KAOLINVEJ 4
9220 AALBORG Ø

PHONE: +45 70231020
FAX: +45 70231031

E-MAIL: SALES@ULTRAAQUA.COM

REFERENCE: OLE GRØNBORG, CEO
E-MAIL: GRONBORG@ULTRAAQUA.COM

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TECHNICAL BACKGROUND
HVLS UV-C SYSTEM – NORTHERN LIGHT™

To: NORDICCO A/S

Author: Ole Grønborg, MSc./ Ph.D and Peter Vittrup Christensen, MSc./Ph.D

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Topic: HVLS UV-C fan disinfection system - Northern Light™

EXECUTIVE SUMMARY IN ENGLISH

There is an obvious possibility in applying UC-C technology for cleaning of SARS-CoV-2 and other bio contaminated air during a pandemic. Evidence shows that the Corona virus is airborne and that poorly ventilated buildings have higher risks of infectious disease transmission between people. Estimations suggest that inhaling about 1000 vira is enough for the Corona virus to take hold. Thus, it is clear that increasing air changes per hour with germ free air lowers the risk of inhaling sufficient Corona viruses to get infected. Viruses are small making them more susceptible to UV-C than other organisms, leading to WHO to recommend UV-C radiation for inactivation of such organisms. One approach to minimize the risk of getting infected is regular opening of windows for ventilation, but such a strategy creates variating and unpredictable airflows and areas with little ventilation. Upper-air UV-C systems are well known for disinfection in hospital rooms and the effect highly increase with fans distributing the germ free air. High Volume Low Speed (HVLS) fans combined with UV-C delivers high rate of germ-free air in a low airspeed downwards manner, diluting virus numbers and lowers the infection risk. Compared to general Upper-UV-C systems without fans improvement of 77 percent has been reported when adding the fans. The product combining a HVLS fan with UV-C integrated in the wings are patent-pending by Nordicco A/S and has been named Northern-Light™. Northern-Light™ is showing an efficiency of 87,9% per air passage over the wings against SARS-CoV-2 by Comsol CFD analysis. No other known technology has paralleled efficiency for such high amounts of air evenly distributed in each recirculation passage.

OPSUMMERING PÅ DANSK

Der er en åbenbar mulighed ved anvendelse af UC-C-teknologi til rengøring af SARS-CoV-2 bioforurenet luft under pandemien. Forskning viser, at virussen er luftbåret, og at dårligt ventilerede bygninger har højere risici for smittefarlig transmission mellem mennesker. Skøn antyder, at inhalation af ca. 1000 vira er nok til, at Corona-viruset kan få fat. Det er således klart, at stigende antal luftudskiftninger i timen med kimfri luft reducerer risikoen for inhalation af tilstrækkelige Corona-vira til at blive inficeret. Virus er små, hvilket gør dem mere modtagelige for UV-C end andre organismer. WHO anbefaler UV-C-stråling til inaktivering af sådanne organismer. En tilgang til at minimere risikoen for at blive smittet er regelmæssig åbning af vinduer til ventilation, men en sådan strategi skaber varierende og uforudsigelig luftstrøm og områder med døde områder. Øvre-luft-UV-C-systemer (Upper Air) er velkendte til desinfektion af luft på hospitalsstuer og effekt forøges med fans, der distribuerer den kimfri luft. HVLS-fans (High Volume Low Speed fans) kombineret med UV-C leverer en stor mængde af kimfri luft ved lav nedadgående hastighed, hvilket fortynder antallet af virus og sænker risikoen for smitte. Sammenlignet med Upper-UV-C-systemer uden ventilatorer er der rapporteret forbedring på 77%. Produktet, der kombinerer en HVLS-ventilator med UV-C, der er interageret i vingerne, er patenteret af Nordicco A/S og er blevet navngivet Northern-Light™. Northern-Light™ er vist effektiv med 87,9% per luftpassage imod SARS-CoV-2 ved Comsol CFD analyse. Der findes ikke anden kendt teknologi der med så høj effektivitet ved en enkelt passage kan desinficere store luftmængder og distribuere det ensartet i store rum.

SCIENTIFIC BACKGROUND

The global health-threatening crisis from the COVID-19 pandemic, caused by the severe acute respiratory syndrome coronavirus (SARS-CoV-2), highlights the scientific and engineering potentials of applying ultraviolet (UV-C) disinfection technologies for bio contaminated air as the major technology for removal of SARS-CoV-2 transmission. Various environmental public settings worldwide, from hospitals and health care facilities to shopping malls, airports and schools, are considering implementation of UV disinfection devices for disinfection of circulating air streams. (Milad, 2020)

Evidence shows that the virus is airborne in tiny droplets travelling for several hours. (*Thorseth, A 2020. DTU.) (Ashrae, 2020).* Authorities now generally recommend regular passive ventilation (opening windows) of indoor spaces to minimize impact of airborne viruses. New evidence of airborne spread cases is a daily event. As an example:

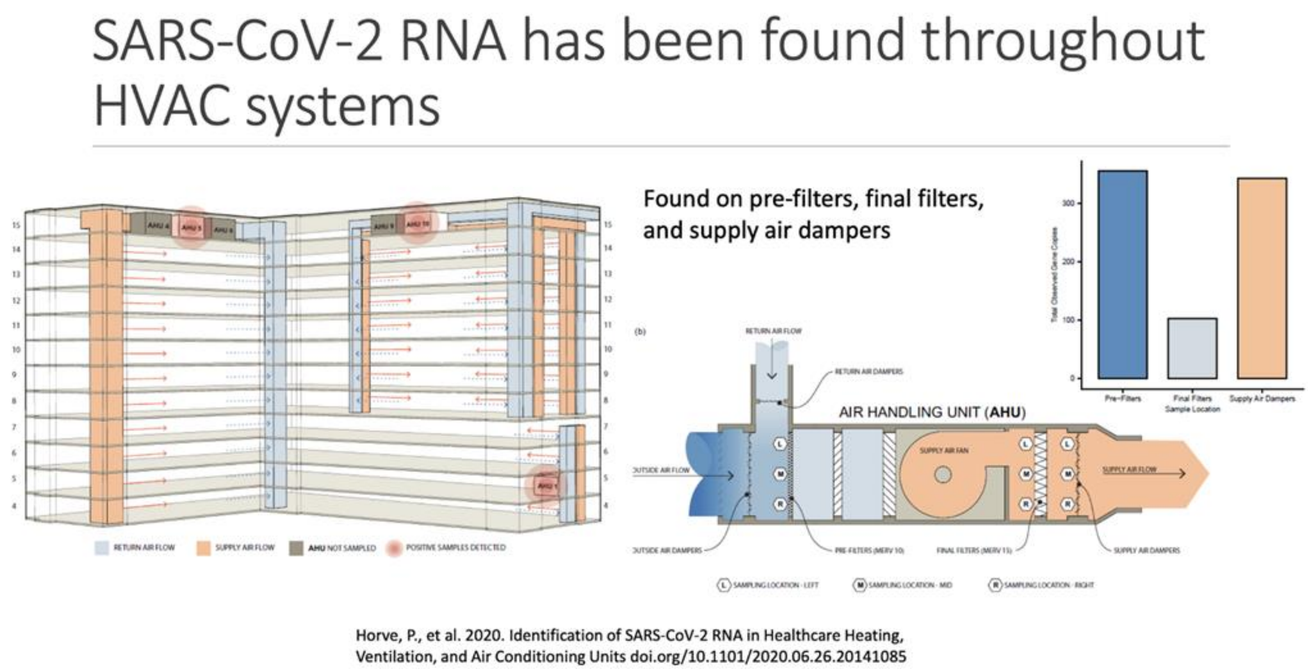


Figure 1

In facilities where there are infectious patients, evidence shows that poorly ventilated buildings have higher risks of infectious disease transmission. (Li et al,2007) demonstrated the association between ventilation and air movements in buildings, and the transmission/spread of infectious diseases.

Coughing by a COVID-19 infected individual can produce about 3000 droplets in a wide size range (10^{-1} to 10^{2} μm). Droplets larger than 100 μm deposit rapidly on surfaces. (Wang, J., 2020) (Garcia et al., 2020). Tiny droplets (0.1−5 μm) are capable of dissolving with the aerosol, remaining airborne, and traveling hundreds of meters. (Garcia et al., 2020) (Morawska, L., et al., 2020) Intermediate size range (5−100 μm) droplets also shrink to tiny sizes due to evaporation, (Garcia et al., 2020) and the peak concentration of droplets in bioaerosols are in two diameter ranges: 0.25−1.0μm and 2.5−10 μm. (Liu, Y,. et al., 2020)

The majority of larger emitted droplets are drawn by gravity to land on surfaces within about 1–2 m from the source (see Figure 2). General dilution ventilation and pressure differentials do not significantly influence short-range transmission. Conversely, dissemination of smaller infectious aerosols, including droplet nuclei resulting from desiccation, can be affected by airflow patterns in a space in general and airflow patterns surrounding the source in particular. Of special interest are small aerosols (<10 μm), which can stay airborne and infectious for extended periods (several minutes, hours, or days) and thus can travel longer distances and infect secondary hosts who had no contact with the primary host. (Ashrae, 2020) (Stadnytskyi,v. et al., 2020)

