Personal Air Filter

Appendix

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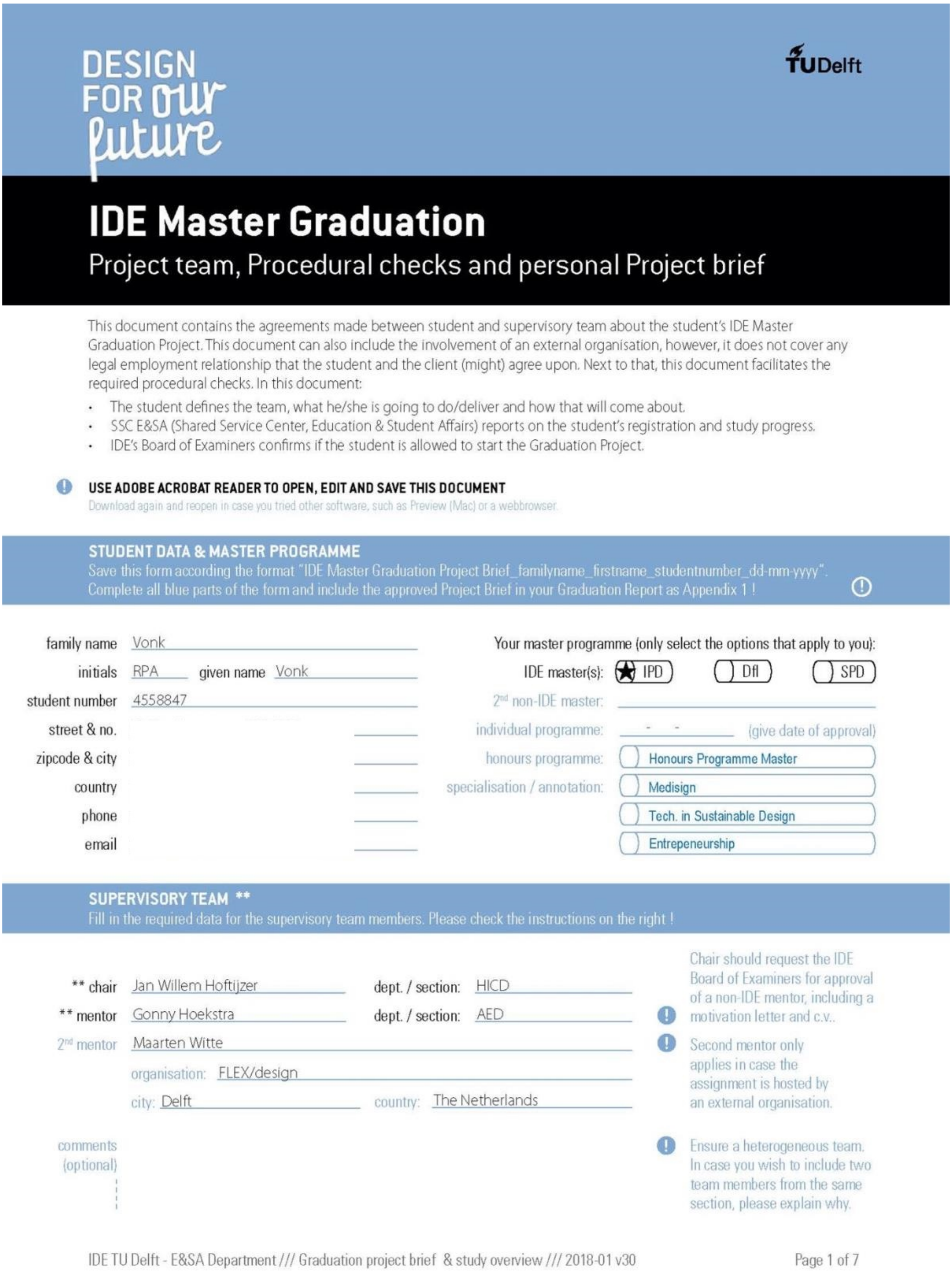
Appendix A: Project Brief



DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Vonk
initials: RPA
given name: Vonk
student number: 4558847
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ● IPD ○ DfI ○ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ○ Honours Programme Master
specialisation / annotation: ○ Medisign
○ Tech. in Sustainable Design
○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Jan Willem Hoftijzer — dept. / section: HICD
** mentor: Gonny Hoekstra — dept. / section: AED
2nd mentor: Maarten Witte
organisation: FLEX/design
city: Delft — country: The Netherlands

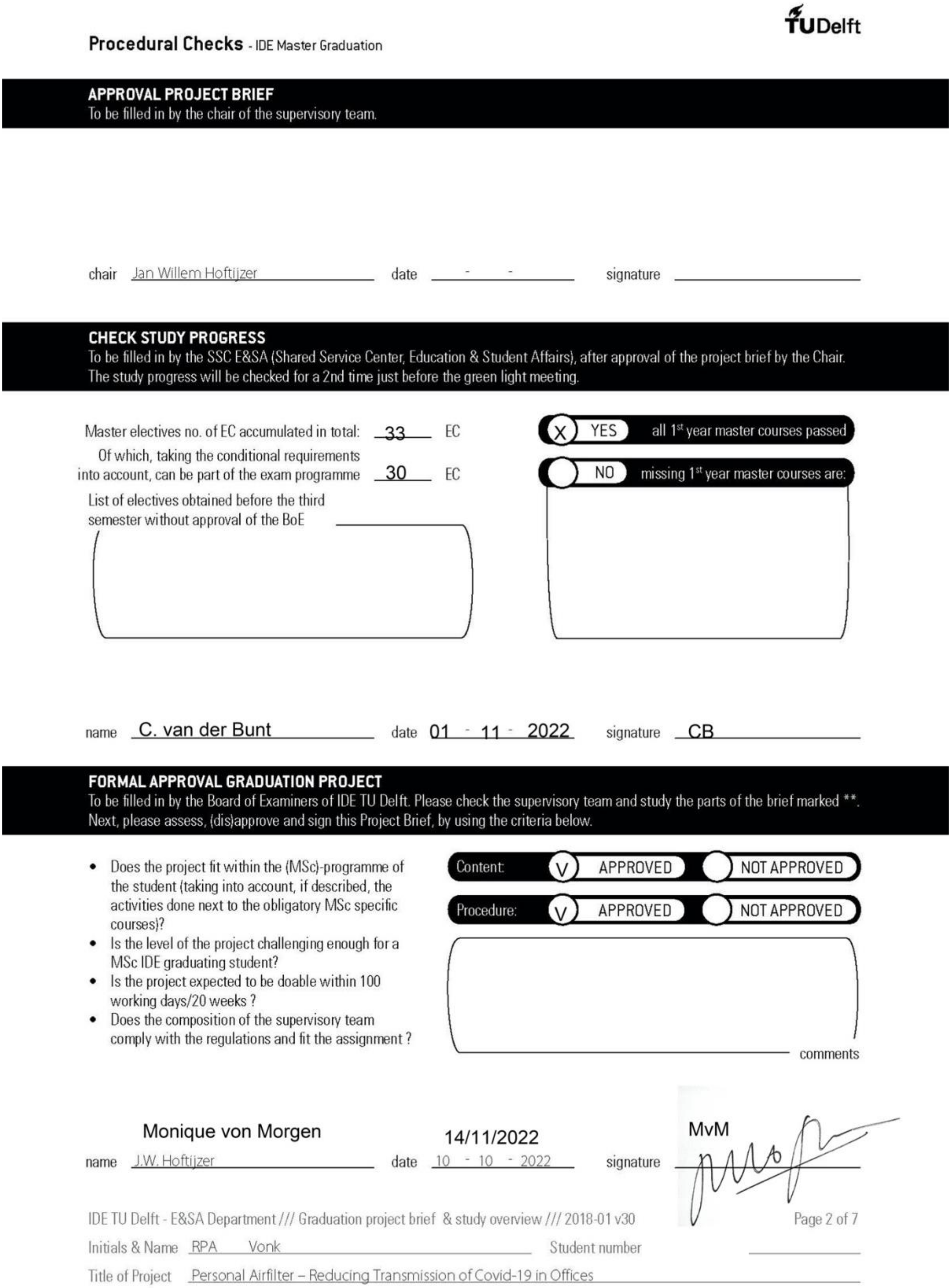
comments (optional):

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 — Page 1 of 7



Procedural Checks - IDE Master Graduation

TUDelft

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Jan Willem Hoftijzer date - - signature

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 33 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

☒ YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name C. van der Bunt date 01 - 11 - 2022 signature CB

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ☑ APPROVED ○ NOT APPROVED

Procedure: ☑ APPROVED ○ NOT APPROVED

comments

Monique von Morgen

14/11/2022

MvM

name J.W. Hoftijzer date 10 - 10 - 2022 signature

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 2 of 7

Initials & Name RPA Vonk Student number

Title of Project Personal Airfilter – Reducing Transmission of Covid-19 in Offices

Personal Airfilter – Reducing Transmission of Covid-19 in Offices project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 26 - 09 - 2022 20 - 04 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

As a result of COVID-19, there is a paradigm shift in our daily working life. Employees are returning to working in their offices as the virus outbreak is reaching the endemic phase (McKinsey, 2022). However, many workplaces do not withstand recommended ventilation precautions increasing the risk of virus transmission (Morawska et al., 2020). There is a design opportunity to supplement general ventilation with airborne infection controls such as local exhaust, high efficiency air filtration, and/or germicidal ultraviolet lights in ventilation systems (Bluyssen et al., 2021).

FLEX/design and Euromate have set up the joint venture XL-air to combat spreading of COVID and other airborne diseases in office environments. FLEX/design is one of the leading industrial design agencies that develops a wide range of consumer products, and smart products and experiences. Euromate is a specialist in cleaning indoor air for 45 years, such as reducing pollution from viruses, bacteria, fine particles, and odors. By joining forces, they want to develop and test a personal air filtering device that reduces aerosols from spreading from one desk to the other.

Currently, there is ongoing research world-wide about the transmission of SARS-Cov-2. There are three known causes for transmission; large respiratory droplets, contaminated surfaces, and aerosols (Morawska et al., 2020). Figure 1 shows how aerosols carry the virus through the air, where indoor environments are particularly known to spread infections rapidly. It is currently not possible to measure the concentration of SARS-Cov-2 virus in the air, however other indicators can be used such as CO2 levels and air refreshment rate (source). Furthermore, Computational Fluid Dynamics (CFD) simulations are able to predict the effectiveness of current and future systems, and new methods are being developed to validate simulation. For example, soap bubbles can be used to replicate and visualize the behavior of aerosols (Bluyssen et al., 2021). The SenseLab at the the Science Centre, TU Delft, has the facilities to test this.

The possible suggestion (figure 2) shows a desk setup with ventilation simulation above can suck a large percentage of air from the user, preventing it from spreading to other tables.
On the other hand, it is clear that this is merely a solution for technical functionality. The system is intrusive, which may result in an undesired user experience. There is a challenge to integrate it neatly in an office environment while complementing the social norms of the users.

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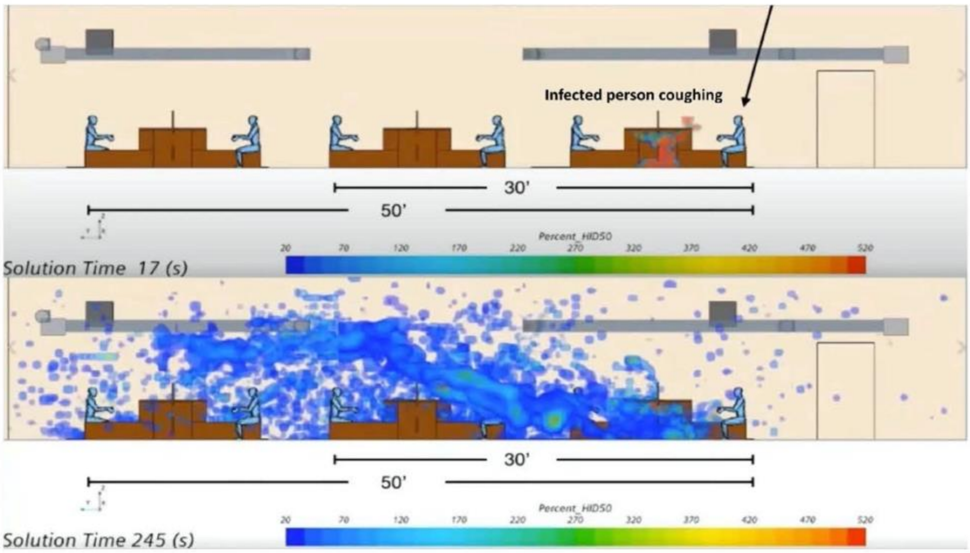


image / figure 1: Spread of aerosols from an infected person coughing in an unventilated office envirnment

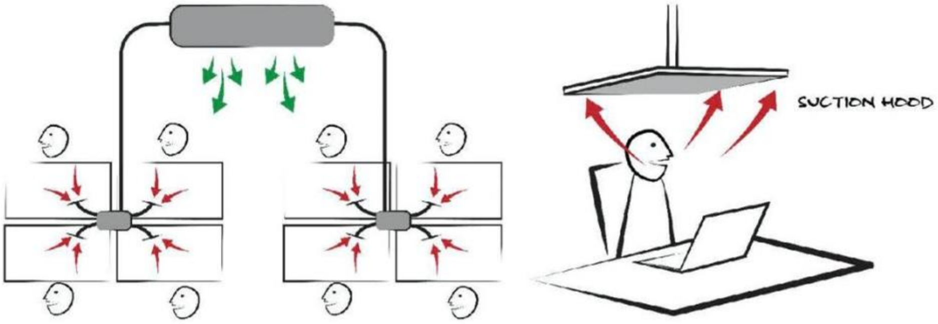


image / figure 2: A possible suggestion from FLEX/design to locally ventilate aerosols from the user

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The challenge lies in designing a device that effectively and efficiently filters aerosols, while providing an attractive & desirable user experience. The personal airfilter should be beneficial to the users and their work environment as well as attractive for offices to implement. The device will be designed to fit a variety of offices, so the types of offices will also need to be defined and justified. Furthermore, the use scenario is focused on seated desk areas to limit the scope and to increase chances of creating a proven working product. The aim is to develop clear and convincing evidence for how effective it is; however, this may be challenging to quantify. Especially how the product interacts in a variety of environmental factors, such as other ventilation methods like natural and mechanical ventilation, may be too challenging to measure but should be considered. Extensive focus on the feasibility of manufacturing and assembly process' are not in the scope of the project, though they can be taken into account in the decision-making process.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The challenge is to develop a personal air filter device for workspaces in offices that reduces aerosols to an acceptable level to prevent SARS-Cov-2 transmissions between desks. The device will be tested and validated to indicate its effectiveness. Besides functionality, the user needs will be researched and taken into account to create a desirable product.

For the graduation project, the goal is to develop and design a prototype for a minimum viable product. The research phase will be designated to user research; understanding motives, behaviors and desires of the user. Furthermore, literature research will go into effective systems for ventilation and filtration. Optimization of airfilter placement and configuration is a large focus area, which will be explored through CFD simulation and validation, where partners from Euromate, SenseLab, and possibly TNO will be useful.

The research will be the inspiration for an idea and conceptualization phase, where stakeholders are involved in the decision-making process. Through rapid goal-oriented prototyping, a range of user and performance tests will be performed.

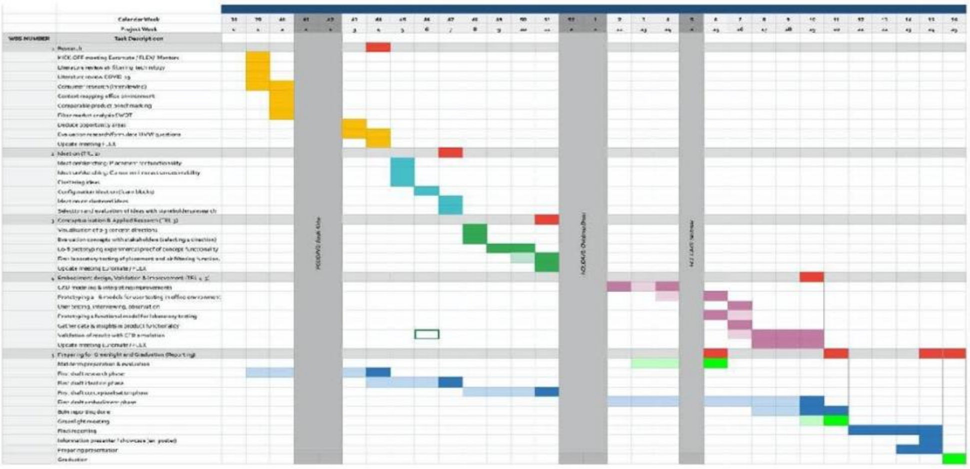
Findings will be taken into account for developing a model and functional prototype of the design, which should justify the desirability, feasibility and viability of the product.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 26 - 9 - 2022

20 - 4 - 2023 end date



Above is an initial planning for the graduation project. As agreed with all parties I will be working 4 days per week, therefore 25 weeks in total, which equates to 100 working days.

This is naturally an initial planning, and as the project progresses goals & milestones will be adjusted to achieve the best outcome for the project. Reporting is done parallel to the project as to prepare ahead of the mid-term and ultimately the final thesis.

Chair/coach meetings will be held bi-weekly until the mid-term and are planned in advance and will be less often later in the project if less coaching is necessary.

Important dates:
Med term evaluation - 26 January 2023
Green light - 16 March 2023 (prognosis)
Graduation - 20 April 2023 (prognosis)

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

There are several reasons why this project is a fitting subject to complete my graduation on.

First and foremost, I enjoy finding simple solutions to highly complex problems. By no means is there a straightforward 'good' solution on the table, but the research and gaining an understanding on the topic will lead to one I believe. Second, there is a fine balance between user experience and the technical performance of the product. On one side, it should be a desirable product, but achieving the functionality will likely be juxtaposing. I find solving this challenge enticing. Third, I find it important that all the things we make in the current day and age are of social interest. The significance of this project speaks for itself, and I believe it could truly have a positive impact.

During the project I have some personal learning goals, which include:

Independence and initiative. I want to learn to be able to lead a project from the beginning to an end. For me, some focus points include gaining experience in setting up and leading meetings, finding and involving relevant people that can contribute to the project, and efficiently planning and organizing the project.

Simulation and validation. I want to become more familiar with using computer aided simulation and how to base design decision making off of it. In the case of this project the most relevant type of simulation will be Computational Fluid Dynamics. In what software I want to practice this I am not sure yet. I also want to learn to validate the findings from the simulation through controlled testing.

Goal oriented prototyping. I want to become more competent in making prototypes in general, but also keeping in mind what it will be used for. I want to become better at developing the right prototypes fitting the design phase and justifying the purpose it will be used for.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name RPA Vonk Student number 4558847

Title of Project Personal Airfilter – Reducing Transmission of Covid-19 in Offices

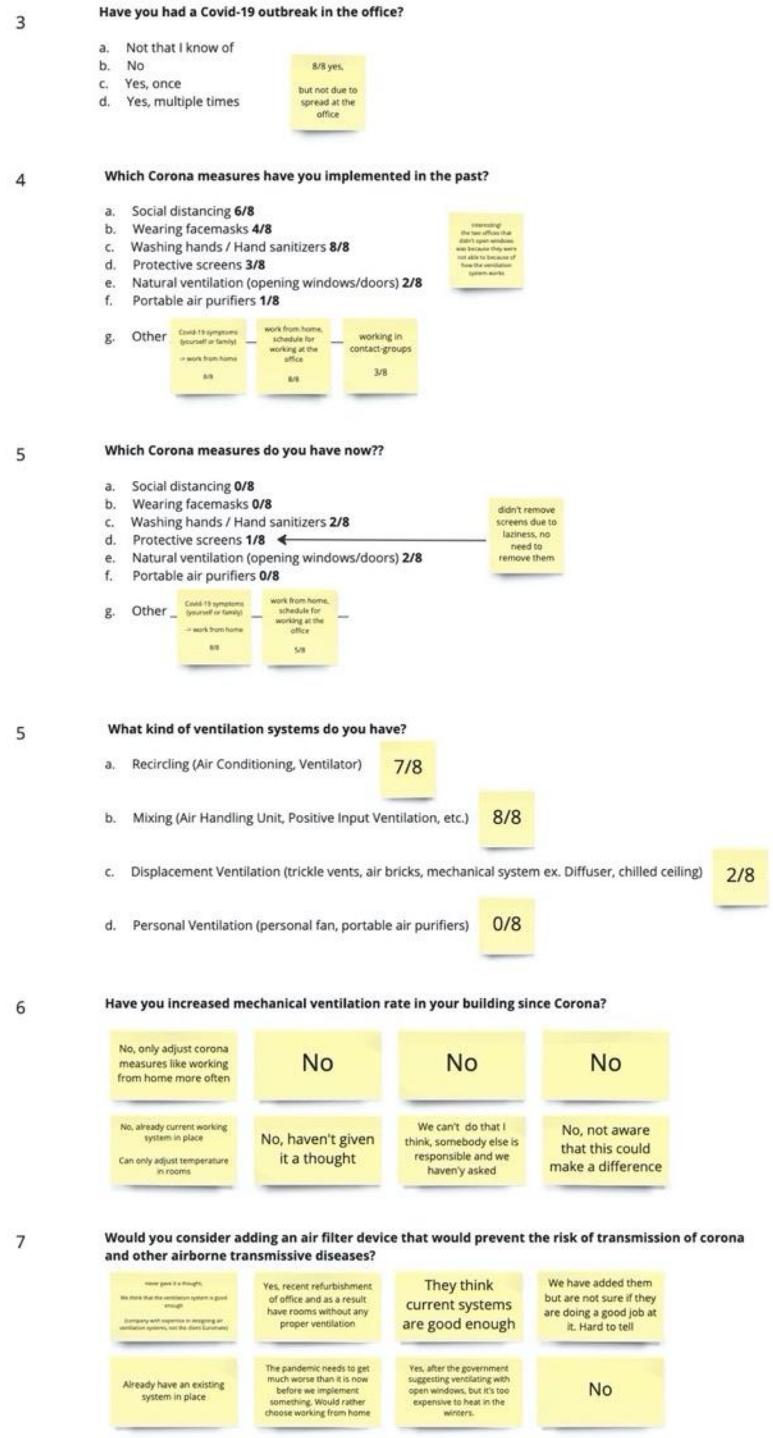
Appendix B: List of Requirements

Product Requirements

Description		*Quantification*					*Verification*		*Tracking*		*Additional Information*
#	*Requirement*	*Unit*	*Target*	*Lower Spec Limit*	*Upper Spec Limit*	*Must have (M)/ Should have (S)/ Could have (C)/ Will not (W)*	**Verification method**	***Result*** *(PASS/ FAIL/not yet verified)*	*Source*	*Last revision*	*Remarks*
1	A | Performance (efficiency)										
1.1	The HEPA filter efficiency used must be at least ____ efficient	%			99.99	M	Check	Not yet verified	Interview Client	13/10/2022	Using certified HEPA meets specifications
1.2	Must be placed in the propagation of the plume by of the user (above) with a distance of:	m	0.5		1	S	Check	Not yet verified	Bluyssen et al., 2019		
1.3	Should use a washable mesh pre filter		99.95			S	Check	Not yet verified	(Ashton, n.d.	14/10/2022	
1.4	Could use an activated carbon filter					C	Check	Not yet verified	(Ashton, n.d.	13/10/2022	
1.5	The fan must produce an air flow rate of at least ___ per person	m3/h	100	50	250	M	Check	Not yet verified	Simulations & Euromate	02/06/2023	
1.6	Should use a forward-inclined centrifugal fan					S	Check	Not yet verified	Bloch & Soares, 1998	12/01/2023	
1.7	The fan should be no louder than ___ with a CADR of 50 m3/h per person	dB	38		48	S	Measure	Not yet verified	Designer	20/03/2023	
1.8	The device should maximise the capture area for aerosols	m2	2	1	3	S	Measure	Not yet verified	Euromate	12/01/2023	
1.10	Could consider filtering to prevent air stratification (dirty air trapped at ceiling)					C	Check	Not yet verified	Euromate	12/01/2023	
1.11	Economic benefits of device (less sick leave, improved employee efficiency) could outweigh the operational energy costs					S	Calculate	Not yet verified	Bekö et al., 2008	14/10/2022	
1.12	The device(s) could interact together to improve performance					C	Check	Not yet verified	FLEX/design	02/06/2023	
2	B | Durability / Reliability										
2.1	The fan should last at least _____ before needing maintenance or replacement	h	21900			S	Check	Not yet verified	Euromate	12/01/2023	(5 years of 12h use per day)
2.2	The fan should be replaceable by the user/employee					S	Check	Not yet verified	Designer	14/10/2022	
2.3	The HEPA filter should not be replaced before ____ of use (under normal circumstances)	months	6			S	Calculate	Not yet verified	Other existing HEPA air purifiers	12/01/2023	
3	C | Environment and circumstances										
3.1	Existing air flows of mixing and recircling ventilation must not make the device dysfunctional (completely obstruction airflow)					M	Simulate	Not yet verified	Euromate	12/01/2023	
3.2	The device could work together with the induced airflows of mixing and recircling ventilation.					C	Simulate	Not yet verified	Simulations	20/03/2023	
3.3	Will not test the device in every ventilation scenario, such as air turbulence from people walking in the room, or an open door					W		Pass	Designer		
4	D | Geometry and Weight										
4.1	Must not weigh more than _____	kg	25			M	Measure	Not yet verified	(EN1005-2 norm for 1 person carrying)	12/01/2023	
4.2	Should not weigh more than _____	kg	10		15	C	Measure	Not yet verified	(NIOSH recommended for 1 person	12/01/2023	
5	E | Safety, Standards, Legislation										
5.1	For the automatic ventilation setting, the device should not be louder than _____ measured from the expected seating position.	dB	38		48	M	Measure	Not yet verified	(EN 16798–1)	12/01/2023	
5.2	The device must allow for adjustment of capacity from 0% (off) and 10% of total capacity to 100% of total capacity. Furthermore, there must be at least 1 additional settings in between that has more than 10% capacity difference.					M	Check	Not yet verified	(NEN 1087)	12/01/2023	
5.3	The supplement filtered air must not induce an air velocity of 0.2m/s within the liveable area	m/s	0.2			M	Measure	Not yet verified	(NEN 1087)	12/01/2023	
5.4	The electric fan must be shielded by a finger guard with a maximum opining of 7mm	mm	7		5	M	Measure	Not yet verified	(CEN/TR 13387:2004)	12/01/2023	upper spec is for children
5.5	The device must not change the air humidity above 70% or below 30%	%		30	70	M	Check	Not yet verified	(NEN 1087)	02/06/2023	
5.6	In case there is lighting, the colour rendering index of the lighting must be at least ___	CRI	80+	75	90+	M	Check	Not yet verified	(NEN 1087)	02/06/2023	
6	F | Storage and transport										
6.1	Product components could be stackable in storage					C	Check	Not yet verified	Designer	02/06/2023	
6.2	Product must fit in a box truck of 2.55m wide and 12m long for shipping					W		Not yet verified	Designer	02/06/2023	
7	G | Installation and maintenance										
7.1	The device must be able to be installed considering 1 power socket per device	power socket	1			M	Check	Not yet verified	Interior Architect Personal Communication	12/01/2023	
7.2	There must be no major architectural changes to install the device (how to quantify this? what are major architectural changes?)					M	Check	Not yet verified	Interior Architect Personal Communication	12/01/2023	
7.3	A specialised installer should not be required to install the device					S	Check	Not yet verified	Designer	12/01/2023	
7.4	HEPA filters must be replaced when static pressure rises above ____ amount	Pa	x			M	Calculate	Not yet verified	Bloch & Soares, 1998	12/01/2023	
7.5	The user must be able to access the HEPA filter without the use of any tools					M	Check	Not yet verified	Designer	12/01/2023	
7.6	An unexperienced (unfamiliar) user should be able to replace the HEPA filter in 1 minute	minute	1			S	Check	Not yet verified	Designer	12/01/2023	
7.7	An acquainted user should be able top replace the filter within 30 seconds	minute	0.5			S	Check	Not yet verified	Designer	12/01/2023	
7.8	The air filter could be replaced in a PaaS system where a 3rd party replaces the filter for the company					C	Check	Not yet verified	FLEX/design	12/01/2023	
7.9	The fan should be replaceable with the use of basic tools only (screwdrivers/allen-keys)					S	Check	Not yet verified	Designer	12/01/2023	
7.10	The air chamber inside of the device should be accessible for cleaning dust other large pollutants etc					S	Check	Not yet verified	Designer	12/01/2023	
8	H | Options and versions										
								Not yet verified			
9	I | Ergonomics, User Interface, ease of use										
9.1	The device must make a continuous noise (as opposed to intermittent noise)					M	Measure	Not yet verified	Bluyssen et al., 2021; EN 16798-1, 2019	12/01/2023	
9.2	The device must not cause draft temperature of more than 1°C in the liveable area of the user	°C	1	0.2	2	M	Measure	Not yet verified	(NEN 1087)	12/01/2023	
9.3	The device should at all times improve air quality (as opposed to worsen it by using a dirty HEPA filter)					S	Test	Not yet verified	Wargocki et al., 2004	12/01/2023	
9.4	The device should not cause a draft or wind-chill effect over the users table	m/s	0.2	0.1	0.2	S	Measure	Not yet verified	(NEN 1087)	12/01/2023	
9.5	The device could provide heated air up to 30°C to the user of local thermal	°C	25	23	30	C	Check	Not yet verified	Designer	12/01/2023	
9.6	The device could provide ____ lumen of additional lighting to the desk area	lumen	500			C	Check	Not yet verified	Designer	02/06/2023	
9.7	Lighting intensity must be adjustable	lumen		300	2000	M	Check	Not yet verified	Designer	02/06/2023	
9.8	The light colour should be between ___ and ___ Kelvin	Kelvin	3500	3000	5000	C	Check	Not yet verified	Designer	02/06/2023	
9.9	The device must enable adjustability of product settings through an interface					M	Check	Not yet verified	(NEN 1087)	12/01/2023	
9.10	The device must show the status of the filter to indicate if it needs to be replaced or not					M	Check	Not yet verified	(NEN 1087)	12/01/2023	
9.11	The device should not distract the user during work					S	Test	Not yet verified	User Study	12/01/2023	
9.12	The device should have an automatic setting to operate autonomously, where it is turned on and off depending if the user is seated at the table					S	Check	Not yet verified	Designer	12/01/2023	
9.13	The device could provide information about air quality (PM2.5), risk of infection, level of pollen					C	Check	Not yet verified	Designer	12/01/2023	
10	J | Appearance, colour, finishing										
10.1	The device should consider future office trends to stay relevant					S	Check	Not yet verified	Interior Architect Personal Communication	12/01/2023	
10.2	The device should convey the feeling of warmth, comfort, and home					S	Test	Not yet verified	Interior Architect Personal Communication	12/01/2023	
11	K | Materials										
11.1	The device must not consist more than 0.1% of (lead, mercury, PBB, PBDE, Hexavalent Chromium, Cadmium, DEHP, BBP, DBP, DIBP					M	Check	Not yet verified	(RoHS 2011/65/EC)	12/01/2023	
								Not yet verified			
12	L | Product life span										
12.1	The product must last at least ____ years	years	5			M	Check	Not yet verified		12/01/2023	
12.2	The lighting must last at least ____ hours	h	30.000	25.000	100.000			Not yet verified		12/01/2023	
13	M | Cost Price										
13.1	Production cost of the Personal Air FIlter should be ____	€	900	300	1500	S	Check	Not yet verified	Interview Ard vcan Bergeijk, client	12/01/2023	
14	N | Production, assembly										
14.1	The housing of the device must be produceable with existing manufacturing methods					M	Check	Not yet verified	Designer	12/01/2023	
14.2	The device can be assembled by x people in x hours	h	x			M	Test	Not yet verified	Designer	12/01/2023	
14.3	The design must make use where possible of standard off the shelf components, such as the filters and the fans.					M	Check	Not yet verified	Designer	12/01/2023	
14.4	The device comes with sufficient documentation for assembly					W		Not yet verified	Designer	12/01/2023	
15	S | Sustainability										
15.1	The benefits of the device should outweigh the ecological footprint of manufacturing and use (how to measure?)		x			S	Calculate	Not yet verified	Designer	12/01/2023	
15.2	The device should be disassemble-able for reuse or recycling					S	Test	Not yet verified	Designer	12/01/2023	
15.3	Where possible, the design should use reusable parts (ex. washable filters)					S	Check	Not yet verified	Designer	12/01/2023	
15.4	The device will not be analysed for a life cycle analysis					W	Check	Not yet verified	Designer	12/01/2023	

Appendix C: Work culture during before, during corona-lockdown periods and now

For a better understanding on behavior of the office faculty management on Covid-19 preventative measures as well as the change in work culture, office employees where interviewed after the empirical study. Two of the eight questioned employees were responsible for the faculty management. The results are shown in Appendix C.



3 **Have you had a Covid-19 outbreak in the office?**

a. Not that I know of
b. No
c. Yes, once
d. Yes, multiple times

8/8 yes,
but not due to spread at the office

4 **Which Corona measures have you implemented in the past?**

a. Social distancing **6/8**
b. Wearing facemasks **4/8**
c. Washing hands / Hand sanitizers **8/8**
d. Protective screens **3/8**
e. Natural ventilation (opening windows/doors) **2/8**
f. Portable air purifiers **1/8**
g. Other

Covid-19 symptoms (yourself or family) -> work from home 8/8

work from home, schedule for working at the office 8/8

working in contact-groups 3/8

5 **Which Corona measures do you have now??**

a. Social distancing **0/8**
b. Wearing facemasks **0/8**
c. Washing hands / Hand sanitizers **2/8**
d. Protective screens **1/8**
e. Natural ventilation (opening windows/doors) **2/8**
f. Portable air purifiers **0/8**
g. Other

didn't remove screens due to laziness, no need to remove them

Covid-19 symptoms (yourself or family) -> work from home 8/8

work from home, schedule for working at the office 5/8

5 **What kind of ventilation systems do you have?**

a. Recircling (Air Conditioning, Ventilator) 7/8
b. Mixing (Air Handling Unit, Positive Input Ventilation, etc.) 8/8
c. Displacement Ventilation (trickle vents, air bricks, mechanical system ex. Diffuser, chilled ceiling) 2/8
d. Personal Ventilation (personal fan, portable air purifiers) 0/8

6 **Have you increased mechanical ventilation rate in your building since Corona?**

No, only adjust corona measures like working from home more often

No

No

No

No, already current working system in place
Can only adjust temperature in rooms

No, haven't given it a thought

We can't do that I think, somebody else is responsible and we haven'y asked

No, not aware that this could make a difference

7 **Would you consider adding an air filter device that would prevent the risk of transmission of corona and other airborne transmissive diseases?**

Yes, recent refurbishment of office and as a result have rooms without any proper ventilation

They think current systems are good enough

We have added them but are not sure if they are doing a good job at it. Hard to tell

Already have an existing system in place

The pandemic needs to get much worse than it is now before we implement something. Would rather choose working from home

Yes, after the government suggesting ventilating with open windows, but it's too expensive to heat in the winters.

No

Work culture has transformed to be more flexible and allows people to work from home more often than before the Coronavirus pandemic. In figure 1, it becomes clear that the majority of offices questioned do not enforce strict Corona-measures anymore to reduce the risk of transmission. According to the client this is culturally dependent, where other cultures such as Asian and southern European may be more precautious (personal communication, 2022) there is therefore potentially a more interesting target market. Nonetheless, the only lasting measure to this date is working from home part-time (for example one or two days in the week) and working from home with Covid-19 symptoms. According to popular belief, the flexible work situation is expected to stay (Personal communication, 2022; The Future Is Flex: Flexible Work Is Here to Stay, Companies and Policy Need to Adapt, 2022).

