DESIGN AND MODELLING OF AN AUTOMATIC WALK-THROUGH DISINFECTANT TUNNEL USING WATER MIST- SYSTEM

***[1]Babalola, Ayoola Abiola; [1]Adetifa, Babatunde. Olusola; [1]Adama, Kayode. Olaleye; [2]Olatunde, Bilikis Olanrewaju; [2]Adeyemi, Hezekiah.Oluwole and [2]Layeni, Abayomi Temitope**

[1]Agricultural Engineering Department, College of Engineering and Environmental Studies, Olabisi Onabanjo University, [2]Mechanical Engineering Department, Olabisi Onabanjo University
*aababalola@oouagoiwoye.edu.ng, aybl2002@gmail.com

ABSTRACT

A proposed walk through disinfectant tunnel is presented as part of local effort at mitigating the rapid spread of the COVID-19 and to enhance the safe utilization of public facilities. The system design was conceived due to the need to reduce the harmful airborne virus that characterizes public buildings. The system is designed according to the NFPA 750 fire fighting mist systems which are currently in use in fire fighting. Components of the designed system include a Pir motion detector, reservoir, water pump, directional valves, distribution blocks, and mist ejection nozzles respectively. It is expected that at ahead of 3.5 m and a flow rate of $2 \times 10^{-5}\ m^3s^{-1}$, a pump of capacity 0.871 Watts will be needed for a public building with 1000 daily users at peak periods of 9 am and 4 pm respectively. Furthermore, a computational flow modelling of the system was carried out using ANSYS Fluent which provided satisfactory performance of the design parameters. It is expected that this study will significantly contribute to the elimination of the active particulate matter that contributes to the spread of the viral infection of COVID 19.

Keywords: Design, Computational flow modeling, Walkthrough disinfectant, Tunnel, Water Mist System, Ansys

Accepted Date:* 20 *Nov., 2020

Introduction/Background of Study.

Globally there has been an outbreak of a novel virus also known as COVID -19 which causes illnesses such as common cold, fever, and difficulty in breathing. The virus is disseminated through drops when symptomatic or asymptomatic carriers cough, sneeze or release droplets via other means, and those droplets get into the oral or nasal orifices of people nearby. The COVID-19 outbreak has significantly affected the way of life in many sectors of the society by shutting down economic livelihoods and exposed the fragile buffer for social groups in the most vulnerable situations, such as the poor, the elderly, persons with disabilities, the youth, and indigenous people respectively (UN, 2020)

While most COVID-19 cases were initially associated with travel, the person-to-person spread is now being reported in almost every country on the planet (IDPH,2019) In the race to slow down the rapid spread of the virus, several mitigation strategies have been identified and highlighted which are meant to slow down the transmission of disease and most importantly to protect individuals at increased risk of infection and the health care and critical infrastructure workforces (CDC, 2019). The fight against this novel pandemic recognizes the utilization of mass public disinfection systems as a sustainable means of curbing the rapid spread of the virus.

According to the Centers for Disease Control and Prevention (CDC, 2019), the primary mode of transmission of the disease was mainly through respiratory droplets which were expelled from the nasal or buccal cavities of symptomatic people during sneezing or coughing. Hence, this gave rise to the advisories of social distancing, hand washing, and public disinfection across various areas. These theories assume that gravity, soap lathers, and antiviral disinfect ants neutralize large droplets (which are bigger than about .0002 inches, or 5 microns, in size) to fall to the ground within a distance of 6 feet (3m) from the infected person(Ghose, 2020). This establishes that the major medium of transmission of the disease is through the air which ranks it among the growing list of communicable diseases that are already discovered.

Principle of Disinfection.

Water-based disinfection and public health protection systems have been around since 1860, and in fact, water mist systems are primarily used in fire fighting and the continued relevance of this technology is growing; an indication that they will be around for years to come (Mcafee, 2016). The mists' large cooling surface gives rapid vaporization and maximum absorption of radiant heat from the air. Water mist is generated through pressure from positive displacement pumps and ejected through specially designed nozzles. It consists of microdroplets of water that is sprayed at a set velocity through an atomized orifice(IWMA, 2013).

