ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 3, Issue 1, January 2014

Modelling the delineation of airflow and new access solution in a standard surgery room

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***Abstract*— This article deals with the mathematical simulation of airflow modelling in a standard surgery room, which disregards part of the air conditioning device is designed for these rooms. A standard surgery is a room with specific geometric buckling. The air supply to the room is solved by a large flow into it with a directed airflow.**

The CFD (computational fluid dynamics) monitors the simulated delineation of the isothermal airflow, considering the barriers (surgical luminaire, operators, etc.) The validation of the experimentally learned delineation of the airflow through its visualization is the subject of this model.

The results of the images flow explain agencies contamination of the surgical field during operations. The result is a gradual increase in the concentration of particles in the surgical field to a comprehensive clean up the entire room. The resulting circular ring around the surgical field consists of aging air in which gradually accumulates entrained particles from the area of the operating room. These particles then emit into the operative field and contaminate it.

***Index Terms*— Airflow, laminar ceiling panel, luminaries flowing**

I. INTRODUCTION

Only one air conditioning airflow supply element, the so-called Laminar ceiling panel, is the main element for forming an environment, which is used for a designing ventilation system. It is used for air distribution and the finest filtration (third filtration level) of the air supply to the room. A standard laminar ceiling panel provides the required cleaning space in the patient operating area, but there is an identical self-contamination effect in all surgeries in practice. The particle concentration in an operating area escalates after some time and the required cleanliness level is decreasing.

Fig 1 – Basic elements of the surgery under consideration: laminar ceiling panel, surgical luminaries, operating table, elements for an air outlet [2].

The particle concentration, which is measured after complete cleaning without operating, is according to surgery certification in order. In practice a complete cleaning is carried out after 90 operating days because of technical and time reasons.

Considering the high air exchange (the air exchange in the patient area is more than 100 times on than in the surgery) the delineation of the airflow is not only a fundamental function parameter of that airflow, but also defines the distribution and particle concentration in the surgery space.

Standard practices in the air-conditioning field for clean rooms in a surgery only focus on the air distribution problems in the space of the operating area, which is less than 30% of the whole room´s capacity.

As the practical measurements indicate, the surrounding space, when considering the airflow in the room, has a relatively important effect on the cleanliness of the air in the operating area. The result is that it is possible to affect

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the particle concentration in a surgery by the airflow´s delineation. The CFD mathematical models for identification of airflow´s delineation is a modern and precise tool.
This article deals with these questions and proposes a hypothetical disposal for the prevention of self-contamination effect presented, i.e., the limiting contamination of the supplied air by particles of auxiliary air, the so-called return air-flow.

II. Materials and Methods

A. *Theory*

The delineation of the airflow is a visualization of the velocity vector distribution in a ventilated room. An idealized undirected delineation of the airflow is in Fig.2 this delineation is determined mainly by the site and character of the outlet area and its distribution air supply elements, than a warm and cool convective flow in a space. The effect of the outlet holes is difficult to determine, because their radius of effectiveness is limited, but they constitute the entire airflow in a room. We can assume that their basic character, which is valid for a free isotherm airflow, will also be valid for the air-outflow from laminar ceiling panel of specific area.

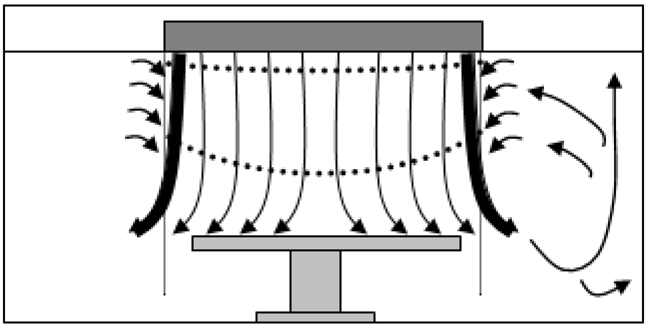

Fig 2 – Simplified airflow delineation in a surgery and primary airflow contamination by the air in the room [2].