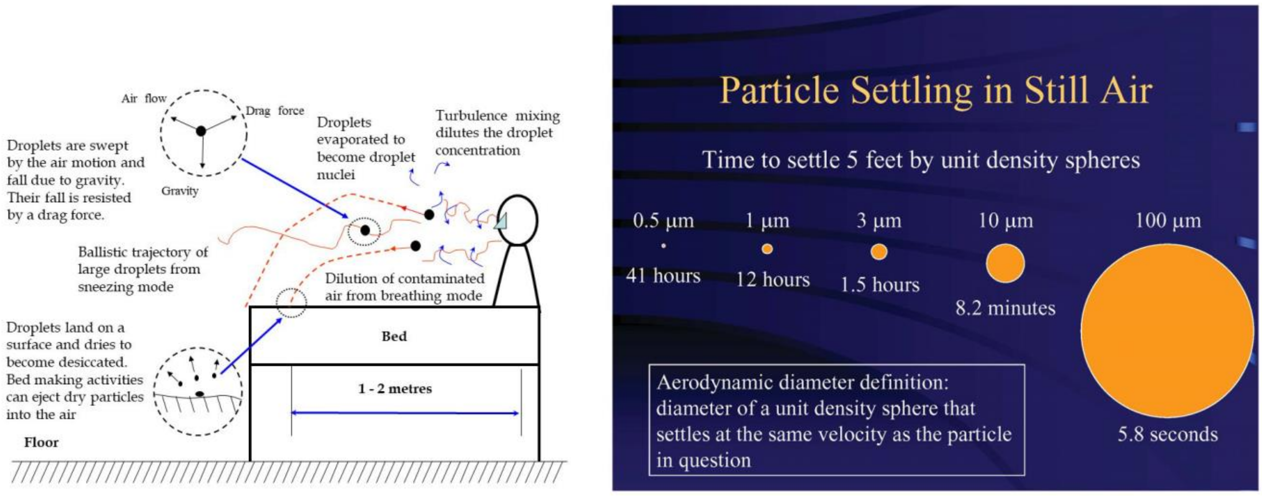


Figure 2 (a) theoretical aerobiology of transmission of droplets and small airborne particles produced by an infected patient with an acute infection (b) Comparative settling times by particle diameter for particles settling in still air. (Ashrae 2020)

BECOMING INFECTED

Becoming infected requires an infectious dose of the virus. An infectious dose is the product of concentration and time. Some experts estimate that inhaling 1,000 infectious virus particles is enough for the Corona virus to take hold. Studies based on influenza suggest that normal breathing (at rest) releases about 20 viral particles/minute. If a nearby person were to inhale all those particles (unlikely), the person would need 50 minutes of exposure to become infected. Speaking increases respiratory droplet production to about 200/minute. So, a direct, face-to-face conversation could infect another person in five minutes (in the unlikely event that the recipient inhales all the exhaled particles from an infected person). (https://www.erinbromage, 2020)

A technique that relates infectious particle concentration, exposure time, and outside air ventilation might be a useful tool to guide analysis of the role ventilation systems can have in managing infectious aerosols. The Wells-Riley equation provides a method to predict the likelihood that a person will be infected by a virus:

Ultraviolet disinfection effectiveness is a function of dose, which is radiant intensity times time:

$$\eta = 1 - e^{-kIt}$$

where:

- η = disinfection effectiveness (decimal)
- k = species-specific constant (cm²/µJ); 1J = 1 w/s)
- I = average irradiance (µw/cm²)
- w = watts
- t = exposure time (seconds)

Calculations done with the Wells-Riley equation can be seen in Figure 3. It is obvious that probability of staying helthy increase with:

1. Increased air changes per hour. (I.e. It is less likely to be infected outdoor than indoor)
2. Increasing room volume. (It is less likely to be infected in large rooms)
3. Less talking and activity in room.

Probability of infection with various supply air rates						
Germ free air supply		ACH	0,33	1,67	5,00	ACH: Air Changes per Hour
Space type	Room volume	Hours in space	Probability of infection			Notes
Open office	255	6	99	61	27	Seated,talking 40% of the time.
Personal office vith gues	38	2	100	88	51	Seated,talking 40% of the time.
2 person office	38	6	100	100	88	Seated,talking 40% of the time.
Classroom	255	6	99	61	27	Seated,talking 40% of the time.
Supermarket customer	20388	0,5	0,5	0,1	0,0	Standing,talking 10% of the time.
Supermarket employee	20388	6	5,8	1,2	0,4	Standing,talking 10% of the time.
Butik customer	5097	0,5	2,0	0,4	0,1	Standing,talking 10% of the time.
Butik employee	5097	6	21,3	4,6	1,6	Standing,talking 10% of the time.

Figure 3.

UV

Disinfection using UV radiation has been a fast growing chemical-free technology over the past decades. UV radiation is highly efficient at controlling microbial growth in any medium, such as water and air, as well as on any type of surface. (Milad, 2020) (*Thorseth, A 2020. DTU.)*

UV-C radiation has a short wavelength and high energy, compared to other UV radiation, which enables
it to function the best in a direct line and at a short distance. Due to the high energy of the UV-C radiation, it is bound to the inverse square law where the propagation of light intensity decreases exponentially with
increasing distance from the light source. Studies developed by (Escombe et al., 2009) and (Casanova et al., 2010) provided that there is a sufficient circulation inside the room to mix the air, upper-room UV fixtures have shown to be an effective asset for use in infection control.

UV-C systems inactivates microorganisms by damaging the structure of nucleic acids and proteins at the molecular level, making them incapable of reproducing. The most important of these is DNA, which is responsible for cell replication (Harm 1980). Absorbed UV photons can damage DNA in a variety of ways, but the most significant damage event is the creation of pyrimidine dimers, where two adjacent thymine or cytosine bases bond with each other, instead of across the double helix as usual (Diffey 1991). In general, the DNA molecule with pyrimidine dimers is unable to function properly, resulting in the organism's inability to replicate or even its death (Diffey 1991; Miller et al. 1999; Setlow 1997; Setlow and Setlow 1962). An organism that cannot reproduce is no longer capable of causing disease.

UV-C systems effectiveness depends primarily on the UV dose (D_{UV} , μJ/cm^2) delivered to the microorganisms:

$$D_{UV} = It$$

where I is the average irradiance in µW/cm2, and t is the exposure time in seconds (note that 1 J = 1 W/s).

The dose is generally interpreted as that occurring on a single pass through the device or system. Although the effect of repeated UV exposure on microorganisms entrained in recirculated air may be cumulative, this effect has not been quantified, and it is conservative to neglect it.

The survival fraction S of a microbial population exposed to UVC energy is an exponential function of dose:

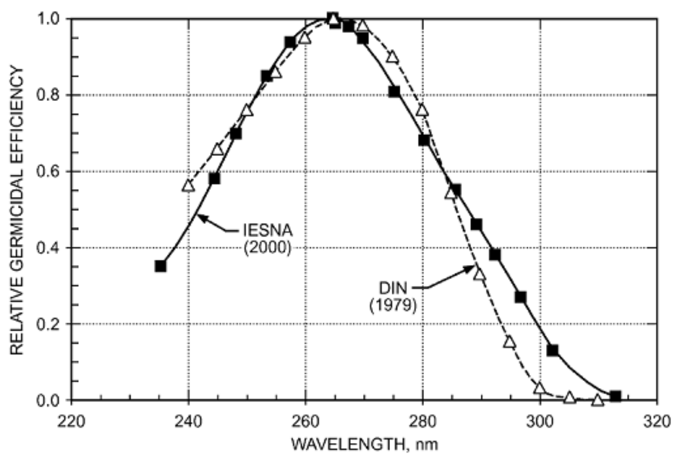
$$S = e^{-kDUV}$$

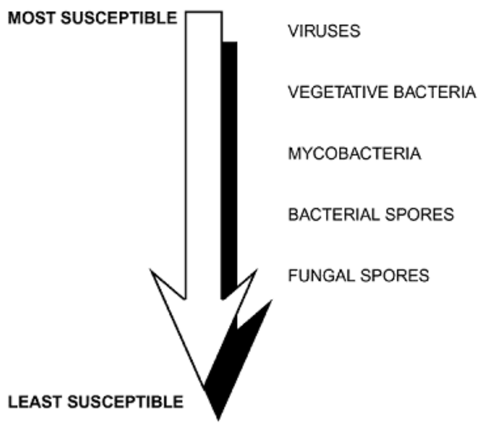
where k is a species-dependent inactivation rate constant, in cm^2/µJ. The resulting single-pass inactivation rate η is the complement of S:

$$\eta = 1 - S$$

Inactivation rate constants (k-values) are species-dependent and relate the susceptibility of a given microorganism population to UV radiation (Hollaender 1943; Jensen 1964; Sharp 1939, 1940). Measured k-values for many species of viruses, bacteria, and fungi have been published in the scientific literature and previously summarized (Brickner et al. 2003; Kowalski 2009; Philips 2006).

As shown in Figure below, virus are generally more susceptible to UVC energy than fungi, but this is not always the case, so a general recommendation is to investigate inactivation rate for each organism.





Based on systematic literature reviews the World Health Organization (WHO) recommended use of bacteria disinfecting UV-C radiation in upper room use as a means of prevention and control of tuberculosis infection (WHO, 2019). (Ko et al., 2000; Peccia et al., 2001). Escombe et al. (2009) studied bactericidal UV radiation in the upper part of rooms in a hospital in Lima without air-conditioning, and found a marked reduction in the risk of transmission of airborne tuberculosis despite the high relative humidity of 77%. (*Thorseth, A 2020. DTU.)*

Centers for Disease Control and Prevention (CDC) has approved UV as an adjunct to filtration for reduction of tuberculosis risk and has published a guideline on its application (CDC 2005, 2009). (Evidence Level A)

Personalized ventilation systems that provide local exhaust source control and/or supply 100% outdoor, highly filtered, or UV-disinfected air directly to the occupant's breathing zone (Cermak et al. 2006; Bolashikov et al., 2009; Pantelic et al. 2009, 2015; Licina et al. 2015a,2015b) offer protection against exposure to contaminated air.

Advanced techniques such as computational fluid dynamics (CFD) analysis, if performed properly with adequate expertise, can predict airflow patterns and probable flow paths of airborne contaminants in a space. Such analyses can be employed as a guiding tool during the early stages of a design cycle (Khankari 2016, 2018a, 2018b, 2018c).

