# Rethinking Natural Ventilation Strategies in Buildings through Simulation

Merve Coşar[1], Gülsu Ulukavak Harputlugil[2], Pieter De Wilde[3]
[1]Hilmi Güner Architecture, Ankara, Türkiye
[2]Çankaya University, Ankara, Türkiye
[3]Starthclyde University, Glasgow, UK.

## Abstract

Natural ventilation using passive approaches can increase indoor air quality without the need for mechanical systems. In the paper, mechanical ventilation has been ignored due to the associated energy use and greenhouse gas emissions. Instead, the study focusses on natural ventilation that can be created with architectural solutions. Specifically, the indoor air quality of a typical office building in Ankara, Türkiye was determined based on measurements, a building occupant survey, and the natural ventilation conditions as well as design alternatives were analysed by modelling and simulating the building using Autodesk CFD. From the simulation results, it was understood that current form of windows were not found suitable for effective and sufficient natural ventilation. As a result, not only design strategies that will increase the natural ventilation potential are put forward, but also strategies for façade elements have been produced in means of wind catchers.

## Highlights

- Natural ventilation using passive approaches can increase indoor air quality
- CFD simulations for natural ventilation give appropriate results for design strategies
- Façade elements in means of wind catchers will enhance natural ventilation potential for current buildings

## Introduction

Modern human beings spend most of their lives inside buildings. This makes indoor air quality an important issue: for people to live healthy, comfortable and productive lives, indoor spaces should provide suitable and desirable conditions in terms of user comfort and human health. Personal and environmental parameters are important factors that determine user comfort and health indoors. Natural ventilation, one of the passive energy systems, allows buildings to ensure indoor air quality without the need for mechanical systems. In today's buildings, the goal is to use passive energy systems whenever possible due reliance of active systems fossil energy and the related greenhouse gas emissions.

With natural ventilation, indoor air quality is maintained through a supply of fresh air to the interior of the building, while energy efficiency is ensured by not using any mechanical system, thus reducing the damage of buildings to the environment. However, designing natural ventilation systems is challenging. Typically, air flow is driven by small pressure differences across windows, doors and similar openings, which are caused by wind and stack effect. The associated air velocities are mostly low. The impact of this ventilation on local indoor air quality depends on a range of contextual factors, such as presence of sources of air pollution and mixing of air.

The aim of this paper is to explore design strategies for natural ventilation by combining literature studies, field studies and CFD simulations on the concepts of indoor air quality, user comfort in indoor spaces, human health, and natural ventilation.

## Literature Review

This section presents the results of literature research on indoor air quality and indoor user comfort, which provide a background for a detailed case study.

### Indoor Air Quality

Indoor air quality is a prime consideration in architectural, structural and environmental design development (Senitkova 2016:2). People now spend most of their time indoors. For this reason, when indoor air quality becomes dangerous for human health, catastrophic results occur (Karaman 2013:6). According to ANSI/ASHRAE Standard 62.1-2022, published in 2022 by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, "acceptable indoor air quality is defined as air "*in which known pollutants do not exceed harmful concentration levels*" and for which "*at least 80% of the people not express any dissatisfaction with the indoor air quality*". According to this definition, in order for the indoor air quality to remain at a reasonable level, the components that make up the air should be considered in the context of a healthy environment as a whole.

The specific chemical, biological and physical properties of the substances that cause indoor air pollution should be considered, along with the concentration levels. The level of indoor air quality has varying degrees of influence on occupants and also depends on the number of occupants, the length of time they have been indoors, and their health history. It is possible to group indoor air pollution sources under the following 5 main headings: i) location of the building, ii) building materials, iii) building furniture, iv) chemical materials used in the building and v) user habits and behaviors (Awbi, 2019).

Although the factors that determine indoor air quality are interrelated, they also affect the rates of pollutants that

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cause indoor air pollution (Darçın 2008:37). To improve indoor air quality:

i) The ambient temperature value should be within the user comfort limits,

ii) Material selection should be done in such a way as to ensure that the surface temperature of the indoor materials is close to the air temperature,

iii) The relative humidity should be within the user comfort limits. However, relative humidity can also cause mold formation on the surfaces and disrupt the chemical components of the building materials in the environment. Therefore, in order to prevent the proliferation of micro-organisms and mold, the relative humidity should be in the appropriate range (Akman 2005: 89-92),

iv) The indoor air movement speed should not be at a level that will disturb the user, but at the same time it should be in a direction that will ensure fresh air is brought into the interior (Darçın 2008: 37),

v) Magnetic and electrical field formation that will adversely affect the user's health in the indoor environment should be prevented (Darçın 2008:37),

vi) While planning the city, the climatic values of the region, the land elevations, the prevailing wind direction should be considered, and the settlements of different city functions should also be considered (Darçın 2008:37),

vii) If there is radon and asbestos in the land structure, it should be prohibited to build on those land (Balanlı & Taygun, 2005; Balanlı, Vural & Tangun 2004).

viii) Products containing pollutants and emitting pollutants should not be selected as construction products (Balanlı and Taygun, 2005; Balanlı, Vural & Tangun 2004).

ix) It should be ensured that indoor air mixtures do not adversely affect user health (Darçın 2008:38).