By using the mist form, the following results can be achieved, (IWMA, 2013; Kaiser,2018)

- Ultrafine droplets create an extensive cooling surface area which allows more coverage than the wetted area of the modern sprinkler system.
- Air entrainment which assists penetration of droplets into harmful particles of the air thereby effectively neutralizing key viral loads that are suspended in the air which can cause harmful infections to human health
- Effective conservation of water through the distribution of fine mist

Materials and Methods

Design Concept

The walkthrough tunnel will model a mini entrance with major components of a Water Mist system which will supply disinfectants in the form of reduced air droplets. A low-pressure water mist system will power the disinfection. Mist systems operate through the process of converting streams of water into tiny droplets about 15 microns in diameter as this is just the right size for absorbing and getting rid of airborne dust, odours, and nano particles in public spaces(Wintering,2015). A typical mist system consists of the following components(IWMA, 2013; Annonymous, 2014):

Pump unit
Mainline
Tubing
Valves
Distribution blocks, and
Nozzles

The pump creates a pressurized flow of water from the source which is made available to the system(Peace Corps, 1994). The pressure created through the pump forces water through sprinklers or perforations in main line or nozzles which forms a spray(Annonymous, 2014). The mainline is a pipe that delivers water from the pump to the distribution blocks from where they are directed to the nozzles. They can be permanent but more often they are portable and made of aluminum alloy or plastic so that they can be moved easily(Peace Corps, 1994). The pump is required to overcome height differences between the point of application and the water source as well as neutralize frictional losses within the system, and provide adequate pressure at the nozzle for good water distribution(Peace Corps, 1994).The flow chart of the system is shown in Figure 1.

Figure 1; The flow chart of the Water BasedMist system.

Mist systems can be categorized into low-pressure systems(175 PSI or less), intermediate-pressure systems(175 PSI and 500 PSI), and high-pressure systems(exceed 500 PSI) respectively. (QRFS,2019) and the system of interest here is the low-pressure system(175 psi).

Design Parameters

The design parameters for the tunnel include

1. The daily requirement for water. The volume of water that will be required to achieve optimum disinfection daily.
2. Frequency of sprinkling. This is the exact amount of water that should be needed for the
3. The time required to spray water on a person that walks through the tunnel.
4. Nozzle type
5. Spacing
6. Installation height
7. Operating pressure
8. Flow rate
9. Design flexibility and Maintenance

Design Calculations

The estimated pressure head required for a Walkthrough tunnel of dimensions 0.43m x 1.21 m x 2m(LxBxW) is given by

$$H_{TOTAL} = H_{STATIC} + H_{DYNAMIC} \quad (1)$$

Where $H_{TOTAL,}$ $H_{STATIC,}$ and $H_{DYNAMIC}$ are the total head, static head, and dynamic head of the system. The Static head is the height between the reservoir and the dischargelevel andthis is taken to be 3.5m

$$H_{DYNAMIC} = \frac{kv^2}{g} \quad (2)$$

K–loss coefficient (Depending on the pipe material)

v- velocity in pipe(ms^{-1})

g- acceleration due to gravity (ms^{-2})

$$V = \frac{Q}{A} \quad (3)$$

Where Q- Flow rate (m^3s^{-1}) and A – Area (m^2)

$$k = k_{fittings} + k_{pipe} \quad (4)$$

The values of $K_{fittings}$ can be obtained from table 1

$$k_{pipe} = \frac{fl}{D} \quad (5)$$

Where f,l, and D are the friction coefficient, pipe length, and pipe diameter respectively.

