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Experimental analysis of solar powered disinfection tunnel mist spray system for coronavirus prevention in public and remote places

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ABSTRACT

There is a pressing need to accelerate the development of advanced technologies to prevent Coronavirus in large gatherings. The present system is an integration of tunnel disinfectant spray system and solar setup which utilises the solar energy to power a pump which pushes the required amount of chemical mixture into the nozzles of the spray system in order to eliminate any incoming virus or bacteria on the clothes of a particular person without wetting it. Data was gathered for a mall in New Delhi related to occupancy levels before and after lockdown. A 47% and 35% spike in energy and disinfectant mixture to pump was evaluated on weekends. A 70% reduction in operating cost was registered for solar based system in comparison to non-solar setup. Optimum conditions by considering efficiency and cost effectiveness evaluated are 8 number of nozzles, nozzle angle 55 degrees spray pressure 200 bar, and pressure 200 bar.

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1. Introduction

The present world has run into deep trouble since the emergence of a deadly virus known as coronavirus (Covid-19). Earlier viruses like swine flu and MERS were also considered dangerous in several countries [1,2]. So far, these viruses consumed several lives in a span of a few months but also has resulted into loss of property, money, time, jobs etc, thereby by severely disabling people from their normal lives and cope with harsh living conditions [3,4]. Recent studies have also predicted the deadly virus to be airborne which could make the virus spread at a tremendous rate among groups or large gathering among people [5,6]. Active researches are being carried all over the world to find a suitable cure or vaccine or medicine that could prohibit its spread among community [7,8]. So far testing is being carried out in worlds top research institutions and is the top priority among people [9]. But to the worlds avail no positive results have been obtained since the outbreak of the coronavirus [10]. The vaccine developed Sput-

nik V has shown certain side effects in 14% of participants, thereby making people susceptible of it [11]. Table 1 Table 2 Table 3

In anticipation of a viable vaccine, people have taken an initiative of self-care but regularly washing their hands, clothes, wearing masks and face shields. Keeping pocket sanitizers for regular hand wash has become a common practice all over the world. People are living in homes and isolating them from the world to prevent catching the virus. Active steps by the government all over the world are being taken like complete or partial lockdown and sanitizing the public areas. But the recent economy disasters have enabled the world to live with this virus rather than avoiding it. This probably is the right option, since people all over the world are losing their jobs, particularly the daily wages worker who may die out of hunger rather than the coronavirus if lockdown continues [Alfano & Ercolano 2020; Dickens et al. 2020].

Various sanitizing machines are being installed in public places or places having huge gathering [12]. One of them is the disinfection tunnel spray system which can sanitize any incoming person in these gathering with sanitizing/person ratio being comparatively higher than other technologies. The mist disinfection tunnel system primarily sprays a correct required amount of chemicals in the tunnel in order to kill any bacterial or virus being attached on

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Table 1

The measurement accuracies and experimental uncertainties associated with sensors and parameters.

Sensors and Parameters	Accuracies and Uncertainties measurement
T-type thermocouples	±0.5C
Flow meter	±5 ml
Pressure transducer	±1.8 mbar
Voltage measurement	±0.06 V
Current measurement	±0.15 A
Silicon Irradiance Sensor (SIS sensor)	±5 W/m ² ± 3.5% of measurement value
Power Temp Coefficient	-0.29%/C

to the clothes of the incoming person [13]. In recent months many public places such as airports, factories, railway station, hotels, banks, supermarkets, college campus, malls, marriage halls and religious gatherings are employing this device to disinfectant incoming people [Shan et al. 2005]. A specific pupil entering the tunnel needs approximately less than twelve seconds to render him completely infection free [14–16]. The individual walking inside the tunnel consumes approximately 0.64 L of chemical mixture in the form of external spray mist. Chemical such as hypochlorite was used in varying amounts between 0.02 per cent to 0.05 per cent weight concentration [17,18].

The present system is an integration of tunnel disinfectant spray system and solar setup which utilises the solar energy to power a pump which pushes the required amount of chemical mixture into the nozzles of the spray system in order to eliminate any incoming virus on the clothes of a particular person. The equipment applies a display system which automatic liquid feeding, automatic reaction entry and exit, fog quantity and spray time.