### Indoor Comfort and Well Being

The main purpose of buildings is to provide an environment where people are more comfortable, safe and productive than the external environment (Sezer 2016:12). Personal and environmental parameters are factors that determine user comfort and health in indoor spaces (Çağlar 2020:65). In order for the users to stay comfortable, healthy and productive, these environmental and personal parameters should be in the appropriate value range. Environmental parameters are: thermal comfort, visual comfort, aural comfort and indoor air quality. Heat, humidity, air movement, cleaning (Filtering), and fresh air intake should all be in the appropriate ranges in terms of providing indoor quality (Kutlu 2018: 71).

Due to the airborne transmission of COVID-19, the concept of indoor air quality in indoor spaces has recently been reconsidered. Leading organizations such as REHVA, ASHRAE, CIBSE and the World Health Organization have published several studies on indoor ventilation in order to create a healthy environment in the context of COVID 19. The World Health Organization published a guide on March 1, 2021 titled “Roadmap to improve and provide indoor ventilation in the context of COVID-19”. This guide was developed through the work of the Environmental and Engineering Control Expert Advisory Panel (ECAP) and the World Health Organization (WHO) Health Network Technical Science for COVID-19. This study aims to reduce the risk of spread of COVID-19 by suggesting natural ventilation indoors. It also includes up-to-date advice on how to evaluate and measure different parameters, particularly in healthcare, non-residential and residential settings. (WHO 2021). In the COVID-19 Ventilation Guide published by CIBSE, the transmission routes of COVID-19 were explained and suggestions were made to reduce the risks. These recommendations also include strategies for mechanical and natural ventilation. They offer ventilation recommendations for spaces without affecting the indoor thermal comfort level, especially in winter (CIBSE 2020: 5). REHVA has published a study with recommendations for improving building service systems during a coronavirus disease outbreak to reduce the risk of COVID 19 transmission due to heating, ventilation and air conditioning systems. In this study, precautions related to building services are discussed. The building functions within the scope of the study are limited to being commercial and public. Residential buildings are not included in this study. The study focused on measures that can be taken by reducing human density in existing structures during or after the epidemic (REHVA 2021).

## Methodology

Indoor air quality is of great importance for the places to create a healthy environment for people. As literature review revealed that IAQ is complex and highly context-specific. There is a need to evaluate the subject with both objective data based on measurements and subjective data based on questionnaires and interviews. For existing buildings, it is possible to measure IAQ using surveys and monitoring, but for designing new buildings or to plan retrofits, it is a need to rely on computational tools (CFD).

In order to merge information gathered from current status of the building and renovation possibilities for improvement of ventilation strategy, this paper explored a specific case study. An office building in Ankara has been chosen as it is a two-story independent office building and therefore its use and operation is unique. Since this building is an independent unit, it was also easy to analyze the current situation and create design alternatives.

Regarding to collecting data for the office building, a survey and several interviews were done with the occupants. User satisfaction of ventilation for both winter and summer time revealed a clue for the ventilation strategies. Besides, monitoring indoor air quality by means of $CO_2$ levels, air flow rate and indoor temperature were the data to determine current situation quantitatively. CFD simulation model (base model) was generated by the data collected by monitoring. Design strategies were proposed by modified/improved base model in simulation.

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### Case Study: Office Building in Ankara

The office building used for a case study is Hilmi Güner Architecture Office. This building is located in the Yaşamkent district of Çankaya in Ankara, the capital city of the Republic of Turkiye. There are mainly residences, green areas and vacant lands in this region. The buildings around the office are mostly 7 floors. The prevailing wind direction is northeast (Figure.1).

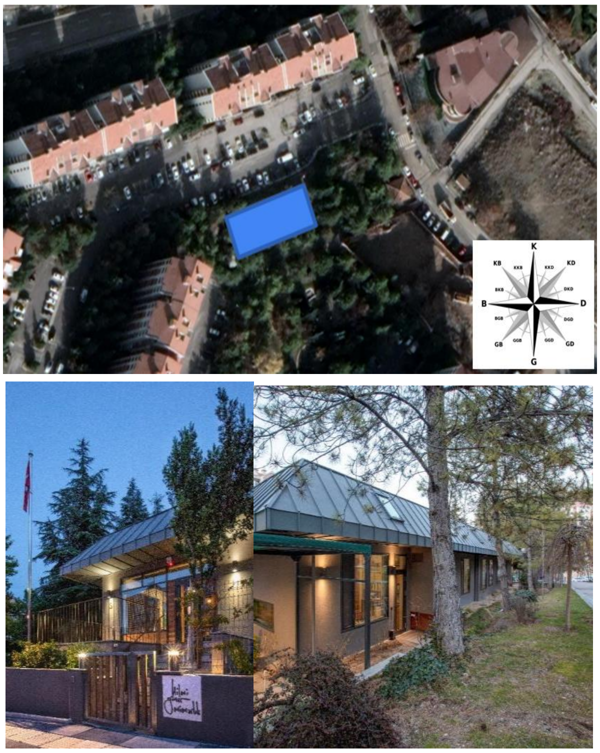


*Figure 1: Office satellite view and photographs from outside.*

In Figure.1 photographs and satellite images of the office and its immediate surroundings are given. The south facade of the office is overlooked by high pine trees. The north façade includes the entrance of the building, and there are parking spaces and a vehicle road. The office consists of 2 floors: the ground floor and the basement floor. The ground floor of the office has an area of approximately 470 m² and consists of an open office, single and double office rooms, meeting rooms and service areas (Figure.2).

