

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	Wenyan Cai
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Studio	
Name / Theme	Healthy buildings with smart ventilation integrated in architecture
Teachers / tutors	Peter van den Engel, Regina Bokel,
Argumentation of choice of the studio	The rapid rise in COVID-19 illnesses and deaths globally makes it an urgent situation to figure out a solution to make ventilation systems decrease indoor infectious risks to ensure the initial daily basic behaviors.

Graduation project	
Title of the graduation project	A hygiene ventilation renovation -- Systematic partial engineering control for small sharing room with ceiling mixing ventilation for "corona-proof"
Goal	
Location:	Kuijpers, Leiden, the Netherlands
The posed problem,	What is renovation on partial control level based on air-recirculation mode of indoor end units in Dutch standard meeting rooms with hybrid ceiling mixing ventilation system to decrease the COVID-19 infectious risk by integrating clean-room techniques with indoor comfort and feasible construction considerations?
research questions	<p>In the aspect of the theoretical ventilation design, the airflow distribution pattern is impacted by the specific geometry of the sample room, the air recirculation mode, the location of the ventilation end facilities and brings about the following sub-research questions:</p> <p>A. What would be the positive impacts from partial ventilation controls that practically help decreasing the infection risks indoors?</p> <p>a. What is role of air-recirculation mode at ceiling mixing HVAC end unit in general ventilation efficiency in the small meeting room?</p> <p>b. What is the impact of air recirculation that may cause the secondary pollution in airborne transmission in the small meeting room?</p> <p>c. What is the feasible renovation based on the general office ventilation system in the Netherlands?</p> <p>d. What partial changes in the ventilation ends would help enhancing the virus removal performance of normal filters?</p> <p>The hypothesis is based on a practical renovation context for coronavirus crisis, an existing meeting room of frequent usage even under COVID-19. When facing with the ideal design and practical achievement, there is always limitation in practice. The limitation between the theoretical design and realistic production raise the series of subsequent influences in different scales:</p> <p>B. What is the infectious disease pathology for the airborne transmission in the small meeting room based on existing anti-epidemic policy?</p> <p>a. What is connection between built environment engineering and epidemiology for practical epidemiological control?</p> <p>b. What is the ventilation design reference from the current</p>

	<p>understanding of COVID-19 epidemiological control?</p> <p>C. What is the epidemiological performance of current building system in the small meeting room of a typical Dutch office building?</p> <p>a. What is the mechanical logics of current ventilation system from the central level to the end level of the system to supply clean air?</p> <p>b. What are the main parameters in ventilation engineering that essentially impact the indoor infection risk via airborne transmission?</p> <p>c. What clean-room techniques can be applied in the middle-end HVAC system to decrease the infection risk via airborne transmission, and at the same time achieve requirements from indoor comfort and installation feasibility?</p>
<p>design assignment in which these result.</p>	<p>The expected main products of this work are:</p> <ul style="list-style-type: none"> • An optimal ceiling mixing air distribution pattern for small meeting room in Kuijpers, Leiden, under the current COVID-19 scenario. • An optimal diffuser design at the unit opening in the hybrid ceiling-mixing ventilation in small meeting room in current ventilation condition in Kuijpers, Leiden, under the current COVID-19 scenario. • An anti-epidemic control strategy based on current air recirculation mode in the office HVAC system to maximize the corona-risk-decreased performance of current general ventilation system. • An evaluation matrix with design parameters that balance among corona-risk-decreased performance, ventilation related indoor comfort and energy efficiency in the small meeting room without air-recirculation in Kuijpers, Leiden, under the epidemic prevention policy. • An adjustable parameter matrix (for example, the air flow rate, outside air fraction and airflow direction) of the substitutional model for standard offices in the Netherlands when facing with respiratory infectious diseases, like COVID-19. • A design workflow for the renovation products, including production, installation, regulation and maintenance. <p>Because of the dynamic design elements, like layout of the room, indoor activities and breathing modes, the ventilation design may not suitable for all the small public communal spaces similar to the meeting room in Kuijpers, Leiden, but will provide a neoteric and practical view for them and other public spaces.</p>
<p>The main objective of this project is bridging the gap between theory and practice by intersecting knowledge base of indoor airborne transmission, general ventilation efficiency researches and computational indoor airflow dynamics modeling within a specific real common design case, a middle-and-end air circulation filtration control strategy in ventilation system for the small meeting room in Kuijpers, Leiden. This research offers a substitutional operation model when facing with infectious expiratory diseases for the public buildings, like offices, with medium hygiene requirements but sometimes high occupant density in small groups for low-activity-level long staying. The research should explore the possible innovation methods and constraints within efficient ventilation strategy to meet the indoor comfort when cutting off the direct indoor air circulation at the hybrid HVAC system end AHU in ceiling mixing ventilation air distribution pattern.</p> <p>The sub-objectives of this research are:</p> <ul style="list-style-type: none"> • Clarify the design constraints for airborne transmission based on different characteristic of particles (in this case, COVID-19 virus-laden droplet nuclei) in common Dutch offices. • Measurement and evaluation of the current indoor comfort and ventilation efficiency of ceiling-mixing air distribution methods with the air-recirculation AHU in the small meeting room in Kuijpers, Leiden. • Evaluation of the possibility of secondary pollution caused by the air recirculation mode in ceiling-mixing indoor end unit in the small meeting room in Kuijpers, Leiden. • Visualization of the infection risk level in the small meeting room in Kuijpers, Leiden under different ventilation designs by a boundary value, the average virus concentration of "acceptable infection risk". • Analysis and evaluation of the relationship between corona-risk-decreased performance and ventilation efficiency of different ventilation strategies applied in the small meeting room in Kuijpers, Leiden with the ceiling-mixing air distribution and direct indoor air recirculation. • Analysis and evaluation of the ventilation-related indoor comfort of the optimal ventilation design in the 	

