med Östra Sjukhuset, vilket tyder på att automatiserade system avsevärt minskar mikrobiell kontaminering. Mann-Whitney U-testet gav ett p-värde på 0,055 och därför implicerar begränsat statistiskt stöd för skillnaden i mikrobiell belastning mellan sjukhusen. Därav tyder resultaten på att det kan finnas en potential för automatiserade avfallshanteringssystem att förbättra sjukhussanering och patientsäkerhet.

Nyckelord: Automatiserade avfallshanteringssystem, Sjukhushygien, Mikrobiell belastning, Kolonibildande enheter (CFUs), Patientsäkerhet

Acknowledgment

Our sincere thanks and deepest gratitude are extended to the team at the Karolinska university laboratory. We are particularly grateful to Johanna Snäll, PhD, Microbiologist, and John Carlsson, Microbiologist, for their exceptional support and cooperation along with Saarah Trädgårdh, Microbiologist. Furthermore, we acknowledge and extend our gratitude to Annika Tiveljung Lindell, Head of Clinical Microbiology, Medical Diagnostics Karolinska (MDK), for facilitating the collaboration with the laboratory.

Our deepest gratitude is also extended to Anna Gyberg, RN, PhD, Development Manager at the Department of Medicine, geriatrics, and Emergency Care, Sahlgrenska University Hospital, Gothenburg, and Mårten Bylund, Planning Manager at Regionservice, Västra Götaland Region. Further, thanks also go to Hanna Bard, Unit Manager, Internal Logistics, and Ingemar Qvarfordt, Senior Consultant, Infection Prevention and Control, Sahlgrenska University Hospital, and Medical Advisor, Department of Patient Safety and Medical Crisis Preparedness, Koncernkontoret, Västra Götaland Region, for their cooperation.

At Södersjukhuset, we are thankful for the collaboration provided by Mihaela Oana Romanitan, MD, PhD, Head of Internal Medicine; Magda Eriksson, Unit Manager, Internal Medicine, Neurology Section, NAVE/Ward 17; and Eva Nygren, former Unit Manager at NAVE, who played crucial roles in the sample collection process. Further, we express our gratitude to Birgitta Wranne for providing data on HAIs at Södersjukhuset.

Lastly, we would like to express our profound gratitude to Magnus Sjöstrand, Senior Sales Manager & Health Care Products Specialist at Envac, for his invaluable cooperation and guidance as project supervisor throughout this study. Additional thanks go to Sara Arrhenius, Chief Marketing Officer, for managing the project financing. Further thanks to Martina Mattsson, Marketing & Communications Manager, Envac North Europe, for her role in organizing the initial stages of this project. We also express our deepest gratitude to the rest of Envac for their exemplary cooperation and hospitality. We also acknowledge the financial compensation provided by Envac for the project.

Contents

Abbreviations

Abbreviation	Expression
AVA	Unit 16 (Södersjukhuset)
CFU	Colony forming unit
EEA	European Economic Area
HAI	Healthcare-Associated Infections
KUL	Karolinska university laboratory
MAVA	Medicinsk akutvårdsavdelning (Medical emergency department) / Unit 356B at Östra Sjukhuset
NAVE	Neurologisk akutvårdsenhet (Neurological emergency unit) / Unit 17 at Södersjukhuset
RODAC	Replicate Organism Detection And Counting
SU	Sahlgrenska University Hospital
WHO	World Healthcare Organization

1 Introduction

Nosocomial infections, or healthcare-associated infections (HAIs), are a significant global health issue that, according to the World Health Organization (WHO), affects millions of patients annually (1). These infections can lead to prolonged hospital stays, long-term disability, increased microbial resistance to antimicrobial agents, significant additional healthcare system costs, high expenses for patients and their families, and, most notably, unnecessary deaths. Moreover, WHO also states that nosocomial infections are the most common adverse outcome in healthcare and represent an extensive global problem, especially in low- and middle-income countries, with hundreds of millions affected worldwide each year.

A study from 2018 investigating changes in the prevalence of hospital-acquired infections in the USA found a prevalence rate of 4.0% in 2011 and 3.2% in 2015, highlighting the ongoing challenges and improvements over time (2). Similarly, an examination of the prevalence of these infections within the EU and EEA between 2016 and 2017 reported that 6.5% of patients in acute care hospitals and 3.9% of residents in long-term care facilities had at least one hospital-acquired infection (3). They also reported an estimated 8.9 million episodes of such infections occurring annually.

Effective waste management is crucial for controlling the spread of bacteria within healthcare facilities. Hospital waste includes a variety of materials, such as used medical supplies, contaminated objects, and other types of waste that may harbor pathogenic microorganisms. Without effective management and disposal of this waste, the risk of cross-contamination between waste, patients, healthcare personnel, and the environment of healthcare facilities increases.

Envac is a Swedish company spearheading the global development of automated waste management systems and is a world leader in the field of pneumatic, pressurized, waste systems (4). The company's approach in the hospital sector marks a significant departure from conventional waste management methods (5). By implementing automated hermetically sealed pipes for waste and laundry systems, Envac offers a sophisticated solution that directly addresses the infection spread risk associated with conventional waste management. These systems use a network of pipes to transport waste and laundry from pickup points to a central collection location, minimizing manual handling and internal waste transportation within hospitals. Hence, the method effectively reduces physical contact with waste and the distance waste travels through hospital environments.

This study conducted a comparative analysis between two hospital settings: one equipped with Envac's automated waste management system and the other using traditional methods. It assessed microbial presence along their waste transport chains to quantify bacterial contamination levels. Thus, the study aimed to provide objective data assessing the hypothesis that automated systems can reduce microbial load, thereby enhancing hospital safety.

1.1 Aim

The aim was to determine if automated hermetically sealed waste management systems reduce the microbial load in a hospital environment.

2 Background

2.1 Automated waste management systems

Envac, established in Sweden, specializes in technology for automated pneumatic waste management (6). This system uses a central vacuum to transport waste, recyclable material, infectious waste, and laundry through built-in channels to a centralized collection point (6). Over time, the technology has been adopted globally, with installations in sustainable cities, hospitals, and airports (6).

In this and the following two passages, the information about the automated waste management system in hospitals was retrieved from an Envac Group page on Healthcare facilities (7). In hospitals, the system uses waste chutes designed for specific types of waste and laundry. The placement and number of chutes are adapted to the needs of the hospital, with separate channels for general hospital waste, recyclable material, and laundry. These chutes are directly connected to an extensive network of air intakes and transport pipes. The automated process reduces the need for manual handling of waste and transport of waste through hospital corridors, minimizing exposure to potentially infectious materials for healthcare staff and patients.

The waste and laundry are transported through a separate network of pipes from entry points to the collection station, as illustrated in Figure 1. This infrastructure is concealed within walls, ceilings, and service corridors to preserve the hospital's functionality and aesthetics. According to Envac, the pipe network design facilitates efficient and hygienic transport to the collection station, typically located in a technical area outside the main building. At the collection station, air and materials are automatically separated. The air that transports the materials through the system is filtered before it is released back into the environment.

After material and air are separated, the solids are compacted into containers, while the soiled laundry bags are isolated and prepared for safe transport to the laundry facility. This platform oversees all processes, ensuring efficiency and minimal human intervention.

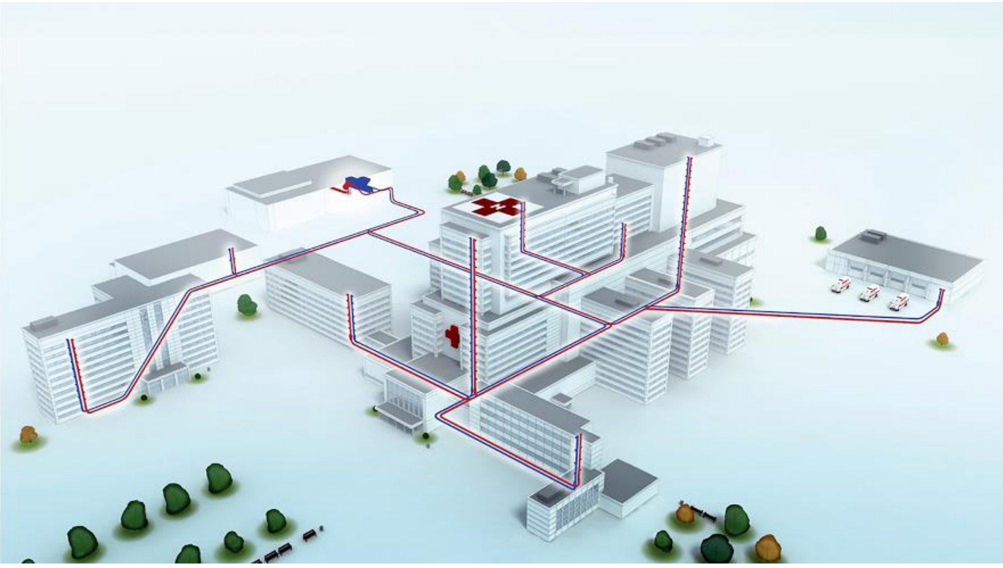

Figure 1: An illustration of how Envac's automated waste management system is integrated into a hospital. The figure shows two separate pipes running through the hospital: one for laundry and one for waste from different departments, both leading to a central collection station (8). The figure was published with Envac's authorization.

