

Germicidal Installation for Disinfection of Small Offices and Residential Premises

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Abstract: These days, COVID-19 makes disinfection and sanification particularly topical. Unfortunately, numerous fraudsters have benefited from this global disaster. Today, the market offers a lot of things meant to protect people against COVID-19: from very expensive respirators, and anti-dust masks with built-in valves freely releasing the air exhaled by a person (possibly sick) into the surrounding space; alcohol hand gels containing significantly less than 70% alcohol and therefore providing no disinfecting effect; ultraviolet lamps of dozens of different types and sizes, many of which have no impact whatsoever on germs and viruses. Actually, the "right" UV lamp is the most convenient means for room or apartment disinfection. You only need some knowledge to choose the right one and to make a simple disinfection device. This problem is discussed in this article.

Keywords: COVID-19, ultraviolet lamps, disinfection, germicidal UV, UV irradiators

1. INTRODUCTION

It is hardly possible to ignore the importance of disinfection during the COVID-19 pandemic. The promised vaccination will unlikely be able to solve all the problems fast and completely. First, just like the influenza vaccine, the COVID-19 vaccine will be effective for only a few months in the human body (like the flu vaccine). Second, Interpol has informed the media that crime syndicates have planned to produce and distribute fake vaccines. Third, experts do not rule out the possibility of repeated coronavirus mutations after mass vaccination begins, and assume that the coronavirus epidemic may recur periodically similar to influenza. Fourth, despite coronavirus and influenza, there are a lot of other pathogens and even tiny insects (such as dust mites invisible to the naked eye) in amenities, especially on the soft furniture, sofas, mattresses, carpets, mats, etc. Plus, the air in the room where an ill person resides also requires periodic disinfection.

2. ULTRAVIOLET AS AN EFFECTIVE DISINFECTION AGENT

Ultraviolet light is a very convenient and effective disinfection agent when it comes to home disinfection. It has long been known that UV light can effectively disinfect surfaces, air, and water. For the first time, the harmful effects of ultraviolet radiation (more accurately of the sunlight within the UV range) on bacteria inside the broth tube was described by A. Downes and T. Blunt in Nature Magazine in 1877:

218 NATURE [July 12, 1877]

THE INFLUENCE OF LIGHT UPON THE DEVELOPMENT OF BACTERIA¹

WE have been engaged during the last few months on an investigation into the effect of light upon the development of bacteria in certain of those solutions in which they are usually produced.

. . .

That light is not essential for the development of bacteria has been long known, but that it is absolutely inimical to their production has not, so far as we are able to ascertain, been previously shown, and we are encouraged, therefore, to lay before the readers of NATURE this statement of our results.

ARTHUR DOWNES; T. P. BLUNT

Figure1. Excerpt of the first-ever article on bactericidal efficiency of UV light.

The following year, the same scientists discovered that blue light (i.e. the portion of the visual light spectrum closest to UV light) is the most effective against bacteria. In 1901, the first mercury light bulb, which was also the source of UV light, was invented. Later, in 1903, Danish rehabilitation physician Niels Finsen received the Nobel Prize "in recognition of his contribution to the treatment of diseases, especially lupus vulgaris" with ultraviolet light.

It can be considered that the era of widespread use of UV light for disinfection in the medical and the commercial sector began when mercury lamps entered the market in 1904-1906. They transmitted short-wavelength UV and were made of quartz glass. Soon after, in 1910, they were initially used for disinfection of potable water in Marseille, France.

In 1929-1930, Gates published his research on the correlation between UV light spectrum and germicidal properties and discovered that 265nm UV light (which is very close to the maximum radiation spectrum of 254nm low-pressure mercury germicidal lamp) is the most effective against bacteria. Also, he understood that UV action on microorganisms is related to nucleic acid ability to absorb UV light and DNA disassociation.



Figure2. Preventive UV exposure of children in kinder gardens and catarrhal diseases treatment at the school medical office

The first large commercial installations for UV disinfection of potable water were installed in Switzerland and Austria in 1955 (in 1985 there were more than 500 such installations in the world). Soon after, UV rays began to be used not only for disinfection. Older people remember well that in the 1960-70s UV exposure was widely used in kinder gardens and schools as a measure of preventive care and treatment for children, see Fig. 2.