small meeting room in Kuijpers, Leiden with ceiling-mixing air distribution and direct indoor air recirculation, while keeping the same fresh air supply and temperature conditioning parameters.

- Exploration of complementary partial ventilation control strategies that can maximize the corona-risk-decreased performance but meeting standard ventilation-related indoor comfort requirements by integrating ventilation technologies for clean rooms.
- Development, design and limited practice of the ventilation system model for the same small meeting rooms in the Netherlands as the one in Kuijpers, Leiden, considering actual corona-risk-decreased feasibility, construction trends, first renovation capital, adjustability based on local construction market.

Process

Method description

This graduation project starts with the research phase. Parameters for the research were established and it was conducted in four major blocks:

The characters of virus nuclei-laid particles and COVID-19 transmission patterns;

The impact of ventilation patterns on airborne transmission;

The indoor comfort codes and latest hygiene requirements for offices or meeting rooms from the Netherlands and global organizations

The clean-room techniques for precise instrument manufacture and medical security health care.

The research uses ScienceDirect database, ResearchGate database, online bouwbesluit, TU Delft repository and offline onsite excursions of the meeting room in Kuijpers and Johnson & Johnson's COVID-19 vaccine factory in Leiden.

Search inputs:

The articles/books had to be published recently, from 2003 onwards. Because COVID-19 (also called SARS-CoV-2) shows the same transmission features as SARS-CoV-1, Beijing SARS, 2003, and a lot of researches about respiratory infectious diseases or airborne transmission is based on that condition. A lot of new researches developed as COVID-19 crisis spreading throughout the world and causing serious loss.

Key words:

COVID-19; respiratory infectious disease; infectious risk; corona virus; epidemic prevention; anti-epidemic policy;

Airborne transmission; air distribution; total volume ventilation, personalized ventilation; body flow; HEPA filter; mixing ventilation;

Online bouwbesluit; ASHREA; office ventilation; hybrid ventilation; fan coil unit; ventilation efficiency; air age; mean concentration rate; CO2 concentration;

Clean room design; ventilation shadow; HVAC diffusers; ventilation grills; UV lighting

Expected results from this phase are the knowledge base of COVID-19, airborne transmission, ventilation efficiency and ventilation for offices, evaluation methods and draft design parameters

The second phase is experiment phase to figure the current ventilation condition (including general mechanical system and air-recirculation pattern at end units) of the typical sample, the small meeting room in Kijpers, Leiden. The research is a fundamental experiment based on the real situation to collect the first-hand input data, check the accuracy of the computational modelling in Phoenics and understand the role of air recirculation in real anti-epidemiological ventilation design. The initial objectives of this phase:

To understand the working mechanism of HVAC end unit for offices: HVAC system for commercial usage usually is more complicated than idea model, with extra consideration of indoor comfort and energy efficiency. The final design product should also put economy and practicality into consideration not only focusing on the corona-risk-decreased performance.