UV-C DOSE FOR INACTIVATION OF THE CORONA VIRUS

Ultraviolet radiation has been explored to reduce the spread of airborne infections at least since the 1930s. Ultraviolet radiation can disinfect surfaces, room air (called upper air systems), and air in ducts. To inactivate an organism (such as a virus), the ultraviolet radiation must strike the organism. Upper air (room) systems rely on air circulation in the room to carry microorganisms to the upper air zone where sufficient ultraviolet light shine on them. (Mphaphlele, 2015; Escombe et al., 2009; DHHS, 2009)

UV-C irradiation is highly effective in inactivating and inhibiting SARS CoV-2 replication (Bianco, et al., 2020)

At a virus density comparable to that observed in SARS-CoV-2 infection, an UV-C dose of just 3.7 mJ/cm^2 was sufficient to achieve a 3-log inactivation, and complete inhibition of all viral concentrations was observed with 16.9 mJ/cm^2. UV-C effect on viruses has been intensely studied by several authors (As an example; Rauth, A.M., 1965)

These results are important for the development of novel sterilizing methods to contain SARS-CoV-2 infection.

RISKS BY USING UV-C

Most people are not exposed to UV-C naturally: UV-C from the sun is primarily filtered by the atmosphere, even at high altitudes (Piazena and Häder, 2009). Human exposure to UV-C typically comes from artificial sources. UV-C penetrates only the outer layers of the skin and hardly reaches the basal layer of the epidermis, nor does it penetrate deeper than the surface layer of the cornea of the eye. Exposure of the eye to UV-C can result in Snow blindness, (photokeratitis), a very painful condition that feels as if sand has been rubbed on the eye. Symptoms of snow blindness take up to 24 hours after exposure to develop and require another approximately 24 hours to subside. Bactericidal UV radiation can be used safely and effectively for disinfection in the air without a significant risk of delayed long-term effects such as skin cancer. (Thorseth, A 2020. DTU.)

Guidance on occupational exposure to UV radiation including UV-C radiation has been published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2004): UV radiation exposure to unprotected eyes / skin should not exceed 30 J/m^2 for radiation at 270 nm, which is the wavelength too maximum for the spectral weighting function that describes actinic (chemical effect of radiation) UV hazard to skin and eye. (Thorseth, A 2020. DTU.)

Reflection, or indirect UV-C radiation can be an issue in UV-C radiated rooms. Careful investigation of such issues should be controlled by technician during installation. An eye level (1.68 – 1.83 m) irradiance measurement using a 254 nm selective radiometer can be used to control in eye height at various locations in a room. In Europe regulations can be found published as ISO 15858, (UV-C Devices — Safety information — Permissible human exposure). Also national standards should be considered. As an example in Denmark; Bek nr 562. Bekendtgørelse om beskyttelse mod udsættelse for kunstig optisk stråling I forbindelse med arbejdet.

VARYING APPROACHES FOR DIFFERENT FACILITY TYPES

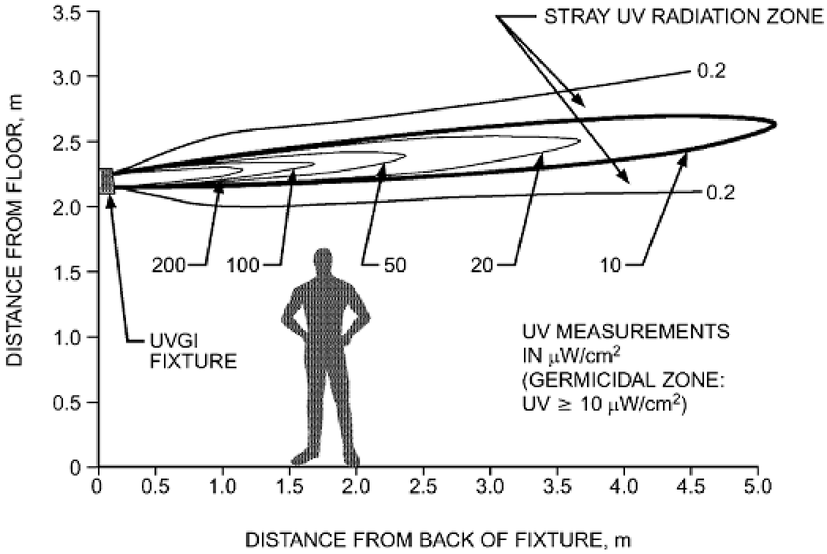
Many buildings are fully or partially naturally ventilated. They may use operable windows and rely on intentional and unintentional openings in the building envelope. These strategies create different risks and benefits. Obviously, the airflow in these buildings is variable and unpredictable, as are the resulting air distribution patterns, so the ability to actively manage risk in such buildings is much reduced. Generally speaking, designs that achieve higher ventilation rates will reduce risk. However, such buildings will be more affected by local outdoor air quality, including the level of allergens and pollutants within the outdoor air, varying temperature and humidity conditions, and flying insects. The World Health Organization has published guidelines for naturally ventilated buildings that should be consulted in such projects (Atkinson et al. 2009).

Upper-air UVC is very effective in areas with no, or minimal, ventilation; 2 air changes per hour (ach) equivalency, up to normal recommended levels of 6 ach can be achieved. Ventilation patterns (natural and mechanical) should promote good air mixing in the space equipped with UVC so that infectious microorganisms encounter the UVC zone and are inactivated, thus reducing the risk of exposure of occupants to airborne infectious agents. Recent studies that have used ventilation and UVC have shown that upper-air UVC is an effective, low-cost intervention for use in TB infection control (Escombe et al. 2009; Mphaphlele et al. 2015).

Ventilation with effective airflow patterns (Pantelic and Tham 2013) is a primary infectious disease control strategy through dilution of room air around a source and removal of infectious agents (CDC 2005).

UPPER-AIR UVC PERFORMANCE AND COST

The effectiveness of upper-air UV-C performance has often been described in terms of equivalent air changes per hour (ACH): that is, by the rate of outside airflow measured in room volumes per hour that would achieve the same reduction of microbial air contamination in a well-mixed space. (Riley et al.'s 1976) study of UV-C efficacy found that one 17 W UVC lamp covering 18.6 m^2 produced 10 equivalent ACH (Air Changes per Hour) versus a natural die-off of 2 ACH when a surrogate for tuberculosis was released in the room. The UVC lamp took less than 20 min to inactivate the bioaerosol, versus over 30 minutes for a natural die-off. In a bioaerosol room study, (McDevitt et al., 2008) showed seasonal variations of between 20 to 1000 equivalent ach for a surrogate for smallpox. (Ko et al., 2001) modeled the cost of using three air-cleansing strategies to control transmission of tuberculosis in a medical waiting room. They calculated a present value per avoided tuberculin skin test conversion (evidence of infection) of $1708 for increased ventilation, $420 for HEPA filtration, and $133 for upper-air UV-C: that is, UVC was less expensive by a factor of 3 to 13. Another metric is cost to provide a typical level of treatment per unit of floor area. The estimated health care benefit, typical of such analyses, was much larger than the cost: roughly $430/$m^2$ per year.



(ASHRAE 2019)

ROLE OF HVLS FANS IN DISINFECTING INDOOR AIR

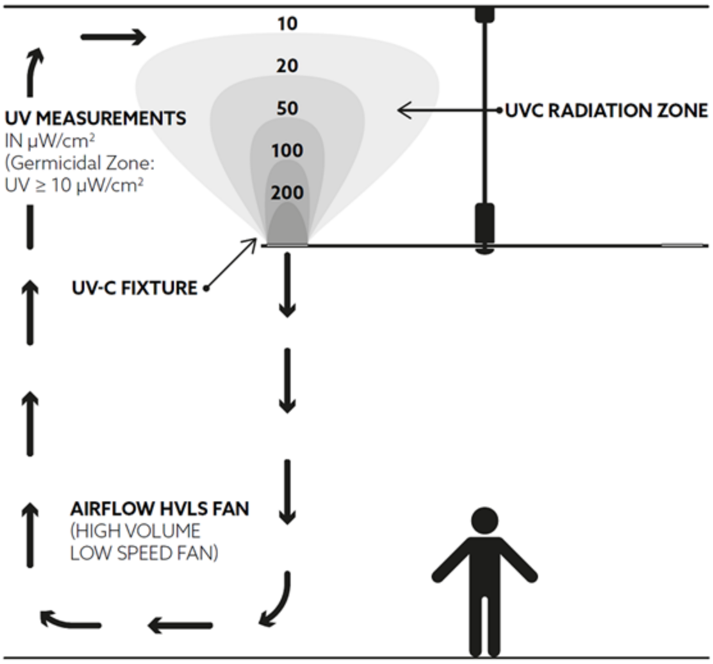
The primary objective of upper-air UV-C placement and use is to interrupt the transmission of airborne infectious pathogens within the indoor environment.

In a room ventilated by an HVLS overhead fan, the air layers are well mixed so the supplied disinfected fresh air can reach the occupant level.

In naturally or HVAC (Heating, Ventilation and Air Conditioning) ventilated spaces, fresh air is uneven distributed throughout the space, so localized areas may have stagnant pockets, resulting in poor air quality and buildup of pollutants including bacteria and virus. Fans disperse these pockets and increase the circulation of fresh disinfected air, evenly distributing it throughout the space, diluting virus number per volume and improving indoor air quality. (C.Canada, 2020)

The use of UV technologies in the HVAC industry is well established and understood. The technology has been paired with HVAC equipment use since the early 1940s and the benefits they provide reduce occupant exposure to contagions by disinfecting indoor air near specially designed UV devices. (C.Canada, 2020)

Increasing of the rate of air circulation between the upper and lower air zones, can improve the performance of upper-room ultraviolet germicidal irradiation (UVGI) systems by up to 77 per cent (C.Canada, 2020)


10
20
50
100
200
UVC RADIATION ZONE
UV MEASUREMENTS
IN µW/cm²
(Germicidal Zone:
UV ≥ 10 µW/cm²
UV-C FIXTURE
AIRFLOW HVLS FAN
(HIGH VOLUME
LOW SPEED FAN)

UPPER-ROOM UV SYSTEM PERFORMANCE BENCHMARKS

To ensure effective inactivation of airborne contagions, upper-room UV design guidelines are provided by NIOSH in partnership with CDC. The most important of these guidelines concerns the selection and positioning of the UV sources. The lamps should be arranged to provide irradiance in a uniform manner. The UV fluence rate should be between 30 and 50 $\mu W/cm^2$. This measure of radiation intensity can be multiplied by the duration of exposure (the time of an air particle in the disinfection zone) in seconds to determine the dose, measured in $\mu J/cm^2$. A suggested simplification of this principle is to use 6.3 watts of lamp power per cubic meter (6.3 W/m^3) of upper zone air volume.