Currently, such directional UV sources with catharal and nasal tubes are produced by the Russian company "Solnyshko". Naturally, today the devices manufactured by this company have a modern design, see Fig. 3, and are made of modern components, but the principle remains the same.



Figure3. UV irradiators type OUF-10-2 and OUF-06 produced by "Solnyshko" and designed for treating bronchitis, tonsillitis, sinusitis, rhinitis, periodontal disease, wounds, etc.

3. MODERN UV GERMICIDAL IRRADIATORS

Currently, UV irradiators are extremely widely used for air and surface disinfection. It is no exaggeration to say that today's market proposes hundreds of such irradiators, manufactured by dozens of big companies from China, India, the USA, Germany, etc. The market also proposes big UV installations (from hundreds of Watts to kilo Watts), see Fig. 4.



Figure4. High power germicidal UV disinfectors used for disinfection of large hospital rooms, lobbies, and public establishments.

Since one UV lamp has limited power due to technical constraints, to get powerful irradiators, many single UV lamps must be combined into one single unit. Portable and mobile UV installations are also available on the market. Such middle power installations are designed for disinfection of small offices, see Fig. 5.



Figure5. Middle power germicidal UV installations

Usually, middle power germicidal UV installations are made of 1 or 2 long lamps which can be placed into a protective container (see Fig. 5b, 5d) or can automatically pop out from such a container (see Fig. 5a). The Chinese company Vortex Safety Lighting manufactures an installation consisting of lamps that pop out of the tubular containers. It costs approximately 500USD and is proposed by many trading companies on the market. A light-weight, low-power portable irradiator of this type (see Fig. 5c) is equipped with lamps protected from mechanical damage with aluminum pins and rims. Such irradiators produced by the Chinese company Shenzhen Guanke Technoligise Ltd., cost approximately 100USD. Protective containers and other elements ensuring protection against mechanical damage are the important properties of compact installations designed for the frequent relocation between offices.

It should be noted that all middle and high-power irradiators are equipped with built-in means preventing dangerous exposure for humans. Amongst such means are timers, remote controls, as well as motion and proximity sensors switching the installation off upon human approach. The low-power UV irradiator range is equally large, see Fig. 6.



Figure6. Low-power germicidal UV installations

Presently, AliExpress, eBay, Amazon, and other online marketplaces offer such irradiators for domestic use. Many of them are equipped with timers and remote controls just like their higher power "brothers". Compact very low-power UV irradiators also hold a large market share, see Fig. 7.



Figure7. Compact very low-power UV irradiators

Finally, there are self-propelled UV robots capable of moving across the room and disinfecting it, see Fig. 8.



Figure8. Automatic robotic germicidal installations with high-power sources of UV radiation.

The irradiators mentioned above are open sources of UV radiation. In all fairness, it has to be added that there are also enclosed UV sources (the so-called "recirculators") designed as a set of UV lamps installed into an enclosed casing, ventilated by the outside air forced by a built-in fan. Such installations are designed for air disinfection and uninterrupted work in the presence of a human. However, since their effectiveness is rather low and similar to the regular aeration, they are not considered in this article.

Accordingly, today the market for germicidal UV irradiators is huge and offers many domestic appliances (see Fig. 6). However, as usual, the huge variety makes the choice difficult. If you read the descriptions accompanying the UV installations proposed on AliExpress, eBay, or Amazon, the choice becomes even more difficult. Often, the descriptions are so ridiculous and wrong that they only cause a complete rejection and distrust to the advertised goods. A simple visual comparison of medical UV irradiation devices with installations, advertised as an effective household germicidal means, cast doubts on the effectiveness of the latter, see Fig. 9.



Figure9. Germicidal UV irradiation installations used for disinfection of hospital rooms (right) and promoted household installations (left).

Thus, in order not to get into a crisis and avoid the purchase of a seemingly effective, but in reality an absolutely useless disinfecting device, let us ponder that further.

Let us take a roundabout approach to the subject and discuss what UV is and which of its part is germicidal.

4. UV IRRADIATION KINDS

According to the globally known classification, UV light occupies a relatively small part of the electromagnetic emission spectrum (segment 3 in Fig. 10).

