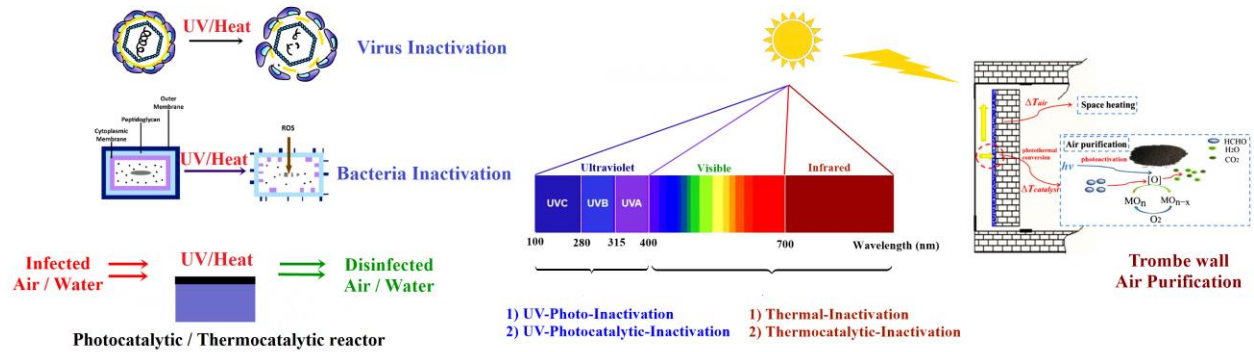


Title: Can Solar Energy take part in fighting against COVID-19 pandemic? A review on inactivation of SARS-CoV-2 in Water and Air using Solar Energy.

GRAPHICAL ABSTRACT:



ABSTRACT:

The world is currently facing the consequences of the COVID-19 pandemic. The pandemic is caused by a novel coronavirus SARS-CoV-2 which is a member of coronaviruses family that made three outbreaks the last 18 years namely Severe Acute Respiratory Syndrome (SARS-CoV) in 2003, Middle East Respiratory Syndrome (MERS-CoV) in 2012, and now in 2019 SARS-CoV-2 (COVID-19). As viruses can be transmitted from a symptomatic or an asymptomatic infected person via various transmission routes which include close contact, coughing or sneezing droplets, aerosols, etc. As viruses are often detected in water as evident from past studies and had led to a considerable number of waterborne diseases due to fecal contamination, industrial, domestic, hospital, and animal wastes in water bodies. Taking the reference Amoy Garden case during SARS-CoV in 2003, the predictions of spreading SARS-CoV-2 by water and aerosols are being made by researchers, some of them found the water samples positive for COVID-19 tests. High concentration of bio-aerosols, volatile organic compounds (VOCs), and other air pollutants also found to worsen the spread of COVID-19 in some of the most polluted countries. This could be more dangerous as compared to other transmission routes. In this study various virus inactivation mechanisms are studied especially physical mechanisms such as UV and Heat which destroy the RNA of viruses. Considering the effective inactivation of viruses which struck in past (SARS-CoV, MERS-CoV, Hepatitis-B, Adenovirus etc.) using UV and heat researchers have suggested applying them for SARS-CoV-2. This article aims to propose solar energy systems for the inactivation of SARS-CoV-2. The various methods studied involve 1) Direct UV, and heat exposure. 2) Photocatalytic / Thermocatalytic / Combined methods for air and water disinfection. Taking into consideration the discrete availability of solar irradiance due to the day-night cycle, and bad weather Thermal Energy Storage (TES) systems to prolong the heat inactivation of the virus by heating air, and water are also suggested. The study also highlighted some Solar driven VOCs removal methods from the air. The systems proposed for this purpose include 1) Trombe wall. 2) Concentrated Solar Collectors (CSC). 3) Combined PV/T air/water purifiers. 4) Integrated Collector Storage (ICS) systems. No current evidences have been found for using these systems in fighting against COVID-

19. Thus the evidence-based study of this paper is aiming to provide a new direction for thermal researchers for research in materials, design, and economic feasibility of solar energy systems to combat with COVID-19.

Keywords: COVID-19, Solar Energy, Catalysis, Water Purification, PV/T, Trombe wall, ICS

List of Abbreviations:

COVID-19	Coronavirus Disease
CoV	Coronavirus
WHO	World Health Organisation
SARS	Severe Acute Respiratory Syndrome
MERS	Middle East Respiratory Syndrome
MHV	Mouse Hepatitis Virus
UV	Ultraviolet
H-CoV	Human Coronavirus
LED	Light Emitting Diode
RNA	Ribonucleic Acid
PPE	Personal Protective Equipment
PC	Photocatalyst
PCR	Photocatalytic Reactor
TC	Thermocatalyst
TCR	Thermocatalytic Reactor
TW	Trombe Wall
PV/T	Photovoltaic/Thermal
TES	Thermal Energy Storage
PCM	Phase Change Materials
MB	Methylene Blue
SWD	Solar Water Disinfection
PCI	Photocatalytic Inactivation
TCI	Thermocatalytic Inactivation
VOCs	Volatile Organic Compounds
HCHO	Formaldehyde
IAQ	Indoor Air Quality
ICS	Integrated Collector Storage
GAM	Generalized Additive Method
CDF	Cumulative Distribution Function

1. **INTRODUCTION:** On December 31, 2019 a pneumonic case reported in Hubei province, China[1], [2]. In the first week of January, 2020 scientists declared the outbreak of Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) in Wuhan, China[3]. Coronaviruses came from a large family which caused a large number of diseases in the last 18 years such as common cold, and even lethal diseases such as SARS-CoV in 2003, Middle East Respiratory Syndrome Coronavirus (MERS-CoV) in 2012 and now in 2019 SARS-CoV-2 which is named as Coronavirus disease (COVID-19) [2], [4]. On March 11, 2020, the World Health

Organization (WHO) declared COVID-19 a global pandemic. WHO identified the transmission route of COVID-19 through respiratory droplets, direct contact, and airborne transmission. According to WHO reports as of May 10, 2020 a total of 4.425 million cases were confirmed, and 302059 deaths were reported in 215 countries.[5] There could be some other COVID-19 transmission routes that have not been reported yet. Past research had found the traces of Coronaviruses and their conservative surrogates in water-bodies such as tap water, hospital wastewater, sewage water, aerosols generated in buildings, etc.[6], [7]. A very few studies had predicted the transmission of SARS-CoV-2 through water. If such predictions prove plausible it could be more dangerous and difficult to control [8], [9]. So the disinfection of water-bodies which could cause COVID-19 transmission should be done. A recent study in Australia by **Ahmed et al.** [10] detected two positive hits of SARS-CoV-2 in untreated water samples collected from two catchments of a wastewater treatment plant in Brisbane, Australia. They also used Monte Carlo simulation to predict the number of infected individuals in those catchments. The model predicted 171 to 1090 infected persons in those catchments considering all the uncertainties and variance in input parameters. The numbers were found in reasonable agreement with the clinical data reported thereafter. Thus a recommendation to adhere to the wastewater sampling and testing in densely populated areas was made.

1.1. **Facts about COVID-19:** The first COVID-19 patient was linked to a seafood market in Wuhan, China with pneumatic symptoms. In that market the selling of live birds, and animals such as bats, snakes, rabbits, etc. was very common. Thus the use of infected birds or animals was supposed to be the potential cause of the viral infection. Further the cases with no history of travel to the market showed viral symptoms and tested positive for COVID-19 proved the human to human transmission of this virus [11]. The potential transmission routes include close contact, coughing or sneezing droplets, aerosols, etc. Now the whole world is facing the spread of COVID-19 and is declared a global pandemic by WHO [12]. Coronaviruses are named so because of the outer crown-like spikes. SARS-CoV-2 has an enveloped spherical shape of 65-125 nm diameter, spikes protruding from the surface which are made up of proteins, single-stranded ribonucleic acid (RNA) as nucleic material of length 26-32 kilobases [11], (1 kilobase = 330 nm) the largest known coronavirus RNA till date, a capsid envelope, and is of a beta-coronaviruses family, which is shown in Fig. 1 [13]. The spikes help the virus in attaching, and entering the target cells of the host [13]–[16]. As similar to its ancestral family members SARS-CoV, and MERS-CoV the SARS-CoV-2 also has the same clinical symptoms leading to lower respiratory tract disease further leading to death especially in the case of elderly and patients with low immune strength [15].

