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Study on environmental quality of a surgical block

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Abstract

This article presents the study of a surgical block with serious deficiencies of Indoor Air Quality (IAQ) located in the Hospital del Rio Hortega (Valladolid, Spain). Block characteristics were identified and symptoms reports collected from 118 workers. At the end of the initial investigation, it was concluded that there was Sick Building Syndrome. Measurements of ventilation and contaminants were made of indoor air (CO, CO_2, TVOC, anaesthetic gases, at six differents points simultaneously) and outdoor air (hospital incinerator). Studies with trace vapors (Xylene) were also performed on installations which crossed the surgical area to see whether a relationship existed between the different surgical areas studied and other areas of the health centre. Actions on contaminating foci, climatization–ventilation and personnel training were finally recommended to Administration to solve the problem.

Keywords: Sick building syndrome: Ventilation; TVOC; Anaesthetic gases; Xylene

1. Introduction

In the last decade many problems of habitability and health in non-industrial buildings have been given the denomination 'Sick Building Syndrome' (SBS). This problem has been difficult to determine and, in addition, it requires great effort on the part of technicians to solve [9]. This article presents the study of a surgical block with serious deficiencies of Indoor Air Quality (IAQ) located in the Hospital del Rio Hortega (Valladolid, Spain). A main point of interest of the project lies in the evaluation criteria adopted for this specific type of occupation [8].

2. Methods

The IAQ study of the surgical area in question has been performed following a methodological proposal which involves four stages of investigation, of gradual application and incremental complexity. After analyzing the information gathered in each phase, the next phase is addressed until, finally, the possible causes of the problem are reached. Consequently, remedial actions to solve the problem are proposed.

2.1. Phase I: Initial investigation

This is the most important phase of the process. It involves the hospital administration, medical personnel, workers representatives and maintenance personnel.

The investigation attempts to gather the maximum quantity of information possible in order to characterize the personnel who work in the building, the symptomatology presented, the building and its installations and the activity within the building.

The personnel are characterized by means of a strictly confidential questionnaire, filled in by a statistically-representative number of occupants. The objectives are to determine the possible causes, the duration of the symptomology, the location of the problem and the work organization. The symptomatology is characterized through medical reports, complaints presented and information from previous surveys. The principal objective is to establish the most frequent and specific symptoms. The building and its installations are characterized by means of a standard

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questionnaire elaborated in collaboration with the maintenance service [5]. The information obtained concerns any modifications performed, utilization of the areas, heating, air conditioning and ventilation installations, revisions and maintenance schedules, and sources of contamination near the building. The activity within the building is determined by an inspection by the technicians for indoor environmental quality. Special attention must be given to potential sources of contamination.

Once this phase is completed, the technician has three possible courses open for action, depending on whether (a) no SBS exists, (b) SBS exists and a series of easy solutions are proposed which can solve the problem, or (c) SBS exists but no problems which cause it can be found, in which case, action continues to the next phase.

2.2. Phases II and III: Measurements of ventilation and contaminants

In these two phases quantitive measures are taken to evaluate the state of the ventilation and the contamination levels. The inspection attempts to detect differences between the use and functioning of the building before and after SBS. This section includes all the measurements on air renewal (both planned and existing) and ventilation [2]. Any contaminants detected are analyzed quantitatively at intervals to determine their involvement in the SBS [4].

Upon finalizing this phase, the technician has two possible courses of action: (a) Propose a series of solutions to resolve the problem, or (b) not propose any solutions and go on to the next phase.

2.3. Phase IV: Clinical study

Health care practitioners must undertake an organized, dispassionate approach to the evaluation of claims not determined by the above strategy phases. Psychological and psychiatric consultation should be considered in many of these cases. Again, careful evaluation of epidemiologic features must be used to help differentiate between illness as a consequence of SBS and that with a psychogenic origin [6]. If the diagnosis of mass psychogenic illness cannot be discarded then returning to phase III is appropriate. The indoor, outdoor, and home environments should also be monitored simultaneously whenever possible. This will identify similarities and differences and enable the physician to determine whether the resolution of complaints on changing environments implicates the cause [7].

This four stage methodological proposal is set out in Fig. 1.