IES Committee Report CR-2-20-V1
IES Photobiology Committee

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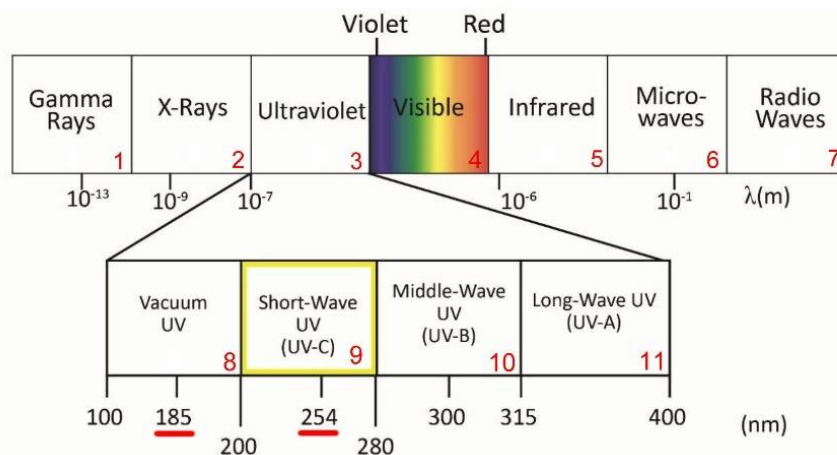


Figure10. Electromagnetic emission spectrum according to data of Illuminating Engineering Society (IES). 1 - gamma radiation; 2 - X-ray radiation; 3 - ultraviolet; 4 - visible light; 5 - infrared radiation; 6 - microwaves; 7 - radio waves.

In its turn, the UV spectrum is divided into 4 segments (8, 9, 10, and 11 in Fig. 10), which are named as follows (with wavelengths, respectively): UV-A (from 315 to 400 nm); UV-B (from 280 to 315 nm); UV-C (from 200 to 280 nm); UV-V, or Vacuum UV (from 100 to 200 nm).

The so-called "near" ultraviolet range (UV-A) with the longest wavelengths is often called "black light", since it is almost invisible to the human eye, although it is closest to the visible spectrum (therefore, it is called "near"). It has no germicidal effect. Ultraviolet radiation UV-B is referred to as the "middle" range. This radiation has low germicidal properties and is used to treat certain skin diseases, such as psoriasis. The sun is the only source of UV-A and UV-B radiation on Earth. The ratio of UV-A and UV-B radiation intensity and the total amount of ultraviolet rays reaching the Earth's surface depend on many atmospheric factors, such as the concentration of atmospheric ozone above the Earth's surface, the height of the Sun above the horizon, the cloud cover of the sky, etc. A slight skin redness followed by a light brown tint is caused by UV-A radiation, while severe sunburn is caused by shorter wavelength UV-B radiation. "Harder" UV-C radiation is almost completely absorbed by the atmospheric ozone layer and does not reach the Earth's surface. UV-V radiation can only propagate in a vacuum, while in the air it is absorbed by oxygen then reacting to ozone (triatomic oxygen modification). However, this particular UV-C radiation provides a germicidal effect. Moreover, not the whole range but a very narrow band of it, see Fig. 11.

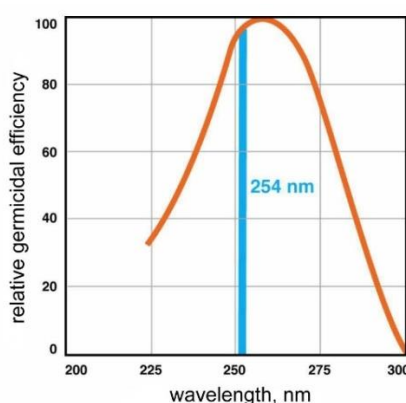


Figure 11. Variation in UV radiation relative germicidal efficiency in function of the wavelength.

265nm UV radiation has the maximum pathogen deactivation ability. However, due to purely technical reasons, it is rather difficult to produce sufficiently high-power rays with such a wavelength in the UV lamp spectrum. Therefore, the wavelength of 254nm is deemed as optimal since it is available from the technical point of view, and is close enough to the maximum effective range. Namely, 254nm wavelength (or more precisely 253,7 nm) is deemed as UV-C standard for UV lamps.

Fig. 11 shows the germicidal effectiveness of UV light drops down significantly even upon the small deviation from this value. Are all the UV lamps proposed on the market and promoted as germicidal irradiate 254nm? Unfortunately, no! What types of UV lamps are available?