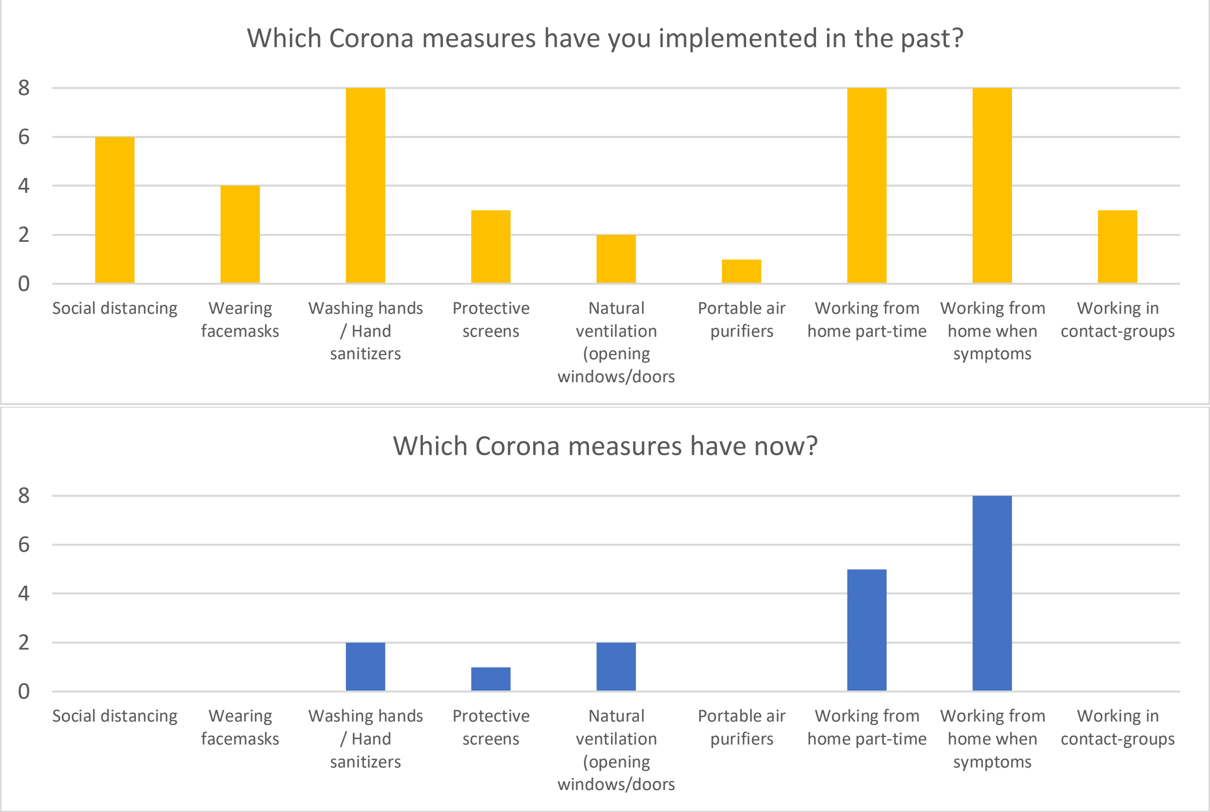
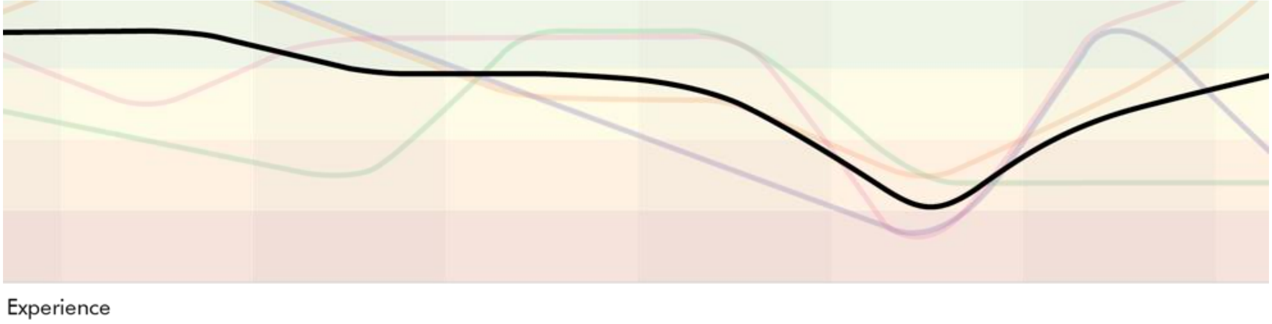
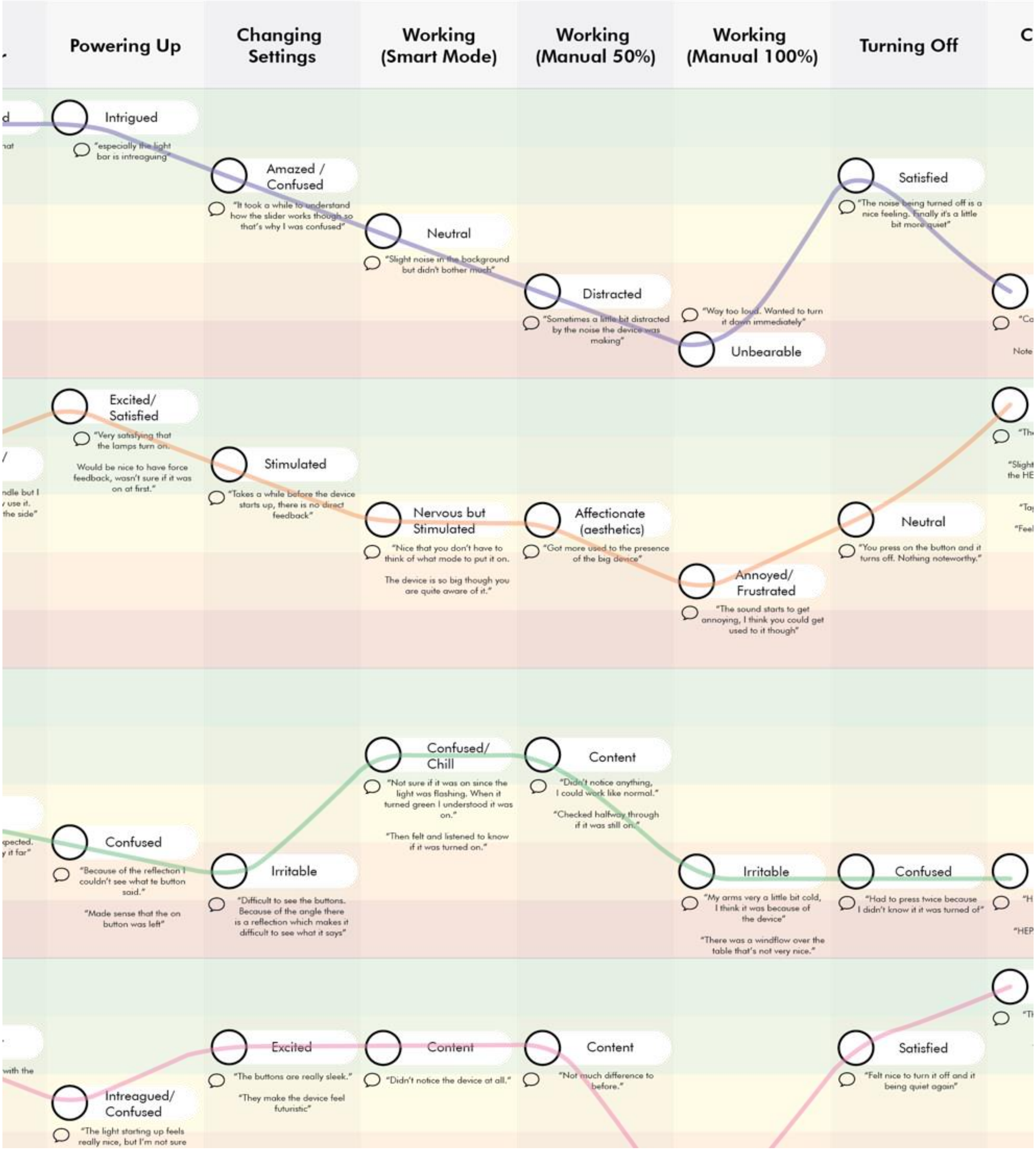


Figure 1: Corona measures taken in offices in Delftechpark during Corona-lockdown periods and now (3 November 2022) Source: author.

Appendix D: User Experience AEG AX7 Air Purifier





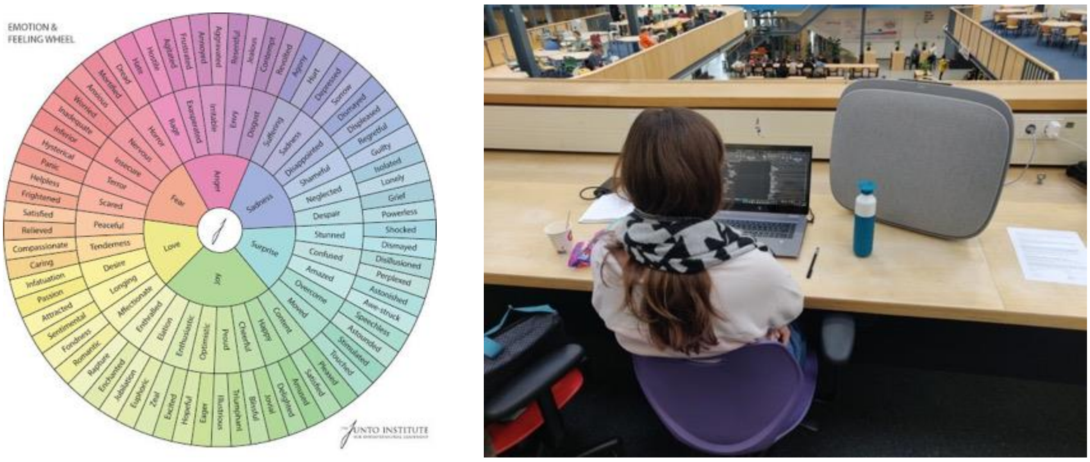
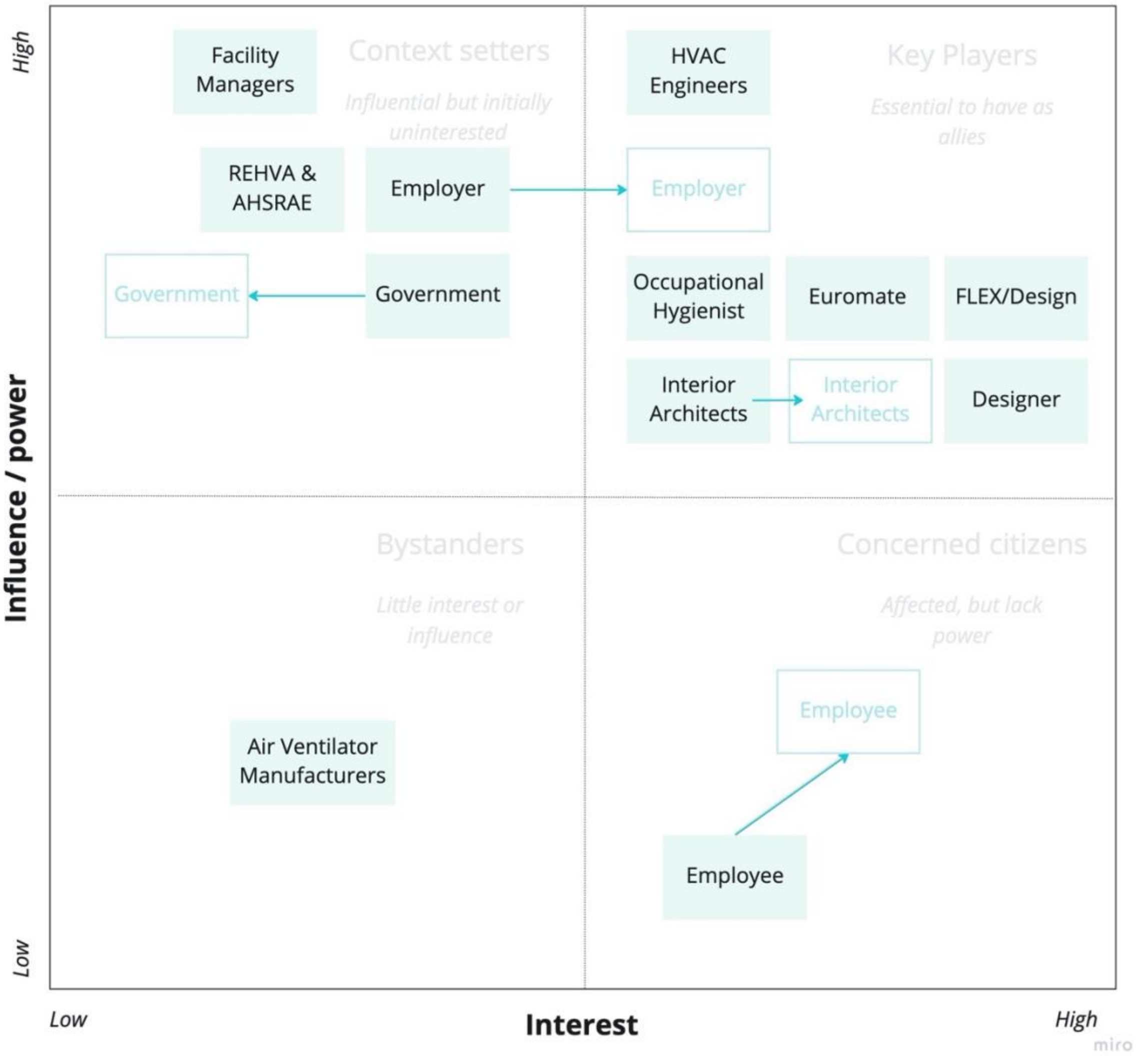


Figure 2: Junto Institute Wheel of Emotions & Feeling (left)(*Emotion Wheel – The Junto Institute*, n.d.). Participant using the AEG AX7 Air purifier (right) Source: Author

Appendix E: Stakeholder Analysis



Key players

Euromate

Euromate is a ventilation manufacturer and producer, and client of the project. They distribute their products to 55 countries globally, with the underlying interest of profits. Euromate performs research & development to find new technologies and gain a competitive advantage over competitors. They are focusing on creating new products that will aid them to achieve their goals, such as the Personal Air Filter (personal communication, 2022). In the relevance of the project, Euromate needs to be engaged & consulted by the designer to incorporate their expertise and interests.

FLEX/Design

FLEX/Design is a design agency that develops a wide range of consumer products, and smart products and experiences. They aim to get a sustainable flow of income by have long term running projects and/or frequent projects with their clients and customer satisfaction by delivering good results. They initiated the project together with Euromate as they see an opportunity area, however, have struggled to find investors. By offering it as a graduation project they hope to bring the idea to a higher level gain more interest (personal communication, 2022).

Designer

The designer is the graduate student, Renzo Vonk. His main priorities are delivering the best result possible within the given timeframe to achieve a high grade. For this he needs to create a unique and meaningful design that is well supported and by research, as well as documentation for people to follow up on the project. He has high influence on initiating the project as well as interest to make it happen.

HVAC Engineers

Heating Ventilation Air Conditioning Engineers play an important role in the designing, implementation, and operation of ventilation systems in buildings within the given budget standards. They ensure that old buildings fulfil the required specifications through retrofitting as well as for new buildings. HVAC Engineers take into account clients' need to ensure the project requirements are met. They can also be involved in the research & development of upcoming technologies and aim to incorporate these into their system design (*Mechanical Engineer w/HVAC Expertise - HVAC Career Map*, n.d.). HVAC Engineers should be engaged throughout the project as they have high influence and expertise on the implementation of portable air purification systems.

Occupational Hygienist

Occupational hygienists work as a consultant or employee for the employer on identifying health hazards that affect the workers. They do this by identifying and assessing the risk and findings suitable solutions. These risks may be chemical, physical, biological or ergonomic and can be present in the workplace in many forms. They have the interest to identify health hazards as a result of airborne transmissive diseases, and the power to propose solutions that can be implemented. Their advice and expertise should be taken into consideration for designing a purposeful product.

Interior Architects

Interior architects design and create indoor spaces for a wide range of applications. They must take into account the functionality, safety, appearance of the building, and user desires. They have large influence as they have the power to suggest and implement changes in offices. The design should appeal to interior arch. Facility managers should be satisfied with the implementation of a personal air filter as they have the power to implement the product into their building.

Context Setters

Employer / Company

The employer is defined as the target company for the personal air filter, which is any company that employs knowledge workers and have an office. They are responsible for the overall performance of the company and typically want to hire the best employees that will ensure profits. The employer has significant influence over what happens in the company and is likely to gain more interest in the project as employee well-being is gaining popularity.

REHVA & ASHRAE

The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) are two umbrella associations concerned with the design and construction of HVAC systems. They consist of HVAC designers, building services engineers, technicians and experts. Both associations publish technical standards to improve building services engineering, energy efficiency, indoor air quality, and sustainable development. Furthermore, they fund research projects related to HVAC systems to accelerate innovation. The design will need to satisfy their standards, and the knowledge from the seminars, publications and journals should be used as a guideline during the project.

Governments
Governments are not limited to a specific country as the project is globally relevant. Their interest in preventative measures for Coronavirus and other airborne transmissive diseases may decline over the coming years as the virus becomes endemic. Nonetheless, governments have legislative power and should therefore be kept as an ally.

Facility Managers
Facility managers are responsible for the maintenance of infrastructure of large buildings. Their major role is to ensure that occupants of the building are satisfied, so that they can make the most of the building and help generate more revenue (*The Key Role of a Facility Manager & Why You Need One*, n.d.). They try to be cost and labor effective (*Facilities Manager Job Description Template*, n.d.)

Concerned citizens

Employee
Employees are the knowledge workers of the potential client companies of the product. Employees are concerned personal well-being at work, building social connections, and income to make a living (personal communication, 2022). As of this day, the employee desires the office environment to facilitate to these needs. The project is focused on improving the well-being of the employee and should therefore consider the user needs & desires to gain their support.

Bystanders

Air Ventilator Manufacturers (from Euromate)
Air Ventilator Manufacturers concerns all the suppliers for the parts Euromate uses to produce their systems. This ranges from manufacturing to assembly to transport. Their interest is to gain the largest profit margin possible and have long lasting stable relationships for production. Manufacturers are bystanders as they have little interest in solving the problem of airborne transmissive diseases, and do not have large influence on implementing the personal air filter in offices. They should however be considered for manufacturing possibilities in later stages of the design process.

Appendix F: Environmental Factors for Employee Ergonomics

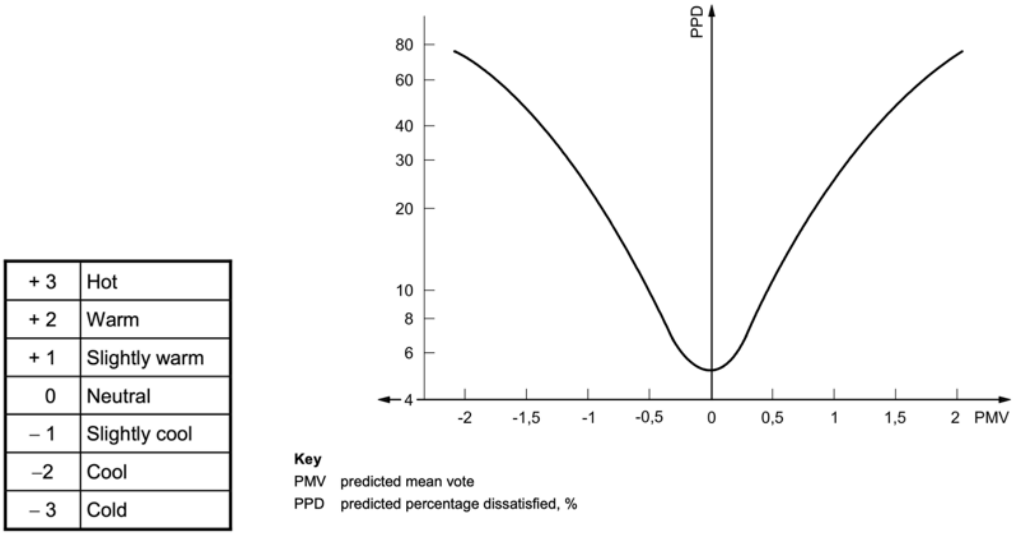
Thermal indoor climate (temperature)

The most important indicators influencing thermal comfort in office buildings are overheating (too high indoor temperatures especially outside heating season) and undercooling (too low temperatures especially during heating season) (van Dijken & Boerstra, 2010).

Comfort/Well-being

Perceived comfort of heat, also called thermal satisfaction, can differ per person as it is influenced by a wide range of factors. The persons age, sex, the time of day, amount of exercise, and diet are some of these factors (Swaminathen, 2021). Thermal dissatisfaction can also be caused by undesired heating or cooling to a specific spot on the body, which is known as local discomfort (ISO 7730, 2005). The most occurring problem for local discomfort is draught. Other factors that can cause local discomfort are large vertical temperature differences between feet and head, a floor that is too warm or cold, and more (ISO 7730, 2005). Most commonly people doing inactive activities, such as desk work, that experience local discomfort. For these reasons, office employees all have their own experience of thermal comfort.

Thermal discomfort is commonly measured in Predicted Mean Vote (PMV), where individuals indicate on a seven-point scale (figure 3) how 'hot' or 'cold' they are. The average PMV can be used to quantify the Predicted Percentage Dissatisfied (PPD) people who feel too 'hot' or too 'cold' (ISO 7730, 2005).



+ 3	Hot
+ 2	Warm
+ 1	Slightly warm
0	Neutral
− 1	Slightly cool
−2	Cool
− 3	Cold

Figure 3: seven-point thermal sensation scale (left), PPD as a function of PMV (right) (ISO 7730, 2005)

Productivity

A literature study conducted indicates that there is a linear relation between operational temperatures and performance in the office (Seppänen et al., 2006). Figure 4 shows that performance is ideal when the indoor temperatures range between 20 and 25 °C; but when the temperature exceeds 25 °C the productivity reduces by 2% for every increase by 1°C (Seppänen et al., 2006).

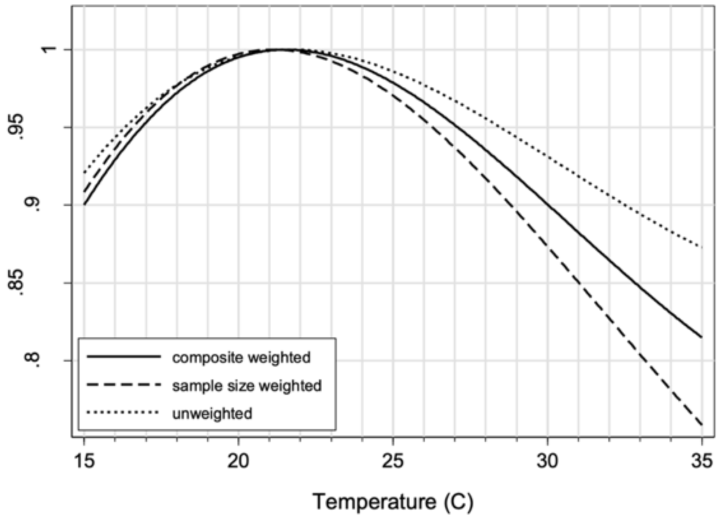


Figure 4: Relation between temperature and relative work performance (y-axis) according to literature review conducted by Seppänen et al. (2006)

Undercooling also has adverse effects to work performance in the office, especially by impacting finger dexterity when the body temperature decreases (van Dijken & Boerstra, 2010). According to Ye et al. (2005), the objective productivity of office workers is 8 to 10% lower when the employees experience the indoor climate as ‘cold’ or ‘cool’. Another study conducted by Lan et al. (Lan et al., 2011) indicates that in a laboratory environment an indoor temperature of 18 °C resulted in a 4% reduction in efficiency as compared to 22 °C.

Control

Multiple studies have shown that effective methods for influencing temperature by the employee can have a positive impact on comfort and performance (van Dijken & Boerstra, 2010; Ye et al., 2005). In a study by Kroner & Stark-Martin, a task ambient conditioning system with local temperature control provided a productivity increase of 4% (Kroner, 1994). Other tools, such as placing a thermostat knob has also been proven to improve the well-being and performance of the employee (Loftness et al., 2003).

Air Quality

Air quality in an office space can be influenced by two factors: fresh air supply and sources of contamination. Both the increase in supply of fresh air and removing contaminants from the air can improve productivity (van Dijken & Boerstra, 2010).

Comfort/Well-being

Besides reducing the spread of SARS-CoV-2 and other airborne transmissive diseases, ventilation plays a vital role in employee well-being. Research indicates that good ventilation is correlates with better health, higher levels of employee satisfaction with the office, lower rates of absence from work, and less exposure to a range of air pollutants (Sundell et al., 2011).

Productivity

According to a study conducted by Kasonen & Tan, the airflow rate per m^2 in an office area influences the productivity as shown in figure x (2004). Taking 80% ventilation efficiency (typical in the Netherlands) in an office space of $10m^2$ for one employee, a supply 20 l/s of fresh air produces 6% increase in productivity compared to 4 l/s (Kosonen & Tan, 2004).

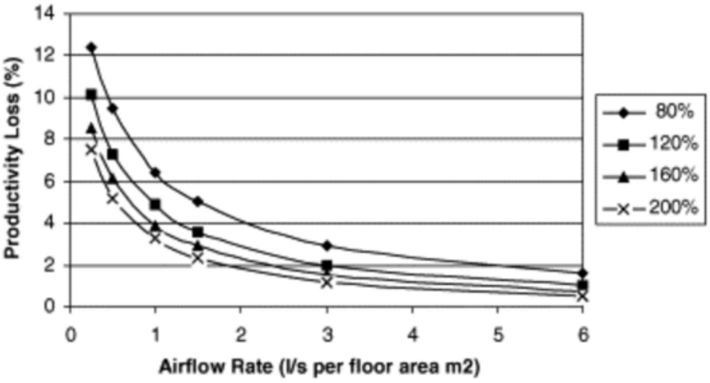


Figure x: Productivity loss in relation to fresh air supply per m2 at different ventilation efficiency levels (Kosonen & Tan, 2004)

During a field study in a call center (Wargocki et al., 2004), the productivity effect of ventilation through a dirty air filter was examined. The handling time per telephone call turned out to be approx. 8% lower indicating an increases in productivity when mechanically ventilated via a new filter, compared to when ventilating via a 1 year old filter. Wargocki et al. suggest changing air filters regularly, not only because airflow resistance increases, but also because air quality decreases as the filter gets older (Wargocki et al., 2004). This has adverse effects on health, comfort, and performance of employees.

Noise

Noise in an office can also influence the performance of an employee. Noise is distinguished in two types: meaningful intermittent noise (ex. phone conversation from a colleague) and continuous noise (generated by ventilation systems).

Comfort/Well-being

Among air quality, noise is the strongest predictor of well-being for office workers according to Klitzman & Stellman (Klitzman & Stellman, 1989). The range of noise in offices are not nearly high enough to cause permanent hearing loss (Stellman & Henifin, 1983). Also, it is suggested that unpredictability of noise rather than the decibel level results in the unfavorable reactions of office workers (Sundstrom et al., 1980).

Productivity

Intermittent noise has been shown to have a negative effect on self-estimated performance in research from Toftum et al. (Toftum et al., 2012). Participants said to be up to 11% more productive without intermittent noise in the office. Noises from others distract employees often or always 44% of the time in flex-offices (Boerstra et al., 2017). Other disturbances to employees are shown in figure 5.

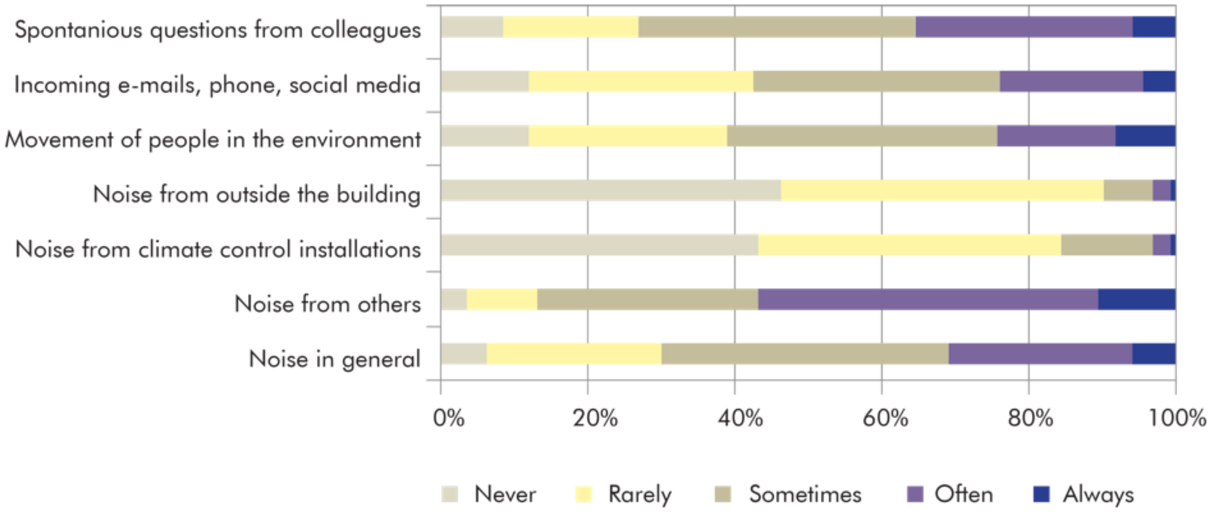


Figure 5: distraction factors in flex-offices (Boerstra et al., 2017)

When considering continuous noise, such as noise generated by the ventilation system, there is still ongoing research to quantify the effects on productivity. Szalma & Hancock propose that the effect of continuous noise is three times weaker than that if intermittent noise (Szalma & Hancock, 2011). Legislation ensures that noise levels in offices do not exceed 38dB continuous sound level caused by building services (EN 16798-1, 2019).

Figure G: Morawska's Controls to Reduce Environmental Risks for Airborne Transmission

1. To remind and highlight to building managers and hospital administrators and infection control teams that engineering controls are effective to control and reduce the risks of airborne infection – and SARS-CoV-2 has the potential and is likely to be causing some infections by this route.

2. To increase the existing ventilation rates (outdoor air change rate) and enhance ventilation effectiveness - using existing systems.

3. To eliminate any air-recirculation within the ventilation system so as to just supply fresh (outdoor) air.

4. To supplement existing ventilation with portable air cleaners (with mechanical filtration systems to capture the airborne micro- droplets), where there are areas of known air stagnation (also referred to as stratification), which are not well-ventilated with the existing system, or isolate high patient exhaled airborne viral loads (e.g. on COVID-19 cohort patient bays or wards).

5. To avoid over-crowding, e.g. pupils sitting at every other desk in school classrooms, or customers at every other table in restaurants, or every other seat in public transport, cinemas, etc.

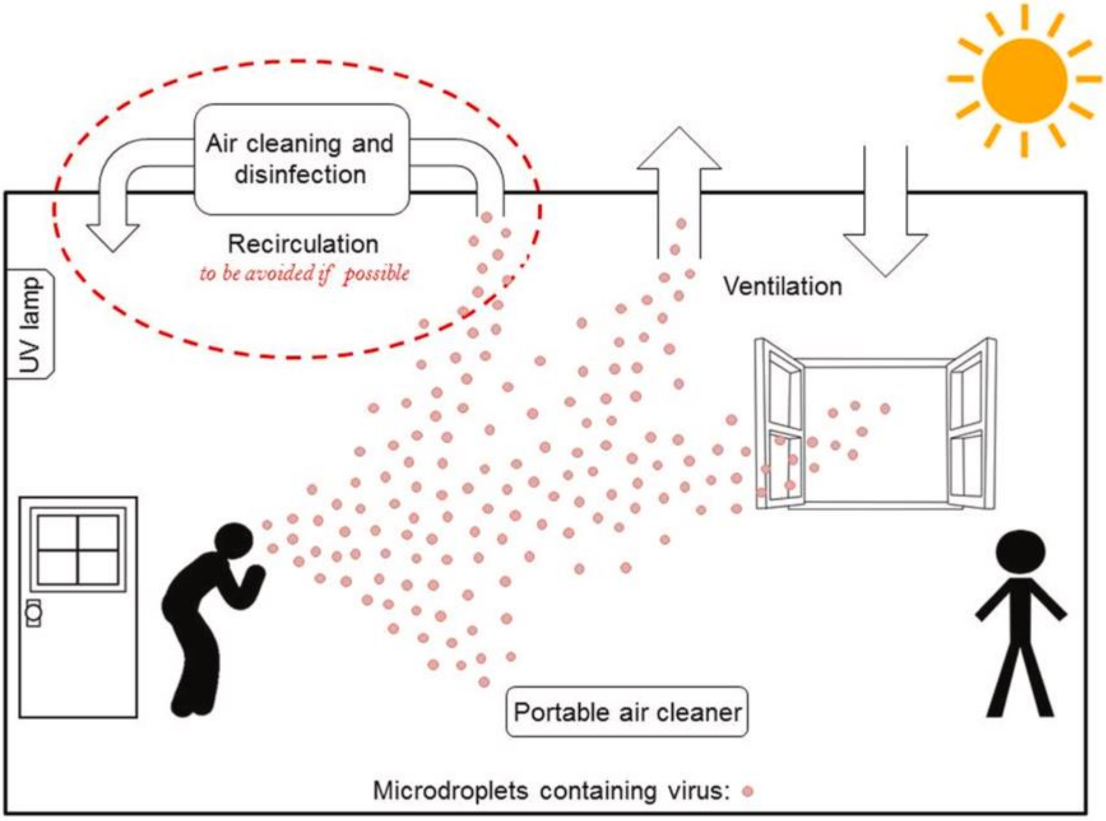


Figure 6: Engineering level controls to reduce the environmental risks for airborne transmission (Morawska et al., 2020)

Appendix H: Environmental Factors for Aerosols

Time & Distance

The size of the droplets influences the travelling time and distance. Research shows that aerosols remain suspended in the air for a long time and distance as they are subject to buoyant forces, whereas larger respiratory travel for a short time and distance as they are subject to gravity (Yin et al., 2022). It was found that aerosols with a radius of 2.5 μm stay in the air for about 41 minutes and respiratory droplet with a radius of 100 μm remain in the air only for 1.5 s (Yin et al., 2022). Figure 7 highlights how droplets emitted by breath travel a shorter distance than those emitted by coughing and sneezing. Risk of infection can be mitigated through social distancing up to 1.5m from a person, however beyond that distance ventilation solutions are suggested to be more effective (REHVA, 2020a).