3.3 Pump Selection

3.3.1 Power requirement for Pump

$$P = \frac{H \times Q \times g \times \rho}{PumpEfficiency} \quad (6)$$

Table 1 :K Values of Fittings

Fitting Items	No of Items	$K_{fttings}$ Vlaue	Item Total
Pipr Entrance	1	005	0.05
90° Bend (Short Radius)	10	0.75	7.5
45°Bend Short Radius	2	0.3	0.6
Butterfly valve(Fully Open)	2	0.3	0.6
Nonreturn Valve	1	1.00	1.00
Bellmouth Outlet	1	0.2	0.2
Total $K_{fittings}$ Value			9.95

Source: Royal Academy of Engineering 2012

Material selection.
A Pir motion detection sensor that will be placed at a certain distance from the tunnel will be used to trigger a DC powered pump which will regulate the spray of the disinfectant and regulate the use of water. For the maximum head of 3.5 m and a flow rate of $2 \times 10^{-2} m^3 s^{-1}$, a pump of capacity 0.871 Watts will be needed for the system. So, to ensure a factor of safety lets say 1.6 Watts. The feedback control schematic is shown in Figure 2.

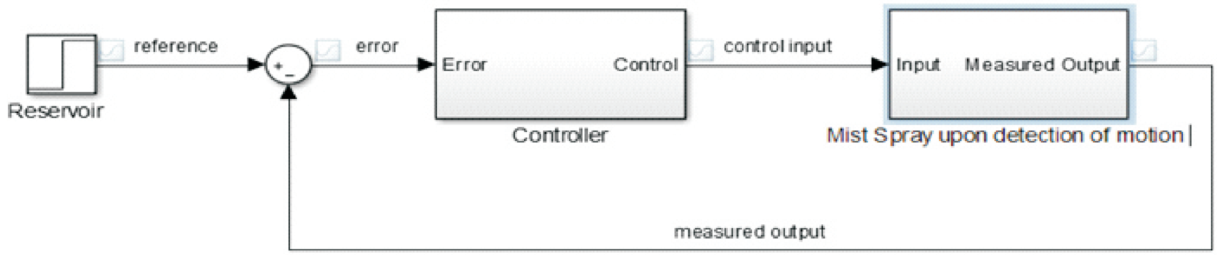


Figure 2: Control diagram of the system.

For a public building with an estimated 1000 users per day, peak periods of use between 8-10 am and 4-6 pm in the evenings, is assumed.Also, the material of interest for the walkthrough tunnel is perspex with 5 mm thickness due to its favorable physical, mechanical and optical properties which will allow the emission of the mist and retention of its disinfecting properties.

Extinction Coefficient
Specifically, the extinction of viral load concentration in ambient air along the flow path at eye level in the tunnel is dependent on several factors such as density, droplet concentration, fluid kinetic energy, the viral load, kinetic energy, and velocity coefficient of the disinfectant solution respectively. To calculate the extinction coefficient (K) of airborne particulate matter, the equations given by (Caliendo*et al.,*2012) are relevant in this regard.

$$\frac{I}{I_0} = e^{-KL} = 10^{-DL}$$

The optical density D can be expressed in terms of air properties

$$D = D_M \frac{C_S}{Y_S}$$

Where $D_m$is the mass optical density(m^2/kg), C_S is the airborne viral concentration(kg/m^3) and $Y_S$is the respiratory yield per person (Caliendo*et al.,*2012). The aerosolization of secretions lubricating the vocal cords is a major source of droplets in humans (Morawska et al., 2009), and the values that highlight the details of these secretions are shown in Table 2.

Tabel 2 shows the droplet concentration at different points of human distribution channels during respiratory activity

Table 2: Droplet concentrations of humans at different respiratory activites

Expiratory Activity	D_1(μm)	D_2(μm)	D_3(μm)	D_4(μm)
Voiced Counting	0.236	0.068	0.007	0.011
Whispered Counting	0.110	0.014	0.004	0.002
Unmodulated Vocalization	0.751	0.139	0.139	0.059
Breathing	0.084	0.009	0.003	0.002

Source: (Morawska et al 2009; Buonano et al., 2020)

The isometric drawing and the structural components of the tunnel is shown in figure 3while figure 4 shows the front dimensions of the tunnel and the mist system