4.1. Low-Pressure Gas-Discharge Lamps

Such lamps are very similar to conventional fluorescent lighting lamps using an electrical discharge in mercury vapor, filling the lamp at a pressure of 0.13Pa-1.3Pa as the source of UV radiation. In conventional lighting lamps, this UV radiation is absorbed by luminophore covering the inner surface of the lamp and then re-emitted within the visible part of the electromagnetic spectrum. Residual UV radiation is prevented from transmitting to the outside by the glass enclosure of the lamp. A UV lamp contains no luminophore (it is transparent) and is enclosed in quartz or ultraviolet glass transparent for UV light. Apart from 254nm rays, regular quartz glass transmits shorter wavelengths of 185nm (UV-V) appearing upon the discharges in mercury vapors, i.e. they produce rather high ozone concentration. In a closed room, ozone is deemed as a highly toxic gas and is forbidden by the health rules. Low-pressure mercury UV-lamps, enclosed in ultraviolet or special titanium, dioxide doped, quartz glass (amalgam) emit a substantial part of output lumen within a resonance line of 253.7nm (produce no ozone). Also, lamps of this type have the highest efficiency among mercury lamps – 30%-50% (ratio of emitted UV flux power to the installed power of UV-lamp, specifically, to the consumed power).

4.2. High-Pressure Gas-Discharge Lamps

The principle of operation of such lamps is almost the same as described above. However, the increased pressure of mercury vapor inside such lamps (up to 15,000Pa) may significantly increase their power (up to several kW). At the same time, the temperature of such a lamp may reach hundreds of degrees. At such a temperature, only quartz glass can be used. Quartz glass transmits short-wavelength UV-V rays producing ozone. Also, lamps of this type have much lower efficiency and useful life compared to the low-pressure lamps.

4.3. Light Emitting Diode Lamps

Online marketplaces like AliExpress, eBay, Amazon offer dozens of different germicidal LED-based UV-C lamps, see Fig. 12.



Figure12. LED-lamps promoted as germicidal.

UV LEDs are also used to build compact very low-power UV irradiators (see Fig. 7).

The buyers' interest in compact lamps and irradiators that do not contain fragile glass bulbs containing mercury is understandable. This interest is used by numerous fraudsters who offer products that are completely useless in terms of germicidal efficiency. Currently, there are only few samples of LEDs capable of irradiate UV-C light of a fraction of Watt designed, but they have very low efficiency. Several leading companies (Sensor Electronic Technology, Nichia Corp., Crystal IS, Semileds) are working on the development of high-power UV-C LEDs, however the breakthrough in this field is not yet in sight.

5. CHOICE OF THE TRUE UV-C LAMP

If numerous fraudsters promote useless LED devices as germicidal UV-C lamps, how can we be sure that promoted low-pressure gas-discharge lamps (see Fig. 7) are really made of expensive ultraviolet glass, instead of regular window glass, not capable of transmitting a large part of UV light? So, how to find the really good device amongst the hundreds of options offered by inexperienced (in terms of the technical parameters of the promoted goods) sellers? How to sift out ashes from cinders in the mix of real characteristics, nonsense, and sometimes outright forgeries contained in the descriptions of domestic UV irradiators?

First of all, we should discuss the UV irradiator power required for domestic application. There is a total mess just like in the case of irradiators. As mentioned above, there are two values of UV irradiator power: power consumed from the supply network and power of output radiation. Manufacturers and sellers usually indicate the power consumption, since it is much higher than the radiated one, and therefore it looks better in advertising brochures. Nevertheless, in the calculations of the power required for disinfection of a given volume, a completely different power is used - the radiation power, which at best is 2-3 times less than the advertised one. In addition, the data on the power of the irradiator and the effectively disinfected volume (or area) reported by various manufacturers and sellers are so different from each other, that it is almost impossible to use them. However, besides the unfair or unaware sellers, there are objective reasons.