For the accuracy: All the CFD analysis is trying to simulate the real situation for the possible future designs. The experiment will provide a database for reality-based simulation and accuracy corrections.

To conclude a standard steady situation from the dynamic reality: The meeting room in Kuijpers, Leiden, with standard size, layout and ventilation pattern, is regarded as the typical small-scale meeting room in offices to analyse. But the real situation is under a dynamic mode under the intermittent operation based on the smart building control system. It is important to do a long-term observation to transfer the dynamic real condition to a general static simulate case during the working hours.

To test secondary pollution possibility at indoor end units: The air recirculation mode reuse the polluted room air to well mix the fresh supply air in this mixing ventilation pattern. The real secondary pollution possibility for this mixing ventilation in the small meeting room is uncertain yet.

The experiments focus on the indoor air quality indicators that directly influenced by the ventilation system, including airflow rate, CO₂ concentration and particle concentration in the breathing zone and at the ceiling level. A series of measurements for Indoor Air Quality were done for the small meeting room –a needy shared place under COVID-19 crisis. These types of measurements were done by using HOBO data loggers (a meter for CO₂, temperature and humidity), an Air Velocity meter and a particle counter.

The three experiments were done in three different times and with different purposes:

pre-research phase to understand the building system;

test phase to explore the indoor infection of the air recirculation mode at the indoor end unit;

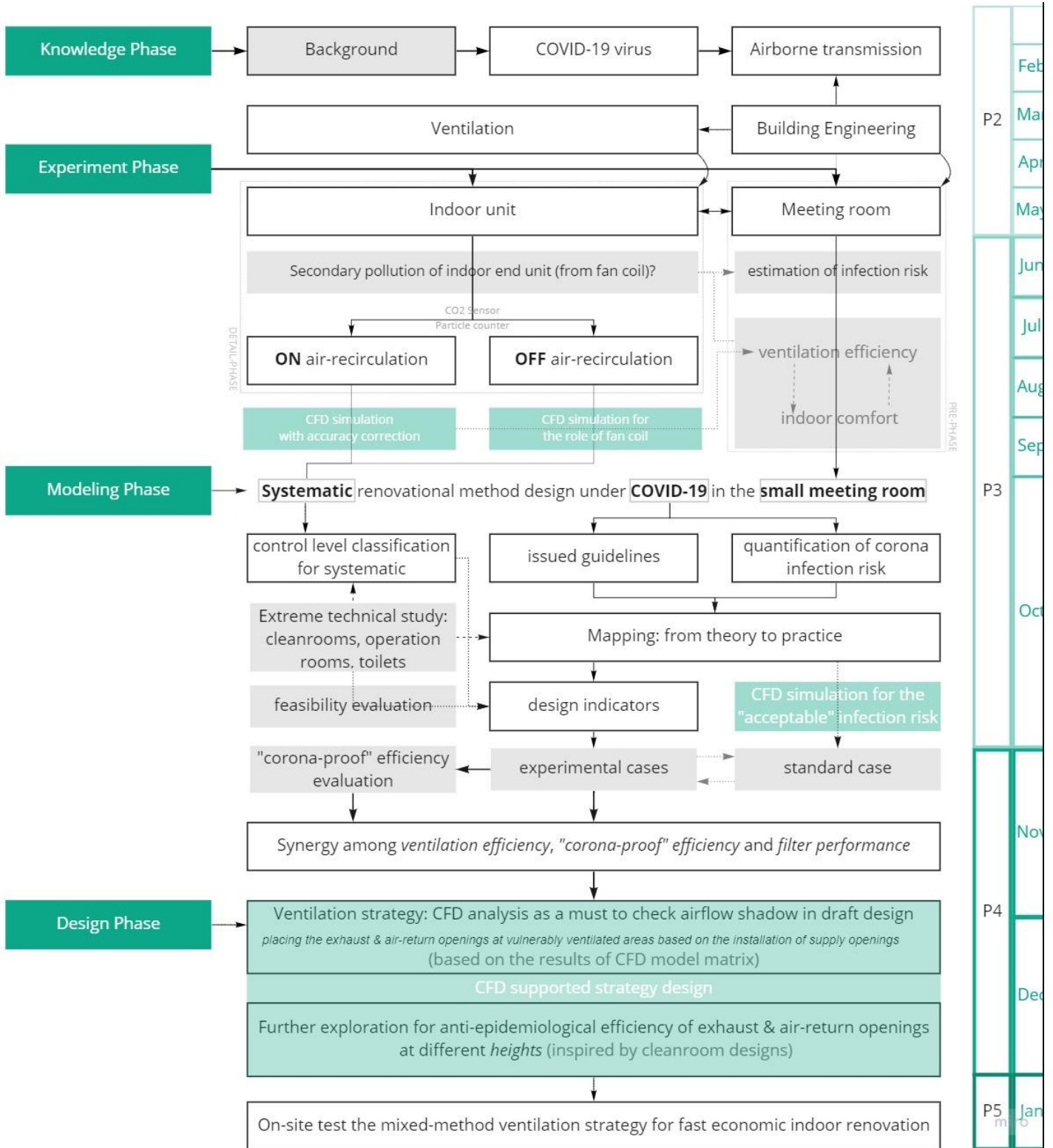
product phase to evaluate the real anti-epidemiological performance of the research outcomes.

