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Studies of hygiene on ocean-going vessels
– Measurement programme of the Sea BG and the BGIA –

Abstract

Around half of all cases of diseases on board German ocean-going vessels are related to the upper respiratory tract. As all ocean-going vessels are equipped with technical air conditioning systems (AC systems), the study investigated whether the hygienic condition of AC systems can be discerned as having an impact on the quality of room air and the health of the crew. To determine this, the study focused on microbiological tests of room air in different work and living quarters and of the AC systems on different types of vessels and under different climatic conditions. Material samples were also studied, such as filter materials from the AC systems. The results indicated that bacteria are dominant in the room air on board ships, in contrast to sites on land. Furthermore, there seems to be a connection between the quality of room air and the length of a vessel's route. Endotoxins were only detected in low quantities on the vessels studied in the framework of the project. The results obtained so far indicate that thorough maintenance of filter units on AC systems on ocean-going vessels is of great importance.

1 Introduction

Based on the observations by occupational physicians of the See-BG (institution for statutory accident insurance and prevention in the maritime industries), approximately 50% of diseases on board German ocean-going vessels relate to the upper respiratory tract. All ocean-going vessels are equipped with heating, ventilating and air-conditioning installations (HVAC installation). Particularly during bad weather or in inhospitable climatic conditions, the seamen spend a large portion of their time in the air-conditioned areas below deck, so they are strongly exposed to the effects of air conditioning. The frequent occurrence of respiratory diseases on ocean-going vessels suggests that there may be a relationship between these diseases and the HVAC installations. No information on this issue could be found in the literature. A VDI Guideline [1] on the hygiene requirements relating to ventilation in passenger transport vehicles has been in existence since February 2004 with a chapter devoted specifically to the requirements aboard vessels. However, little attention is focused here on the microbiological parameters.

The See-BG has therefore cooperated with the BGIA – Institute for Occupational Safety and Health of the German Social Accident Insurance in conducting an extensive study to find out to what extent the hygienic condition of HVAC installations has an effect on the quality of the indoor air and crew health. The focus of the part of the project described here is on the microbiological examination of the indoor air and of the HVAC installations on different types of vessels and in different climatic conditions. With the participation of the BGIA, five voyages were undertaken on two ferries, two container vessels and a research vessel. Air samples were taken in different working areas, living quarters and social rooms at sea and in some cases in port. The outdoor air was used as the reference. In addition, different samples of materials associated with the indoor air were analysed, e.g. filter materials from the HVAC installations.

2 Sampling methods and procedure

To investigate the microbiological contamination of the air in different working areas, two sampling systems working on different sampling principles were employed. These were, firstly, the BGIA's total dust sampling system (PGP-GSP system) adapted to the determination of bioaerosols and, secondly, the Microbial Air Sampler MAS 100 from Merck. The former process makes it possible to determine different microbiological parameters at a flow rate of 3.5 l/min. The, as expected, relatively low concentrations of bioaerosols in the indoor air were collected with the second method, since this permits a larger sample volume with a flow rate of 100 l/min. With the PGP-GSP system, determination of airborne microorganisms were carried out on the filtration principle (**Figure 1**).

Figure 1:
Air sampling on the wheelhouse

The samples obtained in this way were processed by the direct method by placing the impinged filters directly on culture media [2]. The impaction method with the MAS perforated lid impactor was employed as the second sampling method. Here the microorganisms are aspirated from the air through a perforated plate and impacted on solid growth media [3].

In both cases, the cell numbers of bacteria and mould fungi were counted after cultivation (Colony Forming Units = CFU/m³ air). The filtration method was also used for determining the concentration of endotoxins in the air [4]. All sampling methods are standard methods for the determination of the concentrations of bioaerosols within the BG measuring system of hazardous substances (BGMG).

To classify and assess the results, the same parameters were determined in the outdoor air. To document possible microbial contamination of the different components of the HVAC installations on the various ocean-going vessels investigated, material samples were taken from the HVAC installations, e.g. filter columns from the humidifier and air filter mats. Contact samples were taken from the interior of the HVAC installation in order to detect any contamination of the surfaces. All air and material samples were either analysed directly on board in an improvised laboratory or, if storable, after the voyage at the BGIA's microbiological laboratory for their content of bacteria, mould fungi, yeasts

and endotoxins. All the cell counts were determined after cultivation (growth in defined temperature conditions on selected media), and the endotoxin concentrations in the air and material samples were determined with the Limulus Amoebocyte Lysate test (LAL test) at the BGIA laboratory [4].

The sampling sites as well as the type and number of samples are listed for a ferry and a container vessel in **Tables 1** and **2**.