1.2. **Virus Inactivation mechanisms and methods:** As the virus is composed of four main subcomponents namely the glycoproteins (spikes), envelope, capsid, and the RNA as shown in Fig. 1. a). Different inactivation methods are given in the literature, each having different inactivation mechanisms. Three basis for the inactivation, and prevention of SARS-CoV-2 were proposed which are 1) Rupture of membranes 2) Elusion mechanism

and 3) Entrapment mechanism [17]. **Pfaender et al.** [18] explained various inactivation mechanisms and methods briefly for enveloped viruses taking Hepatitis-C virus as a model. They used six different disinfection treatments and observed different mechanisms or inactivation as shown in Fig. 1. b). A set of two physical treatments UV, heat, and four chemical treatments using ethanol, 2-propanol, PVP-I (complex of Iodine), and Triton X-100 (non-ionic surfactant) were used for inactivation of the virus. The heat and UV attacked directly the RNA of the virus, the heat also destroyed the envelope and exposed the capsid of the virus for further attack when incubated at 80°C for 5 minutes which further inhibit the RNA replication. Alcohols did not attack the RNA of the virus but destroyed the envelope and capsid effectively (2 to 3-Log reduction) in 1 minute incubation period. PVP-I killed the virus completely by destroying almost all sub-components. Triton X-100 which is used as a solubilizer for proteins destroyed the envelope of the virus and exposed the capsid of the virus for further attack. **Kampf et al.** studied the persistence of different coronaviruses on different surfaces of common use and their inactivation methods [19]. The study revealed that the previously found coronaviruses remain on surfaces such as glass, plastics, and metals for up to 9 days and can be effectively inactivated using disinfectants of general use in healthcare practices. The study also revealed the higher temperature of such surfaces inhibit the persistence of coronaviruses of these surfaces. An expectation of the same behavior for SARS-CoV-2 was concluded. So cleaning of surfaces with disinfectants such as ethanol, and hypochlorite can inactivate the SARS-CoV-2 effectively in even 1 minute [13]. **Rozenberg et al.** [16] compared the similarities between adenovirus and SARS-CoV-2 and analyzed whether UV inactivation validation of the former could be used for the inactivation of the latter. The study concluded that SARS-CoV-2 is a single-stranded virus which is more sensitive to double-stranded adenovirus, and the UV inactivation attacks the RNA of a virus [18]. The study also suggested the use of UV (254 nm) for 4-Log inactivation as an alternative to chemical disinfectants [16]. Some other researchers explained the mechanisms of inactivation of viruses using antibodies, reactive oxygen species (ROS), and some other techniques to kill them by little injury to infected tissues[15]. Another study revealed the use of neutralizing antibodies from the recovered patients that can be detected even after 24 months and raise the resistance of the body against COVID-19 [14]. Another study discussed about the use of soap to prevent COVID-19 infection, and enlisted some commercially available soap brands in prevention against viruses. The three mechanisms of prevention included membrane destruction, elution (extracting virus from a surface by washing), and virus entrapment followed by washing. The study also suggested not to use soap with hot water as it could cause dermal problems [17].

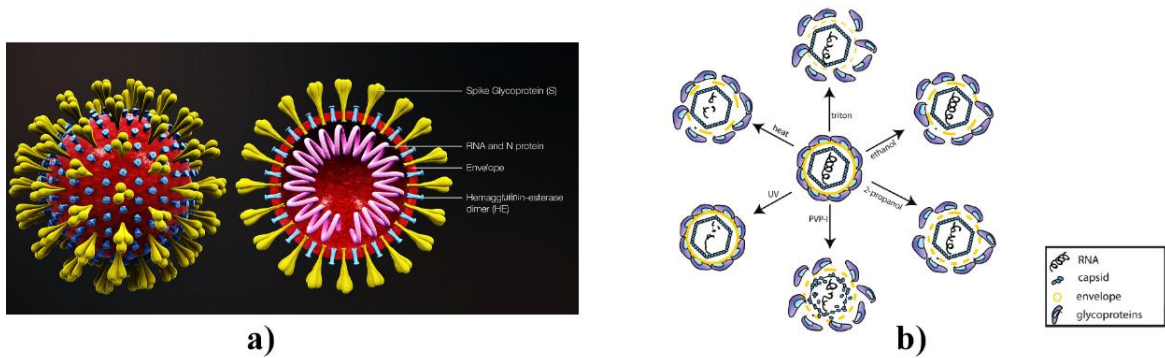


Fig. 1. SARS-CoV-2 structure and virus inactivation mechanisms. a) 3D structure and sectional view of Human-Coronavirus [20]. b) Inactivation mechanisms for the Hepatitis-C virus [18].

- 1.3. **COVID-19 transmission through Water and Air:** Like a lot of researchers had addressed the transmission route of viruses through the water in the past and had highlighted the spread of SARS-CoV [21]–[23]. The main route of COVID-19 spread is via nasal droplets, close contact with infected, touching infected objects, and airborne aerosols, etc. There is a risk of its spread by the use of contaminated water. As viruses are often detected in water as evident from past studies and had led to a considerable number of waterborne diseases such as gastrointestinal illness, viral hepatitis, conjunctivitis, etc.[6], [7], [12], [24]–[27]. The contamination due to the fecal matter, industrial, domestic, hospital, and animal wastes in water bodies generated potential transmission routes for MERS-CoV, SARS-CoV, and MHV which had been reported in the past. [28]–[35]. The Amoy Garden incident during the 2002-2003 outbreak of SARS-CoV had reported the spread among 300 residents of a building in Hong Kong due to wastewater aerosols generated during flushing in toilets which transmitted through building plumbing.[36]–[38]. Taking the reference of such incidents predictions of spreading SARS-CoV-2 by water and aerosols are being made by researchers.[39]–[42]. Some recent studies by various researchers of different parts of the world tested water samples for COVID-19 and found them positive. [43]–[45]. Some of them found up to 1000 genomic copies/liter and with even 75-100% positivity[46].
- 1.4. **Effect of meteorological parameters on COVID-19 spread:** Various recent studies have revealed the dependence of COVID-19 spread on the weather conditions. **Xie and Zhu** [47] in China associated a correlation between the COVID-19 cases and ambient temperature using a Generalized Additive Method (GAM) and found a positive correlation between the two below 2°C and vice versa. A study of pandemic in New York, USA by **Bashir et al.** [48] found a correlation between the local climatic parameters such as temperature, humidity, rainfall, air quality, and wind speed with COVID-19 outspread using Spearman’s correlation method. The study concluded average temperature, minimum temperature, and air quality as significant parameters. Another similar study in Turkey **Şahin** [49] established the correlation between the COVID-19 cases and local climatic parameters throughout the incubation period of 14 days of SARS-CoV-2. The

temperature of the same day, wind speed on 14 days ago, and the population were found more significant parameters. In Jakarta, Indonesia **Tosepu et al.** [50] found average temperature the most significant parameter in correlation with the number of cases. In Brazil **Prata et al.** [51] also similar results with a negative correlation between temperature and number of cases were observed. A threshold value of 25.8°C was reported by a model with a robust mathematical model. A detailed study in Iran **Ahmadi et al.** [52] included intra-provincial movement, solar radiation, and previously infected people in addition to the parameters used by [48]. Partial correlation coefficient method was used to establish the correlation. The analysis shows that population and intra-provincial movements have a direct relationship with the infection rate. The areas with low solar radiation and low humidity are more prone to the outbreak. They also concluded that the COVID-19 outbreak is created due to sunspot phenomenon and predicted such type of pandemics at approximately 10 years of interval. **Jahangiri et al.** [53] in Iran used receiver operating characteristics (ROC) method to estimate the sensitivity and specificity of ambient temperature and population on the rate of increase of COVID-19 spread. Population was concluded more sensitive and strict inspection and preventive actions were suggested for densely populated areas of the country. **Coccia** [54] added one more important parameter in addition to other environmental parameters to the estimation of infection correlations. The emphasis on air pollution to human transmission of COVID-19 was given. The author took the reference of high infection rate and mortality percentage in Italy as a reference for the study. The most polluted cities in Italy were reported with the maximum number of cases. The reason behind that was majorly assumed to be the high concentration of bioaerosols, volatile organic compounds (VOCs). The facts were also supported by the proof that the mortalities caused were majorly among the elderly with a history of other respiratory diseases due to high pollution. Another supporting fact found was the presence of particulate matters (PM) which affects the immunity of children and the elderly. **Ma et al.** [55] investigated the effect of temperature, its diurnal range, and humidity on the deaths due to COVID-19 in Wuhan, China. GAM method was used by making a model with meteorological and pollution data as input. They concluded that the diurnal temperature range showed a positive relationship with the deaths, humidity showed the negative, and a thermally stable and comfortable environment was suggested for the patients in quarantine facilities and hospitals. [56] investigated the authenticity of using the Cumulative Distribution Function (CDF) method as an alternative to the exponential growth method and found it valuable. They also concluded that the mathematical methods couldn't predict the number of COVID-19 cases during initial stages i.e. first 2-3 weeks. The causes of variability of prediction were identified as spread dynamics, population density, individual protection methods, and local meteorological factors etc.

The correlations discussed above may be subjected to many limitations due to area specificity and lack of transparency in the data provided by countries. Thus the

meteorological parameters that affect the COVID-19 spread include average temperature, diurnal temperature range, relative humidity, rainfall, air pollution, aerosols, population density, intra-provincial movement, and solar radiation. Among all these the parameters which showed positive correlation and may increase the outspread of COVID-19 are diurnal temperature range, rainfall, aerosols, population density, and intra-provincial movements. The parameters which show negative correlation and may decrease the outspread of COVID-19 are average temperature, relative humidity, and solar radiation.

