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VOC concentrations in healing environments: a protocol for monitoring activities in inpatient wards and its application on some case studies

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Abstract. *Introduction.* IAQ is one the main topic in which governments are focusing. In architectures for health, several researches are reporting a growing number of data analysis and research works in order to improve users' health. Nowadays many studies are related to biological and physical risks otherwise chemical ones are less investigated. It determinates the need of guideline values for hospitals because the current scenario lacks of specific norms. *Methods.* A research group has started a monitoring of IAQ in inpatient rooms, giving rise to a protocol supported by ISO 16000 and international guidelines. The analysis examines VOCs, and the influence of thermos-hygrometric, ventilation and concentration of pollutants' conditions. *Results.* The application of the protocol on some inpatient rooms permitted to verify the monitoring feasibility. Each investigation (12 weeks per year) considered all the activities, users and processes that affect IAQ, as well as room configuration. Although data analysis reports quite adequate values, several design and management activities affect the performances and VOC values, especially related to Benzene, Carbon Dioxide, and Formaldehyde. *Conclusion.* The analysis is expanding to several hospitals. Although the main goal is to reduce the concentration levels, the aim is to define limit values for VOCs, for guaranteeing healthy healing spaces.

1. Introduction

In recent years, Indoor Air Quality (IAQ) becomes a primary issue that needs more and more to focus because of the increasing of exposed population due to lifestyles and the permanence in confined environments (about 90% of the day). Even European Community (EU) underlines the priority of energy efficiency strategies, in the same time it recommends to reach healthier indoor environments and the development of a specific European strategy on IAQ. Currently several EU countries have introduced in their legislations some actions relating to IAQ; in Italy, there is not any specific reference about this topic [1]. The research analyses the Scientific Literature, World Health Organization (WHO) guidelines, also ISO, CEN and UNI standards, norms and European guidelines and other standard values, such as guideline or reference values regarding outdoor and indoor air.

Since several years, critical factors due to the exposure to indoor air pollutants have been a matter of concern for EU legislators, and an increasing number of states has been addressing policies regarding health promotion strategies. EU has often highlighted the importance to investigate IAQ, the relative impacts on health status and recommendations regarding actions and monitoring activities.

Although the current criticisms, in several countries air quality monitoring are carried out in specific professional workplaces in which chemicals are used, but also in some generic indoor spaces.

Starting from the definition that health promotion is also due to environmental factors, the medical activities that are carried out, the design features, the finishing materials and furniture, the maintenance and management activities, etc., the research work has the aim to provide an analysis on the State of the Art of IAQ in healing environments, in particular related to chemical pollution,

verifying all the factors that affect the air quality and, supported by an investigation on the current state of inpatient ward, giving rise a protocol for healthy inpatient rooms, through the support of Italian Institute of Health (Istituto Superiore di Sanità - ISS).
Hospitals are supposed to preserve Public Health, but they are also highly energy-demanding and socially impact on communities and they can determinate negative effects on quality of health of users and performances of environments [2]. Healthcare facilities are able to deal with the definition of "health" as the complete well-being and which can fit to the future means constructing sustainable structures. These ones work as a whole, which can be productive only if all its components are healthy. Therefore, regarding healthcare facilities, sustainability must be analysed as the major requirement because it must ensure high standards [3-4].
Although there are many evaluation systems that assess building's performance and sustainability, among the criteria the evaluation of IAQ is postponed to the regulations into punctual areas [5].
The purpose of the protocol is to determine the levels of indoor concentrations of specific and selected chemical pollutants and the physical parameters responsible for thermo-hygrometric comfort in inpatient wards that are not normed by legislative regulations. These healing environments must ensure an adequate IAQ with particular attention due to the presence of vulnerable users with precarious health status. In the same time, the purpose of the monitoring activity is also to safeguard healthcare professionals who are subject to a longer period of time (years) to these substances.