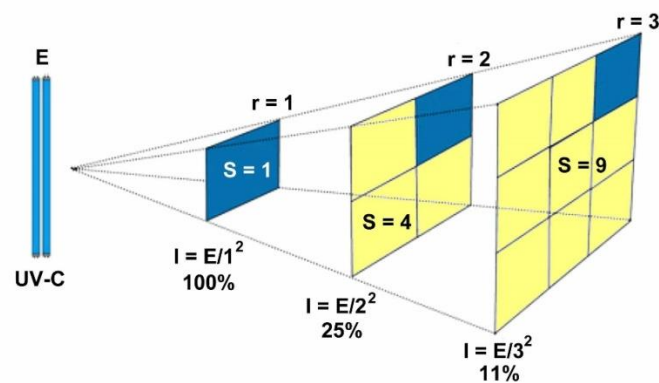


Figure13. Relation of the decrease in the intensity of UV irradiation to the surface to the increase in the distance to the source.

The fact is that the bactericidal efficiency of the irradiator depends on numerous factors that cannot always be taken into account in the calculations, and therefore bring significant uncertainty and inaccuracy in the calculations, primarily, the distance between the UV source and the surface that is to be disinfected. The further away the irradiated surface is from the source of the irradiation, the larger the irradiated area is (quadratically), and the less the irradiation intensity is, see Fig. 13. For example: if we take as 100% the radiation intensity at distance $r = 1\text{m}$ from the source, then at distance $r = 3\text{m}$ the radiation intensity will be only 11%. Do the advertisers consider it indicating data on required irradiator power depending on the certain area? Also, the above dependence shows that a single source of UV radiation installed at a certain distance, opposite the irradiated surface, will produce different irradiation intensities on different segments of the surface. On segments distant from the direct source projection onto the surface, the irradiation intensity may be so weak that instead of a germicidal effect, such weakened radiation (that is, a low germicidal dose) can lead to a completely opposite effect - to mutation of certain pathogens and even to their intensified reproduction. In addition, the intensity of irradiation on surfaces depends on the angle of UV-light arrival and on the reflecting properties of this surface. Considering the very small power and size of UV-light sources (in this example they can be considered as point-lights, see Fig. 8) proposed for domestic use, their negative effect may outweigh their advantages.

There are also problems in estimating the power of the UV source required to sterilize the air inside the room. The issue is not over the radiation intensity attenuation at a big distance. Also, there are other factors, such as room air humidity and movement (e.g. in and out), decrease in UV-lamp luminous power over the time of use, etc. Increased air humidity significantly reduces the intensity of UV radiation at a distance. Insufficient air movement inside the room will prevent distant portions of the air from disinfection. This is especially the case when the room is long and has recessions and partitions.

In general, the germicidal efficiency of UV irradiator depends on its output power and period of exposure. Thus, smaller UV lamps promoted as designed for domestic use are often equipped with remote controls ensuring automatic 3-step time control of switch-off (usually, 15, 30, and 60 minutes). It is assumed that a small room will need only 15 minutes and a bigger one will need only 60 minutes of exposure. However, it is a wrong assumption, since inadequate irradiation intensity at a big distance from the UV lamp (see Fig. 9, left) cannot be compensated by the longer exposure time to get the required germicidal efficiency.

To simplify, the rough estimation of UV source power without reference to many of the factors mentioned above, the following method can be applied.

5.1. Basic Data

1. Germicidal irradiance (GI) of UV-C type UV-source (ratio of germicidal flux to area or volume of the exposed surface)

- 0.2–0.5W per sq.m — for the area of the surface to be disinfected;

- 0.15W per cu.m – for the volume of the air.

2. Residual radiation power of UV source during the use (RRP) – 80%
3. Air humidity (AH) – 60% (upon moisture level increase above 50% the output power of UV source should be increased per app. 25%, i.e. moisture coefficient KH = 1.25)
4. Area of the surface to be disinfected (S) – 50 sq. m

5.2. The Formula for Calculation of UV Source Radiation Power

$$P(r) = (S \times GI \times KH) / RRP = (50 \times 0.35 \times 1.25) / 0.8 = 27W$$

If low-power gas-discharge UV lamp efficiency is 35%, the rated source power is $P(N) = P(r) / \text{Efficiency} = 77W$

Specifically, the estimated rated power of UV source (data indicated in advertising brochures) required for 50 sq.m living room significantly exceeds the output power of irradiators offered for domestic use on AliExpress, eBay, Amazon. So, what to do? You can build a self-made UV irradiator more suitable for a residential area than those offered on the market.

