Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	**Xiao Guang Pan**
Student number	5011221

Studio		
Name / Theme	Healthy buildings with smart ventilation integrated in architecture	
Main mentor	Regina Bokel	Building Physics and Services
Second mentor	Arie Bergsma	Façade & Product Design
Argumentation of choice of the studio	N/A – At BT only one studio available.	

Graduation project	
Title of the graduation project	Effectiveness of ventilation products in reducing the spread of Covid-19
Goal	
Location:	TU Delft Faculty of Architecture & the Built Environment, Delft, The Netherlands
The posed problem,	Institutions and students all throughout the world have been negatively impacted by the COVID-19 shutdown. I have personally experienced the consequences of this. Ventilation was one of the key strategies used when the schools reopened to contain the spread of COVID-19, but its efficacy was unclear. The key recommendation was that in general there should be plenty of ventilation inside the rooms. There are many different sorts of ventilation products available right now, from smart ventilation to individualised ventilation to decentralised façade mounted ventilation. These products are the subject of extensive research to determine how they operate and affect the interior environment. However, there is still a lack of solid information on how they perform in the context of a pandemic like COVID-19. The purpose of this study is to determine whether it is possible to design a ventilation system using practical and cost-effective approaches, the ventilation products mentioned earlier, that might possibly minimise the spread of Covid-19 inside a room without compromising the comfort of the occupants. Therefore, this study should serve as a bridge between the theoretical understanding and research and the actual use of the various ventilation systems and products currently available on the market.
research questions and	**Main question:** How can smart, personal, or decentralised ventilation improve the ventilation system design to make it more COVID-19-proof while not negatively impacting the comfort of the occupants in an educational environment and being both practical and cost-efficient. To help answer this main question multiple sub questions are set up. These are divided in two parts. One part are questions that are mainly focussed

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<td>on background information on the topics. These questions can be easily answered through a literature research. The second part of the question are actually research questions meant to be answered in the following weeks through research, simulating, measuring and surveying.

Sub questions:

Questions that are answered in the literature study:
1. What are the standard ventilation systems?
2. Why are current ventilation designs effective?
3. What ventilation system products are available on the market, specifically in relation to personal ventilation, smart ventilation, and decentralised façade ventilation?
4. How does COVID-19 work and what is the main mechanism of transmission?
5. What do current standards, guidelines, and regulations say about ventilation and COVID-19?
6. Which locations within the Tu Delft faculty of Architecture & the Built Environment are suitable to be used as research locations?
7. What does it mean to be cost-efficient and practical?
8. How does the droplet size affect the long range and short range transmission of COVID-19

Questions that require more research:
1. How can the ventilation system be adapted in response to Covid-19?
2. How does each of the ventilation products affect the highly dynamic short-range transmission of infectious aerosols?
3. How does the usage of the product may cause secondary (long range) infections in the classroom?
4. How is comfort of the occupants impacted by the use of the ventilation products?
5. How can the results of the research be validated through measurements and simulations?
6. What location inside the classroom would be optimal for the ventilation products to be placed in, where the spread of Covid-19 is most reduced by it and the comfort of the occupants impacted the least.</td>
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<td>design assignment in which these result.</td>
<td>The expected results
1. An overview of the ventilation products where these are compared to each based on costs of material and labour and also practicality.
2. An evaluation of efficacy of the ventilation system in reducing the COVID-19 spread inside the room under various conditions.
3. An overview of the results where the comfort of occupants are shown.
4. And lastly a ventilation system design where the existing ventilation system and the ventilation products are integrated into one optimum design for the classroom.</td>
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<td colspan="2">[This should be formulated in such a way that the graduation project can answer these questions. The definition of the problem has to be significant to a clearly defined area of research and design.]</td>
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Process

Method description

[The full literature list given after the method description in its own section]

This research is structured into several phases:

- The conceptualisation phase
- The knowledge gathering phase
- The design & analysis phase
- The concluding phase

