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Low-turbulence displacement-flow for an operating environment

Specifications, prototyping and first measurements of a low-cost solution

Abstract: In developing countries airborne micro-organisms are one of the most common causes of surgical wound infection. In the operating room low-turbulence displacement-flow has been shown to reduce the influence of airborne bacteria. However, due to complexity and cost, current systems are not accessible to all potential users. In this paper a low-cost ventilation system is presented that provides low-turbulence displacement-flow over a surgical operating environment. A stand-alone, simple to assemble, mobile airflow system was developed using the principle of speed compensation for laminar airflow. From visual inspection and measurements, the system was seen to generate a continuous downwards displacement of air over the protected area around the situs. The entire system can be assembled quickly with minimal standard tools, making it very suitable for mobile use, such as in disaster areas. Future work is required to achieve the vertical dimension of a laminar flow field required by the DIN 1946-4. Overall, the low-cost and simple system could provide many potential users access to the technology and thus improving hygiene conditions in their operating environment.

Keywords: Low-turbulence displacement-flow, infection, low-cost, operating environment, hygiene, ventilation

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1 Introduction

Postoperative wound infections as a result of contamination in the operating field and instrument tables via the air cannot be ignored [1]. Especially in developing countries, airborne

microorganisms are one of the most probable sources of surgical wound infection [2]. Therefore, ventilation systems are required that both reduce the influence of airborne bacteria in the operating room (OR) and are affordable. The discussion in which what ventilation system is the most effective regarding infection prevention is ongoing [3]. Nevertheless, the German standard for ventilation systems in the operating room requires a low-turbulence displacement-flow (LTDF) for the highest cleanroom class [4], which has been previously proven to reduce airborne bacterial burden [5].

In Germany, the DIN 1946-4 regulates the requirements for the LTDF and reflects the current state-of-the-art [4]. This standard recommends that the LTDF creates a protective area around the situs, including the persons in the sterile zone, and the sterile devices to be used. At a height of 1.2 m above the ground ($y = 1.2$ m), the level of turbulence must not exceed 20 % at any point in the protected area. The air shall enter the OR consistently at a velocity such that no disturbances affect the direction of flow down to a height of $y = 1$ m. The supply-air volume-flow (air volume supplied per hour) must therefore be estimated as a function of the outlet cross-sectional area and the buoyancy forces. In addition, the standard suggests that the material of air-carrying components is abrasion-resistant, does not provide a culture medium for microorganisms and is harmless to health. A LTDF-system includes various filter stages and a central air handling unit. The laminariser is the last component in the airflow before air enters the OR. An overpressure in the OR is recommended so that no air can enter from adjacent rooms. This is achieved by external air supply. The use of secondary air benefits a higher supply air volume flow [4].

Among other factors, these regulations increase the costs and space requirements of existing systems. In particular, central air handling units which require a considerable amount of space and have to be connected to the OR via ducts, considerably increase costs. In addition, it is challenging to install a displacement flow in existing buildings without sufficient existing ventilation technology. This causes problems for hospitals in developing countries and/or research institutions to integrate such a system.

The above issues indicate the need for an affordable and easy to install system. This paper presents a solution that

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largely meets the DIN requirements while also being cost-effective. Overall, providing access to better surgical hygiene conditions for more potential users.

2 Methods

2.1 Low-cost LTDF construction

The development of a prototype for the generation of the LTDF was based on DIN 1946-4. Requirements were derived and suitable solution variants were devised. Their feasibility under low-cost and mobility aspects were examined. The air conditioning components and constructions were dimensioned according to the chosen solution variant.

2.2 Turbulence evaluation

The system was tested based on the DIN 1946-4 in two ways: a preliminary test to visualize the flow pattern and quantitative flow measurements.