2.4. Thermal environment

Thermal comfort was evaluated according to regulation ISO 7730, using a BRÜEL and KJAER unit, model 1213. The predicted mean vote (PMV) and predicted percentage

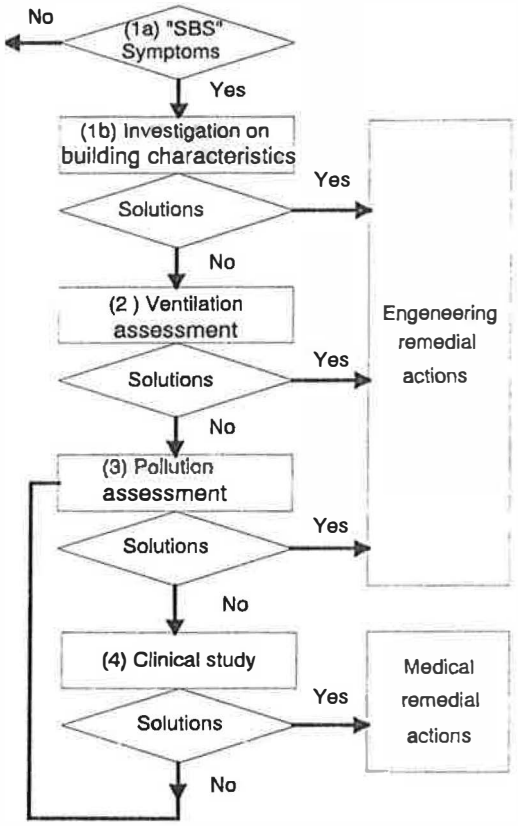


Fig. 1. Flow-chart of an investigation strategy for SBS problems.

of dissatisfaction (PPD) were determined. These factors are functions of six magnitudes: air temperature, average radiant temperature, air velocity, water vapour pressure, individual metabolic rate and thermal insulation provided by clothing used [3].

2.5. Indoor contamination

Indoor contamination was measured with a BRÜEL and KJAER multi-gas model 1302 and a 1303 multi-point sampler and dosifier with six sampling and six dosifying channels. This equipment made it possible to determine constantly the carbon monoxide (CO), carbon dioxide (CO_2) and volatile hydrocarbons referred to methane (TVO) at six different points.

Measurements were taken for periods of 24 h, with operating room activity under the following conditions: air conditioning functioning with high-pressure ventilation and functioning with depressure. Measurements were also taken when there was no operating room activity, under the same conditions as indicated above.

The anaesthetic gases were studied by two methods. Firstly by the maintenance services of the Health Centre, who performed pressure tests on all the anaesthesia gas pipes in the surgical block an verified any possible escapes of nitrogen protoxide. The second test consisted of monitoring the anaesthesia gases during an operation using the

aforementioned instrumentation (BRÜEL and KJAER model 1302, based in photoacoustic spectroscopy), with specific filters to detect isoflurane, halothane and nitrogen protoxide,

2.6. Calibration

All the BRÜEL and KJAER instruments were calibrated for average zero level and standard deviation, environmental conditions and used gases. Analysis certificates and calibration charts were purchased from the manufacturer.

3. Results and conclusions

3.1. Phase I: Initial investigation

3.1.1. Personnel working in the building and symptomatology

The survey presented in our study was elaborated by the preventive medicine service of the health centre, and reflected personal factors (such as age, sex, smoking, hyperreactivity, etc.), professional factors (such as job status, time spent in surgical room, experience of static electricity at work, etc.), type of discomfort, symptomatology and location. The results were not considered excessively reliable, as the climate was hostile to the survey and because not all the personnel who worked in the area were included. Data were collected for 118 workers (among the 126 in surgical areas). Some of the most notable results are presented below.

The personnel most affected were those in the age group of 40 to 50 years old, with a symptom complaint rate of 87%. Being a smoker or having allergies had no effect on the symptomatology. The work situation was difficult to evaluate due to the differing time spent in the area for the distinct groups involved: doctors, registered/practical nurses, hospital attendants and others. The most numerous group, registered nurses and attendants, presented a symptomatology–work time relationship as appeared in Table 1.

For symptomatology onset an association such as Table 2 was established.

The percentage of personnel affected was 47.5%, with an average incidence of 2.15 times in 6 months. The population was primarily female (82.5% women as opposed to 17.5% men), with an average age of 44.45. The personnel presented four illness patterns (Table 3).

