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Air bio-contamination control in hospital environment by UV-C rays and HEPA filters in HVAC systems

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Abstract

The contamination of air-handling units is a widespread phenomenon in buildings with air-conditioning systems, including hospitals. The germicide capacity of UV-C rays is known and, in the air-conditioning apparatuses, the UV-C lamps are generally located inside the air ducts. Aim of the paper is to evaluate the effectiveness of UV-C lamps when they are differently placed, i.e. in a position to directly irradiate the HEPA filters surface. We built ad hoc experimental air-conditioning systems, with HEPA filters and UV-C lamps in the two described positions. The results obtained demonstrate that, for disinfection purpose, the direct irradiation of the HEPA filters by UV-C provides better results than irradiation of the air stream and the effectiveness increases when lowering the relative humidity of the air. The survival curves of the tested microorganisms (fungi) show typical tail shaped curves (two steps survival curves). Additional tests using both HEPA filters alone, and HEPA filters plus UV lamps, have been performed measuring the air pressure drop between entrance and exit the HEPA filters and collecting air samples in order to obtain total microbial and fungal count. The results obtained suggest that, at least in experimental conditions described, the radiation on filter surface reduces significantly the microbial load and the pressure drop through the filter, compared to a situation of not-irradiated HEPA filters.

Introduction

Indoor air quality is an important issue in the hospital environment, especially in at-risk wards, such as operating rooms, intensive care units and hematology units, where the probability of such event is high and with severe consequences (1-6). Air quality is usually achieved by dilution of pollutants, using a suitable flow of adequately filtered air, withdrawn from outdoors, according to the requirements of each specific environment in which it has to be introduced. These requirements are very restrictive, also with reference to biological pollutants (7-11).

The germicide capacity of ultraviolet-C (UV-C) rays is known, and it is explained by the absorption of such rays into the nucleic acid structure, particularly for those with a wavelength equal to 254 nm. The damage by UV-C radiation increases with UV-C dose, a function of intensity of the rays and of exposure time. Several researchers studied the

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mechanisms of action, and the susceptibility to UV-C rays of some microorganisms was defined (12-16). Furthermore, they evaluated the survival curves and the associated mathematical models, during disinfection procedures (17-24). Generally four types of survival curves have been observed for the microorganisms, described by linear-logarithmic graphs, having the log of the surviving microorganisms number plotted as a function of the employed treatment parameter (time of exposure or the doses of UV-C rays).

Such types of graphs are represented through linear curves (A), curves with one shoulder (B), curves with a tail (two stage survival curves (C) or sigmoid curves (D), such as qualitatively reported in (25). The mathematical models representing such curves A, B, C, D can be expressed respectively as:

$$N = N_0\, e^{-\alpha t} \quad \text{A}$$

$$N = N_0\, e^{-\alpha(t-t_c)} \quad t \geq t_c \quad \text{B}$$

$$N = N_0 \left[(1 - F_0)e^{-\alpha_1 t} + F_0\, e^{-\alpha_2 t}\right] \quad \text{C}$$

$$N = N_0 \left[(1 - F_0)e^{-\alpha_1 (t-t_c)} + F_0\, e^{-\alpha_2 (t-t_c)}\right] \quad t \geq t_c \quad \text{D}$$

where:

N and N_0 represent the microorganisms surviving at time t and those initially present at time t=0 respectively;

α and α_i are parameters proportional to the applied UV-C intensity and depend on the sensitivity of the microorganism to the UV-C rays exposure;

F_0 represents the most resistant fraction, characterized by a lower sensitivity to the UV-C rays exposure, in a population of microorganisms, compared to the fraction $(1 - F_0)$ less resistant to such exposure;

t_c is the time during which microorganisms are substantially not inactivated.

Among the different factors influencing the phenomenon of UV-C disinfection there are the air temperature and the air relative humidity (RH) (26-28).