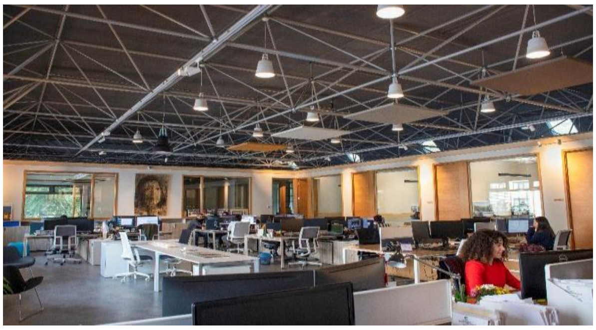


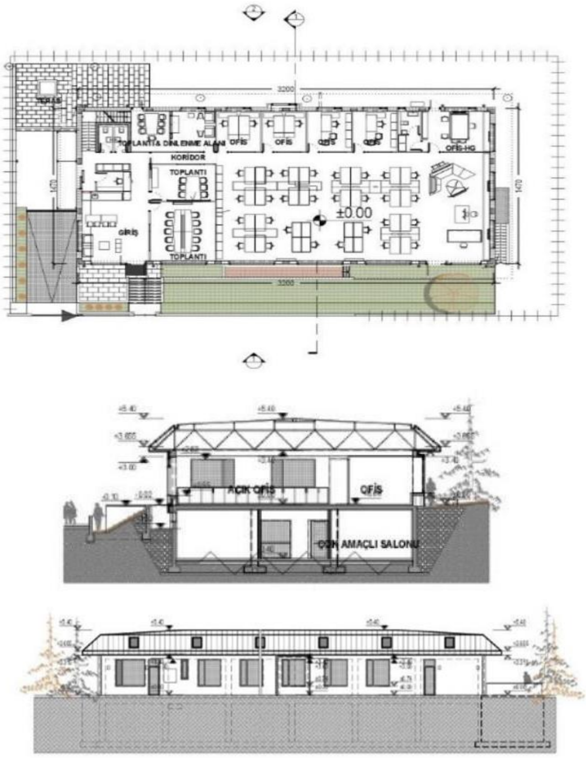
*Figure 2: Photograph of open office area.*

The open office space has a capacity of 29 people to work. However, due to the COVID-19 epidemic, only 21 people work in the open office in order to reduce the density. In the basement of the office there are a dining hall, kitchen, resting area, printing area, prayer room, multi-purpose hall and conference spaces. Due to the COVID-19 outbreak, the multi-purpose hall space has reduced its staff in the open office, and this space has been used as an open office. While conducting the user survey and indoor ventilation efficiency survey, indoor air quality monitoring and simulations, the basement floor of the multi-purpose hall was used as an open office. The roof of the office is crossed with steel trusses. As can be seen in the office section, this situation causes the interior to gain more height than the standard floor height. The north and south facades are the long facades of the office and have large glass surfaces. However, the ventilation openings of windows are limited compared to the whole facade ratio. There are 6 skylights in the north and 2 others in the south, which are used especially for open office ventilation. The plan, sections and the elevations are given in Figure.3.

### Occupant Survey and IAQ Measurements

While exploring the current indoor air quality of the office building, two steps were taken: 1) 'User Satisfaction and Indoor Ventilation Efficiency Survey' applied to office employees, 2) Indoor air quality monitoring for ventilated and non-ventilated periods.

The questionnaire applied to office building employees was conducted in order to find out user satisfaction regarding indoor air quality. When the survey conducted with the users in the office building and the indoor air quality monitoring results are evaluated together, both were found to be consistent.



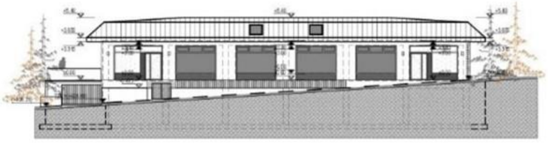


*Figure 3: Plan, section and elevations of the office building.*

Roof windows are used for natural ventilation in the ground floor open office. Since 21 people are working in the open office, not every user can be provided with their own control for heating-cooling and ventilation. Therefore, it was revealed from the monitoring results that, the temperature and $CO_2$ rate decreases with user-controlled ventilation hours which are usually during lunch breaks. However, after windows are closed, rate of $CO_2$ level increases again. Opening sashes on the façade are used in single rooms. At the same time, the control of heating and cooling in these rooms fully controlled by the user. Upon examination of the monitoring results for the space, it was found that the users ventilate the area frequently, and thanks to the temperature control within the space, there was no dissatisfaction with the comfort level. The survey results indicated that users in single-person offices were satisfied with the indoor air quality. However, due to the lack of ventilation openings in the basement open office, the $CO_2$ concentration increased rapidly towards the end of working hours. The majority of respondents who reported discomfort in the survey were employees working in the open office. Indoor air quality measurements were conducted to gain insight into the current air quality, and survey evaluations were performed to understand user satisfaction. These findings provided valuable information on natural ventilation design strategies, which will be further discussed in the next part of the study.

