

## Working conditions in the operating theatre

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WORKING CONDITIONS IN  
THE OPERATING THEATRE

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## WORKING CONDITIONS IN THE OPERATING THEATRE

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Hospital management is often confronted with discussions concerning building or rebuilding of operating wards. Arguments regarding working conditions and well being of the staff cannot easily be weighed. In order to objectify these arguments relevant aspects are surveyed interdependently. The main characteristics are climate, illumination, acoustics, evacuation of anaesthetic gases and concentration of bacteriae and dust particles in the operating room air. The influence of working postures and movements of the operating room personnel is characterised.

Some remarkable conclusions are drawn. Ventilation systems do not operate as was intended, because of the heat production of the surgical team. Microcirculations originating from this may cause high local concentrations of anaesthetic gases and heavily contaminated spots in the incision area. The installed hierarchical air pressure in the ward is disturbed by the intense traffic. The static and dynamic load can give rise to complaints. Unless precautions are taken the working conditions cannot be comfortable for everybody at the same time. Methods have to be developed to check the quality of ventilation systems to visualise microcirculations with respect to bacteriae and anaesthetic gases and to synchronise all different observations. Optimisation of working conditions implies an indispensable cooperation between a variety of medical and technical disciplines that does not develop self-evident.

### INTRODUCTION

Attention for human factors in hospitals is initiated by the genesis of a new general law in the Netherlands on working conditions. This law supersedes a variety of smaller laws that were operative until the late seventies. For a number of reasons one might expect that it will be introduced very gradually: Some of the standards and requirements will hardly be realisable in technical and/or economical respect; the conception of well-being at work and coherent notions such as worksatisfaction and comfort are principally subjective and therefore difficult to quantify; in medicine and health-care a number of protocols, procedures and responsibilities are dictated, inherent to the medical profession. In general one can put the case that there will be exceptive clauses on this law, especially where it concerns the working conditions in health-care.

### OBJECTIVES

Within the framework of the hereafter mentioned starting-points this project is directed towards a wide reconnaissance of presumably interdependent parameters. This has obviously worked out at the cost of a profound treatise on individual items. The main objectives of this study are twofold: The generation of ameliorisation proposals for the optimisation of the working conditions in operating theatres; the derivation of research propo-

sals directed towards suboptimisation of those circumstances that influence the working conditions and/or the treatment of patients in the most unfavourable sense.

### RECONNAISSANCE

In a joint-effort anaesthetists and technologists explored and discussed problem areas concerning the working in and the functioning of operating wards. A number of aims for research were formulated. Clinically relevant are among others:

- comparative studies into the reliability of apparatus,
- more participation of technology in an attempt to integrate measurements such as ECG, EEG, bloodpressures, muscle relaxation, etc. in order to achieve a better trend-monitoring and data-acquisition,-processing and -presentation,
- human factors, focussed on near accidents and critical incidents caused by improperly designed man-machine interfaces,
- environmental factors, indoor climate, infection hazards are probably correlated, nevertheless an integrated investigation has not been established.

More fundamental questions are: ventilation and perfusion, esp. tissue and organ-specific perfusion (brains, liver, kidney); standards for the monitoring of anaesthetic gas mixtures and for the individual variations in the metabolism of muscles; chemosensors; pharmacokinetics; datastorage; neuro-vegetative

stability; genetic variables with regard to anaesthetics.

As previous stated there seems to be a correlation between a number of factors that determine in mutual dependence the environmental conditions under which activities in the operating theatre, intensive care unit and recovery room take place. A lot of fundamental but fragmentary research has been carried out, covering all subjects mostly independently<sup>1</sup>. Therefore this research project is structured according to the starting points formulated hereafter.

#### Physical aspects of the indoor climate.

Some expertise exists in the field of thermophysiological load on people during various activities in relation with their metabolism and feelings of comfort. Thermophysiological models incorporate the insulation value of working clothes. Application of these models is specially meaningful when different activities under different conditions take place within the same accommodation (e.g. swimming pools, ice rinks, homes for the elderly, etc.) The operating-theatre can be characterised as an analogous situation<sup>2</sup>. An integration of the influence of illuminant, acoustical and climatological factors has to be acquired.

#### Evacuation of anaesthetic gases.

Anaesthetic gases in the operating theatre affect the working conditions and as a long-term-effect probably the health of the theatre personnel. For the concentration of anaesthetic gases in the operating room air, measuring methods have been developed that are still up-to-date<sup>3</sup>. A combination of these methods will - together with the measurement of the physical parameters - provide extra information.