This model is based principally on the analysis of the experimentation results using the available data from occupancy, solar radiations based on location and experimental setup. The research analysis was performed for a mall located in New Delhi known as Living style mall, Jasola is selected for experimental analysis. The setup was installed at the entry of the mall in order to understand various parameters such as number of people entering the mall, pump power requirements, water usage, time of the day, amount of chemicals needed, variation of water-chemicals requirements for various days, optimum hydraulic and room conditions and comparison between a solar and non-solar setup.

2. Experimental methodology

2.1. Concept and advantages of disinfection tunnel misting system

The solar setup was integrated with various devices (HVAC, Refrigeration, distillation, powerplant, solar pump) with successful results in previous researches [18]. The disinfection misting system particularly involves water and chemicals mixed in suitable combi-

Table 2

The main components specification and characteristics of the solar disinfection spray system.

S. No	Element	Technical specification	Number of elements	Price (Rs)
1	Solar cell	Loom Solar 180-Watt V Mono Crystalline Panel	2	18,000
2	Inverter	Luminous 30 A, output 220 VAC, 1800 W	1	28,000
3	Solar battery	Luminous LPTT12150H 150Ah Solar Tall Tubular Battery	1	13,000
4	Charge regulator	Techtest 10 Amp Solar Charger Controller Panel Battery Intelligent Regulator with USB Port LCD Display 24/12	1	4000
5	Solar cell fasteners	UV protected multi-contact solar cables and connectors (5 m), power cable (8 m)	1	15,000
6	Pressure water pump		1	40,000
7	Miscellaneous	Room enclosure, hexagonal nozzle series: 0.2 mm, number of nozzles: 8 units, clamps, pressure switch, pump regulator, terminating line, high pressure copper pipe, clips, quick fittings, purge valve, T-connection, L-connection, pipe holder, filter, pressure gauge.	-	5000
Total price				1,23,000

Table 3

Time required for disinfection for various number of nozzles according to pressure variation.

Number of Nozzles	Time for Disinfection (Sec)	Pressure Variation (Bar)	Spray Pressure Required to Achieve Flow Rate (Bar)
8	10	200	18.49
12	8	180	17.14
16	6	160	15.6
20	5	140	13.25

nation forced through the pump in to tubes attached at various point in the tunnel were nozzles are attached at appropriate points facing the incoming person. This high-pressure nozzle emits disinfectants in the form of microfine mist particles which remove any bacteria adherent to the body of the person. Tubes are mostly made up of stainless steel or brass. The water droplets after the action of eliminating the virus is instantly flash evaporated in to the environment. The tunnel system detects any incoming person from a distance of 10–30 cm thereby getting ready for its operation. The ideal detection method the tunnel employs is by infrared radiations which pre-warns the system of any activity inside the chamber. The infrared radiation measures the temperature of the incoming person with a collection accuracy of ± 0.5 °C.

The present technology uses a combination of solar powered pump and misting system which uniformly distributes chemical spray on the clothes of the incoming person. Earlier solar based pumping resulted with good results in earlier researches [17]. These systems are quite efficient in operation with lower overall cost. The presence of solar equipment in the setup also recovers the cost of the equipment in due course of time as this equipment would have worked on normal electricity could have consumed substantial amount of electricity. Thereby having a huge amount to pay at the end of the month. The solar equipment is completely self-dependable equipment using solar energy to produce the required action of misting chemical mixture. The chemical disinfectant mixture is assumed to be so fine that there is absolutely no chance of wetting the system. Its effect can be compared to that of a particular person standing under the fog. The person becomes free from bacteria and viruses but does not degrade the cloth material and wet it. The incoming person needs to stand at a specific position pre indicated by a yellow colour square drawn at the ground. This yellow safe square is a pre indicator to the incoming person as a reference standing position. The square is placed in the middle where all nozzles are directed towards. In order to safe guard the eyes of the person useable goggles are given to the person which can be discarded off later in the bin. The goggles are reused after sanitising them at regular basis. The person is supposed to stand approximately 20 cm away from the nozzle to avoid wetting himself. Water chemical mixture is free from harmful toxic

chemicals that may affect skin. The complete setup is quite compatible with the solar integrated system as the system applies a ratio of 1:3 for chemical and water combination as spray disinfectant to completely sanitize them from viruses and bacteria. Also, a strain filter is attached to the water system before entering the pump to draw out any incoming impurity which may eventually clog the nozzle. Among other benefits that the solar integrated disinfectant system offer is listed below

- Highly suitable for all outdoor applications involving mass gathering.
- Requires only a small area at entrance for the whole setup.
- Simple in construction (no complicated wiring system)
- Eco friendly in nature.
- Works on renewable energy.
- Non-toxic in nature.
- Has high efficiency in eliminating and suppression of bacteria's and viruses.
- Only limited quantity of water required for whole operation.
- Reduced overall and working costs in comparison to other disinfectant systems.