Automated vacuum systems for waste and laundry represent an innovation in hospital waste management by moving away from traditional, labor-intensive methods of waste management, which can involve health risks (6). According to Envac, this technology can help maintain a visually cleaner environment and optimize the use of space within healthcare facilities (6, 7). By eliminating the need for extensive waste storage areas, valuable space is made available to be used for clinical purposes or patient care, improving overall functionality and capacity (6).

These pneumatic systems are designed to minimize direct contact between healthcare workers and waste, which is important for limiting the spread of pathogens (6). Automating waste transport aims to contribute to a more hygienic hospital environment by reducing pests and odors associated with waste. Additionally, it can enhance safety standards, and provide a better working environment for staff (6).

2.2 The hospitals in the study

Södersjukhuset, located in Stockholm, is renowned for its large emergency department, which is one of the biggest in the Nordic countries. The hospital focuses on emergency care and the treatment of major common diseases; where the extensive clinical research is conducted, especially in areas related to these diseases (9). Södersjukhuset aims to combine the resources of a large hospital with close patient contact, highlighting its commitment to patient-centered care (9).

The internal medicine — a medical specialty focusing on internal adult diseases — department at Södersjukhuset is the largest internal medicine operation in Sweden (10). With approximately 500 employees, the operation spans multiple subspecialties, including acute internal medicine, neurology, hematology, endocrinology, pulmonary medicine, allergy, and gastroenterology (10). The clinic serves as a dynamic center for multidisciplinary collaboration and continuing education, also encompassing a comprehensive training program for future healthcare professionals (10).

For this study, wards 16 and 17 within internal medicine at Södersjukhuset were selected. Ward 16 (AVA) focuses on patients with acute conditions and an expected short stay (11). The ward consists of 18 beds and serves as an initial point for patients admitted through the emergency department, where patients can either be discharged directly or transferred to other wards for further investigation and treatment (11). The collaborative work approach means that doctors, nurses, and assistant nurses, among others, work closely together in patient care. Ward 17 (NAVE) specializes in neurological conditions and treats acutely ill patients with a variety of diseases, from epilepsy and multiple sclerosis to brain tumors and vascular conditions in the brain (12). The ward is distinguished by its high staff density and advanced medical technology equipment, especially within its Neurological Intermediate Care Unit (NIMA) (12).

At Södersjukhuset, according to Magda Eriksson, Unit Manager, Internal Medicine, Neurology Section, NAVE/Ward 17, waste is handled using Envac's system. Each department has a sluice room located roughly in the middle of the department, with the chutes placed directly outside. In these sluice rooms, there are wastebaskets and a laundry basket which the staff fill with loose waste and laundry during the working day. Waste from the patient rooms is thrown directly into the chute during the working day. When the laundry basket in the sluice room is filled, the laundry is thrown into the chute. Similarly, waste in the sluice room is handled by throwing the full garbage bags into the chute.

Östra Sjukhuset, part of Sahlgrenska University Hospital (SU), is located in Gothenburg and serves as a vital component within the regional healthcare system (13). The hospital receives patients with a wide range of acute conditions, in addition to those with orthopedic ailments. Moreover, the hospital's emergency department emphasizes an inclusive approach to emergency care, contributing to its ability to handle a diverse patient flow (13).

The internal medicine department at Östra Sjukhuset features an extensive and multidisciplinary structure that includes several specialties, such as cardiology and endocrinology (14). This diversity ensures effective care provision and access to specialist expertise within various fields of internal medicine. The educational climate, as outlined in an external quality review, underscores an environment where continuous professional development is encouraged, and resident doctors have access to research and specialized supervision (14).

Wards MAVA/356B and 353A/B within internal medicine at Östra Sjukhuset were selected. Department MAVA/356B is a medical emergency ward with 27 beds, dedicated to the stabilization and monitoring of patients with severe acute conditions such as chest pain and heart attacks (15). The ward is dynamic, receiving patients from the emergency department and intensive care, and plays a critical role in the hospital's emergency care process (15). Department 353A/B focuses on hematology and thromboembolism and manages a wide range of internal medical conditions (16). This department provides continuous and multifaceted care, with particular support for patients with chronic hematological diseases and a structured plan for both emergency and scheduled care (16).

According to Mårten Bylund, Planning Manager at Regionservice, Västra Götaland Region, waste at Östra Sjukhuset is managed by each department having a sluice room located roughly in the middle of the department. In these sluice rooms, there are containers for waste and a laundry cart for laundry. During the workday, staff throw waste bags from the patient rooms into the containers and fill laundry bags from the staff's changing room and patients into the laundry cart.

Further according to Bylund, early in the morning, around 7 am, staff responsible for waste management arrive at the department. They pull the containers and laundry cart from the sluice room to the corridor that leads to the ward and then to the lift hall, which serves as a temporary recycling room, where waste, recycling, and laundry are stored. From this recycling room, the staff take the containers and use the elevators to the hospital's basement, where the final transportation and the waste sorting and handling system are situated.

2.3 The pathogens in the study

Acinetobacter baumannii is a gram-negative bacterium notable for its survivability across diverse environments (17). As a facultative anaerobe, A. baumannii can live with or without oxygen, aiding its adaptation (17). It forms biofilms and exhibits twitching motility, enhancing its surface colonization (17). It is problematic in intensive care units as it often causes infections like pneumonia and sepsis, and survives on surfaces for extended periods (18). Its robust antibiotic resistance, due to genetic adaptability and resistance gene acquisition, complicates treatment (19).

Staphylococcus aureus is a gram-positive bacterium belonging to the phylum Bacillota (20). It is a common part of the body's microbiota, mainly in the upper respiratory tract (eg the nostrils) but also on the skin (21). About 25% to 30% of the human population carries S. aureus over long periods (21). The presence of this bacterium is usually harmless when confined to these areas; however, it can cause problems if it penetrates the body's protective barriers. Staphylococcus aureus is facultatively anaerobic and can grow under varying conditions, such as high salt concentrations and in a wide temperature range (22).

S. aureus is known to cause a range of diseases, from mild skin infections such as pimples, boils, cellulitis, folliculitis, and carbuncles, to more severe conditions such as scalded skin syndrome and deeper boils (22). The bacterium can also cause life-threatening diseases, including pneumonia, meningitis, osteomyelitis, endocarditis, toxic shock syndrome, bacteremia (infection of the bloodstream), and sepsis (22). The risk of these infections is higher among immunocompromised people, such as the elderly, people who have recently undergone surgery, and those with chronic diseases such as diabetes (22). S. aureus spreads primarily through direct contact, and in hospital settings often either via the hands of healthcare workers or by touching contaminated surfaces and medical equipment such as surgical instruments, catheters, and hospital linens (22, 23). The pathogenic potential of S. aureus is enhanced by its ability to produce toxins and a specific protein that neutralizes antibodies, making it a major challenge in terms of antimicrobial resistance (24).

Pseudomonas aeruginosa, a gram-negative bacterium from the Gammaproteobacteria class, thrives in various environments, including moist areas in healthcare facilities (25, 26). It forms biofilms, increasing its persistence and resistance to cleaning efforts (27). Surviving on surfaces for days to weeks, it causes nosocomial infections like pneumonia urinary tract infections, skin infections, and sepsis in those with weakened immune systems (27, 28). Known for strong antibiotic resistance, it can modify genes and form biofilms that shield against antibiotics (29).

Enterobacterales, a group of gram-negative bacteria, are essential for digestion and gut health but include pathogens like E. coli and Salmonella (30). These facultative anaerobes thrive in both oxygen-rich and anaerobic conditions (30). In hospitals, they spread through contact and contaminated medical equipment, posing risks to patients with compromised immune systems (31, 32). They cause infections ranging from urinary tract infections to sepsis and are highly antibiotic-resistant, utilizing mechanisms like beta-lactamases and efflux pumps (31, 33).

Enterococcus is a genus of gram-positive bacteria that is naturally present in the intestinal flora of humans and animals but can also be found on human skin and in the oral cavity (34). These bacteria thrive in a variety of environments, including soil and water (34). They have a special ability to survive harsh conditions, such as exposure to common antiseptics and disinfectants, enabling them to persist on various surfaces for up to four months (35).

Infections caused by Enterococcus include urinary tract infections, bacteremia, and endocarditis (infection of the heart valves) (34). These bacteria can also cause infections in individuals who have recently undergone surgery, such as for burns, in the abdomen and biliary tract, as well as in connection with catheters and other implanted medical devices (34). Patients at particularly high risk include those with long hospital stays, especially those in intensive care units, as well as people undergoing hemodialysis or with conditions such as diabetes, cancer, or organ transplants (34). The use of invasive devices and exposure to contaminated surfaces, including shared medical equipment, further increase this risk (34).