#### Bacteriological concentration.

It must be pursued that bacteriological sampling is integrated in the previous. Not for the relevancy for the working conditions as a whole - except for the disciplinary rules originating from preventive protocols - but the more so as it afflicts the infection hazards for the patient. A relation between indoor climate and anaesthetic gases on the one side and indoor climate and bacteriological flora on the other has to be demonstrated.

### REGISTRATION OF THE WORKING CONDITIONS

To obtain an overall picture of the working conditions in operating theatres the following quantities or qualities are measured or registered:

Air movements and pressure distribution in the operating ward. This implies measurements inside the theatre with regard to comfort and to the estimation of the evacuation and/or dispersion of gases, bacteries or other undesirable pollutions (dust particles) and inside the total ward where septic and sterile spaces are separated by architectural provisions together with an installed hierarchical airpressure distribution.

Thermal load on the different categories of personnel in relation to specific activities. This contains mapping of climatic zones of the operating theatre and ward and the registration of effects of spotcooling and -heating. Insulation values of different clothing has to be taken into account. Fig. 1 shows the warm

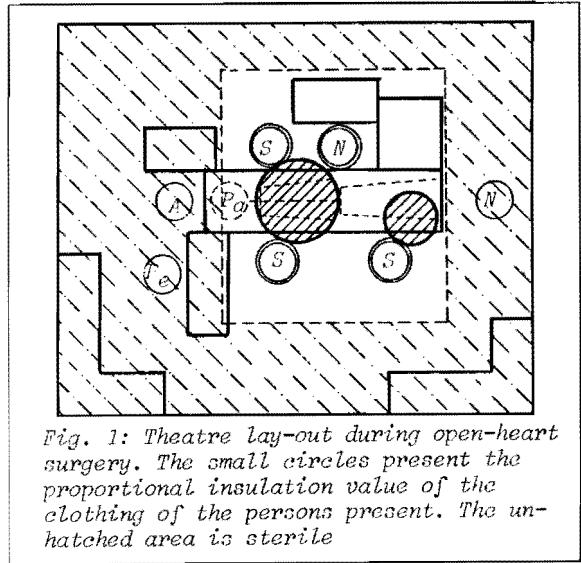


Fig. 1: Theatre lay-out during open-heart surgery. The small circles present the proportional insulation value of the clothing of the persons present. The un-hatched area is sterile

and cold areas in a typical lay-out of the operating theatre during open heart surgery. Thermal conditioning of the patient is of great importance<sup>4</sup>.

Illumination, including general lighting (luminances), the operating lamp in relation to its thermal effects, light intensity, possible disturbance of air movements, colour.

Acoustical parameters are speech intelligibility, signal to noise ratios and reverberation time.

Controls and displays compel for anthropometrical analysis of the working planes of the theatre personnel in relation to the positioning of equipment. Attention should be given to the lay-out of the anaesthesia apparatus including the (patient)-connections before, during and after surgery and to the arrangement of resources and spare materials. The manipulation of the patient during transport, transfer and surgery has to be registered. The arrangements of VDU's and other displays dictate working postures and the observability and interpretation of information depend largely on the redundancy and selection of presented signals.

### MEASURING SESSIONS

As it is impossible to registrate all the before mentioned parameters without disturbing the normal course of surgery a number of experiments have been performed in a mock-up. The simulation enveloped the record of acoustical parameters (reverberation time, background noise level), illumination (intensity, luminance) and climatological conditions (skin temperatures, air movements, frequency of air exchanges). The remaining parameters have been followed during and in between open heart surgery over a period of two weeks. To enable comparison of the results there are some preconditions: Measurements take place in the same theatre and are referred to an adjacent theatre; surgical interventions have to be similar (coronary anastomosis); and performed by the same surgical team.

