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Influence of the shape of surgical lights on the disturbance of the airflow
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ABSTRACT
Operating room ventilation systems are used to keep the wound area of a patient free from airborne bacteria. Surgical lighting is one of the major disturbances in operating room ventilation systems. This paper describes results from a series of measurements that aim to qualify and quantify the influence of the shape of an operating lamp on the disturbance of the air flow around the lamp.

Visualization and particle concentration measurements in combination with a fixed particle source are used to study the upward transport mechanism of particles underneath an operating lamp. Air velocity measurements are used to determine to quantify the size of the wake underneath the lamp. Several different shapes are used in this investigation.

The results of the investigation are used to compare with the laminar flow indexes by Leenemann and Oostlander and to assess how well they describe the performance of a lamp with regard to keeping the air clean. The results from these experiments in the future will be applied for CFD validation.

INTRODUCTION
In an operating room, clean air generally is supplied via a supply plenum positioned in the ceiling in order to prevent airborne bacteria from entering the wound. These plenums are know as laminar downflow systems. Operating lamps are usually situated between this downflow system and the patient on the operating table. Therefore they can result in a major disturbance of the airflow near the operating table. [1]

Manufacturers of operating lamps are aware of this and they try to minimize the influence of their lamps on the airflow. For that two so-called “Laminar Air Flow” (LAF) indices have been used up till now. One according to Leenemann [2] and one according to Oostlander [2]. These indices give an indication of how much the operating lamp will disturb the airflow.

The index according to Leenemann is determined from a formula that takes the surface area of the lamp into account, as well as the heat production and the light output. By taking the light output into account, larger lamps are allowed to disturb the flow more if they produce more light as well.

The index according to Oostlander is adapted from the index of Leenemann. It includes a factor for the shape in the calculation to account for aerodynamic shapes. A calculation method for this shape factor however has not been defined yet, so in practice it is always taken as 1. There is also a correction factor for focal length. A larger focal length allows for a larger distance between lamp and wound area.
Another way to evaluate the performance of a downflow system is to consider the spread of pollutants in an operating room. This assessment method is described in VDI 2167[3]. In this case, a fixed source of pollutants is placed in the room that is to be evaluated. By measuring the amount of particles that reach a certain position on the operating table, the ability of the downflow system to keep that area clean can be determined. In this evaluation method, the effect of the operating lamp is included as part of the total lay-out of the room.

Recent developments show that the VDI assessment method appears to decrease attention for the laminar flow index described above. However, in this method optimization of the lamp shape is more difficult to evaluate as the assessment result is the integrated result for the whole operating theatre design.

Different designs of operating lamps are available and in use in practice. It therefore remains interesting to determine the effect of individual aspects of the operating theatre design in addition to the overall assessment which is a prerequisite.

The goal of this research was to investigate experimentally the influence of the shape of different designs of operating lamps, as applied in practice, on the air flow pattern in a room. The results of these experiments are useful to compare with numerical results and to discuss the laminar air flow indices. In this paper focus will be on the experimental work and results.

![Image](image_url)  
Figure 1. The chamber in which the measurements were performed.

**METHODS**

The measurement setup consisted of a downflow plenum measuring 1.0 by 1.0 m that was positioned centrally in the ceiling of a small glass chamber positioned in a controlled environment.
laboratory environment. The chamber measured $2.0 \times 2.0 \times 1.65$ m, see Figure 1. The exhaust (height: 0.2 m) is located over the full length of the chamber at the left side of the floor.

For the experiment three different shapes of operating lamps were positioned individually underneath the downflow plenum (distance from plenum about 0.25 m, depending on the shape of the lamp). For each case (operating lamp shape) similar measurements were performed.

For these measurements a particle source was positioned on the floor in the centre of the room (height: 0.2 m; particle dimensions: 0.1-5 µm). The resulting particle dispersion was visualized and particle concentrations were measured at 0.2 m underneath the lamp using a particle counter. For the visualization the room was darkened and a light sheet was provided for. For each case two experiments were performed. First, the room was completely filled with smoke after which the downflow system was activated. In this case the ventilation of the area around the lamp shape is visualized. In the second experiment the smoke source, located on the floor, as well as the ventilation system was on continuously. In this the smoke transport from the source position is visualized.

Besides particle measurements, detailed air velocity measurements were performed 0.8 m from the floor. For these measurements an omnidirectional hot-sphere anemometer was used. Turbulence intensity was derived from the standard deviation of the measured average velocity. The measurements were performed under isothermal conditions.

As indicated in the introduction. The set-up was such that the results can be used for CFD validation studies.

**Investigated lamp shapes**

Three different lamp shapes were investigated: a classic closed shape; a semi-open shape with gaps in between the individual lamps, typically applied together with LED lights; an open shape with a configuration that comprises of 6 individual spots that are connected to a central hub. Photos of the investigated shapes are shown in Figure 2. The lamp shapes were suspended from the ceiling by means of thin iron wires.

![Figure 2. the three lamp shapes under consideration.](image)

**Boundary conditions**

Velocity and turbulence conditions of the supply plenum have been measured at 25 positions. This resulted in an average supply velocity of 0.31 m/s, with a maximum deviation from this average of 11%. The air change rate for the room was calculated at $160$ h$^{-1}$. Maximum turbulence intensity was measured at 7% at one of the points on the edge of the supply plenum. Average turbulence intensity was determined at 2.25%. These figures indicate that the airflow directly underneath the plenum can be considered uniform and laminar.
The supply flow rate was measured continuously during the experiments. To verify the isothermal situation, the supply temperature and the temperature of a representative wall inside the room were measured continuously as well.