Table 1
Symptomatology–work time relationship

Work time, days	Less than 60	60–70	70–80	80–90	Over 90
Symptoms, %	40	73	72	85	100

Table 2
Symptomatology onset

Time	At the beginning of the shift	Mid-way through the shift	At the end of the shift
Percentage	17	50	33

The distribution of the total cases among the five areas studied (described in the following section) is shown in Table 4.

3.1.2. Building and installations

The hospital studied has seven floors. The number of surgical areas is 10, two per floor, separated horizontally from the rest of the building by a series of structural elements. Each floor has independent climatization and ventilation equipment. Vertically, the areas are superimposed and are limited by an area (Preventive Medicine) above the highest surgical area and another area (Sterilization, Pathological Anatomy, Endoscopy and Emergency) below the lowest surgical area.

The symptoms reported by the workers affected appeared in all the surgical areas, but there were two floors on which there were a greater number of problems. The activity in each surgical area was completely distinct, thus representing a series of differing effluents.

Each operating room separates the septic zone from the aseptic, but there is no clear identification of the communication pathways. The basic design corresponds to the type of peripheral corridor or lineal circulation plan. The operating rooms had undergone continual modifications, both in structure as well as in the normal installations of the operating room and supporting areas. However, there had been no provision for the interferences between installations, nor posterior revisions of the state of the remaining installations.

New installation and materials in the areas were superimposed on the original ones when modifications had been made. The walls were covered with several coats of paint containing toluene as a dissolvent, and the flooring was of the electrostatic type.

The installations throughout the area were checked only in the case of breakdowns. The registers were found to be in poor condition, some even remaining open during surgical activity.

The airlocks in the surgical areas were not used and remained open, except for those which communicated with areas outside this zone, which remained closed.

3.1.3. Outdoor

Outside the health centre, the greatest focus of contamination were the incinerator of the hospital itself, the carbon heating systems existing near it and the traffic flow (given that the health centre is limited by two large streets with a very high traffic density). The hospital itself was a possible

Table 3
Illness patterns

Symptoms	Sensation of loss of consciousness and dizziness (1)	Irritation of conjuctival mucosa and upper airways (2)	Digestive problems of nausea, vomitting, sensation of a 'epigastrium stab' (3)	Mixed pattern of symptoms (1) and (4)
Cases %	28	7	10	55

focus of contamination for the surgical area, due to the great number of contaminating activities existing, some controlled and others uncontrolled. However, the surgical area was separated from the rest of the hospital by communication pathways.

The assessment was performed during spring–summer seasons.

3.1.4. Climatization–ventilation

The surgical area was ventilated by climatization equipment consisting of a climatizer for each floor, made up of a post-heating battery, a humidifier and a cooling battery. For each of the two operating rooms per floor, the post-heating was set in parallel, thus permitting independent regulation (by mixing hot and cold air). Extraction was directly to the street.

Unfortunately, the systems generally functioned rather poorly. The regulation did not work; the humidifier was a recirculation system which was annulled; the air intake from the exterior was not adequately conducted toward the outdoor; the climatizers and distribution conducts had not been cleaned for at least 15 years; the screens and diffusers had been arbitrarily manipulated both in form and by the personnel; and the air expulsion could be connected independently of the extraction. In addition, the maintenance personnel lacked any concept of overpressure and depressure.

3.1.5. Conclusions of the initial investigations

At the end of this phase it was concluded that there was a SBS based on SX, with the following observations:

(a) The installations which crossed the surgical area should be completely revised, due to the lack of precise information as to their state after so many modifications. Special attention should be given to the anaesthesia gas lines, the health installations and the natural ventilation installations.

(b) The seals in the area could cause contamination by their lack of watertightness or from use of inadequate materials.

(c) At first sight, the climatization–ventilation installation presented a serious deficiency: the exterior air intake of the climatizer did not lead to the exterior. This caused a negative pressure in the operating room which, therefore, could allow contaminated indoor air to be circulated as outdoor air.

(d) Open drainage pipes for residual water existed and the false ceilings connected with adjacent zones or rooms.

(e) The regulation systems did not function, which caused the climatizers and extractors not to work at some times during the day. As both these systems were not locked in, not only was there loss of overpressure in the septic area, but also depressure in the operating rooms.