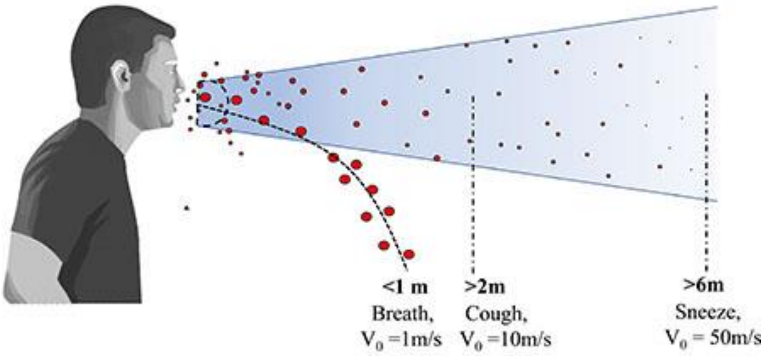


Figure 7: Schematic of droplet transmission ejected during sneezing and coughing. A typical conical jet flow of droplets during sneezing and coughing has a cone angle in the range of 22°−28°(Yin et al., 2022)

According the REHVA, if air cleaners are used in large spaces, they need to be placed close to people in a space and should not be placed in the corner and out of sight (REHVA, 2020b). Ventilation and air purification follow the inverse square-law, therefore placing the device closer to the user within the breathing zone will decrease the airflow rate it will need (DuBois et al., 2022). Besides proximity to the source, research from DuBois et al. suggests that portable air purifiers intended for capturing aerosols should have the largest capture area possible and should consider the thermal rise of air in a room (DuBois et al., 2022).

Temperature & Humidity

The relative difference between the breath of the individual compared to the environment temperature influences the plume propagation. The breath (36°C) hotter than the ambient air will rise (shown in figure 8), whereas a breath colder than the ambient air will move downward as a result of buoyancy forces (Yin et al., 2022). The thermal plume as a result of the persons legs, core, and head rises gently but is turbulent and catches the stagnant ambient air as it rises. Ambient air with aerosols possibly containing Sars-CoV-2 virus will rise to the ceiling (considering no ventilation) as a result of the thermal plume.

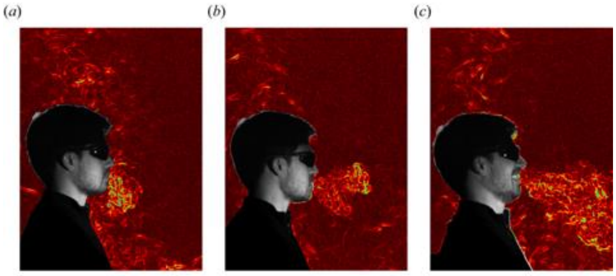


Figure 8: Differential synthetic schlieren images of the thermal plumes produced by a person in a quiescent environment. In panels (*a*–*c*) no mask is worn, The subject is (*a*) sitting quietly breathing through their nose, (*b*) saying ‘also’ when speaking at a conversational volume and (*c*) laughing (Bhagat et al., 2020).

Humidity has also been shown to have effect on the propagation of respiratory droplets and aerosols (Zhao et al., 2020), though in an office environment with existing humidification systems the REHVA does not suggest any adjustments, and warns for side effects:

> *“Small droplets (0.5 – 50 μm) will evaporate faster at any relative humidity (RH) level, … for this reason some humidification in winter is sometimes suggested (to levels of 20-30%), although the use of humidifiers has been associated with higher amounts of total and short-term sick leave. In buildings equipped with centralised humidification, there is no need to change humidification systems' setpoints (usually 25 or 30%), … as there is no direct implication for the risk of transmission of SARS-CoV-2”* (REHVA, 2020b).

Concentration & Number of Individuals

Current models suggest that concentration of aerosols correlate to the number of infections (Kriegel et al., 2020). Figure 9 indicates how a higher fresh air delivery rate, reducing the concentration of aerosols, results in a lower Predicted Infection risk via Aerosols (PIRA). “For an exposure time of two hours a volume flow of 20 m^3 /(h·Per) resulted in five probably infected persons in a room with 20, 40 or 100 persons, but of course only one probably infected person in a room with two persons. For a volume flow of 60 m^3/(h·Per) the number decreases to two probably infected persons in a room with 20, 40 or 100 persons” (Kriegel et al., 2020).

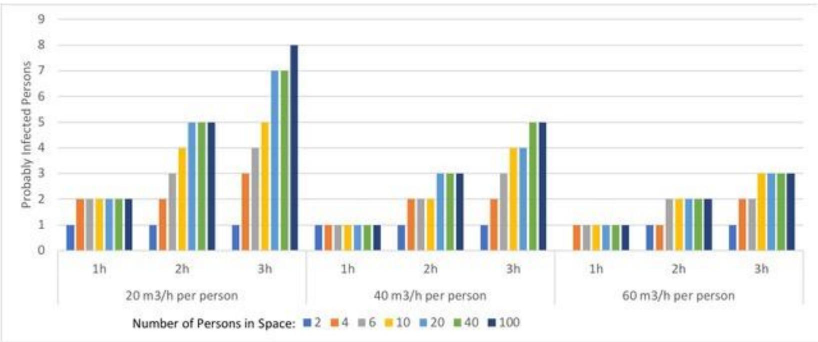


Figure 9: Number of persons probably infected according to a specific volume flow (Kriegel et al., 2020)

Exposure Time

Besides concentration, exposure time also increases the PIRA. The Wells-Riley model in figure10 describes a situation where one or more infected people are in the same room and share the same air as other people susceptible to the virus. It can be used for predicting the probability of infection for airborne transmissive diseases. The exposure time t in the formula indicates as exposure time increases, infection rate increases as well. As a result, indoor areas with where people are exposed for a longer period of time to the Sars-CoV-2 virus will have a higher probability of developing Covid-19.

$$P = 1 - e\frac{-lpqt}{Q}$$

Figure 10: Wells-Riley model for predicting probability of infection (P). $l =$ number of infected individuals in the room, $p =$ average breathing rate of the individuals, $q =$ quanta generation rate, $t =$ exposure time, $Q =$ Air flow rate from HVAC

Appendix I: Ventilation Methods & Strategies (Lipinski et al., 2020)

Table X: Classification of ventilation strategies by airflow dynamics (Lipinksi et al., 2020)

Recirculating ventilation (and comfort systems)	Split air conditioning systems	Room air is processed by the wall or ceiling mounted fan unit and recirculated at speed to ensure furthest reach within the space
	Ceiling fans	Room air is recirculated downwards (or upwards) at speed to ensure wind chill cooling and sufficient spread within the space
	Hybrid ventilation systems	Room air is mixed with external air and recirculated into the space with the help of a fan to ensure farthest distribution and mixing
Mixing ventilation systems	Air handling units (AHU)	Outside air is conditioned and supplied to occupied spaces through ducts using floor or ceiling diffusers. Stale air is mixed with fresh and then disposed of through various outlets thanks to positive pressure from AHUs.
	Mechanical ventilation with heat recovery (MVHR)	Balanced supply and extract systems, mostly localised, that both supply and extract air from the same space. These systems provide heat recovery option to reduce ventilation related heat loss.
	Positive input ventilation	Localised fanned systems supplying fresh air (and relying on façade openings for exhaust using positive pressure). Similar airflow dynamics to AHUs listed above.
Displacement ventilation methods and systems	Continuous extract ventilation	Localised or centralised fan driven systems extracting stale air (relying on building fabric openings such as windows or louvres to let fresh air in utilising negative pressure).
	Natural ventilation measures (Predominantly windows)	Building integrated measures designed to displace stale air and supply fresh air using buoyancy including elements such as windows, passive stacks or solar chimneys.
	Natural ventilation systems	Natural Ventilation products or systems utilising buoyancy in their operation including roof cowls, wall mounted IAQ responsive louvres or IAQ controlled window openers.

Natural Ventilation

Natural ventilation (also referred to as passive ventilation) makes use of natural airflows to provide fresh outdoor without the use of fans. Typically, this is achieved by openings such as trickle vents, grills, and airbricks. There are two types of natural ventilation; buoyancy-driven, and wind-driven. Buoyancy-driven makes use of temperature differences between interior and exterior of the building whereas wind-driven makes use of pressure differences created by wind around the building. These systems often rely on the occupant opening and closing it manually. Natural ventilation can be achieved in a variety of forms, such as single sided ventilation, cross ventilation and stack ventilation.

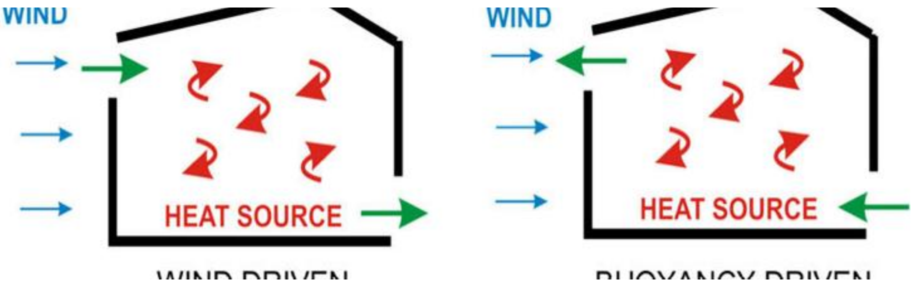


Figure 11: Wind-driven vs. buoyancy-driven natural ventilation (Lishman & Woods, 2009)

Figure 12: Trickle Vent (left), Air Brick (middle), Ventilation Grill (right)

Single Sided Ventilation

Single sided ventilation uses one or more openings on one external wall. This principle uses a pumping activity induced by wind turbulence to create low levels of air inflow and outflow. Single sided ventilation is known to have a weak effect and used when cross ventilation is not possible (GBCSA, n.d.).

Cross Ventilation

Cross ventilation is wind driven, where it uses the pressure difference of windward and leeward facades to create a draft indoors.

Stack Ventilation

Stack ventilation makes use of pressure difference between warm and cold air. Colder air provided to lower levels rises due to exposure to heat and then expelled at a higher level. This method requires height differences.

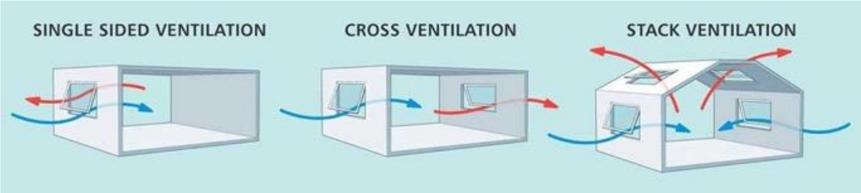


Figure 13: single sided ventilation vs. cross ventilation vs. stack ventilation (https://www.tealproducts.com/wp-content/uploads/2017/07/Natural-Ventilation-Mobile.jpg)

Mechanical Ventilation

Mechanical ventilation makes use of fans to move air in and out of rooms. The systems can vary depending on the size of the room or building. Smaller rooms may have these in the room, whereas larger spaces may use a network of ducts and fans to extract dirty air or blow clean air. Examples range from small portable air purifiers that can be controlled by the occupant to large intricate systems that are centrally or automatically controlled.

Exhaust-Only Ventilation

This type of ventilation works by reducing the pressure inside the building through a mechanical ventilation to another environment. Subsequently, air is drawn into the negative pressure through vents and leaks in the building. This is the working principle of most commercial air purifiers. This method works better in cold climates as warm humid climates affects the pressure differently.

Supply-Only Ventilation

A supply ventilation system uses a fan to blow outdoor air into a room creating positive pressure, forcing contaminated air to escape through vents and leaks in the building.

Balanced Ventilation

Combines the use of both a supply and exhaust fan that are relatively equal. In larger systems Energy Recovery Ventilator (ERV) as well as a Heat Recovery Ventilator (HRV) can be used for energy savings.

Energy-Recovery

Energy recovery systems aim to reduce the use of electricity for heating or cooling air in a ventilation system. In the winter, warm indoor exhaust air is used to heat the colder supply air. In the summer, cooler indoor exhaust air is used to heat the colder supply air.

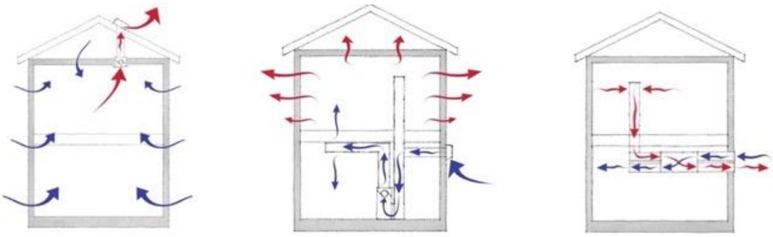


Figure x: Exhaust-Only Ventilation (left), Supply-Only Ventilation (middle) Balanced Ventilation & Energy-Recovery (right)

Hybrid Ventilation

Hybrid ventilation, also commonly referred to as mixed mode, combines both natural and mechanical ventilation. It makes use of operable windows (either manually or automatically controlled) as well as mechanical systems such as air distribution equipment. This method is commonly used when either natural or mechanical ventilation doesn't achieve the desired indoor air quality.

Spot (Local) Ventilation

Spot (commonly referred to as local) ventilation is an additional system used to ventilate a source locally. This is commonly used where sources of pollution, heat, and humidity are at a high level. Common examples of spot ventilation are kitchen extractor hoods, bathroom ventilation, and laminar airflow units.

Task Ambient Conditioning (TAC)

A Task Ambient Conditioning system allows users to control the local airflow and temperature in a controlled area to improve the comfort of the individual. For example, in figure 14 ambient temperature can be controlled through the floor blower outlet and task blower outlet. Room temperature can be set higher than usual so individuals can use the air blowers for wind chill effect.

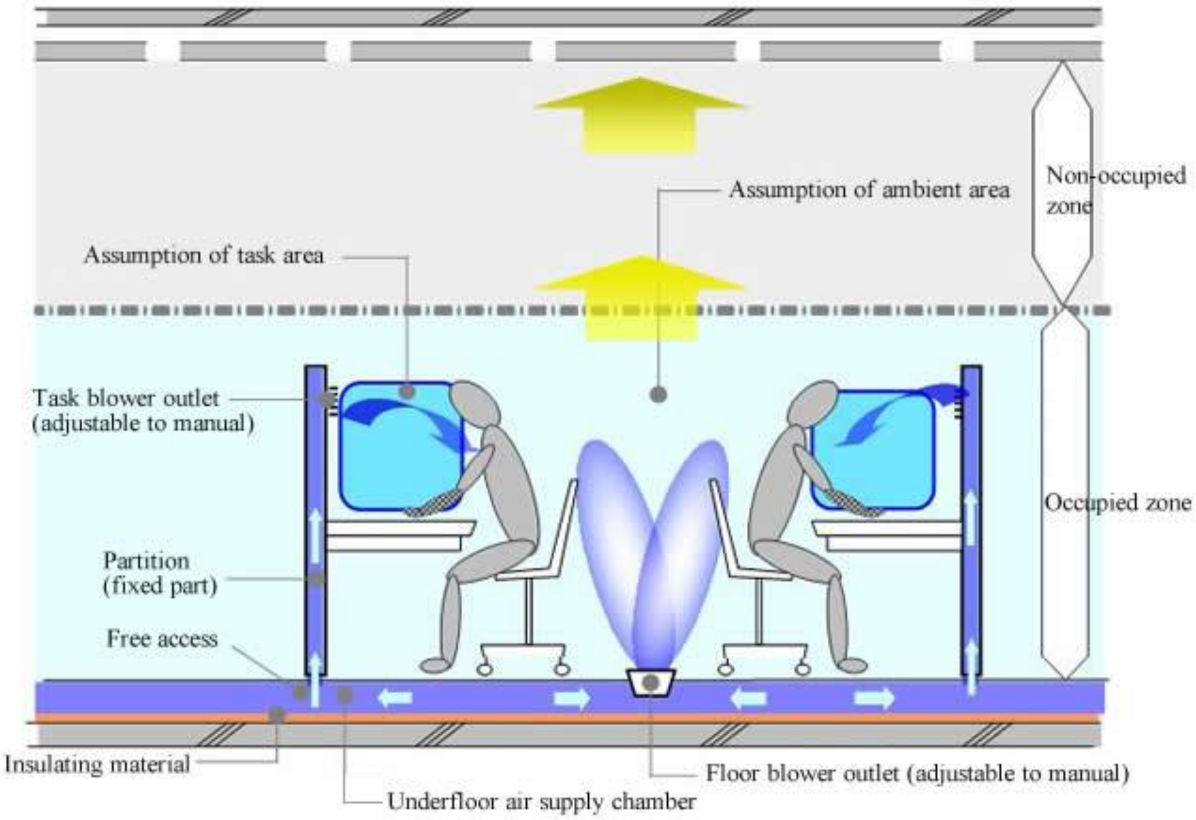


Figure 14: Example setup for Task Ambient Conditioning in an office environment

Recircling ventilation

Recirculating Ceiling Fan

The recircling ceiling fan is used for improving comfort and indoor air quality in warm spaces through the wind chill effect, as well as reducing stratification in the room. Benefits of these systems as opposed to air-conditioning units are that they are cheap and easy to install. On the other hand, as ceiling fans continuously mix air in an environment the contaminated droplets and aerosols from an infected host are spread further than usual, increasing the risk of contamination (Lin, 2015).

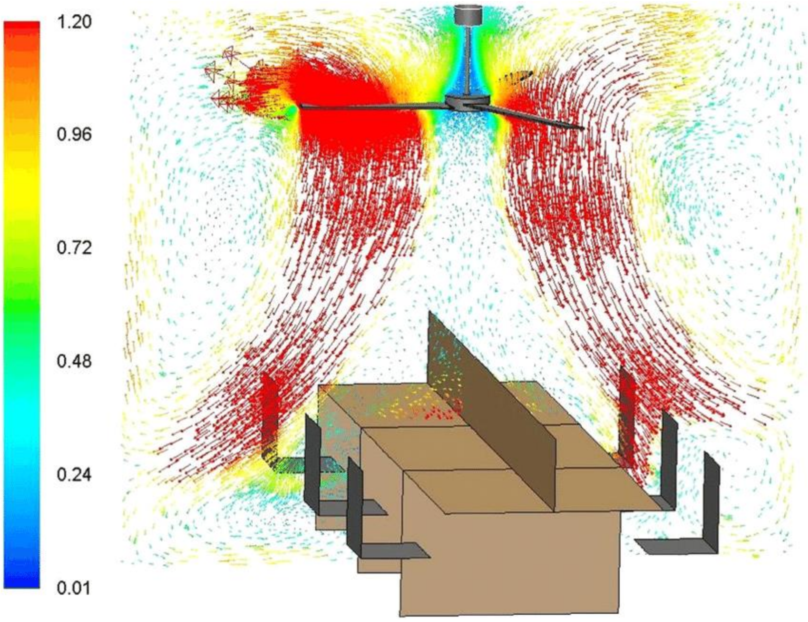


Figure 15: CFD of a typical ceiling fan in an office environment (Kumar et al., n.d.)

Hybrid Ventilation - Natural Ventilation with Heat Recycling (NVHR)

NVHR systems recirculate indoor air and adds fresh air to the environment. These are typically used to keep CO_2 levels below 1000ppm in public spaces such as schools and offices. High levels of volume flow rate (usually 300 l/s or more) are required to achieve this, and with small vent openings this results in high air velocity. According to the University of Oregon, the high flow rate to blow air deep into the room substantially increases the risk of infection even with one infected host (Dietz et al., 2020)

Figure 16: NVHR 1100 system by BreathingBuildings (*Breathing Buildings*, 2020)

Recirculating comfort systems -Heating Ventilation Air Conditioning (HVAC)

These air conditioning systems are similar to hybrid ventilation, only that they do not introduce fresh outdoor air. The system conditions the air, either heating or cooling, and supplied back into the environment at a velocity to reach far into the room. Contaminated air from an infected host is picked up by the system and expelled, increasing the risk of infection (Dietz et al., 2020).

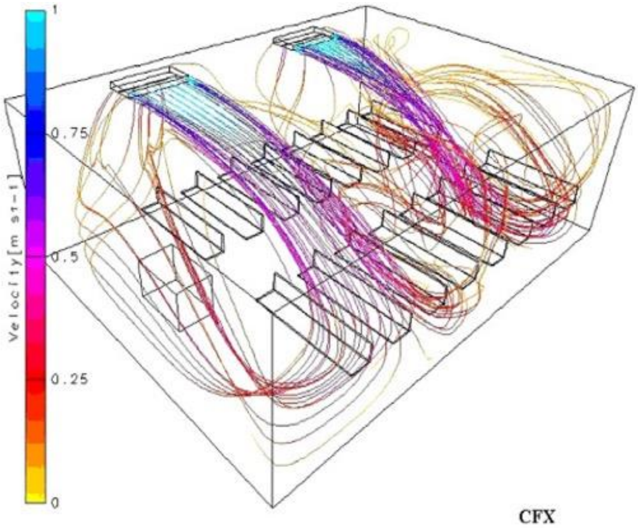


Figure 17: CFD of a typical split AC in a typical lecture room (Lin, 2015)

Mixing ventilation

Air Handling Unit (AHU)

Air handling units draw fresh air and dehumidifies, heats, cools the air as necessary. This air is then expelled throughout the building by floor or ceiling grills mixing with the existing air and creating a positive pressure. Through trickle vents, and other devices air 'leaks' out of the building. Research shows that despite introducing fresh air, significant amount of air is mixed within the spaces. The fan-induced mixing is worsened, enabling contaminated air to spread further (Churazova, 2020).

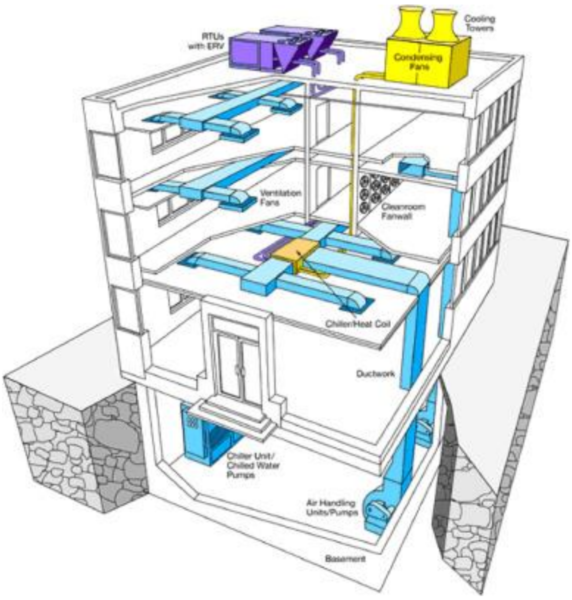


Figure 18: Diagram of a standard AHU system with ventilation on the ceiling (Willwerth, 2013)

Positive Input Ventilation (PIV)

Positive Input Ventilation works similarly to AHU's, with the major difference that the unit is placed locally and does not use complex ducting systems. A fan delivers air with enough velocity to spread throughout a space and has similar mixing properties compared to AHU's.

Figure 19: PIV system placed in the attic of a residential building (Envirovent, n.d.)

Mechanical Ventilation with Heat Recovery (MVHR)

Mechanical Ventilation with Heat Recovery is similar to NVHR but retrieves warm indoor air to heat up incoming fresh air. The system is based on a balance between inflow and outflow as opposed to positive indoor pressure. Though the inflow of fresh air and outflow of stale air is controlled through the same box, there is generally no mixing between the two paths. Similar to the NVHR system, fast airflow out of the device induces mixing of air, thereby increasing the likeliness of contaminated air to mix with fresh air (Lipinski et al., 2020).

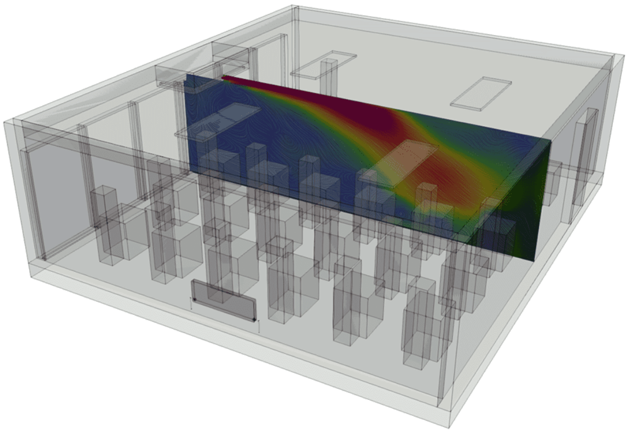


Figure 20: CFD simulation of the AM 800 MVHR system typically used in classroom settings (Jenkins, 2021)

Displacement ventilation

Typically, displacement ventilation supplies conditioned colder air through a diffuser. Diffusers can be placed on the wall, in the corners of the room, or above the floor. The colder air spreads in a thin layer across the room until it is heated by heat sources such as electronics, lights and body heat. As the air becomes warmer and less dense, there is a density difference. This creates a convective flow upwards also referred to as a thermal plume (Skistad et al., 2004). Displacement ventilation can be achieved through natural ventilation measures, and mechanically assisted.

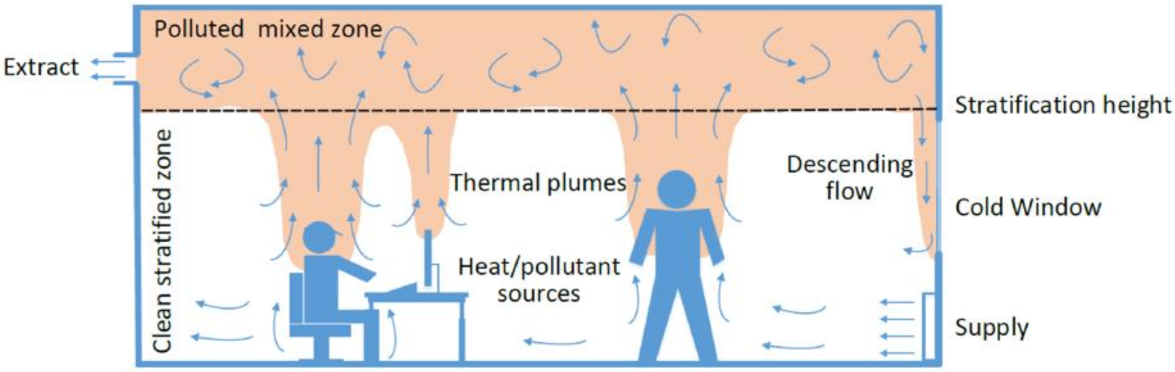


Figure 21: Illustration of displacement ventilation (Javed et al., 2021)

Natural ventilation measures

Single sided, cross, and stack ventilation are the three main methods for natural ventilation described earlier in the chapter. Though they are the most conventional and cheapest ventilation strategy to implement, lack of control such as wind speed and temperature or noise dampening often mean building design opts for mechanical ventilation (Lipinski et al., 2020) Nonetheless, studies show that with a plentiful supply of natural air can remove or dilute contaminants effectively. On the other side, drafts may carry droplets and aerosols from the infected host to other individuals depending on the placement of windows and vents (Lipinski et al., 2020). When designed and implemented with transmission of airborne transmissive diseases in mind, along with additional local mechanical exhausts, natural displacement ventilation can be an effective way to reduce risk of transmission.

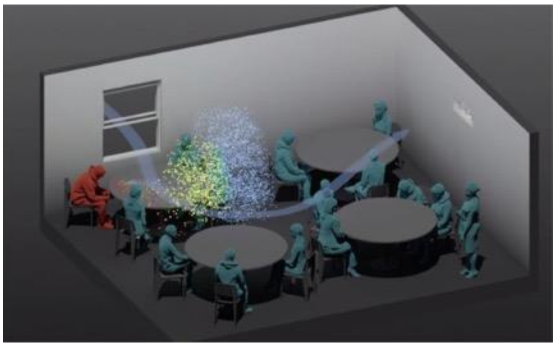


Figure 22: Visualizing how fresh air can carry contaminated air to a vent (Dietz et al., 2020)

Hybrid displacement ventilation (Mechanically assisted)

This system is simple and similar to natural ventilation but assists mechanically when natural drafts are not strong enough. For example, in winter pressure difference is enough for natural flow, however in summer buoyancy can be too weak to drive the airflow. Mechanical systems can aid the airflow, such as mechanical diffusers and or vents.

Thermal plumes

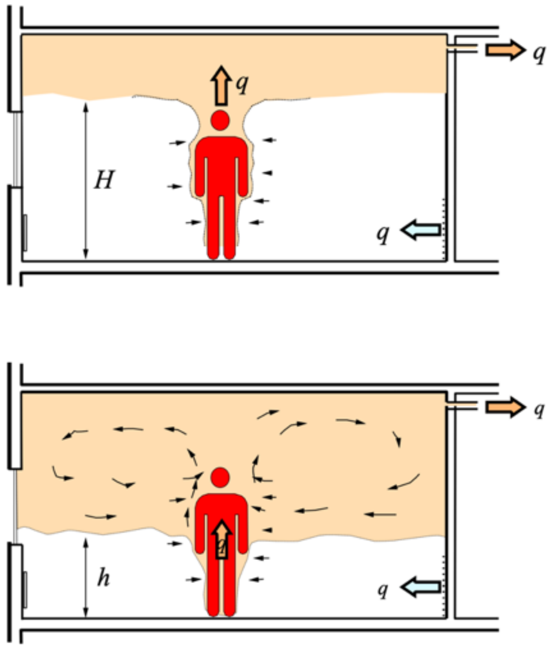


Figure 23: Convective currents of a person

Figure J: Calculating Volumetric Flow Rate by Desired ACH

The volumetric flow rate is proportional to the ACH can be calculated by the following formula:

$$ACH = \frac{60Q}{Vol}$$

Figure 24: ACH formula where ACH is air changes per hour, Q is volumetric flow rate (cubic feet per minute), and Vol is the volume of the room.

As the device is a 'Personal' air filter, calculations are made per person. In the Netherlands, an office employee is entitled to an office area of at least 7m^2 per person (NEN 1824:2010 NL, 2010). A ceiling height of 3m is taken for the calculation of the room volume. Though the product is designed with an international market in mind, this value is used as a guideline for the Personal Air Filter. Table 1 shows the minimal volumetric flow rate the Personal Air Filter will produce according to a range of room sizes (7m^2 and above).

Table 1: Volumetric Flow Rate for 3 ACH in m3/h and cfm depending on room area. Source: Author

Area per Person (m^2)	Room Volume (m^3)	Volumetric Flow Rate (m^3/h) – 3 ACH	Volumetric Flow Rate (cfm) – 3 ACH	Volumetric Flow Rate (m^3/h) – 5 ACH	Volumetric Flow Rate (cfm) – 5 ACH
7	21	17,5	10,3	29,2	17,2
10	30	25,0	14,7	41,7	24,5
15	45	37,5	22,1	62,5	36,8
20	60	50,0	29,5	83,3	49,1
25	75	62,5	36,8	104,2	61,4
30	90	75,0	44,2	125,0	73,6

Appendix K: Evaluation of Air Purification Methods

Results from the analysis summarized in the Harris Profile (table x) to indicate the most suitable air purification technologies. Most important requirements are placed higher as they have a heavier weighting/influence.

	Filtration				**Ozonation**				**Photocatalysis**				*** Adsorption**			
	-2	**-1**	**1**	**2**	**-2**	**-1**	**1**	**2**	**-2**	**-1**	**1**	**2**	**-2**	**-1**	**1**	**2**
Viruses & pollutants			■	■			■			■			▨	▨		
Safety			■	■	■	■				■						
Level of noise	■	■			■	■					■	■				
Cost	■	■					■			■						
Energy Use		■				■				■						

Table 2: Harris profile filtration, ozonation, photocatalysis, and adsorption applied to the Personal Air Filter. *Not completed as provides no relevance to filtering aerosols. Source: Author

Filtration (EPA, HEPA, ULPA)

Most common filtration methods are the use of EPA (Efficiency Particulate Air), HEPA (High-Efficiency Particulate Absorbing), or ULPA (Ultra-Low Penetration Air) filters. Figure 25 suggests how these filters work.

Efficiency for viruses & pollutants

According to ISO standards, the penetration rate defines whether the filter is called EPA (85 - 99.95%), HEPA (99.95 - 99.999%), ULPA (more than 99.999%) (ISO 29463-1:2011, 2011). The higher the efficiency, the lower the penetration of pollutants through the filter. According to Euromate, EPA-12, HEPA-13 or HEPA-14 are suitable for purification for viruses (personal communication, 2022).

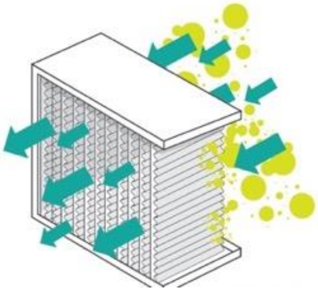


Figure 24: Visualization of HEPA filter filtering particulate matter (*Difference Between a HEPA and ULPA Filter | HEPA vs ULPA Filter*, n.d.)

Performance is commonly defined by the Clean Air Delivery Rate (CADR). CADR (Q_{CADR}) is the product of the filters collection efficiency (E) and airflow rate (Q).

$$Q_{CADR} = EQ$$

Pollutants range in size and matter, affecting whether a purification method is effective or not. Table 3 shows the range of sizes of pollutants.

Common Indoor Pollutant	Particles Size in Microns (µm)
Pollen, mold and plant spores	7-70
Dust mites	3-10
Hairspray	3-10
Large bacteria	1-20
Lead dust	1-3
Auto emissions	1-3
Fungal spores	0.5-7
Cooking odors	0.3-1
Dust	0.2-8
Pet dander	0.15-8
Small bacteria	0.08-1
Tobacco smoke	0.008-0.6
Viruses	0.005-0.001
VOC (volatile organic compounds)	Less than 0.001

Table 3: Sizes of pollutants in micrometers (µm) (*HEPA Filters Vs UV Light | What Is The Difference?*, 2020)

The efficiency indicates what percentage of pollutants are filtered for particles with a size of 0.3 µm. HEPA filters improve in efficiency for particles larger or smaller than 0.3 µm (NIOSH, 2003). As a result, these filters are able to filter pollen, dirt, moisture, bacteria, viruses, and aerosols. Mobile and stationary HEPA filters are commonly used in hospitals for reducing risk of transmission and are shown to be effective for Sars-CoV-2 (Conway-Morris et al., 2021). Furthermore, HEPA help alleviate allergy symptoms from a range of pollutants (Jia-Ying et al., 2018). HEPA filters do not however filter VOC's as these are not particles but gases.

Notably, air velocity influences efficiency as "a simple HEPA-rated filter will perform as an ULPA-rated or better filter by simply lowering the flow velocity through the media" (Perry et al., 2016). Furthermore, a high efficiency rate is intuitively seen delivering higher CADR. Research by Rudnick however suggests that a most optimal filter efficiency for maximizing CADR for particles having diameters less than about 0.1 µm is 82% (Rudnick, 2004). This research does not consider recirculation of polluted air possibly containing viruses.

Safety

HEPA filters have been widely used since the 1950s and show no health hazards to the user when used properly(*Are HEPA Filters Safe?*, n.d.). The filters are produced from fiberglass or PET+PP and shed "minimal amount of fiber with some of the fibers being respirable. These results showed shedding was negligible compared to the number of fibers and/or particulate present in ambient air" (*Are HEPA Filters Safe?*, n.d.). Wargocki et al. suggest changing air filters regularly, not only because airflow resistance increases, but also because air quality decreases as the filter gets older (Wargocki et al., 2004). This has adverse effects on health, comfort, and performance of employees.

Level of Noise

Mobile HEPA filters can produce noise in a range from 30 to 70dB, depending on the model, the amount of CADR, type of filter used, and more (*How to Buy a Quiet Air Purifier*, n.d.). Noise is generated by the fans used or air resonance in the device if improperly designed. Typically, larger devices deliver have a higher CADR relative to noise produced as they become more efficient. Still, most devices produce around 45 to 55dB (*How to Buy a Quiet Air Purifier*, n.d.).