## Improvement of Indoor Air Quality Through Natural Ventilation

In this part of the paper, simulation-based analysis was used to develop strategies for improving indoor air quality through natural ventilation in the ground floor open office space,. In these simulations, the Autodesk CFD program was used to analyze data on indoor air movement and thermal comfort in the current situation and to develop recommendations based on current air movement.

### CFD Simulation

Autodesk CFD software is a computational fluid dynamics simulation tool that engineers and analysts use to calculate how liquids and gases will behave. This software is used to simulate 3D fluid flow and heat transfer through computational fluid dynamics (Autodesk, 2023). The software is based on partial differential equations governing fluid flow and heat transfer, the continuity equation, the Navier-Stokes equations, and the energy equation (URL-1). The software is mostly used by mechanical engineers and includes the following simulations to help engineers: electronic cooling, data center design, lighting design, machinery and valves, AEC/MEP for HVAC design (Autodesk, 2023). The indoor air movement, thermal comfort and natural ventilation potential of the office building were investigated with this CFD software. By means of simulation, it has been possible to evaluate the current situation of air movements and thermal comfort and to carry out effective design studies that can increase the natural ventilation potential.

### Modelling

In order to model the office building in the CFD program, the location of the office and the prevailing wind direction were determined and a model was created accordingly.

In the simulations, winter and summer conditions were evaluated separately. The reason for choosing the date 22.12.2021 for winter conditions is that it is the date when the air temperature is the lowest during the monitoring of indoor air quality. Accordingly, the date 29.08.2021 was chosen for summer conditions since it was the hottest date of the year.

According to these dates, the wind direction for the winter season is mainly northeast and its velocity was 8.3 m/s. For the summer season, the wind direction is taken as northeast and its velocity was 7.76 m/s.

The models utilized in the scenario incorporate a 100% and 10% opening of the skylights for the baseline air flow simulations in winter. Two different models were developed for these two simulation scenarios, in which the only openings used in the building were skylights.

In the air flow scenario model for the summer season, the model was completed with both skylights and other openings in the building, which were assumed to be 100% open during the summer season.

### Simulations

The simulations were evaluated under 3 conditions, and separate evaluations were carried out for summer and winter conditions. These are: i) simulations of indoor air flow and ventilation strategies for the current situation, ii) Current indoor thermal comfort simulations, iii) Design simulations developed for indoor air flow. The simulation process flowchart is given in Figure 4. As can be seen in the figure, each step of the flow, there are several scenarios applied to CFD base model. This study only focuses to the design proposal scenarios.

In the current model of the building in Autodesk CFD software, the air mass is assigned according to the width, depth and height dimensions of the structure. After entering the wind speed data in the direction of the prevailing wind of this air mass, the pressure data was entered on the plane opposite the wind direction. Since external pressure data could not be obtained, the pressure was accepted as 0 Pa. in all simulations made within the scope of this study. The simulation inputs are listed in Table.1. The winter and summer time air conditioning system temperatures were set as 30°C and 18°C, respectively. Besides, the indoor temperatures which were measured during winter and summer have been set as the measured values; for winter 22.7 °C and for summer 25°C.

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Figure 5 depicts the boundary condition values utilized in the current winter season simulations. For these simulations, volumetric flow and temperature calculations were performed for both the air conditioner and the 10% open skylights. Heat transmission coefficient values for the building envelope and facade were input into the software, as well.

*Table.1: Input values of simulation models.*

| **Inputs** | **Values** |
|---|---|
| Heat gain | 60 Watt / person |
| Volumetric Flow | 10 m3/sn |
| Temperature (air conditioner) | 18°C (sum.) /30°C (win.) |
| Volumetric flow (wind) | 7.76 m3/sn |
| Temperature (wind) | 36°C |
| Heat Transfer Coefficient | 0.13 w/mK |
| Pressure | 0 Pa |
| Indoor temperature | 25°C (sum.) /22.7°C (win.) |