Enterococcus bacteria exhibit high antibiotic resistance by rapidly adapting their cellular mechanisms and acquiring resistance genes (36). They change antibiotic targets in their cell walls, produce enzymes that break down antibiotics, and use efflux pumps to remove antibiotics from their cells (36). Their ability to form biofilms also contributes to increased resistance to treatments and the immune response, complicating the treatment of the infections they cause (36).

2.4 Colony forming units

The information on colony forming units, or CFUs for short, in this passage was retrieved from the Mold & Bacteria Consulting Services article Colony Forming Units (CFU) by Jackson Kung'u (37). One CFU represents a single colony of mold, yeast, or bacteria. A colony of bacteria or yeast is defined as a collection of individual cells of one organism growing together. Similarly, for mold, a colony is a collection of the hyphae or filaments of the same mold growing together. CFUs are used to measure the quantity of microorganisms in a sample or on a surface. Hence, depending on the type of sample being examined, colony forming units can be expressed as CFU per unit weight, CFU per unit area, or CFU per unit volume. To count the number of CFUs, a sample is prepared and evenly spread or poured onto the surface of an agar plate, or collected through contact plates, as in this study. The samples are then incubated at an appropriate temperature for several days. The colonies that form are then counted. Since a colony might form from a single cell or a mass of cells or spores CFUs are not an absolute measure of individual cells or spores, but rather an approximation.

2.5 Replicate organism detection and counting plates

In the following passage, the information about replicate organism detection and counting plates was retrieved from an article by Ankur Choudhary on Pharmaguideline (38). Replicate organism detection and counting plates, commonly referred to as RODAC plates, are primarily used for surface sample testing to ensure the cleanliness of cleanrooms, laboratories, and other controlled environments. Through monitoring and assessing the effectiveness of disinfecting procedures, these plates help maintain biosafety by reducing the potential for contamination. RODAC plates are employed to collect samples from various surfaces to determine the microbial load. These plates consist of agar poured into a contact plate. Further, they are shaped by pressing them flat, to allow organisms to adhere to the medium. Proper storage conditions are crucial; RODAC plates should be refrigerated at 4 degrees Celsius, ensuring they do not freeze. The agar in these plates measures 50 millimeters in diameter and has a dome-shaped, arched surface to ensure adequate contact with the sampled surface.

2.6 Statistical analyses

There are two statistical analyses pertinent to this study: the Shapiro-Wilk test and the Mann-Whitney U test. Of them, the Shapiro-Wilk test was first employed to determine the normality of the set of samples. A simple explanation of what the test does is quantifying the similarity of an observed set of data and the normal distribution as a single number, the W-value (39). More precisely, the test statistic, W, is attained by dividing the square of a linear combination of the sample order statistics by the usual symmetric estimate of variance, which is both scale and origin invariant (40). The W-value is then used to derive a p-value, which holds the null hypothesis that the data source is normally distributed (39). Of which, a p-value of less than 0.05 conventionally implies that the source is not normally distributed (39).

The information in this passage for the Mann-Whitney U test was retrieved from the tutorial on DATAtab (41). The Mann-Whitney U test is a non-parametric test for difference testing, specifically testing for differences in central tendency in two groups. The Mann-Whitney U test is an unpaired test assuming independence between sample groups. For the test, one ranks each data point, this ranking process entails ordering all observations from both sample groups together from smallest to largest. Each observation is then assigned an integer rank, starting from 1 for the smallest. If there are tied values, meaning two or more data points of the same value, each tied group receives the average of the ranks that would have been assigned to each member of the group if they had been ranked separately. Further if there are tied values one calculates a tie term, which is used to balance the standard error. The sum of the ranks for each group is then calculated and used as part of the U statistic calculation. The test generates a specific test statistic, the U-value, which, if the sample size is over 25, can be approximated as normally distributed. Thus, a z-value can be calculated, which typically is used to determine a p-value. For said p-value, a cut-off of lower than 0.05 is the convention for statistical significance.

3 Method

3.1 Preparations

The first step in the preparations for the study was disinfecting and cleaning a double-insulated 10-liter hard-sided polypropylene cooler. This process utilized a conventional dish detergent and hot water, supplemented by mechanical agitation with a dish brush. The cooler was then placed on a sanitized table topped with a clean towel and dried using paper towels. The cooler was then disinfected using a broad-spectrum surface disinfectant, Liv Des +72 (Clemondo Group AB, Helsingborg, Sweden), and left to air dry. Subsequently, the lid was secured onto the cooler, which remained sealed until the retrieval of contact plates from the laboratory.

The contact plates were produced by and collected from the L2:02 bacteriology section of the clinical microbiology department at the Karolinska university laboratory (KUL) in Solna. These broad-spectrum RODAC plates consisted of Columbia agar, enriched with 5% defibrinated horse blood and 0.1 g/L L-tryptophan. A total of 60 plates were procured: 48 were designated for sampling, 2 served as laboratory reference standards, and 10 were reserved as contingencies for any potential interruptions in sampling, damage during handling, or premature bacterial colonization. Once collected, the plates were placed into a specially prepared container in a refrigerator, set at 4°C. This container had undergone the same rigorous cleaning process as the cooler and was additionally isolated from the rest of the refrigerator's contents by a quadruple layer of plastic bags.

The last preparations included assembling a kit of supplies for the sampling procedure, duplicated for use at each designated hospital. Each kit consisted of a 70-piece packet of 1-liter plastic freezer bags, surgical masks, and narrow clear adhesive tape housed in a dispenser. Further in the pack were pre-printed labels for numbering the plates. The numbering of the sample sites was done in advance of the sampling and was randomized respectively between the two hospitals. Thus, the numbering for the first hospital to be sampled was randomized over integers from 1 to 24 and over integers from 25 to 48 for the second hospital.

3.2 Collecting the samples

The first hospital to be sampled was Östra Sjukhuset. The contact plates were transported to the hospital in the cooler, which had undergone an additional cleaning after the initial collection of plates. Upon arrival at the hospital, the cooler was stored in a designated office to hold the plates overnight. As they entered storing, in accordance with the procedures outlined both by email and verbally by the L2:02 bacteriology section at KUL, the plates were removed from their bags before they entered storage overnight. An excerpt with the instruction email and its attached protocol is available in appendix 3.

The sampling process commenced at 06:45 the following morning by changing into the standard hospital attire at Östra Sjukhuset and being chaperoned to the sluice — sanitation room for cleaning and disinfecting — room in unit 356B (MAVA). The sampling then began in the sluice room in 353 A/B. There samples were collected from just inside the main entrance in 353 A/B, followed by the corresponding recycling room. Samples were then collected from the corresponding points for MAVA. When all samples had been collected, they were promptly transported in the cooler to KUL for incubation and analysis.

In preparation for the sampling at Södersjukhuset the next day, the cooler was once again cleaned with the same procedure and the next set of plates were taken out of their bags and placed in the cooler for storing overnight. The sampling began the following day at Södersjukhuset at 09:00. The first unit for sample collection was 17 (NAVE), where the procedure started in the sluice. The sampling then proceeded outside the sluice and next to the waste and laundry chutes, which were at the same geographical point. The last samples at NAVE were then collected on and in the direct vicinity of the waste and laundry chutes. This process was repeated for the corresponding points in unit 16 (AVA). Once all samples were collected, they were promptly transported in the cooler to KUL for incubation and analysis.

The sampling procedure was delineated into two distinct roles: the sampler, responsible for handling the contact plates, and the coordinator, tasked with overseeing and managing the rest of the process. Initially, both individuals performed thorough handwashing followed by the application of hand disinfectant. They then donned sterile nitrile gloves to maintain sterility throughout the sampling.

Upon selecting an exact location for sampling, the procedure, as prescribed by the L2:02 bacteriology section at KUL, was stringently followed. The sampler retrieved a contact plate from the cooler and proceeded to the designated sampling site. The lid of the contact plate was removed, and the plate was then gently pressed against the surface for five seconds, ensuring optimal contact without compromising the integrity of the agar. Immediately following this, the lid was placed back onto the plate, and the sampler held the plate in front of the coordinator. The coordinator then labeled the underside of the plate with the site's corresponding number and secured the lid with two narrow strips of clear adhesive tape. The sampler subsequently returned the sealed plate to the cooler, lid side down.

After all samples were collected, the plates were prepared for transport. This process involved placing the plates in pairs into double-bagged sterile 1-liter freezer bags, with the inner bag securely tied. The sampler placed these bags in the cooler, maintaining the orientation with the lids facing downward. Once all plates were securely stored, the coordinator fastened the cooler lid. It remained closed until sampling at the next sampling ward or when the samples were delivered to the laboratory.

The study collected samples from two specific departments at Södersjukhuset and Östra Sjukhuset, with three sampling sites planned for each department to trace the path of the waste. The first sampling site was designed to detect bacteria present at the initial stage of waste collection in the departments. Thus, this initial sampling was in the sluice room, a central point in the departments where waste is collected. The second sampling site was where the waste left the units. At Östra Sjukhuset, this is just inside the units' main entrances. At Södersjukhuset, the corresponding point is just beside the units' waste and laundry chutes, also just outside the sluice rooms. The third sampling site focused on where the unit's handling of the waste concludes. For Östra Sjukhuset, this place is the recycling room, where waste, recycling, and laundry are collected. At Södersjukhuset, the corresponding endpoint is at the waste and laundry chutes. Photographs of the sampling sites can be found in appendix 1.