(f) There were no protocols, maintenance logs or incidence registers for any part of the installation. Revisions and inspections were held only as a result of complaints from the surgical area personnel.

(g) Comments by the workers and the results of the survey led to the conclusion that the problem could be caused by the low quality of the interior air, by lack of thermic comfort and by the presence in the environment of chemical products harmful to health.

3.2. Phase II: Ventilation measurements

This section includes only the most indicative ventilation measurements from the second phase. The velocity measurements of the extraction screens showed that the surgical area had no uniform sweep system. The measurements obtained from one operating room are shown in Table 5.

Similar measurements of the impulsion screen led to the same conclusion for this system.

Table 6 presents the velocities presented in the same operating room as above.

The measurements taken from all the impulsion and extraction screens showed that there were a few screens totally closed or disconnected from the network (due to construction carried out after the installation of the climatizer). On the other hand, a series of elements such as the

Table 4
Personnel case distribution in surgical blocks

Area	1st	2nd	3rd	4th	5th
%	11	30	7	26	25

Table 5
Extraction screen velocity

Screen	1	2	3	4	5
m/s	0.5	0.1	0.1	1.9	0.3

Table 6
Impulsion screen velocity

Screen	a	b	c	d
m/s	2.5	0.1	2.0	1.5

service lift, improper airlock use and windows which communicated with the peripheral hall-ways also disturbed the system's proper functioning. However, measurements of the climatizer impulsion showed that, working properly, it was capable of 18 air renewals per hour. The distribution of the air within the area always used adjustable deflector screens, the impulsions and return air pathways facing each other locally.

Two placement patterns existed: in the operating room the impulsions were located at the top of the wall and return ducts at both the bottom and top of the wall; while in the other rooms both impulsion and return ducts were located in the ceiling. The ceiling placements generated bypass problems between the treated and the extracted air.

According to regulations DIN 24184 and 24185, the filtering system in the operating rooms should consist of three steps: the first should have at least EU4 filters, the second with at least EU7 filters, and the last step with high efficiency filters (99.97%) of either class 8 or class R. However, the installation consisted of only two filters, the first of class EU4 and the second of only 85% efficiency, both lacking controls.

3.3. Phase III: Contaminant measurements

In the section on physical contaminants, the results from the thermic atmosphere stand out. With respect to chemical contaminants, the results from both the indoor and outdoor contaminants are presented. Biological contaminants have not been included in this article due to their slight incidence on the problem and because they are the object of a separate study.

3.3.1. Thermal environment

Over the course of a day widely varying PMV values were obtained, principally due to lack of humidity control in the installation (see Table 7), which reached a relative humidity of 33.5% at specific moments. Most regulations establish that operating rooms (where the use of inflammable anaesthetic gases is possible, volatile liquids are used frequently, and in order to prevent the accumulation of static electricity) should maintain a humidity of about 60% (DIN-1946, on Heating, Ventilation and Air Conditioning of Hospital Systems).

3.3.2. Indoor contamination

All measurements showed negative toxic levels. However, variations in gas and vapour levels during surgery appeared. For example, Fig. 2 presents the evolution of TVO's in one of the six measurements taken.

Studies with trace vapors were also performed on installations which crossed the surgical area, principally on drainage and rain pipes, to see whether a relation existed between the different surgical areas studied and other areas of the health centre. Trace vapor (xylene) flows were measured in each pipe, without surgical activity over a period of 12 h with a period of 1 h between flows.

The study was quite effective. There turned out to be a sharp peak in the wash-up room next to the surgical room in the fourth pouring. Following the tests, an inspection of this room by hospital maintenance personnel found that there was no siphon in the basin of that room and that there were cracks in the drain. Fig. 3 presents the peak detected in the drain flow corresponding to the wash-up room.

The emanations from the paint in the operating area, on which toluene had been used as a thinner, were studied. Emanations were found only when the paint was drying and decreased exponentially. When the ventilation system was functioning, no parts per million could be detected 6 h after painting.

