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AIR FLOW DISTRIBUTION IN AN OPERATING ROOM VENTILATED BY A PERFORATED CEILING

Summary. The efficiency of a vertical downward quasi-laminar flow used for the ventilation of a hospital surgery room is investigated experimentally, with special emphasis on the analysis of airflow patterns in the room and more particularly in the operating field. Tests in laboratory enlight the particular care to be taken in the choice of an adequate ventilation system and measurements on site verify the performence of the system. Flow disturbances by the operating lamp are observed and show the tight link between the choice of a ventilation system and that of the medical equipment in the room, Finally, the setting considered is compared with recommendations available in the literature and some advice to the hospital management is presented.

Introduction

The ventilation of hospitals surgery rooms requires large air renewals, preparation of very clean air and proper locations of terminal units to ensure the correct transport of impurities away from the operating field. Moreover, correct comfort conditions should be maintained. In particular, some operations, such as orthopedic surgery, require very clean air washing. They have given birth to specific air distributions in rooms, the so-called quasi-laminar flows. Most set-ups are now using downward vertical air streams issued from perforated ceilings. Air-conditioning systems are then equipped with high protection or absolute filters (HEPA filters), which act as a porous medium on the air flow and yield low turbulent air jets entering the operating room.

Such quasi-laminar air jets were investigated by Kolasa in a range of Reynolds numbers between 5000 and 25 000, with kinetic energy fluxes between 1.5 and 200 mW, corresponding to mean velocity values in the range of 0.25 to 0.7 m/s (1), (2). Those jets are characterized by a convergence angle that can be reduced to approximately 9° and a quasi fluctuationless flow is indeed observed, even if the flow direction changes. However, this state is very easily disturbed by setting any obstacle in the flow path.

The kinetic energy flux of the convective plume rising above a person sitting quietly in a room at air temperature between 19 and 23°C amounts to 0.5 - 1.2 mW, when measured at about 0.75 m above the head (3). In normal conditions, this corresponds to 0.2 mW/m^3 in office rooms, while the kinetic power of ventilation air jets amounts to 2-6 mW/m^3 and rises to 30-100 mW/m^3 in department stores (2). On the other hand, quasi-laminar jets issued from a perforated ceiling of typical area 9 m^2 with recommended inlet velocities of 0.3 - 0.46 m/s (4) will produce kinetic energy fluxes between 150 and 500 mW, or 6 - 25 mW/m^3. It is thus expected that jets supplied by a perforated ceiling could overcome convective flows produced above the operating staff and equipments, mainly operating lamps. However, it would most probably occur with the creation of turbulent air movements and break up the piston effect of the quasi-laminar downflow. Moreover, obstacles and staff movements will induce further disturbances. Consequently, there is hardly any hope to maintain a full displacement flow in the zone of the operating field (5). A careful analysis of the air distribution processes is therefore recommended in any newly built operating room.

The purpose of ventilation

The tasks of ventilation in operating rooms are twofold (6):

1.- to protect the wound and the equipments in the operating field from airborne bacteria generated inside this zone.
2.- to protect the operating field from contamination by organisms and dirt coming from other parts of the room.

To fulfill task 1, air flowrates producing 400 to 600 air-changes per hour in the operating zone are recommended (4), (7), with inlet velocities between 0.4 and 0.5 m/s. To meet requirement 2, perforated ceiling designs create some protection of the operating field from peripheral zones by :

- air curtains produced by a linear outlet in periphery of the perforated ceiling (Allander ventilation (6));
- plastic drapes isolating completely the operating field(8);
- partial walls or curtains, enclosing the initial part of the downflow (9), (10).

All those procedures are favourable to the creation of the piston effect of the displacement downflow by reducing the occurrence of turbulent mixing on boundaries of the main stream.

Controls of efficiency

Following recommendations (7), (9), the installation should undergo a series of tests before the operating room is used and regular controls throughout operations. Routine tests are air purity controls, by tests of aerobiocontamination, which may provide interesting indications on air diffusion in the operating field if judiciously led, and pressure drop measurements across high protection filters to detect their degree of saturation.

Starting-up tests should verify the efficiency of filters and the airtightness of their jointings. Finally, the air distribution pattern in the room should be determined, by air velocities and temperatures measurements. This task constitutes the object of the present communication.

A perforated ceiling installation

The new University Hospital of Liège (Sart-Tilman) has chosen vertical downflow ventilations with perforated ceiling to equip its operating theaters. A first design was tested in laboratory before a definite choice was taken. Tests were also performed in operating rooms during the installation and further measurements were possible after settlement of high protection filters. Laboratory investigations were carried out on a perforated ceiling constituted by sixteen 0.625 x 0.625 m^2 square supply grids with a central separation band of width 0.2 m (fig.1). Tests were performed for inlet velocities ranging from 0.25 to 0.60 m/s.