Looking at the air conditioning unit (*Heating Ventilation Air Conditioning* - HVAC) systems, several researchers have considered the possibility to adopt the germicide lamps, located inside the HVAC systems or directly on the roof for disinfection purposes (29-34). Inside the HVAC systems, germicide lamps generally are located inside the air ducts; because of the short exposure times, the incident dose on the microorganisms carried by the airflow is low, also for high power plants

In this paper, we report the results of two investigations with different objectives. The first one, performed adding *Aspergillus Niger* and *Actinomices* spp into the HVAC and exposing them to UV-C both in the air stream but also on the surface of HEPA filter. Inactivation curves at different values of relative humidity (RH), 30%, 60% and 90%, are presented.

The second, aimed to quantify the effectiveness in terms of reduction of the overall spontaneous microbial pollution level of the air. The hypothesis was that the direct irradiation of the filter can reduce both its fungal and bacterial contamination and, consequently, the microbial pollution in the airflow.

The effectiveness is evaluated (a) in terms of reduction of the average contamination level, expressed in colony forming unit/ m^3 (CFU/m^3), for the total bacterial and fungal load (typical bio-contaminants of the environment and of the human organism) and (b) in terms of reduction of the pressure load across the filter.

Methods

Experimental facilities

Two *experimental HVAC systems*, with HEPA filters and UV-C lamps (254 nm), were built. They include a heat pump for hot and cold water supply, used for the thermo-hygrometric treatments of the air,

and the regulation system. The facilities are built with appropriate intakes to perform microbiological sampling of airflow. The systems' characteristics have already been described elsewhere (25, 35-36). The main sections of the systems include the air inlet, the mixing section for fresh and recirculation air flow, a section for the insertion of a controlled microbiological contamination, the zone for first filtration stage, the exchange battery for pre-heating or cooling and dehumidification, the steam humidifier with drops separator, the post-heating section, an UV-C lamp and HEPA filter section (efficiency DOP of 99.995%), the fan section, the air outlet, the recirculation duct.

In this context, it is important to underline that the external box of the HVAC system, containing the Air Conditioning Unit (ACU), consists of removable sandwich panels that guarantee an optimum airtight. They are made with stainless steel sheets with finished surface, to avoid the growth of bio-film and to obtain a good reflection coefficient, to increase the germicide action of UV-C lamps. In this way, the ACU internal surfaces are accessible for cleaning after every phase of the experimental campaign. The positioning of the fan guarantees that, in case of test with controlled bio-contamination, air leaks are avoided.

The filtration and irradiation section houses the germicidal lamps, assembled with their standard supports on a stainless steel squared frame.

The first experimental apparatus (25, 35) was dedicated to the investigation on the selected fungal populations, about the effectiveness of the *direct irradiation* of the filter, different from the traditional irradiation of the air flow, and it has been used with full recirculating air, in order to avoid dilution of the fungal load employed.

In this ACU, there is a fan with a static prevalence of 100 Pa and a capacity of 1,500 m^3/h driven by a single-phase electric motor fed at 220V. The heating devices for the temperature control are three armoured electric resistors, fed at 220 V and regulated through a temperature probe, that can absorb power up to 5,000 W. The steam distribution for the RH controls of the circulating air inside the ACU is a stainless steel linear distributor; it introduces steam, obtained by a submersed electrodes humidifier, which can reduce the water pollution by 99.8%. The humidifier is controlled by a humidity probe with modulating signal and it absorbs a power of 5.8 kW supplied by an electrical transformer, providing 8 kg/h of sterile steam. The humidifier with submersed electrodes is fed by the water line of the laboratory. This type of humidifier operates through the Joule effect using as electrical resistance that of the water, which heats and evaporates. An anti-foam system (AFS) can detect and discard the foam produced in the cylinder. Since the steam produced inside the ACU can condensate, the distributor is positioned sub-horizontally, with a slope of 2-3% in order to avoid biological growth.

The germicidal lamps, with their standard supports for fluorescent lamps, are mounted on supports built ad hoc, standing on a squared frame. Four lamps (PHILIPS TUV UV - C G15T8 LONG LIFE, 15 W each) are used. They are tubular quartz lamps, 450 mm long, 26 mm diameter, fed at 220 V, with a specific UV-C emission of 40 μW/cm^2 and they are located on the airflow. The lamps can be directed both towards the airflow, or point directly towards the filtering medium.

The last ACU section houses the aluminum sledges containing the HEPA filter employed during the experiments, with efficiency DOP of 99.995%, mounted at a distance of 150 mm away from the germicidal lamps.