2. Methodology

Starting from a literature review on the state of the art of chemical pollution in inpatient wards [6], the current knowledge and experiences in chemical pollution monitoring in healthcare facilities, the research aims to investigate the inpatient rooms for understanding the knowledge related to chemical pollution and for highlighting possible health risks in hospital settings.
The research team investigates inpatient rooms analysing VOCs, and the relative influence of thermo-hygrometric, ventilation and concentration of pollutants' parameters, for giving rise to new strategies on the design and management of inpatient room for healthier hospital settings. In fact, as ISS highlights, supported by the scientific literature and norms, it is of primary importance to investigate selected VOCs for defining guideline values on concentration levels.
The selection of operative strategies (pollutants' type, detection and analytical methodologies, instrumentation, etc.) has been made with some expertise on the field, considering the specific indoor air standards ISO 16000 and the guidelines (ISTISAN Reports by ISS) drawn up by the National Study Group on Indoor Air of ISS.
In order to define the monitoring activity and identify the appropriate monitoring and analysis techniques, the scope of the monitoring activity, the pollutants to be analysed and the duration of monitoring activity have been defined. In addition, it is necessary to introduce a microclimatic control unit for measuring the following parameters: temperature, relative humidity and air velocity, CO and CO_2 too. In addition, for understanding the indoor pollution values, it must also be provided with an outdoor location that is closer to the room analysed, taking into account the façade and fixing points available for the positioning of passive samplers.
Among the VOCs, *Acetaldehyde, Acetone, Benzene, Chloroform, Dichloromethane, Ethylbenzene, Formaldehyde, m,p,o, Xylene Styrene, Tetrachlorethylene* and *Trichlorethylene* concentrations are investigated because they are considered the most dangerous air pollutants; moreover they can be influenced by the features of hospitals and they can be emitted from building materials and furniture.
Inpatient wards are investigated in the monitoring activity. The choice of the functional unit and hospital rooms is defined by both punctual features to be investigated (solar exposure, room configuration, etc.) and their availability. In fact, in order to start the investigation, the positioning of samplers should take place in an empty room after cleaning activities (when it is possible).
In addition, the design features of inpatient rooms have not always been the most suitable for the positioning of sampling instrument as stated by ISO 16000 and ISTISAN Reports. For this reason, sampling strategy needs to be adapted to each case study.
As already well-known, chemical pollution of indoor air affects the quality of spaces, and the need of portable, rapid, high-sensitivity instruments and techniques to evaluate indoor exposure to VOCs is

becoming increasingly. According to the prescriptions, it is required that the positioning is carried out when the room is empty and already sanitized, at a distance between 1 and 2 m from the wall and at a height of about 1.2 m from the floor (breathing zone for patients), taking account naturally also of the activities that must perform by the medical staff.
In order to identify the contribution to indoor VOC concentrations, it is considered appropriate to compare them with the corresponding external concentrations near the environmental unit, taking into account the façade and the fixing points available for the positioning of the samplers.
For investigations of IAQ within healing environments it is required a strong cooperation with the medical director and responsible for hospital safety, with which have inspections and identify inpatient rooms for the detecting campaign.
In addition, to taking note daily of all the events, the charge nurse of the hospital ward investigated has to fill in an activity log day-to-day of the inpatient room, such as specific features and cleaning of the room, specific treatments to which patients were subjects, presence of visitors, etc. [7-8]. It is requested that the charge nurse fills in an activity log [8].
The protocol defines that the investigation is carried out during a year, divided into summer and winter sessions. The duration of each sampling is 7 days. It allows to evaluate a long period of time and take into account possible changes due to health activities, seasonal microclimate, the variability of natural/mechanical ventilation system, etc.
The purpose of the investigation is to define the annual value of concentrations. For an ease access and use of instrumentation, as well as for safety and economic reasons to avoid the risk of theft of instrumentation (staying for a week in a hospital), the research group opts for passive samplers (Radiello®). Although it is well-known that active sampling method provides similar analytical performance, without requiring the determination of VOCs' uptake rates.
As very low concentrations are expected, VOCs are pre-concentrated on solid sorbents. Enrichment is carried out using tubes containing three different carbon-based sorbents, arranged from weak to strong sorption strength, because target VOCs range from low volatility to high volatility. Multi-sorbent tubes show better adsorption performance than tubes containing one absorbent for vVOCs
The data processing is carried out by ISS. The samples should be processed with the survey log, filled out by a survey's detector. The samples, after extraction with solvent, are subjected to the GC-MS and HPLC analysis [8].
In conclusion, for carrying out the analysis, it is necessary to collect all relevant information concerning the hospitals, the activities inside the room analysed, as well as specific information about instrumentation adopted for the sampling.
For the evaluations to be carried out, it is essential to obtain several information about the healthcare facility and its healthcare processes. Information about its evolution are useful references to better understand construction materials, as well as technical data sheets and supplies, safety data sheets, etc., easy accessible for recent built interventions. In particular, for each structure the following data are required plans and section drawings of the functional area, technical data of mechanical equipment within the room, the finishing materials and furniture of the room, chemical risk assessment, prepared by the security manager, products used for cleaning and disinfecting, with their technical data sheets.