And the measurement results were analysed by multiple methods:

General data analysis via graphs, Wells-Riley calculation, contaminant removal efficiency calculation, air change efficiency calculation and the Draught Rate (DR) equation from the NEN-EN-ISO 7730 (2005).

During the third phase, CFD (Computational Fluid Dynamics) modeling of the indoor end unit in the ceiling mixing ventilated sample meeting room is done in Phoenix for current ventilation efficiency performance and for further prediction of particle movement. With the initial simulation accuracy achieved, the predictions are further compared and analyzed to obtain ventilation results with a high level of protection against epidemics. The relationship among general air distribution pattern, air recirculation mode at the end control level and extra optimization from local filter will be explored by the computational simulation. And further discussions about the ventilation efficiency and infection risk quantification will be based on the earlier simulation results. In that way, the efficacy of epidemic prevention can be analyzed based on comparison of the predictions on ventilation airflow routes, mean and local air ages and mean and local contaminant concentration rate of tracer gas under different ventilation strategies with a matrix of control variants. Assessment of indoor comfort, estimation of construction feasibility, establishment of an infection risk assessment system based on parameters from the research phase results are followed after the CFD simulation.

The fourth phase is to integrate the simulation result, an optimal efficacy of epidemic prevention, with clean-room techniques and existing ventilation guidelines from research phase results, a high-end ventilation method. The retrofit design is to decrease the ventilation shadow of occupants and direct ventilation flow to avoid them in any other occupant's ventilation shadow. Because it is a practical renovation design, feasibility study, including market demanding, assembly and cost forecast, on the construction market is needy.



Literature and general practical preference

The experimental ventilation design is based on a compromise between experimental resources, airborne transmission theories, the current ventilation system and operation mode of a real room. The main efforts will focus on the corona-virus exposure rate of occupants under current anti-epidemic policies. There are four main phases in the research program for the ventilation design:

Knowledge Phase:

Literature research of airborne transmission, traditional efficient ventilation design and clean-room ventilation design;

Experiment Phase:

Onsite experiment and analysis of current ventilation conditions in the meeting room in Kuijpers, Leiden;
Experimental test of the possible secondary pollution at the indoor end unit through air recirculation mode;

Simulation Phase:

Computational simulations of current ventilation conditions in the meeting room in Kuijpers, Leiden;
Setting a standard case with the well-mixing and symmetrically distributed airflow pattern as the initial reference for the infection risk calculation and evaluation;
Predictive computational simulations of ventilation conditions with different air-recirculation setting and total airflow routes on the ceiling level in the meeting room in Kuijpers, Leiden, to sketch out the essential engineering parameters for epidemiological ventilation design;

Design Phase:

Strategy design referring to clean-room techniques and other advanced building engineering to improve the anti-epidemic performance;
Renovation design based on optimal ventilation parameters with the maximum feasibility for commercial purposes;
Detail adjustments for the indoor comfort under the maximum operation of the existing whole ventilation system when applying the conclusive strategic renovation design.
This research is based on human health, thus, epidemic prevention and indoor comfort are the design priorities. While, the renovation efficiency and construction costs are of third or fourth importance. They will be taken into consideration based on the marketing experience and experimental results.