Additionally, fixtures with louvers should be a minimum of 2 m above the finished floor. The minimum height requirements do not guarantee acceptable exposure at occupant levels. While exposure can be estimated in a simulated environment with specialty software.

Research conducted by the University of Colorado and sponsored by CDC and NIOSH has shown the disinfection of room air requires 6 to 12 air changes per hour, much more than the 0.5 to 2 air changes per hour that is typically required for odour and carbon dioxide (CO_2) control in ventilated spaces per ASHRAE 62.1 (See "Relevant Studies," (C.Canada, 2020)). Bringing in this amount of outdoor air to a facility can have significant energy and equipment implications.

By introducing HVLS fans, the volume of air that is actively cleaned in the disinfection zone is more frequently circulated back to the occupant level and replaced in the disinfection zone by air with a higher concentration of contaminants. By continually mixing the disinfection zone and occupant breathing zone air volumes, the effectiveness of the UV system is improved. This reduces the concentration of contaminants in the space without the need for a three to six-time increase in outdoor air rates. (C.Canada, 2020)

In the second stage of the mentioned study with 12 per cent system effectiveness without air mixing, a ceiling fan was added to ensure air mixing in the space. While operating the fan at a moderate speed, the system's effectiveness rose to 87 per cent. It is important to note circulating fans, whether operating in forward or reverse, can achieve effective kill rates. (C.Canada, 2020)

According to a study published in Environmental Health Perspectives, increasing air changes per hour and using a mixing fan enhances UV's effectiveness in inactivating aerosols of the pathogen S. marcescens. This increase in ventilation rates and mixing of upper and lower air volumes led to a reduction in pathogens, resulting in a safer, healthier indoor environment. (C.Canada, 2020)

HVLS APPLICATION DESIGN GUIDANCE

Overall, the application process for integrating HVLS fans in upper-room UV-C systems closely resemble that of common destratification applications. The key exception is a large change in the desired number of air turnovers per hour and how the turnover metrics for each scenario are defined. While a standard destratification application may target two total building air turnovers per hour (i.e. total fan airflow versus total space air volume), UV applications should target a minimum of 25 zonal air turnovers per hour between the upper air volume (disinfection zone) and the lower air volumes (everything below the disinfection zone). This calculation method better represents the efficiency improvement mechanism HVLS fans provide to UV systems and more accurately predict required fan quantities.

Peak UV germicidal wavelength resides between 265 to 270 nm. By damaging nucleic acids (both DNA- and RNA-based) and causing mutations that prevent replication, UV technology can render bacteria and viruses ineffective. Upper-room UV is considered the most effective application for room air disinfection by the Illuminating Engineering Society (IES) and is referenced as the safest, most effective application of UV-C wavelength use, where feasible. (C.Canada, 2020)

In summary, upper-room UV applications are the most effective when combined with HVLS fans where large volumes of air are constantly and actively mixed. This results in higher equivalent air changes per hour in terms of air disinfection. Thus, even when confined to an upper room application for safe occupation of the space, good air mixing (ideally with low-velocity ceiling fans) results in a high equivalent air change per hour in the lower, occupied space. An upper-room system ensures recirculated air in the space is cleaned, effectively reducing the risk of person-to-person transmission in a room where both an infectious source (sick person) and other susceptible persons share the same air. (C.Canada, 2020)

Combining an Upper UV-C device (UV-C in wings) with a HVLS ventilator is patented by Nordicco, developed in cooperation between Nordicco A/S and Ultraaqua A/S, and simply is a safe upper UV-C device combined with a fan. The product combining the two technologies has been named Northern Light™

NORTHERN LIGHT™ PRODUCT DEVELOPMENT

The Northern Light™ fan has been developed combining state of the art industrial fans from Nordicco A/S with high power UV systems from Ultraaqua A/S. The approach has been scientific with multiple 3D UV Integrated CFD (Computational Fluid Dynamics) simulations ensuring optimum performance, see appendix 1.

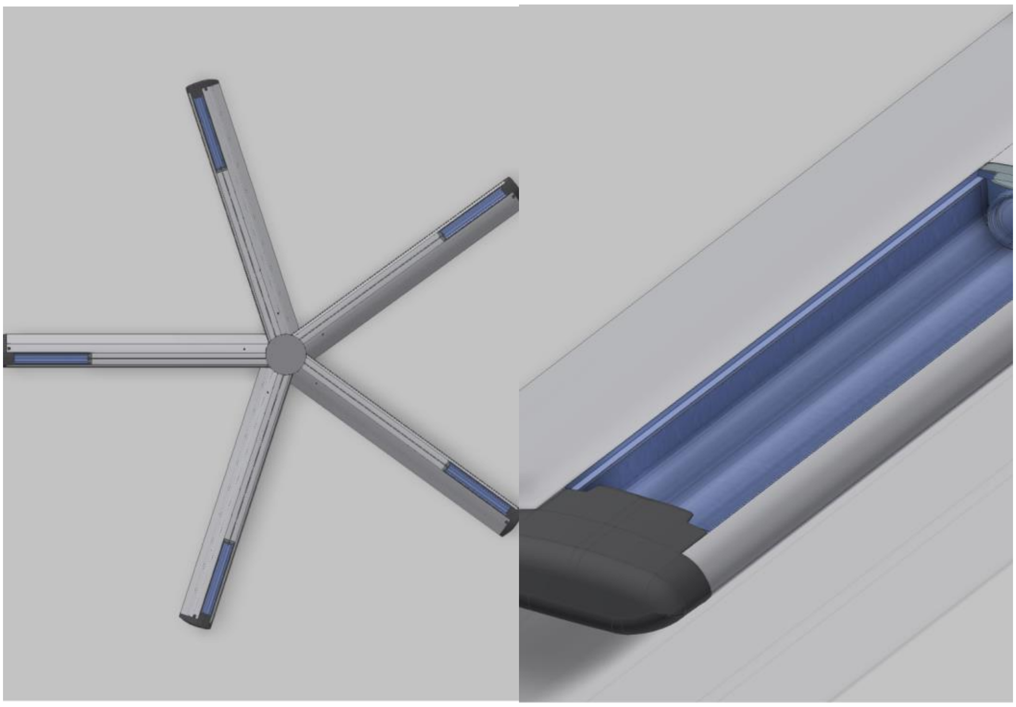
Even though industries in general trust CFD based design the final product is undergoing final validation by the Danish Technological Institute with live viral experiments. The final design is a powerful unit capable of disinfecting huge amount of air creating outdoor like conditions indoor. Since the unit is as powerful as reasonable for indoor use it is important to be careful during installation and commissioning not to exceed limits for UVC exposure in working space.

NORTHERN LIGHT™ COMSOL MULTIPHYSICS LIGHT MODEL AND COMPUTATIONAL FLUIDIC DYNAMICS (CFD) SIMULATION.

Peter Vittrup Christensen, MSc./PhD. Senior R&D Specialist, Ultraaqua A/S

Lamp inside wing simulation geometry.

For the simulations of the SARS-CoV-2 inactivation efficiency the 3D geometry of the fan design including UV systems integrated into the simulation software. The geometry below is the final design.



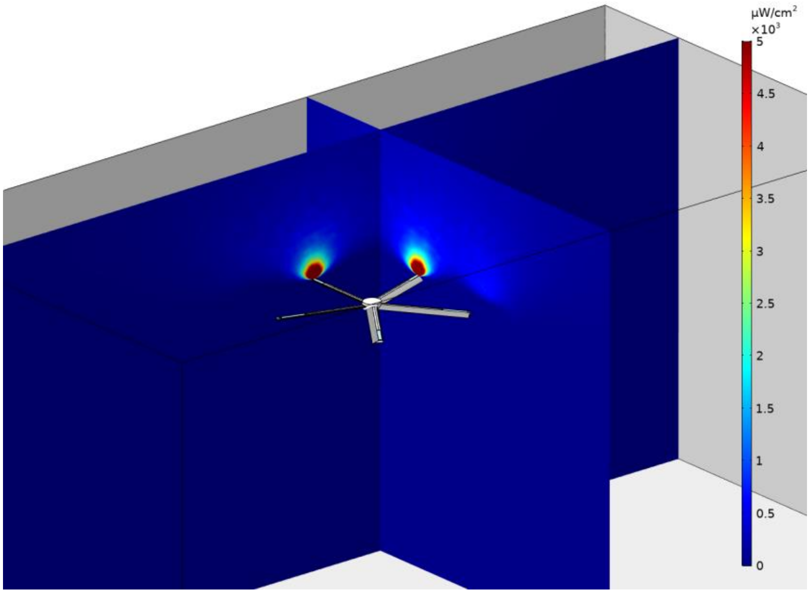
The 3D model is setup using the dimension of the room in which the physical tests are conducted and includes the UV lamps and UV reflector build into the fan.