3.3 Sample analysis

Upon collection, all samples were transported to the L2:02 bacteriology section of the clinical microbiology department at the Karolinska university laboratory for analysis. The laboratory staff then incubated and analyzed the samples according to the European Committee on Antimicrobial Susceptibility Testing (EUCAST) guidelines. The analysis encompassed CFU counting per plate, to a maximum of 100 CFUs per plate, pathogen identification using a Bruker Microflex LRF (Bruker GmbH, Bremen, Germany), and antimicrobial susceptibility testing. The pathogens that were controlled for in the study and the corresponding standard antibiotics for susceptibility testing are listed in table 1.

Table 1: The pathogens that were controlled for in the study and the corresponding standard antibiotics for susceptibility testing.

Enterobacterales	Pseudomonas aeruginosa	Acinetobacter baumannii group	Staphylococcus aureus	Enterococci
Piperacillin-tazobactam	Piperacillin-tazobactam	Imipenem	Isoxazolyl penicillin	Ampicillin
Cefotaxime	Ceftazidime	Meropenem	Clindamycin	Piperacillin-tazobactam
Ceftazidime	Ciprofloxacin	Trimethoprim-sulfamethoxazole	Trimethoprim-sulfamethoxazole	Vancomycin
Ertapenem		Ciprofloxacin		Imipenem
Imipenem				
Meropenem				
Trimethoprim-sulfamethoxazole				
Ciprofloxacin				

3.4 Statistical analysis

Some of the sample sites were reported with over 100 CFUs, which was the cap to which KUL counted CFUs. Thus, we, the authors, counted the CFUs on those plates from images of the plates. This was done via the Microsoft Image Editor (Microsoft Corporation, Redmond, Washington, USA) to place blue dots on all CFUs accompanied by counting them with the mobile phone app Click Counter (Max Vel, Android, Google Play). Images of all the plates that were reported with over 100 CFUs, with blue dots on each CFU, each representing one count, can be found in appendix 1.

The statistical analysis began by calculating the mean, standard deviation, and median of all CFU-counts, this was done with the average, stdev.s, and median functions in Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA). Excel also facilitated the rest of the calculations for the statistical analysis, which are presented in appendix 2. After the initial analysis, all sample sites without a direct equivalent between the two hospitals were eliminated to ascertain direct comparability. The remaining sites were as demonstrated by table 2 and included 32 of the total 48 samples.

Table 2: The pairings of sample sites between the hospitals and units. The pairings are in rows.

Östra Sjukhuset		**Södersjukhuset**	
MAVA	#22 Door handle out from	AVA	#35 Door button to exit

	the sluice room		from the sluice room
	#5 Wall behind the laundry basket in the sluice room		#48 Wall behind the laundry basket in the sluice room
	#18 Door lock button in sluice room		#43 Light switch to turn on the lights in the sluice room
	#21 Waste container handle in the sluice room		#30 Handle on the laundry chute
	#16 Waste container handle in the recycling room		#46 Handle on the waste chute
	#20 Wall where the laundry cart stops in the corridor		#29 Wall next to the door opener button
	#1 Corridor door button		#37 Door opener to enter the sluice room
	#14 Corridor handrail		#33 Handrail near the chute
353 A/B	#24 Door handle out from the sluice room	NAVE	#28 Door button to exit from the sluice room
	#3 Wall behind the laundry basket in the sluice room		#39 Wall behind the laundry basket
	#7 In front of the fridge/the shelf in the sluice room		#42 Shelf at waist height
	#19 Waste container handle in the sluice room		#40 Handle on the laundry chute
	#10 Waste container handle in the recycling room		#38 Handle on the waste chute
	#17 Wall where laundry cart stops		#27 Wall next to the door opener button
	#11 Corridor door button		#34 Door opener to enter the sluice room
	#13 Corridor handrail		#26 Handrail near the chute

Then a Shapiro-Wilk test was used to determine normality in the distribution of the CFU counts of the sample sites in table 2, which was done using the equations below (42). It began with sorting the CFU values from small to large and then calculations proceeded with equations 1 to 3, where W is the test statistic. The first calculation was the sum of squares, SS, shown in equation 1.

$$SS = \sum_{i=1}^{n}(x_i - \bar{x})^2 \qquad [1]$$

For the calculation of the sum of squares, n was determined as $m = \frac{n}{2}$, if n is even, else $m = \frac{n-1}{2}$. x_i represent each CFU value of the sorted CFU values from 1 to n ($n = 32$). Then the b-term, which was used as an auxiliary for an easier equation for W, was determined, as shown in equation 2.

$$b = \sum_{i=1}^{m} a_i(x_{n+1-i} - x_i) \qquad [2]$$

For the b-term, the a_i coefficients were read from a table (43). x_i was the same as from equation 1, and x_{n+1-i} described the reverse order of x_i. Afterwards, the test statistic, W, was calculated as shown in equation 3.

$$W = \frac{b^2}{SS} \qquad [3]$$

Based on the Shapiro-Wilk test, it was decided that non-parametric statistical analysis was most prudent. Assuming independence between the samples a Mann-Whitney U test was employed. The method for this test was according to the instructions from DATAtab, which are the ones described below (41).

The Mann-Whitney U test began by assigning ascending rankings for each of the relevant CFU counts from smallest to largest. For tied CFU counts, the mean rank of all CFU counts with that specific count was assigned to each of those counts. After, the rank sums, T_1 and T_2, for Östra Sjukhuset and Södersjukhuset were calculated. Then the tie term that was needed for the standard error was determined using equation 4; where k is the number of tied ranks, and t_i is the number of elements sharing rank i.

$$\sum_{i=1}^{k} \frac{t_i^3 - t_i}{12} \qquad [4]$$

Then the test statistic, the U-value, was calculated using the following equations, where n_1 was the number of samples from Östra Sjukhuset and n_2 was the number of samples from Södersjukhuset, both of which were the same number, 16. The calculation of the U-value was divided into three parts, the first two of which were the U_1 and U_2 values, shown in equations 5 and 6 respectively, where U_1 was the test statistic for Östra Sjukhuset and U_2 was the test statistic for Södersjukhuset.

$$U_1 = n_1 \cdot n_2 + \frac{n_1 \cdot (n_1 + 1)}{2} - T_1 \qquad [5]$$
$$U_2 = n_1 \cdot n_2 + \frac{n_2 \cdot (n_2 + 1)}{2} - T_2 \qquad [6]$$

Of the U-values, the smallest was chosen, as shown in equation 7.

$$U = min(U_1, U_2) \qquad [7]$$

Then, μ_U, the expected value of U, was calculated using equation 8.

$$\mu_U = \frac{n_1 - n_2}{2} \qquad [8]$$

Afterwards, the standard error of U, $\sigma_{U_{corr}}$, was calculated using equation 9.

$$\sigma_{U_{corr}} = \sqrt{\frac{n_1 \cdot n_2}{n \cdot (n-1)} \cdot \left(\frac{n^3 - n}{12} - \sum_{i=1}^{k} \frac{t_i^3 - t_i}{12}\right)} \qquad [9]$$

Lastly, the z-value was calculated using equation 10.

$$z = \frac{U - \mu_U}{\sigma_{U_{corr}}} \quad [10]$$

As the total number of samples was 32, normal distribution was assumed for the z-score (41), which enabled the p-value to be determined exactly through a calculator (44). The use of p-values determined the statistical significance of the observed differences between the CFU counts at the hospitals. A p-value less than 0.05 was considered indicative of a statistically significant difference in microbial load between the environments.

4 Results

4.1 Colony forming units

The mean colony forming unit count per plate at Östra Sjukhuset was 98.0 with a standard deviation of ±146, at Södersjukhuset it was 49.7 with a standard deviation of ±64.5. Thus, Södersjukhuset had about a 49.3% decrease in mean CFU count compared to Östra Sjukhuset. The median CFU count per plate at Östra Sjukhuset was 41.0, and the median CFU count per plate at Södersjukhuset was 38.5. Hence, there was an approximately 6.10% decrease from Södersjukhuset to Östra Sjukhuset. All CFU counts are presented in table 3.

Table 3: The CFU counts at all sample sites in the study. For the sites that were reported with more than 100 CFUs, the authors' counts, which were used for all statistical analyses, are reported in parentheses below the count reported from KUL.