Monitoring the anaesthetic gases during a surgical operation, it was found that although these gases were mechanically introduced into the patient, afterwards they were not extracted and led to the exterior, but were exhaled by the patient within the operating room. This non-standard practice was already viewed with suspicion by the personnel, but no objective quantification of its incidence existed. This information was gained by photoacoustic spectroscopy. The results obtained during a surgical operation without mechanical gas extraction are shown in Fig. 4, while results with mechanical extraction are presented in Fig. 5. Given that the Threshold Limit Value adopted by American Conference of Government Industrial Hygienists in 1994 [1] for an 8-h exposure to nitrogen protoxide are 25 ppm (no Short-Time Exposure Limit value exists for this gas), the importance of the extraction of patient gas exhalations in an operating room is evident. This is even more true in that the simultaneous presence of various gases may result in an additive or multiplying effect, with a more marked symptomatology.

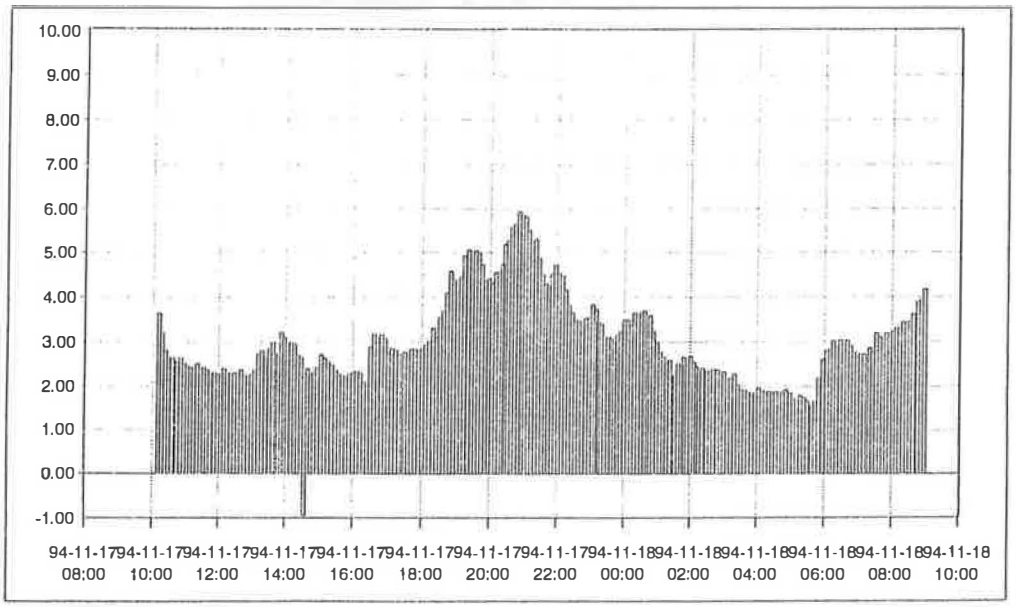
3.3.3. Outdoor contamination

The studies performed in the exterior of the area are based on specific focus of the hospital and focus near it. Among the former, the combustion analysis performed on the hospital incinerator stands out. The foci near the hospital were studied using data furnished by the Environmental Office of the Town Hall of Valladolid. This group

Table 7
Predicted mean vote measurements

Hour	8:00 a.m.	10:00 a.m.	12:00 a.m.	14:00 a.m.	16:00 a.m.
PMV	−0.7	−0.5	0.3	0.4	0.6

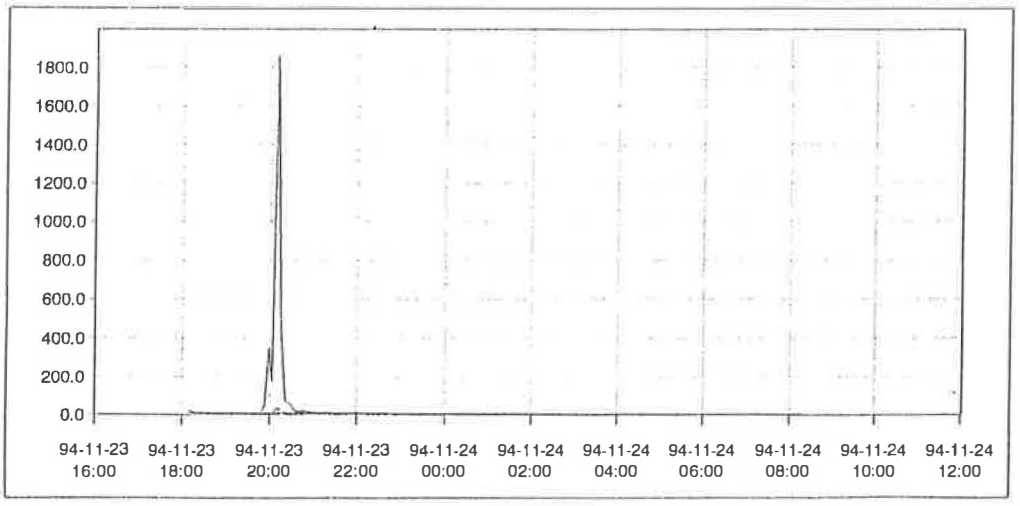
SETTINGS:		GENERAL INFORMATION:		COMMENTS:
Sampling Interval:	Cont.	Start Time:	1994-11-17 09:00	
Time bet. measureme	371 s	Stop Time:	1994-11-18 09:00	
Normalization temp.	20.0 °C	Compression time:	None	
Cross Compensation:	No	Warnings:	Yes	
Water Vapour Compens:	Yes	Data Edited:	No	DATABASE: 17NOQ3MT
Air Pressure:	715.00 mmHg	Resolution:	100 %	USER PRG: None