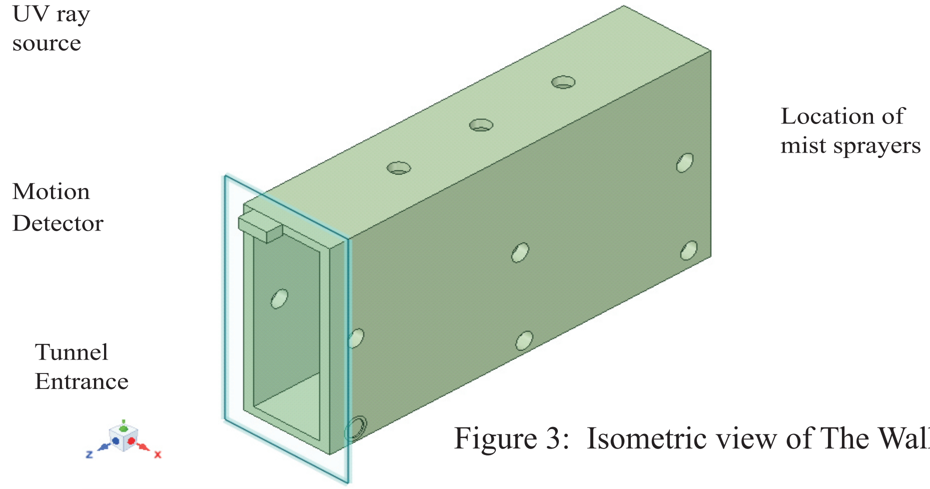


Figure 3: Isometric view of The Walkthrough tunnel

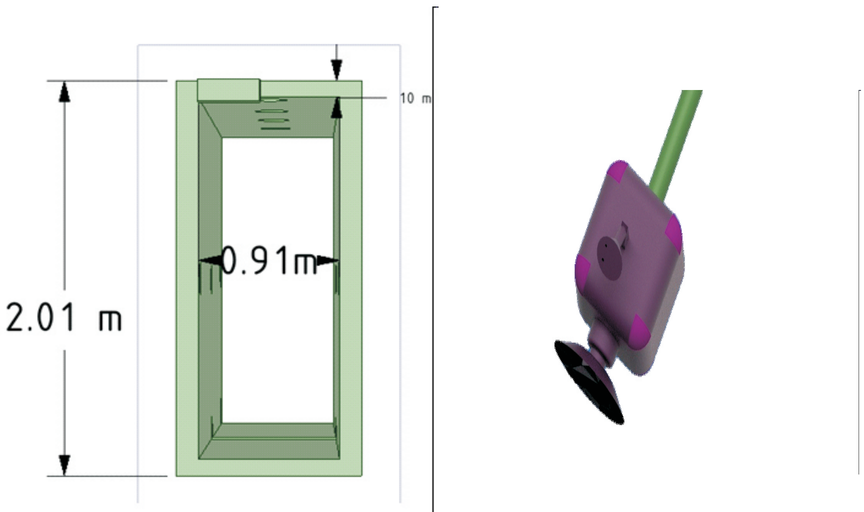


Figure 4: Dimensions of the Tunne and Mist nozzle

The nozzles will be spaced at 0.5m along the vertical and horizontal axes of the tunnel to ensure uniform application of the disinfectants respectively.Pvc pipes of 6.75mmwill be used to convey the disinfectant from the pump.

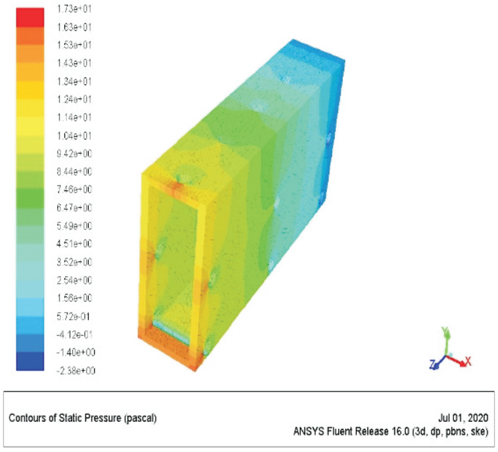
Design Modelling

The flow of the disinfectant through the tunnel was be modelled using ANSYS FLUENT highlighting the velocity, pressure, and energy of the mixture in the disinfectant tunnel.The boundary conditions modelling parameters are highlighted below. A section properties of the tunnel was used for the simulation. Table 3 shows the boundary parameters for the simulation.