Starting velocity field will be consistent because of the airflow through the laminar element. The airflow will be laminar. By flowing through the surrounding fixed air the effect of air viscosity also assets there and a boundary layer of the air blend from inlet and from the room is generated. It is impossible to say something definite about the flow character in the remaining space with the back flows. Involvement of this problem is very complicated due to effect of a large number of mutually commensurate forces. The airflow from the laminar ceiling panel can be characterized as an axially, symmetrical and cone. In the starting area the airflow develops as unconfined, with a low output rate and a very low degree of turbulence. Inertia is assumed to be the dominant acting force. However, it is possible that at low outflow velocities the effect of buoyancy forces find its use. They are caused by the temperature difference between supply air and ambient air in the room. To differentiate moderately and strongly non-isothermal flows there is used Archimedes Number Ar, in comparison with the number of determining the influence of inertial forces, Reynolds number, defined by [3]:

$$Ar = \frac{g \cdot l}{w^2} \cdot \frac{T_1 - T_2}{T_2} \qquad \mathrm{Re} = \frac{w \cdot d}{\gamma} \qquad (1.1)$$

Where
g…..gravitational acceleration [$m.s^{-2}$]
l…...distance of the inlet from the measured point [m]
w….outlet velocity from the inlet [m.s-1]
T1…thermodynamic temperature of room air [K]
T2…thermodynamic temperature of the vent air [K]
d…..hydraulic diameter of the outlet area [m]
γ…..kinematic viscosity of the air [$m^2.s^{-1}$]
Although working temperature differences are small due to large air exchanges in the surgery room during operating, air driven by low speed makes the flowing sensitive to buoyancy forces. The value of Ar is much higher for laminar ceiling panel than e.g. for conventional rectangular diffuser. The effect of buoyancy forces can be

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neglected when Ar <0.001 which in the case of unidirectional airflow from the laminar ceiling panel does not occur in any case. Anyway, the ratio of Ar/Re is at least favorable with low velocity flow. Outlet air temperature from the laminar ceiling panel affects the velocity of unidirectional flow in the operating field. In most cases it is a slightly non-isothermal flow, i.e., the air particles are accelerated (t2 < t1), respectively decelerated (t2 > t1). The particle velocity change due to thermal forces at the above mentioned temperatures and orbit about 2.1 meters (distance from the laminar element to the operating table) ranges around about 0.05 m/s.
This idea (discussed in current publications) is very general and it is necessary to correct it. Modern methods of mathematical modelling of air flow are used for refinement.

B. Methods applied

A mathematical model was devised using ADAPCO STAR CCM+ software, to create the graphic delineation of the airflow, including the effects of factor in surgery, see Fig 1. The actual constructed surgery is 5 x 6 x 3 m in size, which is respected by this model.
The actual airflow is not particularly affected by barriers (surgical luminaires, stands, suppliers and various elements of medical equipment). This equipment is often quite large, and they also can be sources of warm, which make turbulence in flowing their warm surfaces. The air-quality is very closely related to the delineation of airflow at a specific point in space. From this point of view we can do some partial resume about air-quality distribution in a space from a base of the identification of airflow delineations created by 3D mathematical models, see Fig 3.
For the computation a geometric model of the surgery was used with aggregate of 361 315 computing elements. The applied models of the internal equipment (lights, operating table) are geometrically identical; their simplification is related to some immaterial parts of the internal equipment (medical technology, tables, breathing apparatus, anesthesia, etc.
A steady three-dimensional airflow with an effect of air turbulence was selected for the conditions of the simulation. The Realizable K-Epsilon model was selected as the turbulence model for the boundary layer computation of the Two-Layer All y+ Wall Treatment model.
The air was modelled like an ideal gas. The airflow was solved like isothermal. The „Segregated flow“ was chosen for the solution. Iteration ran to converting status.