Cost / Energy Use

HEPA air purifiers are generally inexpensive for upfront costs. In the long run, maintenance can become costly as HEPA filters need to be replaced once every half year to a year. Typically, HEPA filters alone can cost 50 – 500 Euros. As for energy use "air purifiers don't use a whole lot of electricity. They have a maximum wattage of anywhere between 40W and 200W (even the biggest ones max out at 100W), and that's for the highest speed settings. You can easily run an air purifier on a lower 10-30 watt setting" (*How Much Electricity Does An Air Purifier Use? Do They Use A Lot? (Calc.)*, n.d.).

$$Power\ consumption = \frac{Watts \times kWh\ cost \times h}{1000}$$

Large HEPA air purifier (Blueair Classic 680i), 65m^2, 450 CADR, running 100W max all year
= 270 euros per year
Medium HEPA air purifier (Coway AP-1512HH Mighty), 28m^2, 250 CADR, running 77W max all year
= 210 euros per year
Small HEPA air purifier (Levoit LVH132 HEPA air purifier), 12m^2, 40 CADR, running 24W max all year
= 65 euros per year

*Prices are calculated using 0.312 Euro per kWh

Adsorption (Activated Carbon)

The most common adsorption filter is the activated carbon filter.

Efficiency for viruses & pollutants

These can adsorb for liquids (water purification) or gases (air purification) onto the surface of the filter. For air, this method is most effective in filtering VOCs, odors, and other gaseous pollutants from the air (Myers, 2018). This can include tobacco or cooking smoke, paint fumes, and cleaning products (EPA, 2022; Myers, 2018). These filters however do not filter viruses or other particulate matter.

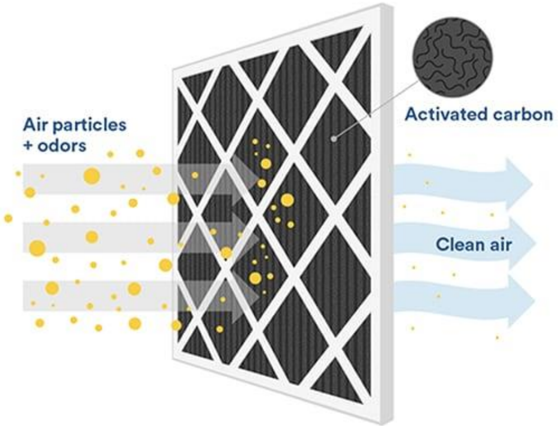


Figure 26: Visualizing how a carbon filter works (*How Does a Carbon Filter Work?*, n.d.)

As adsorption filters are not relevant for the intended use of the Personal Air Purifyer, the safety, noise level and cost/energy use are not further analyzed.

Ozonation

The two most common methods using ozonation for filtering are electrostatic precipitators and ion generators. Electrostatic precipitators ionize particles through an electric charge to attract them to collector plates with the opposite charge. Ionizers discharge charged ions that are spread through the air to bind and trapped in filters (Luengas et al., 2015).

Efficiency for viruses & pollutants

Electrostatic filters for a particle range of 0.3 to 6 μm is more than 90%, and for ionizers between 75% and 95% (Bliss, 2015). At this moment of time, there is no data available whether negative ion generators are effective against aerosols containing SARS-CoV-2. However, considering the size range of bio aerosols produced it falls within the field of range ozonation filters remove, therefore airborne viruses should be captured and inactivated (Luengas et al., 2015).

Safety

Ozonation filter can create charged particles, such as ozone or volatile organic compounds (VOCs). Both electrostatic precipitators and ionizers generate ozone from charging oxygen, which can be harmful to health. When small amounts of ozone are inhaled, it can cause health issues such as damage to the lungs, chest pains, coughing, shortness of breath and throat irritation (Poppendieck et al., 2014).

Level of Noise

Considering noise, there is no clear difference between a mechanical (HEPA) filter compared to a electrostatic air cleaner. A study by Afshari et al. measured a noise level of 50dB for electrostatic precipitation filter (Afshari et al., 2020). This is further supported by a study my Zuraimi, where it was “concluded that, in terms of noise generation, electrostatic precipitators are comparable to media-based portable air cleaners” (Zuraimi et al., 2011).

Cost

Initial investment cost of an electrostatic precipitator or ionizer is higher than that of a HEPA filter-based air purifier. On the long run, there is less maintenance cost as the plates do not need to be replaced. Plates of the electrostatic precipitator and ionizer can be cleaned and reused. Though no concrete number were found to support this, it is argued that ozonation is more cost effective relative to HEPA filter.

Energy Use

Electrostatic Precipitators and Ionizers use less power than other air purification units (Afshari et al., 2020).

Photocatalysis

The most common method of photocatalysis in air purification is using ultraviolet germicidal irradiation (UVGI) or UV-C light. It kills or deactivates micro-organisms by decomposing nuclei and altering DNA/RNA. UVGI and UV-C are used in a wide range of applications such as air purification, water purification, and food.

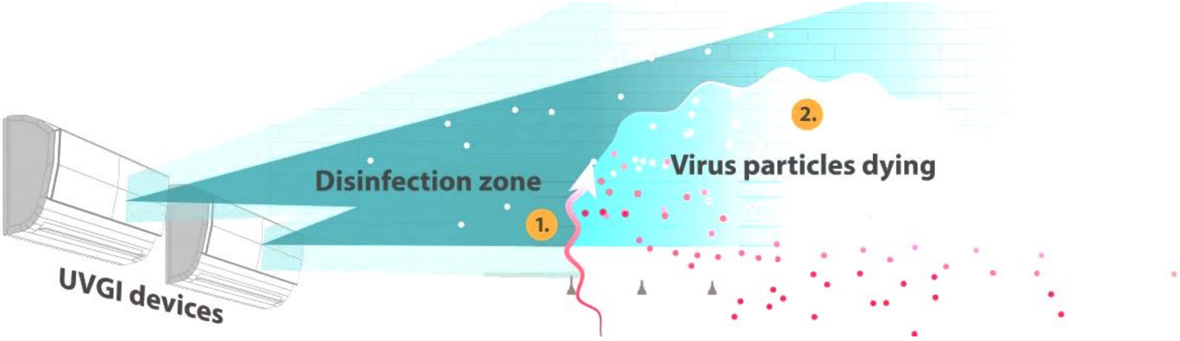


Figure 27: Visualization of upper-room UVGI for air purification

Efficiency for viruses & pollutants

Though UV-C has been shown to be able to completely kill all SARS-CoV-2 viruses, it is heavily time and light intensity dependent (Sellera et al., 2021). For example, an average consumer air purifier using UV-C has a 6mW/cm^2 lamp then it would take 12.5 seconds to deactivate 99.9% of the viruses. For a more powerful map at 16.8mW/cm^2 it would take 4.46 seconds to deactivate 99.9% of the viruses. As air passes through the device at an estimated 0.35 seconds, it would need to pass through 35 or 15 times respectively before completely eliminating all pathogens (Robertson, 2021).

Safety

Similar to ozonation, UV-C can produce ozone s, which can be harmful in indoor spaces. For example, “there are no standardised testing procedures to determine the conditions for use of this method in indoor air spaces that exclude health hazards linked to ion and ozone generators” (ASHRAE, 2022; Medical Advisory Secretariat, 2005).

Furthermore, direct exposure of UV-C to humans can be harmful, such as damaging skin tissue or the eyes (European Commission, 2016). It is advised to use UV-C with wavelengths longer than 240 nm to minimize the adverse risks (Morawska et al., 2020).

Level of Noise

As UV-C air purifiers have little resistance and require flow velocity, small fans can be used. These are therefore much quieter relative to HEPA air purifiers. Upper-room UVGI systems such as in figure 28 require no fans and are completely quiet. No quantitative data could be found for the level of noise in dB for these systems.

Cost/Energy Use

Though energy consumption is higher than that of HEPA filters (approx. 80 Euros per year, 350kWh/1600 oper. Hrs.), UV-C and UVGI systems are more cost effective in the long run (*Air Purification with UV Light or HEPA Filters? UV Light Is More Effective, Saves Costs and Maintenance*, n.d.). Lamps are expected to last 10 years, with 1600 operating hours per year. The lamps require less frequent maintenance and will save significant costs.

Appendix L: Comparison Between Axial and Centrifugal Fans

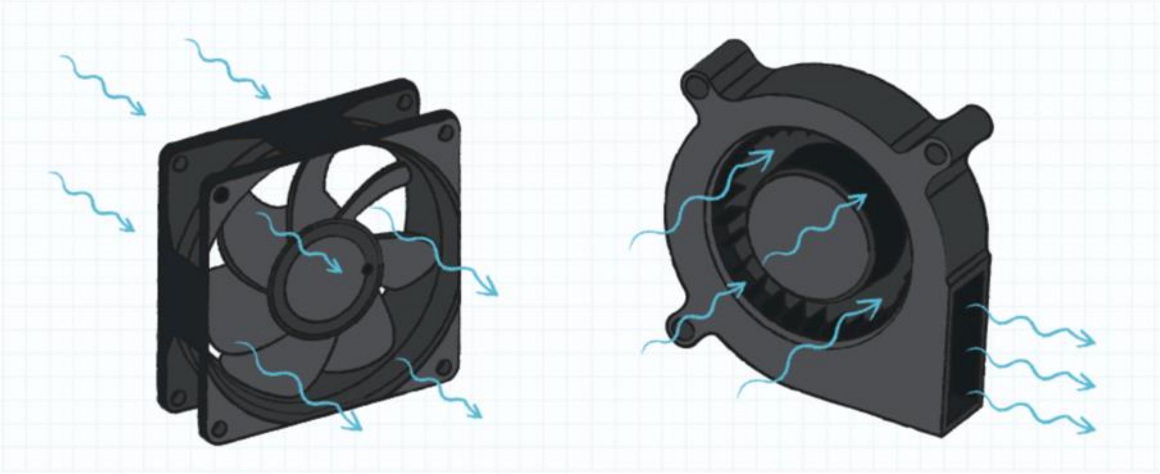


Figure 28: Axial fan (left), centrifugal fan (right) (Smoot, n.d.)

Table 4 provides a comparison between the two methods.

Table 4: comparison between axial and centrifugal fans (Smoot, n.d.)

Axial Fans	Centrifugal Fans
High Volume/Low Pressure	High Pressure/Low Volume
Airflow parallel to axis	Airflow perpendicular to axis
Higher operating speed than centrifugal	Lower operating speed than axial
Compact designs	Better for specific directed cooling
Lower power usage than centrifugal	Typically uses more power than axial
Less audible noise than centrifugal	More audible noise than axial
Typically, less expensive than centrifugal	Durable and resistant to harsh environments

Appendix M: Fan Laws (Powell, 2015)

1. $\frac{CFM_{NEW}}{CFM_{OLD}} = \frac{RPM_{NEW}}{RPM_{OLD}}$

"The first fan law relates the airflow rate to the fan rotational speed: Volume flow rate (CFM) is directly proportional to the fan rotational speed (RPM). If the fan RPM is increased, the fan will discharge a greater volume of air in exact proportion to the change in speed."

2. $\frac{SP_{NEW}}{SP_{OLD}} = \left(\frac{RPM_{NEW}}{RPM_{OLD}}\right)^2$

"The second fan law relates the fan total pressure or fan static pressure (SP) to the fan rotational speed: Total or static pressure is proportional to the square of the fan rotational speed."

3. $\frac{BHP_{NEW}}{BHP_{OLD}} = \left(\frac{RPM_{NEW}}{RPM_{OLD}}\right)^3$

"The third fan law relates the total or static air power (and the impeller power), to the fan rotational speed: Power, is proportional to the cube of the fan rotational speed."

Appendix X: PMI Method Design Direction Ideas

PLUS	MINUS	INTERESTING
+ Fitting style for office	- Difficult to make modular system	! Potential to change the angle of the exhaust for a better circular airflow
+ Placement easy in an office	- Hard for packaging to get it thin	! Colour variations
+ Easy to change filter		

PLUS	MINUS	INTERESTING
+	-	!
+	-	!
+	-	!
+	-	!

PLUS	MINUS	INTERESTING
+	-	!
+	-	!
+	-	!
+	-	!

PLUS	MINUS	INTERESTING
+	-	!
+	-	!
+	-	!
+	-	!

PLUS	MINUS	INTERESTING
+	-	!
+	-	!
+	-	!
+	-	!

PLUS	MINUS	INTERESTING
+	-	!
+	-	!
+	-	!
+	-	!

Appendix X: Weighted Criteria Design Direction Ideas

Prioritization Criteria	**Value**						
Breath Propagation	25	4	4	8	8	2	2
Capture Area	25	9	9	4	7	4	4
Expected Draft Temp.	20	4	3	8	5	3	3
Suitable in Office	20	7	8	9	4	6	7
Installation Difficulty	15	8	8	4	2	9	4
Changing HEPA ease	15	8	5	6	6	7	7
Euromate Brand Identity	10	6	6	6	4	3	2
Market Fit	10	7	7	9	3	5	6
Expected Cost	5	4	4	7	4	7	8
TOTAL		**935**	**890**	**975**	**765**	**685**	**635**

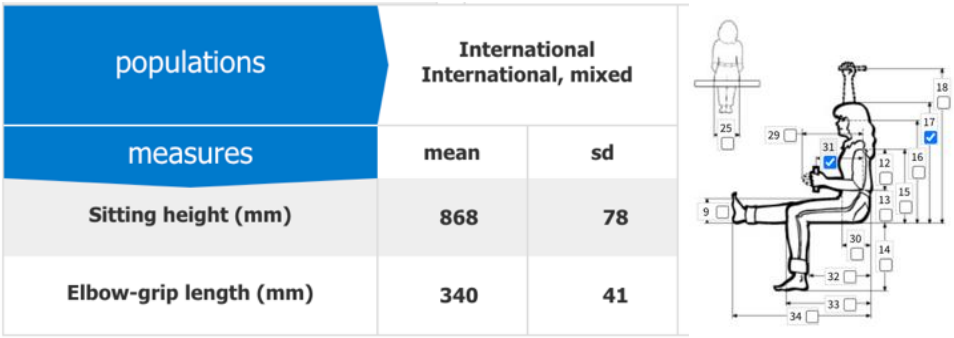
Appendix P: Testing Placement of Air Purifier Relative to Breath

Test Setup

A test setup seen in figure 29 was made to test a different height placement of a prototype air purifier relative to the user. Figure 30 shows the 10 scenarios tested. A SD011 Particulate Matter (PM) 2.5 sensor was placed in between the smoke pen and air purifier to get quantitative data (figure 31). Through an Arduino ESP2688 the values for PM could be recorded in a spreadsheet format. A camera filmed each experiment with a dark background (to distinguish the smoke) to visualize the air flow. Each scenario was tested twice. The videos of the scenarios were overlayed (multiplied) as to show both video recordings of all scenarios at once.

Figure 29: Visualization of proposed test setup Update this image to show all 10 scenarios tested

A smoke pen was placed at the average place of the user’s mouth: 1000mm away from the air purifier horizontally and 850mm high from the ground (figure 32) (DINED, 2019). The prototype air purifier (figure x) could be placed at each height to test the difference consistently. Furthermore, the air purifier had the option to add an exhaust pipe, thereby moving the exhaust air flow to the side of the table. A carton rectangle could be added at h3 to mimic the dividing wall concept.



populations	International International, mixed	
measures	mean	sd
Sitting height (mm)	868	78
Elbow-grip length (mm)	340	41

Figure 32: DINED average sitting height for placement of smoke pen

Taking measurements

SDS011 PM meter
- Distance to pollutant source (mouth/smoke pen)
- Arduino code setup
- Logging data to translate to Excel for data analysis (ArduSpreadsheet)
- Moment there is no visible smoke coming from the pen, recording starts (because from this moment there is no more PM being released by the pen)

Video recordings air flow
- Tripod with camera to compare between scenario's
- Dark background for better visibility of smoke

Air velocity
- Grid to consistently measure air velocity across different scenario's
- Use anemometer with accuracy up to one-hundredth m/s (very low air velocities)

Testing Procedure

Start/stop video recording
- Start before doing everything else
- Stop when there is no more visible smoke

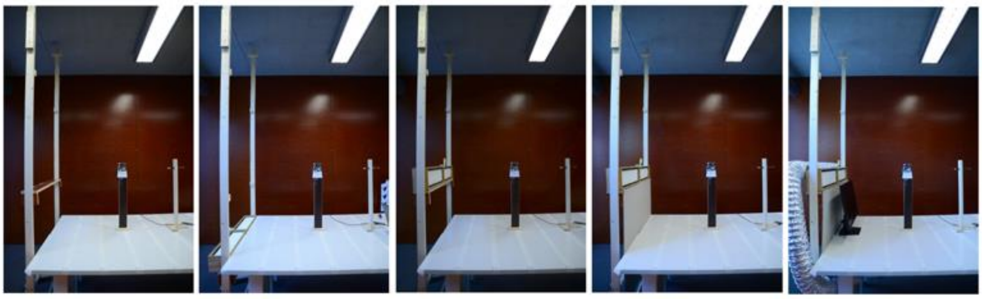
Recording PM levels
- Click 'start' before lighting fuse

Method for lighting smoke pen
- 1cm fuse
- Lighting for 10 seconds
- Blow out fire after 15 seconds

Wait
- Record PM levels for 10 minutes after fuse has gone out (no more visible smoke)

Record Air Velocity
- Measure wind velocity suing anemometer for 10 seconds (1 measurement per second)
- Take average
- Repeat at each coordinate
- Log data in spreadsheet

After test
- Open the door for fresh outdoor air
- Use large fan to blow air out of the room faster
- Blow until PM2.5 levels are below 25 µg/m³



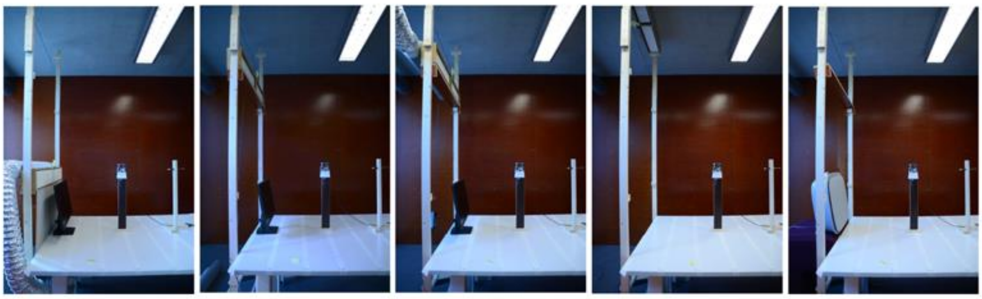
Scenario 0
Control

Scenario 1
'level with table'

Scenario 2
590mm above table

Scenario 2.1
590mm above table + dividing wall

Scenario 2.2
590mm above table + dividing wall + exhaust



Scenario 2.3
590mm above table + dividing wall + exhaust + cover

Scenario 3
1160mm above table

Scenario 3.5
1160mm above table + exhaust

Scenario 4
1700mm above table

Scenario 5
AEG AX7 'level with table'

Figure 30: Test setup for varying height placement of an air purifier

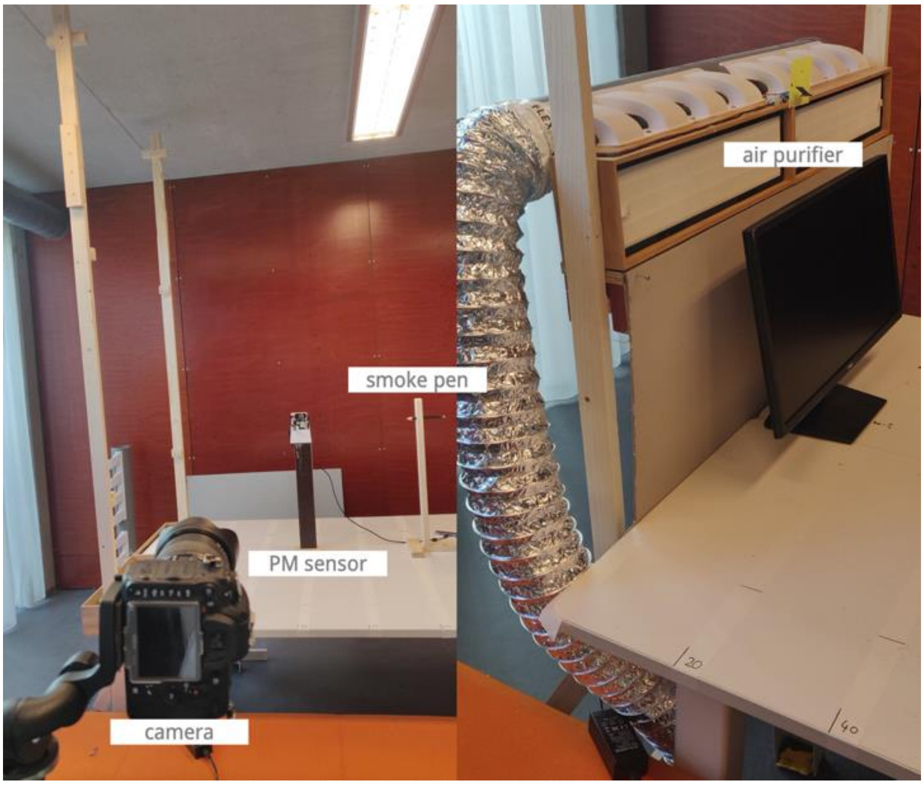
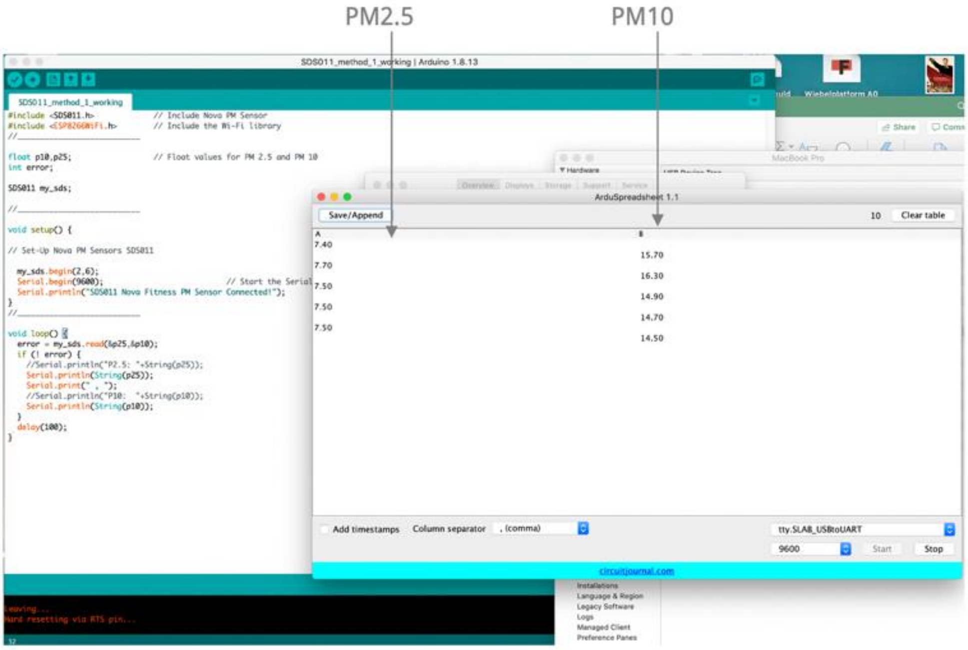


Figure 31: Test setup for smoke pen test placement of filter



```
#include <SDS011.h>             // Include Nova PM Sensor
#include <ESP8266WiFi.h>        // Include the Wi-Fi library
//_____________________________

float p10,p25;                  // Float values for PM 2.5 and PM 10
int error;

SDS011 my_sds;

//_____________________________

void setup() {

// Set-Up Nova PM Sensors SDS011

  my_sds.begin(2,6);
  Serial.begin(9600);                        // Start the Serial
  Serial.println("SDS011 Nova Fitness PM Sensor Connected!");
}
//_____________________________

void loop() {
  error = my_sds.read(&p25,&p10);
  if (! error) {
    //Serial.println("P2.5: "+String(p25));
    Serial.println(String(p25));
    Serial.print(" , ");
    //Serial.println("P10:  "+String(p10));
    Serial.println(String(p10));
  }
  delay(100);
}
```

A	B
7.40	15.70
7.70	16.30
7.50	14.90
7.50	14.70
7.50	14.50

☐ Add timestamps

Column separator , (comma)

tty.SLAB_USBtoUART

9600

Figure 33: Arduino ESP2688 setup to measure PM2.5 and PM10 with SDS011 sensor

Appendix Q: Results Placement Air Purifier Relative to Breath

The results are compiled and presented individually in three sections: visualizing air flow, PM2.5 levels, and air velocity.

Visualizing Air Flow

It can be observed that the smoke rapidly rises, as it is much hotter (ca. 300 °C) than the surrounding air. The control scenario 0 shows the smoke visibly moving vertically. Scenarios 2, 2.1, and 5 show the smoke moving slightly more horizontal towards the air purifier compared to the other scenarios.

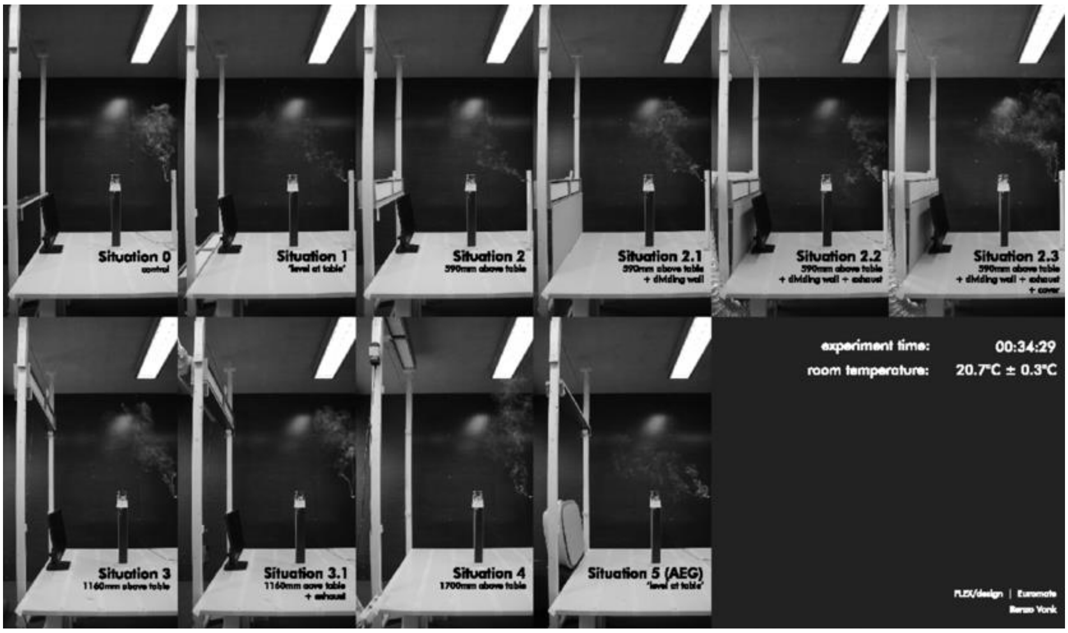


Figure 34: Snapshot of video compilation demonstrating air flow direction for each scenario described in chapter 5.4.1

PM2.5 levels

The PM2.5 average values recorded are shown in figure 35. It can be observed that all scenario's faster at decreasing PM levels as compared to control test. The AEG air purifier (situation 5) has the fastest rate of decline in PM2.5 levels in the air. Situation 2.1 (dividing wall) has the second fastest rate of decline compared to other scenarios with situation 1 following closely. Situation 4 takes longest (excluding control). Furthermore, situations where exhaust is used (2.2, 2.3, 3.1) less effective than their counterparts (2.1, 3).

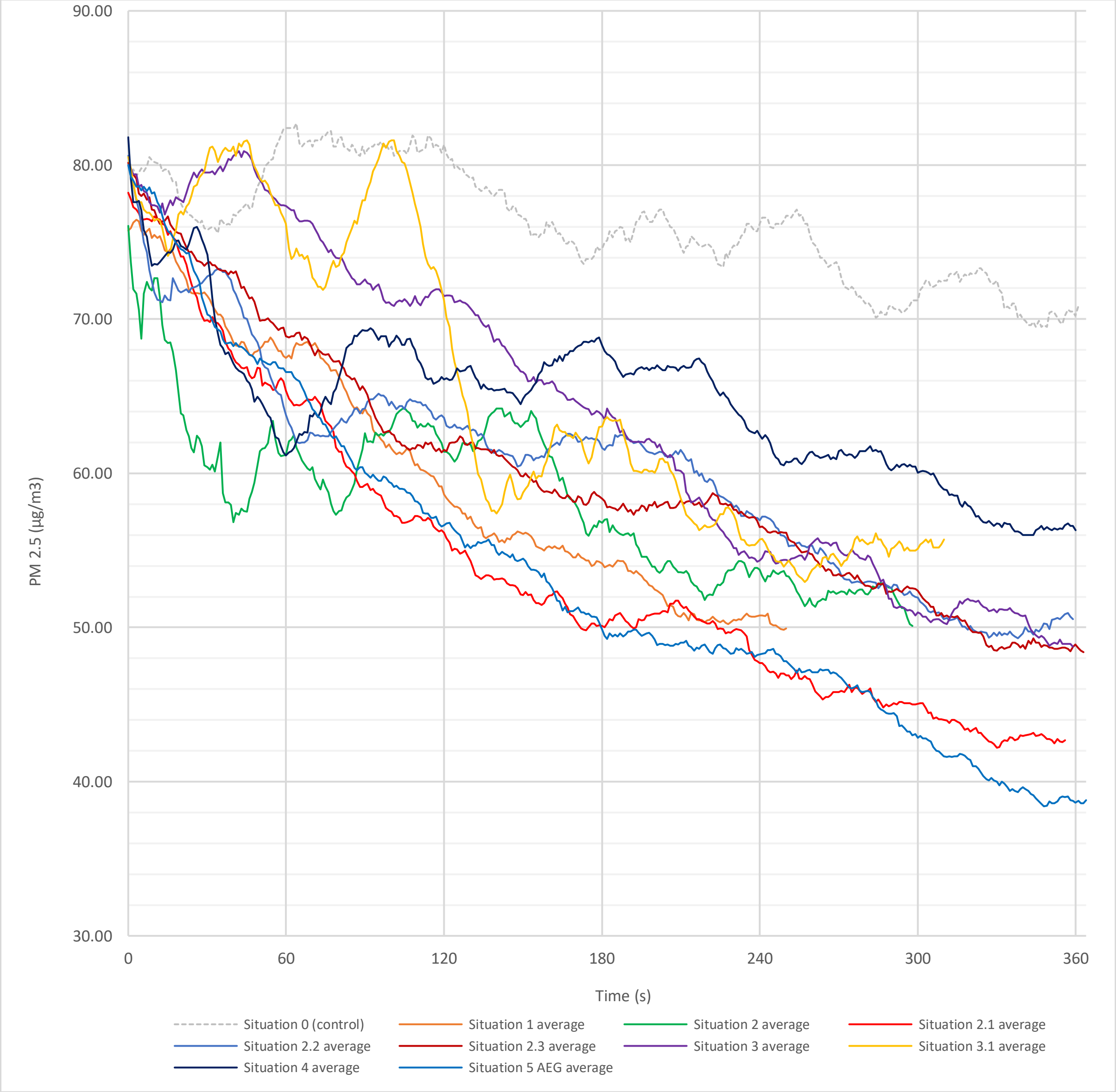


Figure 34: PM2.5 levels over time for various scenario's as described in chapter 5.4.1. Source: Author

Air Velocity

Figure x shows the air velocity measurements at various points in 3D space. The control scenario shows zero air velocity, which indicates that there is no draft in the room. Notably, the scenarios with highest measured air velocities were scenarios 2, 2.1, and 5. Scenario's 2.2 and 2.3 with exhaust show considerably lower air velocities than the counterparts without exhaust. Scenarios 3, 3.1, and 4 show low air velocity in proximity of the air purifier, and further no air movement.

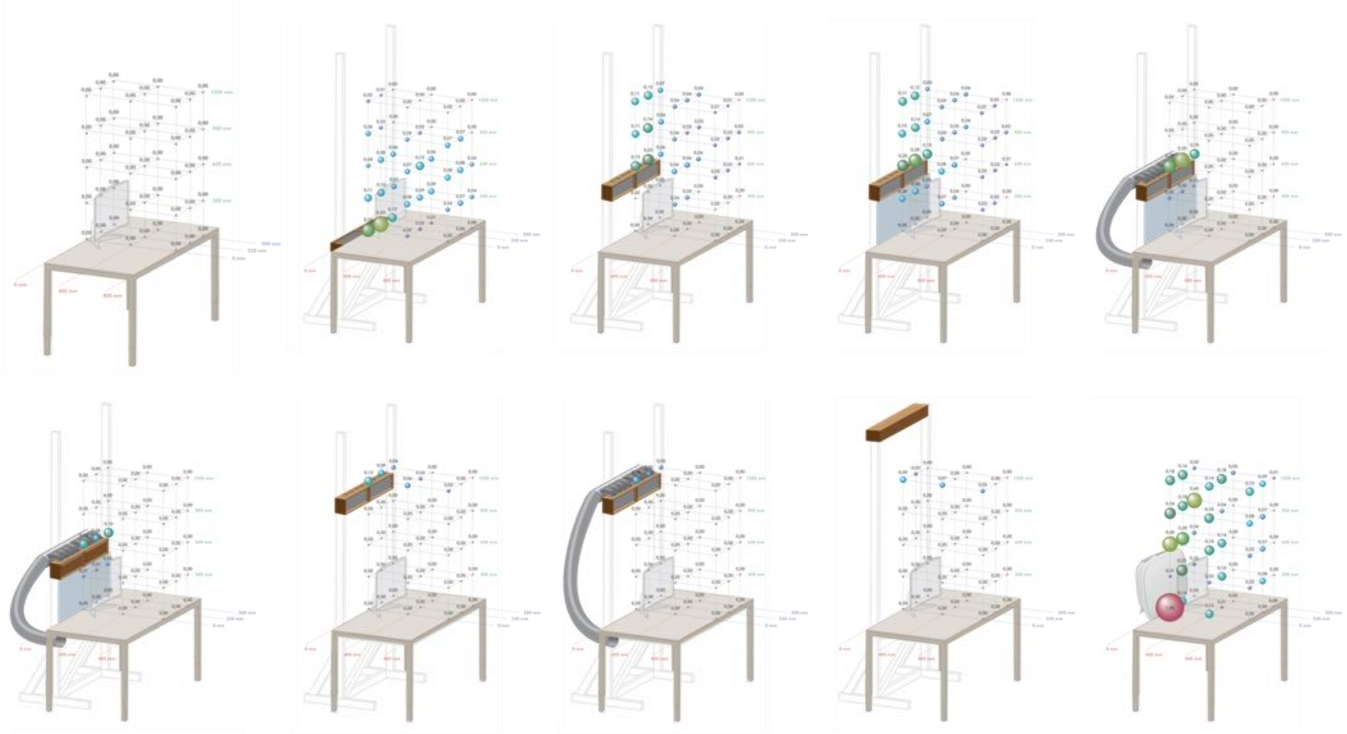


Figure 35: Air velocity measurements per scenario as described in chapter 5.4.1. Source: Author

Discussion

From the video recordings of the scenarios with the fastest rate of decline of PM2.5 (scenario 5, 2.1,1), the smoke travels most horizontal. This may explain why the value dropped faster for these scenarios in the PM2.5 measurements, as the smoke may be filtered quicker. On the other hand, the air purifier being closer to the sensor may also explain the faster rate of decline of PM2.5. The air is purified where the sensor is, therefore, it is expected to have cleaner air in the lower levels. It would be interesting to do the same measurements, but with the PM sensor placed much higher. Possibly opposite results would be observed.

