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An Investigation on Natural Window Ventilation: Improving Indoor Air Quality and Energy Efficiency in an Office Building

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Abstract
With the increment in time spent indoors, the contingence between building occupants and indoor air pollution has been lengthened. Accordingly, indoor air quality became a significant factor since the poor conditions can influence the occupants' health and efficiency. Indoor air quality is mainly concerned with physical and thermophysical factors in conditioned environments and is related to occupants' satisfaction levels on a variety of variables such as fresh air adequacy, air temperature, odor, humidity, and air velocity. This paper aims to investigate natural ventilation occupant-control methods to improve indoor air quality and increase building energy efficiency considering clean air intake levels and indoor air temperature levels. For this, variables related to climatic conditions, ventilation systems, and occupant's control on window opening were investigated to provide healthy and liveable conditions. To comply with these goals, in an open-plan office building, the levels of indoor air quality were determined with the help of DesignBuilder simulation by comparing obtained values under different case modeling variations.
Keywords: Indoor Air Quality, Natural Ventilation, Energy Efficiency, Office Building.

1. Introduction

According to the United States Environmental Protection Agency (USEPA, 2014), air pollution, which is defined as pollutants as particles and gasses in the atmosphere, can harm people's health and comfort at any rate and exposure to contaminants that can bring about premature deaths, health risks, especially on the cardiovascular system. A research study has been carried out in 25 cities of 12 countries with 39 million population where the number of deaths caused by air pollution was 10.000 (Oshrieh, 2019).
In recent years, indoor air pollution has much more severe impacts than outdoor air since the time spent indoors increased up to 90% (USEPA, 1989). Increased time indoors extends the exposure between the indoor contaminants and building occupants. Due to unavoidable pollutants indoors, maintaining a healthy and comfortable environment for building occupants depends on the sustained clean air intake, indoor temperature, and adequate ventilation which are significant determinants of Indoor Air Quality (IAQ). However, achieving good levels of IAQ is related to higher energy demand in the case of ventilation systems. In the last 50 years, the total energy use is rising each year by the recent development trends and strategies (IEA, 2019). Additionally, the building sector takes up to approximately 40% of the total energy consumption, and almost 20% of greenhouse gas emissions (IPCC, 2013).
Natural Ventilation and Energy Efficient Building Design can be taken as suitable solutions for both of these concerns of air pollution and energy use (Sartori I, 2007; Bangalee MZI, 2012). While it requires action to carry out these solutions there is not any obtained strategy or methodology for improving IAQ indoors. The existing European ventilation standards do not have requisite health-based outlooks on IAQ, they only allow main categories of comfort levels on their assessments for ventilation demands (ECA, 1992). In the meanwhile, the recent regulations only put out air-tight construction that is associated with impacts on IAQ, occupant's health, and productivity in new buildings (Seppänen, 2012).
Ventilation, which is defined as the replacement of polluted indoor air with clean air from outdoor to indoor, can happen unintentionally through openings of the building envelope, or intentionally as different decided strategies such as natural, mechanical, or combined as hybrid or mixed-mode (Awbi, 2015). Choosing between different available strategies while delivering outdoor air to the inside, the climatic and cultural aspects should be taken into consideration (de Oliveira Fernandes, 2016) since the IAQ parameters are highly dependent on the physical conditions of the building environment, along with occupant behavior. As in the case of seasonal changes of hot or cold periods, the waste of heating and cooling energy should be avoided (Jin, 2015). Buildings designed following its climatic conditions are an exemplar of tackling the problem of energy consumption efficiency (Rahbarianyazd, 2018). Natural ventilation is becoming a more preferred option since the studies show that it is highly effective in lowering cooling energy and enhancing indoor air quality according to climatic zones and building design (Wu, 2012). It can be considered if the climatic conditions are suitable, and the ventilation rate is controllable. The operation of

windows is a significant determinant for high-performance natural ventilation. In the available literature, the occupant behavior on window-control has been studied across with various variables as occupancy rate, indoor and outdoor temperatures, concentrations of CO_2 along with climatic conditions of sun, wind, noise, light, and outdoor pollution rates (Stazi, 2017; Zhou, 2018, Chenari, 2016).

In natural ventilation, the window control methodologies as an occupant-operated control system or automated windows can be applied according to the circumstances. The occupant-operated control can be preferred since it is an elementary and energy-efficient way. However, due to the exterior changing conditions, occupant-operated control can be unmanageable by spontaneous preferences of occupants. To avoid this, another strategy can be used which the occupants are informed about the window opening schedules based on climate and weather data according to maintain heating and cooling demands and they know when to open or close the windows accordingly. When occupants may be unable to determine the optimum window control scheduling to attain energy efficiency and thermal comfort, applying indicators to inform occupants when and how to perform an operation would become a feasible technique to control mixed-mode ventilation in buildings using hand-operated windows (Chen, 2019).