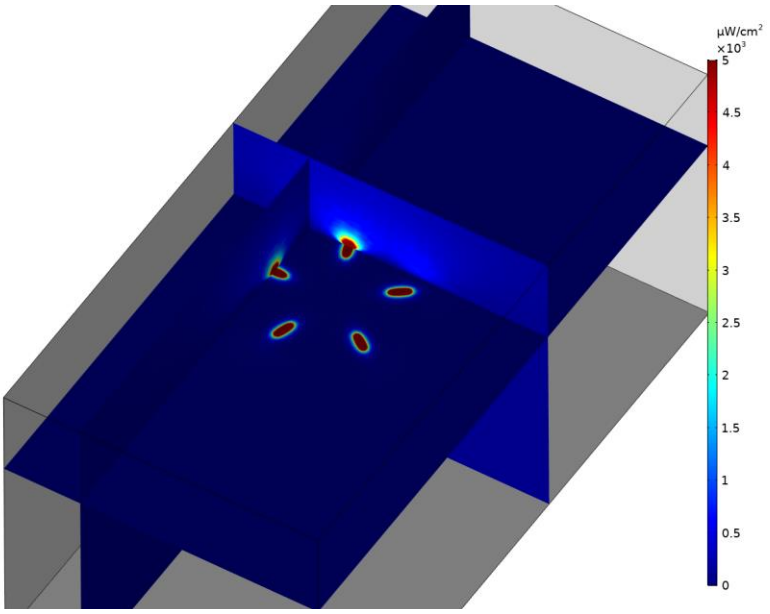
Fluence Rate (UV Intensity).

In the development phase, several lamp types, lamp placement and reflector design has been investigated to reach optimum performance. The optimization has focused on 1) matching the fluence rate distribution with the velocity distribution to ensure a narrow dose distribution and thus a higher energy efficiency, 2) sufficient UV dose to ensure an adequate degree of SARS-CoV-2 inactivation and 3) a UV fluence rate in the lower parts of the room where people are present low enough to meet safety requirements.

The resulting design provides a combination of residence time and fluence rate in the disinfection zone above the fan that ensures close to 88% inactivation of SARS-CoV-2 per passage while staying inside human exposure regulations. Since the room air is constantly recirculating over the wings the efficiency over a full working day is superior to any other known virus fighting technology.

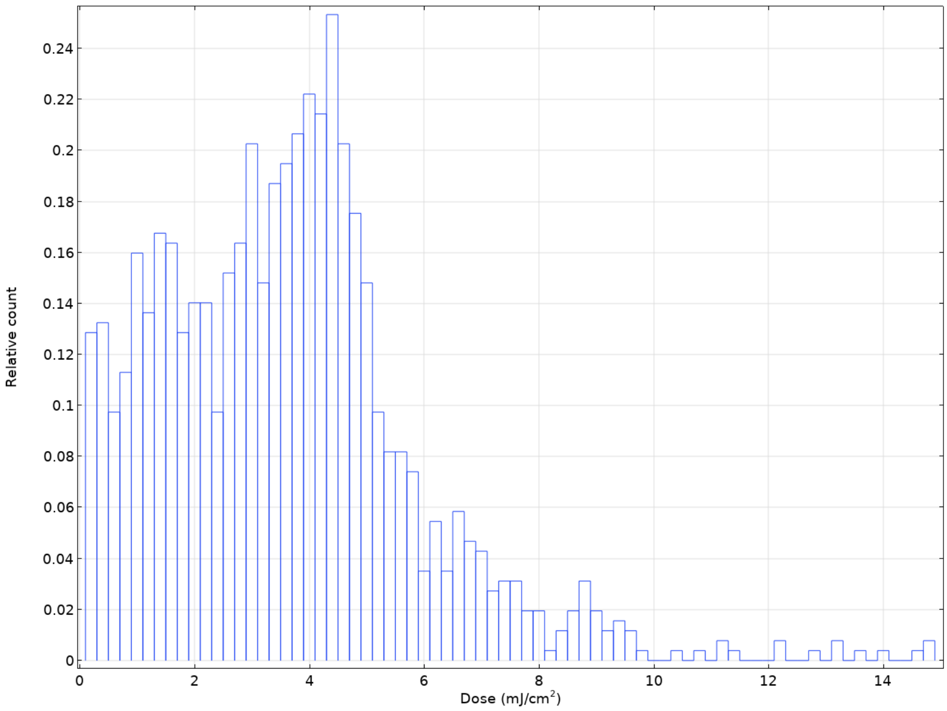
The figure below shows the fluence rate distribution in the room.





Dose distribution

To achieve good dose distribution, it is important to install the fan in the right distance to the ceiling and get a uniform airflow. Design goal is a narrow dose distribution since an unnecessary high dose is a waste of energy on already inactivated virus. Although the optimal use of the UVC energy emitted by the lamps is obtained when all organisms obtain the same dose, in practice this cannot not be obtained as both the residence time and fluence rate are distributions, and thus the resulting dose will also be a distribution. The final design has a been optimized to narrow the dose distribution and ensure sufficient dose to inactivate the SARS-CoV-2.



Conclusion

It has been shown by simulation that an 87.9% inactivation of SARS-CoV-2 can be achieved with the Northern LightTM fan per passage of recirculating ventilation air. The degree of inactivation has been calculated from the modelled dose distribution using a UV sensitivity reported in the literature (k-value of 1.87 cm2/mJ (Bianco et al., 2020)). The effect is expected to effectively reduce likelihood of inhaling the around 1000 SARS-CoV-2 that leads to Covid19 disease in treated areas.

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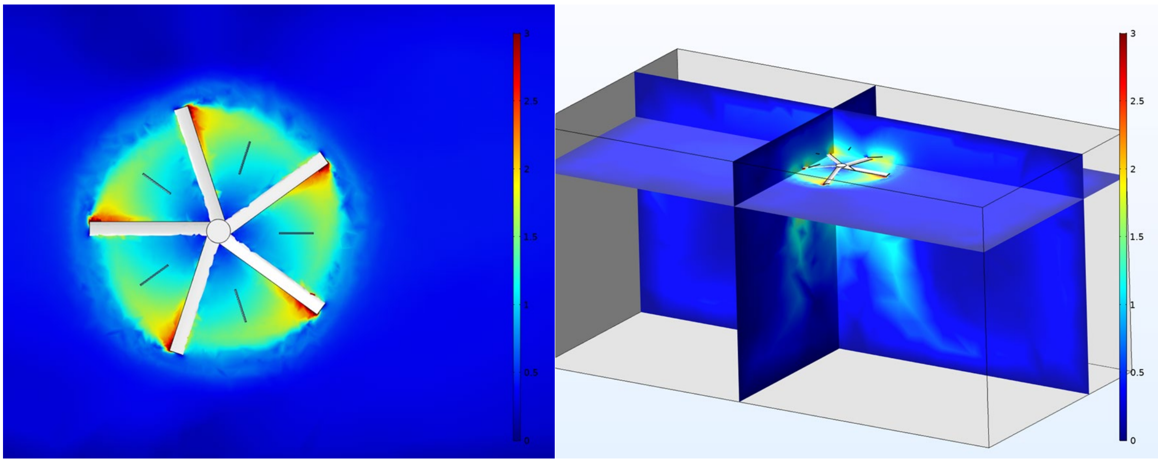
Appendix 1. Northern Light product development

COMSOL Multiphysics light model and Computational Fluid Dynamics (CFD) simulation 1&2.

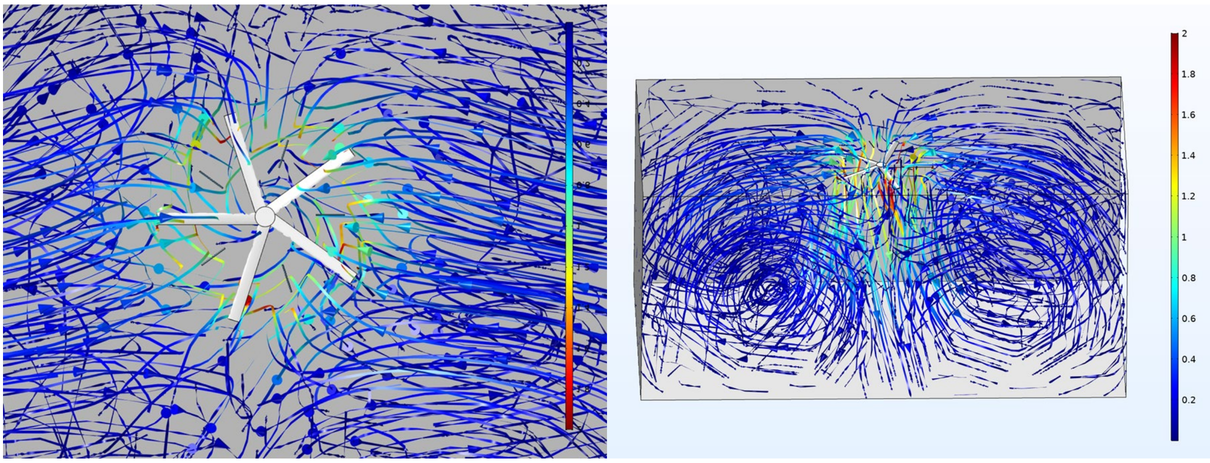
Peter Vittrup Christensen, MSc./PhD. Senior R&D Specialist, Ultraaqua A/S

Model 1&2: 5x60W=300W lamps mounted fixed between wings with reflector below. Conclusion; Potential is clear, but it is relatively complicated and not so elegant in design.