Table 1:
Ferry, voyage in January 2002, temperate climate, winter

Sampling sites	**Sample type**	**Determined parameters**	**Number of samples per site**
Outdoor air on deck (reference) Room without air conditioning, I (reference) Room without air conditioning, II (reference) Air-conditioned room, deck IV, short distance from the central HVAC installation Air-conditioned room, deck IV, long distance from HVAC installation Cabin (HVAC installation, starboard) Office (HVAC installation, port side)	Air Filtration (PGP-GSP)	Mould fungi, yeasts (TCC and SS) Bacteria (TCC and SS) Endotoxin content	Endotoxins 3, mould fungi 6, bacteria 12
Outdoor air on deck (reference) Room without air conditioning, I (reference) Room without air conditioning, II (reference) Air-conditioned room, deck IV, short distance from the central HVAC installation Air-conditioned room, deck IV, long distance from the central HVAC installation Cabin (HVAC installation, starboard) Office (HVAC installation, port side)	Air Impaction (MAS 100)	Mould fungi, yeasts (TCC and SS) Bacteria (TCC and SS)	Mould fungi 8, bacteria 4
HVAC installation, deck IV HVAC installation, starboard HVAC installation, port side	Filter material from filter column of the HVAC installation	Mould fungi (TCC) Bacteria (TCC)	3

TCC = Total Cell Count, SS = Species Spectrum, HVAC = Heating, Ventilating and Air Conditioning

Table 2:
Container vessel, voyage in April 2002, transition from temperate climate (spring) to tropical climate.

Sampling sites	Sample type	Determined parameters	Number of samples per site
Outdoor air on deck at sea (reference) Outdoor air on deck in port (reference) Wheelhouse (longest distance from the central HVAC installation) Mess room Officer's cabin (medium distance from the central HVAC installation) Crew's cabin (short distance from the central HVAC installation) Engine control room (air-refrigeration installation)	Air Filtration (PGP-GSP)	Mould fungi (TCC and SS) Bacteria (TCC and SS) Endotoxins	Endotoxins 3, mould fungi 6, bacteria 12
Outdoor air on deck at sea (reference) Outdoor air on deck in port (reference) Wheelhouse (longest distance from the central HVAC installation) Mess room Officer's cabin (medium distance from the central HVAC installation) Crew's cabin (short distance from the central HVAC installation) Engine control room (air-refrigeration installation)	Air Impaction (MAS 100)	Mould fungi (TCC and SS) Bacteria (TCC and SS)	Mould fungi 4, bacteria 4
Interior surface of the humidifier, supply air terminal units, HVAC installation, port side, air-refrigeration installation	Contact sampling	Mould fungi Bacteria	
Supply air filtration of the main HVAC installation	Filter material	Mould fungi (TCC and SS) Bacteria (TCC and SS)	1

3 Results and discussion

The results for the ferry and container vessel are presented and discussed in the following sections.

3.1 Ferry

3.1.1 Air samples

From earlier determinations taken on a vessel in port, few data were available on the microorganism content of the air in different rooms aboard [5]. By investigating the indoor air for bacteria and mould fungi, the study sought to determine the bioaerosol content of the air-conditioned air in the colder

months of the year. As a comparison and to classify the results, two non-air-conditioned rooms and the outdoor air were sampled as references.

Unlike the container vessel, the ferry had large common rooms with several HVAC installations, some of which had to supply rooms with conditioned air over long distances. Three HVAC installations were included in the study in order to check whether the air supply was maintained at the same standard of quality from the beginning to end of the air-distribution system. To this end, air samples at a short distance and at an extremely long distance from the central HVAC installation were analysed. **Table 3** presents the results.

Table 3:
Ferry, content of mould fungi, bacteria and endotoxins of air samples

Sampling site	Mould fungi in CFU/m^3 air		Bacteria in CFU/m^3 air		Endotoxins in EU/m^3 air
	PGP-GSP	MAS 100	PGP-GSP	MAS 100	PGP-GSP
Air-conditioned room (HVAC installation on deck IV, short distance from the HVAC installation)	22	< 10	100	40	1.1
Air-conditioned room (HVAC installation on deck IV, long distance from the central HVAC installation)	15	< 10	15	95	1.1
Crew's cabin (HVAC installation, starboard)	29	10	1,433	365	1.1
Crew's office (HVAC installation, port side)	19	< 10	194	40	1.3
Room I without air conditioning (reference)	36	15	1,472	3,455	1.1
Room II without air conditioning (reference)	114	45	22	30	1.1
Outdoor air on deck (reference)	129	150	36	35	1.8

CFU = Colony Forming Unit; EU = Endotoxin Unit

Microorganism concentrations of similar magnitudes were ascertained with both sampling systems (filtration and impaction). With two exceptions (room I without air conditioning and the crew's cabin), the contents of mould fungi and bacteria in the air were low in all investigated rooms and were on the same scale as in the referenced outdoor air, which can be termed the "natural background level". Endotoxins were also only detected on a small scale.