Automated windows can be also preferred to prevent undesired spontaneous control of building users. On the other hand, the automated window control and HVAC systems can be costly and not energy-efficient in comparison with simple and passive natural ventilation systems.

This research's main aim to establish a theoretical comparison between two different ventilation methodologies, combined HVAC + Natural Ventilation system and only Natural Ventilation as occupant-operated window control on different climatic zones. In the study, current demands and climatic conditions of an open-plan office building, ventilation systems, window-opening control are considered as the determinants to improve IAQ levels with controlled clean air intake, to ensure optimum indoor air temperature rates while providing satisfactory indoor air ventilation and lowering energy use.

2. Material and Methods

2.1. The Case Study Building Design

As a quotative research method, to run a natural ventilation simulation to analyze energy use and indoor air quality, a six-story open plan office reference building has been modeled with different case variations which are applied according to the decided ventilation systems and climatic conditions. Building modeling and simulation data have been investigated to correlate collected data in between natural window ventilation, and IAQ and Energy Efficiency by using Design Builder software. The significant determinants of natural window ventilation are determined as building design characteristics as building location, climatic conditions, window configuration, and occupant behavior as occupant control on the window opening. The research parameters to be examined are determined as clean air intake levels, indoor air temperature rates, and energy use of the building.

The total building area is 9000 m² occupied with open-plan office spaces, and technical, utility service spaces, bathrooms, and staircases on the middle of each floor. (Fig. 1). The floor plans were created as identical at each floor with a fixed size of 1,50 x 6,00 m repetitive windows 1,20 above the floor level at all sides. Each floor has a 30% window-to-wall ratio with a 30% glazing area which 25% openable glazing area, and HVAC systems are considered available all day long. The occupancy is expected as 8.00 am to 6.00 pm scheduling under regional codes of Turkey.

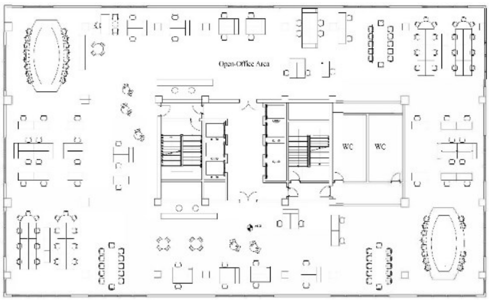

Figure 1. The Floor Plan of the Case Study Building

2.2. Climatic Conditions

To be able to make a comparison on the effectiveness of natural ventilation strategies under different exterior conditions three distinct climatic zones as the developed cities of Turkey including İstanbul (Temperate), İzmir (Hot), and Ankara (Cold) are selected. The heating and cooling setpoint temperatures are determined as 22˚C and 25˚C, natural ventilation setpoint min temperature is determined as 22˚C. The construction infiltration rate of airtightness is defined as 0.3 ac/h) on building crack and openings.

2.3. Natural Ventilation Strategies

To analyze the impact of natural ventilation done by occupant control with work-day scheduling comparison to the combined strategy of HVAC along with natural ventilation, all of the modeling variations according to climate date of cities are created. The natural ventilation operation has been scheduled as linked by the open-plan office occupancy by zone with an outside air rate of 5 ac/h. Air temperature distribution mode is taken as mixed including underfloor distribution exterior and interior.

For the HVAC scenarios (C_1) the mechanical ventilation method is determined as minimum fresh air rate based on the sum of both per person and per area without a heat recovery along with a heating system of HW collectors. For the Natural Ventilation only scenarios (C_2), the HVAC systems are eliminated, the window operation is based on the occupancy rate of the area.

3. Results and Discussion

For all of the climatic scenarios the energy use of the building higher at C_1 scenarios than C_2 due to mechanical ventilation and HVAC systems. Even if, the indoor air temperature and ventilation rates are met at better performance in Ankara at C_1 scenarios since with the support of HVAC systems the comfort levels are provided easily, by the zone heating the highest energy use are seen in this climatic zone (Fig.2). Ankara in C_2 scenarios demonstrates that the fresh air ventilation rates are significantly decreasing since the outdoor air temperatures are also decreasing with the occupant-control tendency on closing the windows (Fig.3).

