IAQ in office buildings located in the north and in the south of Italy

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ABSTRACT
An investigation method based on the HACCP system was applied to eleven representative office buildings with HVAC system located in different latitudes in Italy, to evaluate the microbiological quality of the air supplied. Bacterial and fungal levels near supply air diffusers pointed out medium-low contamination and analysis of data showed a higher microbial load in the buildings located in the South of Italy with respect to those in the North.

IAQ of five buildings was examined in more detail. Air samples demonstrated an overall good microbial removal efficiency of the examined HVAC system. Water from the humidification unit was assessed for pathogens and bacterial contamination. Microclimatic parameters showed an overall condition of comfort, but CO_2 concentration at times reached fairly high values. VOCs concentration was higher indoors than outdoors. The application of HACCP system highlighted some critical situations giving the possibility of preventing the occurrence of deleterious health effects.

INDEX TERMS
HACCP system; HVAC system; Airborne bacteria; Airborne fungi; Health effect

INTRODUCTION
Indoor air quality is becoming an increasingly important issue for occupational and public health (Clarke and Nikkel, 1995). Over recent decades, there have been many changes in the way buildings are constructed and operated. To some extent, modifications in building design have been driven by the need for increased energy efficiency (Jones, 1998). Modern houses and offices are much better insulated than in the past. Improved insulation has been accompanied by several other changes to the management of indoor environment, and progress in construction technology has led to a greater use of synthetic building materials (D'Amato *et al*., 1994), modern office equipment (e.g. photocopiers, laser printers, computers), cleaning products and the introduction of HVAC systems (Heating Ventilation and Air Conditioning) (Nathanson, 1995). Moreover, outdoor air pollution can also contribute to indoor air contamination (Clarke and Nikkel, 1995). The changes mentioned above have undoubtedly made buildings more comfortable. However, they have also provided an environment in which airborne contaminants are readily produced and may build up to concentrations considerably higher than those typically encountered outside (Teichman, 1995).

The HVAC system modifies air quality and can affect indoor micro-organisms' concentration (Parat *et al*., 1997) by means of its different components (filters, humidifiers, cooling and warming systems). A massive proliferation of micro-organisms may take place in a HVAC unit in the presence of certain risk factors such as low-efficiency filters, cold mist humidifiers using water recycling, areas in which condensed water remains stagnant, large recirculation of air and faulty or deficient maintenance conditions (Reynolds *et al*., 1990).

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In addition, the ageing population, the increasing number of sensitive individuals and a tendency to spend more time indoors (90% of their time) further worsen the deleterious health effects related to microbiological indoor air quality (Seltzer, 1995).

Currently, the problem of microbiological indoor air quality is dealt with using a retrospective approach. The purpose of this study is to apply a preventive approach to indoor air quality control of eleven office buildings using an investigation protocol based on the application of the HACCP (Hazard Analysis Critical Control Point) system.

METHODS

Theoretical approach

A preventive approach to microbiological indoor air quality control was applied as an alternative to the retrospective investigation methods currently used. Based on this approach, an investigation protocol for the evaluation of microbiological risks related to the indoor environment was developed using the HACCP system. This is a useful method for risk evaluation and control commonly applied in the field of food production control.

This investigation protocol was designed using a sequence of steps. The first step is Hazard Analysis with the identification of the Critical Points (CPs) in the investigated buildings. This step is based on an on-site visit using a check-list to evaluate the presence of bioaerosol sources and on occupant interviews by means of a questionnaire, in order to determine possible complaints or problems in the investigated buildings. The second step is the determination of Critical Control Points (CCPs). CCPs are chosen among Critical Points (CPs) and they represent the minimal number of points where a microbiological control should be done.

In the following steps, for each CCP, microbiological parameters, analytical methods and critical limits have to be established. Finally, corrective actions, that are measures to be undertaken if critical limits have been overcome, are decided. The protocol was applied to the evaluation of indoor air quality in office buildings.