The second experimental apparatus (36) has been dedicated to the evaluation of the total contamination level in the air and to the measurement of the pressure load through

the filter. This ACU was used with only fresh air and without air recirculation.

The humidifier with submersed electrodes (NORDMANN model NOVAP 3000) is fed with the water line of the laboratory. It is electrically fed at 220 V, with a nominal power of 3 kW, providing 8 kg/h of sterile steam.

The post-heating section consists of an armoured battery, fed by a three-phase power supply, able to absorb a total electrical power of 6,000 W. It is constituted of nine candles of 667 W each, connected three to three with a star connection, and controlled by separate thermostats.

Twelve tubular quartz lamps, fed with single-phase electrical line for a total power of 240 W, directly radiate the HEPA filter surface, located at a distance of 20 cm; in groups of six, they can be separately turned on. Between upstream and downstream of the filter is located a differential pressure transducer to measure the pressure drops through the filter. On the removable sandwich panels that cover the section containing pre-filter and HEPA filter respectively, four openings are made, upstream and downstream of each filter, to allow taking air samples for microbiological investigations.

The fan section consists of a centrifugal fan, able to guarantee a flow rate of 1,000 m^3/h with an available static pressure of 200 Pa, driven by a 0.55 kW three-phase electric motor.

Measurement protocols

First step

The objectives pursued during the first step of the experiments with UV-C as air disinfectant were to verify the effectiveness of the association of mechanical filters and UV-C apparatuses against the survival of the selected fungal populations and to evaluate the opportunity of irradiating a filtering medium at high efficiency, to prolong, if possible, the operative life of the mechanical filter itself.

To perform the research phases and to reach correct conclusions, it has been necessary to plan correctly the different steps. Before each measurement campaign, we performed (a) detection of possible air leakages from the plant, (b) cleaning and (c) disinfection of inner surfaces, (d) disinfection of inaccessible parts using "Fumispore". After the introduction of the fungal dose and the start-up of the plant, three air samples were drawn in order to determine the initial situation. The air sampling was performed by means of an active air sampler device.

Preliminary phase: empty plant. Determination of the right dose of fungi to be introduced into the ACU. Quantification of the natural decay of the microbial concentration due to three simultaneous events: (a) micro dispersion outside the ACU, (b) deposit of fungi onto the internal surfaces, (c) lysis of the fungi due to the mechanical collision against the hard surfaces of the plant.

First experimental conditions: HEPA filter inside the plant with UV-C operating on the air flow;

Second experimental conditions: HEPA filter inside the plant with UV-C operating on the filter surface.

During the preliminary, first and second phases, air samples and samples from the inner surfaces of ACU have been collected. For air, we performed three samples for each sampling interval; the sampling intervals were time 0, after 15 min, after 30 min, after 45 min, after 1, 2, 4 and 6 hours. For the surfaces, several samples were drawn at the end of the single experiment. Measurements have been executed at temperature of 26° and RH of 60% on microorganisms *Aspergillus niger* and *Actinomyces* spp. For the last ones an additional investigation at 30% and 90% RH has been performed, in order to evaluate

the effect of RH on the effectiveness of UV-C irradiation.

Second step

The *experiment* has been carried out during the Fall and Spring months and it has been divided in two phases, each with a duration of 16 weeks, although the operational life of HEPA filters is set in Italy equal to 12 weeks (37). For both phases, the ACU has worked at winter functioning regime without air recirculation (RH = 45% ±5%; AT = 25°±1°), in order to simulate the working conditions of a hospital HVAC system.

During the first phase, airflow was undergoing only mechanical filtration by means of the medium efficiency filter and a HEPA filter. In the second phase, the HEPA filter surface was irradiated with UV-C rays by means of low-pressure mercury vapor lamps; all twelve lamps were turned on.

Before each phase, the removable panels were taken away, the plant cleaned and disinfected, new pre-filter and HEPA filter installed. Then the panels have been relocated and air leaks test performed before starting the experiment. Shutters of the air recirculation ducts were kept closed.

We performed microbiological air sampling weekly in both phases, by means of a Surface Air System (SAS) sampler PBI®. Total microbial count (TMC) and total fungal counts (TFC) were investigated. The samples were collected from the intakes before and after HEPA filter station.