Table 3: Boundary conditions for the simulation

Parameters	Value
Length of tunnel	1.5m
Height	0.5m
Diameter of pipe	0.005m
Velocity of flow	2.5 m/s

The simulation was conducted for a turbulent regime with a Reynoldsnumber of 111,569
Parameters of interest highlighted in the simulation are the dissipation rate of the mist, kinetic energy, absolute pressure, static pressure, and velocity contours respectively.The pressure chart is shown in Figure 5(A and B)



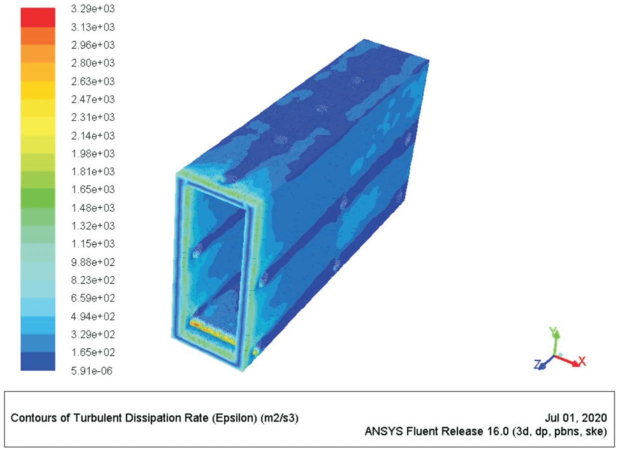


Figure 5AStatic pressure contours 5B Turbulentdisipation Rate

From figure 5A, it can be seen that contour lines for the static pressure imposed on the physical domain will be the highest at the nozzle tips as well as the direct contact of the mist. Similarly, the turbulent **dissipation** rate shows that the material selected will influence the dissipation of the energy of the fluid at a rate of 1.32e+03(m^2s^{-1}) which gives a good retention time for the disinfectant to be effective even after use. Figure 6 shows the velocity vector and flow energy charts respectively.