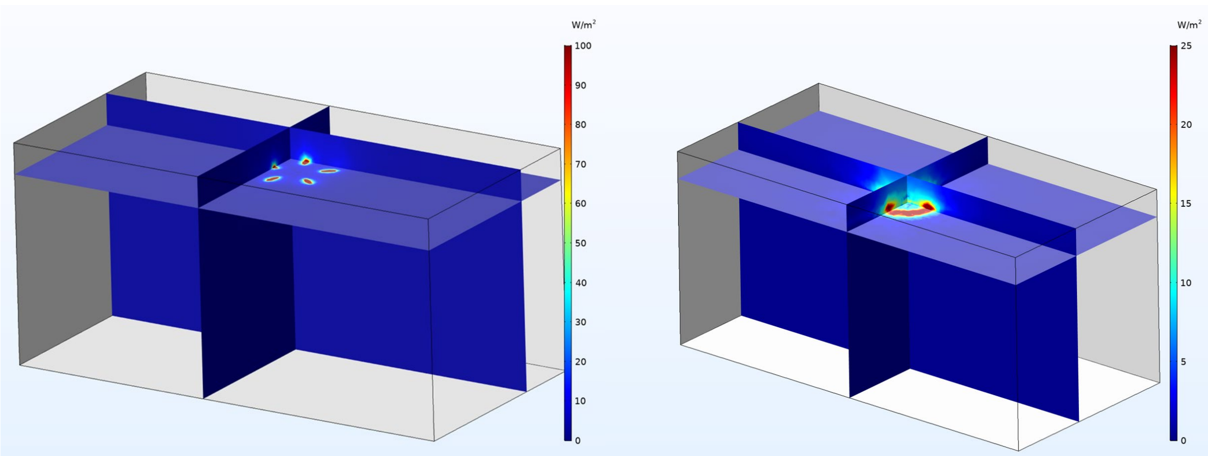
Velocity profiles:



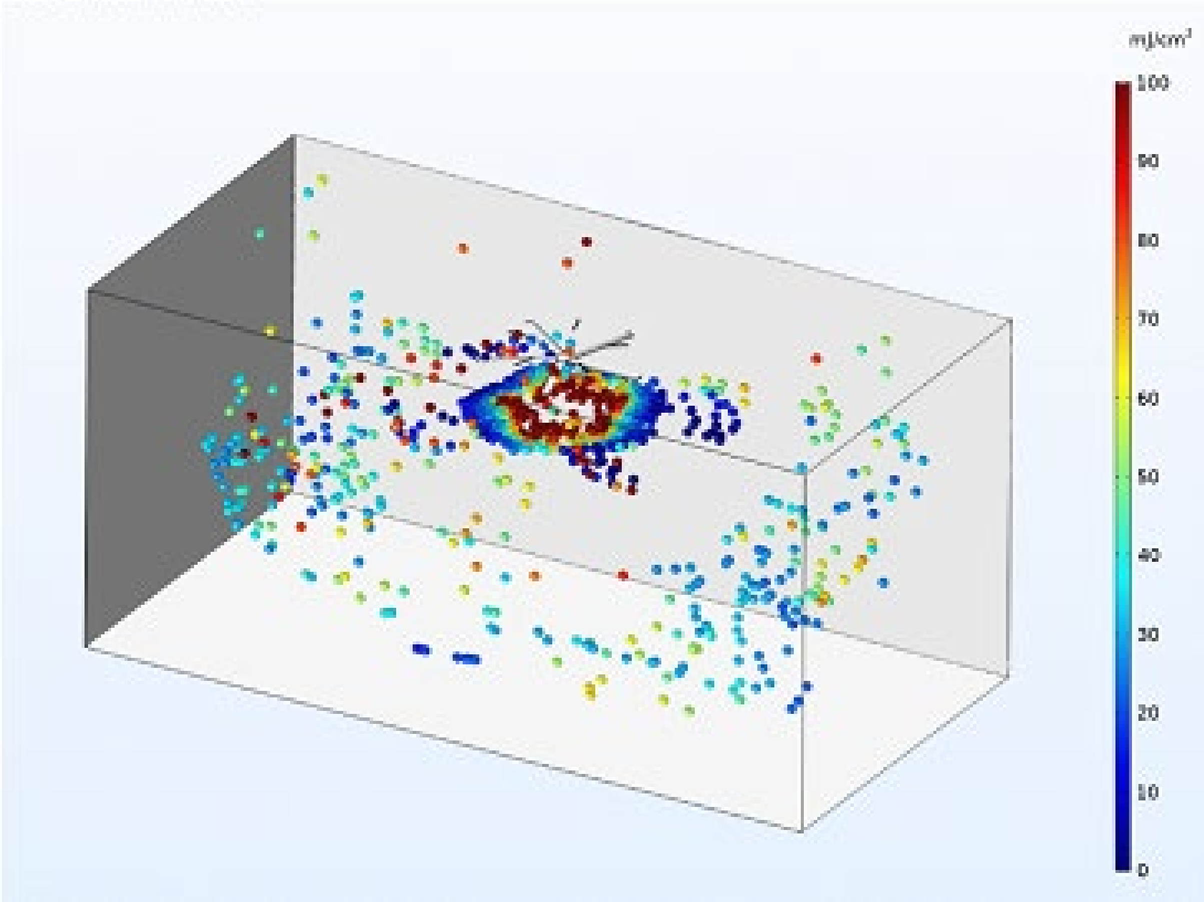
Streamlines



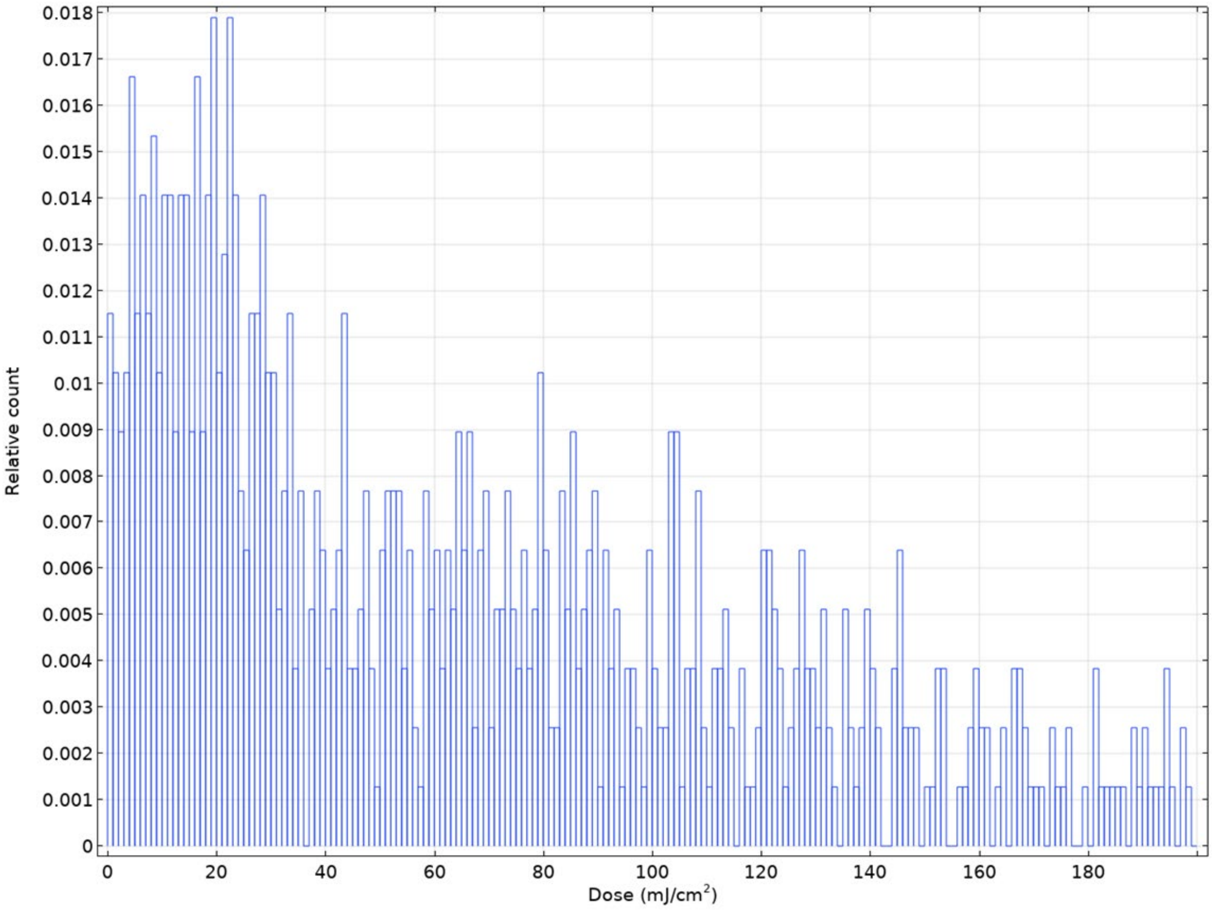
Fluence Rate (UV Intensity)



Dose accumulation



Dose distribution

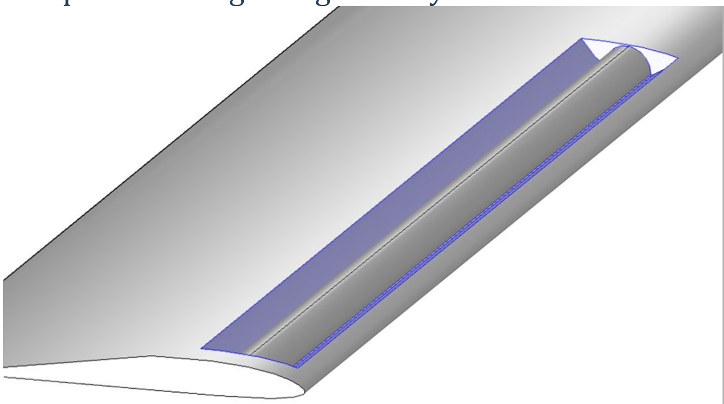


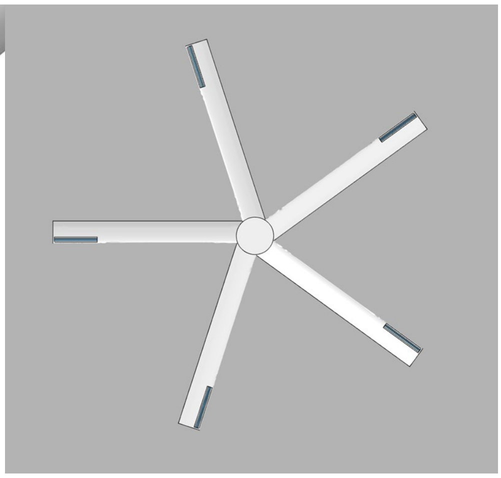
COMSOL Multiphysics light model and Computational Fluid Dynamics (CFD) simulation 3.