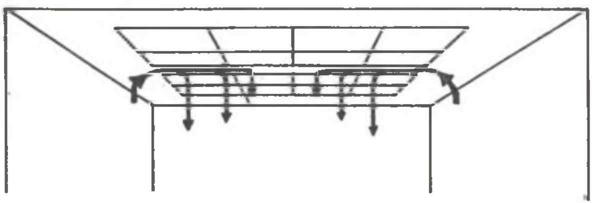

Fig. 1. Laboratory setting; effect of central band

Rys. 1. Pomiary laboratoryjne; wpływ pasa centralnie rozdzielającego siatkę

The air was supplied on the sides of two parallelipipedic plenums on two sides of the perforated ceiling, distributing it to four ducts running above the ceiling. From those ducts, it departed to divergents leading to the filters and then to the outlets grids. Inside those ductings, the air experienced a great amount of collisions and a very poor equilibrium of the perforated ceiling resulted. As sketched on figure 2., velocities were very unevenly distributed across the downflow jet.

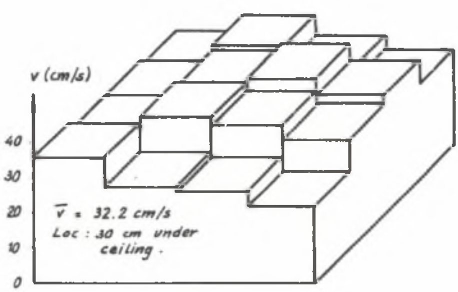

Fig. 2. Sketch of velocities averaged on each grid. (mean inlet velocity: 0,32 m/s, distance from ceiling: 30 cm)

Rys. 2. Szkic prędkości uśrednionych dla każdego kwadratu siatki pomiarowej (średnia prędkość nawiewu 0,32 m/s, odległość od sufitu 30 cm)

This phenomenon was emphasized downward and yielded separate air sub-jets of different kinetic energy which favoured turbulent diffusion in the operating field. Moreover, when heat loads were introduced into the field, the separation zones between sub-jets acted as ducts for natural convection plumes occurring above those loads. Finally, visualizations and measurements of horizontal components of the velocities showed a poor protection of the clean zone by the downflow boundaries. In particular, peripheral air was allowed to work its way into the main stream along the non supplied central band (figure 1). This evidence called for a protection of the initial part of the jet by vertical walls or curtains around the perforated ceiling.

The University Hospital setting

The final setting adopted by the University Hospital Center is determined by the above mentioned conclusions. The perforated ceiling is introduced into a 70 cm deep cavity. Air is supplied by side feeding of a plenum covering the perforated ceiling's entire area. Inside the operating room, recycling air is exhausted through outlets approximately at the height of the operating table and located in two opposite walls. In those same walls, air exhausts to the outside are placed at floor level.

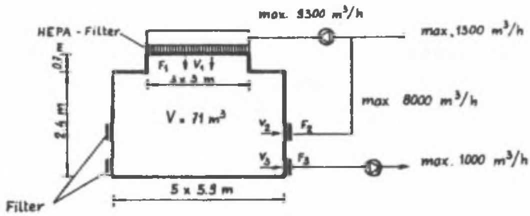

Fig. 3. The Liege University Hospital set-up with nominal airflow rates

Rys. 3. Rozwiązanie stosowane w Szpitalu Uniwersyteckim w Liege z nominalnymi natężeniami przepływu powietrza

Measurements were first performed for airflow rates ranging from 6000 to 8000 m^3/h, with full recycling. High protection filters were replaced by perforated screens providing equivalent pressure drops. This situation induced quite an important parasitic turbulence in the main airstream. Consequently, conclusions were verified after the settlement of filters, but in part load operation. In both cases, air humidity and temperature controls were not possible, but if the temperature of the supplied air varied, spatial gradients remained negligeable thoughout the tests.

Figures 4 and 5 depict the air patterns observed during the part load test. It is characterized by the following:

Inlet airflowrate : 4320 m^3/h Recycled air : 3168 m^3/h
Inlet mean velocity : 0.16 m/s Rejected air : 786 m^3/h
Operating conditions : 2 occupants, normal furniture, maximum light from operating lamp.

The above conditions yield a mass conservation residue of 366 m^3/h ensuring a correct overpressure of the operating room with respect to nearby rooms. They produce a net air renewal of 146 m^3/hm^2 of ground surface, or 200 Vol/h in the operating zone delimited by the main stream.