In each intake, the following samples were collected:

3 samples to investigate TMC at 22°, in order to evaluate the growth at environment temperature, by Rodac plates with Trypticase Soy Agar (TSA) medium, incubated for 48 hours;

3 samples to investigate TMC at 37°, in order to evaluate the growth at the body temperature, by Rodac plates with TSA medium, incubated for 48 hours;

3 samples to investigate TFC at 26°, in order to evaluate the growth at environment temperature, by Rodac plates with Sabouraud Dextrose Agar (SDA) medium with chloramphenicol, incubated for five days;

3 samples to investigate TFC at 37°, in order to evaluate the growth at the body temperature, by Rodac plates with SDA medium with chloramphenicol, incubated for five days.

Overall, 24 samples were collected in each sampling campaign. The total number of sampling campaigns was equal to 14 during the first phase and 16 during the second phase, with a total amount of 336 samples during the first phase and 384 during the second phase.

Each air sample went on for one minute aspiring a volume of 180 L. It means that for each type of investigation 540 L of air were examined.

The average number of CFU/m^3 was calculated for each experiment and the difference among the means, upstream and downstream the HEPA filter, was evaluated for each phase.

Results

Results of the experimental study, performed during the first step, are presented in Figures 1 through 3; in particular, we report the curves of survival as a function of the time for tested microorganisms.

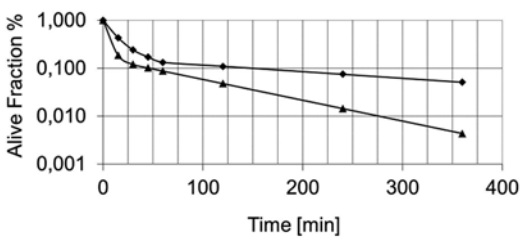

Figure 1 - Decay curves for *Aspergillus niger* at T=26° and RH=60%: UV-C irradiation on airflow (diamonds) and on HEPA filter surface (triangles).

Figure 1 shows the survival curves at 26° and 60% RH for *Aspergillus niger* in case of germicide lamps irradiating the air stream and the HEPA filter surface, respectively.

The irradiation of filter surface caused a microorganism decay much more rapid compared to the irradiation of air stream, and this occurred both for the most resistant and the least resistant fraction. Table 1 reports the value of the decay constants α_1 and α_2.

Nevertheless, the increase of decay constant α_2 of the most resistant fraction of *Aspergillus* population is more marked than the increase of decay constant α_1 relative to the least resistant one: consequently, the irradiation on filter surface is much more effective for the most resistant fraction F_0.

The Figure 2 shows the survival curve of *Actinomyces* spp for the same temperature (26°) and RH equal to 30%, 60% and 90%, respectively. From a qualitative point of view, the curves related to 60% of RH present similar trends to the previous ones, but decay is less rapid for the least resistant and more rapid for the most resistant fraction, as shown in Table 2, where we report the values of α_1 and α_2.

As shown in the figure, by increasing RH, effectiveness of UV radiations decreases for both ways of application, in the air stream and on the filter surface and, for RH equal to 90%, the advantage of irradiating the filter instead of air stream is quite non-existent.

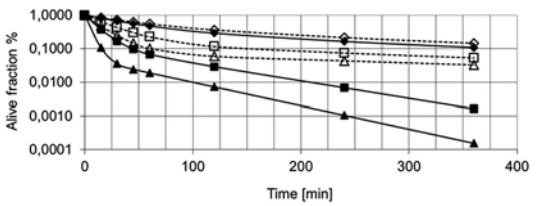

Figure 2 - Summary of decay curves for *Actinomyces* spp at T=26° for different values of RH, with UV-C on air flow (empty symbols and dashed lines) and UV-C on filter surface (filled symbols and solid lines): RH=30% (triangles), 60% (squares), 90% (diamonds).

In Figure 3, we report - for *Actinomyces* spp - the values of the ratio, for different RH conditions at same temperature and for α_1 and α_2 respectively, between the decay constants in case of direct irradiation of the HEPA filter and in case of irradiation of airflow. Figure 3 confirms that UV radiation on filter surface, especially for the less resistant fraction (α_1), involves an effectiveness much higher than irradiating the air stream, but such advantage decreases

Table 1 - Values of the decay constants for *Aspergillus niger* (t=26° and RH=60%).