To the author's best knowledge it is the first study proposing the use of solar energy in fighting against COVID-19. The main work in this study includes (1) In the Introduction part of this study the facts about SARS-CoV-2 are discussed by reviewing some recent and past studies. Various virus inactivation mechanisms are also discussed taking the reference of other viruses. Virus transmission through water and air is also reviewed. Some recent mathematical studies also reviewed to understand the behavior of COVID-19 spread with the variation of meteorological parameters. (2) In the second part the study proposes UV and Heat inactivation methods to fight against SARS-CoV-2 present in water and air. Looking at the potential threat of virus transmission through bio-aerosols generation due to VOCs, and other respiratory and immune threatening associated with it some methods for VOCs oxidation are also included. (3) In the third part various solar air and water disinfection systems are reviewed and proposed for the viral inactivation during the COVID-19 pandemic. A small review of TES and ICS systems is also added. (4) At last some conclusions and suggestions have been made for the proposed UV and Heat inactivation methods for disinfection of facial masks, PPE kits, health care equipment, public transport, food items, household water, utensils, portable quarantine facilities, hospital wards, etc.

2. **PROPOSED INACTIVATION METHODS OF COVID-19 IN WATER AND AIR:** As per the literature reviewed the most effective method to inactivate the virus is by the destruction of its subcomponents. Most of the preventive or inactivation methods make use of chemicals that have the limitations of storage, safety, supply, handling and their by-products could be carcinogenic to affect human health [16]. To inactivate virus from water and air such chemicals could not be possible on a larger scale thus the use of UV light and heat is suggested as these mechanisms are effective and can be used for disinfection of large quantity of water such as hospital wastewater, drinking water, water for washing vegetables & fruits, inactivating airborne viruses outside the host in the quarantine facilities, facial masks, Personal Protective Equipment (PPE) kits, hospital beds, etc.
 - 2.1. **Proposed UV-Inactivation for COVID-19:** A lot of studies proposed the use of Ultraviolet (UV) light for disinfection of water and air against bacteria, and viruses by DNA

and RNA damaging by photo-inactivation (PI) and photo-catalytic-inactivation (PCI), thus inhibiting protein formation in such pathogens [57]–[64]. It was found that out of the complete UV spectrum UV-C was most effective for water and air disinfection against viruses [57], [58], [65], [66]. Another group of researchers performed studies on the disinfection of facial masks, and PPE kits using UV-C radiation [67]–[69]. PI and PCI can be performed using solar radiation, the limitation of which is the unavailability due to the absorption of UV-C by the ozone layer. Solar radiations consist of UV-A and UV-B which are ineffective because bacteria and viruses build resistance against them [57]. UV-C can be artificially generated using UV lamps, LEDs, portable devices, etc. [70]–[74]. There are few limitations of using UV disinfection of water such as it was found in some studies that UV-C is not sufficient for a considerable reduction of deadly viruses such as Adenovirus, Poliovirus, and Hepatitis-B virus. Also, the disinfection of water using the artificial UV method is not feasible at large scale disinfection such as for large water-bodies, sewage water, hospital wastewater, etc. UV systems also face problems due to trapped viruses in the hidden corners where UV illumination could not reach. Thus looking at the severity caused by pandemic COVID-19 it is suggested not to rely only on UV disinfection[75]. Some researchers suggested a combination of UV and thermal inactivation techniques for COVID-19 [69], [75].

- 2.1.1. **UV-Inactivation for Water disinfection: Lisa et al.** [57] Evaluated the performance of a handheld UV-C water disinfection device in Germany to verify the claim (99.9% reduction of pathogens) made by the manufacturer SteriPEN®[76]. The device provides around 8000 treatments of 500ml water, comes with a chargeable battery, compatible with almost all types of bottle materials except quartz, sensors embedded for automatic working, and automatic prolongation of the working cycle in cool ambient conditions. It functions simply by putting the UV knob inside a pre-filtered water in a bottle and stirring it in the due action for about 48 seconds of irradiation by PI. The effect of using different bottle materials was also studied as shown in *Fig. 2*. The research concluded that the water needs to be turbidity free before disinfection, stirring gave better results irrespective of the bottle material, and the claim made by the manufacturer was true.



Fig. 2. The handheld water disinfection device SteriPEN® [57], [76]

Minh et al. [77] investigated the performance of a UV-LED based wastewater treatment for reuse or discharge. A strong virus surrogate was used as a pathogen for experimental study. A UV-LED system with an array of LEDs was used as a UV light source as shown in *Fig. 3*. A lab-scale UV reactor was designed in which the sample was placed at a distance of 3 cm from the LED with a peak wavelength emission of 277 nm. The effect of the wastewater flow rate on the transmittance of UV light was measured which showed a decrease with an increase in flow rate. Before UV disinfection an inclined settler and filter system was also used for turbidity reduction. A 3.7-Log reduction of pathogens at a low flow rate was observed at a UV dose of 69.4 mJ/cm². The disinfection rate reduced with an increase in water flow rate. The effect, cause, and reversal of fouling on the UV reactor was also discussed.

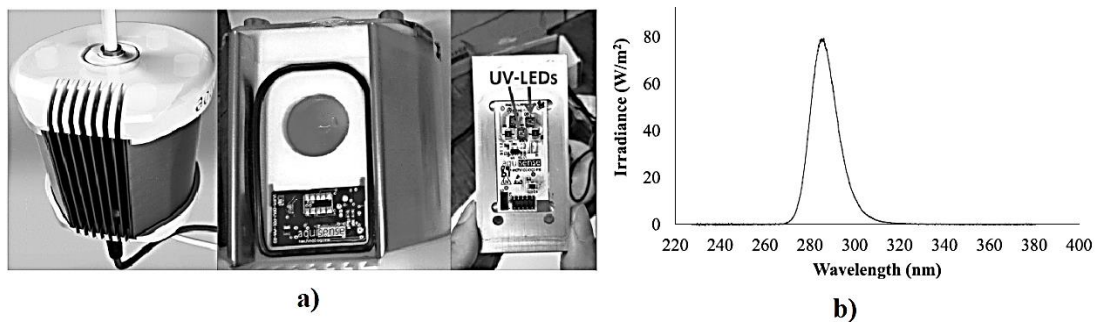


Fig. 3. UV-LED for water disinfection [77] a) Flow through type UV reactor. b) Spectral behavior of LED.

Oguma et al. [78] designed a ring-shaped LED system with twenty LEDs for water disinfection. An experimental setup was designed to emit peak emission at 285 nm for the inactivation of E-coli, adenovirus, MS2, and single-stranded Q β virus in water. It was the first study applying UV for adenovirus inactivation. As it was found that 185 mJ/cm² of irradiation was required to inactivate viruses, this setup was designed keeping in mind the similar requirements. The authors suggested applying the

combinations of different wavelengths for effective inactivation of viruses keeping in mind the efficiency of LED. The same group investigated the inactivation kinetics and LED efficiency against five same set of microorganisms [79]. Three LEDs with peak emission at 265, 280, and 300 nm were used and results were compared with conventionally used 254 nm low pressure LED. It was observed that different microorganisms responded differently to the different peak emission wavelengths. It was concluded that among all the 280 nm LED showed higher inactivation and consumed lower energy. Another group of researchers **Nyangaresi et al.** [72] studied the effect of using a single, and a combination of multiple UV-LEDs for water disinfection against E-coli. The LEDs used were having the peak emission at 267, 275, and 310 nm wavelength, and three combinations using two of them as shown in Fig. 4 a) & b). The experimental results show that 3-Log and 4-Log reduction of E-coli required 8.78, and 11.52 mJ/cm² at 267 nm as shown in Fig. 4 c). Two bacterial reactivation mechanisms namely dark repair and photo-reactivation were also compared and found that the former was lower as compared to the latter. 275 nm LED showed better test results against photo-reactivation and was concluded better for water disinfection.

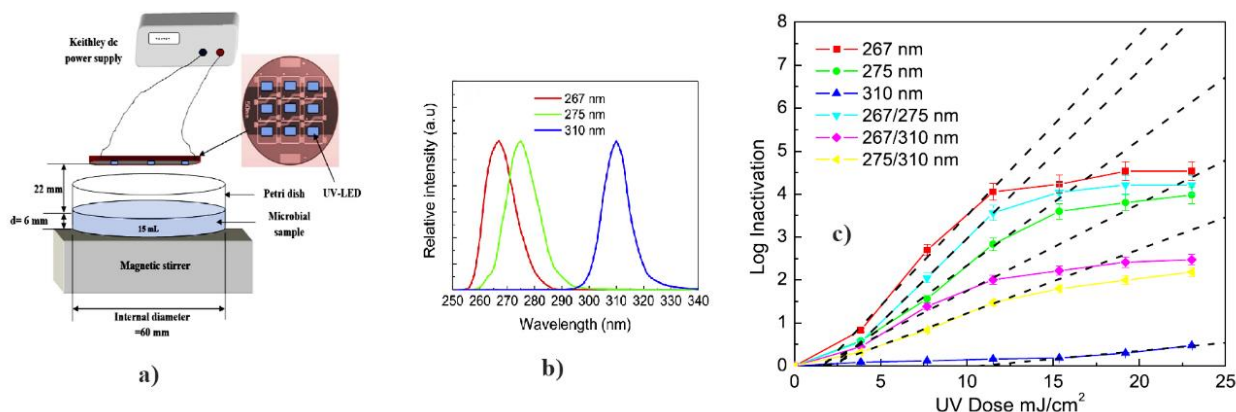


Fig. 4. Water disinfection using UV-LED [72] a) UV-LED setup. b) Spectral emission of three different UV-LEDs. c) Log inactivation of E-coli for different wavelengths and energy dose.