#### Physical aspects.

Fig. 2 provides an overview of the measuring points. Not illustrated are the skin temperature sensors that were now and then fixed to

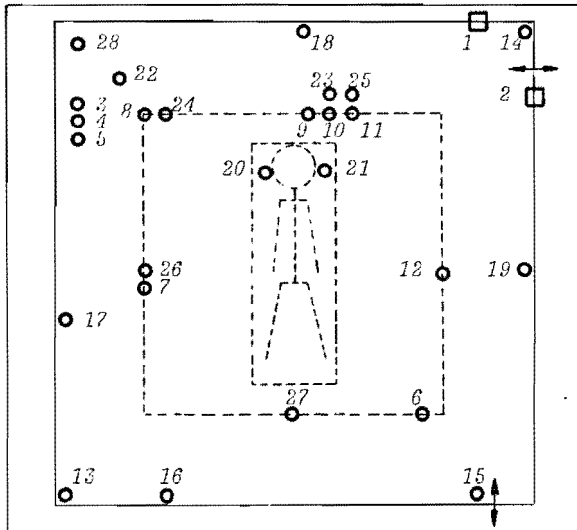


Fig. 2: Recording the indoor climate  
 1.  $\Delta p$  theatre-corridor; 2.  $\Delta p$  theatre-lobby; 3-5.  $T_A$  (0.5, 1.5, 3.0 m); 6-12.  $T_A$  inlet; 13, 14.  $T_A$  outlet; 15-19.  $T$  wall (2.9 m); 20.  $T$  floor; 21, 22.  $T$  ceiling; 23, 24. omnidirectional  $v_A$  (2.2 m); 25-27. directional  $v_A$  (2.9 m); 28.  $T$  dew point (rel. humidity)

the theatre personnel in an attempt to objectify comfort feelings. At the end of each session subjective impressions were gathered concerning the experience of temperature, relative humidity etc. in search for a possible relation between measuring results and subjective impressions.

#### Anaesthetic gases, bacteria, dust particles.

The theatre personnel is exposed to the anaesthetic gases that circulate freely in the air. The literature that deals with the evacuation of anaesthetic gases spends much attention to the epidemiological effects. Significant seems liver damage among anaesthesia personnel<sup>5,6</sup>. Most of this research has the handicap that the effects are overshadowed by factors that are hardly measurable (e.g. stress during work). An imperfection in former research is the negotiation of the movements and positions of the theatre personnel and the existence of micro-circulations in the operating room air, causing high local concentrations of anaesthetic gases or other pollutants<sup>7,8</sup>. Measuring these concentrations in the outgoing air makes therefore no sense. Also the hypothesis that equal distribution of dustparticles and bacteria is determined by the main air stream is invalid, at least for the combination of laminar and turbulent air flows that exist in many operating theatres. The gathering and analysis of air samples has been carried out continuously (miranalyzer) and intermittently (gas chromatograph). The sampling places are shown in fig. 3.

The presence of bacteria is highly determined by human activities. Therefore the recording of these activities has been carried out simultaneously with the sampling of bacteria. The sampling place is located near the incision area. The sampling frequency is 4/hour. Extra samples were taken at critical moments during the course of the surgical intervention. For evaluation purposes a continuous measurement of dust particles is performed. The

sensor is placed in the surgical lamp.

#### Activity patterns.

The standardization of activities is based on the amount of particles, dispersed by man in motion. Postures and movements were recorded manually every 30 seconds. The arbitrary scores corresponding to the activities are deduced from the scarce literature on this subject<sup>9,10</sup>. (See table 1). Outstanding events

1	motionless person sitting or standing
5	calm motion of head or hands
10	motion of trunk or upper extremities
25	stand up or sit down
50	walk more than 3 steps, entrance or exit

Table 1: Scores per activity

(e.g. perspiration, vivid communication, noticeable stress) as well as the course of the surgical intervention were registered with catchwords (e.g. intubation, perfusion on, etc.). To check over the observations video-recordings have been made of two complete sessions.

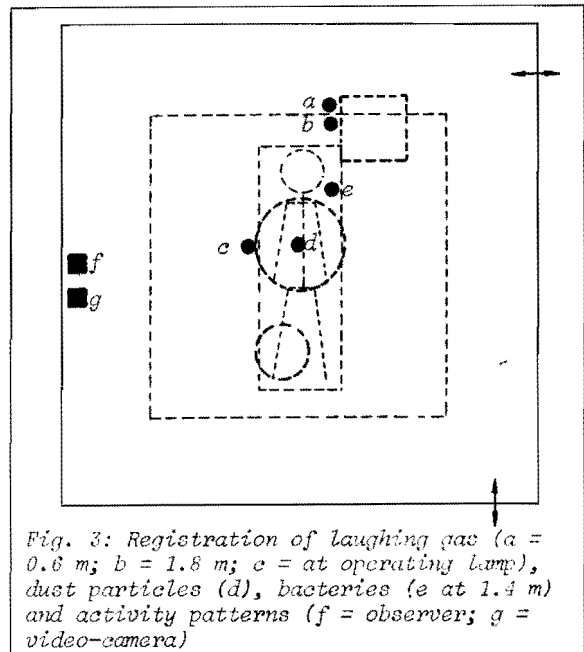


Fig. 3: Registration of laughing gas (a = 0.6 m; b = 1.8 m; c = at operating lamp), dust particles (d), bacteria (e at 1.4 m) and activity patterns (f = observer; g = video-camera)