3. Results and Application

For the reliability and validation of the protocol, it has been tested on some case studies, in particular on three inpatient rooms in some hospitals in Lombardy (Italy) [7]:

- the inpatient room of Hospital 1 (H1) is a single room (20 m^2), located at the first floor and endowed with mechanical forced ventilation system; the finishing materials are made in polyvinyl chloride (PVC), and windows with aluminium frames and double glazing; the general furniture are made of solid wood, steel and PVC, or eco-leather;
- the room of Hospital 2 (H2) is a double room (17 m^2), located at the first floor and devoid of forced mechanical ventilation systems, for which the air exchange takes place through window opening several times a day (about 15 minutes per window opening); the room has a radiator, located under the window; the window frames are wooden, while standard furnishings are

made of laminate and steel. The technical data sheets report that in October 2015 the walls have been painted with a photocatalytic water-based paint and new floor in PVC with a product suitable for high humidity places such as cheese factories and food industries;

- the room of Hospital 3 (H3) is a double room (24 m^2), located at the first floor (threefold body), with a bathroom; the room has a mechanical forced ventilation system, floors and walls have homogeneous vinyl wall covering and windows with steel frames and highly performing glasses. The inpatient ward was inaugurated one year before the monitoring activity.

Table 1. The values obtained by the monitoring in H1, H2 and H3 [7].