Appendix R: Raw Data Air Velocity Measurements

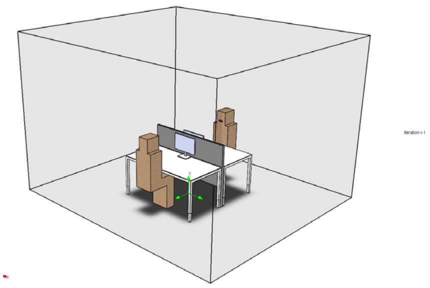
Coordinates	**Situation 0** Velocity (m/s)	**Situation 1** Velocity (m/s)	**Situation 2** Velocity (m/s)	**Situation 2.1** Velocity (m/s)	**Situation 2.2** Velocity (m/s)	**Situation 2.3** Velocity (m/s)	**Situation 3** Velocity (m/s)	**Situation 3.1** Velocity (m/s)	**Situation 4** Velocity (m/s)	**Situation 5** Velocity (m/s)
0, 0, 0	0,00	0,35	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,90
0, 0, 25.7	0,00	0,43	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,14
0, 0, 51.5	0,00	0,12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
40, 0, 0	0,00	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,13
40, 0, 25.7	0,00	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01
40, 0, 51.5	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
80, 0, 0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
80, 0, 25.7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
80, 0, 51.5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0, 30, 0	0,00	0,11	0,00	0,08	0,02	0,01	0,00	0,00	0,00	0,01
0, 30, 25.7	0,00	0,10	0,00	0,08	0,02	0,01	0,00	0,00	0,00	0,22
0, 30, 51.5	0,00	0,07	0,00	0,05	0,01	0,02	0,00	0,00	0,00	0,02
40, 30, 0	0,00	0,08	0,05	0,07	0,00	0,00	0,00	0,00	0,00	0,03
40, 30, 25.7	0,00	0,09	0,05	0,04	0,00	0,00	0,00	0,00	0,00	0,12
40, 30, 51.5	0,00	0,09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
80, 30, 0	0,00	0,04	0,00	0,03	0,00	0,00	0,00	0,00	0,00	0,02
80, 30, 25.7	0,00	0,07	0,00	0,02	0,00	0,00	0,00	0,00	0,00	0,08
80, 30, 51.5	0,00	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0, 60, 0	0,00	0,04	0,15	0,20	0,28	0,14	0,00	0,00	0,00	0,40
0, 60, 25.7	0,00	0,08	0,25	0,28	0,35	0,08	0,00	0,00	0,00	0,28
0, 60, 51.5	0,00	0,06	0,06	0,15	0,15	0,15	0,00	0,00	0,00	0,04
40, 60, 0	0,00	0,07	0,06	0,08	0,00	0,00	0,00	0,00	0,00	0,18
40, 60, 25.7	0,00	0,12	0,06	0,07	0,00	0,00	0,00	0,00	0,00	0,14
40, 60, 51.5	0,00	0,06	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00
80, 60, 0	0,00	0,08	0,03	0,03	0,00	0,00	0,00	0,00	0,00	0,05
80, 60, 25.7	0,00	0,08	0,02	0,03	0,00	0,00	0,00	0,00	0,00	0,07
80, 60, 51.5	0,00	0,04	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00
0, 90, 0	0,00	0,06	0,11	0,10	0,00	0,00	0,00	0,00	0,00	0,24
0, 90, 25.7	0,00	0,03	0,14	0,14	0,00	0,00	0,00	0,00	0,00	0,18
0, 90, 51.5	0,00	0,00	0,06	0,07	0,00	0,00	0,00	0,00	0,00	0,40
40, 90, 0	0,00	0,05	0,04	0,05	0,00	0,00	0,00	0,00	0,00	0,18
40, 90, 25.7	0,00	0,02	0,03	0,05	0,00	0,00	0,00	0,00	0,00	0,04
40, 90, 51.5	0,00	0,00	0,03	0,04	0,00	0,00	0,00	0,00	0,00	0,00
80, 90, 0	0,00	0,07	0,02	0,02	0,00	0,00	0,00	0,00	0,00	0,08
80, 90, 25.7	0,00	0,07	0,02	0,02	0,00	0,00	0,00	0,00	0,00	0,07
80, 90, 51.5	0,00	0,00	0,02	0,02	0,00	0,00	0,00	0,00	0,00	0,00
0, 120, 0	0,00	0,02	0,11	0,11	0,00	0,00	0,12	0,08	0,09	0,18
0, 120, 25.7	0,00	0,01	0,12	0,12	0,00	0,00	0,09	0,05	0,03	0,16
0, 120, 51.5	0,00	0,00	0,07	0,05	0,00	0,00	0,04	0,05	0,00	0,02
40, 120, 0	0,00	0,00	0,04	0,05	0,00	0,00	0,06	0,00	0,07	0,14
40, 120, 25.7	0,00	0,00	0,04	0,04	0,00	0,00	0,03	0,00	0,00	0,18
40, 120, 51.5	0,00	0,00	0,04	0,04	0,00	0,00	0,00	0,00	0,00	0,05
80, 120, 0	0,00	0,00	0,01	0,02	0,00	0,00	0,02	0,00	0,05	0,13
80, 120, 25.7	0,00	0,00	0,01	0,02	0,00	0,00	0,00	0,00	0,00	0,09
80, 120, 51.5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01

Table 5: Air Velocity (m/s) measurements per scenario

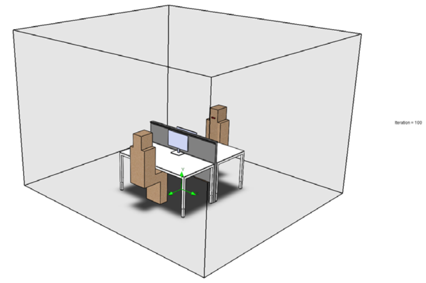
Appendix S: CFD Analysis Report

Dividing Wall

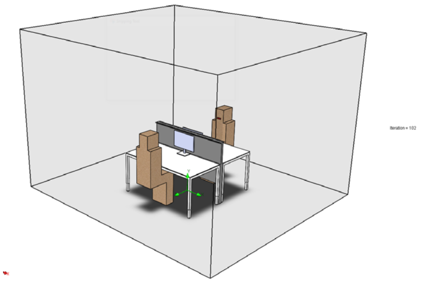
Perspective Diagram of Test Setup



Dividing Wall
Height 400 | 0 Degrees Exhaust



Dividing Wall
Height 400 | 30 Degrees Exhaust



Dividing Wall
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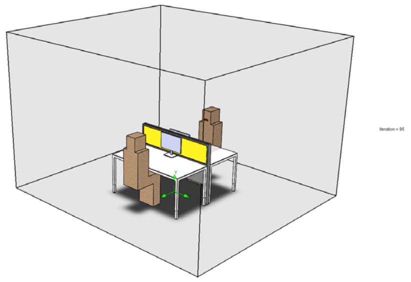
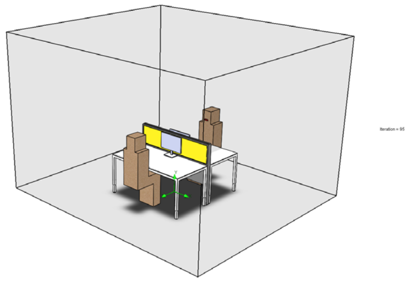


Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover



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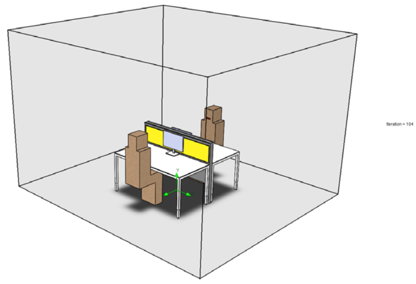
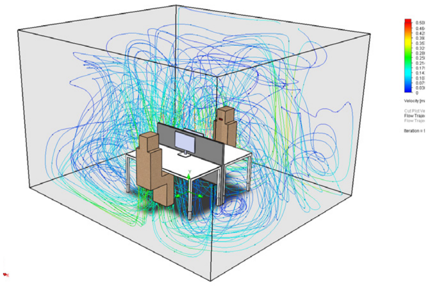
+ cover



Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



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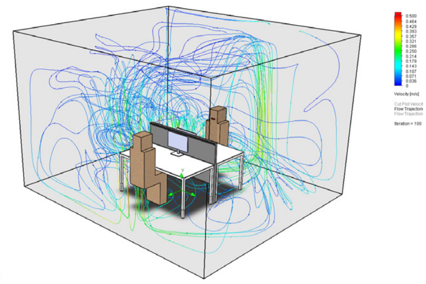

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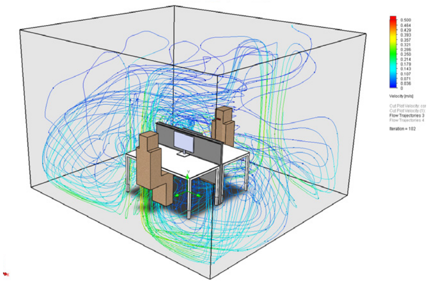

Dividing Wall
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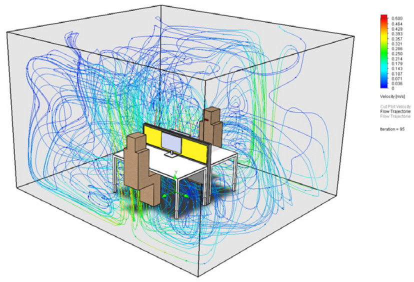
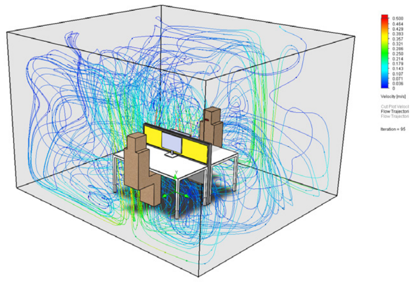
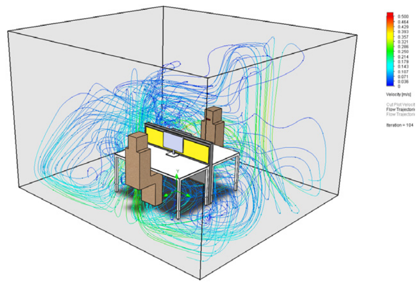


Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover



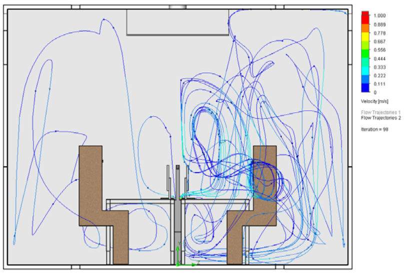
Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover



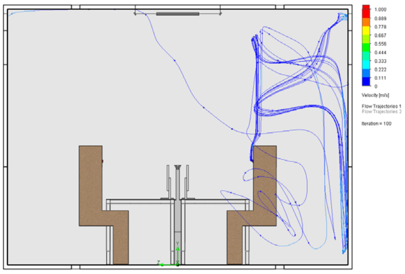
Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

Dividing Wall

Air Velocity & Trajectory Plot - Breathing Person Right Side (0.0002 m3/s)



Dividing Wall
Height 400 | 0 Degrees Exhaust



Dividing Wall
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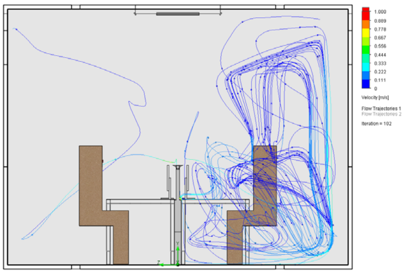

Dividing Wall
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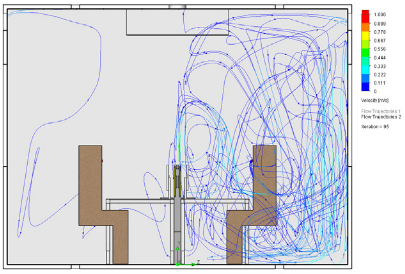
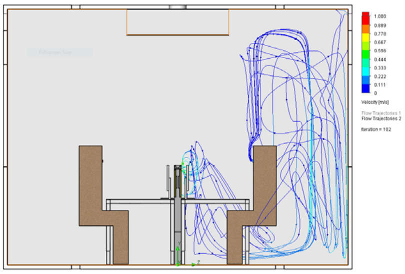
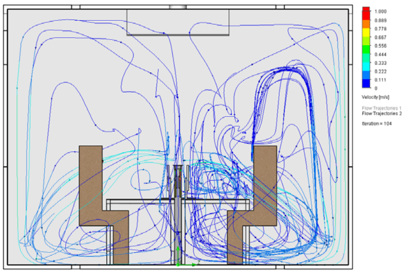


Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover

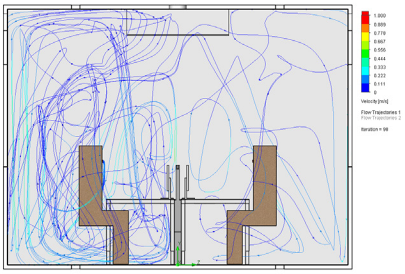


Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover

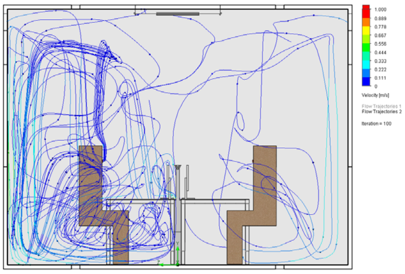


Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

Air Velocity & Trajectory Plot - Breathing Person Left Side (0.0002 m3/s)



Dividing Wall
Height 400 | 0 Degrees Exhaust



Dividing Wall
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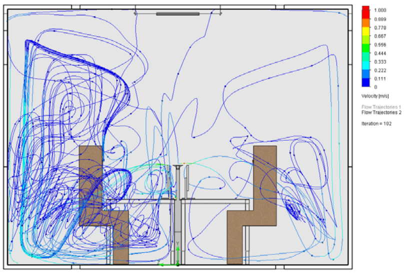
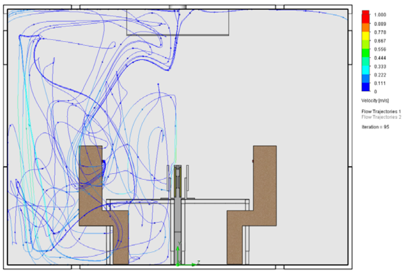
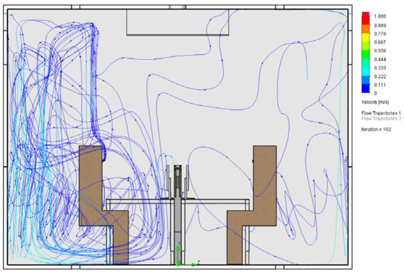


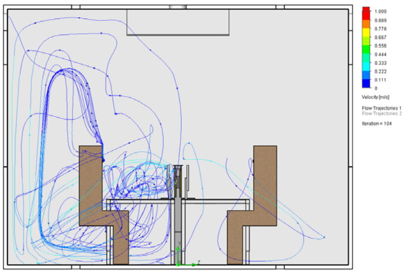
Dividing Wall
Height 400 | 60 Degrees Exhaust



Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover



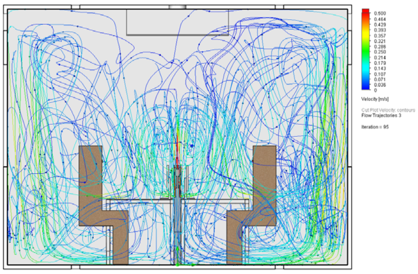
Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover



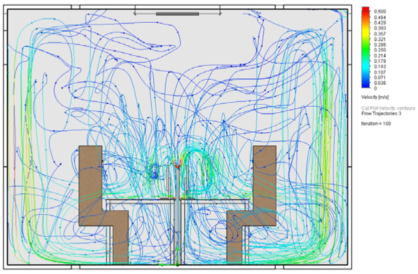
Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

Dividing Wall

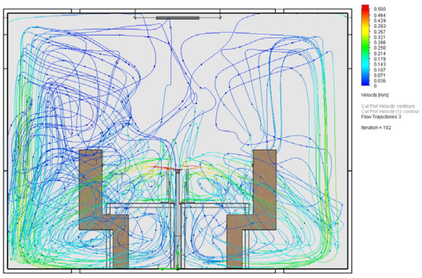
Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



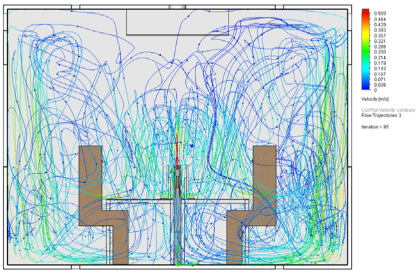
Dividing Wall
Height 400 | 0 Degrees Exhaust



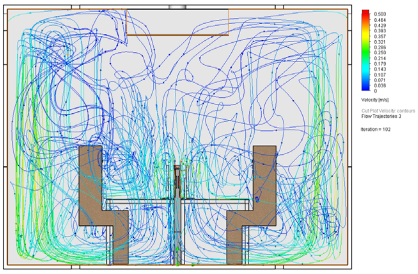
Dividing Wall
Height 400 | 30 Degrees Exhaust



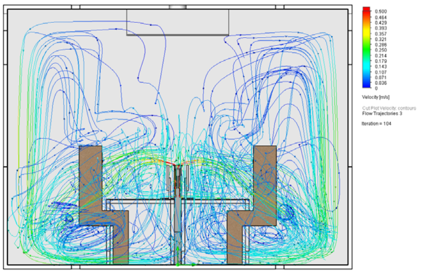
Dividing Wall
Height 400 | 60 Degrees Exhaust



Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover

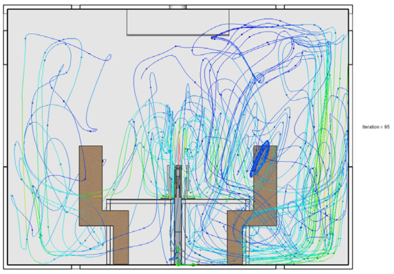


Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover

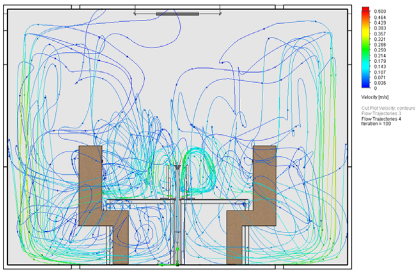


Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

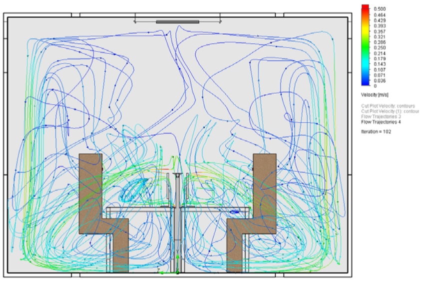
Air Velocity & Trajectory Plot - Intake + Exhaust



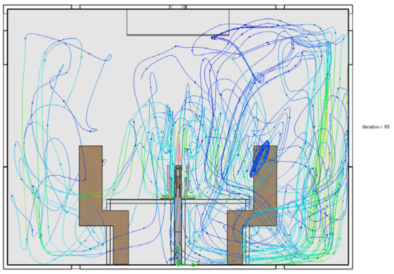
Dividing Wall
Height 400 | 0 Degrees Exhaust



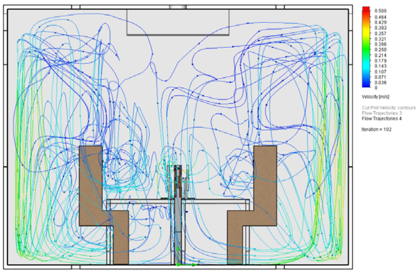
Dividing Wall
Height 400 | 30 Degrees Exhaust



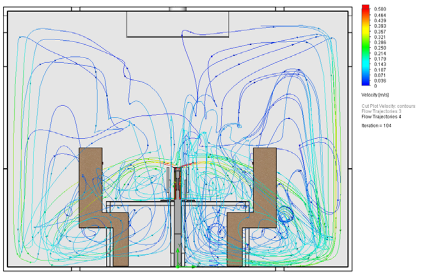
Dividing Wall
Height 400 | 60 Degrees Exhaust



Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover



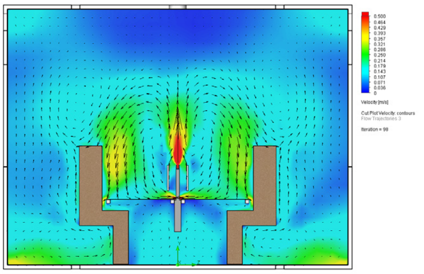
Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover



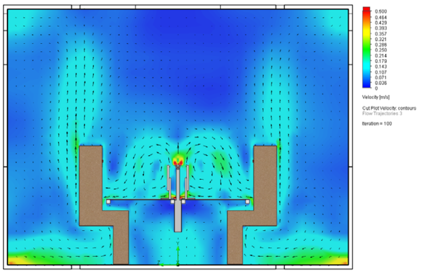
Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

Dividing Wall

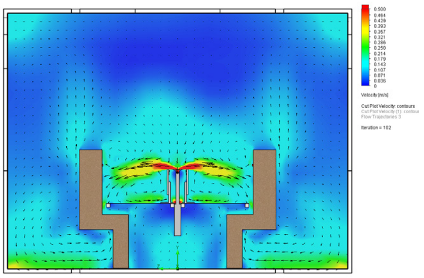
Air Velocity Cut Plot



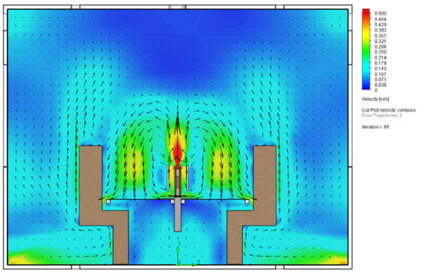
Dividing Wall
Height 400 | 0 Degrees Exhaust



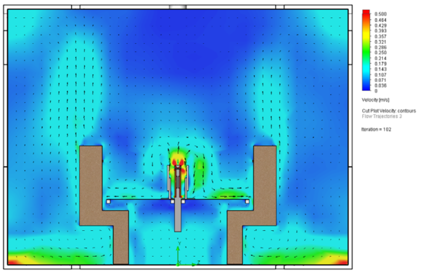
Dividing Wall
Height 400 | 30 Degrees Exhaust



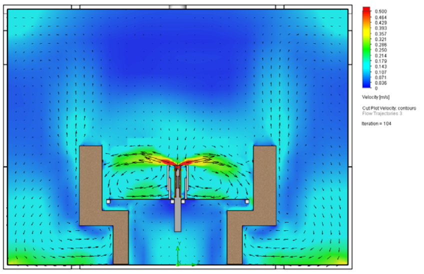
Dividing Wall
Height 400 | 60 Degrees Exhaust



Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover

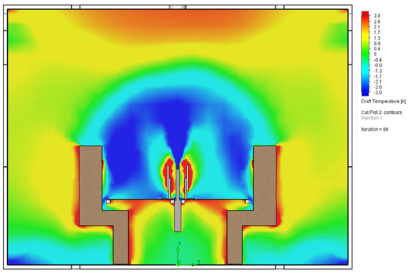


Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover

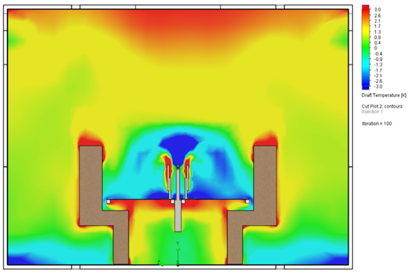


Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

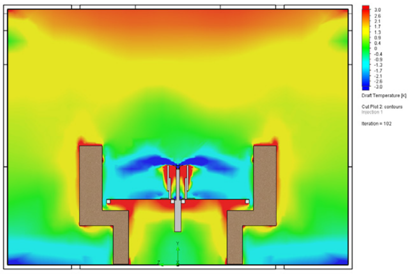
Draft Temperature Cut Plot



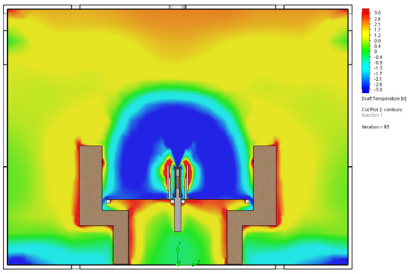
Dividing Wall
Height 400 | 0 Degrees Exhaust



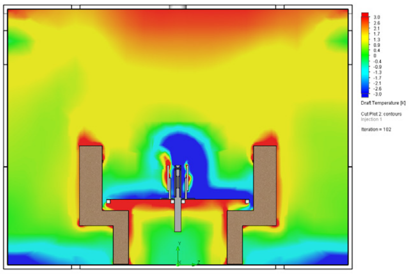
Dividing Wall
Height 400 | 30 Degrees Exhaust



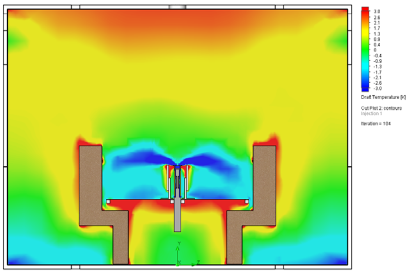
Dividing Wall
Height 400 | 60 Degrees Exhaust



Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover



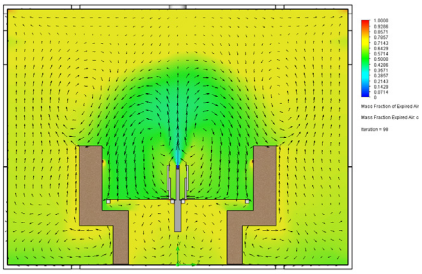
Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover



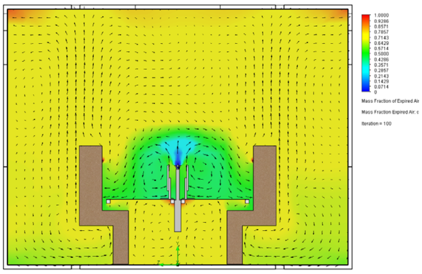
Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

Dividing Wall

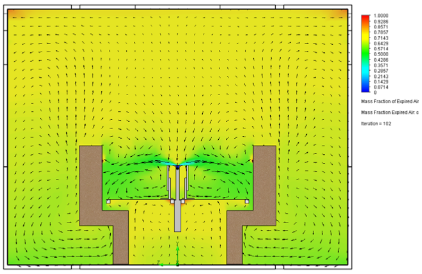
Mass Fraction Expired Air



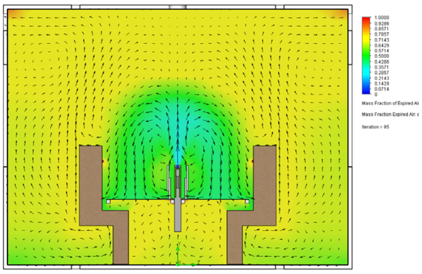
Dividing Wall
Height 400 | 0 Degrees Exhaust



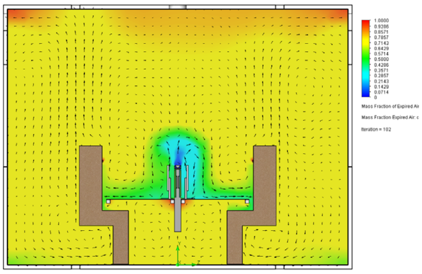
Dividing Wall
Height 400 | 30 Degrees Exhaust



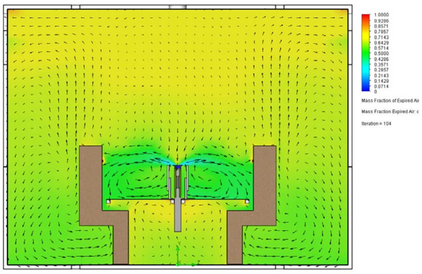
Dividing Wall
Height 400 | 60 Degrees Exhaust



Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover

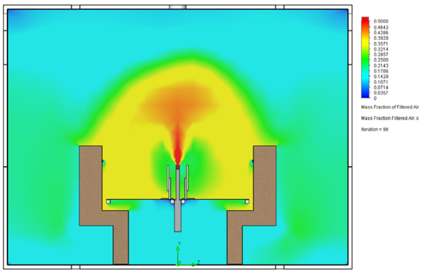


Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover

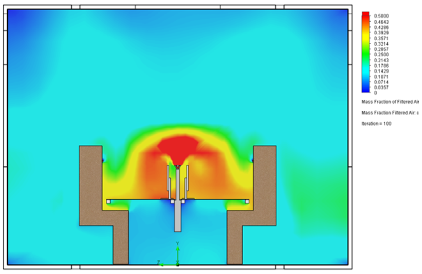


Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

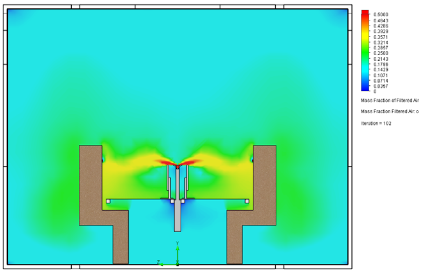
Mass Fraction Filtered Air



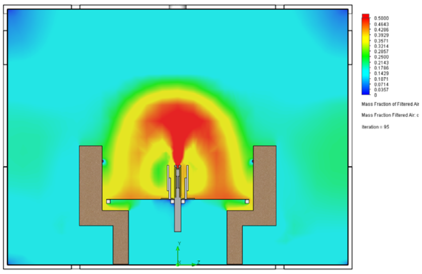
Dividing Wall
Height 400 | 0 Degrees Exhaust



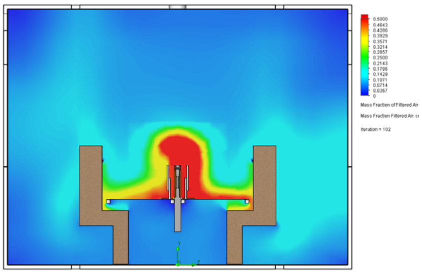
Dividing Wall
Height 400 | 30 Degrees Exhaust



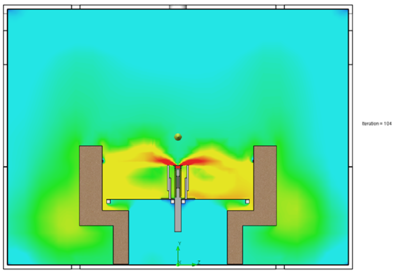
Dividing Wall
Height 400 | 60 Degrees Exhaust



Dividing Wall
Height 400 | 0 Degrees Exhaust
+ cover



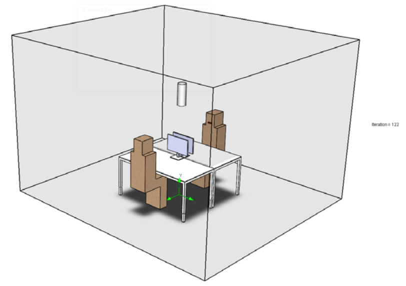
Dividing Wall
Height 400 | 30 Degrees Exhaust
+ cover



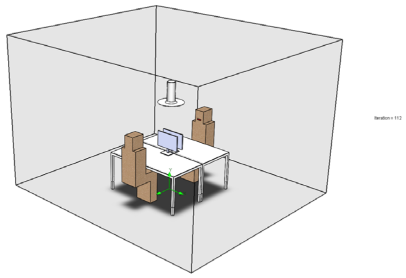
Dividing Wall
Height 400 | 60 Degree Exhaust
+ cover

Hanging Lamp

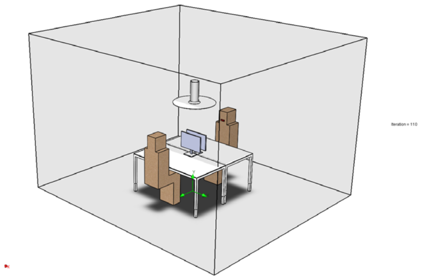
Perspective Diagram of Test Setup



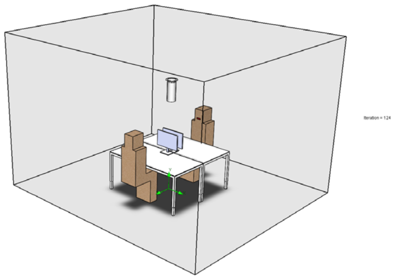
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



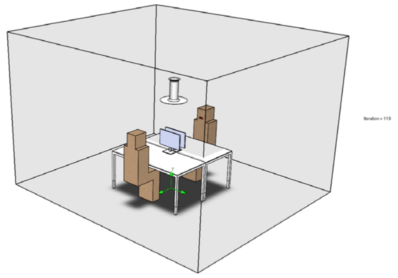
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



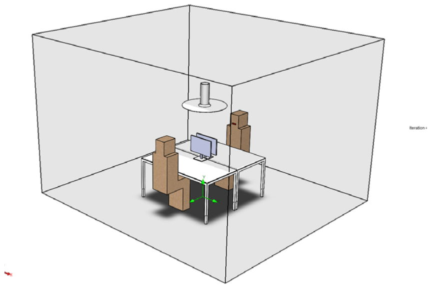
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



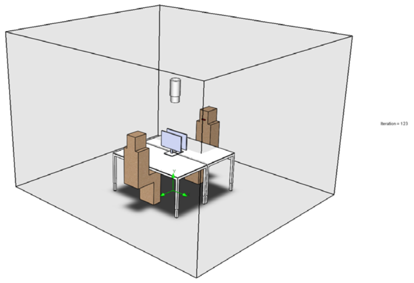
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



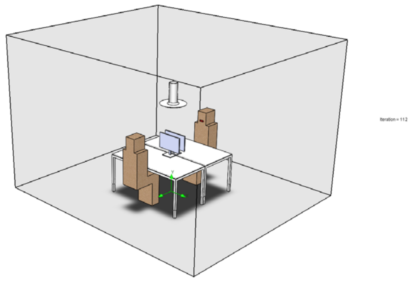
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



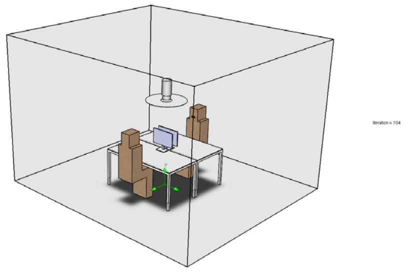
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



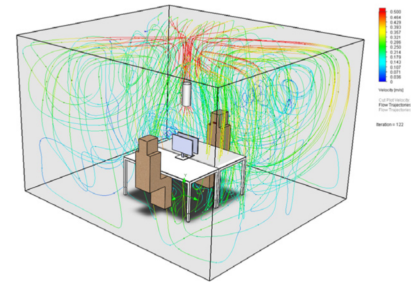
Hanging Lamp
Diameter 500 | 180 Degrees Exhaust



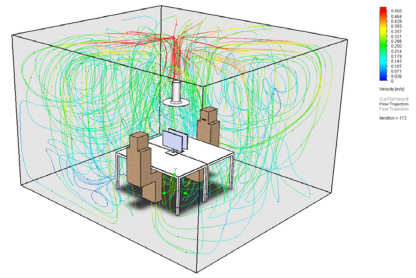
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