This research start with the two phases of conceptualisation and the knowledge gathering phase. These two phases are part of a larger literature study that is conducted in these two phases. In short the conceptualisation phase is where the orientation of the problem starts. Here information about the problem is found and analysed. After this the knowledge gathering phase begins. This is phase is more in-depth to the previous phase, but is still part of the larger literature study. In this literature study information about COVID-19 is researched in more depth to understand what it is according to the literature and how it is primarily spread. The use of ventilation systems, including the effectiveness of various types and their impact on the spread of COVID-19 are also explored. For the location, research is done on which factors are most important in selecting a suitable test location, such as size, capacity, and the type of ventilation used in the room. In terms of ventilation products, there is looked at what systems are currently available on the market and their effectiveness in ventilating a room. Furthermore, information is researched on how to calculate the risk infection inside a room. For this information is found from databases like ScienceDirect, JSTOR, and ResearchGate and the TU Delft repository. Lastly the key indicators such as comfort, economics, and practicality are defined along with the main question, sub questions, the objectives and lastly the expected results.

The next phase is design and analysis. In this phase, the focus is on research into the ventilation products, the actual testing, simulating, measuring and the analysis of data. It starts by setting up the base situation. Within the base situation the following activities are conducted under normal usage conditions:

- Measurements:
  - Temperature – HOBO data loggers
  - Humidity – HOBO data loggers
  - Co2 – HOBO data loggers
  - Sound – decibel meter
  - Particle count – particle counter
  - Air velocity – air velocity meter
- Simulated:
  - Temperature – Phoenics
  - Humidity – Phoenics
  - Mean/local age of air – Phoenics
  - Particle count – Phoenics
  - The airflow – Phoenics
- Surveyed:
  - People:
    - Comfort:
      - Temperature
      - Humidity
      - Sound
      - Concentration

Simulating and measuring are done since no simulation is a perfect representation of reality. Consequently, differences may be discovered and analyzed to see how they came to be when the results of the measurement and the simulation are compared. In addition, the survey is carried out to learn how people normally interact with the space.

After setting up the base situation the room is prepared for use of ventilation products. These ventilation products are first analysed in terms of how they bring air inside the room based on a couple parameters. These parameters are:

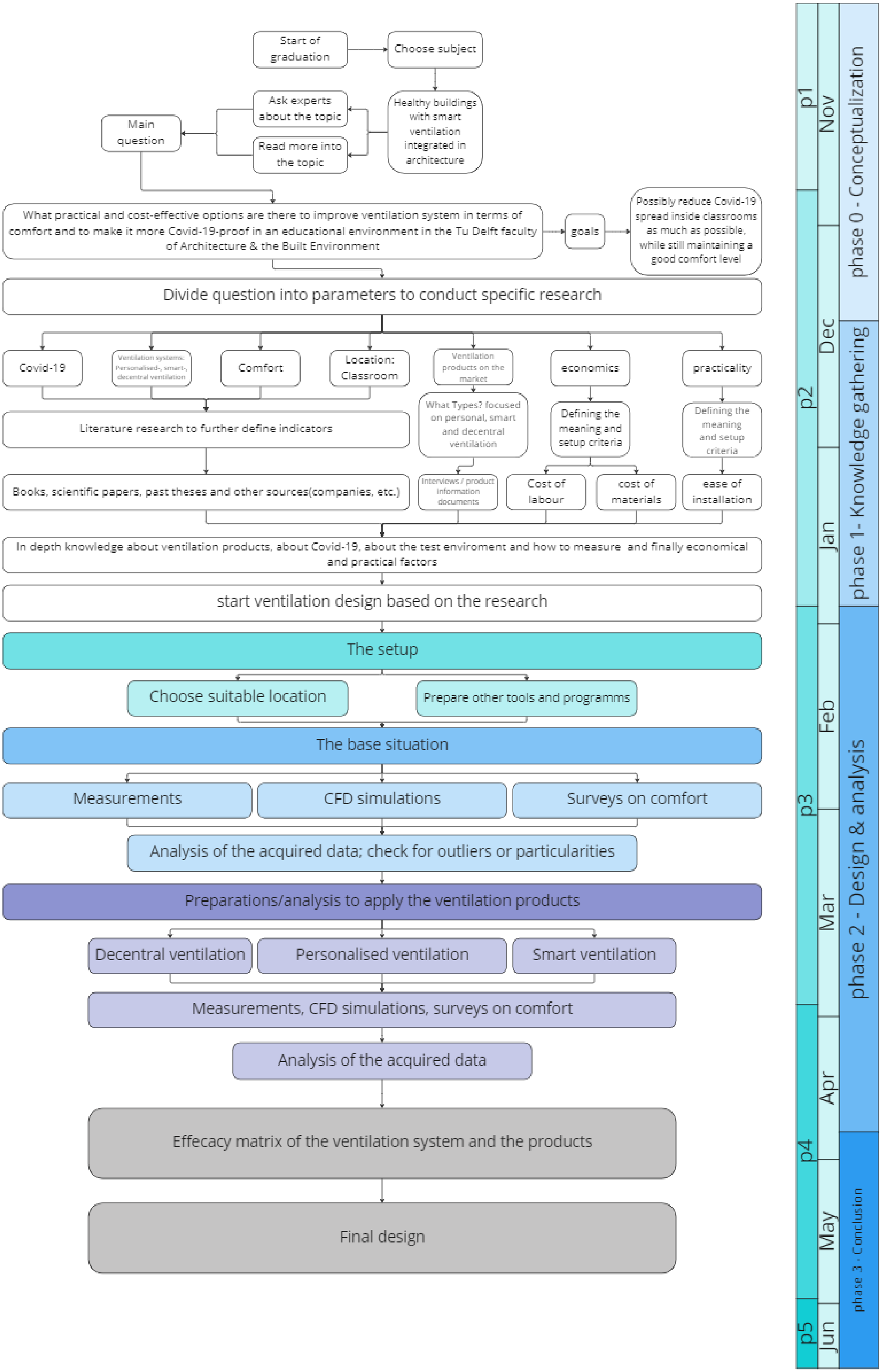
- Temperature – To see what temperature range is available. Too cold or too hot obviously brings discomfort with it.
- Velocity – This is in the same vein as the temperature parameter. Either too fast or too slow and it brings discomfort with it.
- Volume i.e. air change rate per hour(ACH) and also m3 per hour(m3/h) – If the volume is not enough the effect of the product might not be noticeable compared to the existing ventilation system that is still there.
- Direction – Directly blowing air in the direction of the people might discomfort them. Thus it is important to know what directions can it do.
- Regime – Lastly if the product is all the time on full blast even when there are not many people in the room will be very energy inefficient.

An important note on the ventilation products: Since products are not always available, the room is prepared for the use of substitute products. This means that the properties of the product are researched then a substitute is created. While the original might not be available for testing, the measurements and simulations won't be bothered by it.

After that is finished the simulations and the surveys of the room when the products are applied is started. For each case the product is applied in combination with the normal ventilation system. This research includes testing various placements to determine their impact. Further discussions about ventilation efficiency and infection risk quantification are mainly based on the simulation results. Through this, the efficacy of spread prevention of the products was able to be analysed by comparing the predictions of ventilation airflow routes and mean and local air ages. Therefore there would be three main cases with subcases based on the placement of the product. Upon finishing the simulations, measurements and surveys an analysis and comparison is done on the results and data. The data is analysed to provide more insight into how the products may have impacted the spread of Covid-19. A comparison is done on the simulation and measurement data to explore the relationship between the general air distribution pattern, the air recirculation inside the room, and the various ventilation products. This is done to find how the general air distribution pattern and the air recirculation might be affected by each of the ventilation products. After the CFD simulation, indoor comfort was assessed, economic feasibility and practicality of the systems were analysed. This all

The final phase is the conclusion phase. This includes the integration of simulation results and the optimal efficacy of epidemic prevention through the use of existing ventilation products into design that possibly reduces COVID-19. A final conclusion on the effectiveness of the product, the perceived comfort inside the rooms, and the spread of Covid-19 inside the classrooms is given, taking into consideration economic and practical factors. Furthermore a reflection on the research and design of the process is given to advise where to future research to finetune the design further.