Östra Sjukhuset	Sample Site	CFUs / plate	Södersjukhuset	Sample Site	CFU / plate
MAVA	#22 Door handle out from sluice room	100 (142)	AVA	#35 Door button to exit from the sluice room	45
	#5 Wall behind the laundry basket in the sluice room	16		#48 Wall behind the laundry basket	11
	#18 Door lock button in sluice room	27		#43 Light switch to turn on the sluice room	14
	#21 Waste container handle in the sluice room	30		#30 Handle on the laundry chute	98
	#16 Waste container handle in the recycling room	100 (622)		#46 Handle on the waste chute	11
	#4 Bottom of the laundry cart in sluice room	4		#45 The wall above the waste bag	1
	#12 Laundry cart handle	12		#31 Shelf at waist height	49
	#9 Elevator button	34		#25 The wall above the waste chute	6
	#6 Recycling room door button	40		#41 The wall above laundry chute	49
	#20 Wall where laundry cart stops in the corridor	12		#29 Wall next to the door opener button	35
	#1 Corridor door button	63		#37 Door opener to enter the sluice room	61
	#14 Corridor handrail	100 (271)		#33 Handrail near the chute	100 (187)

353 A/B	#24 Door handle out from the sluice room	100 (154)	NAVE	#28 Door button to exit from the sluice room	42
	#3 Wall behind the laundry basket in the sluice room	52		#39 Wall behind the laundry basket	7
	#7 In front of the fridge/the shelf in the sluice room	93		#42 Shelf at waist height	19
	#19 Waste container handle in the sluice room	14		#40 Handle on the laundry chute	8
	#10 Waste container handle in the recycling room	75		#38 Handle on the waste chute	51
	# 8 Bottom of the laundry basket	27		#47 The wall above the waste bag	28
	#15 Laundry basket handle	15		#36 Light switch to turn on the sluice room	13
	#23 Elevator button	42		#32 The wall above waste chute	53
	#2 Recycling room door button	100 (119)		#44 The wall above laundry chute	43
	#17 Wall where laundry cart stops	44		#27 Wall next to the door opener button	1
	#11 Corridor door button	100 (416)		#34 Door opener to enter the sluice room	100 (287)
	#13 Corridor handrail	27		#26 Handrail near the chute	73

4.2 Statistical analysis

The Shapiro-Wilk test determined that the data was not normally distributed. The Mann-Whitney U test yielded a z-value of -1.60, and hence a p-value of 0.055. For Östra Sjukhuset the mean rank in the Mann-Whitney U test was approximately 19.2 and the median rank was 20.0. Correspondingly for Södersjukhuset, the mean rank was 13.8 and the median rank was 14.5.

4.3 Pathogens

Pathogens were identified at both hospitals in the study. Of them, the only case of antimicrobial resistance was at Östra Sjukhuset. At Östra Sjukhuset, the elevator button at MAVA showed 34 CFUs, of which 2 were identified as Staphylococcus aureus, showing sensitivity to the following antibiotics: isoxazolylpenicillin, erythromycin, clindamycin, linezolid, trimethoprim-sulfamethoxazole, norfloxacin, rifampicin, fusidic acid, and gentamicin. The recycling room door button at unit 353 A/B exhibited a higher contamination level with 100 reported CFUs, 119 according to the authors' count, including 3 CFUs of Enterococcus faecalis, which was resistant to cefadroxil but susceptible to ampicillin, imipenem, linezolid, and vancomycin. At Södersjukhuset, the wall above the laundry chute at AVA showed 49 CFUs with 5 CFUs of Staphylococcus aureus, sensitive to isoxazolylpenicillin, erythromycin, clindamycin, linezolid, trimethoprim-sulfamethoxazole, norfloxacin, rifampicin, fusidic acid, and gentamicin. The handrail near the chute at AVA and the door button to exit the sluice room at NAVE displayed 100, 187 according to the authors' count, and 42 CFUs respectively, with Staphylococcus aureus identified in 5 and 8 CFUs, both exhibiting the same antibiotic sensitivity. These findings are also available on pages two and three in appendix 2.

5 Discussion

The analysis revealed a substantial decrease in mean CFU counts at a 49.3% decrease at Södersjukhuset, which employs the automated hermetically sealed waste management system, compared to Östra Sjukhuset, which uses the conventional system. However, the median comparison between the two hospitals revealed a considerably smaller decrease of 6.10%. Moreover, the standard deviation for the two hospitals is substantial, as is evident when viewing table 3, with both being larger than 100% of their respective mean values.

The Mann-Whitney U test yielded a p-value of 0.055, slightly above the conventional threshold of 0.05 for statistical significance (45). This outcome lends support to the potentially impactful role of automated hermetically sealed waste management systems in improving hospital hygiene and patient safety. Nonetheless, the null hypothesis, which states that there is no difference between the hospitals, cannot be conventionally rejected based on this result. Understanding p-values helps clarify the implications of this finding. A p-value measures the probability of observing the results, or more extreme ones, if the null hypothesis, the presumption that there is no difference, is true (45). Typically, a p-value of less than 0.05 is used as a cutoff for statistical significance, meaning there is less than a 5% chance that the observed data, or more extreme, could occur under the null hypothesis (45). The p-value of 0.055 obtained in this analysis suggests a 5.5% probability, which marginally exceeds the threshold of 5%. Hence, the theoretical significance cannot be formally declared, but the p-value is still indicative of a difference (45).

The pathogen distribution analysis revealed that the elevator button at Östra Sjukhuset in the recycling room at MAVA carried 34 CFUs, including 2 of Staphylococcus aureus. The recycling room door button at 353 A/B showed contamination levels exceeding 100 CFUs, including 3 CFUs of Enterococcus faecalis that exhibited resistance to Cefadroxil but increased susceptibility to Imipenem. In addition, two samples from Östra Sjukhuset #19, Waste container handle in the sluice room, and #10, Waste container handle in the recycling room, in unit 353 A/B grew mold. Conversely, Södersjukhuset displayed 49 CFUs including 5 of Staphylococcus aureus next to the door button at AVA and recorded over 100 and 42 CFUs at the corridor handrail and sluice room door button respectively, with Staphylococcus aureus found in 5 and 8 CFUs. The closer proximity of these sampling sites compared to those at Östra Sjukhuset might have influenced pathogen detection rates. The instance of antibiotic resistance lends circumstantial support, meaning it should not be interpreted as conclusive, to the notion that conventional waste management systems might be associated with less controlled microbial environments.

In the context of assessing hospital-acquired infection (HAI) rates, data sourced from Södersjukhuset and Östra Sjukhuset, utilizing the nationally standardized marker-based medical record review, reveal that Södersjukhuset reported lower incidence rates over the past three years. Specifically, the HAI rates at Södersjukhuset were reported as 2% in 2021, 5.5% in 2022, and 0.5% in 2023. In contrast, Östra Sjukhuset exhibited a downward trend but consistently higher rates showing 5.7% in 2022, 4.9% in 2023, and 3.8% in 2024. These statistics, provided by respective hospital staff, Birgitta Wranne, Strategic Business Developer for the Department of Quality and Patient Safety at Södersjukhuset and Anna Gyberg, registered nurse, PhD, Development Manager at the Department of Medicine, geriatrics, and Emergency Care, Sahlgrenska University Hospital, underscore the potential efficacy of automated hermetically sealed waste management systems in mitigating cross-contamination and reducing the spread of infections. However, according to Wranne, it is essential to acknowledge the inherent statistical imprecision in the method used to derive these rates. Further according to Wranne, the marker-based medical record review is subject to considerable variability due to its small sample size, which does not produce statistically reliable data since it does not comprehensively capture all instances of HAIs. Thus, the data should be interpreted with caution regarding its absolute accuracy.

The impact of cleaning services on hospitals can significantly affect the outcomes of studies like this. Variations in the efficacy of cleaning protocols, frequency of cleaning, and the products used can all influence levels of microbial presence. Hence, the results may reflect not just the waste management system's efficiency but also the standards of cleaning practices. Additionally, patient flow and hospital capacity are critical factors; hospitals with high patient turnover or those operating at or near maximum capacity may experience different levels of bacterial contamination compared to those with lower patient flow and capacity usage. This can lead to increased movement and interaction within the hospital, raising the risk of cross-contamination. During this study, both hospitals experienced regular patient flow, and the hospitals and individual units were selected to have similar capacity and patient flow to minimize variability.

During this study, the recycling rooms at Östra Sjukhuset were temporarily relocated to the elevator halls. This relocation was necessitated by reconstructions but did not impact the study's outcomes, as the relocated facilities functioned identically to their original settings.

In summary, the results underline the necessity of exploring enhancements of waste management strategies within healthcare settings. The data suggest that automated hermetically sealed systems, such as the one employed by Södersjukhuset, may offer advantages in reducing microbial loads. Given the statistical analysis and the practical implications observed, it becomes imperative for healthcare facilities to take hygiene into higher consideration, and to consider the potential benefits in adopting such technologies as part of a comprehensive infection control strategy.

Future research should focus on extending this study to a broader range of healthcare environments and incorporating a larger sample size and temporal scope to enhance the statistical robustness of the findings. Longitudinal studies could provide more definitive evidence of the impact of automated waste management systems over time, tracking changes in microbial load and infection rates across different seasons and operational conditions. Additionally, integrating real-time monitoring of microbial loads could help in understanding the dynamic interactions between waste management practices and hospital hygiene.

Moreover, studies should explore the psychological and operational impacts of introducing automated systems in hospital settings. Understanding how these systems affect staff workflow and morale, as well as patient perceptions of hospitals, could provide valuable insights into the broader implications of technological advancements in healthcare.