Appearance of a typical Disinfection misting system during the setup is shown in Fig. 1.

2.2. Uncertainty study of the experimental measurements

The primary reason of carrying out error and uncertainty analysis for any given experimental research is since human errors are very common even machines may have some small errors in the calculation of a property which also needs to be taken in consideration and calibrated likewise. The advantage of error analysis removes any irregularity in the research thereby taking all points of evaluation of properties in consideration. In this research Holmanns formula is considered for evaluating the error and uncertainty analysis. The following table depicted below displays all the equipment's which measured various properties in the system along with its errors. The analysis also takes in consideration the electrical and the hydraulic equipment parameters.

A table is prescribed below in order to display all the relative errors and experimental uncertainties in various equipment while measuring the several parameters of the applied system. The solar irradiance calculation remains quite uncertain due to several measurement parameters. Hence error of 0.06% is assumed in the analysis for a reference cell signal also taking the electronic equipment in consideration.

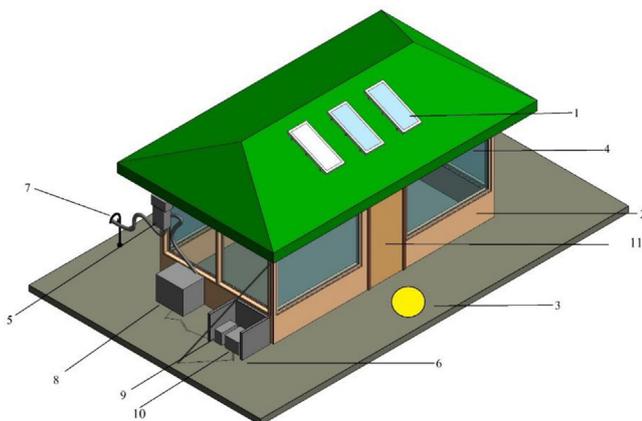


Fig. 1. Typical disinfection misting system.

The total percentage of uncertainty is determined in this experiment by applying the Holmanns equation provided below:

The total percentage uncertainty = square root of [(uncertainty in T-type thermocouples)² + (uncertainty in Flow meter)² + (uncertainty in Pressure transducer)² + (uncertainty in Voltage measurement)² + (uncertainty in Current measurement)² + (uncertainty in SiS sensor)² + (uncertainty in Power Temp Coefficient)²]

The total percentage uncertainty = Square root of [(0.5)² + (0.005)² + (1.8)² + (0.06)² + (5)² + (0.29)²]

The total percentage uncertainty = ±5.34%

Hence the total uncertainty associated with the system comes close to 5.34% which for the analysis of a solar setup is suitable, satisfactory and in accordance with previous researches [Khan et al. 2016; Khan et al. 2019].

3. System setup

The setup primarily comprises of a solar PV cell attached at the top of enclosure denoted by 1. Point 2 denotes the enclosure which is made up of mild steel. The incoming person needs to stand on the elliptical yellow space point 3 for temperature detection from IR detector attached at the top of the incoming enclosure at point 11. Further point 4 specifies one sprinkler attached at a certain height where all other sprinklers are attached in series at same height. Point 5 denotes all the box containing electrical connection like transformer and relay. Point 6 is the charge regulator connected between inverter and battery system. Point 7 shows the pipe diverted to the tank to extract disinfectant mixture. Point 8 shows the water mist pump which in turn is connected to point 9 and point 10 which are the battery and inverter system of the solar setup. The current system was divided into four major parts:

- Hydraulic components description
- Solar components description
- Enclosure components description