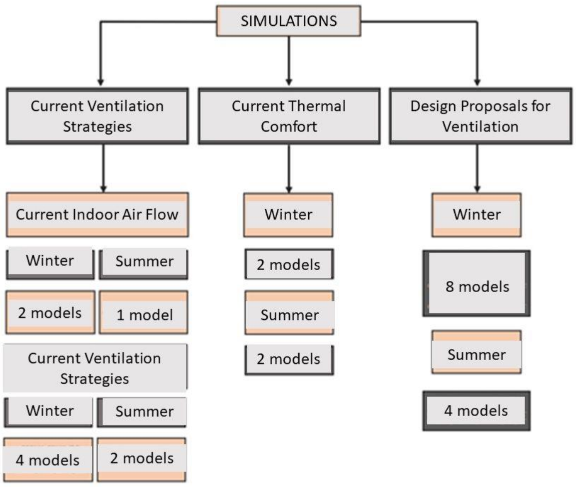

*Figure 4: Flow chart of the simulations.*

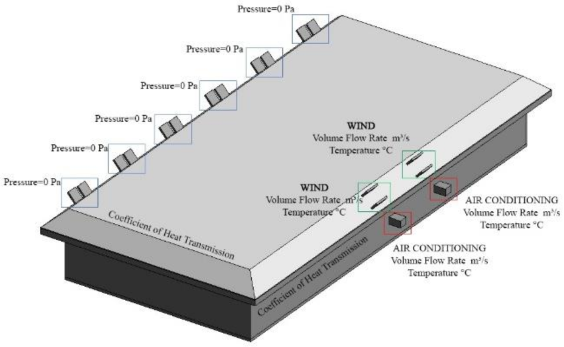

*Figure 5: The input values and boundary conditions of the simulation in the winter season.*

*Table 2: The codes of simulation scenario.*

| **The Codes of Each Scenario** | |
|---|---|
| **RRW** | **R**oom **R**oof **W**indow |
| **OW** | **O**ffice **W**indow |
| **RW** | **R**oof **W**indow |
| **IDC** | **I**nterior **D**oors **C**losed |
| **IDO** | **I**nterior **D**oors **O**pen |
| **100** | **100**% open window |
| **50** | **50**% open window |
| **10** | **10**% open window |
| **P** | **P**osition of the window |
| **S** | **S**ize of the window |
| **WC** | **W**ind **C**atcher |

In Table.2, the simulation codes are given based on the scenario it belongs. The simulations for indoor flow in the current situation and natural ventilation strategies made with Autodesk CFD, analyzes the situation where only the skylights are 100% open and 10% open. The models for current ventilation strategies that were executed are listed in Table.3.

*Table 3: The list of current ventilation strategies simulation codes.*

| **Scenario Codes** | **Seasons** | **Wind Direction** | **Wind Velocity (m/s)** |
|---|---|---|---|
| RRW100_0W100_IDC | Winter | NE | 8,3 |
| RRW10_0W50_IDC | Winter | NE | 8,3 |
| RRW100_0W100_RW100_IDC | Winter | NE | 8,3 |
| RRW50_0W50_RW50_IDC | Winter | NE | 8,3 |
| RRW100_0W100_IDC | Summer | NE | 7,76 |
| RRW100_0W100_RW100_IDC | Summer | NE | 7,76 |

*Table 4: The list of alternative ventilation strategies simulation codes.*

| **Scenario Codes** | **Seasons** | **Wind Direction** | **Wind Velocity (m/s)** |
|---|---|---|---|
| ORW100_RRW100_0WS100_IDO | Winter | NE | 8,3 |
| ORW10_RRW10_0WS50_IDO | Winter | NE | 8,3 |
| ORW10_RRW10_OWP50_IDO | Winter | NE | 8,3 |
| ORW100_RRW100_OWP100_IDO | Winter | NE | 8,3 |
| ORW100_RRW100_0WS100_IDO_WC | Winter | NE | 8,3 |
| ORW10_RRW10_0WS50_IDO_WC | Winter | NE | 8,3 |
| ORW10_RRW10_OWP50_IDO_WC | Winter | NE | 8,3 |
| ORW100_RRW100_OWP100_IDO_WC | Winter | NE | 8,3 |
| ORW100_RRW100_0WS100_IDO | Summer | NE | 7,76 |
| ORW100_RRW100_OWP100_IDO | Summer | NE | 7,76 |
| ORW100_RRW100_0WS100_IDO_WC | Summer | NE | 7,76 |
| ORW100_RRW100_OWP100_IDO_WC | Summer | NE | 7,76 |

Apart from the simulation of existing ventilation strategies, scenarios for applications that can be made to improve ventilation in the existing building are also modeled. Accordingly, the improvement results were evaluated with 12 different scenarios obtained by i) enlarging the window sizes for ventilation, ii) changing the position of the windows on the wall, and iii) applying the wind catchers. The codes of the scenarios are given in Table.4. There is a wider set of simulations were collected, however, for this paper, only the results obtained with wind catcher applications are discussed.

## Wind Catchers

As a strategy to improve natural ventilation, wind catcher elements are installed in front of the open office facade windows, as shown in Figure 6, to allow for better airflow. In the detail of the wind catcher given in Figure 7, the perforated panel placed inside the box profile frame is mounted on the box profile of the joinery. The perforated panel inserted into the box profile can be replaced with panels with different materials and spaces. The angle of the wind catcher can be adjusted according to the direction and strength of the wind during the day with the rails at different angles placed on the hard ground at the landscape level. The wind catcher element in 4 different lengths also has a modular system and can be lengthened and shortened based on the requirement.