α [1/min]	Radiation condition		$\alpha_{i,\text{ HEPA filter}} / \alpha_{i,\text{air flow}}$
	On air flow	On filter surface	
α_2	0.0032	0.01	3.125
α_1	0.0725	0.189	2.607

Table 2 - Values of the decay constants for *Actinomyces* spp (T=26° and RH=60%).

α_i [1/min]	Radiation condition		$\alpha_{i,\text{ HEPA filter}} / \alpha_{i,\text{air flow}}$
	On air flow	On Filter surface	
α_2	0.0028	0.012	4.286
α_1	0.0352	0.078	2.216

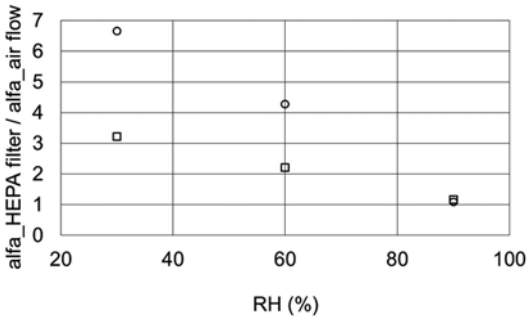

Figure 3 - Summary of decay constants for *Actinomyces* spp at T=26° for different values of RH. Squares: ratio between α_1 in case of UV-C on filter surface and α_1 in case of UV-C on airflow. Circles: ratio between α_2 in case of UV-C on filter surface and α_2 in case of UV-C on airflow.

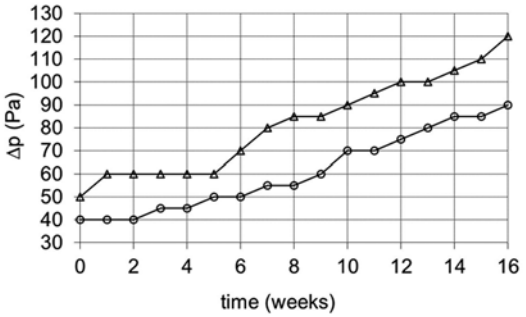

Figure 4 - Pressure drops through the medium efficiency filter as a function of the time during first (circles) and second (triangles) experimental phase.

with the increase of RH. For high values of RH, the absorption of UV-C radiation by the steam becomes very high and, therefore, the effect of UV rays is reduced, especially for more resistant fraction of population. With low values of RH, the direct irradiation of HEPA filter has amplifying effects on the decay, and also the resistant fraction decays faster.

With regard to the analyzed population, a significant effect can be seen on the decay constants of the direct irradiation of HEPA filter. By considering the role of RH, we can conclude that the gain of effectiveness of direct irradiation is null for high level of RH but it remains significant within the interval of RH between 30% and 60%, which is the usual interval in confined rooms controlled by HVAC systems, in particular in healthcare buildings.

Results of the experimental study, performed during the second step, are presented in Figures 4 and 5, related to the pressure measurements, and in Figures from 6 to 12, related to the CFU count. Figure 4 shows the pressure drops through the medium efficiency filter as a function of time. The curves refer to the first and second phase, i.e. in case of mechanical filtration only, by means of the medium efficiency filter and a HEPA filter, and in case of direct irradiation with UV-C rays of HEPA filter surface. The final value of pressure drops (at the end of the 16 weeks of experimental campaign) is about double, if compared to the value measured for a new filter, and this is true without significant difference both for the first and the second phase. Actually, in case of irradiated filter, the pressure drops are a little higher; this is probably due to the increase of outdoor pollution related to the opening of a yard, not far from the external inlet of the ACU, and it could be related to the seasonal increase in outdoor pollen in the air.