Flowchart:


Start of graduation
Choose subject
Healthy buildings with smart ventilation integrated in architecture
Ask experts about the topic
Read more into the topic
Main question
What practical and cost-effective options are there to improve ventilation system in terms of comfort and to make it more Covid-19-proof in an educational environment in the Tu Delft faculty of Architecture & the Built Environment
goals
Possibly reduce Covid-19 spread inside classrooms as much as possible, while still maintaining a good comfort level
Divide question into parameters to conduct specific research
Covid-19
Ventilation systems: Personalised-, smart-, decentral ventilation
Comfort
Location: Classroom
Ventilation products on the market
economics
practicality
Literature research to further define indicators
What Types? focused on personal, smart and decentral ventilation
Defining the meaning and setup criteria
Defining the meaning and setup criteria
Books, scientific papers, past theses and other sources(companies, etc.)
Interviews / product information documents
Cost of labour
cost of materials
ease of installation
In depth knowledge about ventilation products, about Covid-19, about the test enviroment and how to measure and finally economical and practical factors
start ventilation design based on the research
The setup
Choose suitable location
Prepare other tools and programms
The base situation
Measurements
CFD simulations
Surveys on comfort
Analysis of the acquired data; check for outliers or particularities
Preparations/analysis to apply the ventilation products
Decentral ventilation
Personalised ventilation
Smart ventilation
Measurements, CFD simulations, surveys on comfort
Analysis of the acquired data
Effecacy matrix of the ventilation system and the products
Final design
p1
p2
p3
p4
p5
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
phase 0 - Conceptualization
phase 1 - Knowledge gathering
phase 2 - Design & analysis
phase 3 - Conclusion

Literature and general practical preference

The scientific papers used:

Cluster 1 - Covid 19 calculating methods

1. Airborne contagion and air hygiene – An Ecological study of Droplet Infections
   Writers: William Firth Wells

2. Airborne spread of measles in a suburban elementary school
   Writers: E.C. Riley, G. Murphy, R. L. Riley
   DOI: 10.1093/oxfordjournals.aje.a112560

3. Risk of indoor airborne infection transmission estimated from carbon dioxide concentration(source)
   Writers: S. N. Rudnick, D. K. Milton
   DOI: 10.1034/j.1600-0668.2003.00189.x

4. Assessing and controlling infection risk with Wells-Riley model and spatial flow impact factor [SFIF]
   Writers: Yong Guo, Hua Qian, Zhiwei Sun, Jianping Cao, Fei Liu, Xibei Luo, Ruijie Ling, Louise B. Weschler, Jinhan Mo, Yinping Zhang
   DOI: https://doi.org/10.1016/j.scs.2021.102719

Cluster 2 - Information regarding reducing Covid-19 spread in classrooms through ventilation

5. It Is Time to Address Airborne Transmission of Coronavirus Disease 2019 (COVID-19)
   Writers: Lidia Morawska and Donald K. Milton

6. Ventilation regimes of school classrooms against airborne transmission of infectious respiratory droplets: A review(source)
   Writers: Er Ding, Dadi Zhang, Philomena M. Bluyssen
   DOI: https://doi.org/10.1016/j.buildenv.2021.108484

7. Recommendations for ventilation of indoor spaces to reduce COVID-19 transmission(source)
   Writers: Chung-Yen Chen, Ping-Hui Chen, Jia-Kun Chen, Ta-Chen Su
   DOI: https://doi.org/10.1016/j.jfma.2021.08.007