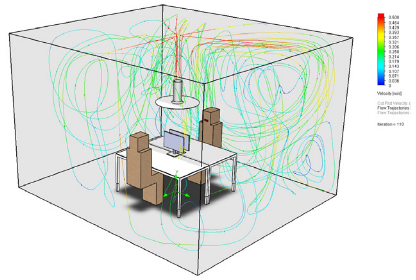
Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



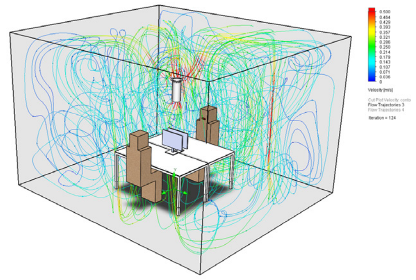
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



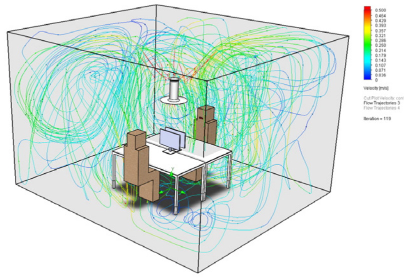
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



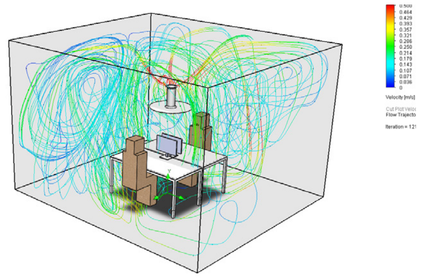
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



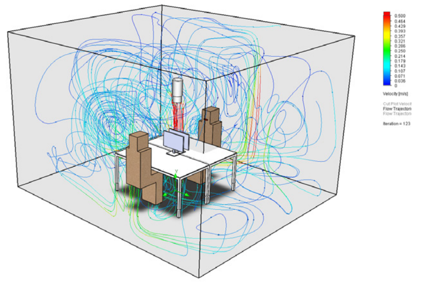
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



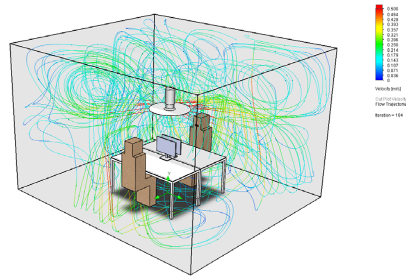
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust

MISSING

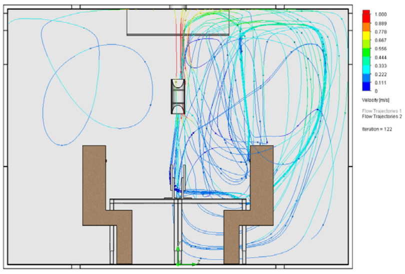
Hanging Lamp
Diameter 750 | 180 Degrees Exhaust



Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

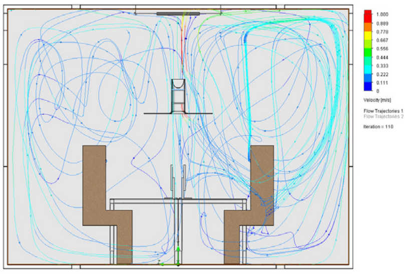
Hanging Lamp

Air Velocity & Trajectory Plot - Breathing Person Right Side (0.0002 m3/s)

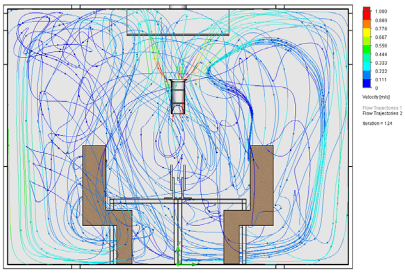


Hanging Lamp
Diameter 200 | 0 Degrees Exhaust

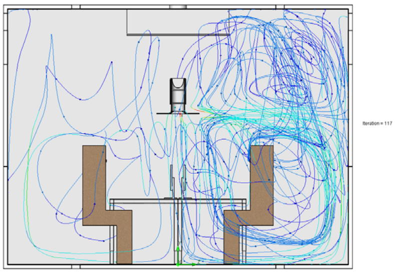
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



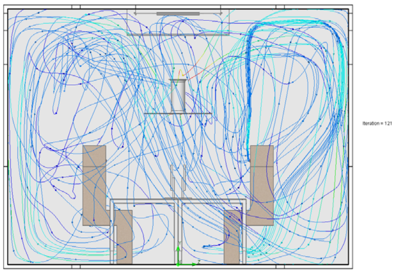
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



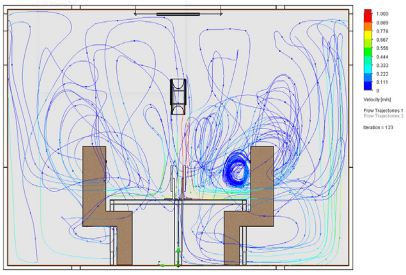
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



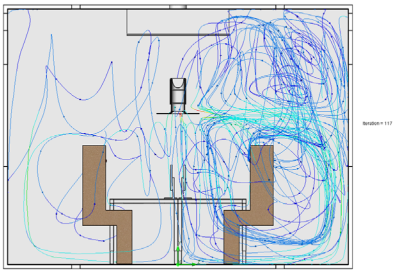
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



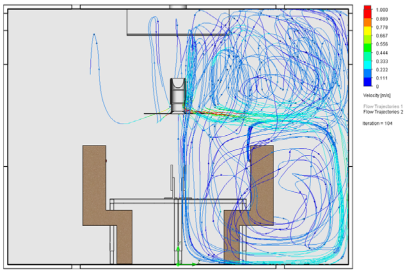
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust

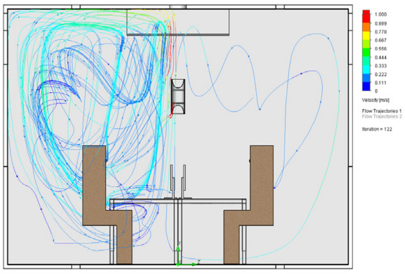


Hanging Lamp
Diameter 500 | 180 Degrees Exhaust

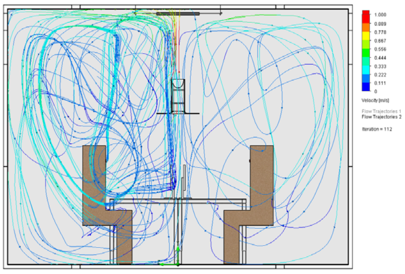


Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Air Velocity & Trajectory Plot - Breathing Person Left Side (0.0002 m3/s)

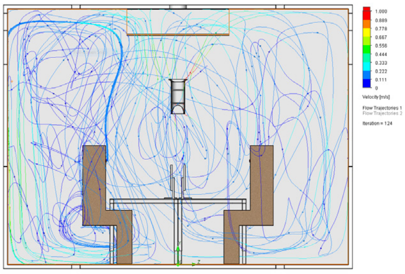


Hanging Lamp
Diameter 200 | 0 Degrees Exhaust

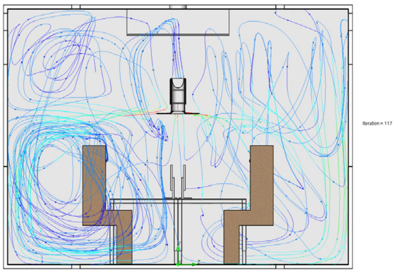


Hanging Lamp
Diameter 500 | 0 Degrees Exhaust

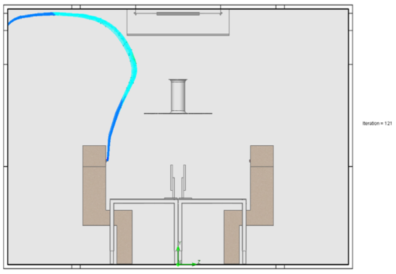
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



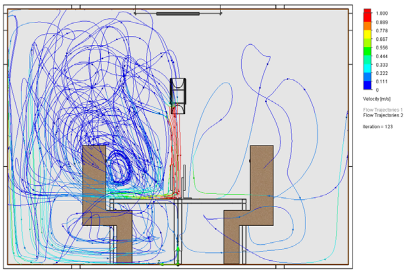
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



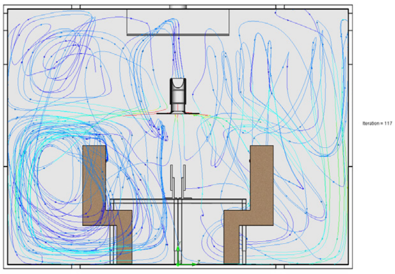
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



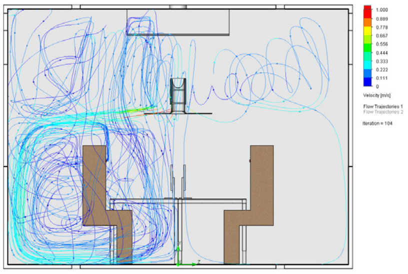
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



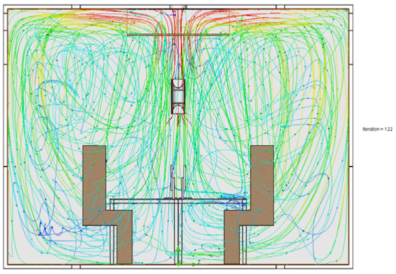
Hanging Lamp
Diameter 750 | 180 Degrees Exhaust



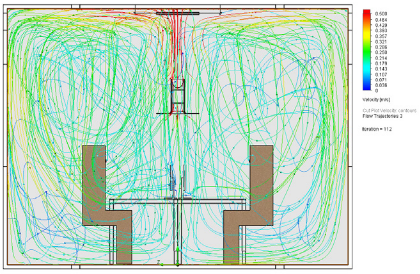
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

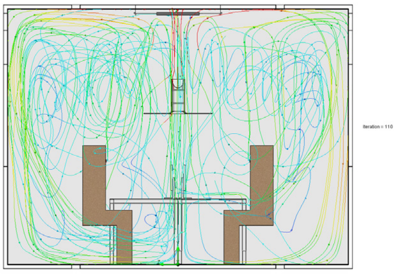
Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



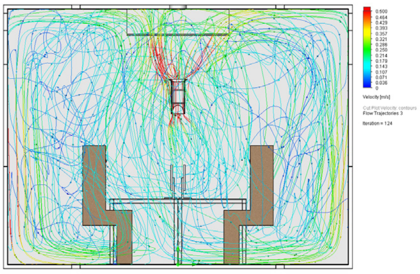
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



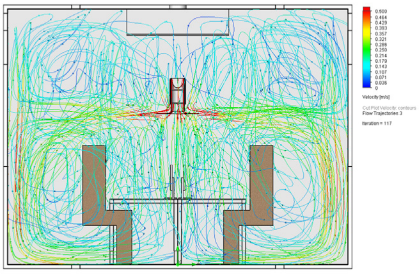
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



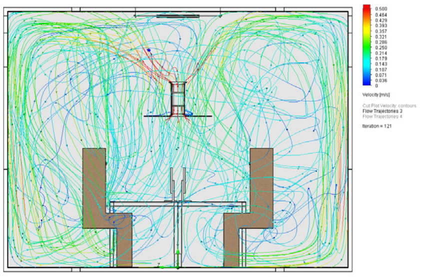
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



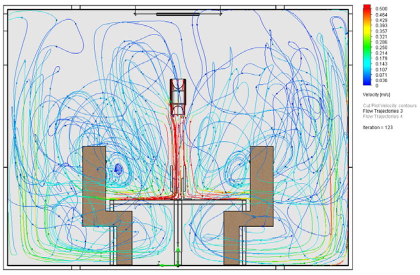
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



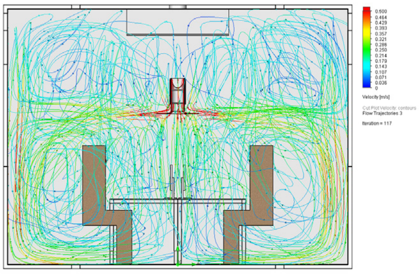
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



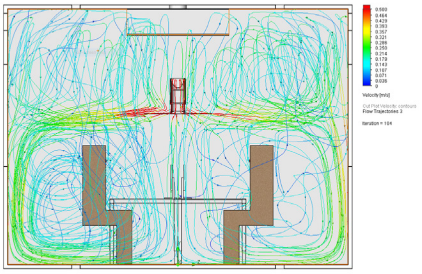
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



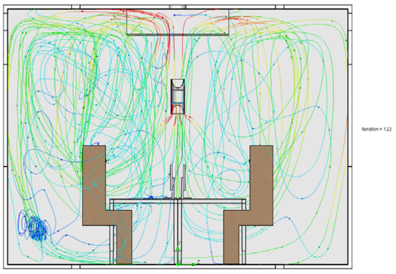
Hanging Lamp
Diameter 500 | 180 Degrees Exhaust



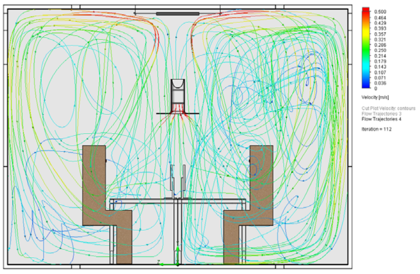
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

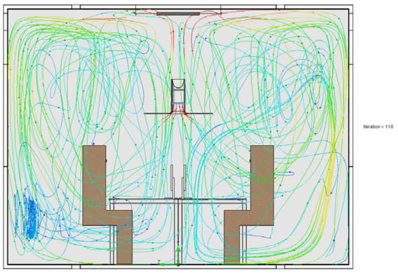
Air Velocity & Trajectory Plot - Intake + Exhaust



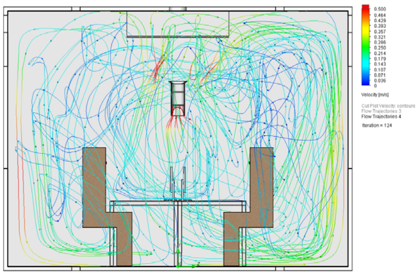
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



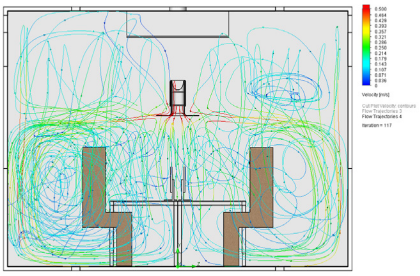
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



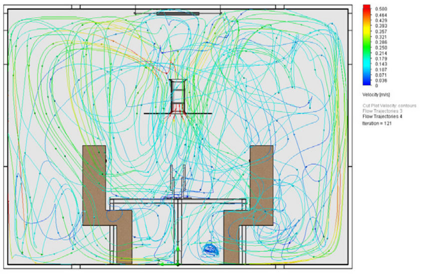
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



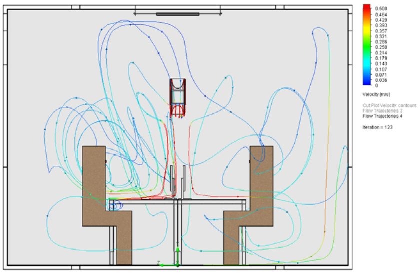
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



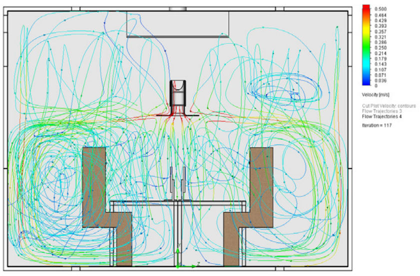
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



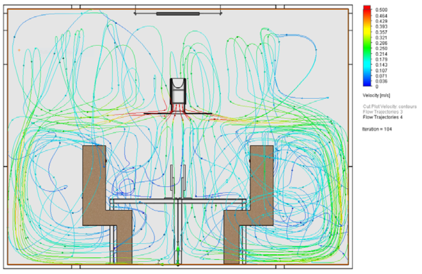
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



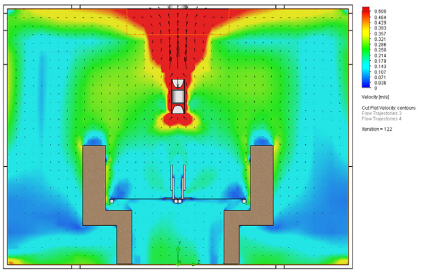
Hanging Lamp
Diameter 750 | 180 Degrees Exhaust



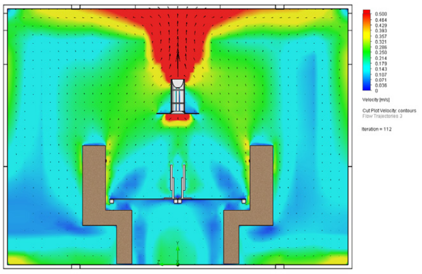
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

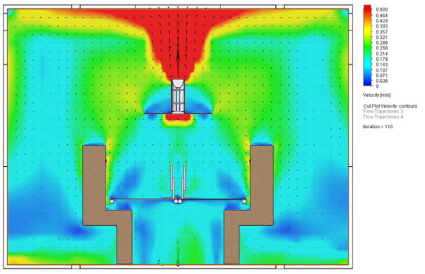
Air Velocity Cut Plot



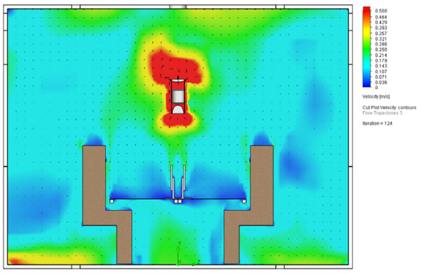
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



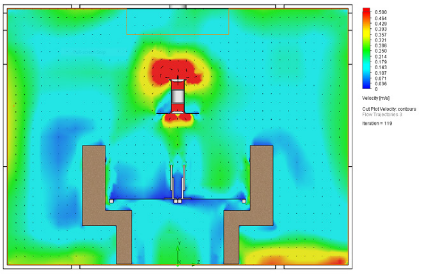
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



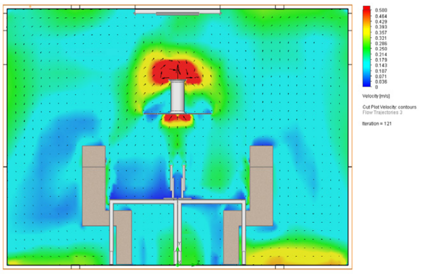
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



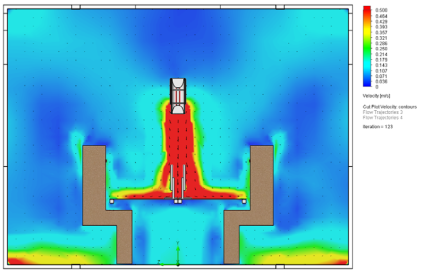
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



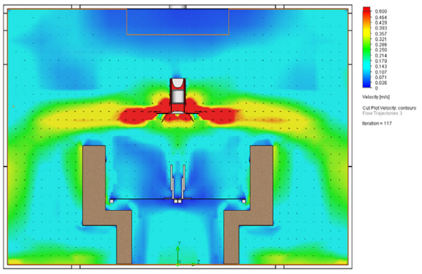
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



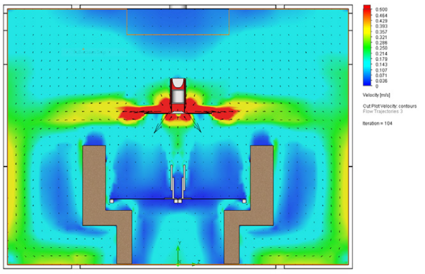
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



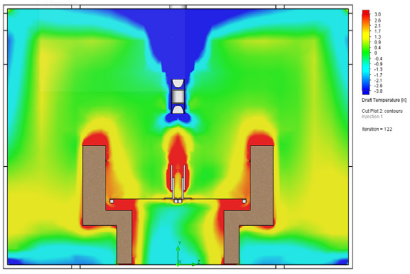
Hanging Lamp
Diameter 500 | 180 Degrees Exhaust



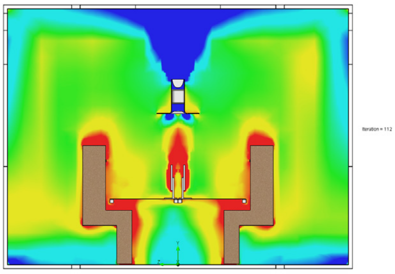
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

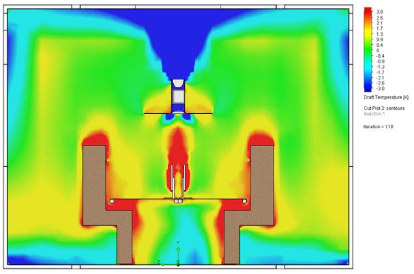
Draft Temperature Cut Plot



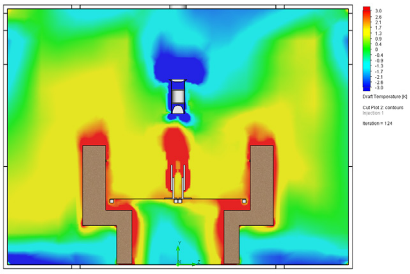
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



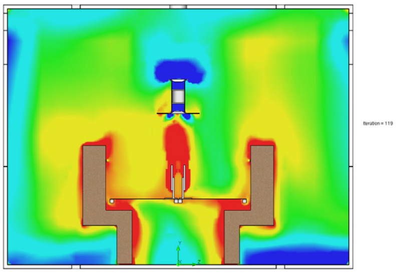
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



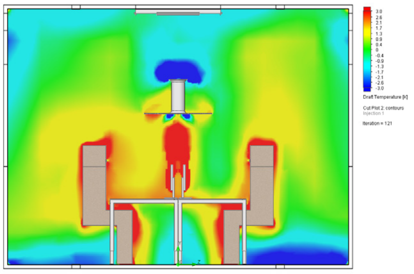
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



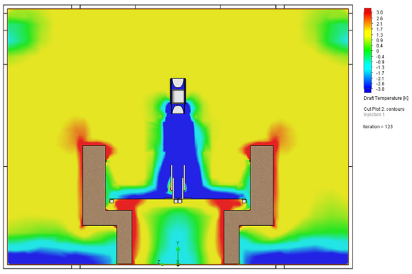
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



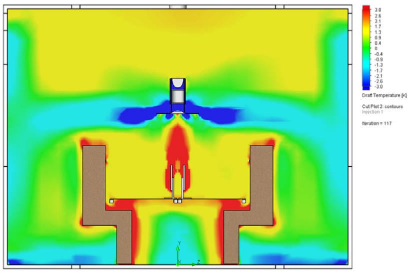
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



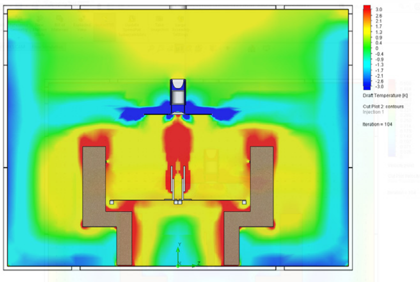
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



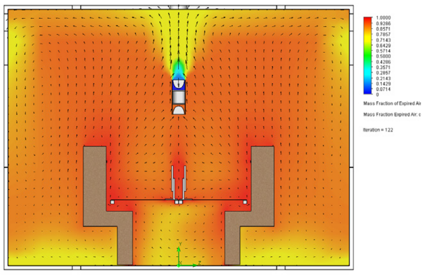
Hanging Lamp
Diameter 750 | 180 Degrees Exhaust



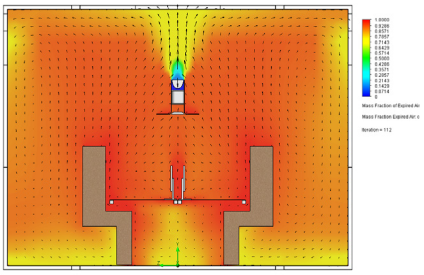
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

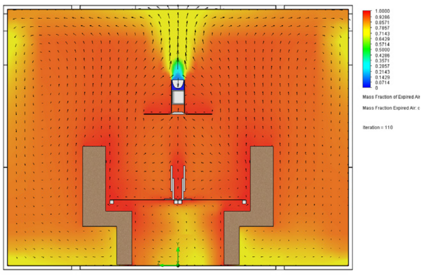
Mass Fraction Expired Air



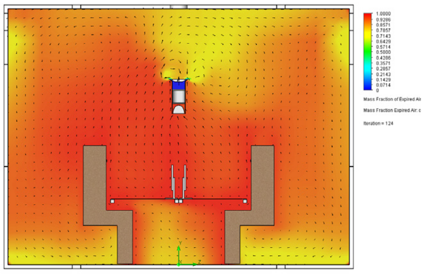
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



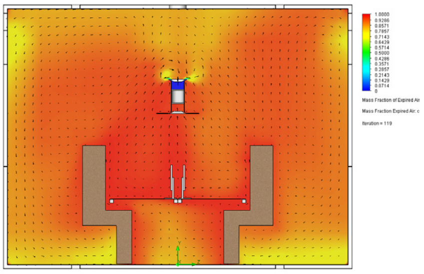
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



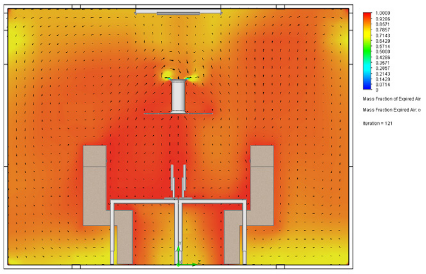
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



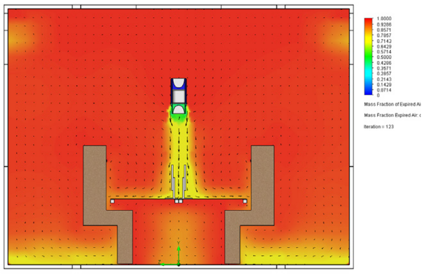
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



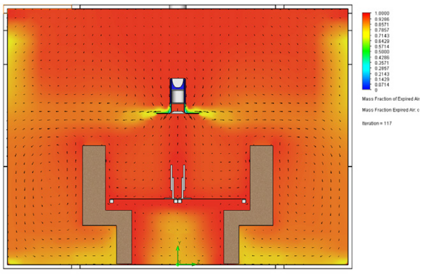
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



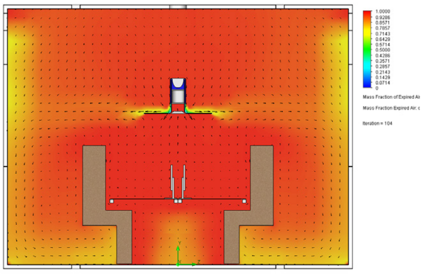
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



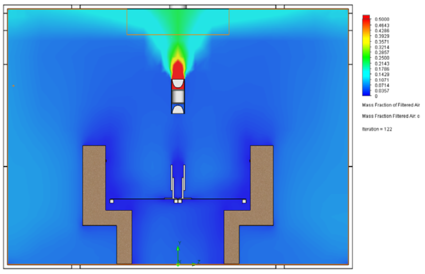
Hanging Lamp
Diameter 500 | 180 Degrees Exhaust



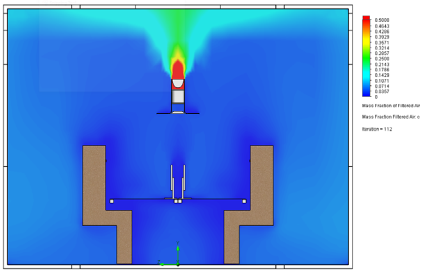
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

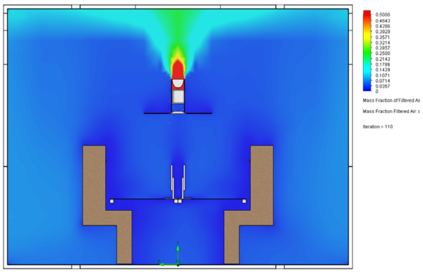
Mass Fraction Filtered Air



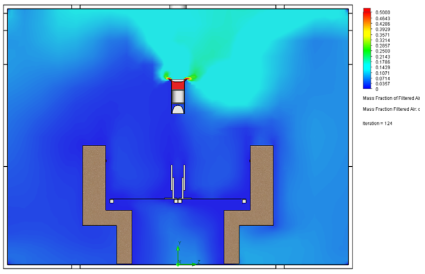
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



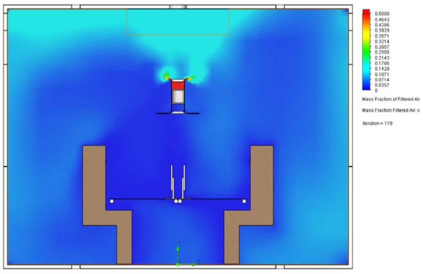
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



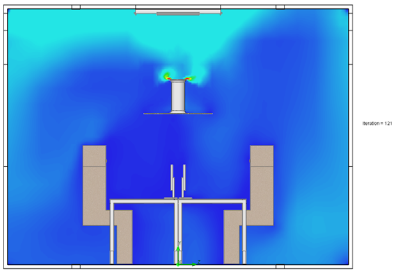
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



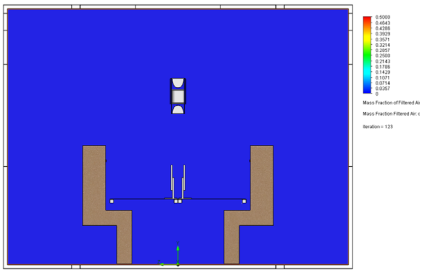
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



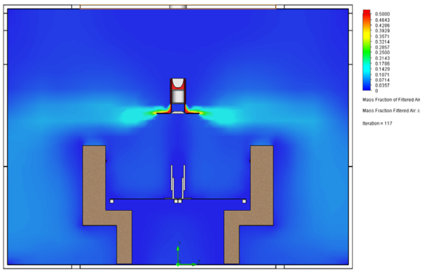
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



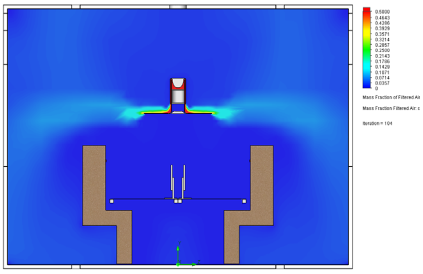
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



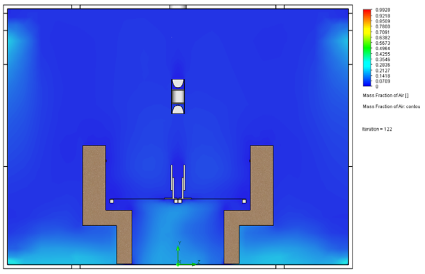
Hanging Lamp
Diameter 750 | 180 Degrees Exhaust



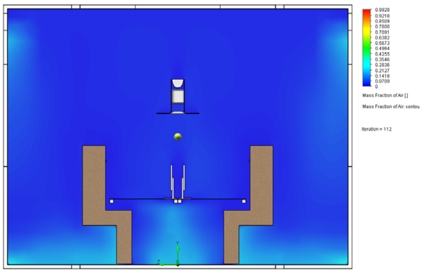
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp

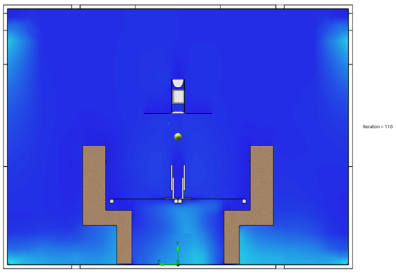
Mass Fraction Air



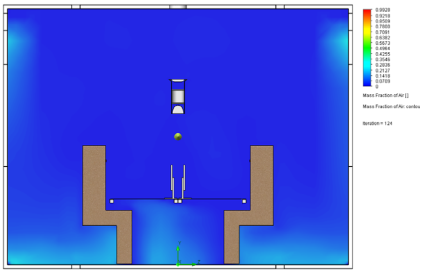
Hanging Lamp
Diameter 200 | 0 Degrees Exhaust



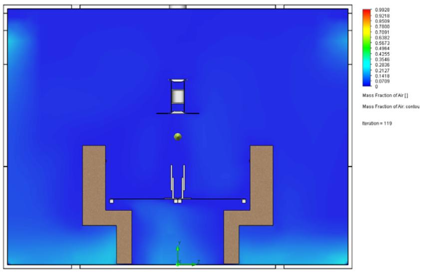
Hanging Lamp
Diameter 500 | 0 Degrees Exhaust



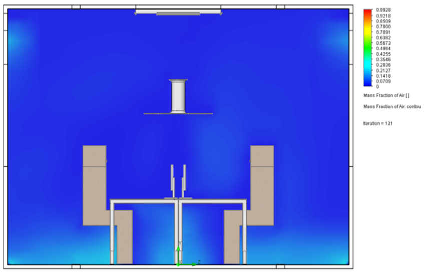
Hanging Lamp
Diameter 800 | 0 Degrees Exhaust



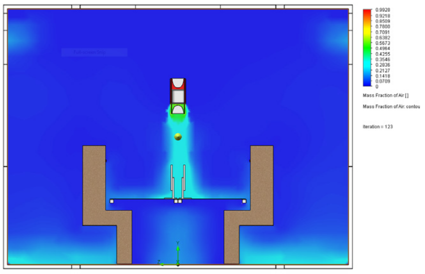
Hanging Lamp
Diameter 200 | 90 Degrees Exhaust



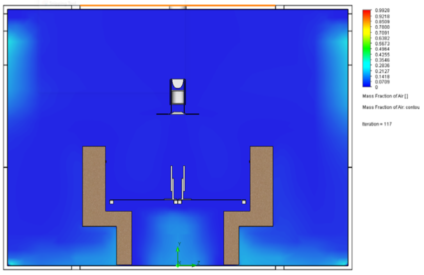
Hanging Lamp
Diameter 500 | 90 Degrees Exhaust



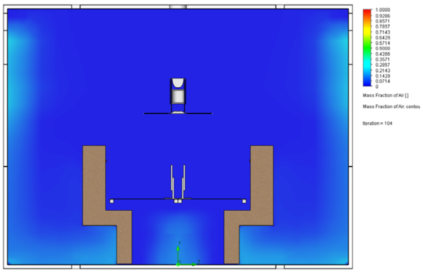
Hanging Lamp
Diameter 800 | 90 Degrees Exhaust



Hanging Lamp
Diameter 200 | 180 Degrees Exhaust



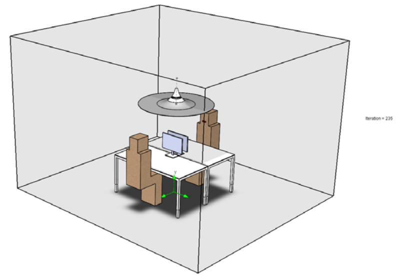
Hanging Lamp
Diameter 500 | 180 Degrees Exhaust



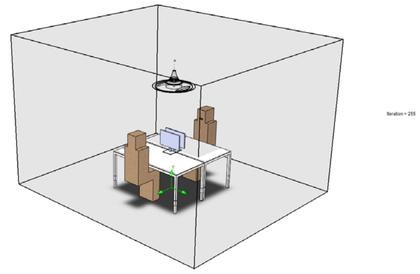
Hanging Lamp
Diameter 800 | 180 Degrees Exhaust