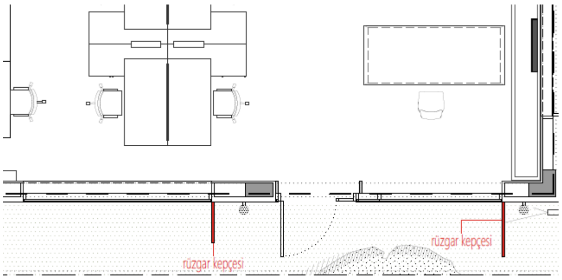

*Figure 6: Wind catchers.*

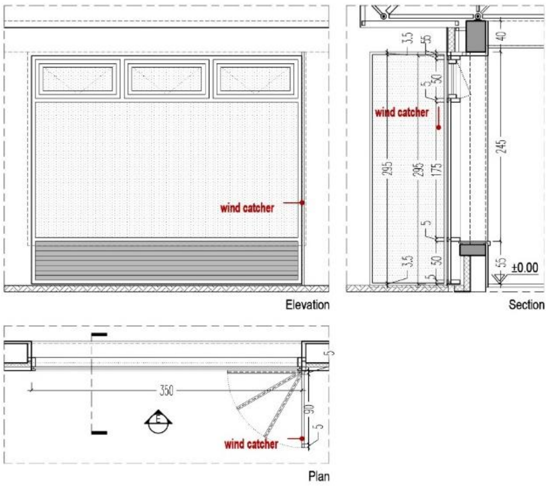

*Figure 7: Details of wind catchers.*

When a wind catcher applied to the current windows, a significant amount of fresh air taken indoors was observed. By wind catcher, it is seen that air flow caused by the wind within the office has increased (Figure 8). However, this situation negatively affects the indoor comfort conditions in the winter season. Therefore, the choice of this strategy for short-term ambient ventilation is important in terms of user comfort.

<u>*ORW10_RRW10_0WS50_IDO_WC*</u>*:* In this simulation, the wind catcher element was implemented with the window ratios reduced by 50% compared to the initial one. Besides, the roof windows were only 10% opened. In this situation, it is obviously seen that the air change was decreased when comparing with100% opened windows with original size (Figure 9). In Figure 10, similar model with the change in the position of the window applied to simulation. It can be seen that almost the same amount of air change occurred which can be winter season operation.

<u>*ORW100_RRW100_OWP100_IDO_WC:*</u> In this simulation, wind catcher elements are placed at 1.30 higher than the opening sash in the open office windows. In Figure 11, it is seen that the wind flow in the open office has increased. However, this situation negatively affects the indoor comfort conditions in the winter season. Therefore, the choice of this strategy for short-term ambient ventilation is important in terms of user comfort.

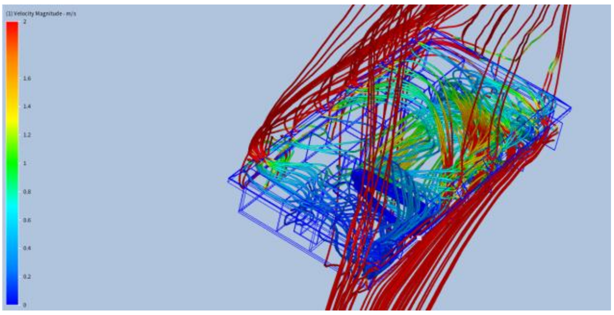

*Figure 8. ORW100_RRW100_0WS100_IDO_WC*

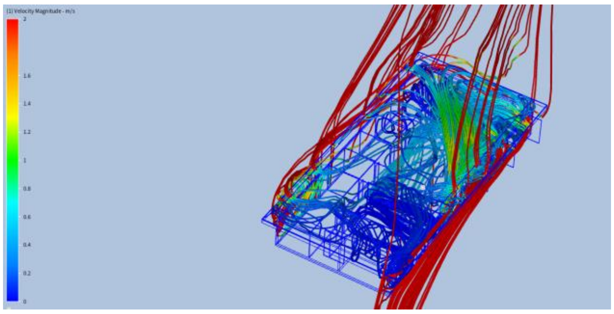

*Figure 9. ORW10_RRW10_0WS50_IDO_WC*

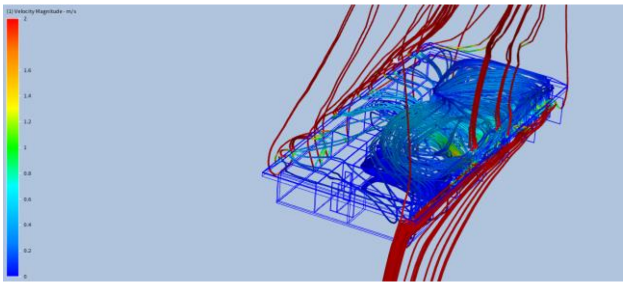

*Figure 10. ORW10_RRW10_OWP50_IDO_WC*

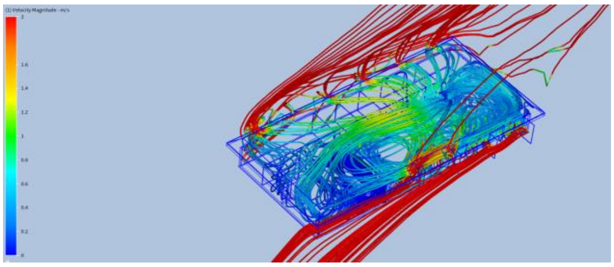

*Figure 11. ORW100_RRW100_OWP100_IDO_WC*

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### Summer Condition

For summer conditions, the wind speed is accepted as 7.76 m/s and the wind direction is from northeast.