8. Ventilation strategies and design impacts on indoor airborne transmission: A review
   Writers: Nima Izadyar, Wendy Miller
   DOI: https://doi.org/10.1016/j.buildenv.2022.109158

Cluster 3 - indoor air quality measuring methods

9. Room-level ventilation in schools and universities(source)
   Writers: V. Faye McNeill, Richard Corsi, J. Alex Huffman, Cathleen King, Robert Klein, Michael Lamore, Do Young Maeng, Shelly L. Miller, Nga Lee Ng, Paula Olsiewski, Krystal J. Godri Pollitt, Rachel Segalman, Alex Sessions, Todd Squires, Sabrina Westgate
   DOI: https://doi.org/10.1016/j.aeaoa.2022.100152

10. CO_2 monitoring to assess ventilation rate: practical suggestions from a laboratory study
    Writers: Dadi Zhang, Er Ding, Philomena M. Bluyssen
    DOI: https://doi.org/10.34641/clima.2022.93

11. Guidance to assess ventilation performance of a classroom based on CO_2 monitoring
    Writers: Dadi Zhang, Er Ding and Philomena M. Bluyssen
    DOI: https://doi.org/10.1177/1420326X211058743

Cluster 4 - decentral ventilation

12. Ventilation Strategy for Proper IAQ in Existing Nurseries Buildings - Lesson Learned from the Research during COVID-19 Pandemic
    Writers: Katarzyna Ratajczak
    DOI: https://doi.org/10.4209/aaqr.210337

13. Natural ventilation strategy and related issues to prevent coronavirus disease 2019 (COVID-19) airborne transmission in a school building
    Writers: Sowoo Park, Younhee Choi, Doosam Song, Eun Kyung Kimd
    DOI: https://doi.org/10.1016/j.scitotenv.2021.147764

14. Variations in classroom ventilation during the COVID-19 pandemic: Insights from monitoring 36 naturally ventilated classrooms in the UK during 2021
    Writers: Henry C. Burridge, Stavros Bontitsopoulos, Christopher Brown, Holly Carter, Katherine Roberts, Carolanne Vouriot, Dale Weston, Mark Mon-Williams, Natalie Williams, Catherine Noakes
    DOI: https://doi.org/10.1016/j.jobe.2022.105459

15. Analysis of different ventilation strategies and CO2 distribution in a naturally ventilated classroom
    Writers: Alvaro Muelas, Pilar Remacha, Antonio Pina, Eduardo Tizné, Said El-Kadmiri, Ana Ruiz, Diego Aranda, Javier Ballester
    DOI: https://doi.org/10.1016/j.atmosenv.2022.119176

Cluster 5 - Smart ventilation based on c02

16. Improving the indoor / outdoor ratio of (ultra)fine particles in a school
    Writers: Van Dijken, Froukje; te Kulve, Marije; Ursem, W.N.J.

17. A novel CO2-based demand-controlled ventilation strategy to limit the spread of COVID-19 in the indoor environment
    Writers: Bingxu Li, Wenjian Cai
    DOI: https://doi.org/10.1016/j.buildenv.2022.109232

18. Evaluation of real-life demand-controlled ventilation from the perception of indoor air quality with probable implications
    Writers: Zakia Afroz, Gary Higgins, G.M. Shafiullah, Tania Urmee
    DOI: https://doi.org/10.1016/j.enbuild.2020.110018

19. Flexible operation of active distribution network using integrated smart buildings with heating, ventilation and air-conditioning systems
    Writers: Tao Jianga, Zening Lia, Xiaolong Jinb, Houhe Chena, Xue Lia, Yunfei Mub
    DOI: https://doi.org/10.1016/j.apenergy.2018.05.091

20. Ventilation and thermal conditions in secondary schools in the Netherlands: Effects of COVID-19 pandemic control and prevention measures
    Writers: Er Ding, Dadi Zhang, Amneh Hamida, Clara García-Sánchez, Lotte Jonker, Annemarijn R. de Boer , Patricia C.J.L. Bruijning , Kimberly J. Linde d, Inge M. Wouters, Philomena M. Bluyssen
    DOI: https://doi.org/10.1016/j.buildenv.2022.109922