6. SELF-MADE UV IRRADIATOR

The general concept of such an installation is to use a dispensed rather than a point UV source. Such dispensed source distributes the irradiation over the surface or volume to be disinfected and includes several UV lamps (instead of only one UV lamp), with a total power of about 100W. Each lamp can be installed at a distance of 1m-2m from each other, and the number of lamps may vary depending on the size of the room or the area of the surface to be disinfected.



Figure14. Different designs of screw caps of UV lamps available on the market

From this perspective, initially, it is necessary to choose the "correct" lamp: 1) capable of providing the necessary germicidal flow; and 2) suitable for creating a self-made irradiation installation. For this, first, we should focus on lamp screw cap design, see Fig. 14.

It is clear that it is too difficult to construct the irradiation installation based on the lamps with such screw caps, see Fig. 14. That is why I chose a common threaded round screw cap type E27.

The next step is to choose a lamp ensuring irradiation within the UV-C range. Initially, it must be a gas-discharge rather than a LED-lamp. However, it is absolutely impossible to check the actual quality of the gas-discharge lamp when ordering from AliExpress, eBay, and Amazon. The only solution is to purchase lamps of well-known brands with markings on the lamp itself, on its packaging, and in the accompanying documents. Along with completely no-name lamps without any markings, the same marketplaces offer lamps produced by leading manufacturers, see Table 1.

Table1. Leading Chinese brands of domestic low-power UV lamps offered on AliExpress, eBay, and Amazon

Brand	<i>Tranyton</i>	<i>Coospider</i>	<i>Goldviss</i>	<i>Leboom</i>	<i>Kingrate</i>
Manufacturer	Zhongshan Donglian Lighting Co.	Aopu Lighting Co.	Dongguan Goldviss Biotechnology Ltd.	ChangxingLeboom Lighting Product. Co.	KingrateLigting Technology Co.

Lamps produced by these manufacturers (with E27 screw caps) have appropriate markings indicating power, supply voltage, UV-C range, and sometimes even the wavelength of the emitted UV light (254nm or 257.3nm), see Fig. 15.



Figure 15. UV lamps with standard screw caps E27 produced by the leading Chinese manufacturers

Lamps of those brands with different power and design are widely available on the market, see Fig. 16.

Four 25W UV lamps is a good combination for a self-made domestic irradiator. However, how does one check the performance of the purchased lamp at home? UV-V (producing ozone) lamps are the easiest in this context. If you feel the specific ozone odor near the lamp when it is on, you can be sure that it is UV-



Figure 16. Leading brands of E27 UV lamps with different power and design widely available on the market.

V. However, if you donot want to be exposed to the danger ozone effects and have purchased the lamp operating within UV-C range only without ozone, you will certainly need special indicators.

The QuantaDose™ UV-C intensity test card manufactured by Quanta X Technology Co. (USA) is the simplest and the most available UV-C range indicator designed for domestic purposes.

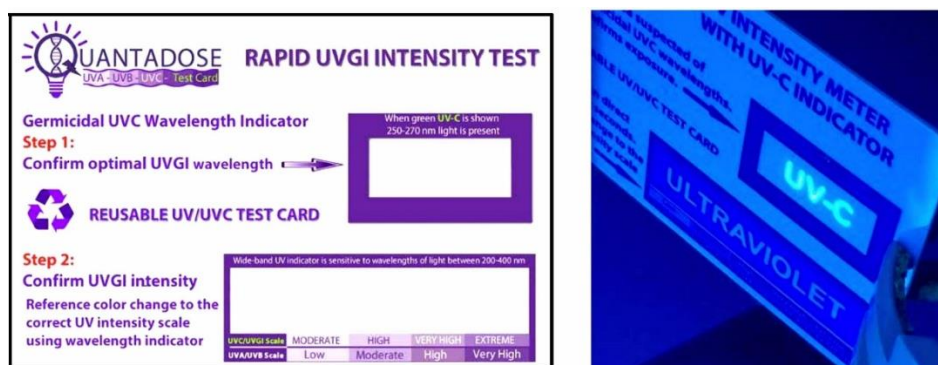


Figure 17. Quanta X Technology Co. plastic test card designed for checking the UV irradiation range (top field) and irradiation intensity (bottom field).