## RESULTS

The environmental variables (air temperature  $T_A$ , surface temperatures, mean radiant temperature  $T_{MRT}$ , relative air velocity  $v$ , relative humidity r.h.) and individual variables (metabolism/activity level  $M$ , intrinsic clothing resistance  $CLO$ ) are combined and interpreted in the thermophysiological model (fig. 4). The air temperature varied between 18,5°C and 22°C. Together with the internal heat production (2,5 kW) this compels for an inlet temperature of 15°C. On the premise of efficient mixture of the fresh air in the theatre this will cause no problems, however the penetration depth is to great so an uncomfortable draught for the non-sterile team will result. Surface temperatures were constant (walls  $21 \pm 1^\circ\text{C}$ ), or allowable (lamp  $53^\circ\text{C}$ ). Air velocities  $> 0,2 \text{ m/s}$  and  $\Delta T > 2^\circ\text{C}$  give rise to complaints by the anaesthesia personnel.

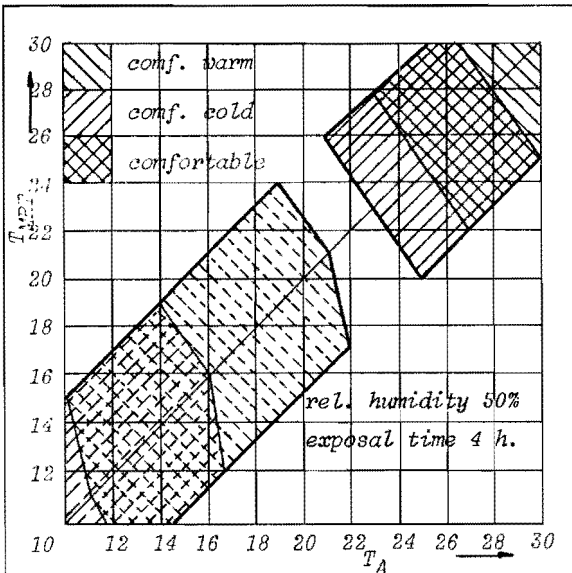


Fig. 4: Comfort domains for surgeon (--) and anaesthesiologist (—) with respectively a metabolism of 110 and 70 W/m<sup>2</sup>, dressed up to 1.1 and 0.5 CLO and exposed to air velocities of 0.3 and 0.4 m/s

Convective heat originating from the surgical team and the operating lamp (approximately 700 W) causes ascending air streams in the surgical area (chimney effect) in spite of the installed ventilation and air conditioning system (fig. 5). Problems arising from this chimney effect will be discussed later.

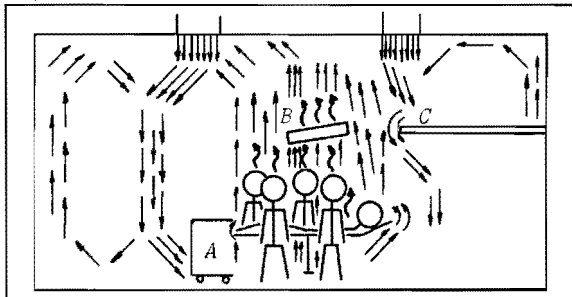


Fig. 5: Chimney effect: Each curved bold arrow presents approximately 100 W. A: instrument table, B: surgical lamp, C: connections for anaesthetic equipment

Relative humidity varied between 45 and 60%. This is according to accepted directives. To make a distinction between personal variables a division into three categories is made: patients, surgical team, non-sterile staff (see table 2). With regard to the thermal comfort of the patient it is stated that the climatological situation is harmless if some precautions are taken (pre-heated infusion liquids, pre-heated underlay, warmed and moistened anaesthetic gases).

	anaest.	surgeon
Metabolism, M(W/m <sup>2</sup> )	70	110
Clothing resistance, CLO	0,5	1,1
Relative air velocity, v(m/s)	0,4	0,3
Relative humidity, r.h.(-)	0,5	0,5
Exposition time, t(hours)	4	4

Table 2: Personal and environmental variables from surgeon and anaesthesiologist averaged over all sessions

Fig. 4 indicates that there is no overlap in the comfort areas of surgeon and anaesthesiologist so some precautions have to be taken e.g. extra clothing for the non-sterile team or spot-heating.