Peter Vittrup Christensen, MSc./PhD. Senior R&D Specialist, Ultraaqua A/S

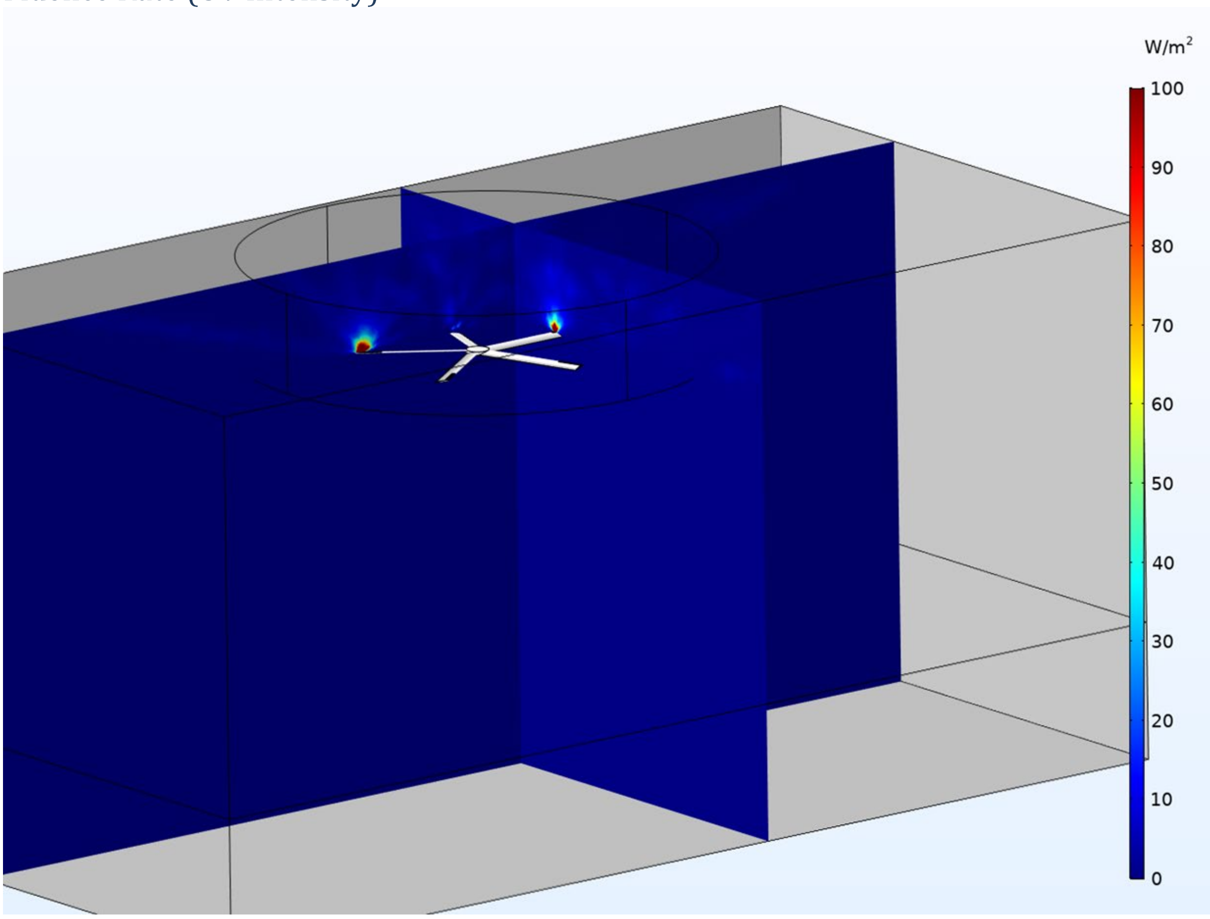
First model with lamps in wings. 5x24W has been used. The implementation of the lamps in the wings is approximate as we have tried to squeeze them in even though there was not really room in current wing design.

Lamp inside wing CFD geometry.

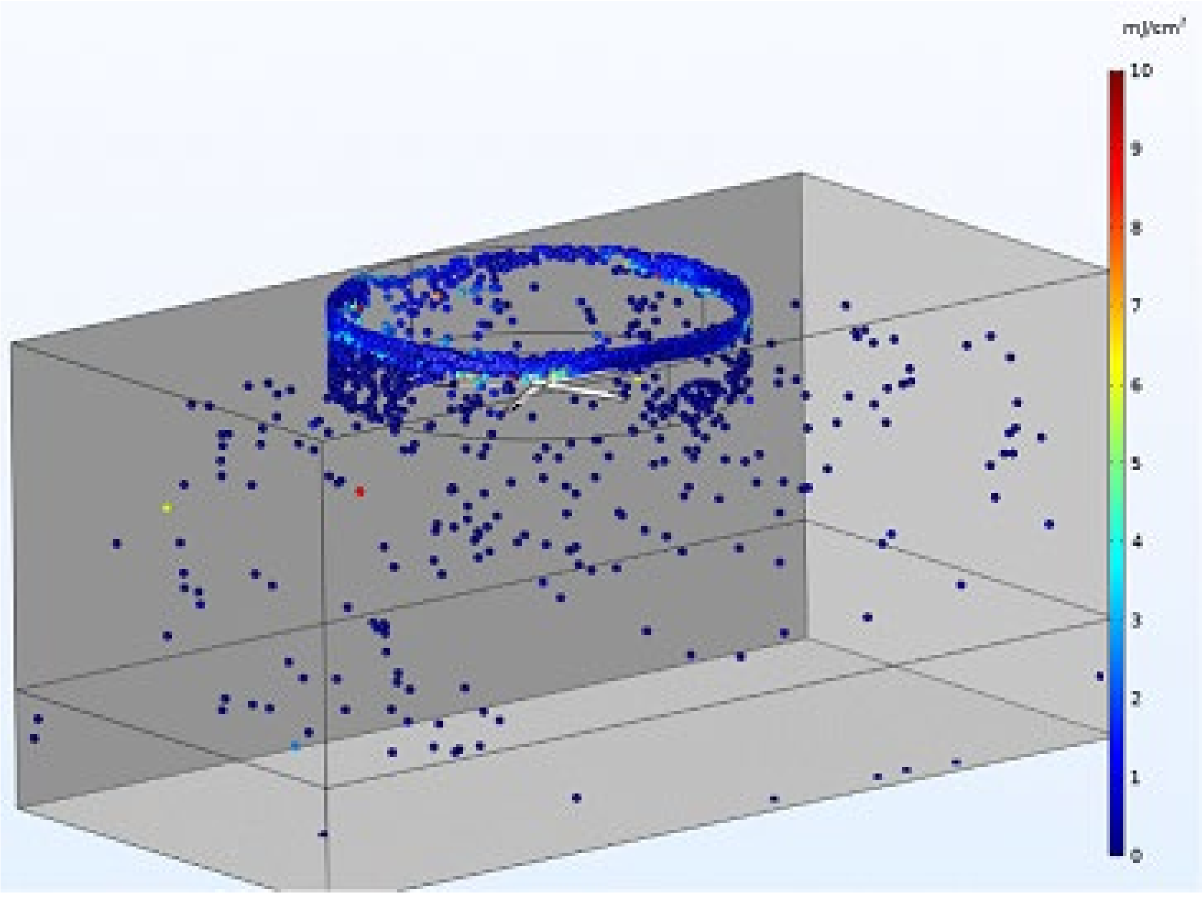




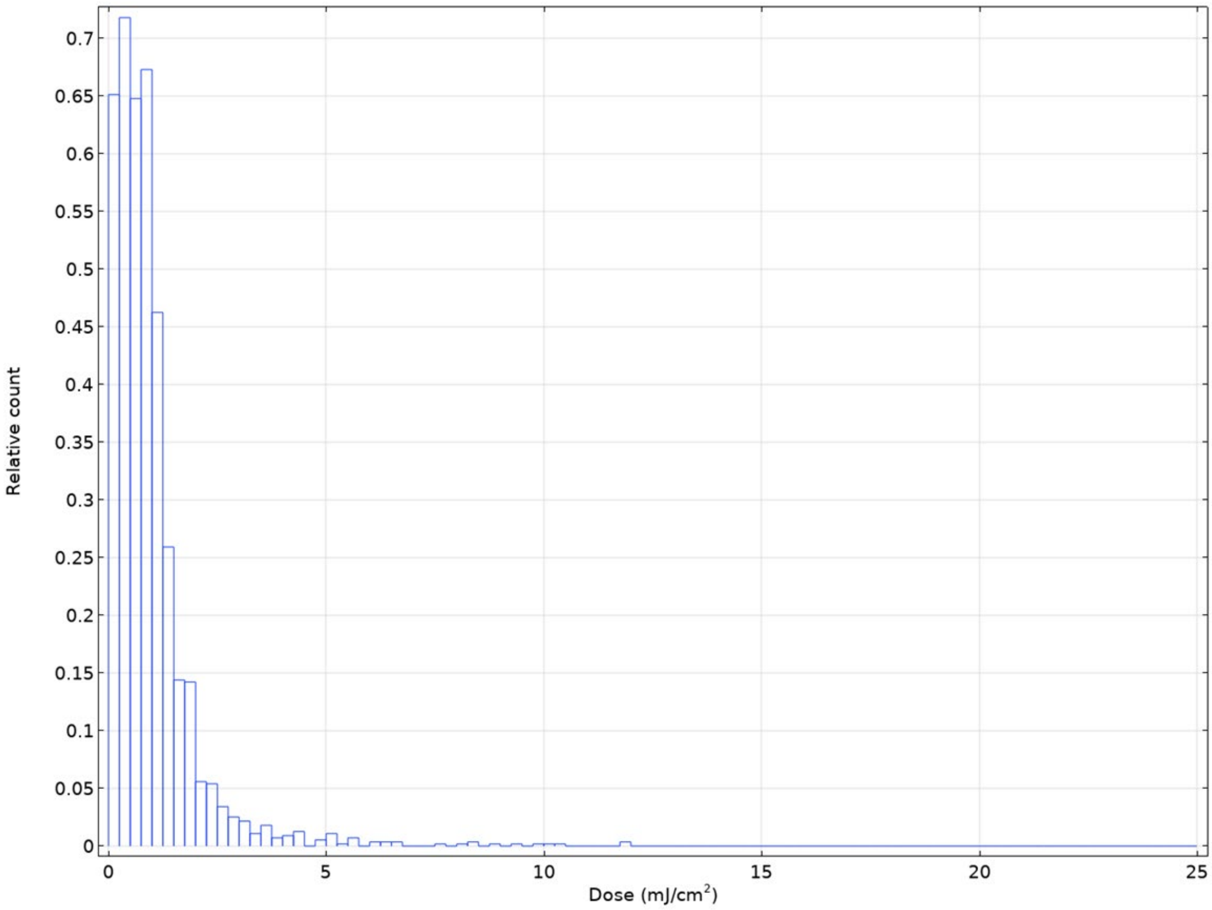
Fluence Rate (UV Intensity)