2.2.1 Flow visualisation

The flow visualisation was done according to the normative specifications [4]. A vaporized fluid was emitted approx. 300 mm below the air outlet perpendicular to the flow direction and visually documented. The flow pattern made visible in this way is evaluated solely visually. This qualitative examination of the flow pattern is intended to show that the air sinks steadily and without obvious disturbances to the floor. However, the DIN 1946-4 does not further specify ‘steadily’ for the visual examination.

2.2.2 Air flow measurement

The measurements of turbulence level and air velocity were made using a thermoelectric air-flow sensor (FVA 605 TA, Ahlborn Mess- und Regelungstechnik GmbH, Holzkirchen, DE). Its measuring principle is based on the electrical heating of a wire and the measurement of its cooling behavior in an air flow. The sensor measuring range is 0.15 m/s to 5.0 m/s. The design of the low-cost LTDF made it possible to measure both over the entire and a smaller outlet cross-sectional area (1/3 of original outlet size) to also consider increased air velocities. For the measurement over the entire outlet cross-sectional area, 17 measurement points were distributed according to the

Figure 1: Measuring points (blue) in the horizontal plane below one of the two air outlets shown in top view, dimensions in millimeters. See Figure 3 for the definition of the coordinate system.

Figure 2: Measuring points (blue) below the smaller outlet area shown in top view, dimensions in millimeters. See Figure 3 for the definition of the coordinate system.

DIN 1946-4 as shown in Figure 1. The positions of the measurement points below the smaller outlet cross-sectional area are shown in Figure 2 as P1, P2, P3. The air flow was measured for two minutes and averaged at three different

Figure 3: Construction of the LTDF-system. 1: smaller outlet cross-sectional area (Figure 2), 2: entire outlet cross-sectional area (Figure 1), 3: truss framework, 4: fan, 5: first filter class, y: height above the ground

heights ($y = 2$ m, $y = 1.50$ m and $y = 1.20$ m) for each measurement position.

3 Results

Two air outlets with a length of 1.28 m, a width of 1.95 m and a height of 0.33 m each, were constructed and built out of plywood with a thickness of 9 mm. These were attached to a truss framework (length 6 m x width 3 m x height 2.72 m, model FD34, LTT Group GmbH, Bocholt, DE). The bottom of the outlets is located 2.39 m above the ground. Particle filters (class H13, complies to a separation efficiency of 99.5 % for a particle size of 0.3 - 0.5 μm [6], AS Luftfilter GmbH, Metzingen, DE) were installed as last component that the air passes, acting as both, a filter and a laminariser. The first filter stage (class F7, complies to a separation efficiency of 80 - 90 % for a particle size of 0.4 μm [7], Helios Ventilatoren GmbH + Co KG, Villingen-Schwenningen, DE) was connected downstream to the fans. Ducts out of expanded polypropylene ($\varnothing$ 0.3 m, ComfoPipe Compact, Zehnder Schweiz GmbH, Gränichen, CH) were attached via tool-free detachable connections. This allows a flexible extension of the system, e.g. for the extraction of outside air. The current system uses secondary air. For all components, the focus was on the lowest possible pressure loss at reasonable duct diameters. In order to realize the displacement flow, the fan (RR EC 200 B, Helios Ventilatoren GmbH + Co KG, Villingen-Schwenningen, DE) was chosen accordingly. The approach works according to the principle of speed compensation. This requires the dynamic forces of the supplied air to be greater than disturbing forces (e.g. thermal lift) [8]. The entire setup is shown in Figure 3.

In order to compensate for heat gains, energy must be applied which is known as “cooling load”. The required air velocity (load speed) depends on the disturbances in the room, especially the cooling load. First and foremost, the thermal loads of people and technical equipment in the room must be considered [9]. Based on the expected number of people and technical equipment in the protection zone as well as lighting, the cooling load density in the protection zone was estimated to 1529 W.