This test card costs approximately 10USD and allows verification of the UV-C range irradiation and roughly estimates the UV flow near the lamp. A home test showed that this card is capable of working with lamps of 25W and above. If the lamp produces ozone, the card gives much clearer results. For example, if you take the card close to the ozone-free 25W lamp, you will see faint luminous white letters UV-C in the top field. If you take the card close to the ozone producing lamp, the letters will turn much brighter and green. In the bottom field, you will see "Low" for the ozone-free lamp and "Moderate" for the ozone producing lamp. It seems that the indication depends on the total intensity of UV flow produced by the lamp. An ozone producing lamp has higher UV flow intensity than a purely UV-C lamp, blocking the UV-V part of the light by the glass enclosure. However, it does not mean that the germicidal efficiency of UV lamp producing ozone is higher, since the UV-V range segment of luminous flux does not ensure the adequate germicidal effect.

Additional elements (apart from the lamps) required for the construction of self-made irradiators are shown in Fig. 18.



Figure18. A set of additional elements required for the assembly of the simplest self-made UV irradiator.

First, a simple irradiator consisting of several identical modules equipped with UV lamps, see Fig. 19, can be more complicated and amended by a small fan ensuring forced air circulation inside the room. This will significantly improve the efficiency of air disinfection in the room.



Figure19. A single module which can be completed with UV lamps of different types.

Additionally, the installation can be equipped with an additional time delay module to allow people to leave the room before UV lamps are activated, as well as to automatically turn off the lamps before people enter the room (approximately 30-60 minutes after lamp activation). This simple module consists of two of the simplest and cheapest single-function timers T1 and T2 with turn-on delay. In

the diagram, see Fig. 20, after 1 min delay, the T1 timer contact supplies the mains voltage to six in-parallel standard sockets, while the two in-series (to increase the switching capacity) T2 timer contacts disconnect the voltage after a set delay (up to 1 hour).

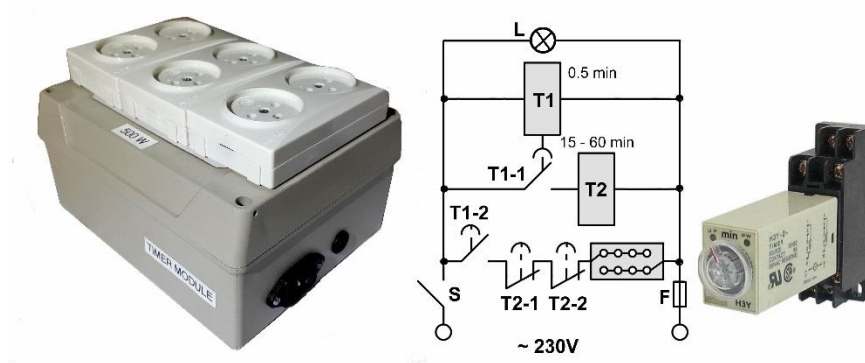


Figure20. Appearance and circuit diagram of an additional time delay module with 6 in-parallel outputs (for separate modules with lamps and a fan) providing a delayed activation and deactivation of UV lamps.

Due to the modular design, the above mentioned installation can be used both for the efficient germicidal treatment of the surfaces (see Fig. 21), and air (see Fig. 22), in the rooms of a different area and for disinfection of different objects (such as clothes, shoes, masks, gloves, telephone, computer, etc.).



Figure21. An example of using a self-made irradiator for disinfection of upholstered furniture



Figure22. An example of using a self-made irradiator for disinfection of carpet

In this case, you will need only one lamp placed inside the closed cardboard box with inner walls covered with aluminum foil (or at least sprayed with silver vanish) reflecting UV rays. Such a simple enclosure is much cheaper than the branded container, see Fig. 23.



Figure23. Branded container for germicidal UV installation designed for the treatment of objects and carton box with an inner reflecting coating of the same efficiency used with one lamp of the described modular irradiator

Thanks to the modular design, the described irradiator with the spread UV sources ensures much more efficient disinfection of residential premises and allows to vary radiation power within the wide range, depending on the room size, as well as to use lamps of different types and output power and to disinfect different household items. Plus, it is very compact, has a very simple design, you can make it by yourself and dismantle it to single modules.

Warning: Hard UV-C and UV-V rays are harmful for human and animal skin and eyes. Make sure that people and animals leave the room before activating the irradiator!

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