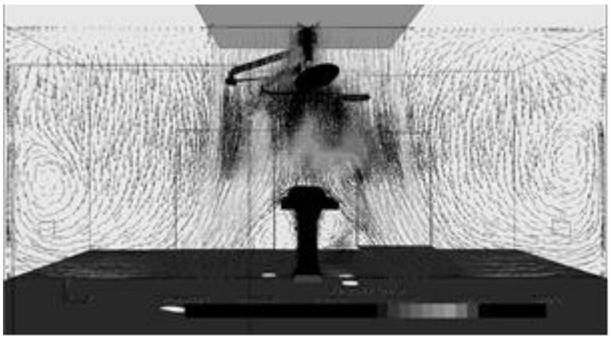

Fig 3a – Vector airflow delineation. Profile of surgery with standard laminar ceiling panel [3].

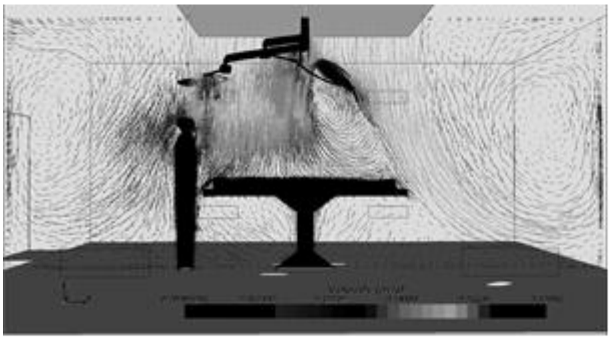

Fig 3b – Vector airflow delineation. Axial of surgery with standard laminar ceiling panel [3].

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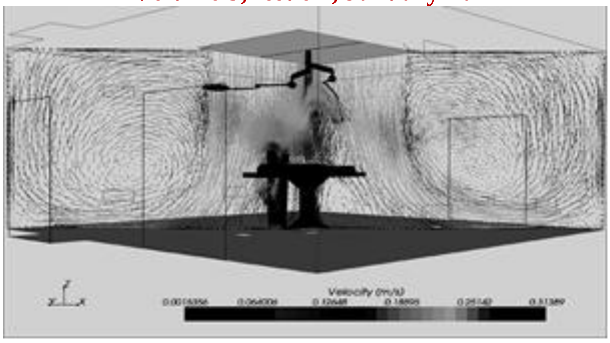

Fig 3c – Vector airflow delineation. Diagonal of surgery with standard laminar ceiling panel [3].

III. RESULTS

Generally you can submit that space of clean area is a space, which is completely blown over by vent air. It is a space, where the air is not blended with air from room. The area is not identical to the size of large-air-supply element. You can't consider the supply airflow to be laminar, neither in sector under laminar ceiling. But it is a directional flow, namely in the middle section with the main impact of the inertial forces.

There are turbulences because of air viscosity and of the blending air with the surrounding air at the border of the airflow supply. The ventilation can be defined as diluent and compressed in the middle section. The air viscosity asserts there mainly in the boundary layer. Starting a dynamic area is consistent because of the airflow through the laminar element. The airflow is unidirectional. The effect of air viscosity also assets there by flowing through the surrounding fixed air, and a boundary layer of the air blend from inlet and from the room is generated. The air velocity profile changes, breaking the effect of the boundary layer assets.

Previous assumptions can be ascertained by mathematical models (from the base of the particle concentration measured in the individual sections and from the base of the fume experiment in a surgery) that nowadays generally uses a system of mixed-flow ventilation from top to bottom.

The large deformation of the primary airflow the surgical luminaries flowing around is apparent in Fig 3.

The main source of the particles in a surgery are surgical scrubs, dermal flakes and fluid, dressing material and the particulate emitted by medical equipment. The particles are light; they do not settle down in the airflow in a surgery because of their size of 0.5 µm and they are wafted by a flow back to the patient operating area.

The best way to distribute the particle concentration so it doesn´t blend into the patient operating area, is a change in the delineation of the airflow. The change has to partly eliminate the back flow, which is visible in Fig 3.