3.1. Hydraulic components description

The primary area of concern was the hydraulic components which comprised of equipment's applied to issue water through the nozzles. It consisted of a water misting pump, cartridge filter, piping system, ring connector and nozzles. The pump attached is basically of 1 kW power of high pressure programmable infrared sensor mist type, working between pressure of 140–200 bar. The pump is place above the spray room setup besides the solar setup. The specifications of the pump are AC 165–220 V, 50 Hz, and single phase. The water drawn in by the pump from the storage tank requires a cartridge filter in order to remove any impurity or sediment present in the water, which may eventually clog the nozzles. Further the piping required to connect the outlet of the pump to the misting room inlet is made up of an all-weather resistant nylon hose pipe, especially designed to withstand the misting pressure. The required length of nylon pipe is roughly 4 m with outer diameter of is 1/5th of an inch or 50.8 mm. The nylon pipe is further connected to the hose pipe with the help of a compression ring nickel plated brass connector which seals up the connection between the nozzles and pipe. The nozzles were made up of brass with stainless steel head with an opening of 0.008 in., forming a fine fog like mist with billions of microscopic droplets dispersed on the clothes of the incoming person. The diameter of the nozzle is 0.3 mm. The standard full cone type turbulence nozzles have been applied in the analysis. The figure given below displays all the elements required for hydraulic setup in the system.

3.2. Solar PV components description

The current rise in the utilization of equipment of solar energy has been considerable and is possibly going to explode once the sub-par efficiency is achieved [Eicker et al. 2014; Atieh & Shariff 2013; Sharma, 2011]. India geographic location is close to equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun throughout the year. The primary energy provider to the pump set for disinfectants to be released into the room comprises of a solar setup which is placed at the roof of the room. This not only captures the radiations but also converts the radiation into useful electricity later being stored into the battery system. The current study takes in consideration the irradiance, wavelength and frequency of the radiations emitted on the PV cells. The PV panel comprises of a generator solar array in addition to junctions and protector parts. The solar cells attached at the top further are an amalgamation product of p-n junctions attached on silicon-based semiconductor sheet material. The setup further comprises of an inverter of 700 VA which transforms DC to AC, as the pump requirements is specified as AC.

3.3. Tunnel enclosure description

The main frame was made up of Mild steel material with 6 mm poly carbonate covering the tunnel. Room dimensions of 30 × 30 × 3 having a per meter weight of 2 kg in Fig. 1.

4. Result and discussion

In this paper, a novel combined solar-based disinfection tunnel system for a mall is designed, developed, and analysed. A performance based parametric analysis is initiated by varying aspects of operational parameters. Complete analysis of the research is exclusively explained in upcoming sections herein.

In the earlier section of the study, the selected malls occupancy levels before and after lockdown was discussed. Further in this section overall pump power and disinfectant requirement for a particular mall are defined, enumerating the specific hours in a day or a week where requirements can seriously surge high. Further a comparative analysis is provided for the whole system with or without the addition of solar setup, thereby providing an estimation of the variation in operating costs throughout the week. The study further highlights the importance between disinfection time and number of nozzles by establishing the trend of minimising the disinfection time by increasing the number of nozzles. For effective action, the study incorporates the various angles the nozzle can be fixed in order to achieve maximum coverage area for a single person entering the room. The study explains various coverage area- angle relationship for both men and women. Further a comparison between various solar collectors based on their conversion efficiency for PV output is studied by varying irradiance. The comparison is further performed between the various collectors based on their respective areas for power generation by varying solar irradiance.

4.1. Pump power requirements on daily basis

The pump power requirements for various days of a particular week were evaluated in Watts as depicted in the given figure. The general trend followed by occupancy is displayed as a rise was registered during afternoon and evening since people leaving the office visited the mall for various reasons. Further a spike in occupancy level was seen for the time frame 3 pm–6 pm thereby requiring higher energy to pump the disinfectant mixture. Hence during the above time interval surplus amount of disinfectant mixture

should be ready for the incoming people to be sanitized. Highest number of people came in on weekends (specially Sunday), hence additional power maybe required by the pump to operate in such circumstances. The solar setup is designed to handle at all extreme conditions but during festivities the number may rise exponentially during which surplus energy can be obtained from the grid. For rest of the days of the week the pump power requirement remained same except for Friday when the weekend begins and people start pouring in the mall.