2.1.2. **UV-Inactivation for Air disinfection:** As viruses can be transmitted from a symptomatic or an asymptomatic infected person to others through direct contact, food, respiratory droplets, aerosols, etc. Under certain environmental conditions airborne droplets, and aerosols can remain in the air for hours [13]. Therefore it is important to inactivate viruses in the air. In the past few researchers had done studies on the inactivation of various viruses such as influenza virus [80], Hepatitis-B virus [81], Murine-Norovirus [82], adenovirus [25], and other potential surrogates using PI and PCI techniques. Most of the studies included the UV and TiO₂ based PCI techniques. **Nakano et al.** [80] studied the inactivation of the influenza virus i.e. a single strand enveloped RNA virus using UV-A and TiO₂ thin film as a catalyst. A 4-Log viral reduction was observed within a short duration by the mechanism of protein degradation. It was found that the inactivation was

dependent on UV-A irradiation, irradiance time, and temperature. **Zan et al.** [81] studied the effect of using TiO₂ coated ceramic in the PCI of the Hepatitis-B virus using a mercury lamp at 365 nm. It was found that using the TiO₂ catalyst the virus can be inactivated at even weak UV light. The TiO₂ being a narrow band semiconductor oxide generates reactive oxygen species (ROS) such as hydroxyl, and superoxide when it is energized, which attacks the protein capsid of a virus, breaks its binding sites thus it can easily inactivate the chlorine, and UV resistant viruses [83]. **Vohra et al.** [84] studied the enhancement of PCI of airborne microbes. A Silver-ion doped TiO₂ -reactor on the recirculation air setup was tested for different microbes. The results showed complete inactivation time was reduced by many folds for each tested microbe as compared to the case without using Ag⁺ doped TiO₂ catalyst.

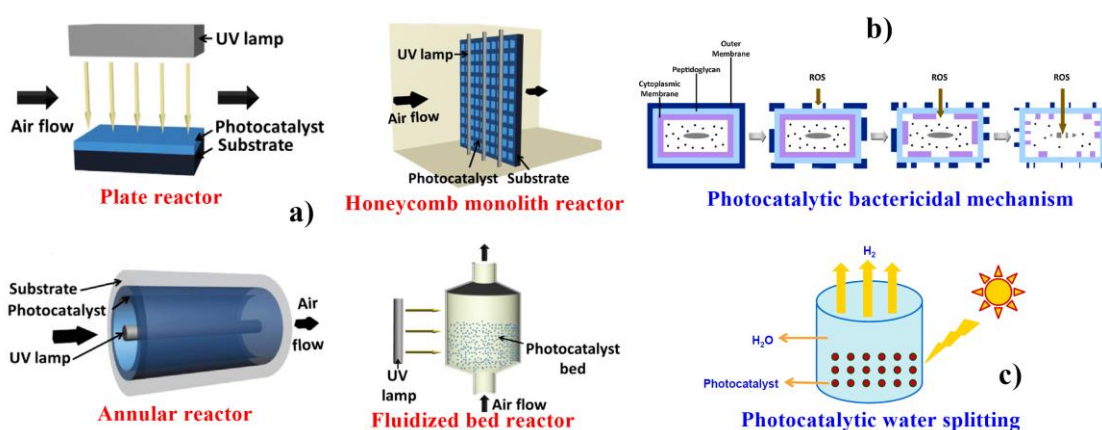


Fig. 5. Photo-catalytic reactor for air purification. a) Various designs used by researchers [85]. b) The PC bactericidal mechanism [85]. c) PC H₂ generation by PC water splitting reactor [86].

Ren et al. [85] reviewed the mechanism, materials, and designs used for PCI of pathogens, and air pollutants. The various Photocatalytic Reactor (PCR) designs are shown in Fig. 5. a). The designs are important as the effectiveness of the PCR depends on the geometry, specific surface area, and distribution of PCs. The steps of bactericidal reaction as shown in Fig. 5. b), are 1) The outer membrane is destroyed by the ROS which exposed the inner layers of bacteria. 2) The ROS enters through the permeable outer membrane into the cytoplasmic layer and destroy it. 3) Now ROS can reach and destroy the intercellular components of bacteria which causes its death. In contrast the viruses have a simpler structure that contains only protein shell (capsid) and DNA or RNA as the interior genome. Thus the PI and PCI of viruses are done by destruction of the outer capsid, and further destruction of the internal genome leading to its death. Nano-technology researchers had contributed to the design of PCRs by preparing various synthesized PCs in the form of nanoparticles, nanobelts, nanotubes, nanobrushes, etc. Some research work using PC reactions to generate H₂ fuel using water splitting reactions was also found[86]. **Benigno et al.** [87] did the realistic study of PCR for the elimination of indoor pollutants. TiO₂ sol-gel film was used in an

annular reactor. It was concluded that PC-reactor with UV-A performed comparably as that of conventional UV-C based reactor. Thus PCs reduce the cost of the reactor and eliminated the use of harmful UV-C radiations. Seven different VOCs were oxidized in the reactor.

2.2. **Thermal Inactivation for Water and Air disinfection:** The cases of SARS-CoV had been studied by researchers and was found to remain in the stool of patients up to 3 weeks after infection [29], [88]. The stability of COVID-19 in water is also reported. A lot of studies revealed the reduced stability of conservative surrogates of COVID-19 in warmer water as compared to colder water. The comparison has been made on the reduction time of different virus populations in different samples of water from different sources as shown in *Fig. 6*. It can be seen that at low temperatures the 99.9% population reduction time is higher for each sample collected from all the sources of infected water. If we take the case of tap water shown in *Fig. 6*, the disinfection time for H-CoV is reduced to half with 19°C increase in water temperature [31]. It is also seen that Coronaviruses die easily in wastewater as compared to freshwater, the reason being the less stability of enveloped viruses in such environments due to solid settling. At higher temperatures the viruses die because of denaturation of proteins and agitated extracellular enzymes. [30], [31], [89]. Thus after reviewing the behavioral characteristics of COVID-19 and its conservative surrogates in the water at different temperatures, there is a scope for thermal researchers to take part in fighting against the COVID-19 pandemic by Thermal Inactivation (TI) techniques.

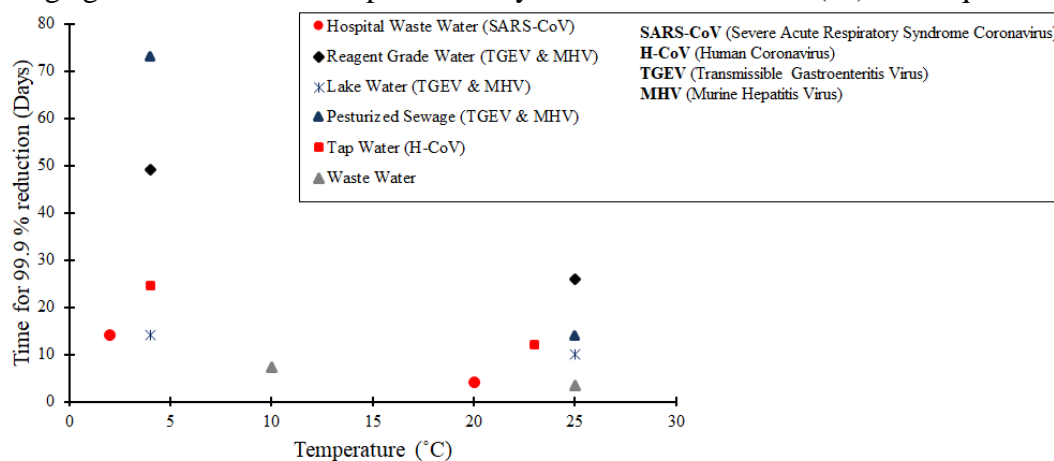


Fig. 6. Inactivation of viruses in different sources of water at different temperatures [31], [90].