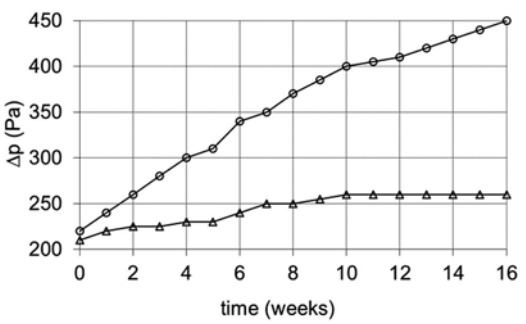

Figure 5 - Pressure drops through the HEPA filter as a function of the time during first (circles) and second (triangles) experimental phase.

The trends of pressure drop through the HEPA filter, for not irradiated and irradiated filter, are shown in figure 5. During the first phase they nearly doubled as it occurs for the medium efficiency filter, during the second phase, in case of UV-C irradiation, their increasing, with respect to the initial condition, was only equal to 24%. This is probably related to the fact that UV-C rays, incident to the filter surface, avoid microorganism growth and in this way delay the filter contamination.

This hypothesis is supported by the qualitative microbial check performed on the surfaces of the filter, both upstream and downstream. With regard to the samples collected from pre-filter surface, in the first experimental phase (without UV-C rays), the microbial growth was so high that it has been impossible to count the CFUs. For the second phase, the growth from the upstream pre-filter surface was intense as in the first phase, while the microbial growth from the downstream surface permitted the identification and the count of *Aspergillus* spp.*, Penicillium* spp. and other filamentous fungi. Therefore, microbial contamination of the pre-filter downstream surface is reduced with respect to the first experimental phase.

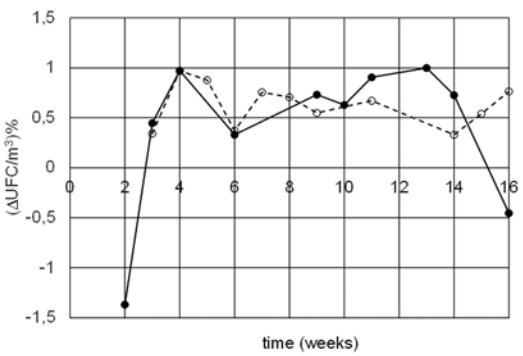

Figure 6 - Average number of bacterial (TSA 22°) CFU/m^3: percentage difference through the HEPA filter as a function of the time during first (filled circles and solid lines) and second (empty circles and dashed lines) experimental phase.

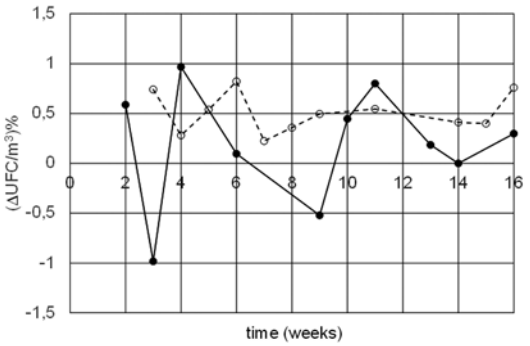

Figure 7 - Average number of bacterial (TSA 37°) CFU/m^3: percentage difference through the HEPA filter as a function of the time during first (filled circles and solid lines) and second (empty circles and dashed lines) experimental phase.

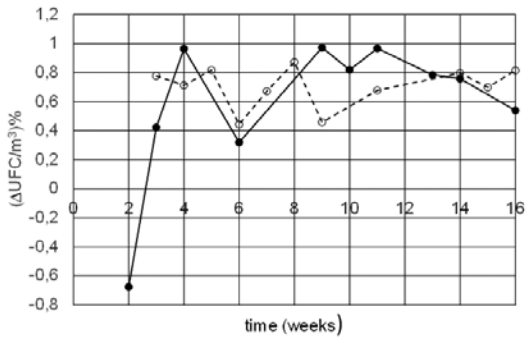

Figure 8 - Average number of fungal (SDA 26°) CFU/m^3: percentage difference through the HEPA filter as a function of the time during first (filled circles and solid lines) and second (empty circles and dashed lines) experimental phase.

Figures from 6 to 9 show the percentage difference between average number of CFU/m^3, upstream and downstream of the HEPA filter, observed in each sampling campaign for first and second experimental phases, with regard to bacterial count (at 22° and 37° respectively in figures 6 and 7) and to fungal count (at 26° and 37° respectively in figures 8 and 9).