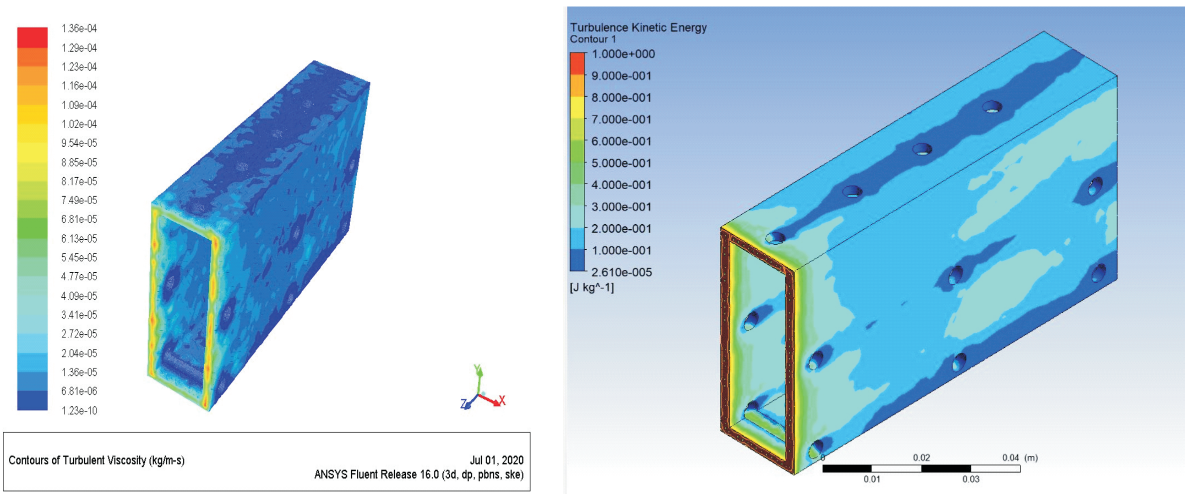


Figure 6 Showing the velocity vectorsandflow Kinetic energy respectively

From figure 6, it is evident that the turbulent viscosity of the kinetic energy will be highest at the entry points of the mists into the tunnel while the walls of the tunnel will remain critical in ensuring the energy is effectively utilized in defusing any active particulate contaminant using the active energy of the mist. The turbulent viscosity will ensure that the mist spray remains active at the applied velocity as indicated by the values of 9.54e-05kg/m-s. Figure 7 shows the velocity profile and vector dynamics of the fluid in the tunnel respectively.

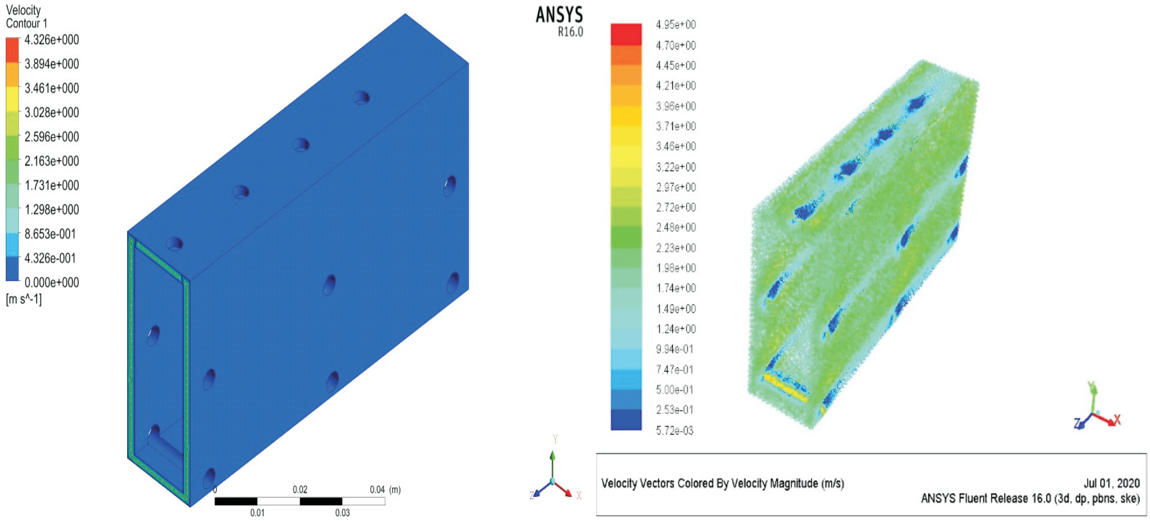


Figure 7 Showing the velocity profile and the velocity vector of the fluid.

The velocity profile in figure 7 shows that the effect of the velocity of flow will remain a critical component of the system and the effectiveness of the disinfection will heavily depend on the ease of the mist reaching the area of application. From the simulated profiles, it was clear that the boundary conditions of a turbulent mist coming out a 2.5m/s was going to enhance the system performance and ensure the system successfully takes care of destructive constituent in and around the ambient environment of the tunnel

Conclusion

It is expected that the walkthrough tunnel will significantly reduce the risk of infection from COVID-19 in public facilities in addition to other preventive measures like hand washing, use of protective masks, and social distancing. Hence, the implementation of this proposal will greatly enhance public safety and ensure a better working environment for public workers. The estimated bill of quantity is shown in Table 4.