C	Location:	Measurement	Line	Scale	Unit	Alarm lim.
3	montacargas	TOC ref. Methane	I	1E+00	ppm	0.00E+00 ppm

Fig. 2. Evolution of TVO's in a 24 h measurement.

SETTINGS:		GENERAL INFORMATION:		COMMENTS:
Sampling Interval:	Cont.	Start Time:	1994-11-23 16:00	
Time bet. measureme	360 s	Stop Time:	1994-11-24 10:00	
Normalization temp.	20.0 °C	Compression time:	None	
Cross Compensation:	No	Warnings:	Yes	
Water Vapour Compens:	Yes	Data Edited:	No	DATABASE: 23NOQ4E2
Air Pressure:	715.00 mmHg	Resolution:	100 %	USER PRG: None



C	Location:	Measurement	Line	Scale	Unit	Alarm lim.
1	MUESTRA	TOC ref. Methane	—	1E+00	ppm	0.00E+00 ppm
2	ZONA SUCIA	TOC ref. Methane	---	1E+00	ppm	0.00E+00 ppm
3	PAT.SAL.ENF	TOC ref. Methane		1E+00	ppm	0.00E+00 ppm
4	ZONA CENTR	TOC ref. Methane	--	1E+00	ppm	0.00E+00 ppm
5	SERVICIOS IZ	TOC ref. Methane	---	1E+00	ppm	0.00E+00 ppm
6	PAT.PAS.ENT	TOC ref. Methane	-	1E+00	ppm	0.00E+00 ppm

Fig. 3. Peak of trace vapor detection in the drain flow corresponding to the wash-up room.