Table 3 shows the average number of CFU/m^3 observed in each experimental

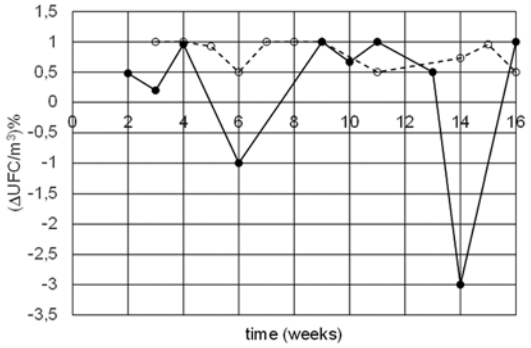

Figure 9 - Average number of fungal (SDA 37°) CFU/m^3: percentage difference through the HEPA filter as a function of the time during first (filled circles and solid lines) and second (empty circles and dashed lines) experimental phase.

condition and corresponding percentage difference through the HEPA filter.

The decreasing in CFU/m^3 obtained adding UV-C rays seems to be higher for fungal counts, in comparison with bacterial counts, both for those growing at environmental temperature and those thermo-tolerant. It has to be noted that the data related to fungal count at 37° are not significant, due to the very low values of detected CFU.

By considering the average value (in time) of the percentage differences through the HEPA filter reported in Figures from 6 to 9 for bacterial and fungal contamination, we can obtain the gain of effectiveness of phase 2 with respect to phase 1 as the ratio between these average percentage differences. Results are summarized in Table 4. It has to be noted that in some cases the contamination level is higher downstream HEPA filter with respect to upstream, due to uncontrollable events during the sampling. This negative result mainly refers to bacterial count at 37° and it is observed with regard to first experimental phase; with regard to the second phase, it has been noted a reduced effectiveness of the direct irradiation on this population with respect to other microbial populations.

Finally, by considering the average value (in time) of the percentage differences through the HEPA filter for cumulative bacterial and fungal contamination respectively, we can obtain again the increase of effectiveness of phase 2 with respect to phase 1 by an overall point of view. Results are summarized in Table 5.

By considering the average values reported in table 4 and 5 and the trends shown in figures 6-9, one can see that in general an overall increase of effectiveness for the contamination level reduction occurs, due to the direct irradiation.

Table 3 - Average number of CFU/m^3 of microorganisms counted in the two experimental phases (A = upstream HEPA filter, B = downstream HEPA filter)

CFU/m^3	Without UV-C rays		With UV-C rays	
	A	B	A	B
Bacterial count (22°)	68,98	31,36	116,81	48,92
Bacterial count (37°)	39,26	17,02	17,67	8,85
Fungal count (26°)	42,45	19,33	88,9	22,52
Fungal count (37°)	5,26	1,62	3,71	0,50

Table 4 – Average percentage difference between CFU/m^3 upstream HEPA filter and downstream HEPA filter of microorganisms during the two experimental phases and corresponding gain

	Δ (%) $_{\text{Without UV-C rays}}$	Δ (%) $_{\text{With UV-C rays}}$	$\frac{\Delta\% \text{ With UV-C}}{\Delta\% \text{ Without UV-C}}$
Bacterial count (22°)	0,391	0,604	1,543
Bacterial count (37°)	-0,203	0,129	-0,64
Fungal count (26°)	0,203	0,829	4,075
Fungal count (37°)	0,535	0,719	1,344

Table 5 – Average percentage difference between CFU/m^3 upstream HEPA filter and downstream HEPA filter of bacterial and fungal microorganisms during the two experimental phases and corresponding gain

	Δ(%) $_{\text{Without UV-C rays}}$	Δ(%) $_{\text{With UV-C rays}}$	$\frac{\Delta\% \text{ With UV-C}}{\Delta\% \text{ Without UV-C}}$
Bacterial count (22° and 37°)	0,213	0,403	1,889
Fungal count (37° and 26°)	0,533	0,724	1,358

Discussion

Effectiveness of UV radiation lamps to reduce bio contamination of HEPA filters has been experimentally studied by means of *ad-hoc* built air conditioning units (25, 35-36). Experimental measurements performed during a first step of the experimental campaign on *Aspergillus Niger* and *Actinomyces* spp (35), submitted to UV-C radiation, can enable us to state that:

The irradiation of the filter surface is much more effective than the irradiation of the air stream, at least for RH lower than 60%; the effectiveness increases with the lowering of the RH of the air.