Table 4 Estimated of Bill of Quantity

S/N	Item	Qty	Expected Cost
1	PIR motion detection sensor and circuit	1	10,000
2	DC Water pump	1	40,000
3	Main pump	1	50,000
4	2,000-litre Overhead tank	1	45000
5	Disinfectant(SodiumHypochlorite)	25 litres	10,000
6	Perspex Glass	2 sheets	100,000
	12.75 mm pipe	3 lengths	10,000
	Tubings and nozzles	15	50,000
	Instrumented systems for performance measurement		200,000
	Smaller tank(chamber tank)	1	15,000
	Transportation, labour and Miscellaneous		50,000
Total			500,000

References

Buonanno, G., Stabile, L., & Morawska, L. (2020). Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment. *Environment international*, *141*, 105794. https://doi.org/10.1016/j.envint.2020.105794

Caliendo, A., Ciambellib., P., De Guglielmoa, M.L Meob, M.G and Russo P (2012)Simulation of People Evacuation in the Event of a Road Tunnel Fire.SIIV - 5th International Congress - Sustainability of Road Infrastructures. Procedia - Social and Behavioral Sciences 53 (2012) 178 – 188. DOI: 10.1016/j.sbspro.2012.09.871

CDC, (2019), Implementation of Mitigation Strategies for Communities with Local COVID-19 Transmission, available online https://www.cdc.gov/coronavirus/2019-ncov/downloads/community-mitigation-strategy.pdf

IDPH (2019) Novel Corona Virus https://idph.iowa.gov/emerging-health-issues/novel-coronavirus

Ghose T, (2020) How are people being infected with COVID-19?. Available online at https://www.livescience.com/how-covid-19-spreads-transmission-routes.html last visited on 6th May 2020

IWMA, (2013). Water mist fire protection: The most innovative fire fighting technology available today - introduction & general description, international standardization, testing & approvals. Iwma Seminars OnEminars On Water Mist Technology Dubai International Convention And And Exhibition Centre. Available online at https://iwma.net/fileadmin/user_upload/Seminar_Dubai_2013/Marioff_Nigro_Introduction_Dubai_2013.pdf last visited on 10th May 2020

Kaiser L. (2018). What are the water mist systems? Available online at https://www.orrprotection.com/mcfp/blog/what-are-water-mist-systems last visited May 7th, 2020

Mahmoud S. M (2019). Experimental Study to Evaluate Mist System Performance International Journal of Innovative Research in Advanced Engineering 2(9).Pp 41-48

McAfee J. (2016) Water Mist Systems: the Future of Fire Protection Technology. Available online at https://www.fireengineering.com/2016/03/21/280749/water-mist-systems-the-future-of-fire-protection-technology/#gref last visited on the 7th May 2020

Morawska L., Johnson G.R., Ristovski Z.D., Hargreaves M., Mengersen K., Corbett S., Chao C.Y.H., Li Y., and Katoshevski D (2009). Size Distribution And Sites Of Origin Of Droplets Expelled From The Human Respiratory Tract During Expiratory Activities. J. Aerosol Sci. 2009;40:256–269. doi: 10.1016/j.jaerosci.2008.11.002.

Peace Corp (1994). Irrigation Reference Manual. Available online at http://www.nzdl.org/gsdlmod?e=d-00000-00---off-0cdl--00-0----0-10-0---0---0direct-10---4-------0-0l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-10&a=d&c=cdl&cl=CL1.136&d=HASH013e8d1a442c5a625761db09.3.6.5#HASH013e8d1a442c5a625761db09.3.6.5 last visited on the 6th May 2020

QRFS, (2019). What are Water Mist Fire Sprinkler Systems? Available online at https://www.qrfs.com/blog/175-what-are-water-mist-fire-sprinkler-systems/ last visited on the 10th of May 2020.

Ramkumar R., Kesavan M. and Ragupathy A. (2015) Experimental Evaluation of Evaporative Cooler Using Agro Materials International Journal of Air-Conditioning and Refrigeration 23(4) https://doi.org/10.1142/S2010132515500285

UN (2020), Social Impact of COVID-19m available online at https://www.un.org/development/desa/dspd/2020/04/social-impact-of-covid-19/

Wintering G. (2015) Differences Between Water Spray Systems, Sprinklers, and Water Mist Systems. Available online at https://fogco.com/differences-between-water-spray-systems-sprinklers-and-water-mist-systems/ Last visited 6th May 2020