The largest microorganism concentrations were found in room I with counts of 1,472 (PGP-GSP) and 3,455 (MAS 100) CFU bacteria/m³ air. This room did not have any mechanical ventilation or air conditioning. However, the source of the high concentrations of bacteria compared to the other rooms was not obvious. Since the determinations in the referenced rooms yielded very different results, this reference was omitted during subsequent voyages.

In the crew's cabin, which was supplied with air by the starboard HVAC installation, the cell counts at 1,433 (PGP-GSP) and 365 (MAS 100) CFU bacteria/m³ air were higher than in the other rooms. This may be associated with the fact that the filter material from the humidifier (**Figure 2**) of this HVAC installation at $8.5 * 10^5$ CFU bacteria/g material also showed the highest count of the three HVAC installations (**Table 4**).

Figure 2:
Bag filter, supply air filter of the HVAC installation

Table 4:
Ferry, concentrations of mould fungi, bacteria and yeasts in filter materials from HVAC installation

Filter sample from	Moulds in CFU/g	Bacteria in CFU/g	Yeasts in CFU/g
HVAC installation, deck IV	$2.2 * 10^2$	$5.7 * 10^3$	0
HVAC installation, port side	$4.0 * 10^2$	$3.6 * 10^3$	0
HVAC installation, starboard	$7.4 * 10^2$	$8.5 * 10^5$	$1.5 * 10^4$

CFU = Colony Forming Units

No relationship was established between the distance of the air-conditioned room from the central HVAC installation and the microorganism concentration in the indoor air of the analysed cabins for the HVAC installation selected here that served the rooms on deck IV.

3.1.2 Material samples

Of the investigated filter samples, the filter material from the humidifier from the HVAC installation serving the rooms on the starboard side proved to be most heavily contaminated (Table 4). Overall, the concentrations of mould fungi spores in all three samples were below 1,000 CFU/g, whereas the concentrations of bacteria varied more strongly: The filter sample from the starboard HVAC installation at $8.5 * 10^5$ CFU bacteria/g is two powers of ten higher than the other two samples. Yeast concentrations were also detected in the sample from the starboard HVAC installation.

Like the material samples, the air samples from the room served by the starboard HVAC installation proved to have the highest concentrations of bacteria (Table 3).

3.2 Container vessel

3.2.1 Air samples

On the container vessel, two HVAC installations were covered by the study. One centrally served various work areas and social rooms (e.g. wheelhouse, mess room) and the living quarters (e.g. officer's and crew's cabins) on different decks, while the second, an air-refrigeration installation, exclusively served the engine control room.

On this voyage, the air samples were again gathered in rooms that were either as close as possible to or as far away as possible from the central HVAC installation. Sampling with the two above-mentioned sampling systems was conducted in the three climatic zones that the vessel passed through on its voyage: the temperate zone in the Atlantic, the warmer climate in the Mediterranean and the tropical zone in the Indian Ocean. The purpose of this procedure was to explain the effect of climate on the living conditions for the airborne microorganisms.

Table 5 lists the results obtained with the impaction method, which are identical to those obtained with the filtration technique. Endotoxins have been disregarded, as determination here, as on the ferry, only yielded minimal levels.

Table 5:
Container vessel, content of mould fungi and bacteria of air samples (impaction method)

Climatic zone / Sampling site	Temperate	Warm	Tropical	Temperate	Warm	Tropical
	Mould fungi in CFU/m³			Bacteria in CFU/m³		
Crew's cabin (short distance from the central HVAC installation)	940	118	138	1,440	1,633	1,355
Officer's cabin (medium distance from the central HVAC installation)	85	28	20	723	319	4,100
Wheelhouse (long distance from the central HVAC installation)	35	45	3	128	377	400
Mess room	5	8	3	58	333	293
Engine control room (air-refrigeration installation)	5	13	8	380	78	175
Outdoor air at sea (reference)	25	0	5	15	5	3
Outdoor air in port (reference)	-	-	533	-	-	183

CFU = Colony Forming Units

To classify and assess the results from the indoor air determinations, the content of microorganisms of the outdoor air was detected as a reference. This sampling was carried out at sea and in one case – in the tropical climatic zone towards the end of the measurement voyage – in port in order to document the background contamination of the air used for air conditioning (**Figure 3**).