The survival curves of the tested fungi show a typical tail shape (two steps survival curve).

The investigation performed during the second step of the experimental campaign (36) seems to confirm that, in field conditions, the radiation on filter surface can contribute to reduce the microbial load, compared to the case of not-irradiated filter. In addition, the pressure drop through the irradiated filter increases with time more slowly and the doubling of the value, compared to the start conditions, could occur in a period approximately four times longer than the doubling time of the not irradiated filter.

Furthermore, the multiple reflections caused by the internal surfaces of ACU walls probably allowed that also the pre-filter surface facing the lamps could be partially protected from microbial colonization. Also the microbiological results suggest encouraging the use of UV-C rays in addition to HEPA filters. For these reasons, the UV-C direct irradiation could offer a useful contribution both to improve the hospital air quality and to increase the HEPA filters operating life. The reduced pressure losses through the irradiated filter have positive effects with regard to energy saving, both for the direct effect on energy consumption, and because the fan of the ACU can work longer at the maximum performance operating conditions.

Anyway, it must be underlined that these data are preliminary, as they report the

results observed in only one HEPA filter for each phase and they are related to a - not controlled - observational study. Therefore, the experiment needs to be repeated on a significant sample of HEPA filters and in even more controlled experimental conditions. However, the adjoint value of this work is also represented by the fact that the experimental conditions are very similar to the real operating conditions of the ACU.

In addition, it is necessary to evaluate and compare the total costs with reference to the operating life of filters and lamps and taking into account the energy costs for the lamps. Finally, a risk assessment must be addressed with regard to the contamination of the air downstream the irradiated filter, characterized by a lower total microbial load but with a greater presence, which cannot be excluded a priori, of more resistant microorganisms.

In conclusion, the evaluation of pressure losses shows that there is no doubt about the effectiveness of UV-C irradiation on the operating life of the HEPA filter; also the evaluation of the microbial load highlights the effectiveness of direct irradiation, although additional investigation should be performed to confirm the obtained results.

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Riassunto

Controllo della biocontaminazione dell'aria negli ambienti ospedalieri con l'impiego combinato di raggi UV-C e di filtri HEPA negli impianti di condizionamento

La contaminazione delle Unità Trattamento Aria è un fenomeno diffuso negli edifici dotati di impianti di condizionamento dell'aria, inclusi gli ospedali. La capacità germicida dei raggi UV-C è nota e, negli impianti di condizionamento dell'aria, le lampade UV-C si trovano generalmente all'interno delle canalizzazioni. Scopo del lavoro è valutare l'efficacia delle lampade UV-C nel caso siano posizionate in modo diverso, in modo da irradiare direttamente la superficie dei filtri HEPA. Abbiamo realizzato un impianto sperimentale di climatizzazione ad hoc, con filtri HEPA e lampade UV-C nelle due posizioni descritte. I risultati ottenuti dimostrano che, ai fini della disinfezione, l'irraggiamento diretto dei filtri HEPA mediante UV-C fornisce risultati migliori dell'irraggiamento del flusso d'aria e l'efficacia aumenta quando si abbassa l'umidità relativa dell'aria. Le curve di sopravvivenza dei microrganismi indagati (funghi) mostrano la tipica forma a coda (curve di sopravvivenza a due fasi). Test aggiuntivi sono stati eseguiti, utilizzando sia i filtri HEPA da soli, sia i filtri HEPA irraggiati dalle lampade UV, misurando la caduta di pressione dell'aria tra l'ingresso e l'uscita dei filtri HEPA e raccogliendo campioni d'aria al fine di ottenere il conteggio microbico e fungino totale a monte e a valle del filtro. I risultati ottenuti suggeriscono che, almeno nelle condizioni sperimentali descritte, la radiazione sulla superficie del filtro riduce significativamente sia il carico microbico sia la caduta di pressione attraverso il filtro, rispetto a una situazione di filtri HEPA non irradiati.

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