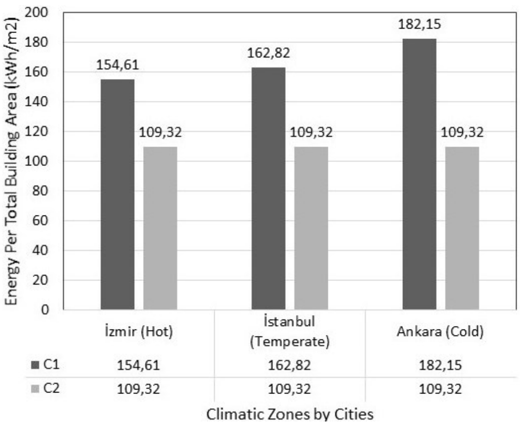

Figure 2. Energy Per Total Building Area (kWh/m2) by Climatic Zones

For the hot climatic zone, the city of İzmir C_1 scenario is suitable due to internal heat gains during the year is higher than the other two cities and ventilation cooling demand for the optimum comfort level at the summer period is harder to achieve with only following the natural ventilation strategy even the window-control left to the building occupants. In İzmir, for C_2 scenarios there are several peak points of fresh air intake rate including summer month (July) at its highest (6,3 ac/h) and following during heating and cooling period as (May, and October) at other peak points (4,4 ac/h and 4,2 ac/h) since the occupant-control tendency on opening the windows during heating periods. The indoor air temperatures show a similar trend since outdoor air temperatures have the tendency on slight increments heating and cooling period (Fig.4).

For the temperate climatic zone, the city of İstanbul in C_1 scenarios, the total fresh air rate (ac/h) through all mechanical ventilation, natural ventilation, and infiltration peaks up to steady 6,9 ach/h during the summer period (June, July), and decreases down to almost 0,7 ach/h along with air temperature degrees down to 23˚C. In comparison to the İzmir case, the indoor air temperatures vary during the year and have a peak point of 26 ˚C in the C_2 scenario.

The indoor air temperature trends in all cases clearly show the general tendencies of natural ventilation rates reducing as the ambient air temperature increases during the day (Fig.3 and Fig.4). Between C_1 and C_2 scenarios, the most visible difference is the fresh air intake rates since when the mechanical ventilation is available, occupant's tendency on opening windows decreases by their provided comfort levels indoors. Only in Ankara, the indoor air temperature in C_2 stayed at lower degrees at 22,3˚C since HVAC systems are not available.

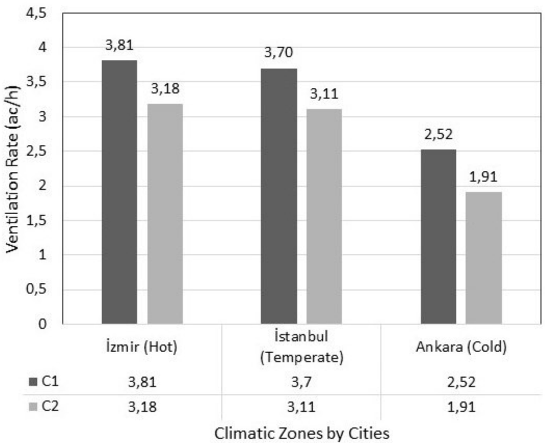

Figure 3. Annual Fresh Air Ventilation Rate (ac/h) by Climatic Zones

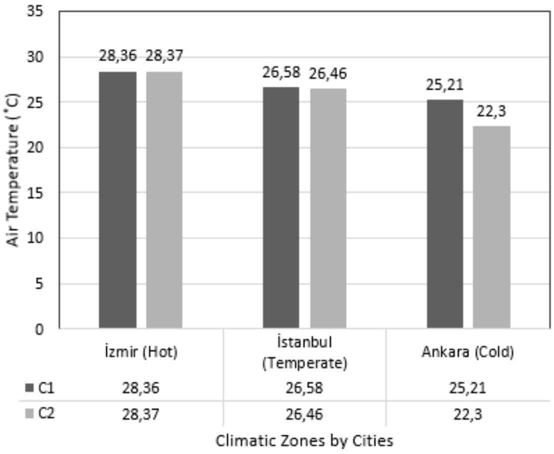

Figure 4. Annual Air Temperature (˚C) by Climatic Zones

4. Conclusions

The research establishes that the performance of the HVAC along with natural ventilation control systems ensures better indoor conditions, especially in cold and hot climates. However, the combined strategy consumes more energy due to mechanical ventilation and HVAC uses active energy. Ensuring comfort levels of indoor air quality and temperature through natural ventilation consumes less energy, but it is a less convenient strategy to follow when hot and cold climatic conditions require more maintenance to meet comfort indoor temperatures.

By the results, it is recommended to either uses a completely automated natural ventilation control system to obtain maximum energy savings potential or to provide occupant autonomous for natural ventilation controls to obtain a reduced budget for initial installation and maintenance costs. On the other hand, to be able to meet comfort levels of indoor air quality as air ventilation rates and indoor air temperatures, the combined strategy will be more suitable for the distinct climatic zones of hot and cold. To be able to decide on optimum ventilation strategy to follow occupant-control behaviors and climatic conditions should be examined and opened for further discussion on the topics of window-control methodologies and building design parameters.

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Conflict of Interests

The authors declare no conflict of interest.

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