CRITERIA	Unit of Measurement	INDOOR / OUTDOOR	GUIDELINE VALUES		HOSPITAL 1					HOSPITAL 2					HOSPITAL 3				
					INVESTIGATION					INVESTIGATION					INVESTIGATION				
			Value	Reference	MEAN WINTER	MEAN SUMMER	MEAN	MEDIAN	MODE	MEAN WINTER	MEAN SUMMER	MEAN	MEDIAN	MODE	MEAN WINTER	MEAN SUMMER	MEAN	MEDIAN	MODE
temperature	°C	INDOOR	21°C - 24°C	ASHRAE 170 (2008)	23,7	25,3	24,5	24,7	23,1	25,0	25,8	25,4	25,8	25,9	24,0	24,9	24,5	24,4	24,4
relative umidity	%	INDOOR	40 - 60%	ASHRAE 170 (2008)	42,3	47,5	45	48	48	36,3	39,5	38	38	38	51,7	47,0	49	50	56
Benzene	μg/m^3	OUTDOOR	5 μg/m3 (year)	European Directive 2008/50/EC (2008)	2,5	2,4	2,5	2,6	2,6	3,5	2,2	2,8	2,1	2,1	0,6	0,7	0,7	0,5	0,4
	μg/m^3	INDOOR	5 μg/m3 (year) from 2013 2 mg/m3 (year) from 2018 2 mg/m3 (life time)	ANSES (2011) ANSES (2011) WHO (2010)	2,6	2,8	2,7	2,7	2,1	4,5	2,3	3,4	3,3	3,3	0,6	0,8	0,7	0,6	0,5
Acetaldehyde	μg/m^3	OUTDOOR			2,6	3,4	3,0	3,1	0,8	4,4	3,3	3,9	3,0	2,3	2,4	2,5	2,5	2,1	2,1
	μg/m^3	INDOOR	160 μg/m3 (year)	ANSES (2011)	4,4	10,5	7,4	5,5	5,6	11,8	12,3	12,0	12,5	4,8	3,5	3,9	3,7	3,2	3,0
Formaldehyde	μg/m^3	OUTDOOR			4,7	8,0	6,3	7,5	2,8	5,9	6,1	6,0	7,3	7,9	7,0	6,7	6,9	7,2	7,3
	μg/m^3	INDOOR	100 μg/m3 (30 min) 30 μg/m3 (year) from 2018 10 μg/m3 (year) from 2023	WHO (2000) and WHO (2010) ANSES (2011) ANSES (2011)	5,1	12,4	8,7	8,2	7,9	9,6	10,7	10,2	10,0	8,5	8,7	8,1	8,4	8,0	7,9
Styrene	μg/m^3	OUTDOOR			< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	0,2	0,4	0,3	0,1	< 0,01	0,6	0,3	0,5	0,5	0,5
	μg/m^3	INDOOR	260 μg/m3 (week)	WHO (2000)	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	0,4	0,5	0,5	0,4	< 0,01	0,7	0,4	0,5	0,6	0,6
Acetone	μg/m^3	OUTDOOR			4,0	3,7	3,9	3,8	3,0	4,2	4,2	4,2	4,0	4,7	2,7	2,3	2,5	2,8	3,2
	μg/m^3	INDOOR	11,88 μg/m^3 (24h)	ONTARIO MOE (2012)	3,7	5,9	4,8	5,3	5,5	5,9	8,3	7,1	6,7	5,9	13,5	8,6	11,0	10,6	12,0
Xylene m,p,o	μg/m^3	OUTDOOR			4,7	1,4	3,0	1,9	1,1	5,1	3,0	4,0	3,5	3,6	1,3	1,4	1,4	1,4	1,4
	μg/m^3	INDOOR	870 μg/m3 (year)	IPCS – WHO (1997)	4,1	1,4	2,7	1,7	1,3	5,4	2,9	4,1	4,1	3,9	2,5	1,5	2,0	2,1	2,1
Ethylbenzene	μg/m^3	OUTDOOR			1,5	1,5	1,5	1,3	2,5	3,1	1,9	2,5	2,0	1,4	0,8	0,7	0,8	0,7	1,1
	μg/m^3	INDOOR	220 μg/m3 (year)	IPCS – WHO (1997)	1,8	1,4	1,6	1,6	2,4	1,4	1,2	1,3	1,2	1,0	0,9	0,7	0,8	0,8	1,2
Chloroform (trichloromethane)	μg/m^3	OUTDOOR			< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
	μg/m^3	INDOOR	10 μg/m3 (year)	CIDAD-WHO (2004)	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
Tetrachloroethylene	μg/m^3	OUTDOOR			2,7	5,3	4,0	4,7	< 0,01	1,3	4,8	3,1	3,5	< 0,01	1,7	1,7	1,7	1,7	2,3
	μg/m^3	INDOOR	250 μg/m3 (year)	WHO (2010)	3,5	10,7	7,1	7,5	7,0	2,6	8,6	5,6	4,4	< 0,01	2,4	2,6	2,5	2,8	2,8
Trichloroethylene	μg/m^3	OUTDOOR			2,3	1,0	1,6	1,6	1,8	5,0	2,1	3,5	2,8	5,3	1,4	0,8	1,1	0,8	1,9
	μg/m^3	INDOOR	800 μg/m3 (year)	ANSES (2011)	2,3	1,0	1,7	1,4	1,4	2,4	2,2	2,3	2,4	3,2	2,1	1,0	1,6	0,9	2,8
Dichloromethane	μg/m^3	OUTDOOR			3,4	2,4	2,9	2,3	2,1	4,7	3,1	3,9	3,5	0,6	1,4	0,7	1,0	0,6	0,6
	μg/m^3	INDOOR	450 μg/m3	WHO (2000)	4,1	3,5	3,8	3,0	5,3	3,8	3,5	3,6	3,0	0,8	3,1	1,0	2,1	0,9	0,7
Toluene	μg/m^3	OUTDOOR			11,5	21,2	16,4	17,5	7,7	25,7	24,0	24,8	27,0	27,0	37,8	29,3	33,6	36,0	36,0
	μg/m^3	INDOOR	260 μg/m3 (week)	WHO (2000)	16,8	37,3	27,0	26,0	19,0	34,0	50,0	42,0	42,5	41,0	57,3	47,7	52,5	48,0	48,0
Carbon monoxide	mg/m^3	INDOOR	7 mg/m3 (24 h)	WHO (2010)	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2
Carbon dioxide	ppm	INDOOR	1000 ppm (week)	Reports ISTISAN 16/15 (2016)	1114	1198	1156	1165	1222	788	1040	914	1000	1000	990	937	963	987	1016