The reverberation time (0,5-0,8 sec.) in the theatre is according to the directives. The background noise level (L<sub>A</sub> = 50 dB(A)) and NR (45) are too high consequent on the high noise production of the air inlet and the shorting of quelling material in the air channels. The illumination intensity of the operating lamp is variable between 16.000-105.000 lux. The colour temperature is 3700°K and no shades existed in the incision area. The reflection factors as well as the luminances are according to the guide-lines. The profit of extreme light intensity levels (> 100.000 lux) must be doubted because then there is nothing more to be gained than glare. The general lighting (300-1500 lux) is adequate.

Fig. 6 shows the average concentration laughing-gas in the breathing zone of the anaesthesiologist. During all sessions this concentration exceeded the U.S. standard (25 ppm). This high

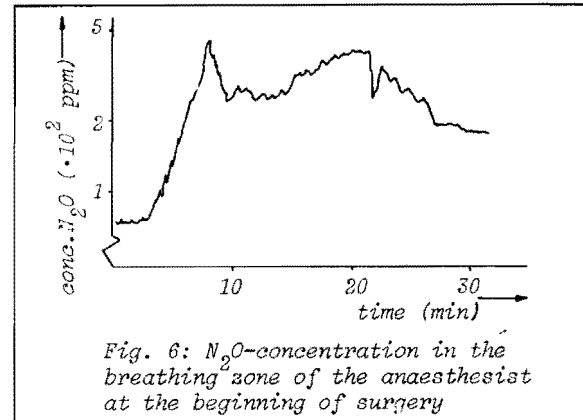


Fig. 6: N<sub>2</sub>O-concentration in the breathing zone of the anaesthesiologist at the beginning of surgery

level originates from leakages in connections but also from operation errors. The effect from connecting the rebreathing to the suction system can be calculated from:

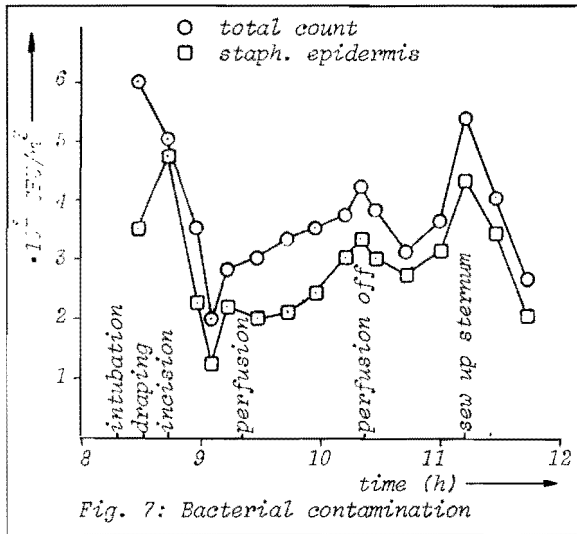
$$C_{max} = q \cdot 10^6 / l \cdot V \text{ (ppm)}$$

in which q = average laughing-gas flow (0,42 m<sup>3</sup>/hour); l = theatre volume (115 m<sup>3</sup>); V = number of air changes (20/hour) resulting in:

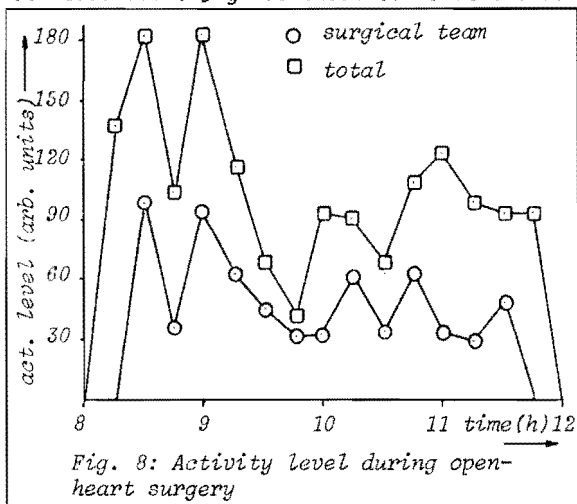
$$C_{max} = 200 \text{ ppm.}$$

When the suction system is connected the average concentration is 91 ppm and when disconnected 191 ppm during the period of administration. A general conclusion may be that under all circumstances this is 4 to 8 times higher than the U.S. standard. The results may even be flattered due to the presence of microcirculations.