A lot of studies proposed the use of thermal energy for the disinfection of water against bacteria, and viruses by Thermocatalytic Inactivation (TCI). Few studies revealed that a temperature range of 40-80°C is required when transition metal oxides such as MnO₂, CuO, and TiO₂ used as Thermal Catalyst (TC) in Thermocatalytic Reactors (TCR) [91]–[95]. Few studies found that disinfection can be possible even at room temperature when used with noble metals such as Pt, Pd, Au, and Ag for TCR [94], [96]–[99]. As it is evident from *Fig. 6*, SARS-CoV-2 and its conservative surrogates

are sensitive to higher temperatures. The temperature range discussed in the literature for water disinfection against COVID-19 lies in the range suggested for TCR reactions for water purification [12], [30], [31], [89]. Thus thermal inactivation is a tentative research area for thermal researchers in fighting against COVID-19 [92]–[94], [99]–[102]. **Lee et al.** [82] studied the TCI of a surrogate for Human-Norovirus under various environmental conditions. It was found that the virus survived for about 40 days on a diaper and in fecal deposits. Inactivation time was reduced from 40 days to 24 days by increasing the temperature from 18°C to 30°C without any catalyst which can be reduced to even one hour at 56°C. It was also observed that the virus was susceptible to freezing and thawing but was stable at room temperature.

3. **PROPOSED SOLAR ENERGY SYSTEMS FOR INACTIVATION OF COVID-19:** Solar energy being a good source of UV, and other thermal radiations are being used for air purification against microorganisms, and other pollutants using different mechanisms. Some PC solar systems were found in the literature for air and water purification. **Ching et al.** [103] investigated the PC degradation of formaldehyde (HCHO) using solar energy. The reactor was made of borosilicate glass with an inner coating of TiO₂ sol-gel film. The performance of TiO₂ sol-gel film was compared with that of Degussa-P25-TiO₂ coating, the latter was found superior due to more surface area. A mathematical correlation was derived and its results were found in good agreement with the experimental results. Solar UV-A with 0.6 mW/cm² was used as a light source which gave 5-Log reduction of HCHO in about 60 minutes in the presence of TiO₂. **Nie et al.** [99] identified the need for air purification in houses, cars, offices, and other occupied spaces. Indoor air pollutants are mainly volatile organic compounds (VOCs) among which HCHO is a major carcinogenic pollutant. HCHO is widely found in many building materials such as fibreboard, glues adhesives, insulation materials, etc which can be oxidized to CO₂ and H₂O by TCR using transition metal oxides and noble metals when the suitable temperature is provided as shown in *Fig. 7 c*), [96]. **Yu et al.** [93] studied the TC oxidation reaction using MnO_x-CeO₂ using solar energy as a heat source in China. A test chamber was conducted and pass-through experiments were performed. A numerical model of HCHO oxidation and system performance was made and was found in good agreement with the experimental results. A parametric study was performed to study the effects of initial HCHO concentration, indoor air temperature, solar irradiation, and ambient temperature on the oxidation performance. It was concluded that initial HCHO concentration was an important parameter than solar irradiation, and ambient temperature. The use of solar energy reduced the oxidation time to one-third for the threshold limit of Chinese indoor air quality (IAQ) standards.
 - 3.1. **Trombe Wall for Air disinfection:** A conventional Trombe Wall (TW) or solar wall stores the thermal energy from the sun during the day time in some material say in thermal pebbles or masonry wall painted black and releases the same during night time by radiation into the comfort space. **Yu et al.** [101] considered a Photocatalytic Trombe wall (PC-TW) for space heating and air disinfection in China. TiO₂-P25 was coated on the inner surface of the

glazing of TW. The UV part of incoming solar irradiance was absorbed by TiO_2 for oxidation of HCHO. The remaining visible and IR part was absorbed by the thermal mass for space heating. The reaction kinetics, mass transfer model, thermal model of the setup was made and simulation results were in good agreement with the experimental results. Using the models seasonal performance and economic study was done. The system removed 100 mg of HCHO and cleaned 164 m^3 of air daily per m^2 of the wall area. An increase in heating contribution from the thermal wall was observed as compared to conventional TW. A 12.1 years payback period was calculated for the PC-TW setup. **Wu et al.** [104] did a numerical investigation of the PC-TW system. Based on experimental data in literature a 2D numerical model of purification kinetics and thermal behavior of PC-TW was made and simulated using COMSOL multiphysics software. The effect of environmental parameters such as solar intensity, an inlet temperature of the air, and wind velocity was observed on the oxidation and thermal performance. The airflow behavior was demonstrated using velocity, concentration, and temperature field contours for four different widths of the air gap. The major conclusions of the study were, 1) With an increase in radiation intensity the thermal efficiency increase, but the purification first increase then decrease. 2) At 15°C ambient temperature the purification was maximum. 3) The thermal efficiency decreased with inlet temperature increase. 4) The thermal performance was maximum for 4 cm and purification of air was maximum at 5 cm width of the air gap.

Bendong et al. [94] proposed a novel Thermocatalytic Trombe Wall (TC-TW) using solar energy for simultaneous space heating and formaldehyde oxidation. As the HCHO conversion was greatly dependent on the air temperature as shown in $\text{MnO}_x\text{-CeO}_2$ was used as TC as its absorptivity was higher i.e. 0.92 - 0.98 (close to black paint) than that of TiO_2 in the solar spectrum range (200 - 1600 nm). The catalyst temperature increased to about 90°C which increases the HCHO conversion as compared to the reference case without TC-TW. One more added advantage was observed with using solar energy as compared to an electric heater due to combined photo-thermo-catalytic inactivation. A total energy of 97.4 kWh/m^2 was reported based on a verified numerical model. A parametric study was performed and the variation of heating efficiency, HCHO degradation efficiency, and integrated efficiency with solar irradiation, ambient temperature, catalyst thickness, and air gap thickness was observed. It was concluded that solar irradiation and air gap thickness had a considerable effect on integrated efficiency. An air gap of 10 cm thickness was suggested for better integrated efficiency. The same group of researchers proposed a novel design of sandwiched TC-TW as shown in *Fig. 7. b) & d)* intending to increase thermal and air purification performance as compared to conventional TC-TW [100]. The reaction kinetics, mass transfer model, thermal model of the setup was made and simulated for three days in six heating months of a year using MATLAB using the meteorological data of Hefei, China from Energy-plus software. The results showed a 2 cm thickness of the insulation layer improved clean air capacity by 20.9% and a thermal load reduction by

34.9%. Thus the proposed setup performed the thermal load reduction and HCFC oxidation satisfactorily.

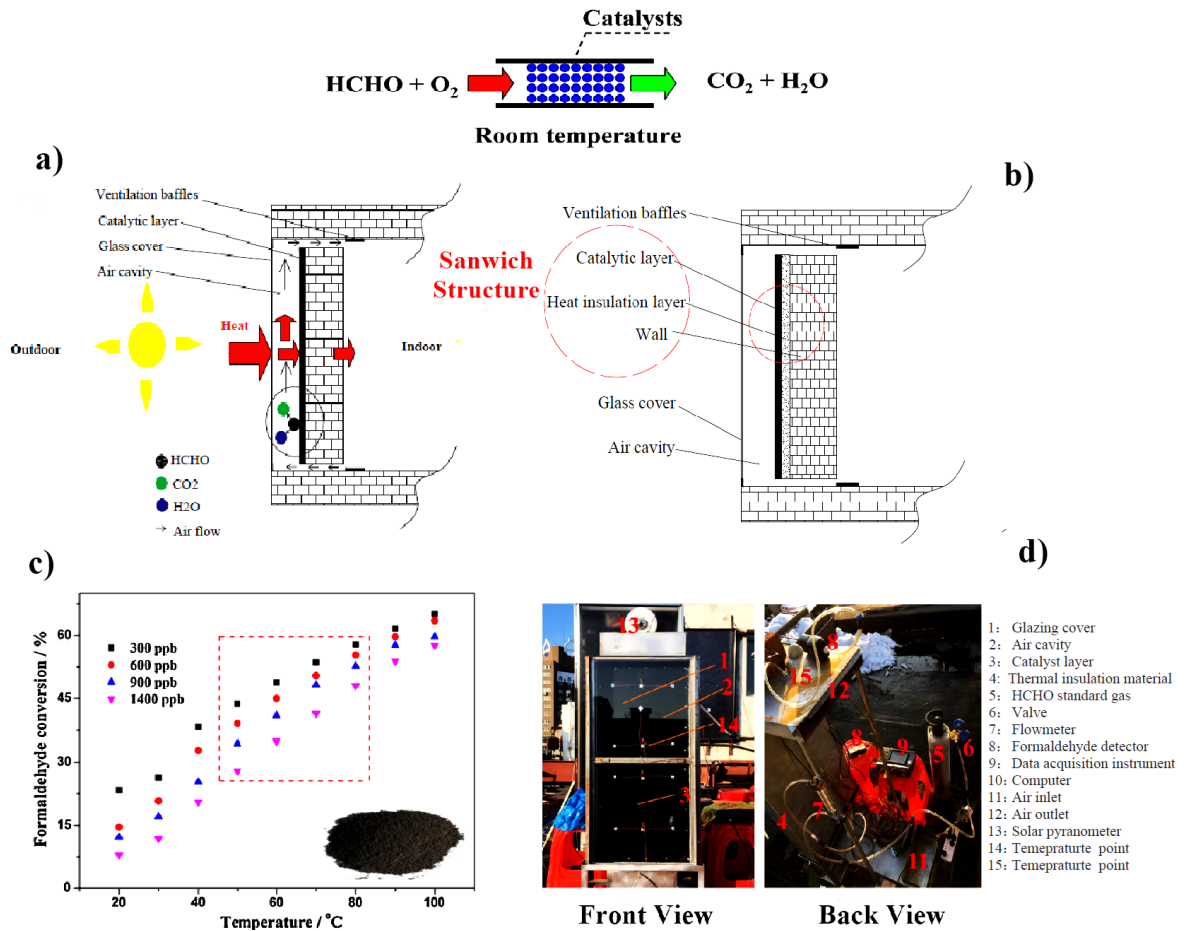


Fig. 7. TC-TW system. a) Conventional TC-TW working [93]. b) Proposed sandwich TC-TW with a 2cm insulation layer between the TC layer and wall [100]. c) HCHO conversion behavior of $\text{MnO}_x\text{-CeO}_2$ with temperature and at different initial concentrations [93]. d) Experimental setup of the sandwiched TC-TW system [100].