Legend
above the guideline value up to 20%
above the guideline value, > 20 %

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The analysis of each case studies was conducted for 1 year. For each pollutant, several analysis have been developed for analysing the trends during the year, the relationship with temperature and relative humidity, etc. and the correlation of events and medical activities during the weeks.
In general, as Table 1 shows, all the values are guaranteed. Data analysis highlights that Benzene, Formaldehyde and Carbon Dioxide values are not adequate for users' health.

3.1. Benzene
In general, the values do not respond to the guideline values. Only H3 presents acceptable values during all the sampling activity; on the contrary, H1, although its mode value is quite acceptable, the mean exceeds the guideline value. H2 shows the higher values for indoor with peaks of about 6 $\mu g/m^3$. The outdoor values respond to the limit, normed by Directive 2008/50/EC.
The indoor levels of benzene have concentrations that do not differ significantly among the inpatient wards of H1 and H2 considered, with mean values between 2,5 and 3,4 $\mu g/m^3$, instead of H3 of a mean equal to 0,7 $\mu g/m^3$. From the analysis, H1 and H2 show two different trends: in the first, Benzene concentrations are higher in summer season (average 2,8 $\mu g/m^3$, compared to the winter one with an average of 2,5 $\mu g/m^3$) - confirmed also by H3 data, while in the second in winter season (average of 4,5 $\mu g/m^3$, compared to the summer one, around 2,3 $\mu g/m^3$).
The difference is strictly related to the activation of the ventilation systems - only several month later - that have been fully operational at the end of winter season and all of the summer one, which causes the window opening several times a day, in proximity of vehicular traffic.
In conclusion, the differences are related principally to: urban contexts in which the hospital is localized (the neighborhood of H2 greatly affects the indoor air); efficiency of ventilation systems that permits regular air exchange in the room; solar exposure that affects the temperature and, therefore the emission of materials; contributions of detergents and cleaning products for detergents and cleaning; possible inadequate behavior by users related to smoking.

3.2. Formaldehyde
The mean values respond totally to the guideline values by WHO (2000 and 2010) and *Agence Nationale de Sécurité Sanitaire de l'Alimentation, de l'Environnement et du Travail* (ANSES), referring to annual value of 30 $\mu g/m^3$. On the contrary, regarding the annual value of 10 $\mu g/m^3$ (ANSES for 2022), there are three different results related to the hospitals: H1 – its mean value respects the guideline value (8 $\mu g/m^3$), but during summer season the values are very higher; H2 – its mean value exceeds the guidelines; H3 - its mean value and all the investigation values are lower than the guideline ones.
Starting from the data analysis, the investigation highlighted that:

- H1, in which the room lacks of window opening, indoor (8 $\mu g/m^3$) and outdoor (5,8 $\mu g/m^3$) concentrations of formaldehyde demonstrates the presence of internal sources and a not totally sufficient air change with ventilation system. The higher values are related to summer season, and probably to solar exposure and high temperatures (the mean value during summer season is equal to 25,3 °C) affected the performances of furniture and finishing materials;
- H2, that missed in the first months of the ventilation systems, the high indoor values of 10,2 $\mu g/m^3$ compared to the outdoor air, 6 $\mu g/m^3$, indicates both the presence of outdoor and indoor pollutant sources. In particular the last are strongly related to the emissions of furniture and finishing, laid in the room some weeks before the inpatient ward re-opening;
- H3 presents the same conditions of H2; although the facilities was completed one year before the sampling activity, the not regular window opening determines emissions, even if reduced, of finishing materials during the time with constant values during the entire sampling.