A very good equilibrium of the perforated ceiling is observed and the presence of the cavity creates a favourable protection of the operating zone by the vertical downward flow. The presence of the operating lamp perturbs the main stream in two ways :

- 1. its heat load creates a rising plume, which, however, does not reach the ceiling level;
- 2. it creates an "aerodynamic shadow" in its wake, yielding slow air movements and high turbulent diffusion right above the operating table. The efficiency of the ventilation in terms of removing the airborne bacteria around the wound is therefore greatly reduced.

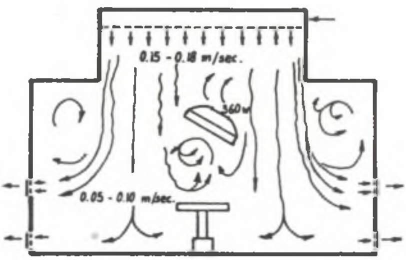

Fig. 4. Air movements in plane perpendicular to exhausts

Rys. 4. Ruch powietrza w płaszczyźnie prostopadłej do otworów odciągowych

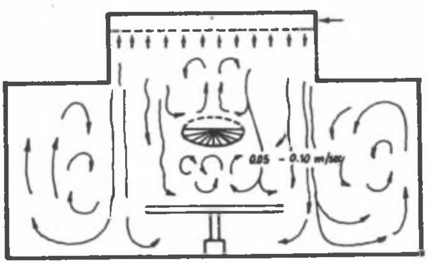

Fig. 5. Air movements in plane parallel to exhausts

Rys. 5. Ruch powietrza w płaszczyźnie równoległej do otworów odciągowych

Finally, the investigated ventilation was confronted with various recommendations. Table 1 presents this comparison.

Table 1

	Inlet velocity (m/s)	Air renewal in room (Vol/h) (Vol/h)	Air renewal in operating zone (Vol/h)
Present investigation ($4320 m^3/h$)	0.16	61	200
Present investigation (nominal conditions)	0.34	131	430
ASHRAE recommendations	0.46 ± 1	-	690
Allander		-	80
Recknagel	0.4 - 0.5	400 - 600	400 - 600
Joubert	0.5	min. 50	750

The set-up considered is located at the lower limit of general recommendations, as well for inlet velocity values as for air renewal rates in the operating zone. We should, however, stress that most of the hospital's operating rooms will not be used for operations crucially depending on the air purity. It was advised to increase airflow rates in rooms dedicated to such operations or choose a more specific system of ventilation.

Conclusions

Laboratory tests of a perforated ceiling for operating rooms downward quasi-laminar ventilation pointed out the particular care to be taken in the choice of an adequate ventilation set-up. Tests in an actual room showed a correct protection of the operating zone by a stream issued from a perforated ceiling located in a directing cavity. They also pointed out the need to choose operating lamps creating minimal disturbances to the main stream. Finally, comparing the investigated case to recommendations, advice could be given to the management of the hospital for correct operation of the ventilation system.

Acknowledgments

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ROZDZIAŁ POWIETRZA W SALI OPERACYJNEJ WENTYLOWANEJ PRZEZ PERFOROWANY SUFIT

S t r e s z c z e n i e

Badano eksperymentalnie wydajność pionowego, skierowanego w dół, quasi-laminarnego przepływu wykorzystanego do wentylacji szpitalnej sali operacyjnej, ze specjalnym uwzględnieniem rozpływu powietrza w pomieszczeniu, a zwłaszcza w obszarze operacyjnym. Badnia laboratoryjne potwierdziły, że odpowiedni system wentylacyjny nalaży dobierać ze szczególną uwagą; badania w obiekcie naturalnym zweryfikowały działanie tego systemu. Stwierdzono obecność zakłóceń przepływu przez działanie lampy operacyjnej i wskazano na ścisłe powiązanie między doborem systemu wentylacyjnego a doborem wyposażenia medycznego w sali. Porównano rozważany układ z dostępnymi w literaturze wytycznymi i przedstawiono pewne wskazówki dla kierownictwa szpitala.

РАСПРЕДЕЛЕНИЕ ВОЗДУХА В ОПЕРАЦИОННОМ ЗАЛЕ ВЕНТИЛИРОВАННОМ С ПОМОЩЬЮ ПЕРФОРИРОВАННОГО ПОТОЛКА

Р е з ю м е

Экспериментально исследовалась эффективность вертикального, направленного вниз квазиламинарного течения, использованного для вентиляции больничного операционного зала, с особым учётом распространения воздуха в помещении, прежде всего в операционной зоне. Лабораторные исследования подтвердили, что данную вентиляционную систему надо подобрать с особым вниманием, а испытания в натуральных условиях доказали правильность этой системы.

Были обнаружены возмущения течения из-за влияния операционной лампы и были указаны тесные связи между подбором вентиляционной системы и подбором медицинского оборудования зала.

Рассматриваемая система была сравнена с доступными в литературе директивными указаниями.

Также даются некоторые замечания для заведующих больниц.