By means of the stability limits for a displacement flow [8], the required volume was determined to be 298 $\text{m}^3/(\text{h} \cdot \text{m}^2)$. In ventilation systems, forces occur as a result of friction and flow separation, which inhibit the flow process. The resulting loss of fluid mechanical energy manifests itself as a pressure drop in the system [10]. The pressure drop in the designed system was estimated to be 302 Pa. Based on this, fans were selected that compensate 360 Pa at the determined

volume flow. This results in a margin of 1.19. According to the manufacturer, the particle filters placed at the outlet are sufficient to produce a low-turbulence flow pattern. However, to further reduce turbulence fabric laminarisators (model PA-36/28, Franz Eckert GmbH, Waldkirch) can be optionally attached by means of magnetic strips below the outlet. The costs for the whole air conditioning system amount to approx. 3,500 €, including the truss framework to approx. 6,800 €.

Using the entire outlet cross-sectional area, the flow visualisation showed that the air sinks steadily down to a height of approx. $y = 1.3$ m (Figure 4).

Figure 4: Left figure: flow visualisation without ventilation system, right figure: with low-turbulence displacement-flow

Table 1: Measurements with a thermoelectric air-flow sensor at 2 m above the ground below the smaller outlet cross-sectional area. See Figure 2 for the measurement points. The asterisks mark values outside the measuring range of the sensor.

Position	Air velocity [m/s]	Turbulence level [%]
P1	0.20	10.62
P2	0.12*	21.36*
P3	0.27	4.99

The air flow measurements using the full outlet surface were at none of the 17 positions (Figure 1) within the sensor measuring range, as the air velocity was below 0.15 m/s. Therefore, these measuring positions were not evaluated. At a height of $y = 2$ m, and the flow diverted into the smaller outlet cross-sectional area, the values in Table 1 were measured. The

air velocity decreased rapidly with the lower height ($y = 1.5$ m, $y = 1.2$ m). As a result, the measurements on the other levels were outside the measuring range.

4 Discussion

The presented LTDF system can be categorized as low-cost with 3,500 € (6,800 € including the truss framework). The truss framework enables mobile use and simple assembly. This allows both installation in rooms without the need for fixing to ceilings, and simple spatial delimitation through the installation of tent tarpaulins and thus use outside buildings.

The visual inspection revealed air sinking down to the height of $y = 1.3$ m, which is close to the height of 1 m as required by DIN 1946-4 (Figure 4). However, it should be noted that there are no further specifications on how to set the limit from which flow pattern it can no longer be classified as ‘steadily’. Different measurement results (air velocity and turbulence level) at horizontal measurement positions indicate that the air is not distributed homogeneously throughout the outlet cross-sectional area. When the flow was diverted into the smaller outlet cross-sectional area, the level of turbulence according to the DIN was almost below 20 % (at a height of $y = 2$ m). The velocity decreased rapidly with the lower height, which leads to the assumption that the turbulence level is higher at lower heights. This work demonstrates that it is potentially possible to develop a LTDF under the aspect of low-cost, which largely satisfies the essential normative requirements.

The following points were identified for further optimization of the system:

Abrasion on air-carrying components cannot be excluded but could be compensated for with the terminal filters. Nevertheless, a coating of the plywood surface according to the DIN 1946-4 with an abrasion-resistant material such as melamine resin would extend the filter service life. In order to ensure that the filters are functional, they should be regularly monitored by means of a differential pressure manometer.

The required fresh air supply would be easily possible if the system were used outside existing buildings. For use inside a building, a connection with air ducts to the outside must be established. For this purpose, simply additional fans and two filter stages would have to be connected to the ventilation system. The supply of the outside air is important to generate an overpressure. In addition, it allows a higher volume flow, if necessary. A symmetrical air intake close to the ground and the installation of a cooling system would additionally benefit

the air sinking. Moreover, the system must be extended in order to distribute the air homogeneously within the outlet.

The operating environment offers many new opportunities for institutions in both teaching and research. For example, examining various aspects required in the DIN 1946-4 standard for their sense of purpose. In addition, such a low-cost system could give users from developing countries and crisis areas access to ventilation technology.

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