*ORW100_RRW100_0WS100_IDO:* Due to the increase in window sizes, indoor air movements have increased. Since it is summer conditions, this ventilation preference can be preferred all day long (Figure 12).

*ORW100_RRW100_OWP100_IDO:* Similarly, due to the change in window position, indoor air flow have increased (Figure 13).

*ORW100_RRW100_0WS100_IDO_WC:* Indoor air flow have increased due to the increase in both wind catcher and window sizes. However, when compared with the initial simulation, it seems that the main contributing factor is the wind catcher (Figure 14).

*ORW100_RRW100_OWP100_IDO_WC*: Similarly, indoor air movements have increased due to the change in both the wind catcher and window position (Figure 15).

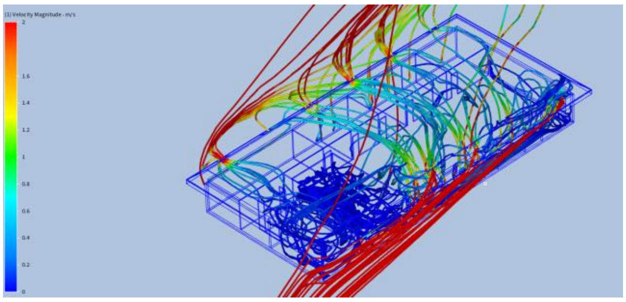

*Figure 12. ORW100_RRW100_0WS100_IDO*

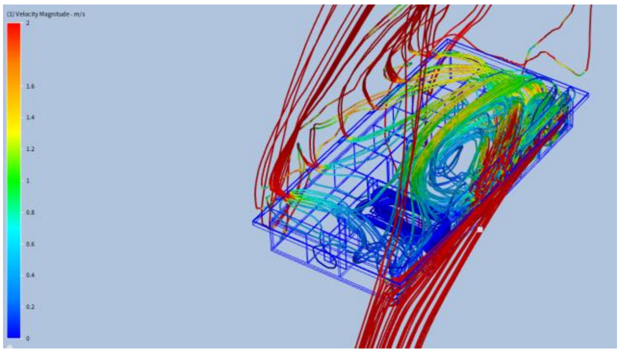

*Figure 13. ORW100_RRW100_OWP100_IDO*

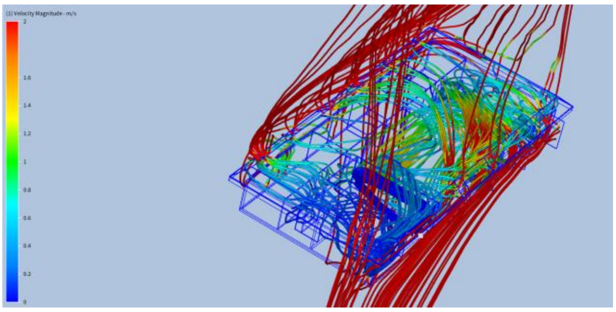

*Figure 14. ORW100_RRW100_0WS100_IDO_WC*

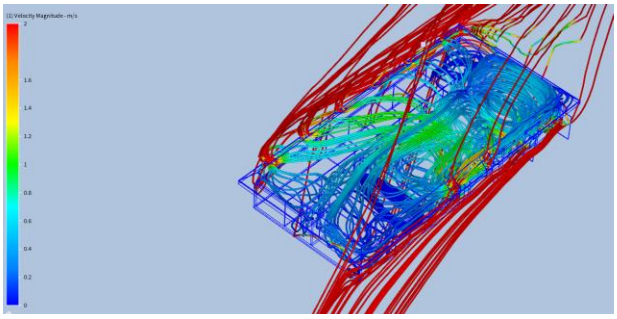

*Figure 15. ORW100_RRW100_OWP100_IDO_WC*

## Discussion and Conclusion

Within the scope of this study, mechanical ventilation has been completely ignored and limited to natural ventilation principles that can be created with architectural solutions (window sizes, positions, number, etc.). Within this study, the indoor air quality of an office building in Ankara was determined based on measurements, user satisfaction was evaluated with the survey conducted with the users, and the natural ventilation conditions were analyzed by modeling the building in Autodesk CFD simulation program.