6 Conclusion

This study provides some evidence for the effectiveness of automated hermetically sealed waste management systems, like the one implemented at Södersjukhuset. The system at Södersjukhuset showed a 49.3% decrease in mean and a 6.10% decrease in median microbial load compared to the conventional system at Östra Sjukhuset. Statistical analysis with a Mann-Whitney U test yielded a p-value of 0.055, slightly above the threshold of 0.05. Therefore, while the study suggests a reduction in microbial load, the results are not statistically significant at the 5% level. Overall, the study lends some support to the notion of automated hermetically sealed waste management systems reducing the microbial load in hospitals.

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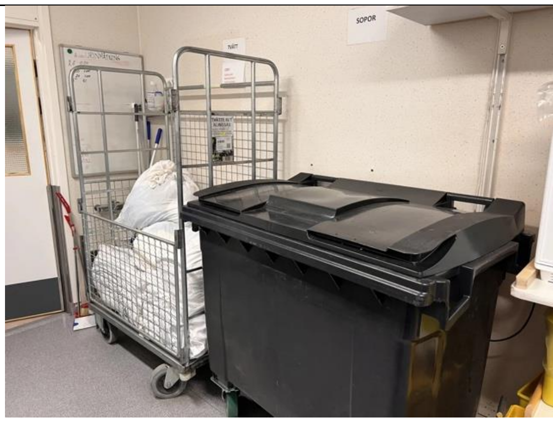
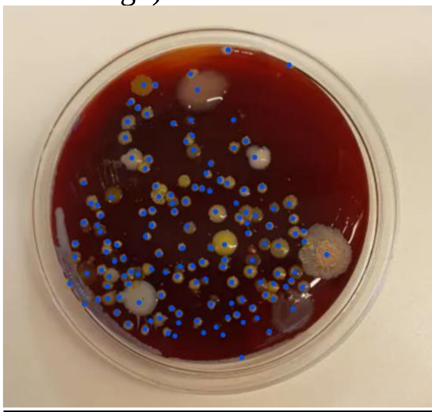
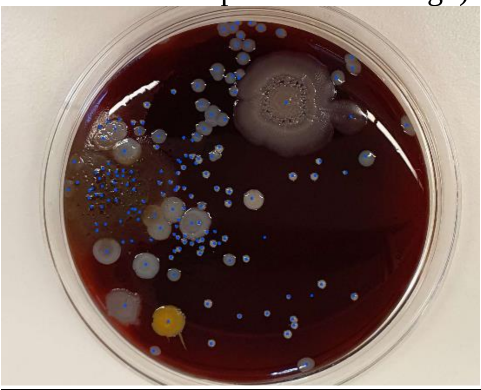
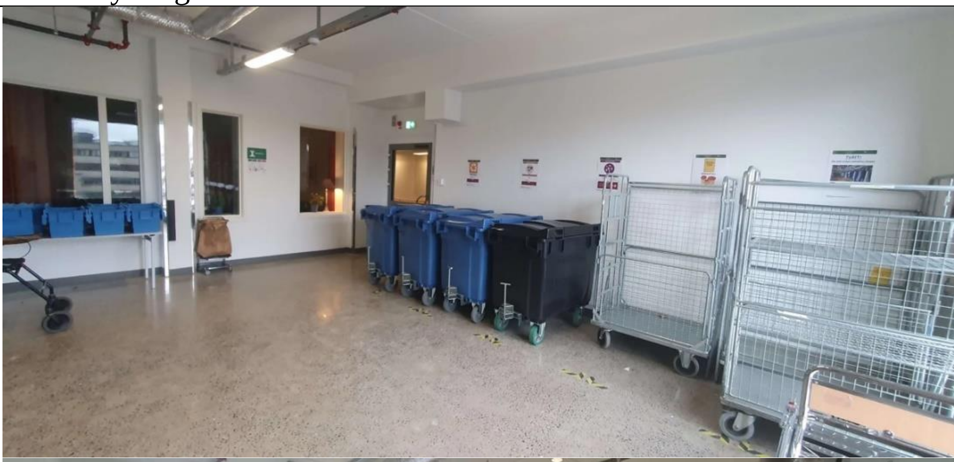
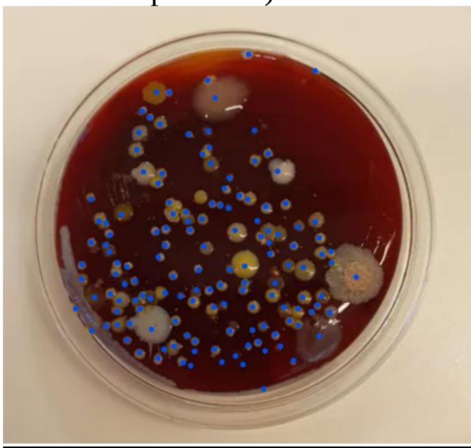
Appendix 1: The sample sites

<table>
<tr><td colspan="4">Östra Sjukhuset</td></tr>
<tr><td colspan="2">MAVA
Unit 356B</td><td colspan="2">353 A/B</td></tr>
<tr><td colspan="2">
</td><td colspan="2"></td></tr>
<tr><td colspan="4">Sluice room</td></tr>
<tr><td>#4</td><td>Bottom of the laundry cart</td><td>#8</td><td>Bottom of the laundry cart</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
</table>

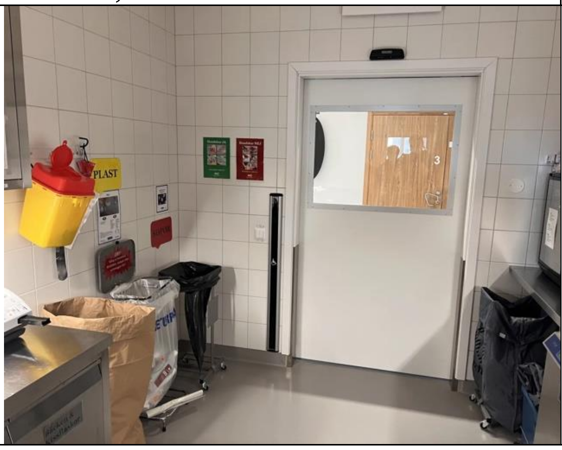
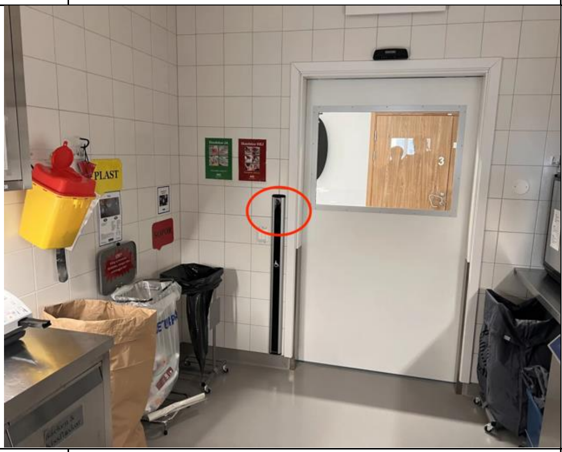
#21	Handle of the waste container (The waste bin)	#19	Handle of the waste container (the waste bin)
			
#22	Door handle on the exit path (Where the waste is transported out through) 	#24	Door handle on the exit path (where the waste is transported out through) 
#18	Door button to exit from the sluice room	#7	Spare: Shelf at waist height (this department had no button to unlock the sluice room)
			
#5	Wall behind the laundry basket	#3	Wall behind the laundry basket

#12	Handle of the laundry basket	#15	Handle of the laundry basket
			
The corridor/hallway			
#20	Wall near the button for the door opener (where the waste is transported out through)	#17	Wall near the button for the door opener (where the waste is transported out through)
			
#1	Door opener to exit the department	#11	Door opener to exit the department 

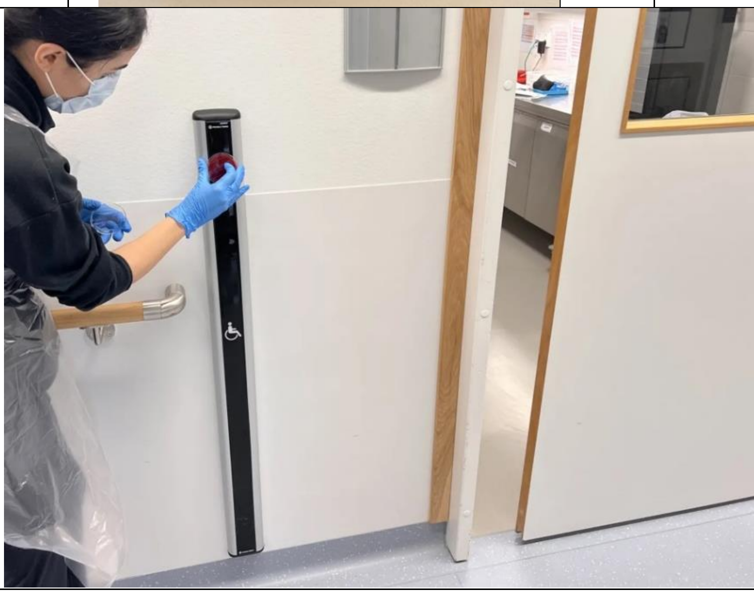
			
#14	Handrail near the exit 	#13	Handrail near the exit
The Recycling Room			
 			

#9	Door button to open the recycling room (where the waste is transported from the department)	#2	Door button to open the recycling room (where the waste is transported from the department) 
#6	Elevator button	#23	Elevator button
			