4.2. Disinfectant requirements for Different days of the week

The current situation after lockdown has displayed a sense of unpredictability in the minds of the population. Thereby the mall owners should pre-order the disinfectant mixture sprayed on the people for smooth functioning of without stopping entry into the mall. Highest occupancy was recorded during afternoon and evening, thereby requiring higher quantity of disinfectant mixture to be pumped. Biggest spike in disinfection requirement was seen for the time frame 6 pm–9 pm. During the above time interval surplus amount of disinfectant mixture should be ready for the incoming people to be sanitized. Highest number of people came in on weekends (specially Sunday), hence disinfectant mixture should be pre ready for sanitization process. The sanitization room is designed to handle at all conditions but during festivities the number may rise exponentially during which surplus disinfectant should be pre ordered. For rest of the days of the week the disinfectant requirements remain the same except for Friday when the weekend begins.

4.3. Evaluation of optimum conditions for disinfection system

In order to estimate the lowest time, spray pressure and pressure for the required disinfection system, different number of nozzles were connected in series in the piping system. The incoming person stepped into the setup and time, pressure and spray pressure of the nozzle was noted as soon as all areas of the person was approximated to be sprayed on. The minimum time of 5 s was required when 20 nozzles (with a pressure rating of 140 bar) were attached in the system while a maximum time of 10 s was required when 8 nozzles (with a pressure rating of 200 bar) were incorporated in the setup. Other intermediate pressures, time and number of nozzles are displayed in the Table 4.

Also, to achieve the required flow rate by varying the pressure, the variation between spray pressure required and Number of nozzles is shown in Fig. 2 where the time required for disinfection decreases the spray pressure required to achieve the flow rate also decreases. For minimum time required, the spray pressure maintained in the nozzle is about 13.25 bar whereas for maximum time the spray pressure to be maintained is close to 18.49 bar. With higher number of nozzles arrangement, the initial cost does increase but in the long run the nozzles are subjected to less pressure, thereby resulting in lower wear and tear (lower replacement cost). Further the operating pressure required in a smaller number of nozzles is about 200 bar which would require more power, add-

Table 4
Comparison of spray area coverage between men and women.

Angle of Nozzle (degrees)	Spray Coverage for Women (cm)	Spray Coverage for Men (cm)
45	145	165.7
55	182.2	208.2
65	223	254.8
75	268.6	306.9
85	320.7	366.5

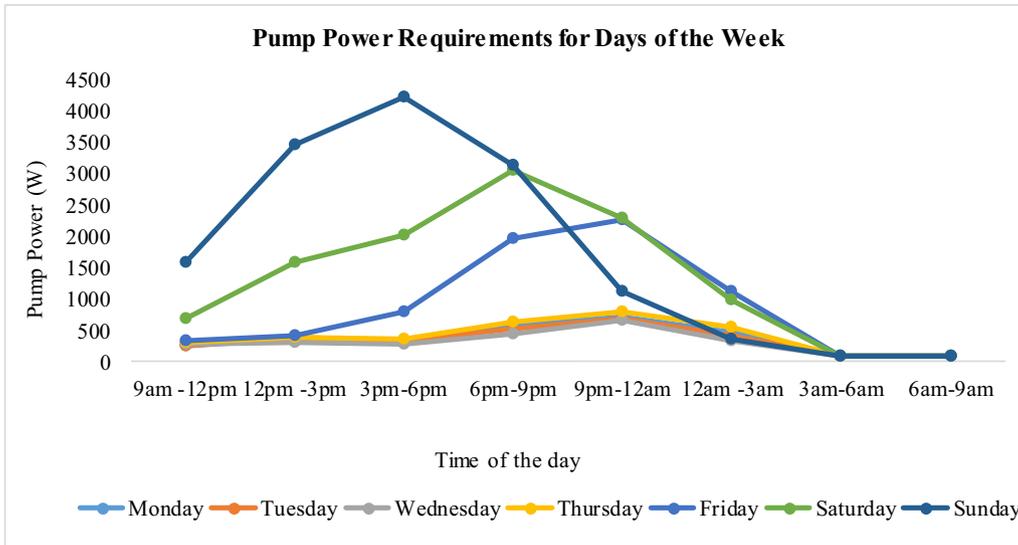


Fig. 2. Variation in pump power for different days of the week.