Dose accumulation



Dose distribution



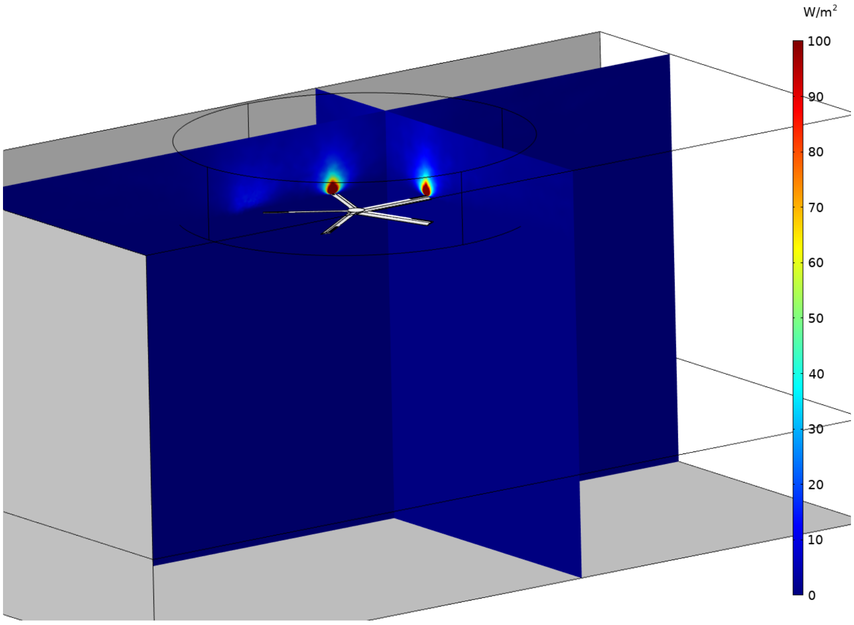
COMSOL Multiphysics light model and Computational Fluid Dynamics (CFD) simulation 4.

Peter Vittrup Christensen, MSc./PhD. Senior R&D Specialist, Ultraaqua A/S

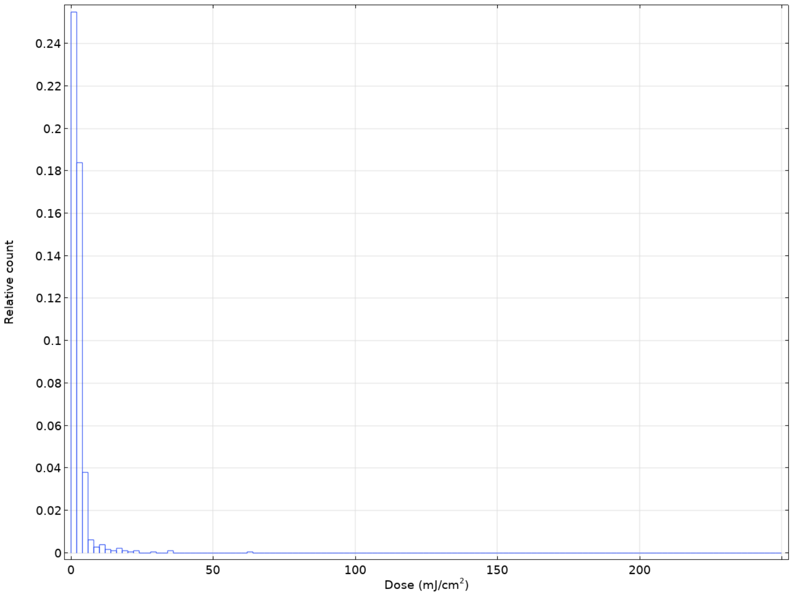
Like simulation 3 but HVLS UV-C in reverse.

Fluence rate distribution and dose distribution. After one pass logR=0.77.

Fluence Rate (UV Intensity)



Dose distribution



Appendix 2. Comparison to Empirical MS2 virus test

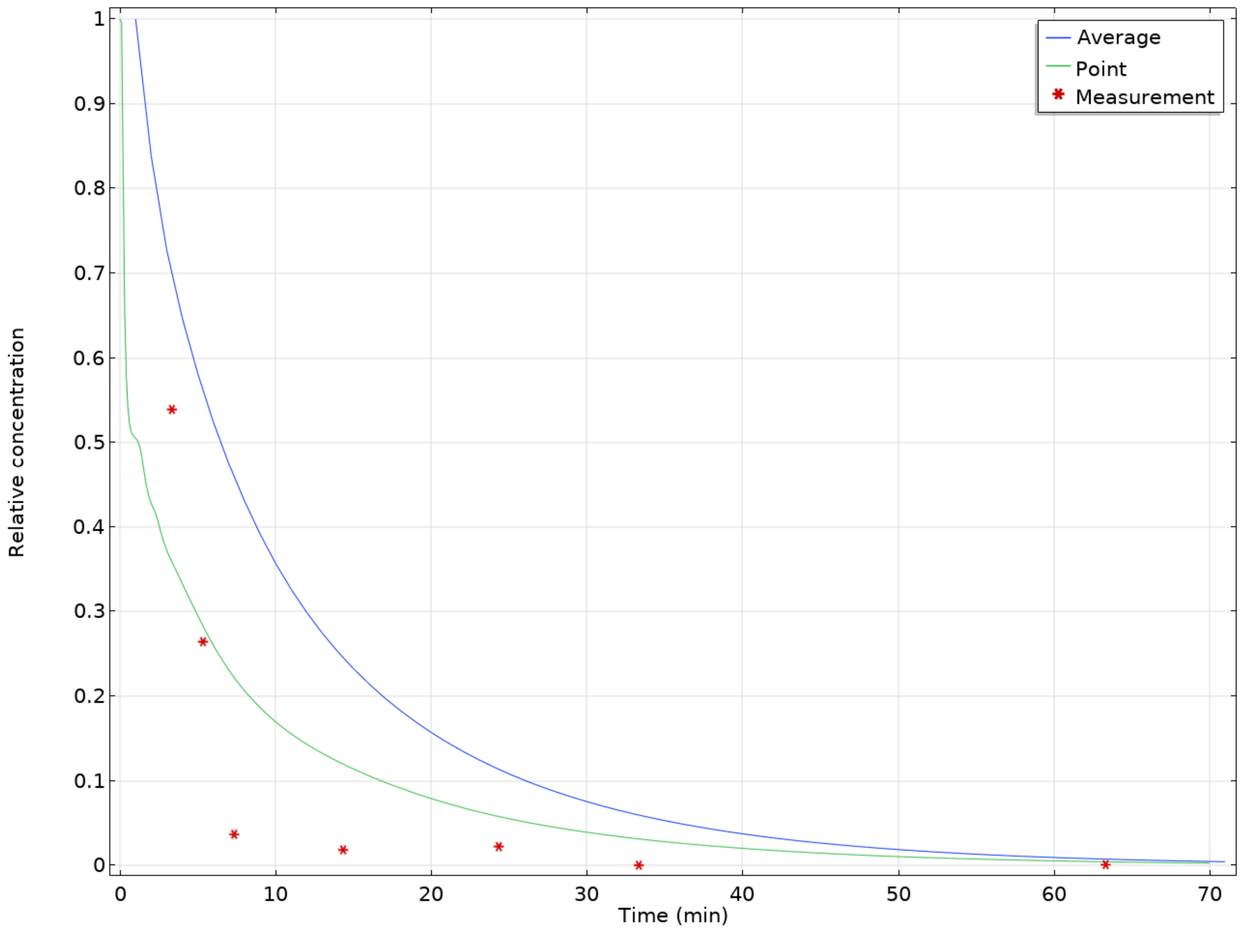
Peter Vittrup Christensen, MSc./PhD. Senior R&D Specialist, Ultraaqua A/S
Appendix added on the report on the 26-11-2021.

This appendix is an addition to the report covering a comparison between the original simulation for SARS-COV-2 virus with the empirical test conducted by the Danish Technological Institute. The empirical test performed by the Danish Technological Institute was performed using the test virus MS2.

The Simulation performed is identical to the previous found in appendix 1, with the same room geometry etc. but with the exception that the virus inactivation rate is modelled using an advection-dispersion-reaction approach rather than a particle tracing approach. The following parameters and assumptions were used in the model.

Simulation parameters and assumptions – MS2 comparison

- Light source effect output at 100% at simulation t = 0, thus heating time of the lamp is omitted.
- Initially the virus is assumed to be the same throughout the room (homogeneous concentration).
- Virus UV sensitivity for MS2 used (k=0.1184 mJ/cm^2)
- Ceiling reflection assumed at 1.5%
- All aerosols follow the air flow and are not subject to gravitational forces or evaporation.



General uncertainties when comparing the results:

- The effect of the room humidity on the MS2 virus UV sensitivity.
- The start concentration of the virus at all locations in the room, how well is the air mixed at t=0.
- General uncertainty when sampling the virus during the empirical test.
- In the empirical test the aerosol particle size will also include larger particles that will sediment faster, along with smaller aerosols that will dry out.