Reflection

Relevance

As it was mentioned before, the aim of this project is to combine the theoretical airborne transmission researches with the practical general gathering spaces. The corona-risk-decreased ventilation strategy for a shared space could consequently decrease the risk of being exposed to the possible virus-laden indoor airborne and be comfortable for people in the necessary social activity. The project has two phases: in response to the on-going outbreak, rapid analyses will provide actionable advice for health care professionals, crisis managers, and logisticians responding to the Covid-19 epidemic. In a second phase, the project will focus on tying together the learning from this outbreak and develop a suite of open-source tools and methods to prevent help contain and mitigate the effects of (future) epidemics and pandemics outbreaks.

Time planning

For this interdisciplinary graduate research, the graduation plan for the 15 months is schemed as below:

P1

Nov 2020 - Choosing the graduation topic;
Methodology learning and exploration of multiple research methods.

Dec 2020 - Literature study of ventilation basis, COVID-19 virus, airborne transmission and indoor air distribution patterns.

P2

Feb 2021 - Literature study of building engineering for disease prevention, droplet & airborne transmission, virus nuclei-laid particles, personalized ventilation and total volume ventilation.

Choosing the design spatial scale, a typical Dutch small meeting room.

Mar 2021 - Literature study of Wells–Riley formula, Rehva Ventilation Effectiveness calculation, HEPA filter, clean room knowledge basis.

Draft modeling practice in Phoenics of different air distribution patterns.

On-site excursion of Johnson & Johnson's COVID-19 vaccine factory in Leiden.

Apr 2021 - Experiment and measurement of the air quality in small meeting room under the regular operation mode in Kuijpers, Leiden.

- Documentation of measurements and long-term observation of the operation modes of the sample meeting room.

May 2021 - Literature study of indoor end unit and hybrid HVAC system.

Clarifying the research question about air recirculation pattern of air handling unit in ceiling mixing ventilation system.

Documentation of front phase research results.

Draft design based on assumption that avoiding air recirculation will decrease the infectious risk.

P3

Jun 2021 - CFD simulation of current sample meeting room with accuracy correction referring to the measurement results.

Building up the air-recirculation model in the Phonics with the help from Peter van den Engel and the CHAM team.

Literature research about CO₂ as the tracer gas in on-site experiments and computational simulation.

Jul 2021 – ON/OFF air recirculation experiment in the sample meeting room in Kuijpers, Leiden by particle counter and CO₂ meters.

Literature study about the mechanical logics about mixing ventilation and its efficient performance.

Aug 2021 – Analyzing the ON/OFF air recirculation experiment results for the impacts from air recirculation at the indoor end unit in the sample meeting room

Modeling the ON/OFF air recirculation experiment for the accuracy correction of the CFD analysis method.

Sep 2021 – Systematic mapping of the relationship among pathology, engineering and theoretical ventilation design.

Literature study about quantification of corona infection risk.

Literature study about the current issued guidelines.

Oct 2021 - Literature review of building engineering for disease prevention and advanced ventilation techniques for clean rooms.

Feasibility evaluation.

Classification of the control level in ventilation system based on the understanding of the whole building system.

Selecting the variant matrix in CFD simulation for an optimal ventilation strategy.

P4

Nov 2021 - Detail design in the mid-end HVAC system.

Analyzing the CFD modeling results.

Strategy design based on the optimal ventilation conditions from CFD modeling.

Practical design based on the simulation and evaluation matrix results.

Commercial design for assembly, operation and maintenance.

Dec 2021 - Testing the design results in CFD and through on-site experiments in the sample meeting room.

Documentation of all the research results

P5

Jan 2022 - Documentation of all the research results.

Final presentation.