3.2. Solar PV/T Systems for Water and Air disinfection: In most of the overpopulated countries like India, China, etc. water sanitation is a problem in rural parts, and it is difficult to lay down potable water pipes there[105]. Thus Solar Water Disinfection (SWD) can be used to sanitize water[95], [106].

SWD technologies mainly include the following:

1. Solar UV based PCI of pathogens and oxidation of VOCs pollutants into CO_2 and H_2O [99].
2. Solar UV caused direct cellular damage to the DNA and RNA of pathogens [66].
3. Solar photochemical inactivation pathogens and oxidation of VOCs [107].
4. Solar photovoltaic (PV) generated electricity to energize UV-lamps to disinfect water [63], [73].

5. Solar thermal energy to drive TCI of pathogens and oxidation of VOCs. [92], [94], [100].

The existing water purification techniques find some limitations such as slow disinfection, low capacity, and most of these systems require auxiliary devices such as pumps for recirculation[63], [95]. A lot of efforts had been made by researchers to increase the functionality of SWD systems such as, use of aluminum foil reflectors [107]–[109], selective coating/paints [91], [108], [110], solar concentration[106], [109], and addition of photo-catalytic additives[91]–[93], [99], [111]. Solar energy that reaches earth surface is composed of 5% UV, 50% visible, and 45% Infrared (IR) radiations. The PCI mainly uses the UV part of solar radiation [57]–[64]. Some researchers have made efforts to use visible, and IR part of solar radiations for water disinfection[93], [97]. Solar PV/T hybrid systems are designed to take the advantage of full spectrum of solar radiations for simultaneous electricity generation and thermal heat utilization. Many researchers investigated experimentally the performances of PV/T hybrid water disinfection systems[63], [112]–[115].

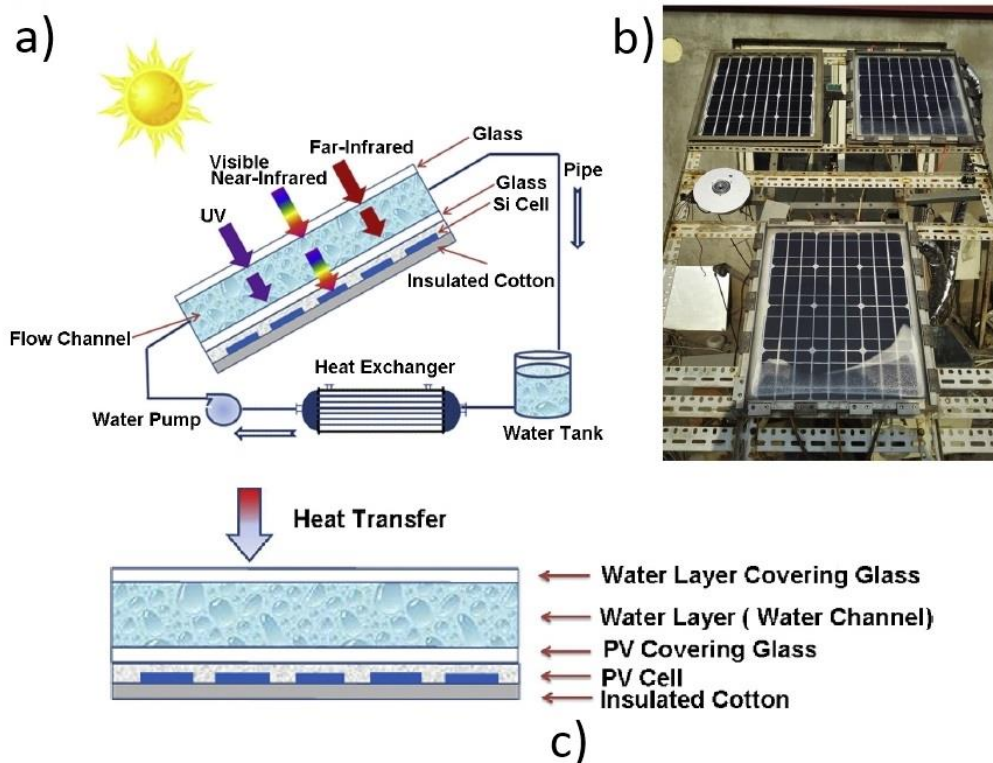


Fig. 8. PV/T water disinfection system a) Schematic of PV/T hybrid system b) Experimental setup c) Different layers of absorber [95].

Jin et al.[95] studied the performance of a PV/T hybrid SWD and electricity generation system simultaneously in Tianjin, China. The experimental setup used is shown in *Fig. 8*.

It consisted of a mono-crystalline PV cell, a borosilicate covering glass, and an optional provision of a heat exchanger. The glass cover used had a transmissivity of 0.83 and 0.9 for UV and IR radiation. The E-coli (Strain 12) pathogen was used as a pollutant which was used as an indicator of fecal waste in the water. The DNA damage took place due to UV-A and UV-B radiations directly. It was observed that water temperature exceeding 45°C further inhibited the DNA repair of pathogens. The use of heat exchanger reduced the maximum temperature (50 °C to 30 °C) and was declared infeasible due to increased cost and reduced water purification. A mathematical model for ambient temperature and solar irradiation was made and simulated results were found in good agreement with the experimental results. The model was used to simulate the performance of setup in two different locations for feasibility analysis namely Lhasa, China (29.65°N, 91.14°E), and Chennai, India (13.08°N, 80.27°E). Heat absorbed by water reduced the PV temperature which increased the electrical efficiency of setup. An economic study was also performed by considering various costs for 25 years lifetime of setup, and found the system economic with 134 days payback period. Chennai was found more compatible with 232 days with water temperature above 45°C as compared to 14 days in Lhasa.

Wang et al. [113] were the first group to propose a PV/T hybrid SWD system. They studied the degradation of harmful pollutants which enter the water through pharmaceutical waste, surfactants, industrial waste, etc. using PV/T hybrid SWD system in Tianjin, China. Three organic pollutants 4-chlorophenol, Methylene Blue (MB), and Acid Red 26 were used to demonstrate the performance. A mono-crystalline PV panel covered with iron tempered glass was used as a PV unit, and a borosilicate glass (BSG) cover was used to cover the water envelope. A mixture of pollutants in deionized water with photo-catalyst (suspended TiO₂ nanoparticles) was made to run in the water envelope having 6.5-liter capacity. The effect of using different pollutant concentrations (5-20 mg/liter) on UV transmittance, and concentration reduction was observed. The PV produced 10W power which was sufficient to run the pump. A 99% reduction of pollutants by converting them into CO₂ and H₂O was achieved by exposing the setup for 90-120 minutes in light. The same group [114] in their earlier research performed the reduction experiments with only MB as a pollutant using PV/T as shown in *Fig. 9*. The system demonstrated the use of UV for photo-oxidation, visible + Near IR for electricity generation, and Far IR for heating water in a single autonomous system.