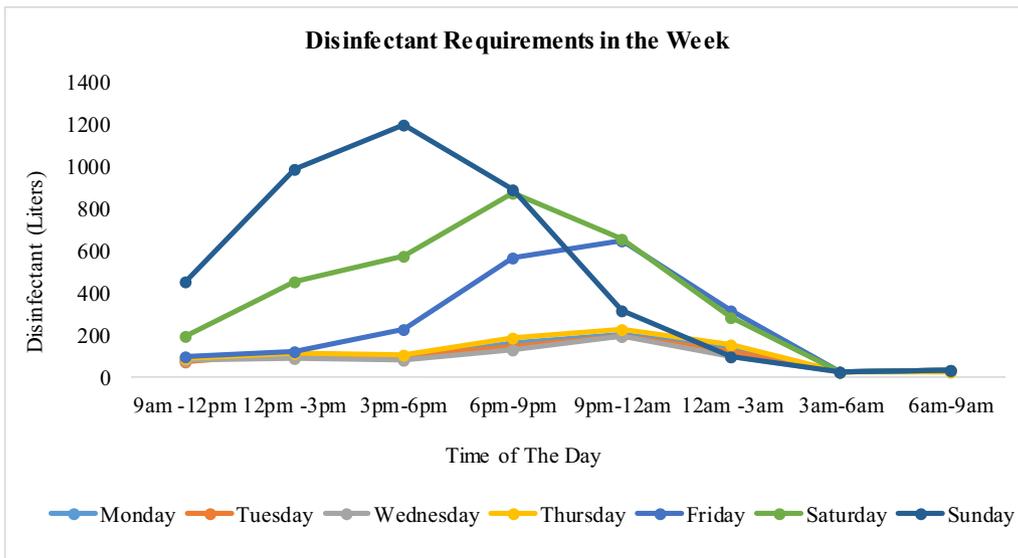


Fig. 3. Variation in disinfectant requirements for different days of the week.

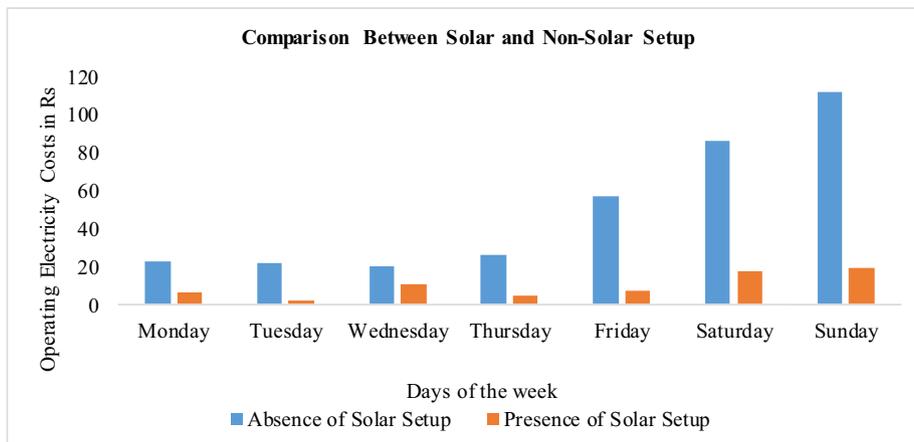


Fig. 4. Operating costs comparison for a solar and Non- Solar setup.

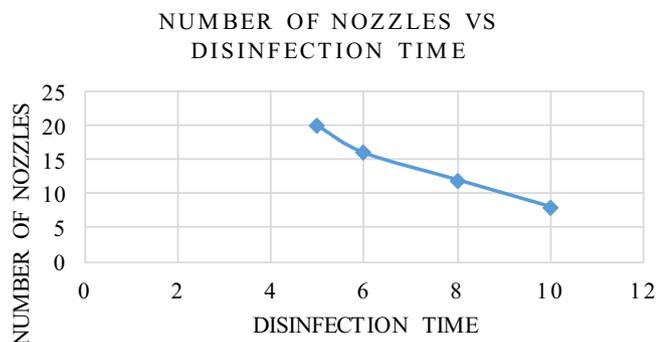


Fig. 5. Time required for disinfection according to number of nozzles.

ing to the operating cost due to bigger pump requirements. Henceforth, it is recommended to apply at least 16 and above number of nozzles to avoid higher pressure requirement in mist spray disinfection room arrangement (Fig. 3, Fig. 4, Fig. 5).