Sampling site

The air sampling was carried out in 11 office buildings with HVAC systems, located in urban or suburban zones in five cities in the North and in the South of Italy. For each building one or more Air Treatment Units (ATUs) were investigated (Table 1), according to the extension and position of the covered area in the building and the age of the plants. For each ATU three or four offices were monitored.

Table 1 Description of the office buildings and ATUs investigate

	City	Building[a]	ATU[b]	Room type
North	Turin	A	1	Office
		B	4	3 Offices /1 Classroom /1 Canteen
		C	4	2 Offices /1 Kitchen /1 Canteen
	Milan	D	5	2 Offices /2 Classrooms/1 Bar
		E	3	2 Offices/1 Canteen
South				
	Rome	F	6	3 Offices/ 2 Classrooms/1 Canteen
		G	7	4 Offices /2 Classrooms/ 1 Canteen
	Naples	H	2	2 Offices
		I	1	1 Offices
	Palermo	L	2	2 Offices
		M	1	1 Offices

[a]Letters refer to the different buildings examined in the city.
[b]Number of ATUs examined for each building.

Microbiological and chemical analysis

In all buildings investigated, airborne bacteria and fungi were collected near supply air diffusers using an impactor sampler at a volume rate of 200 and 400 L, respectively for fungal and bacterial counts. Bacteria were grown on Trypticase Soy Agar (TSA) supplemented with cycloheximide; Rose Bengala agar supplemented with chloramfenicol was used for fungal load evaluation. Samples were incubated 24–48 h at 37°C and 48–72 h at 22 °C for bacterial counts and 4–8 days at 24°C for fungal enumeration.

Five buildings were examined in more detail (A in Turin, H and I in Naples, L and M in Palermo) by collecting samples also at the breathing zone level (at 1.5 m from the floor, at the workstation level) and fan-coil air flow to evaluate bacterial and fungal air contamination. At the same time outdoor air samples were analysed for bacterial and fungal concentrations. Each air sample was collected and analysed in triplicate.

Besides microbiological samples, some chemical and physical parameters were also measured. Microclimatic parameters (temperature, relative humidity, air flow and comfort indices) were recorded using a mobile environmental monitoring station equipped with a number of probes, according to ISO 7726 (ISO 7726, 1998): globe thermometer, psychrometer (with forced ventilation), hot wire anemometer and CO_2 probe. VOCs samples were collected by pumping the air through a sampling tube containing Carbotrap at a flow rate of 300 mL/min for the entire working day (8 h). The samples, after solvent desorption with CS_2, were analysed by gas chromatography coupled with mass spectrometry. $PM_{2.5}$ concentration was measured (one sample for each ATU) according to EPA protocols (US-EPA 1997) using inertial impactor environmental monitoring (24 h at a flow rate 1 m^3/h).