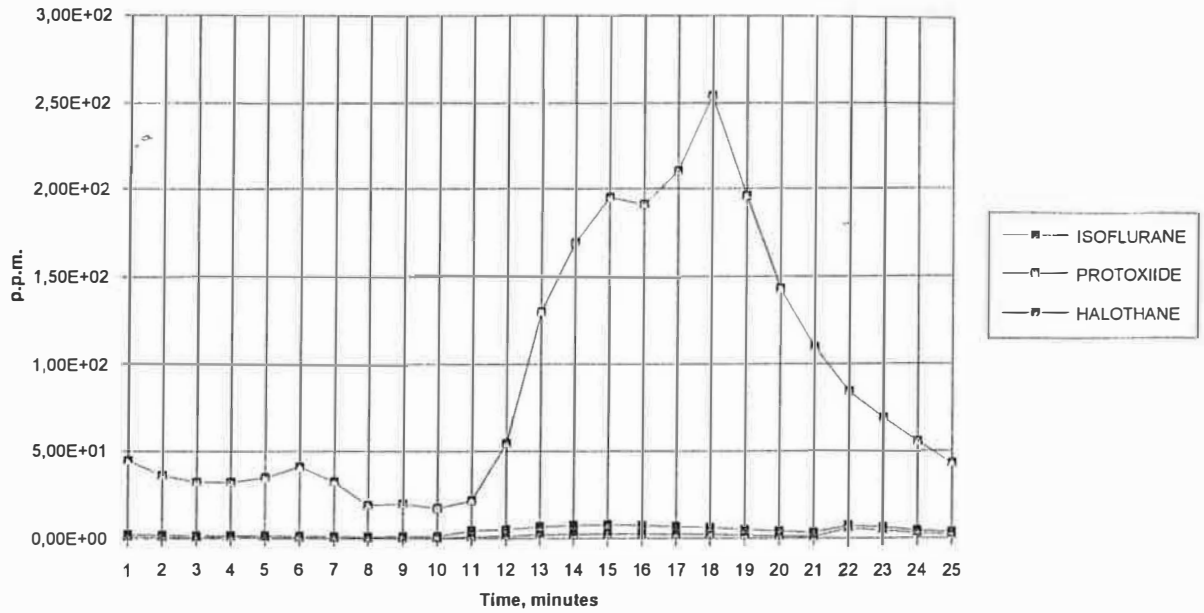


Fig. 4. Evolution of anaesthetic gases during a surgical operation without mechanical gas extraction

provided us with contamination data taken at a stall near the health centre over a period of 6 months with a measurement every 3 h. These data did not present abnormal values with respect to the rest of the city.

3.3.4. Conclusions from ventilation and contaminant measurements

The experimental results on ventilation and contaminant measurements lead to the following conclusions:

(a) The reported PMV is not so far from the comfort range (± 0.5).

(b) Indoor air quality was affected by the state of the installations crossing the area. Furthermore, it can be stated that the indoor air contamination originated in the area surroundings.

(c) The ventilation system needed an urgent revision of filters, cleaning and balance. Training should be given on how to operate it.

(d) Outdoor contamination could not be related to the problems in IAQ, although the external air intake in the functioning of the climitization–ventilation equipment meant this possibility could not be eliminated.

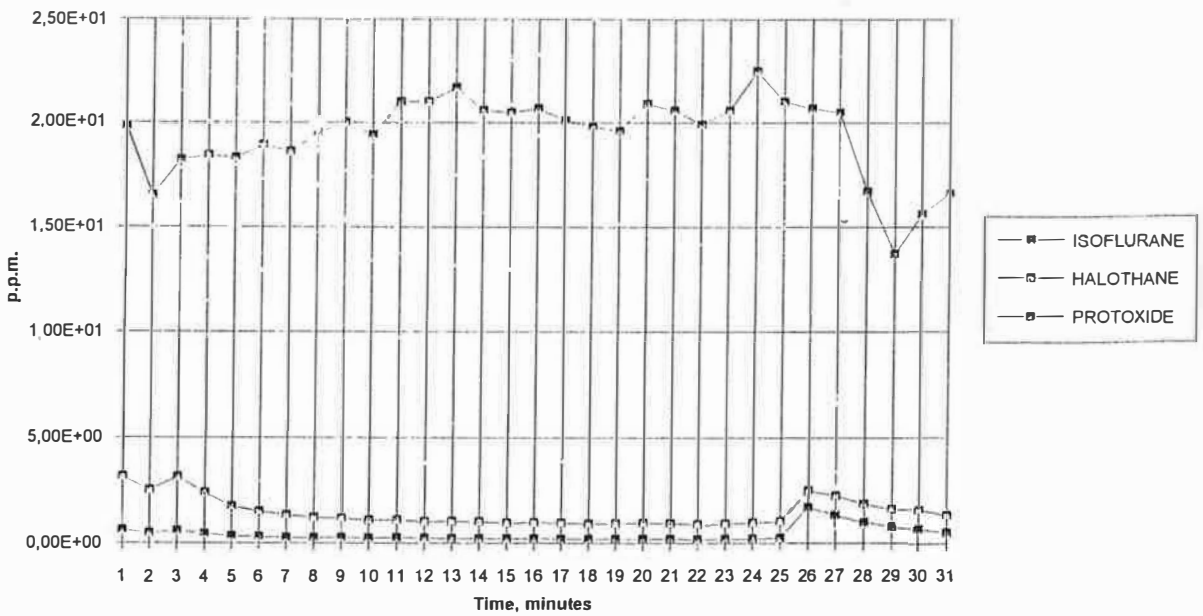


Fig. 5. Evolution of anaesthetic gases during a surgical operation with mechanical gas extraction

(e) The nitrogen protoxide levels present during operations surpassed acceptable limits.