Hanging Lamp Iterations

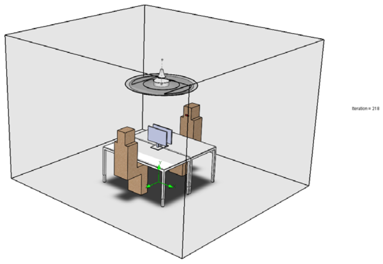
Perspective Diagram of Test Setup



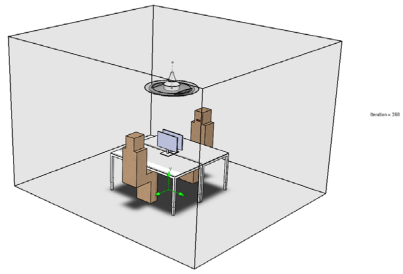
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



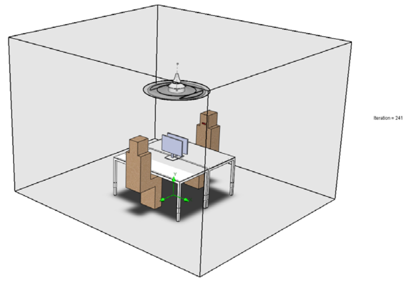
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher

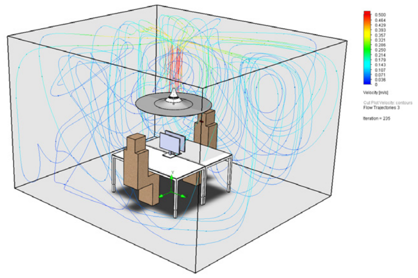


Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher

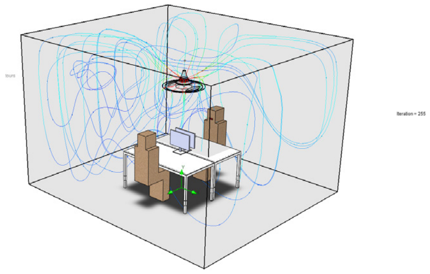


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

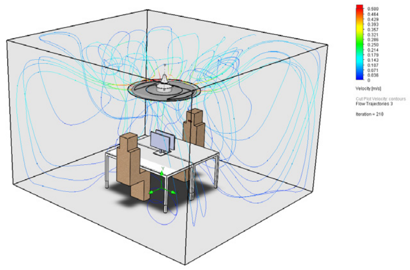
Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



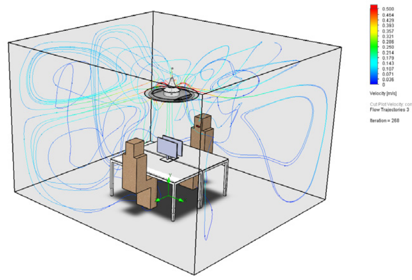
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



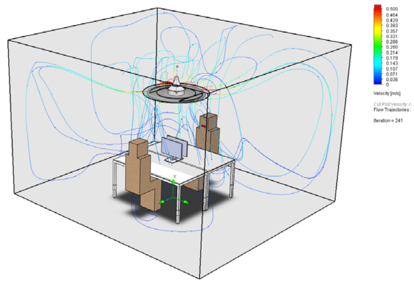
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher



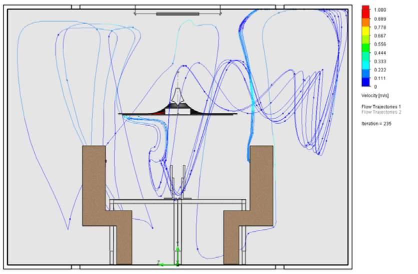
Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher



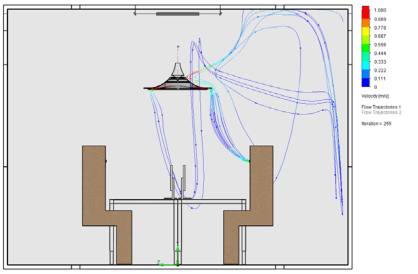
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

Hanging Lamp Iterations

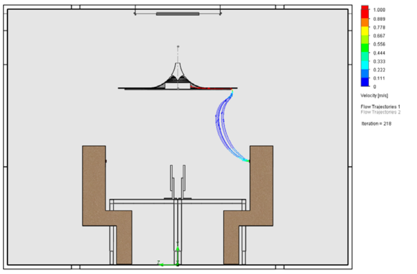
Air Velocity & Trajectory Plot - Breathing Person Right Side (0.0002 m3/s)



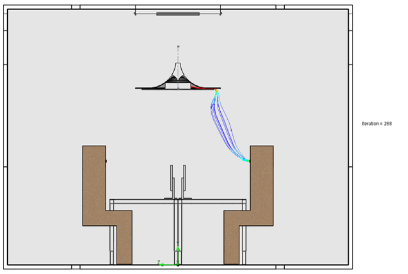
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



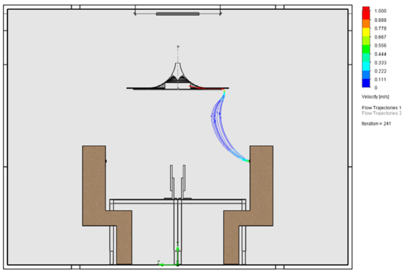
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher

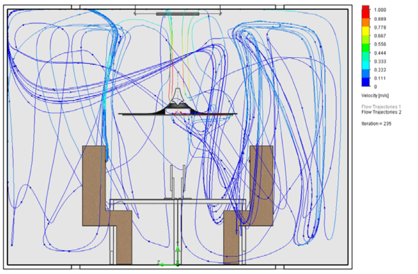


Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher

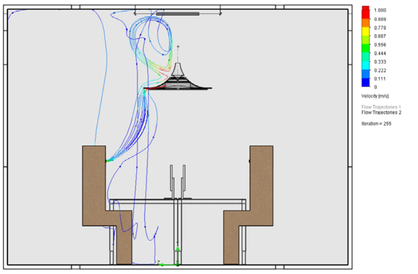


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

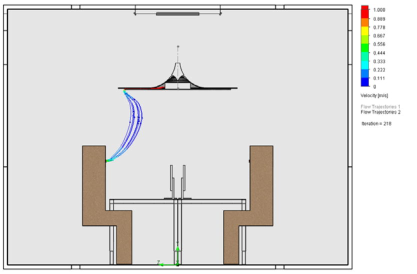
Air Velocity & Trajectory Plot - Breathing Person Left Side (0.0002 m3/s)

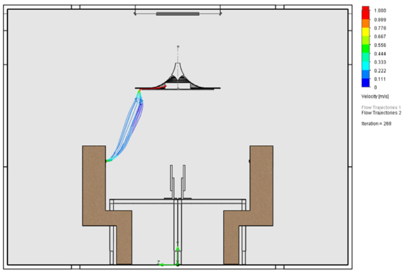


Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust

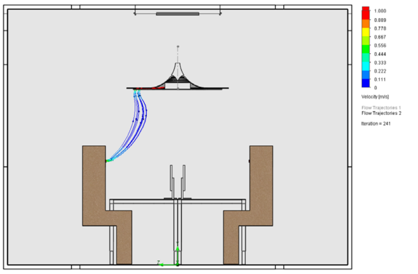


Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher





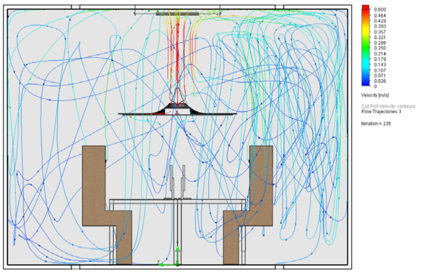
Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher



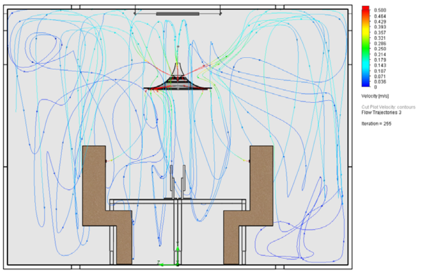
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

Hanging Lamp Iterations

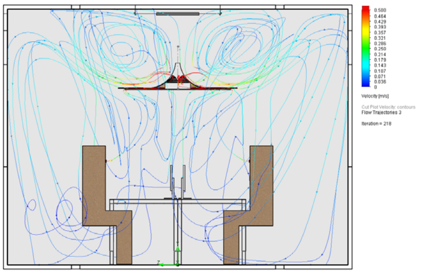
Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



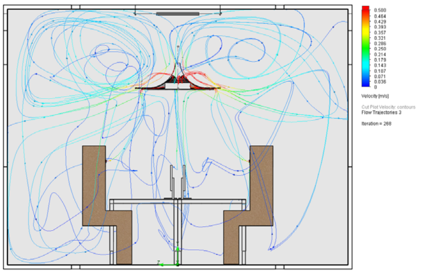
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



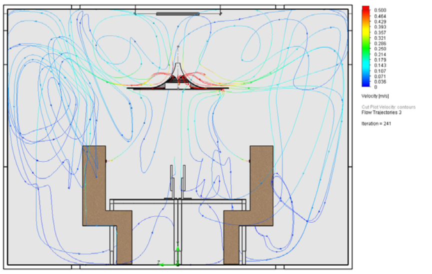
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher

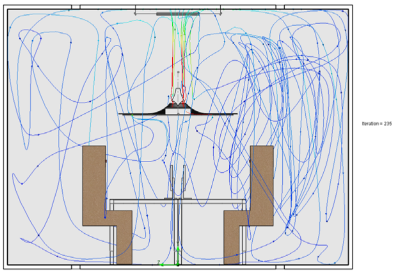


Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher

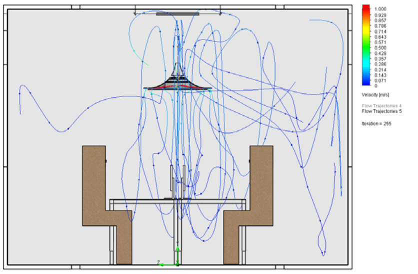


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

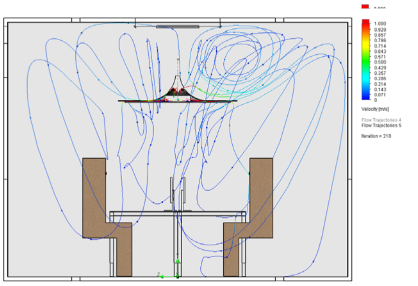
Air Velocity & Trajectory Plot - Intake



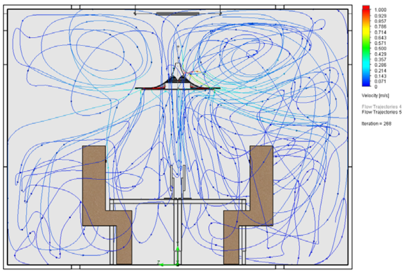
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



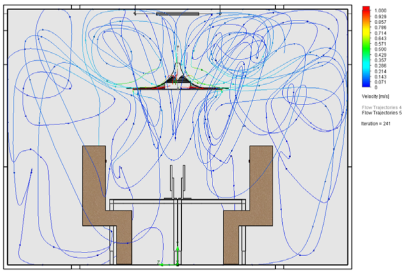
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher



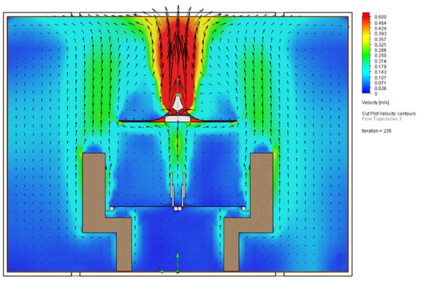
Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher



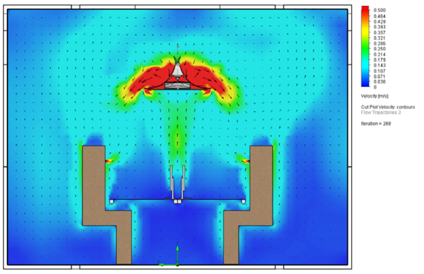
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

Hanging Lamp Iterations

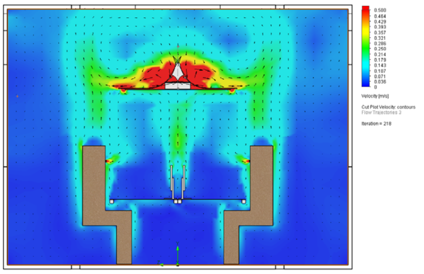
Air Velocity Cut Plot



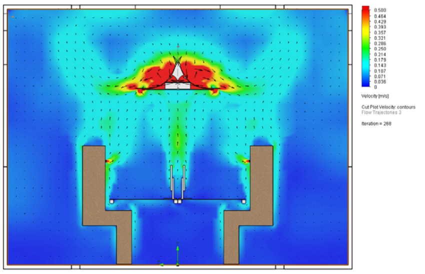
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



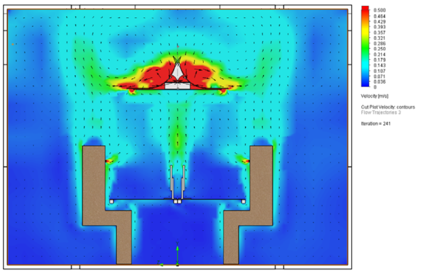
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher

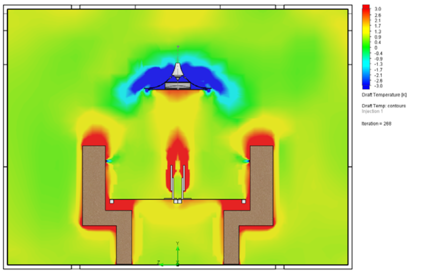


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

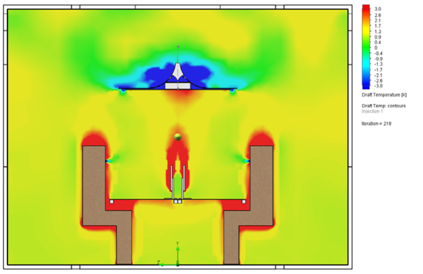
Draft Temperature Cut Plot

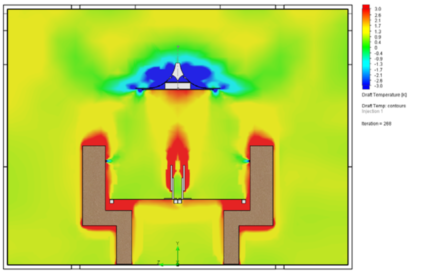
MISSING

Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust

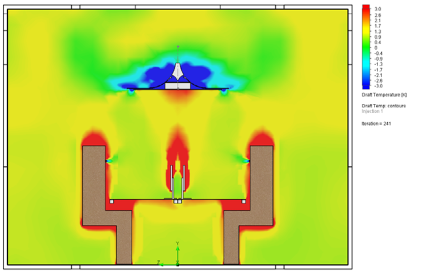


Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher





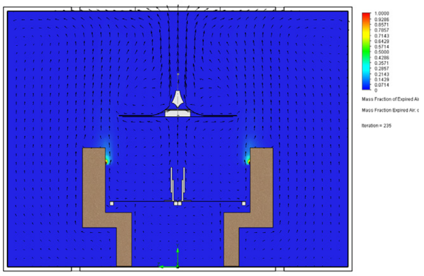
Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher



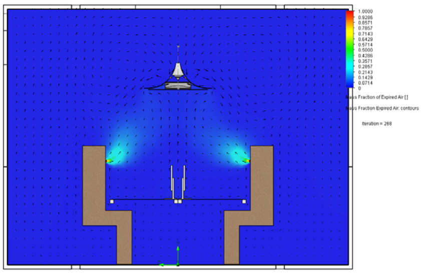
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

Hanging Lamp Iterations

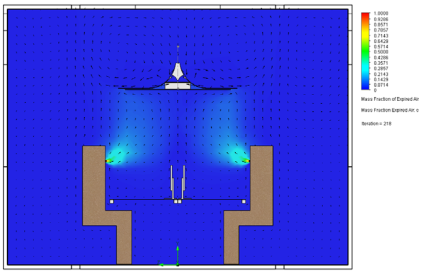
Mass Fraction Expired Air



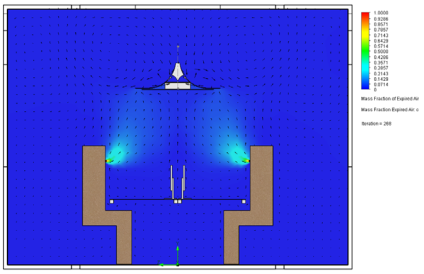
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



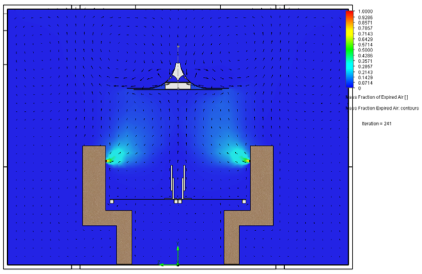
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher

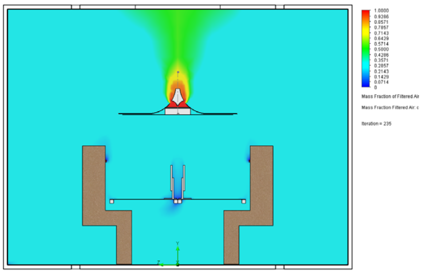


Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher

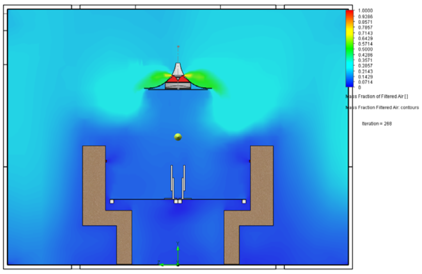


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

Mass Fraction Filtered Air



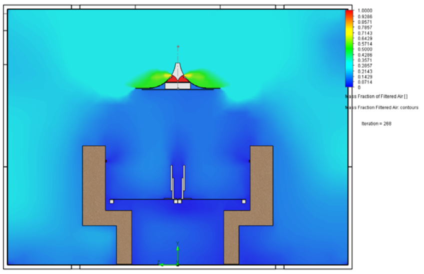
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



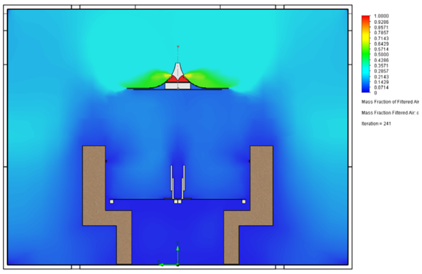
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher

MISSING

Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher



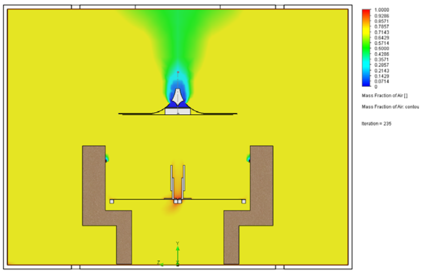
Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher



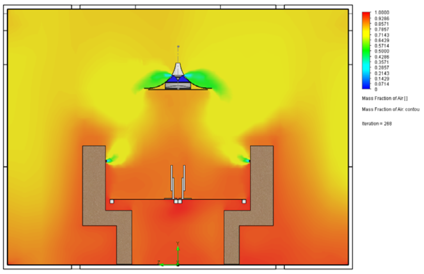
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

Hanging Lamp Iterations

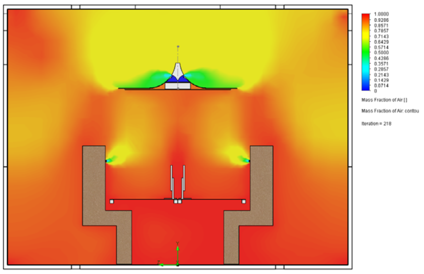
Mass Fraction Air



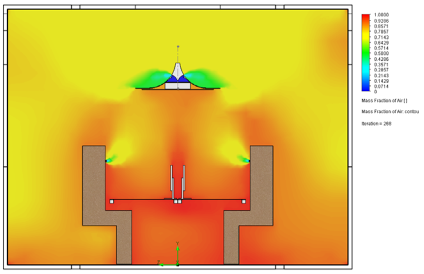
Hanging Lamp V2
Diameter 1000 | 0 Degrees Exhaust



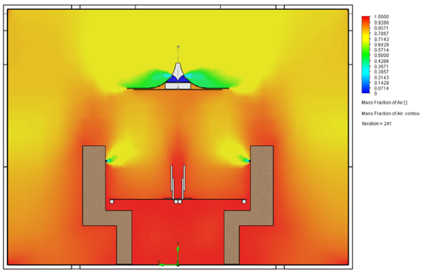
Hanging Lamp V3
Diameter 800 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1400 | 90 Degrees Exhaust
300mm higher



Hanging Lamp V3
Diameter 1000 | 90 Degrees Exhaust
300mm higher

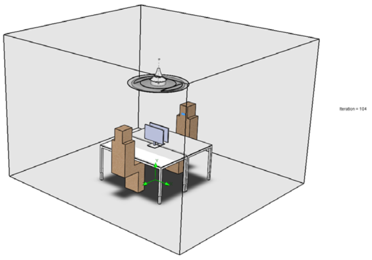


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher

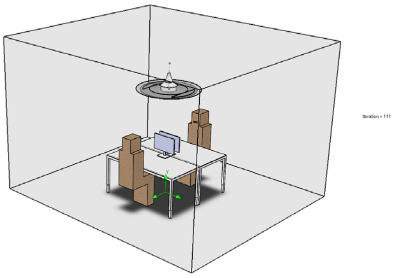
Varying Filter Speed Hanging Lamp V3 Diameter 1200 | 90 Degrees Exhaust 300mm higher

Test Setup

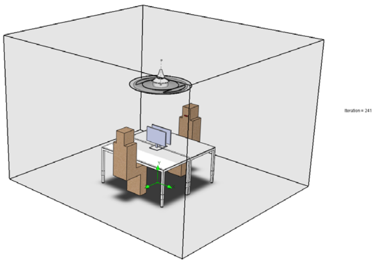
Perspective Diagram of Test Setup



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

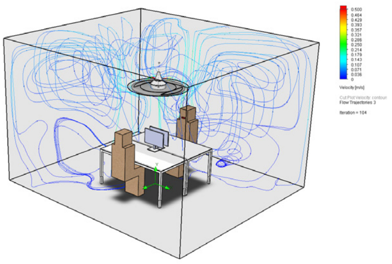


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h

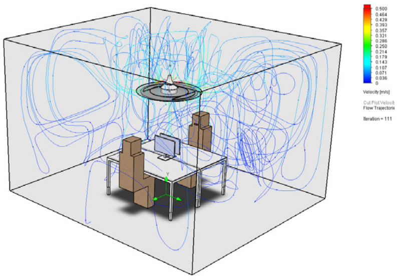


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

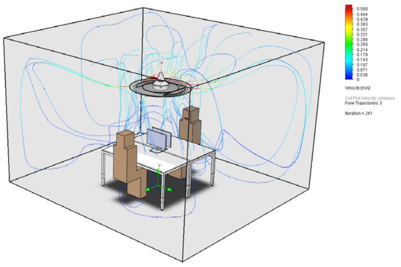
Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h



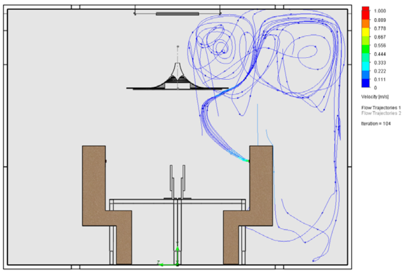
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h



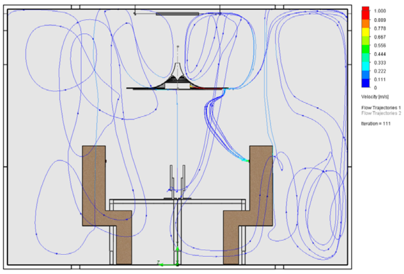
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

Varying Filter Speed Hanging Lamp V3 Diameter 1200 | 90 Degrees Exhaust 300mm higher

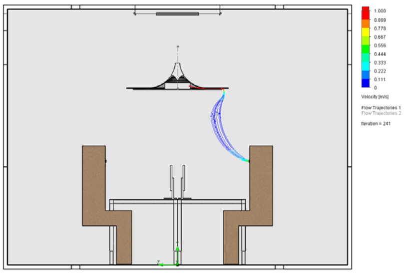
Air Velocity & Trajectory Plot - Breathing Person Right Side (0.0002 m3/s)



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

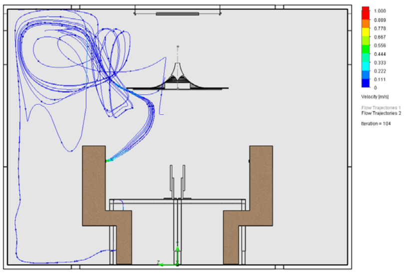


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h

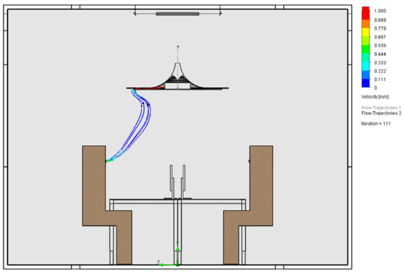


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

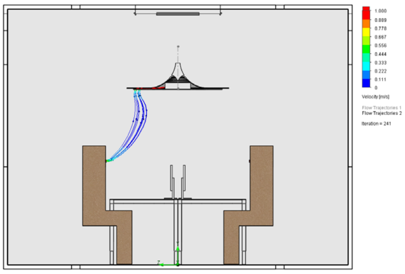
Air Velocity & Trajectory Plot - Breathing Person Left Side (0.0002 m3/s)



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

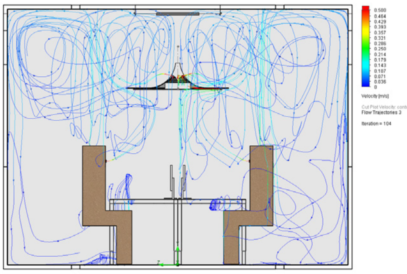


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h

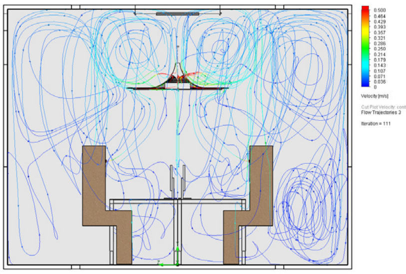


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

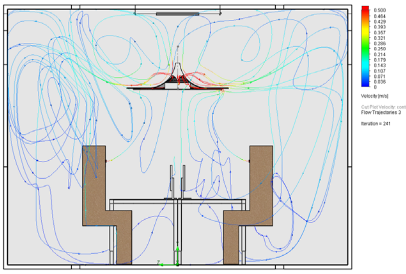
Air Velocity & Trajectory Plot - Breathing Person Both (0.0002 m3/s) + Intake + Exhaust



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

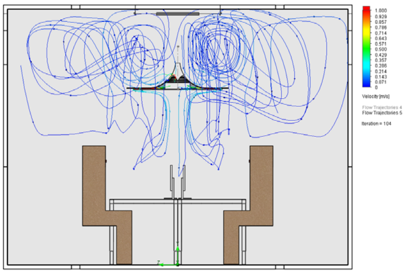


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h

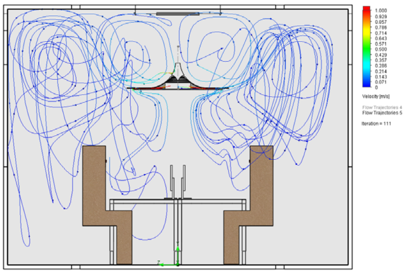


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

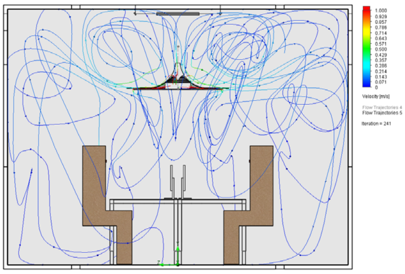
Air Velocity & Trajectory Plot - Intake



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h



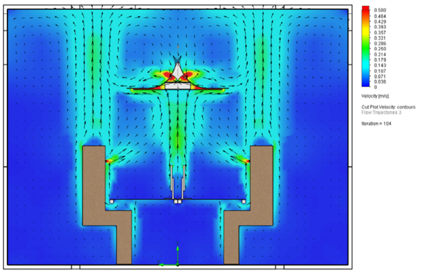
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h



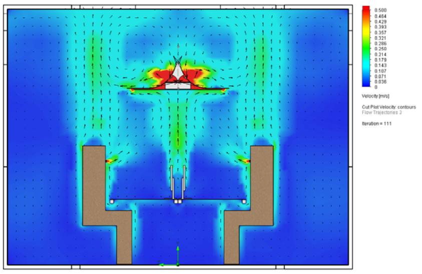
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

Varying Filter Speed Hanging Lamp V3 Diameter 1200 | 90 Degrees Exhaust 300mm higher

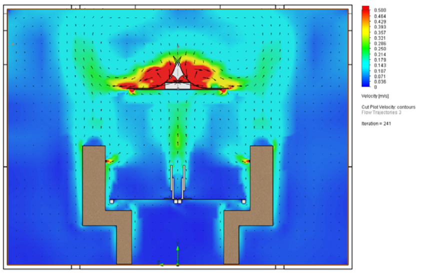
Air Velocity Cut Plot



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

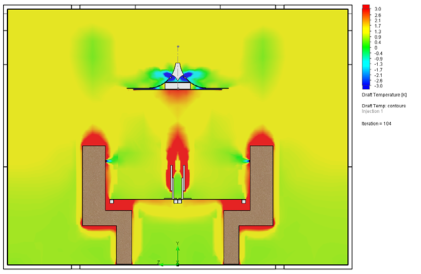


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h

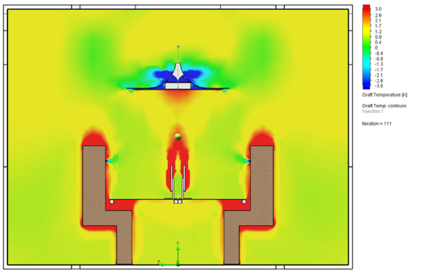


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

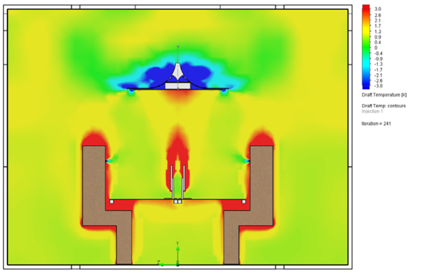
Draft Temperature Cut Plot



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

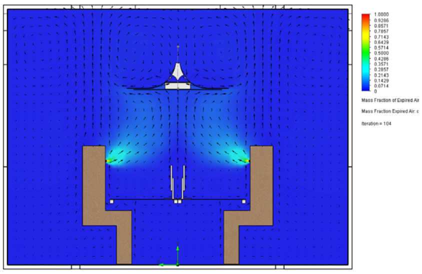


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h

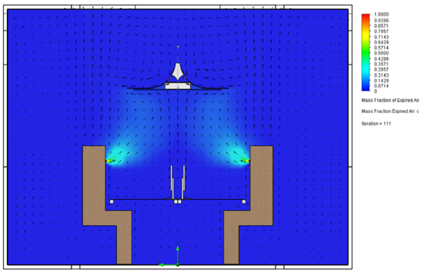


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

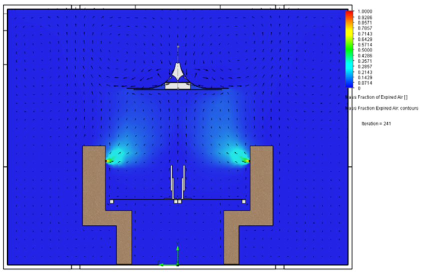
Mass Fraction Expired Air



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

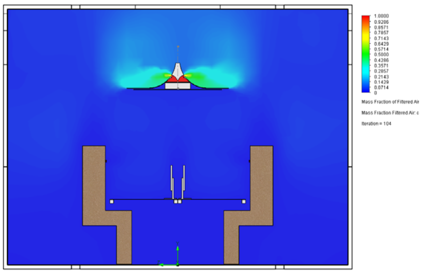


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h

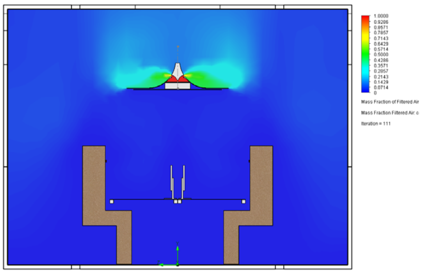


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

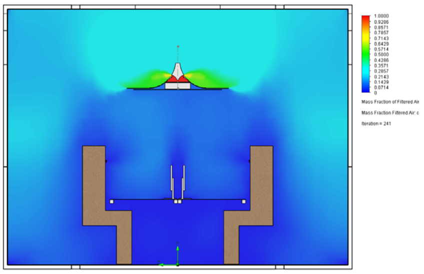
Mass Fraction Filtered Air



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h



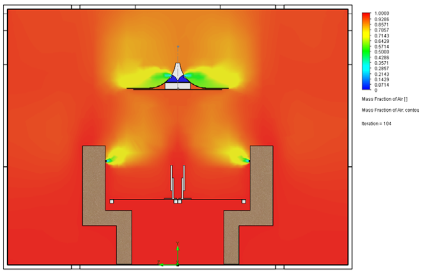
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h



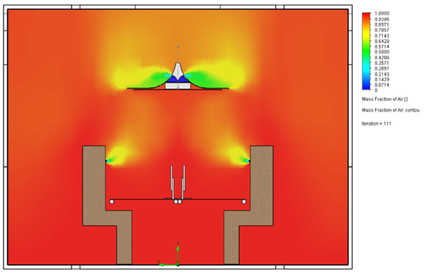
Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

Varying Filter Speed Hanging Lamp V3 Diameter 1200 | 90 Degrees Exhaust 300mm higher

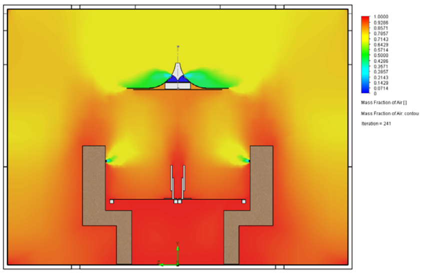
Mass Fraction Air



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 50m3/h

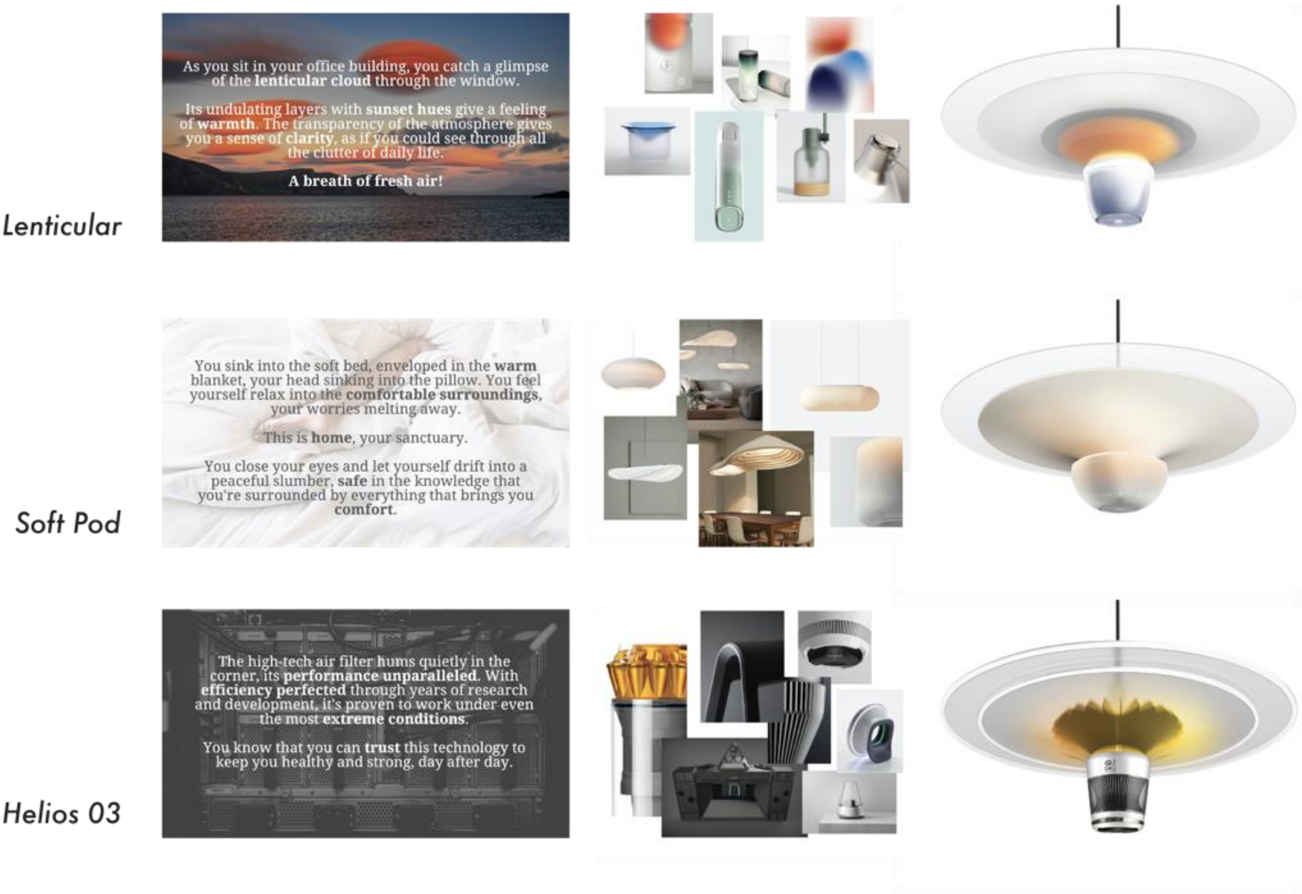


Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 100m3/h



Hanging Lamp V3
Diameter 1200 | 90 Degrees Exhaust
300mm higher | 200m3/h

Figure T: Storytelling, Moodboard and Resulting Design Proposals



As you sit in your office building, you catch a glimpse of the **lenticular cloud** through the window.