#16	Lid to the container (handle) 	#10	Lid to the container (handle)


Brännbart
sopor

<table>
<tr><td colspan="4">Södersjukhuset</td></tr>
<tr><td colspan="2">NAVE
Ward 17, Internal Medicine</td><td colspan="2">AVA
Ward 16, Internal Medicine</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="4">Sluice room</td></tr>
<tr><td>#28</td><td>Door button to exit from the sluice room</td><td>#35</td><td>Door button to exit from the sluice room</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>#36</td><td>Light switch to turn on the sluice room</td><td>#43</td><td>Light switch to turn on the sluice room</td></tr>
<tr><td>#47</td><td>The wall above the waste bag</td><td>#45</td><td>The wall above the waste bag</td></tr>
<tr><td colspan="2">
</td><td colspan="2"></td></tr>
<tr><td>#42</td><td>Shelf at waist height</td><td>#31</td><td>Shelf at waist height</td></tr>
</table>

			
#39	Wall behind the laundry basket	#48	Wall behind the laundry basket
			
The corridor/hallway			
#27	Wall next to the door opener button	#29	Wall next to the door opener button
#26	Handrail near the chute	#33	Handrail near the chute 

			
#34	Door opener to enter the sluice room 	#37	Door opener to enter the sluice room
			
Waste and laundry chute			

#38	Handle on the waste chute	#46	Handle on the waste chute

#40	Handle on the laundry chute	#30	Handle on the laundry chute
#32	The wall above waste chute	#25	The wall above waste chute
#44	The wall above laundry chute	#41	The wall above laundry chute

Appendix 2: Statistical Analyses in Excel

Images of the Excel sheet data was used for all the statistical analyses that were performed during the study "Automated Hermetically Sealed vs. Conventional Waste Management Systems in Hospitals: A Comparative Study of Microbial Presence". The first two images are listing the findings and calculations of means, standard deviation, and median for the two hospitals. Then there are two images, both on page 4, of the parings of sample sites for the statistical analyses. Thereafter, in sequential order, are images of the Excel sheet for the calculations of the Shapiro-Wilk test and the Mann-Whitney U test.

	Östra Sjukhuset														
	Sample Site	CFU	Pathogens	Pathogen CFU	Antibiotic 1	Antibiotic 2	Antibiotic 3	Antibiotic 4	Antibiotic 5	Antibiotic 6	Antibiotic 7	Antibiotic 8	Antibiotic 9	Comments	
MAVA	#22 Door handle out from sluice room	142												More than 100 CFU:s	
	#5 Wall behind the laundry basket in the sluice room	16													
	#18 Door lock button in sluice room	27													
	#21 Waste container handle in the sluice room	30													
	#16 Waste container handle in the recycling room	622												More than 100 CFU:s	
	#4 Bottom of the laundry cart in sluice room	4													
	#12 Laundry cart handle	12													
	#9 Elevator button	34	Staphylococcus aureu	2	Isoxazolylpenicillin: S-	Erytromycin: S-	Klindamycin: S-	Linezolid: S-	Trimetoprim-sulfa: S-	Norfloxacin: S-	Rifampicin: S-	Fusidinsyra: S-	Gentamicin: S-	Staphylococci that are sensitive to isoxazolyl penicillin are also sensitive to cefuroxime, piperacillin-tazobactam, and carbapenems, sensitive at high doses to cefotaxime and ceftriaxone, but naturally resistant to ceftazidime.	
	#6 Recycling room door button	40													
	#20 Wall where laundry cart stops in the corridor	12													
	#1 Corridor door button	63													
	#14 Corridor handrail	271													
353 A/B	#24 Door handle out from the sluice room	154												More than 100 CFU:s	
	#3 Wall behind the laundry basket in the sluice room	52													
	#7 In front of the fridge/the shelf in the sluice room	93													
	#19 Waste container handle in the sluice room	14												Mold developed on the sample	
	#10 Waste container handle in the recycling room	75												Mold developed on the sample	
	# 8 Bottom of the laundry basket	27													
	#15 Laundry basket handle	15													
	#23 Elevator button	42													
	#2 Recycling room door button	119	Enterococcus faecalis	3	Ampicillin: S-	Cefadroxil: R-	Imipenem: I-	Linezolid: S-	Vankomycin: S-					More than 100 CFU:s	
	#17 Wall where laundry cart stops	44													
	#11 Corridor door button	416												More than 100 CFU:s	
	#13 Corridor handrail	27													
		Mean													%-diff mean
		97,95833333													0,50701829
		SD													%-diff median
		146,3457726													0,93902439
		Median													
		41													

	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
60	**Södersjukhuset**														
61		**Sample Site**	**CFU**	**Pathogens**	**Pathogen CFU**	**Antibiotic 1**	**Antibiotic 2**	**Antibiotic 3**	**Antibiotic 4**	**Antibiotic 5**	**Antibiotic 6**	**Antibiotic 7**	**Antibiotic 8**	**Antibiotic 9**	**Comments**
62	**AVA**	#35 Door button to exit from the sluice room	45												
63		#48 Wall behind the laundry basket	11												
64		#43 Light switch to turn on the sluice room	14												
65		#30 Handle on the laundry chute	98												
66		#46 Handle on the waste chute	11												
67		#45 The wall above the waste bag	1												
68		#31 Shelf at waist height	49												
69		#25 The wall above the waste chute	6												
70		#41 The wall above laundry chute	49	Staphylococcus aureus	5	Isoxazolylpenicillin: S-	Erytromycin: S-	Klindamycin: S-	Linezolid: S-	Trimetropin-sulfa: S-	Norfloxacin: S-	Rifampicin: S-	Fusidinsyra: S-	Gentamicin: S-	
71		#29 Wall next to the door opener button	35												
72		#37 Door opener to enter the sluice room	61												
73		#33 Handrail near the chute	187	Staphylococcus aureus	5	Isoxazolylpenicillin: S-	Erytromycin: S-	Klindamycin: S-	Linezolid: S-	Trimetropin-sulfa: S-	Norfloxacin: S-	Rifampicin: S-	Fusidinsyra: S-	Gentamicin: S-	Staphylococci that are sensitive to isoxazolyl penicillin are also sensitive to cefuroxime, piperacillin-tazobactam, and carbapenems, sensitive at high doses to cefotaxime and ceftriaxone, but naturally resistant to ceftazidime. More than 100 CFU:s
74	**NAVE**	#28 Door button to exit from the sluice room	42	Staphylococcus aureus	8	Isoxazolylpenicillin: S-	Erytromycin: S-	Klindamycin: S-	Linezolid: S-	Trimetropin-sulfa: S-	Norfloxacin: S-	Rifampicin: S-	Fusidinsyra: S-	Gentamicin: S-	
75		#39 Wall behind the laundry basket	7												
76		#42 Shelf at waist height	19												
77		#40 Handle on the laundry chute	8												
78		#38 Handle on the waste chute	51												
79		#47 The wall above the waste bag	28												
80		#36 Light switch to turn on the sluice room	13												
81		#32 The wall above waste chute	53												
82		#44 The wall above laundry chute	43												
83		#27 Wall next to the door opener button	1												
84		#34 Door opener to enter the sluice room	287												More than 100 CFU:s
85		#26 Handrail near the chute	73												
86															
87			Mean												
88			49,66667												
89			SD												
90			64,52749												
91			Median												
92			38,5												

	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
100	**Södersjukhuset**														
101		**Sample Site**	**CFU**	**Pathogens**	**Pathogen CFU**	**Antibiotic 1**	**Antibiotic 2**	**Antibiotic 3**	**Antibiotic 4**	**Antibiotic 5**	**Antibiotic 6**	**Antibiotic 7**	**Antibiotic 8**	**Antibiotic 9**	**Comments**
102	**AVA**	#35 Door button to exit from the sluice room	45												
103		#48 Wall behind the laundry basket in the sluice room	11												
104		#43 Light switch to turn on the lights in the sluice room	14												
105		#30 Handle on the laundry chute	98												
106		#46 Handle on the waste chute	11												
107		#29 Wall next to the door opener button	35												
108		#37 Door opener to enter the sluice room	61												
109		#33 Handrail near the chute	192	Staphylococcus aureus	5	Isoxazolylpenicillin: S-	Erytromycin: S-	Klindamycin: S-	Linezolid: S-	Trimetropin-sulfa: S-	Norfloxacin: S-	Rifampicin: S-	Fusidinsyra: S-	Gentamicin: S-	Staphylococci that are sensitive to isoxazolyl penicillin are also sensitive to cefuroxime, piperacillin-tazobactam, and carbapenems, sensitive at high doses to cefotaxime and ceftriaxone, but naturally resistant to ceftazidime. More than 100 CFU:s
110	**NAVE**	#28 Door button to exit from the sluice room	42	Staphylococcus aureus	8	Isoxazolylpenicillin: S-	Erytromycin: S-	Klindamycin: S-	Linezolid: S-	Trimetropin-sulfa: S-	Norfloxacin: S-	Rifampicin: S-	Fusidinsyra: S-	Gentamicin: S-	
111		#39 Wall behind the laundry basket	7												
112		#42 Shelf at waist height	19												
113		#40 Handle on the laundry chute	8												
114		#38 Handle on the waste chute	51												
115		#27 Wall next to the door opener button	1												
116		#34 Door opener to enter the sluice room	287												More than 100 CFU:s
117		#26 Handrail near the chute	73												