Therefore, the main factors that affect the air performances are related to: solar exposure and high temperatures related to finishing materials, without windows opening (as H1 demonstrated); emission of finishing materials and furniture; high concentrations, without an enough dilution, of detergents for extraordinary cleaning activity.

3.3. Carbon Dioxide

The values do not respond totally to the guideline values for week value, on the contrary the annual one is respected by two case studies. For each case studies there are several observations: H1 recorded the worst values, exceeding the reference value; H2 presents the lowest values of the investigation, more than 50% of samplings are lower (or equal) than 1000 ppm, and those that overcome the limit exceed of more than 100 ppm; H3 presents lower values: more than 50% of samplings are lower than 1000 ppm, and those that overcome it are very close the guideline values.
The main factors that affect the presence of Carbon Dioxide are related to vehicular traffic (related to outdoor air), the lack of window openings (for air changing), and, mainly, by human occupancy.

4. Conclusions

Although many pollutants investigated respect guideline and/or reference values, the present results have shown that there are significant sources of VOCs in the inpatient room recently renovated: for example, the concentrations of formaldehyde and acetaldehyde are, on average, twice as much as those measured in outdoor environments. This demonstrates how even nowadays the absence of any specific legislations on IAQ issues and suggestions on design and management strategies can weaken management controls and decision-making.
Starting from the analysis, and although the values are adequate for existing international references, many implementations can be done for reaching healthier environments for public health.
The data collected permit to analyze VOC concentrations. Although the data respect the guidelines values, new frontiers should suggest to reduce more and more their presence in hospital settings. In general, the air monitoring demonstrate that a deepen knowledge on IAQ issue can be strategic in order to continuous improvement of indoor environmental quality. For managers and hospital planners, it is essential to pay attention to the design approach, the choice of specific materials, the periodic maintenance of AHUs and post maintenance assessment, the choice of cleaning and disinfection products compatible with finishing materials and adequate operational, etc.
The application of the protocol permitted to highlight some criticisms, deficiencies and implementations to be integrated in the application: simpler activity logs for hospital staff, and useful dimension for being integrated with patients' medical records; warning close to the samplers, for avoiding mistakes during the weekly monitoring; register meteorological factors, for supporting the data analysis; more collaboration with the medical director for guaranteeing regular monitoring activities and collaboration with hospital staff; more collaboration with hospital staff and users; more scheduled monitoring program and consistency of investigation requirements, with regular monitoring activity (i.e. every first week of the month); obtaining all the information about the project and management. It can be a useful tool for a wide application and analysis of critical issues in inpatient rooms' design, also for a broad analysis that permits to compare the data analysis.

References

[1] Settimo G 2017 Existing Indoor Air Quality in healthcare facilities (New York Springer Public Health) 13-26
[2] Buffoli M, Gola M, Rostagno M, Capolongo S and Nachiero D. 2014 *Ann Ig.* **26(5)** 418-25
[3] Bottero MC, Buffoli M, Capolongo S, Cavagliato E, di Noia M, Gola M, et al. 2015 Improving Sustainability During Hospital Design and Operation: A Multidisciplinary Evaluation Tool (Cham Springer) 31-114
[4] Buffoli M, Capolongo S, di Noia M, Gherardi G and Gola M 2015 Improving Sustainability During Hospital Design and Operation: A Multidisciplinary Evaluation Tool (Cham Springer) 23-30
[5] Brambilla A, Rebecchi A and Capolongo S 2019 *Ann Ig.* **31** 165-180
[6] Gola M, Settimo G and Capolongo S 2019 *Journal of Healthcare Engineering* 8358306
[7] Gola M, Settimo G and Capolongo S 2019 *Facilities* (in press)
[8] Settimo G, Gola M, Mannoni V, De Felice M, Padula G, Mele A, Tolino B and Capolongo S 2017 Indoor Air Quality in healthcare facilities (New York Springer Public Health) 107-118