Its undulating layers with **sunset hues** give a feeling of **warmth**. The transparency of the atmosphere gives you a sense of **clarity**, as if you could see through all the clutter of daily life.

A breath of fresh air!

You sink into the soft bed, enveloped in the **warm** blanket, your head sinking into the pillow. You feel yourself relax into the **comfortable surroundings**, your worries melting away.

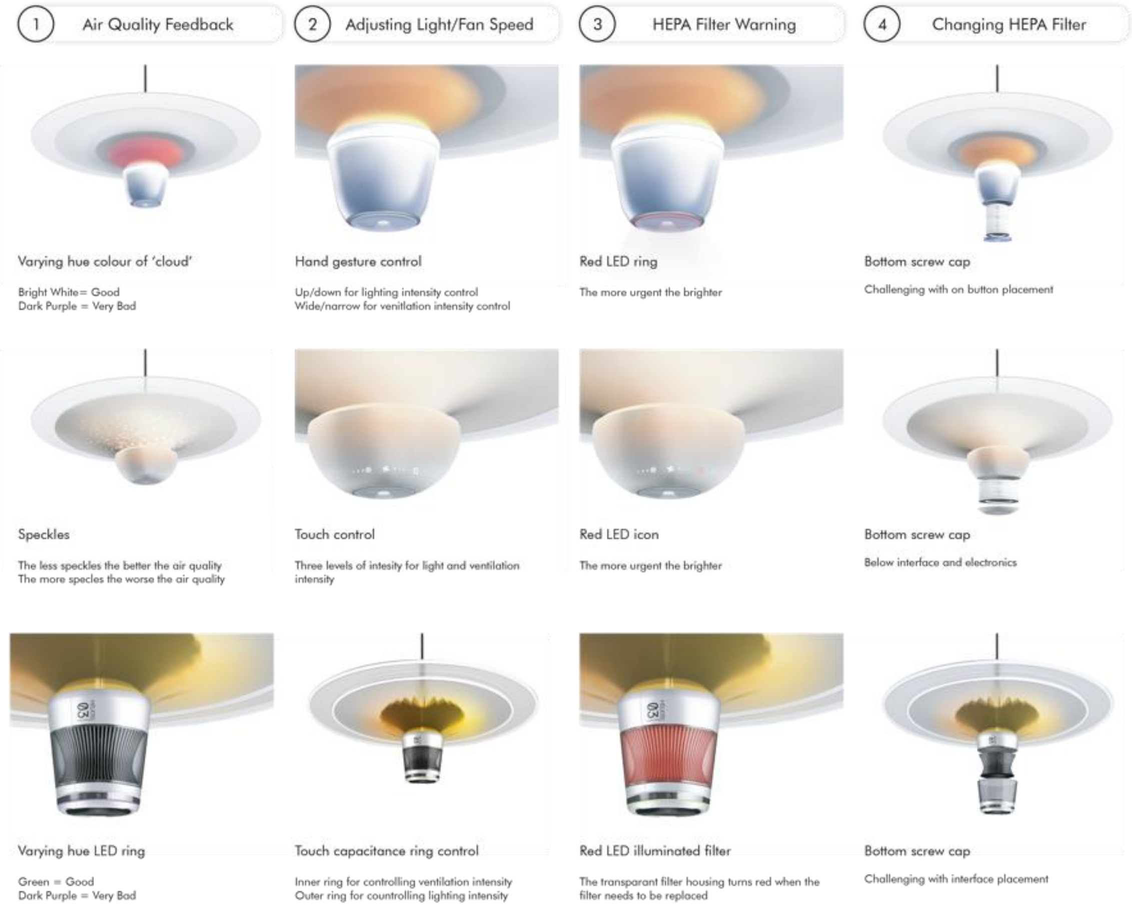
This is **home**, your sanctuary.

You close your eyes and let yourself drift into a peaceful slumber, **safe** in the knowledge that you're surrounded by everything that brings you **comfort**.

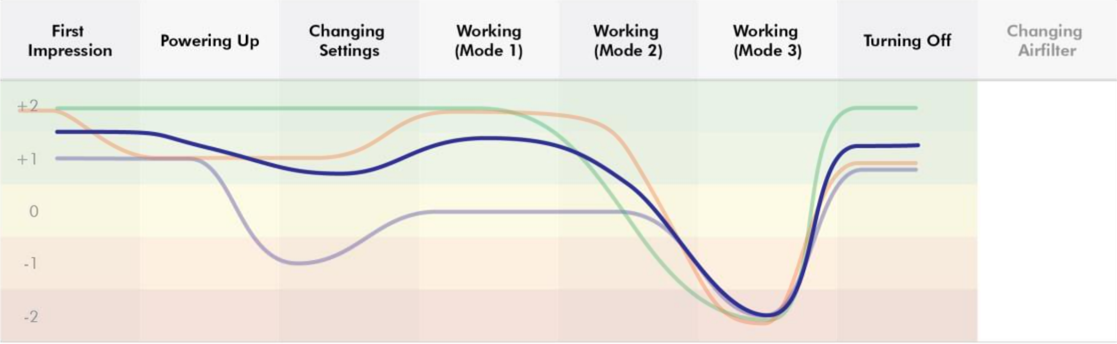
The high-tech air filter hums quietly in the corner, its **performance unparalleled**. With **efficiency perfected** through years of research and development, it's proven to work under even the most **extreme conditions**.

You know that you can **trust** this technology to keep you healthy and strong, day after day.

Figure U: UI Options Teardrop Iteration 1

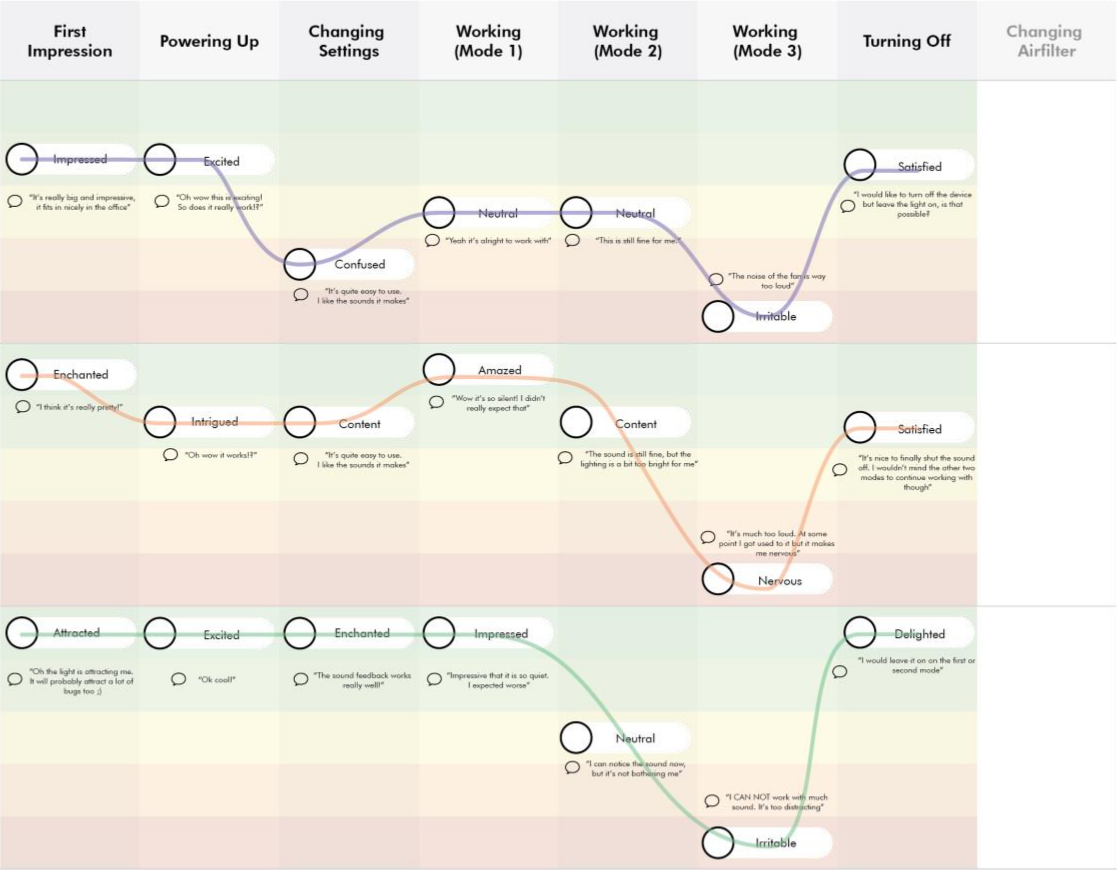


Appendix V – User Journey Results Personal Air FIlter



Average User Experience

Impressed	Excited	Confused	Neutral	Neutral	Irritable	Satisfied
Enchanted	Intrigued	Content	Amazed	Content	Nervous	Satisfied
Attracted	Excited	Enchanted	Impressed	Neutral	Irritable	Delighted



"It's really big and impressive, it fits in nicely in the office"

"Oh wow this is exciting! So does it really work!?"

"It's quite easy to use. I like the sounds it makes"

"Yeah it's alright to work with"

"This is still fine for me."

"The noise of the fan is way too loud"

"I would like to turn off the device but leave the light on, is that possible?

"I think it's really pretty!"

"Oh wow it works!?"

"It's quite easy to use. I like the sounds it makes"

"Wow it's so silent! I didn't really expect that"

"The sound is still fine, but the lighting is a bit too bright for me"

"It's much too loud. At some point I got used to it but it makes me nervous"

"It's nice to finally shut the sound off. I wouldn't mind the other two modes to continue working with though"

"Oh the light is attracting me. It will probably attract a lot of bugs too ;)

"Ok cool!"

"The sound feedback works really well!"

"Impressive that it is so quiet. I expected worse"

"I can notice the sound now, but it's not bothering me"

"I CAN NOT work with much sound. It's too distracting"

"I would leave it on on the first or second mode"

User Experience per Participant

Appendix W – Cost Estimation Calculation

Housing

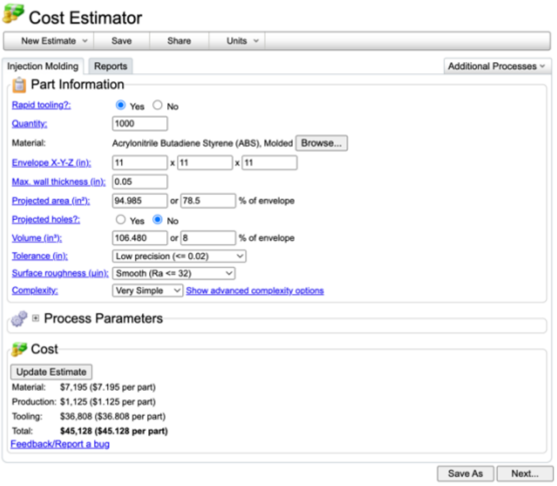
Parts from the InstantPot AP100 and MEDION air purifier were weighed to give an indication of the material used:

Top Grill: ~ 55g
Top housing: ~ 220g
Bottom Housing: ~ 175g
HEPA Access Cap: ~ 65g
Total: ~ 515g

Low-End:

Tooling =	**€155 (per part)**
Part (material + Production) =	**€18,80 (per part)**
TOTAL =	**€173.80 (per part)**

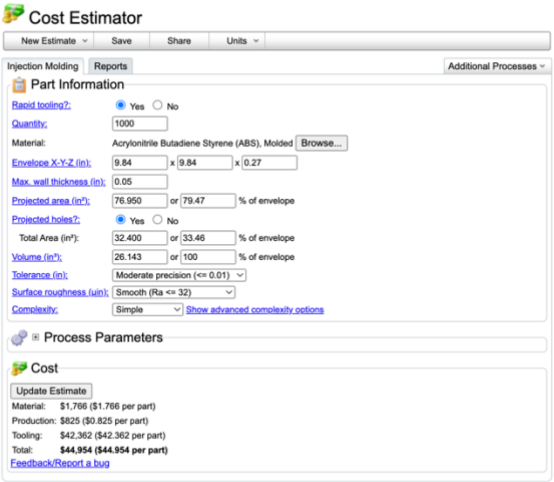
Top Housing: Tooling = €33,71
Part (material + prod.) = €7,60
Total = €40,31



Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 11 x 11 x 11
Max. wall thickness (in): 0.05
Projected area (in²): 94.985 or 78.5 % of envelope
Projected holes?: ○ Yes ● No
Volume (in³): 106.480 or 8 % of envelope
Tolerance (in): Low precision (<= 0.02)
Surface roughness (uin): Smooth (Ra <= 32)
Complexity: Very Simple

Material: $7,195 ($7.195 per part)
Production: $1,125 ($1.125 per part)
Tooling: $36,808 ($36.808 per part)
Total: **$45,128 ($45.128 per part)**

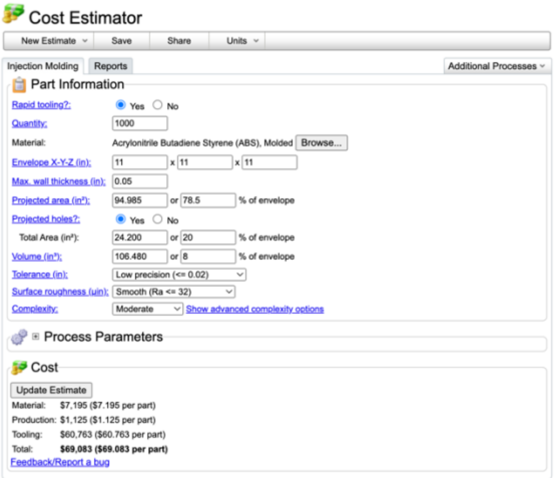
Top Grill: Tooling = €38,80
Part (material + prod.) = €2,38
Total = €41,18



Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 9.84 x 9.84 x 0.27
Max. wall thickness (in): 0.05
Projected area (in²): 76.950 or 79.47 % of envelope
Projected holes?: ● Yes ○ No
Total Area (in²): 32.400 or 33.46 % of envelope
Volume (in³): 26.143 or 100 % of envelope
Tolerance (in): Moderate precision (<= 0.01)
Surface roughness (uin): Smooth (Ra <= 32)
Complexity: Simple

Material: $1,766 ($1.766 per part)
Production: $825 ($0.825 per part)
Tooling: $42,362 ($42.362 per part)
Total: **$44,954 ($44.954 per part)**

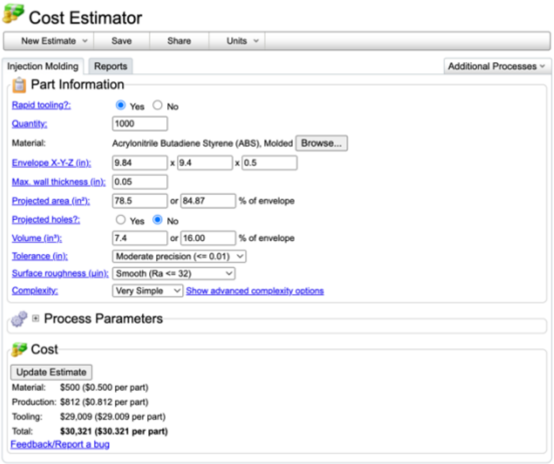
Bottom Housing: Tooling = €55,60
Part (material + prod.) = €7,60
Total = €63,20



Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 11 x 11 x 11
Max. wall thickness (in): 0.05
Projected area (in²): 94.985 or 78.5 % of envelope
Projected holes?: ● Yes ○ No
Total Area (in²): 24.200 or 20 % of envelope
Volume (in³): 106.480 or 8 % of envelope
Tolerance (in): Low precision (<= 0.02)
Surface roughness (uin): Smooth (Ra <= 32)
Complexity: Moderate

Material: $7,195 ($7.195 per part)
Production: $1,125 ($1.125 per part)
Tooling: $60,763 ($60.763 per part)
Total: **$69,083 ($69.083 per part)**

Bottom HEPA Access Cap: Tooling = €26,60
Part (material + prod.) = € 1,20
Total = €27,80



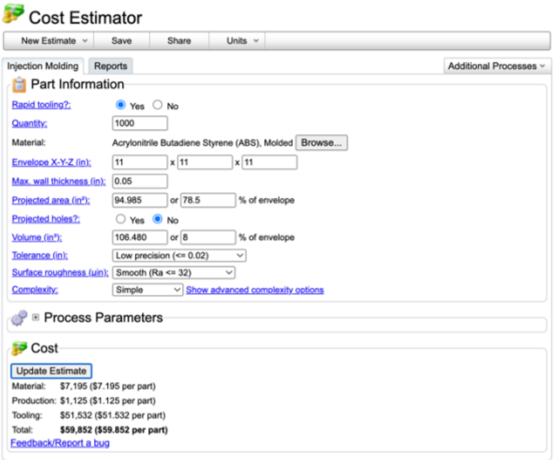
Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 9.84 x 9.4 x 0.5
Max. wall thickness (in): 0.05
Projected area (in²): 78.5 or 84.87 % of envelope
Projected holes?: ○ Yes ● No
Volume (in³): 7.4 or 16.00 % of envelope
Tolerance (in): Moderate precision (<= 0.01)
Surface roughness (uin): Smooth (Ra <= 32)
Complexity: Very Simple

Material: $500 ($0.500 per part)
Production: $812 ($0.812 per part)
Tooling: $29,009 ($29.009 per part)
Total: **$30,321 ($30.321 per part)**

High-End:

Tooling = **€206 (per part)**
Part (material + Production) = **€18,80 (per part)**
TOTAL = **€224,80 (per part)**

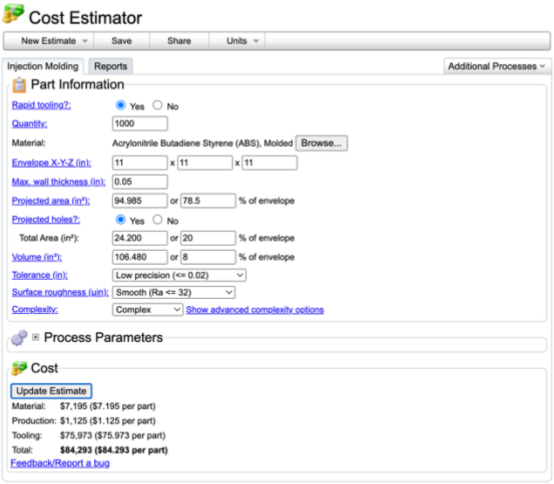
Top Housing: Tooling = €47,20
Part (material + prod.) = €7,60
Total = €54,80



Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 11 x 11 x 11
Max. wall thickness (in): 0.05
Projected area (in²): 94.985 or 78.5 % of envelope
Projected holes?: ○ Yes ● No
Volume (in³): 106.480 or 8 % of envelope
Tolerance (in): Low precision (<= 0.02)
Surface roughness (μin): Smooth (Ra <= 32)
Complexity: Simple

Material: $7,195 ($7.195 per part)
Production: $1,125 ($1.125 per part)
Tooling: $51,532 ($51.532 per part)
Total: **$59,852 ($59.852 per part)**

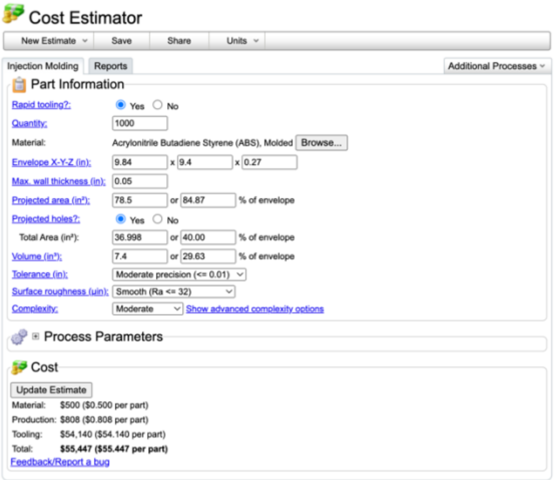
Bottom Housing: Tooling = €69,60
Part (material + prod.) = €7,60
Total = €67,20



Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 11 x 11 x 11
Max. wall thickness (in): 0.05
Projected area (in²): 94.985 or 78.5 % of envelope
Projected holes?: ● Yes ○ No
Total Area (in²): 24.200 or 20 % of envelope
Volume (in³): 106.480 or 8 % of envelope
Tolerance (in): Low precision (<= 0.02)
Surface roughness (μin): Smooth (Ra <= 32)
Complexity: Complex

Material: $7,195 ($7.195 per part)
Production: $1,125 ($1.125 per part)
Tooling: $75,973 ($75.973 per part)
Total: **$84,293 ($84.293 per part)**

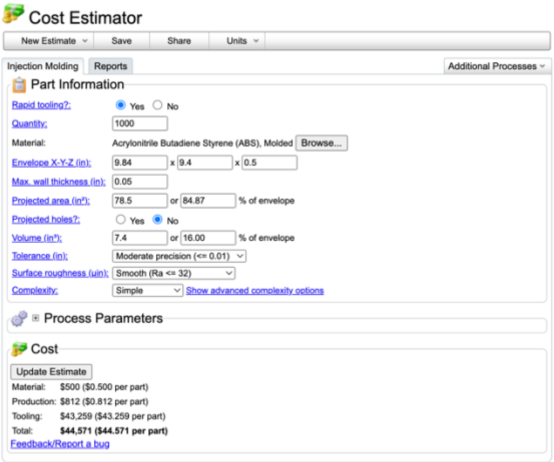
Top Grill: Tooling = €49,60
Part (material + prod.) = €2,38
Total = €51,98



Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 9.84 x 9.4 x 0.27
Max. wall thickness (in): 0.05
Projected area (in²): 78.5 or 84.87 % of envelope
Projected holes?: ● Yes ○ No
Total Area (in²): 36.998 or 40.00 % of envelope
Volume (in³): 7.4 or 29.63 % of envelope
Tolerance (in): Moderate precision (<= 0.01)
Surface roughness (μin): Smooth (Ra <= 32)
Complexity: Moderate

Material: $500 ($0.500 per part)
Production: $808 ($0.808 per part)
Tooling: $54,140 ($54.140 per part)
Total: **$55,447 ($55.447 per part)**

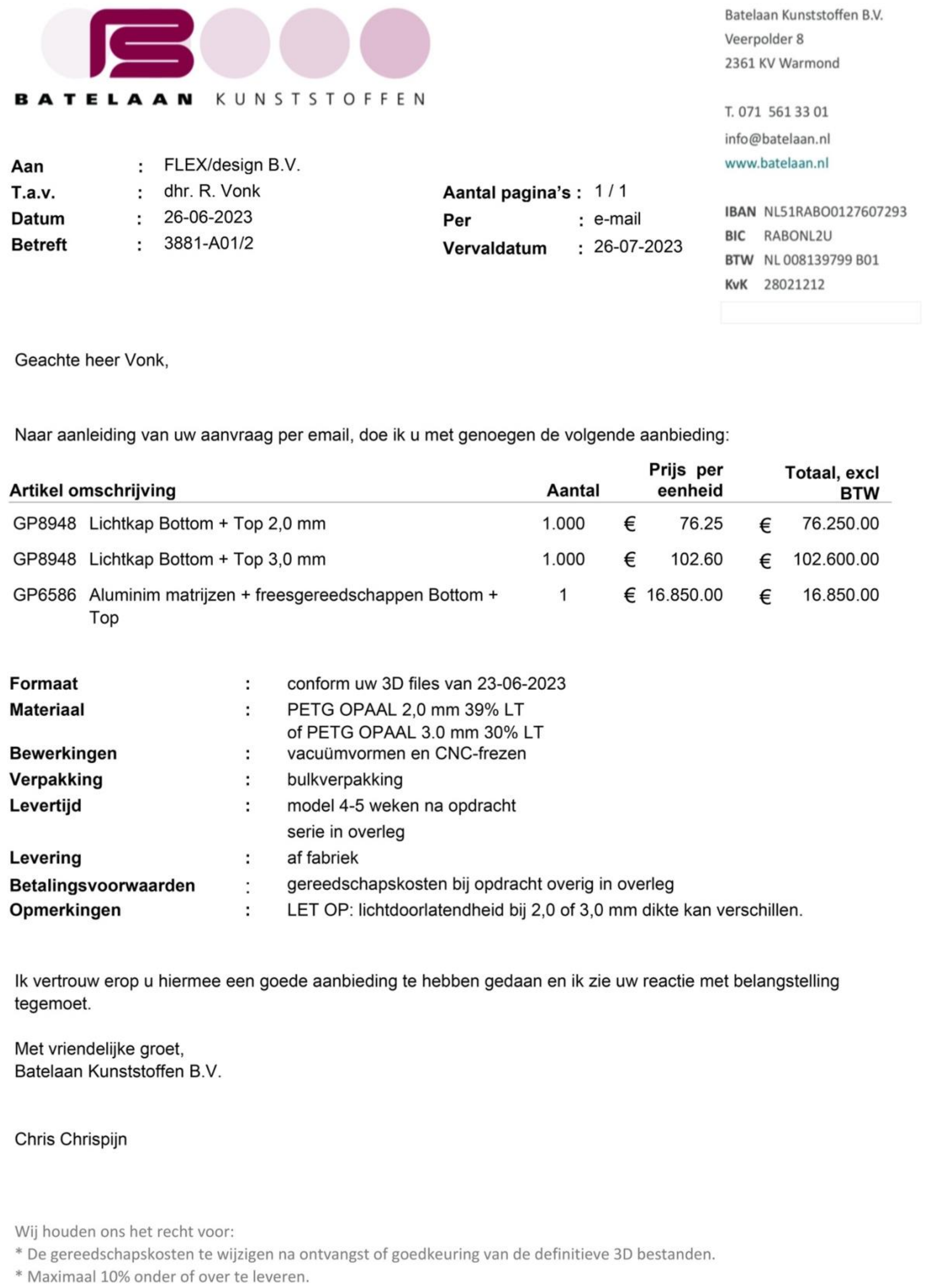
Bottom HEPA Access Cap: Tooling = €39,66
Part (material + prod.) = € 1,20
Total = €40,86



Rapid tooling?: ● Yes ○ No
Quantity: 1000
Material: Acrylonitrile Butadiene Styrene (ABS), Molded
Envelope X-Y-Z (in): 9.84 x 9.4 x 0.5
Max. wall thickness (in): 0.05
Projected area (in²): 78.5 or 84.87 % of envelope
Projected holes?: ○ Yes ● No
Volume (in³): 7.4 or 16.00 % of envelope
Tolerance (in): Moderate precision (<= 0.01)
Surface roughness (μin): Smooth (Ra <= 32)
Complexity: Simple

Material: $500 ($0.500 per part)
Production: $812 ($0.812 per part)
Tooling: $43,259 ($43.259 per part)
Total: **$44,571 ($44.571 per part)**

Hood (Quotation Batelaan Kunststoffen)



BATELAAN KUNSTSTOFFEN

Batelaan Kunststoffen B.V.
Veerpolder 8
2361 KV Warmond

T. 071 561 33 01
info@batelaan.nl
www.batelaan.nl

IBAN NL51RABO0127607293
BIC RABONL2U
BTW NL 008139799 B01
KvK 28021212

Aan : FLEX/design B.V.
T.a.v. : dhr. R. Vonk
Datum : 26-06-2023
Betreft : 3881-A01/2

Aantal pagina's : 1 / 1
Per : e-mail
Vervaldatum : 26-07-2023

Geachte heer Vonk,

Naar aanleiding van uw aanvraag per email, doe ik u met genoegen de volgende aanbieding:

Artikel omschrijving		**Aantal**	**Prijs per eenheid**	**Totaal, excl BTW**
GP8948	Lichtkap Bottom + Top 2,0 mm	1.000	€ 76.25	€ 76.250.00
GP8948	Lichtkap Bottom + Top 3,0 mm	1.000	€ 102.60	€ 102.600.00
GP6586	Aluminim matrijzen + freesgereedschappen Bottom + Top	1	€ 16.850.00	€ 16.850.00

Formaat : conform uw 3D files van 23-06-2023
Materiaal : PETG OPAAL 2,0 mm 39% LT
of PETG OPAAL 3.0 mm 30% LT
Bewerkingen : vacuümvormen en CNC-frezen
Verpakking : bulkverpakking
Levertijd : model 4-5 weken na opdracht
serie in overleg
Levering : af fabriek
Betalingsvoorwaarden : gereedschapskosten bij opdracht overig in overleg
Opmerkingen : LET OP: lichtdoorlatendheid bij 2,0 of 3,0 mm dikte kan verschillen.

Ik vertrouw erop u hiermee een goede aanbieding te hebben gedaan en ik zie uw reactie met belangstelling tegemoet.

Met vriendelijke groet,
Batelaan Kunststoffen B.V.

Chris Chrispijn

Wij houden ons het recht voor:
* De gereedschapskosten te wijzigen na ontvangst of goedkeuring van de definitieve 3D bestanden.
* Maximaal 10% onder of over te leveren.

Off-the Shelf

Fan Unit & Electronics:
To get a rough estimation of the fan unit price, existing air purifiers were benchmarked. It is assumed that the fan unit is 15% of the total unit price (personal communication FLEX/design, 2023).

Low-end:

	Retail Price (€)	**15% (€)**	**Link**
Instant Air Purifier AP100	48,50	7,28	https://www.amazon.nl/Instant-Air-Purifier-schimmelsporen-filtersysteem/dp/B093CDLGN1
MEDION MD199878	59,95	9,00	https://www.medion.com/nl/shop/luchtreiniger
Air Purifier With True Hepa Filter With Uv-c Light	44,95	6,75	https://www.fruugo.nl/air-purifier-with-true-hepa-filter-with-uv-c-light-mini-air-purifier-removes-9997-smoke-allergens-dustwhite/p-152723758-323144643?language=en&ac=ProductCasterAPI&utm_source=organic_shopping&utm_medium=organic
AVERAGE	**51,17**	**7,70**	

High-end:

	Retail Price (€)	**15%**	**Link**
Philips 800 AC0820/10R1	119,99	18,00	https://www.philips.nl/c-p/AC0820_10R1/800-serie-luchtzuiveraar?clickref=1011lwVpnt94&origin=2_nl_nl___1100l233847_____shopforwardbing_____Comparison%2FReview___pz&utm_source=1100l233847&utm_medium=affiliate&utm_campaign=partnerize&utm_content=Comparison%2Freview&utm_term=shopforwardbing
AX3 LUCHTREINIGER 40 M² 180 M3/H	199,95	30,00	https://www.aeg.nl/home-comfort/air-comfort/air-purifiers/oxygen-air-purifier/ax31-201gy/?gclid=Cj0KCQjwwISlBhD6ARIsAESAmp5v7JUJ0BqcKyhJH9oijTjsM16eBGND2HdK_Oje4NvmrWIuIQWmR84aAqcPEALw_wcB&gclsrc=aw.ds
Duux Bright Smart Zwart	159,00	23,85	https://www.coolblue.nl/product/884806/duux-bright-smart-zwart.html?cmt=c_a%2Ccid_20259860605%2Caid_156853042984%2Ctid_pla-293946777986%2Cgn_g%2Cd_c&utm_source=google&utm_medium=cpc&utm_content=shopping&gclid=Cj0KCQjwwISlBhD6ARIsAESAmp6beStwOH_jMgksni17U78lqT9jybRamJAFKV5oc5a05TW0ZsGbRfYaAlD3EALw_wcB
AVERAGE	**160,00**	**24,00**	

Lighting:

Low-end:

	Price per 1000 (€)	**Price per Unit (€)**	**Link**
LED Tube T9 13W Bean Angle 150° PC 3 Years Warranty LED Circular Tube	3.500,00	3,50	https://nbhuateng.en.made-in-china.com/product/xFVAjcZowNhW/China-LED-Tube-T9-13W-Bean-Angle-150-deg-PC-3-Years-Warranty-LED-Circular-Tube.html
LED Lighting Input Voltage AC220-240V CCT 6000K Power 24W LED Circular Tube	5.130,00	5,13	https://nbhuateng.en.made-in-china.com/product/FZITpUkGZwhR/China-LED-Lighting-Input-Voltage-AC220-240V-CCT-6000K-Power-24W-LED-Circular-Tube.html
High Quality T9 22W 32W 40W 3000K 4100K 5000K 6500K Circular Fluorescent Light	2.750,00	2,75	https://2f83ed327329328f.en.made-in-china.com/product/OzifxFuKkhUN/China-High-Quality-T9-22W-32W-40W-3000K-4100K-5000K-6500K-Circular-Fluorescent-Light.html
AVERAGE	**3.800,00**	**3,80**	

Assembly

Low-end costs for assembly take hourly salary of china into account (**€**5/h), whereas high-end is locally produced in the Netherlands(**€**25/h) (E. Thomassen, 2018). In discussion with engineers at FLEX/design, a very rough estimate of the total assembly time is 30 minutes per device (Personal communication FLEX/design, 2023).

Low-end assembly cost (per unit): €2,50
High-end assembly cost(per unit): €12,50

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