In order to efficiently disinfect the incoming person, it is necessary to correctly align and angle the nozzles so that they can cover the area effectively with minimum wastage of the chemical mixture. The nozzles should be aligned in such a way that the mist system covers the complete body below the shoulder (avoiding face) of the incoming person with minimum amount of chemicals going down the drain. Hence the spray coverage area is a function of the number of nozzles attached in the disinfection room and the pressure variation in the system. The nozzles are attached at the bottom and top of the room aligned at an angle to completely cover the incoming person. Further nozzle coverage area differs for women and men separately as men tend to be longer than women. Hence an average height of men 200 cm and women 175 cm are considered in the analysis and calculated in the table below.

Different nozzle angles are applied in the angle to estimate the coverage area within the room. The trend clearly predicts that for a 8-nozzle arrangement, as the angle of nozzle aligned increases the nozzle spray coverage area also increases. Hence an optimum spray area based on coverage from both sides of the room is 254.8 cm for which the nozzle needs to be arranged at 65 degrees for a room height of 200 cm. Conversely for women, since majority women are shorter than most men, therefore the maximum spray height achieved is close to 223.7 cm for nozzle angled at 65 degrees for a room height of 175 cm. Therefore, at different heights, separate disinfection rooms need to be installed since the coverage area varies for both men and women. Furthermore, separate disinfection rooms will speed up the process of entry in public places thereby avoiding any undue rush or traffic at peak hours.

Due to high requirement of chemical and water mixture issued from the nozzles in large gathering, there is a danger of nozzle wear and damage. The nozzles due to high pressure and water mixture issued needs to be addressed properly so as to predict nozzle life beforehand. Regular flow rate measurement from each nozzle needs to be monitored and eventually any damaged nozzle needs to be replaced by a new one in due course of time [13–22].

5. Conclusions

The current study incorporates a combined system which comprises of a solar based disinfection tunnel mist system. The system was developed and analysed by varying several performance-based parameters of the system. The integrated solar disinfection room facilitates elimination of bacteria and virus for any incoming person by spraying a mist of disinfectant over entire clothes in a nature-friendly manner. In order to facilitate the required energy for the pump, a solar setup is attached which not only provides a

clean source of energy but also furnishes substantially lower operating costs in comparison to electricity-based pumps. The major findings of the current research are explained in points as provided below;

Highest requirement for disinfection mixture was registered during Sunday and Saturday close to 55% and 43% respectively. Further during afternoon and evening the total requirement increased for all days of the week.

Comparatively, lower operating costs was achieved for solar setup of the order 70% since maximum electricity was procured during pumping action. Zenith operating cost was found on weekends when the occupancy levels were high.

Optimum conditions for disinfectant room by considering efficiency and cost effectiveness is provided as: Number of Nozzles – 8, Time for Disinfection – 10 s and spray pressure required to achieve flow rate – 18.49 bar

The optimum spray area based on coverage from both sides of the room for men and women is 254.8 cm and 223.7 cm respectively for which the nozzle needs to be arranged at 65 degrees. Room height of 200 cm and 175 cm was used for men and women respectively.

A linear rise in overall power generation has been observed by increasing panel efficiency and solar irradiation with maximum efficiency achieved in 18% based panels.

The total uncertainty associated with the system comes close to 5.34% which for the analysis of a solar setup is suitable and satisfactory.

To sum up, the analysis results of this research, stipulate that the proposed solar-assisted disinfection system is capable of providing an efficient sanitization to all incoming people in mass populated places in a nature-friendly manner. However more analysis can be intimidated to investigate the initial financial investments of the whole system. Furthermore, a method for cost reduction of chemical can be evaluated in order to save the environment from harmful impacts.

CRedit authorship contribution statement

Osama Khan: Conceptualization. **Mohd Zaheen Khan:** Methodology, Software. **M. Emran Khan:** Investigation. **Alok Goyal:** Visualization. **Bhupendra Kumar Bhatt:** Writing - review & editing. **Amaanullah:** Formal analysis. **Mohd Parvez:** Data curation, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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