Cluster 6 - personal ventilation

21. Personal Control over Indoor Climate in Offices – Impact on Comfort, Health and Productivity - Proefschift
    Writer: Atze Christiaan Boerstra

22. A systematic literature review on smart and personalized ventilation using CO2 concentration monitoring and control
Writers: Ge Song, Zhengtao Ai, Zhengxuan Liu, Guoqiang Zhang
DOI: https://doi.org/10.1016/j.egyr.2022.05.243

23. Air Terminal Devices Developed for Personal Ventilation Systems
Writers: Imre Csáky
DOI: https://doi.org/10.3390/en13071688

24. Personal Ventilation: from research to practical use
Writers: Arsen Melikov, Henning Grønbæk, Jan Bach Nielsen
DOI: -

Cluster 7 - simulation methods

25. CFD modelling of airborne pathogen transmission of COVID-19 in confined spaces under different ventilation strategies
Writers: Hamid Motamedi, Mohammadreza Shirzadi, Yoshihide Tominaga, Parham A. Mirzaei
DOI: https://doi.org/10.1016/j.scs.2021.103397

26. The multi-dimensional challenges of controlling SARS-CoV-2 transmission in indoor spaces: Insights from the linkage of a microscopic pedestrian simulation and virus transmission models
Writers: Dorine Duives, You Chang, Martijn Sparnaaij, Berend Wouda, Doris Boschma, Yangfan Liu, Yufei Yuan, Winnie Daamen, Mart de Jong, Colin Teberg, Kevin Schachtschneider, Reina Sikkema, Linda van Veen,
Quirine ten Bosch
DOI: https://doi.org/10.1101/2021.04.12.21255349

The books used:

27. Ventilation of Buildings by Hazim Awbi

28. Building Services Engineering by David V. Chadderton

29. Naturally Ventilated Buildings by Derek Clements-Croome

30. Industrial Competitiveness and Design Evolution by Takahiro Fujimoto and Fumihiko Ikuine

31. ADAPTIVE THERMAL COMFORT principles and practice by Fergus Nicol, Michael Humphreys and Susan Roaf

32. Thermal Comfort Assessment of Buildings by Salvatore Carlucci

33. Indoor Air Quality The Latest Sampling and Analytical Methods by Kathleen Hess-Kosa

The standards and regulation used:

34. Rehva Ventilation Effectiveness

35. Programma van Eisen Frisse Scholen 2021

36. ANSI/ASHRAE Standard 62.1-2019

37. Het bouwbesluit

38. NEN/ISO norm:
    a. NEN 1087 Ventilatie van gebouwen - Bepalingsmethoden voor nieuwbouw
    b. The ISO 16000 series – indoor air quality

c. NEN-EN 16798-1:2019 en - Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6

Reflection

During my premaster and first year of my master's degree, I was personally impacted by the effects of the Covid-19 pandemic. The university was initially closed and I had to follow classes online. Fortunately, the university was allowed to reopen later on with restrictions in place. However throughout this period of approximately one and a half years, I experienced the negative effects of suboptimal educational conditions, including a lack of access to materials, limited social interaction, and a decrease in concentration. Along with my interest in climate design, I also saw this graduation project as a chance to merge both technical and design elements, as well as a way to help lessen future experiences like the Covid-19 pandemic.

Relevance

In order to effectively address shared spaces in the built environment, this project aims to integrate theoretical research on airborne transmission with practical considerations. The resulting ventilation plan may potentially reduce the risk of breathing air contaminated with viruses while also ensuring the comfort of individuals taking part in social activities. The analyses performed for this study are expected to offer useful guidance on how to address the Covid-19 pandemic in educational spaces and decrease its impacts. As a result, schools will be able to open more swiftly and the adverse consequences that children around the world have been dealing with will be reduced.