According to the method planned to be followed within the scope of the paper, first of all, concepts related to indoor air quality, user comfort in indoor spaces, human health and natural ventilation are discussed in order to develop user-oriented natural ventilation strategies in buildings in the context of indoor air quality and healthy environment. In the light of the information obtained from the literature, data about the office structure in Ankara selected for the field study has been collected. The first step of the fieldwork is to conduct a survey to determine indoor air quality, user profile, comfort level, complaints, mechanical/natural ventilation habits. When the results based on the survey are examined, it is understood that the satisfaction of the users with the thermal comfort and air quality of the environment they are in is not very high, and almost half of the users complain. The users have stated that they want to be able to control the heating-cooling settings and the opening and closing of the windows for the comfort he needs in the indoor environment. In addition, with the pollutant measurements made in the indoor environment, the need for fresh air in the indoor environment was tried to be understood through the amount of $CO_2$. In line with the user survey, it has been understood that it is possible to increase the indoor air quality with the natural ventilation that the user can control in the indoor environment. In order to increase indoor air quality based on natural ventilation, to understand how indoor air circulation occurs and to determine strategies for obtaining better results, simulation studies including air flow and thermal behaviors have been carried out. In the simulation results, it was understood that for an effective indoor circulation, design suggestions should be made to the current situation. As a result, the directions, numbers and positions of the windows in their current form were not found suitable for effective and sufficient natural ventilation. In spatial planning, there is a need for more windows or façade elements that direct the wind for natural ventilation in the area where there is an open office, in other words, where there are many users working together. It is necessary to ensure that the windows and façade elements can be opened at several different levels in a user-controlled manner.

The best scenario for winter season is the one with reduced size of windows which is 10% opened, together with wind catcher. Although the windows are partially open, not completely, it does not create a high discomfort in the indoor environment. Thus, long-term ventilation can be done in the interior. In this way, fresh air intake to the interior is provided regularly. For the summer conditions, best results is gathered by the model which has the skylights on both facades are 100% opened, the position of the windows is lowered and wind catchers are attached to the facade. In this scenario, maximum fresh air inlet and polluted air outlet are provided to the interior. In summer conditions, since there is no annoyance in terms of thermal comfort, the scenario that gives the maximum level for fresh air intake was appropriate. Within the scope of this study, while design strategies that will increase the natural ventilation potential are put forward, strategies for façade elements have been produced considering that they are applicable. Natural ventilation, which is one of the factors in providing indoor air quality throughout the year, can also disrupt the thermal comfort of the indoor environment, causing more energy consumption due to heat loss, especially in winter. As future work, a study will be required on energy efficiency, and it is thought that alternative ventilation techniques should be investigated in the future in the light of the obtained data.

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## References

Akman, A. (2005). Human Health, Healthy Building and Building Biology. Yapı 279, 89 – 92.

Autodesk (2023). Autodesk CFD: Simulation software for engineering complex liquid, gas, and air systems. https://www.autodesk.com/products/cfd/overview, ET. 26.1.2023.

Awbi, H., 2019, "Ventilation Systems: Design and Performance" Routledge; 1st edition.

Balanlı, A. and T. Taygun Gökçe (2005). Yapı Biyolojisi ve Asbest. Mimar.İst 16, 107 –110.

CIBSE (2021). COVID-19 Ventilation Guidance Version 4. https://www.pps.co.com/wp-content/uploads/2020/11/Covid_19_Ventilation_guidance_v4.pdf, ET. 8.1.2023.

Çağlar, B. (2020), The Importance of the Design for Human Principle in the Indoor Air Quality. Journal of Sustainable Engineering Practices and Technological Developments 2, 63–76.

Darçın, P. (2008). Natural Ventilation Principles for Removing Indoor Air Pollution [Master's Thesis, Yıldız Teknik University].

Karaman, E. (2013). Determination Of Antimicrobial Activity of PVC Material Containing Silver Ions For Improvement Of Indoor Air Quality [Master's Thesis, Hacettepe University].

Kutlu, R. (2018). The Effects of Environmental Factors on Space Quality and Human Health. The Turkish Online Journal of Design Art and Communication 1, 67–78. DOI: 10.7456/10801100/007.

REHVA (2020). REHVA COVID-19 Kılavuz Belgesi 17 Kasım 2020. https://iskid.org.tr/wp-content/uploads/2020/04/REHVA-COVID-19-TR.pdf, ET. 8.1.2023.

Senitkova, I. J. (2016). Indoor air quality-buildings design. MATEC Web of Conferences 93, 6. DOI: 10.1051/matecconf/20179303001.

Sezer Şenkal, F. (2015). Evaluation of User Satisfaction in terms of Comfort Conditions: An Example of an Education Building. Trakya University Journal of Engineering Sciences 1, 11-19. https://dergipark.org.tr/tr/download/article-file/201004, ET. 08.01.2023.

URL-1: https://knowledge.autodesk.com/support/cfd/learn-explore/caas/CloudHelp/cloudhelp/2021/ENU/SimCFD-Learning/files/Reference-Material/GUID-B737967D-DF1E-4A7E-AAED-CFD7FD41D0CD-html.html, E.T. 21.01.2023.

WHO (2021). World Health Organization, Roadmap to improve and ensure good indoor ventilation in the context of COVID-19. https://www.who.int/publications/i/item/9789240021280, ET. 30.5.2021.

https://doi.org/10.26868/25222708.2023.1462