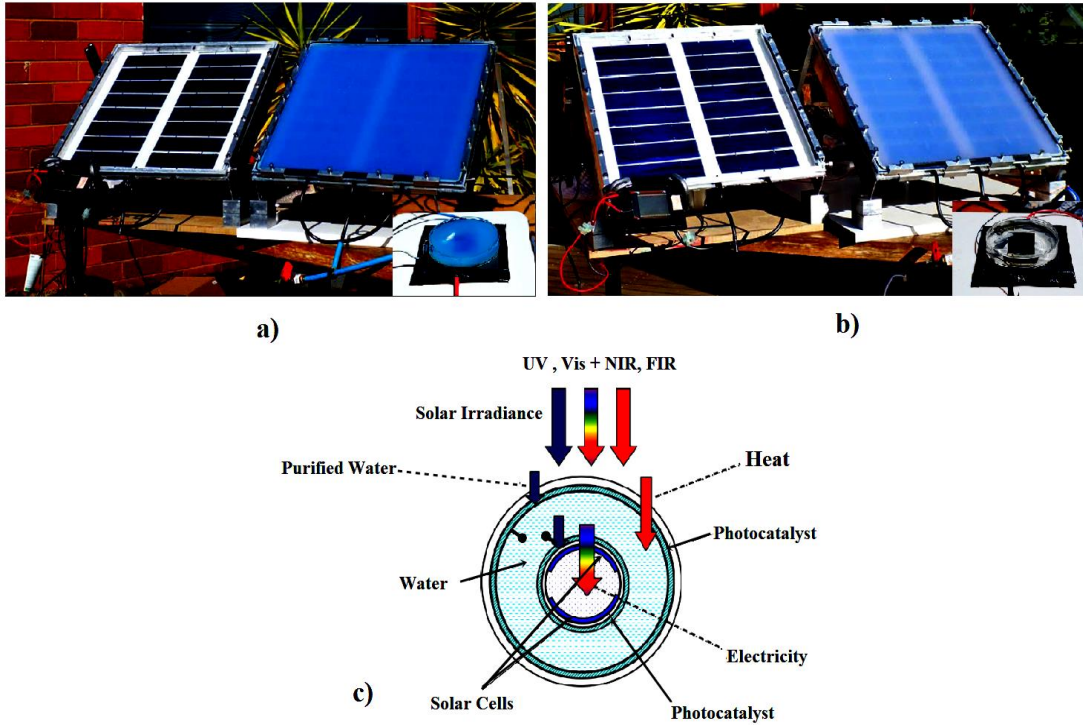


Fig. 9. PV/T SWD system. a) The reference set-up in left and MB contaminated in right before the experiment. b) Reduced MB concentration after performing reduction. c) A proposed cylindrical setup for ease in the flow of water [114].

The performance of a lab-scale setup was tested in two seasons namely summer, and autumn of Australia. A better log reduction of MB was observed for summer (6-Log) as compared to that of (0.25-Log) in autumn. The MB dye reduced the transmittance of light through the water layer considerably (45% for MB, water, and TiO_2 mixture) and affected the PV performance. As the MB concentration reduced after 18 minutes as shown in Fig. 9. a) & b) the PV output increased due to increased transmittance of Visible + Near IR radiation. The same group of researchers suggested a tubular PV/T hybrid SWD reactor of cylindrical configuration as shown in Fig. 9. c) for better flow of water and double surface area for catalytic layer deposition [115].

- 3.3. **Concentrated Solar Collectors for Water and Air disinfection: McLoughlin et al.** [109] used a compound parabolic collector (CPC) with PV/T hybrid SWD system working on the photo-catalysis principle. The main objectives of the study were (1) To incorporate CPC in water disinfection. (2) To study the effect of the collector area on disinfection. (3) To access the continuous photo-catalyst suspension in water for continuous flow. An experimental setup composed of a CPC and 8 Pyrex tubes with two different collector areas (1m^2 , and 3m^2). TiO_2 was added in water as a slurry in three different concentrations (3, 6, and 9 mg/liter). It was concluded that using CPC, and increasing the collector area had a positive impact on E-coli (Strain 12) pathogen inactivation considerably. But the TiO_2

concentration gave mixed results at high concentration due to reduced UV transmittance, thus low concentration was suggested. Another similar study by **Navntoft et al.** [107] used aluminum reflectors for solar concentrator in a field disinfection study of well water in Spain. Water samples were filled in plastic water bottles, and BSG tube. E-coli was used as a target pathogen and its regrowth after disinfection was also discussed. The disinfection performance was in the order with CPC with BSG tube being the best, then BSG tube without CPC, and least for plastic bottle requiring 90, 120, and 180 minutes for 6-Log reduction in E-coli population in water respectively. The effect of aluminum degradation with time on CPC performance was also considered, and it was found that the reflectivity of aluminum reduced from a constant value of 87% to variable values between 27-72% after 3 years. New CPC performed well as compared to old ones even in cloudy conditions. Similarly **Nalwanga et al.** [106] evaluated the disinfection of E-coli using a 25 liter BS glass batch reactor as shown in *Fig. 10 a)* used with CPC tested for 17 months in Kampala, Uganda. They pointed out the problem with using plastic bottles for UV disinfection i.e. irregular shape of bottles, incident radiation on the exposed side, and absorption of UV-B solar radiation. The effect of yearly ambient conditions namely sunny, cloudy, and overcast. A satisfactory inactivation of the E-coli population was observed but the overcast conditions resulted in incomplete disinfection [112]. **Qin et al.** [112] used a V-trough concentrator in PV/T water purification system with TiO₂ as a PC. A comparison was made using Acid Red 26 as an indicator for performance as shown in *Fig. 10 b), c)*. Results showed a reduction of discoloring time by 33.3%, and 54.5% for initial pollutant concentration of 10 mg/liter, and 20mg/liter respectively with the use of V-trough concentrator and maximum 33W of electrical power is generated by PV. The same group of researchers later used the same setup to evaluate its performance against E. coli, and Salmonella for water disinfection. The combination of V-trough collector and small amount of H₂O₂ greatly enhanced the performance of water disinfection. The system took about 1.25, and 2.5 hours for 5-Log reduction of E. coli, and Salmonella respectively as shown in *Fig. 10 c)*. along with 43 W of maximum power generation [116].

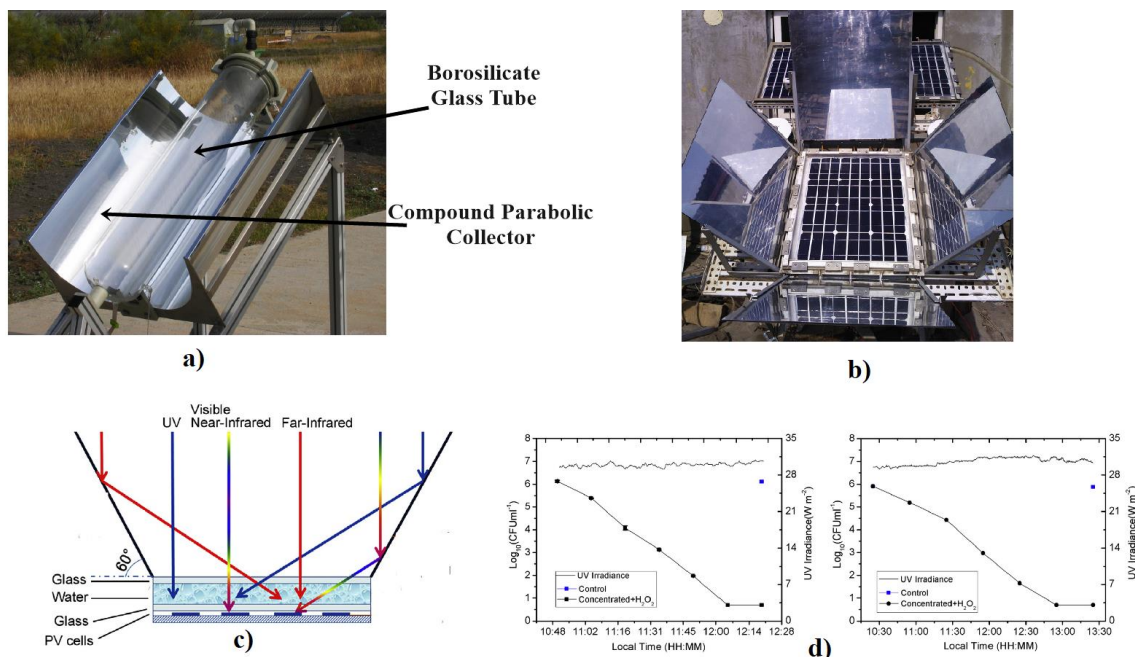


Fig. 10. Concentrated SWD system. a) CPC collector and borosilicate glass tube system [106]. b) V-trough concentrated system [116]. c) Mechanism of SWD using V-trough collector [116]. d) Log reduction of *E. coli* (left), and *Salmonella* (right) [116].

3.4. **Integrated Collector Storage (ICS) for water heating:** As it is evident from the literature that some viruses are susceptible to high temperature [30], [31], [89]. The same behavior was observed for coronaviruses [117], [118]. Heating is an effective physical mechanism of the inactivation of viruses that destroy the RNA of viruses [18]. The traces of SARS-CoV-2 had been predicted by some researchers [43]–[46]. Thus it becomes important to inactivate viruses to reduce the increasing number of COVID-19 patients. As shown in Fig. 6. for 99.9% reduction of H-CoV from water takes about 12.1 minutes when the temperature of the water reaches 23°C and around 2 minutes for hospital wastewater [31]. Thus it is quite significant that a further increase in water temperature could reduce the disinfection time [30], [31], [89]. A study revealed the inactivation of Hepatitis-C virus by incubation at 80°C for 5 minutes, and predicted the same for SARS-CoV-2 [18], [19]. Thus an effective water heating system with good capacity is required. ICS is a type of water heater which collects the solar energy to heat water, and also reduces the heat losses due to the integrated system as shown in Fig. 11. [119]. In ICS systems the solar to heat conversion rate are good, and these systems are compact as compared to conventional flat plate thermosiphon (FPT) water heaters [120]. These systems are generally designed for domestic purpose water capacity (100-200 liters). Kadambi et al. [121] evaluated the performance of a 70-liter capacity ICS and observed that for 1.5 m² collector area 50-53% the thermal efficiency was about 50%. Water temperature was observed in the range 50-80°C if no water is drawn from the ICS during the day. A temperature as high as 86°C was also observed during experiments at 3:30 p.m. during peak sunshine hours. A similar study

in India by **Dharuman et al.** [122] obtained 50-60°C water temperature using an ICS with 170 liters capacity with a 1.3m² collector area. The suitable applications of ICS were identified in bathing, laundry, cleaning, sanitization of food containers, etc. The cost was also estimated to be 30% less than that of the FPT water heater. **Mohsen et al.** [123] investigated the performance of a compact solar water heater and a parametric study by varying the depth of the water tank and the number of glazing was performed. It was found that with a tank height of 10cm the water heater can heat water up-to 65°C and can supply it for 24 hours in July month of Amman, the capital of Jordan. **Borello et al.** [124] studied experimentally and numerically the performance of an ICS with a simple design for tents to be installed in case of emergencies such as post-earthquake situations in Africa. **Garnier et al.** [125] investigated numerically the performance of ICS in Scottish weather and validated the data against the results of three months of experimental study. During the study the water temperature was likely to exceed 70°C as shown in *Fig. 11*, and the study was concluded reliable based on different statistical indicators.