Figure 3:
Air sampling in port

In all indoor air samples, the total colony counts for bacteria were higher than those for mould fungi. With the exception of the value obtained in the first determination in the crew's cabin (temperate climatic zone, heating period), the concentrations of mould fungi in the air of all investigated rooms were low throughout the voyage. They were mainly of the order of the outdoor reference values measured at sea, which can be regarded as the "natural background level". Unlike the air at sea, the outdoor air in tropical ports showed significantly higher concentrations of mould fungi.

At every time of sampling (in temperate, warm and tropical voyage regions), higher concentrations of bacteria were recorded in the indoor air than in the outdoor air at sea. The content of bacteria in the air of the crew's cabin, which was only a short distance from the central HVAC installation, ranged from 1,355 to 1,633 CFU/m³ and was thus consistently higher at all three sampling times than in the other rooms, irrespective of the climatic zone. On the other hand, the concentration of bacteria in the air of the officer's cabin, which was further away from the central HVAC installation than the crew's cabin, achieved the highest of all the values determined for this parameter only when the last sample was taken in the tropical climatic zone.

On the wheelhouse, which was furthest away from the central HVAC installation, equally high values were detected in all three climatic regions and covered the middle range compared to the other sampling sites. These results suggest that the concentration of bacteria decreases with increasing distance from the central HVAC installation and that this is a possible source for the bacterial contamination of the indoor air.

The lowest concentration of mould fungi and bacteria was recorded in the engine control room which had an own air-refrigeration installation.

3.2.2 Material samples

Possible microbial contamination of surfaces was assessed by analysing contact samples from the interior of the HVAC installation and the air-refrigeration installation (**Figure 4**) and from the supply air terminal units in the cabins. Furthermore, the colony counts of bacteria, mould fungi and yeasts were determined in material samples from the supply air filters (bag filters) of the HVAC installation (**Table 6**).

Figure 4:
Analysis of contact samples from the air-refrigeration installation of the engine control room

Table 6:
Container vessel, concentrations of mould fungi, bacteria and yeasts in filter materials from the HVAC installation; growth stages of contact samples from the air-refrigeration installation of the engine control room

Sample	Mould fungi in CFU/g	Bacteria in CFU/g	Yeasts in CFU/g
Bag filter (large) HVAC installation, heavily contaminated	$2.5 * 10^4$	$4.6 * 10^4$	$4.3 * 10^3$
Bag filter (small) HVAC installation, slightly contaminated	$3.3 * 10^2$	$8.3 * 10^2$	$5.0 * 10^2$
Contact samples from ECR, air-refrigeration installation	Strong growth	Very strong growth	---

CFU = Colony Forming Unit; ECR = Engine Control Room

While the majority of the contact sample tests showed strongly diverging results which were not amenable to interpretation, in the material samples from the bag filters, different concentrations of microorganisms were ascertained that correlated with the degree of soiling. The high concentrations particularly of bacteria in the filter material may possibly be a source of the contamination of the indoor air. The fact that only a fraction of the equally high concentrations of mould fungi in the filter was detected in the indoor air may be due to the size of the spores, causing most of them to be intercepted by the filter material.

4 Summary and outlook

With the participation of the BGIA, five voyages on ocean-going vessels were carried out in differing climatic conditions. Air samples were taken in different working, social and living areas and investigated for their content of various bioaerosols. The results of the voyages up to now show that, unlike ashore areas, bacteria predominate in the indoor air aboard. The highest cell counts tended to be found in the cabins. Furthermore, there appears to be a relationship between room air quality and the route of the voyage: The longer the voyage and the more climatic zones are passed through, the higher the microorganism concentrations detected in the air samples.

In cases of visibly contaminated air filters, bacteriological examinations revealed an elevated content of microorganisms in the filter material. Higher bioaerosol concentrations were consequently also determined in the associated areas aboard.

A decrease in bioaerosol concentration with increasing distance from the central HVAC installation was ascertained on the container vessel. However, measurements on the container vessel in the tropics showed the highest colony counts in the working area midway from the central HVAC installation. On the vessels covered by the project, endotoxins were only detected in minimal quantities.

The results available to date indicate that careful maintenance of the filter units of HVAC installations on ocean-going vessels is very important to prevent them from being colonized by microorganisms on an abnormal scale and, thus, becoming a source of the microbial contamination of the indoor air.

The See-BG is continuing these investigations on further vessels so that representative statements and recommendations for the German merchant fleet can be made on the basis of the extensive stock of data.

5 References

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