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
100	**Östra Sjukhuset**														
101		**Sample Site**	**CFU**	**Pathogens**	**Pathogen CFU**	**Antibiotic 1**	**Antibiotic 2**	**Antibiotic 3**	**Antibiotic 4**	**Antibiotic 5**	**Antibiotic 6**	**Antibiotic 7**	**Antibiotic 8**	**Antibiotic 9**	**Comments**
102	**MAVA**	#22 Door handle out from sluice room	142												More than 100 CFU:s
103		#5 Wall behind the laundry basket in the sluice room	16												
104		#18 Door lock button in sluice room	27												
105		#21 Waste container handle in the sluice room	30												
106		#16 Waste container handle in the recycling room	622												More than 100 CFU:s
107		#20 Wall where the laundry cart stops in the corridor	12												
108		#1 Corridor door button	63												
109		#14 Corridor handrail	271												
110	**353 A/B**	#24 Door handle out from the sluice room	154												More than 100 CFU:s
111		#3 Wall behind the laundry basket in the sluice room	52												
112		#7 In front of the fridge/the shelf in the sluice room	93												
113		#19 Waste container handle in the sluice room	14												Mold developed on the sample
114		#10 Waste container handle in the recycling room	75												Mold developed on the sample
115		#17 Wall where laundry cart stops	44												
116		#11 Corridor door button	416												More than 100 CFU:s
117		#13 Corridor handrail	27												

	D	E	F	G	H	I	J	K	L	M
121	**Shapiro-Wilk Test**	Average	SS-addends	SS	m	a	b-addends	b	W	Shapiro-Wilk P value
122	1	94,15625	8678,086914	565820,2188	18	0,4068	252,6228	603,4424	0,643566133	≈0
123	7		7596,211914			0,2813	115,0517			
124	8		7422,899414			0,2415	67,3785			
125	11		6914,961914			0,2121	55,146			
126	11		6914,961914			0,1883	34,0823			
127	12		6749,649414			0,1678	23,8276			
128	14		6425,024414			0,1496	19,1488			
129	14		6425,024414			0,1331	11,1804			
130	16		6108,399414			0,1179	9,0783			
131	19		5648,461914			0,1036	5,8016			
132	27		4509,961914			0,09	4,14			
133	27		4509,961914			0,077	2,772			
134	30		4116,024414			0,0645	1,9995			
135	35		3499,461914			0,0523	0,8891			
136	42		2720,274414			0,0404	0,3636			
137	44		2515,649414			0,0287	0,0287			
138	45		2416,336914			0,0172	-0,0172			
139	51		1862,461914			0,0057	-0,0513			
140	52		1777,149414			0	0			
141	61		1099,336914			0	0			
142	63		970,7119141			0	0			
143	73		447,5869141			0	0			
144	75		366,9619141			0	0			
145	93		1,336914063			0	0			
146	98		14,77441406			0	0			
147	142		2289,024414			0	0			
148	154		3581,274414			0	0			
149	192		9573,399414			0	0			
150	271		31273,71191			0	0			
151	287		37188,71191			0	0			
152	416		103583,3994			0	0			
153	622		278619,0244			0	0			

	A	B	C	D	E	F	G	H	I
158	Mann-Whitney U-Test								
159	**Östra Sjukhuset**								
160		**Sample Site**	**CFU**	**Rank**	**T_1**	**n_1**	**U_1**	**Mean rank**	**Median rank**
161	**MAVA**	#22 Door handle out from sluice room	142	26	306,5	16	85,5	19,15625	20
162		#5 Wall behind the laundry basket in the sluice room	16	9					
163		#18 Door lock button in sluice room	27	11,5					
164		#21 Waste container handle in the sluice room	30	13					
165		#16 Waste container handle in the recycling room	622	32					
166		#20 Wall where the laundry cart stops in the corridor	12	6					
167		#1 Corridor door button	63	21					
168		#14 Corridor handrail	271	29					
169	**353 A/B**	#24 Door handle out from the sluice room	154	27					
170		#3 Wall behind the laundry basket in the sluice room	52	19					
171		#7 In front of the fridge/the shelf in the sluice room	93	24					
172		#19 Waste container handle in the sluice room	14	7,5					
173		#10 Waste container handle in the recycling room	75	23					
174		#17 Wall where laundry cart stops	44	16					
175		#11 Corridor door button	416	31					
176		#13 Corridor handrail	27	11,5					
177	**Södersjukhuset**								
178		**Sample Site**	**CFU**	**Rank**	**T_2**	**n_2**	**U_2**	**Mean rank**	**Median rank**
179	**AVA**	#35 Door button to exit from the sluice room	45	17	221,5	16	170,5	13,84375	14,5
180		#48 Wall behind the laundry basket in the sluice room	11	4,5					
181		#43 Light switch to turn on the lights in the sluice room	14	7,5					
182		#30 Handle on the laundry chute	98	25					
183		#46 Handle on the waste chute	11	4,5					
184		#29 Wall next to the door opener button	35	14					
185		#37 Door opener to enter the sluice room	61	20					
186		#33 Handrail near the chute	192	28					
187	**NAVE**	#28 Door button to exit from the sluice room	42	15					
188		#39 Wall behind the laundry basket	7	2					
189		#42 Shelf at waist height	19	10					
190		#40 Handle on the laundry chute	8	3					
191		#38 Handle on the waste chute	51	18					
192		#27 Wall next to the door opener button	1	1					
193		#34 Door opener to enter the sluice room	287	30					
194		#26 Handrail near the chute	73	22					
195	**Tie-term**	**U=min(U_1, U_2)**	**n**	**μ_u**	**SE of U**	**z-value**	**p-value**		
196	1,5	85,5	32	128	26,52570269	-1,602219572	0,0546		

Appendix 3: Karolinska university laboratory email

The following excerpt is from the email that Johanna Snäll, microbiologist at the Karolinska university laboratory containing some of the instructions that were given on the sampling procedure for “Automated Hermetically Sealed vs. Conventional Waste Management Systems in Hospitals: A Comparative Study of Microbial Presence”.

Original instructions:
”Låt plattorna anta rumstemperatur.
Märk plattan på plattans undersida och fyll i protokollet ”Mikrobiologisk miljöundersöking” (MIK3527).
Locket tas av och agarytan trycks mot ytan som skall provtas ca 5 sekunder, utan att roteras. Tejpa ihop provtagna plattor och skicka dem i dubbla plastpåsar med locket nedåt till laboratoriet. Skicka med ifyllt protokoll till laboratoriet.

Angående första punkten ”Låt plattorna anta rumstemperatur”; de ska förvaras i kyl och det är fördelaktigt om man tar fram och ställer dem i rumstemperatur kvällen innan man planerar att utföra provtagningen. Annars finns det risk att det blidas mycket kondens i locket som kan rinna ner på ytan och förstöra/försvåra avläsningen av växten.”

Translated instructions:
”Allow the plates to reach room temperature.
Label the plate on the underside and fill out the 'Microbiological Environmental Investigation' protocol (MIK3527).
Remove the lid and press the agar surface against the surface to be sampled for about 5 seconds, without rotating. Tape the sampled plates together and send them in double plastic bags with the lid facing down to the laboratory. Include the completed protocol with the shipment to the laboratory.

Regarding the first point 'Allow the plates to reach room temperature'; they should be stored in the refrigerator and it is advantageous to take them out and set them at room temperature the evening before planning the sampling. Otherwise, there is a risk that too much condensation in the lid could drip onto the surface and hinder or complicate the reading of the growth.”

The attached protocol, provided by Johanna Snäll from Karolinska university laboratory, outlines the specific procedures for sample collection in this study. It includes a detailed form designed for the systematic documentation of all collected samples.

Provtagningsdatum:	Avsändare (Avdelning, sjukhus): Kombikakod:
Provtagare:	Beställare (Namn): Tfn nr:

Luftundersökning			**Ytundersökning**		
Sedimentationsplatta, tillverkningsdatum:			Rodacplatta, tillverkningsdatum:		
Provtagningsställe	Lab ID	CFU dag 2	Provtagningsställe	Lab ID	CFU dag 2

TRITA – CBH-GRU-2024:161
Stockholm, Sverige 2024

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