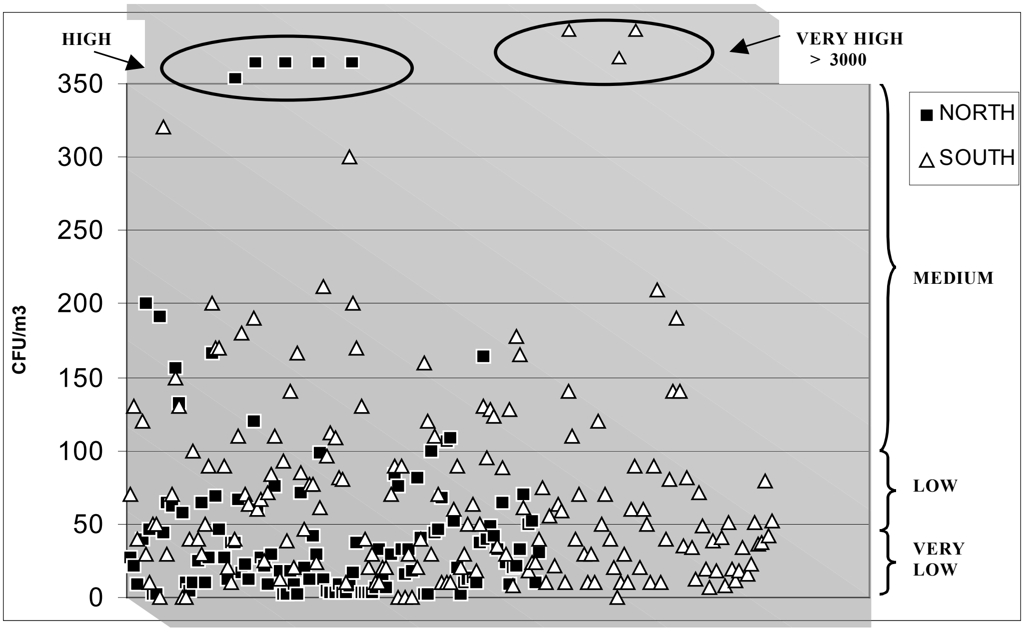
Tap water, collected in the air humidification unit of the ATUs, was analysed for *Legionella* spp. (ISO 11731, 1998), *Pseudomonas aeruginosa* (prEN 12780, 1999) and total bacterial load (22°C and 37°C) (EN ISO 6222, 1999).

RESULTS

Air microbial contamination levels near supply air diffusers were generally medium–low in all buildings examined. Figure 1 shows the level of airborne bacteria and fungi in the investigated buildings. The buildings in the North of Italy show bacterial and fungal concentrations distributed in a very low contamination range (0–50 CFU m^{-3}) (Commission of European Communities, 1993); in contrast, microbial indoor air concentrations of the office buildings located in the South were in the medium–low range (50–500 CFU m^{-3}). Also, among the highest contamination values measured, higher values were found in the South (fungal concentration > 3000 CFU m^{-3} in two offices of the building H and bacterial concentration of 1472 CFU m^{-3} in one office of the same building) than in the North (fungal concentration of 560 CFU m^{-3} in two offices of building E and bacterial concentration of 560 CFU m^{-3} in two offices of the same building).

The IAQ of five buildings was examined in more detail. ATUs removal efficiency was calculated comparing the bacterial and fungal load of outdoor air collected at the intake points with the indoor air at the first and last ventilation shafts. Microbial concentration was found to be lower indoors than outdoors, showing a microbiological removal efficiency of the ATU ranging from 12% to 99%.

Figure 1 Airborne bacterial and fungal concentrations (CFU·m^{-3}) in the office buildings in the North and in the South of Italy.



All the five buildings examined (L and M in Palermo, H and I in Naples and A in Turin) showed low or very low levels for indoor fungal contamination, but medium–low levels of bacterial concentration were found in the same buildings. Only two anomalous offices were found, in Naples, with high values of fungal and bacterial concentrations monitored both in indoor air and at the air diffusers and fan-coil . In order to discover the reasons for this situation, additional analysis should be done. Generally, no significant differences were found for airborne microbial contamination of supply air diffusers, indoor air (breathing zone) and fan-coils.

Microclimatic parameters measured in indoor air and comfort indices (Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD)) showed the overall condition of microclimatic comfort in buildings H and I (Naples). A cold discomfort condition was recorded in building A (Turin) and in several offices of the buildings L and M (Palermo).

In this study we also evaluated CO_2 levels in indoor air office buildings, since this parameter can, under certain conditions, provide a good indication of the ventilation rate. In all buildings CO_2 concentration was around 1000 µg m^{-3} (that is, the limit value for determining the adequacy of outdoor air supply) (Nathanson, 1995) with the highest levels of 956 µg m^{-3} in building L (Palermo), 944 µg m^{-3} in building H (Naples) and 606 µg m^{-3} in building A (Turin).