During the particle measurements, the particle concentration in the supply was measured continuously, to verify that the particle concentration in the supply air remained negligible.

**LAF index calculation**

As the measured lamp shapes did not emit any light or heat, the LAF-index cannot be determined. However the relative magnitude can be obtained by applying the same average heat and light output for all lamps.

The LAF according to Leenemann is calculated from:

\[ L_L = \frac{P \cdot A_G}{E^2}, \]  

(1)

Where \( P \) is the total amount of Power produced by the lamp in Watt, \( A_G \) is the surface area in \( \text{cm}^2 \), and \( E \) is the Illuminance in klx. As optical and thermal properties are not taken into account, and there is no definition for the shape adjustment factor of Oostlander, both can be reduced to:

\[ L_L \sim L_O \sim A_G, \]  

(2)

**RESULTS**

**Observations**

Figure 3 shows results from the first type of visualization study for the classic closed lamp shape. In this case the room is filled with particles after which the ventilation system is activated. The photographs show several consecutive situations with an interval of 3.3 seconds after the ventilation system is turned on and indicates how the area around the lamp is ventilated. Near the floor of the room no smoke can be seen. This is because the field lit by the projector was slightly smaller than the room itself.

![Figure 3. Visualization of the ventilation of the room when turning on the ventilation in the room filled with smoke (photographs are in consecutive order with an interval of 3.3 seconds).](image-url)
Results from the second set of visualizations, using a continuous smoke source near the floor are shown in Figure 4. The resulting pattern shows how the smoke is distributed in the room. The particle source is nearly constant with some individual puffs of smoke. These can be traced over subsequent photographs. This allows to see the flow pattern more clearly. In order to determine the extent of the clean area, these images have been averaged in order to see the extent of the clean area. The result of this averaging is shown in Figure 5. In this figure the averaged visualization results for the other lamp shapes and the empty room are shown as well.

Figure 4. Smoke visualisation using a continuous source
Particle measurements
The results of the particle measurements are expressed in a scale similar to the one applied in VDI 2167 [3],

$$PR = -10 \log \left( \frac{C_x}{C_{ref}} \right), \quad (3)$$

Where $C_x$ is the measured particle concentration, and $C_{ref}$ is the particle concentration in a fully mixed room. A protection factor (PR) of 0 is as good as mixing ventilation, while PR=1 means a concentration 10 times lower than for mixing ventilation. The difference between the VDI 2167 and this calculation is that the measured concentration is not in the target area. If there is any upward transport towards the spot underneath the lamp, this may result in a value below 0. Table 1 summarizes the results from the different measurements. In the case of the open structured lamp, the smoke concentration underneath the lamp was equal to the concentration measured directly underneath the plenum.

<table>
<thead>
<tr>
<th>Lamp shape</th>
<th>Surface area [m$^2$]</th>
<th>Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>0.26</td>
<td>-0.09</td>
</tr>
<tr>
<td>Semi-open</td>
<td>0.35</td>
<td>-0.76</td>
</tr>
<tr>
<td>Open</td>
<td>0.05</td>
<td>&gt;2</td>
</tr>
</tbody>
</table>

Velocity and turbulence measurements
All effects observed during the visualization show up in the velocity measurements as well. Turbulence intensity is highest at the interface of the downflow area and the surrounding area, where velocity gradients are highest. The dominant frequency in the turbulence spectrum matches the frequency of the largest eddies that are visible in the visualisations.
CONCLUSIONS

From the observations it is clear that the different shapes of the lamp affect the surrounding airflow. In case of an empty room a large eddy develops in the lower right corner of the room. This eddy pushes the laminar downflow area to the left of the room (direction of the exhaust). As a result the smoke from the source can enter the eddy directly.

As shown in Figure 5, the open shape (with individual spots) did not alter the flow pattern, compared to the empty case, in a visible way. On the other hand, the closed shape blocks the airflow so that the clean air has to go around, enlarging the clean area next to the lamp. The eddy in the lower right corner remains present and is similar to the empty case. For the semi-open shape the eddy in the lower right corner disappears. Instead, the upward transport mechanism underneath the lamp was more pronounced than in the other cases.

These visualization results are confirmed with the particle measurement results. For the semi-open shape the worst protection factor was derived. The slightly higher velocities measured in the middle underneath the semi-open lamp correspond to an upward airstream.

The upward transport mechanism as seen with the semi-open lamp shape is most likely caused by the air that passes through the gaps. They then act as small jets, inducing the air underneath the lamp. As a result of that an upward transport will develop. The air underneath the lamp
therefore is diluted more than in the case of a completely closed shape. If there is a pollution source close underneath the lamp, this dilution effect might be beneficial. It is unclear how far down this upwards transport reaches, but in this situation, it was at least 1 meter. An arrangement with spots (open shape) suffers from neither the upwards transport, nor the patch of still air underneath the lamp.

Comparison of the results shown in Table 1 indicate that there is a relationship these particle measurements and the laminar flow index of these lamp shapes.

DISCUSSION

The experiments show a few shortcomings when compared to a realistic situation. Both the room and the plenum are much smaller than in a real situation. The airflow in a normal operating room may react in a different way.

The fact that only three lamp shapes were tested and the fact that no two different lamp shapes with the same surface area were tested means that no definite conclusion can be drawn on the applicability of the LAF-index. The measurements however can be used to validate CFD models that can fill this gap.

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