A new final element for the air supply to a surgery was designed, the so-called two-way laminar ceiling panel with a side inlet for the air supply. The mathematical simulations of the delineation of the airflow are in Fig 4.

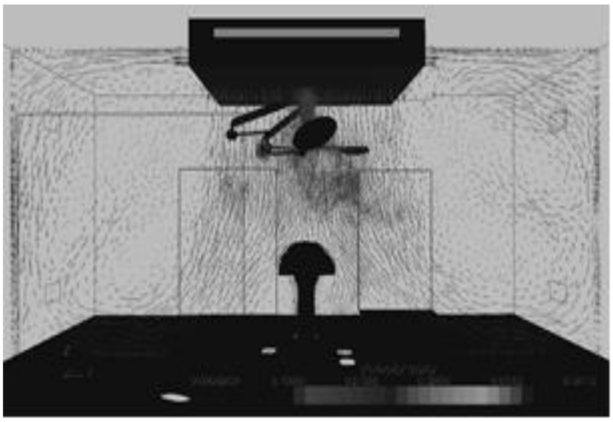

Fig 4a – Vector airflow delineation. The profile of a surgery with a two-way laminar ceiling panel with a side air supply [2].

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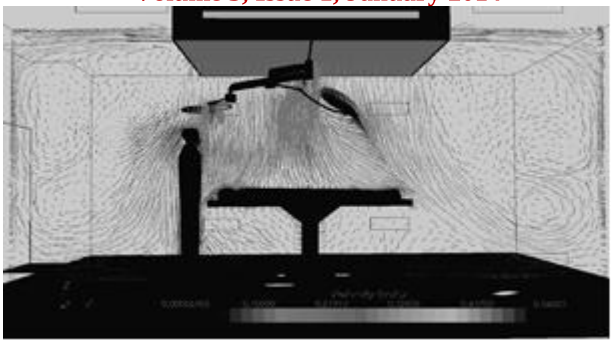

Fig 4b – Vector airflow delineation. The axial of a surgery with a two-way laminar ceiling panel with a side air supply [2].

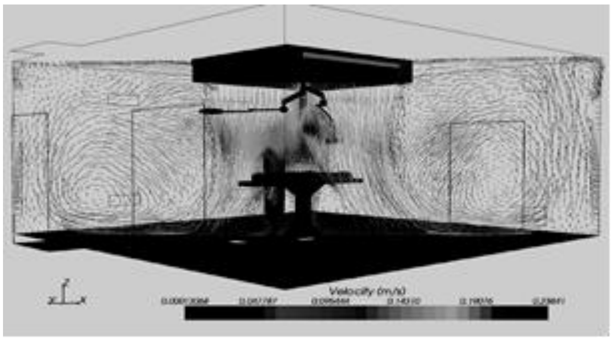

Fig 4c – Vector airflow delineation. The diagonal of a surgery with a two-way laminar ceiling panel with a side air supply [2].

IV. CONCLUSION

The identification of the delineation of the airflow by the CFD method has proved the complexity of the actual airflow in a surgery.
Airflow velocity vectors display these solved problems and they are becoming a trend for other consideration about distribution of particle concentration as it is noted in text.
From [4] as stated there in clause 54: "It has to be proved that air flow profiles pose no contamination risk, i.e., there has to be a secure air flow in order not to spread particles from stuff, work procedure or equipment to an area with extreme risks for preparation." That is a patient operating area in our case. The general result is, as mentioned above, that airflow delineation modelling is an available means for risk assessment of specific room contamination.

CFD models, which display the delineation of the airflow are actual tools for optimizing the distribution of airflow in cases such as a unidirectional airflow in a surgery. The design of a new air supply element for a surgery, a two-way laminar ceiling panel, is the result, analyzing the delineation of airflow, using standard air-conditioning elements.
The article was supported by the project: Systems engineering environment for sustainable construction FAST-S-12-17.

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ISSN: 2319-5967
ISO 9001:2008 Certified
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