VOCs analysis showed indoor levels to be higher than outdoor levels in all buildings investigated. Such results are consistent with those reported by other authors (Nathanson, 1995), since all the buildings contain a large variety of chemical sources (e.g. plastics, cigarette smoke, cleaning compounds). The VOCs concentration in Palermo ranged from 112 to 354 µg m^{-3} in building L and from 271 to 445 µg m^{-3} in building M. In Naples the VOCs values ranged from 248 to 594 µg m^{-3} in building H and from 140 to 455 µg m^{-3} in building I. The main compounds identified included 2-butanone, 4-methyl-2-pentanone, Styrene, methylcyclopentane, Limonene and BTX.

In all buildings examined the indoor air concentrations of $PM_{2.5}$ were lower than outdoor ones, with values between 15 and 27 μg m^{-3}, according to other analogous investigations (Jones, 1999).

The microbial analyses performed on the humidification water of the ATUs in the buildings, revealed a total bacterial load ranging from 14×10^2 to 58×10^4 CFU/mL for bacteria at 22°C and from 5×10^2 to 93×10^3 CFU/mL for bacteria at 37°C. *Legionella* spp. was found in building H in Naples at levels of 300 UFC/L, but *pneumophyla* species was excluded.

Another important contamination was pointed out in building L in Palermo, where *Pseudomonas aeruginosa* was determined at a concentration of 100 CFU/100 mL.

DISCUSSION

- As far as microbial air contamination levels are concerned, all buildings investigated (n = 11) did not show any particular condition of risk for the health of the occupants.
- Dealing with the five buildings investigated in more detail, the analysis of the data referred to building L located in Palermo highlighted the presence of *Pseudomonas aeruginosa* in the humidification water tank (100 CFU/100 mL).This micro-organism is an opportunistic pathogen causing infections and pneumonia in immunocompromised patients and in old people. The contamination of the humidification water unit could cause a serious risk for the occupant's health, since *P. aeruginosa* could be aerosolized and released in indoor air. HVAC are often cited as *P. aeruginosa* amplification and spreading sites (Stetzenbach, 1997). The finding of a high bacterial load and *P. aeruginosa* contamination pointed out the inadequacy of the cleaning operations and the need to improve the maintenance of this section of the ATU.
- Analysis of the results obtained for buildings L and M located in Palermo did not reveal any critical levels of VOCs, $PM_{2.5}$, CO_2 and microbial contamination (breathing zones, fan-coils and supply air diffusers) in indoor air. Microclimatic parameters measured in indoor air and comfort indices showed a cold discomfort condition in several offices, which is typical of HVAC systems heating of air based on the use of fan-coils.
- In building H in Naples *Legionella* spp. was found (*pneumophyla* species excluded) in the humidification water of one ATU. The finding of *Legionella* spp. other than *pneumophyla* underlines the presence of environmental conditions suitable for *Legionella* genus growth and, therefore, the potential risk for *Legionella* contamination in indoor air. In fact, it is thought that *Legionella* transmission occurs via the inhalation of aerosols and a common denominator in most outbreaks is a source of contaminated water inside or around the building (Jones 1999).
- Buildings H and I in Naples did not show any significant concern about chemical–physical parameters. Instead a critical bacterial and fungal indoor air contamination was pointed out in building H.
- In building A in Turin both microbial and chemical–physical parameters did not reveal specific problems, except for an overall cold discomfort condition. Moreover a CO_2 concentration in this office building lower than those encountered in the buildings located in the South of Italy underlines a good ventilation rate.
- Finally, all the ATUs investigated demonstrate an overall good microbial removal efficiency.

CONCLUSION AND IMPLICATIONS

The preventive approach used in this study and based on the application of the HACCP system allowed the pointing out of anomalous situations in buildings where IAQ problems have never been previously reported. Although this approach may be initially more expensive and time consuming, it proves to be useful by preventing building environmental problems. In addition this monitoring approach allowed revealing some critical points of the HVAC systems in the buildings investigated, preventing the risk of the occurrence of occupants' complaints.

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