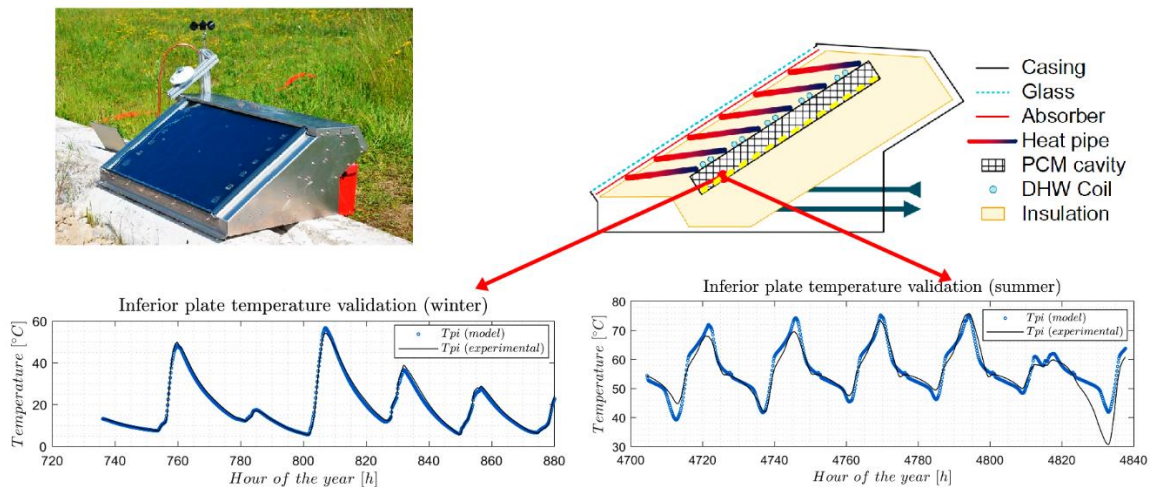


Fig. 11. ICS Solar water heating system with PCM for energy storage and heat pipes for compact design [126].

3.5. **Thermal Energy Storage (TES) in Water/ Air Heating:** To bridge the gap between the demand and supply of solar energy due to its discrete nature TES systems are used[127]. **Ma et al.** [55] also investigated the effect of temperature, its diurnal range, and humidity on the deaths due to COVID-19 in Wuhan, China. They concluded that the diurnal temperature range showed a positive relationship with the deaths of patients. Thus a thermally stable and comfortable environment was suggested for the patients in quarantine facilities and hospitals. TES systems are also used for flattening the diurnal temperature range and increase the comfort levels [128]–[131]. TES systems accumulate the thermal energy received on the collector surface of water/air heater when it is in excess and used during the demand hours when there is the unavailability of the Sun. Among the three popular modes of energy storage namely sensible, latent, and thermo-chemical thermal energy storage, the Latent Energy Storage is an attractive method because of its high energy

storage density, nearly isothermal heat storage[132], [133]. **Ojike et al.** [134] compared the performance of paraffin wax and palm oil as PCM in LHS for low temperature passive solar air heating systems for agricultural applications. **Iten et al.** [135] reviewed the use of PCMs as thermal energy storage for free air heating and cooling of buildings. They reviewed various PCM applications in buildings such as the use of PCMs in building envelope, in the roof, in the solar chimney, in TW, incorporation with air-conditioning system, etc. They emphasized the use of a passive heating system more than active ones because of low initial investments, and running costs. A few studies on the incorporation of PCMs in TW are found[136]–[139]. **Omara et al.** [140] reviewed TW for passive solar heating with PCM for energy storage in place of conventional masonry thermal storage material. After classifying various types of TWs, and PCMs in lying in a medium temperature range of 21-70°C they explained the mechanism of TW with PCM, and discussed the hourly, daily, and seasonal energy savings using PCMs. **Dong et al.** [24] investigated experimentally the effect of providing a gap behind the absorber surface of a TW. The TW provided a temperature range of 28-41°C in the room for a longer time as compared to without the PCM case.

A group of researchers **Bilardo et al.** [126], [141] incorporated PCM in the ICS solar water heater. They investigated numerically and experimentally the performance of the ICS with PCM in France. The prototype was composed of a flat plate collector, heat pipe, Polyethylene glycol as PCM, and copper tube windings on the absorber surface for hot water extraction as shown in *Fig. 11*. An electrical analogy method was used to make the model of ICS. The numerical results were validated against the experimental results and found in good agreement. With a collector area of 0.5m², and 0.02m³ PCM the prototype achieved 79.3°C maximum temperature. A daily production of 120 liters of hot water ~ 55°C was heated with six ICS prototypes (3m² collector area) when arranged in parallel.

- 4. CONCLUSIONS:** In the context of fighting against COVID-19 this article reviewed in detail the facts about the physical inactivation mechanisms for inactivation of the SARS-CoV-2. The detection of viruses in the water bodies has alarmed the researchers as it could be more dangerous transmission routes for COVID-19 spread and could worsen the condition in the countries with approaching monsoon season. The facts about SARS-CoV-2 and other coronaviruses have been collected from the literature. The various inactivation mechanisms have been explained taking the reference of bactericidal, virucidal, and oxidation mechanisms of VOCs. The study includes detailed information related to physical inactivation methods of pathogens and VOCs in water and air which are UV-inactivation and Thermal-Inactivation. Solar energy being a good source of both UV and heat is portrayed as a method to disinfect air and water from COVID-19. The literature review includes various studies making the use of solar energy for water and air disinfection. The methods used for inactivation using UV and heat include photo-inactivation, thermal-inactivation, photo-catalysis, and thermo-catalysis. The use of solar energy systems such as TW, PC-TW, TC-TW, CSC, PV/T, and ICS for Water/

Air heating and disinfection has been reviewed. Strong evidence of virus inactivation using the aforesaid methods have been found in the literature which leads to the following conclusions:

- The problem of COVID-19 could get worsen in case of faulty sewage system, faulty building plumbing, and aerosol generation due to precipitation in countries with approaching monsoon season.
- The presence of air pollutants such as VOCs and particulate matter may worsen the condition of COVID-19 spread due to the generation and transmission of bio-aerosols. These pollutants also affect the immunity of kids and the elderly, so they also need to be removed from the air.
- UV, and heat inactivation mechanisms for COVID-19 are comparable to chemical inactivation methods. Due to the lack of evidence it is difficult to say about the superiority among these.
- UV-C can be directly used for the inactivation of viruses and removing VOCs. UV-A, UV-B, Visible, and IR part of solar electromagnetic radiation need the incorporation of catalysts such as transition metal oxides such as TiO₂, and MnO_x-CeO₂ and noble materials Pt, Pd, Au, and Ag.
- Solar air, and water heating systems such as TW, CPC, PV/T, and ICS can take part in combating COVID-19 in countries with good insolation in the coming days. This could help in breaking the chain of transmission of SARS-CoV-2 outside the host.
- Thermal energy storage (TES) can be used for storing excess thermal energy to stretch the working hours of solar systems for air or water disinfection. Diurnal temperature variation is also balanced using TES which could provide better thermal comfort to the patients for fast recovery.
- The thermal inactivation of viruses takes less time in wastewater as compared to freshwater due to solid settling. Thus solar heat could be sufficient enough to inactivate SARS-CoV-2.

As there is no immediate hope for the development of a vaccine or other cure of this deadly virus as per the Author's knowledge to date. Prevention is the only cure to restrict the spread, and to break the chain of transmission it is very important to inactivate SARS-CoV-2 outside the host. The proposed UV and heat inactivation system can be useful in the disinfection of facial masks, PPE kits, health care equipment, public transport, food items, household water, utensils, portable quarantine facilities, hospital wards, etc. TES and ICS systems can also be used for thermal comfort management and heating water for countries fighting against COVID-19 along with the cold climatic conditions. Such solar systems can be used for the local medical assistance in the distant places.

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