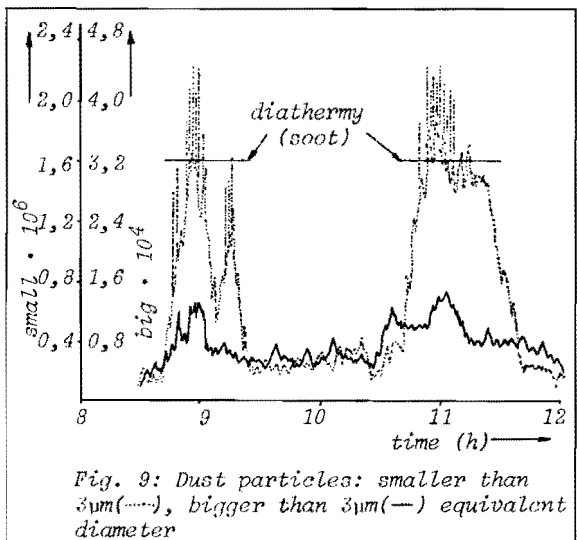
The average concentration of bacteria varied between 290-610 CFU/m<sup>3</sup> (colony forming unit). The overall average during 12 sessions was 360 ± 140 CFU/m<sup>3</sup>. Fig. 7 shows the typical course during a session. This is too high referring to Galson & Goddard<sup>11</sup> or Duvlis & Drescher<sup>12</sup> who recommend respectively 124-174 and 113-217 CFU/m<sup>3</sup> for the air contamination level during open heart surgery. However, the sampling place was located in the ascending air (chimney effect), therefore the situation in the incision area might be more favourable. The correlation between the activity patterns (fig. 8) of the surgical team and the concen-



tration of dust particles (fig. 9) is demonstrated. Table 3 gives these correlations as



calculated from the Spearman non-parametrical rank correlation test. The elaboration of measuring data has been hampered by the disturbance of diathermy (emission of soot) and synchronisation of all measurements. The results are in harmony with findings of earlier investigators<sup>13</sup>. The similarity between the contours in the figures 7, 8 and 9 is remarkable.



	Act 2	Dust 1	Dust 2
Act 1	0,6266 (160;0,001)	0,1478 (145;0,038)	0,1350 (138;0,057)
Act 2		0,1476 (145;0,038)	0,1517 (138;0,038)
Dust 1			0,6683 (145;0,001)

Table 3: Correlation between activity levels and dust particles. Act 1: activity level surgical team; Act 2: overall activity level; Dust 1: particles > 3.10<sup>-6</sup>m; Dust 2: particles 0,5.10<sup>-6</sup> - 3.10<sup>-6</sup>m

DISCUSSION

It is possible to create an indoor climate in the operating theatre in which the complete staff feels comfortable. To effect this situation variables like clothing resistance and heat transfer by radiation must be manipulated. The insulation value of the clothing of the non-sterile staff must increase and radiant spotheating can compensate the effects of draught in the areas with higher air velocities.

The consequences of the ascending of warm air in the sterile area caused by the heat production of the surgical team and the operating lamp (chimney effect) need further analysis. This might contaminate the surgical area because shedded skin particles can be transported by the ascending air. Also the influence of the chimney effect on the originally installed and intended air stream pattern should be examined. All theatre personnel including the female should wear sealed off trousers, skirts and rubber overshoes. Cleaning instructions should be revised.

The toxicological risks of exposal to sub-anaesthetic concentrations of laughing gas and halothane during prolonged exposal times need further investigation. A MAC-(maximum allowable concentration) value must be set up. For this purpose measuring and registration methods must be developed that provide information about local concentrations of anaesthetic gases, exposal times and influence of air stream patterns. Anaesthetic apparatus have to be designed optimal with regard to the leakage of gases and the slovenliness or operation errors of the staff.

The custom of transporting the patient to the theatre in his own bed has unknown consequences to the occurrence of post-operative infection. At the same time the manual transfer to and from the operating table causes inadmissible strain to the staff. To these respects the organisation and design of patient transport systems require more attention<sup>14</sup>.

Although technical provisions can improve the working conditions in the operating theatre, it must be stated that disciplinary behaviour is a prerequisite for optimal finish of the tasks to be performed and only a multidisciplinary approach in research will result in optimal working conditions in the operating theatre.

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