3.4. Actions

3.4.1. Contaminating focus

The focus of contamination detected in the previous phases were of two types: those associated with the activity of the area, such as anaesthesia gases; and those associated with the surroundings of the area, such as effluents of the drainage pipes which surrounded the area.

The first focus is eliminated by using mechanical extractors applied to the patients. Such equipment is connected to the vacuum net. The second focus involves a much more complex intervention, due to the existence of covered registers and small yards which are difficult to control. Nevertheless, revision of the ventilation columns, the sewage boxes, the siphones corresponding to the drainage pipes which crossed the area and of the drainage pipe shunts was proposed.

3.4.2. Climatization–ventilation

Climatization–ventilation was accomplished with the same equipment, using totally outdoor air. The introduction of the following measures was considered necessary: leading the outdoor air intake of the installation, sealing the rooms where the climatizers were located, cutting off all connections with false ceilings and adjacent area, and performing a general cleaning of the rooms studied.

Likewise, the sealing of unused drains and sewers, installing the corresponding siphons, and general cleaning of the inside of the climatizer were advised. Furthermore, substituting filters with an efficiency of at least 95% for the existing ones, repairing the regulator, adding a humidification system, cleaning the conducts and screens, balancing the system, and preparing a protocol for system maintenance were recommended.

As a complement, making the personnel of the area aware of the proper use of the regulators, excludors, windows and of the bad habits which generally worsen the functioning of the installation was proposed. It was considered of the utmost importance to insist on the education of the maintenance personnel for an adequate preventive and predictive labour on the system, which should be included in written form in a series of protocols and also reflected in the maintenance logs.

3.4.3. Sociopsychologic factors

The problem was initially faced by the Maintenance Service itself of the Hospital. This service, without the adequate personnel, equipment or technological capacity to handle the problem, looked for specific, concrete causes. However, this procedure did not lead to the desired results, in fact causing among the workers affected a feeling of defencelessness and distrust against the Hospital Administration.

It must be pointed out that the worker's representatives suggested only the construction of a new health centre as a solution to the problem, and that they were supported in their intransigent position by the communication media.

One more negative factor was that the Health Centre personnel received lower salaries than professionals of equal positions working in other levels of health care and under different administrations. These injustices were aggravated by a high case-load pressure in the case of the operating area personnel.

In short, the situation served to bring to light the personnel's dissatisfaction with aspects not directly connected with the nature of the problem.

3.4.4. Recommendations

This section presents a series of recommendations aimed at those responsible for hospital buildings with problems of indoor environmental quality, oriented towards obtaining low-cost solutions in a short time period with minimal incidence in the centre's activity.

Such problems should be handled by personnel with sufficient capacity to make a global study of the building affected. That is, to study all the factors involved, an interdisciplinary team must exist. The personnel who perform the investigation must possess technical knowledge, have the necessary means available and have sufficient time to perform the most exhaustive study possible. The investigation itself should always include a definite methodology, this being the only way to effect the investigation in the shortest time possible, with the least effort.

The Administration of the building should be the party most interested in solving the problem. If this is not so, the problem tends to become the escape valve of a social conflict, on which all the dissatisfactions of the personnel are manifested.

The maintenance personnel should not be the investigators of the problem, as they may accept attitudes which are in fact reproachable. Neither should they be held as the only parties responsible, because the present lack of quality in an indoor environment is always the sum of lack of quality in previous actions (whether of building design or modifications), of deficiencies in work organization, of a lack in personnel training, and even of the existence of other types of labour problems, etc. The collaboration of the maintenance service with the technicians who study the problem is essential.

The information gathered by the investigation team should be transmitted by their spokesperson (who must be the only one who communicates the results). The spokesperson will make reports to the person designated by the building Administration, who will in turn inform the

worker's representatives as clearly and realistically as possible.

The personnel who suffer the effects of lack of environmental quality should be made aware of the problem and of the importance of their collaboration, neither magnifying the problem or hiding it. Only a realistic attitude to the problem leads to a proper evaluation: the workers should constantly ask the Administration to handle the problem and to inform them of the results as they are obtained, but at the same time they should not interfere.

In summary, it is essential to use scientific methods in evaluating any building-related illness or complaint. Probative data are needed to conclude that there has been a cause and effect relationship between exposure and an illness or complaint, after which appropriate modifications to the environment should be made.

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