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Published in:
Sisäilmastoseminaari 2021. Verkkoseminaari 9.3.2021

Published: 01/01/2021

Document Version
Publisher's PDF, also known as Version of record

PERFORMANCE ANALYSIS OF THE MODERN DEMAND-BASED VENTILATION IN FINNISH APARTMENT BUILDINGS

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ABSTRACT

In general, new Finnish apartment buildings are equipped with mechanical balanced demand-based ventilation. The airflow rate in the kitchen hood is boosted on demand to improve pollutant extraction during cooking. The focus of the paper was to present the simulation results from a case building equipped with such a system. The airflow rates are calculated for the room and apartment for various ventilation mode scenarios in the analysis. A significant imbalance of over 10% between the supply and exhaust airflows at the room and apartment levels was observed in the boosting mode. This imbalance creates a pressure difference over the building envelope particularly in small studio apartments. A new solution to guarantee the designed airflow rates was proposed and assessed. The new design was able to stay within 10% of the designed airflow rates.

INTRODUCTION

The general purpose of residential ventilation is to provide a sufficient amount of fresh and clean air to the occupants with an acceptable energy consumption level[1]. The air quality and airflow rate parameters are introduced in the building codes or recommendations. In Finland, most newly built apartment buildings are equipped with demand-based mechanical balanced ventilation with a heat recovery[2]. The demand is to guarantee the pollutant extraction with the kitchen hood in cooking mode. Starting from 2018, the building code requires to boost the airflow rate in the kitchen during the cooking mode, as it is the primary source of indoor pollutants in modern residential buildings. The building code requires that the kitchen hood airflow rate should be at least 25 l/s while cooking to ensure pollutant extraction and 8 l/s in normal mode. The system is implemented with additional dampers needed to enable two ventilation modes: normal and boosting. In larger apartments, bathroom and toilet exhaust airflow rates are decreased to provide an increased exhaust airflow rate for the kitchen hood. In small studio apartments, the bathroom exhaust reduction is not possible due to the minimum required airflow rate of 10 l/s, and hence the apartment supply airflow is increased instead[2].

In airtight buildings, it is required to control the ratio of supply and exhaust airflow rates accurately. Otherwise, the unbalanced ventilation could lead to an unnecessary high-pressure difference over the building envelope, and furthermore, to structural moisture damage, pollutant extraction or draught[3]. It has been found that the boosting mode in apartment buildings does not work as desired. It is not well known in which operation conditions airflow balance can be reached, and how it is possible to guarantee the designed performance. To close the research gap, the kitchen boost system performance was analyzed concerning various operation conditions. The airflow balance at the room and zone levels and the pressure difference over building envelope were calculated, and further advancement suggestions are given. The main research question is to assess whether a ventilation system with a kitchen hood boosting mode works as designed, what are the possible shortcomings and how they can be addressed.

METHODOLOGY

A building in Helsinki, Southern Finland, was selected for the analysis. It was built in 2019 and has a complex structure, and one staircase was chosen for the analysis. The staircase has five floors with a floor height of 3 m, where the first floor is non-residential, and the 4 above are residential. The ventilation system is a centralized demand-based balanced mechanical system with heat recovery, shown in Figure 1.

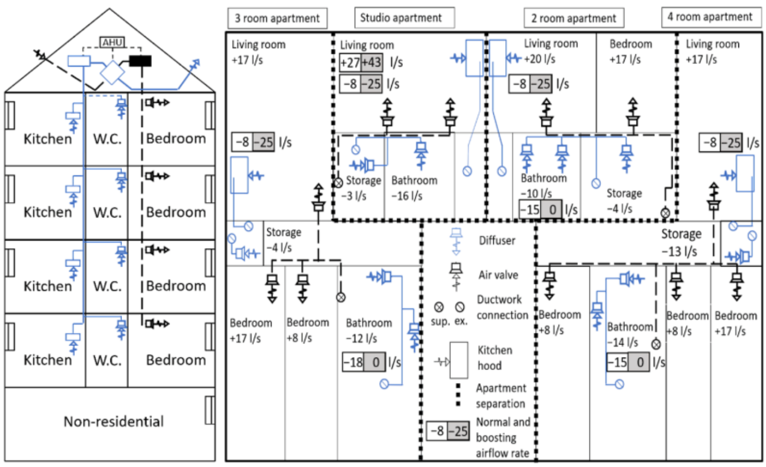


Figure 1. Scheme of the ventilation system in the case building on the left and airflow rate of rooms in differently sized apartments on one floor during normal and boosting modes.

The designed air change rate is 1 1/h at the apartment level with a minimum of 0.5 1/h on room level. The air is supplied in the living rooms and bedrooms and extracted in the bathrooms, toilets, storages and kitchens. The exhaust airflow rate is set to be equal to supply. The apartment airflow rates for studio, two- ,three- and four-room apartments are 27 l/s, 37 l/s, 42 l/s and 50 l/s, respectively.

The kitchen hood has two operating modes: normal with 8 l/s and boosting with 25 l/s. The boosting is introduced at the apartment level in two ways: apartment airflow increment and borrowing. The total airflow rate (both supply and exhaust) is increased by 30% in the boosting mode in the studios. An on/off damper is installed in the living room branch to supply more air in the boosting mode. The damper is closed in the normal mode. The borrowing principle is used in larger apartments. The boosting exhaust airflow of the kitchen range hood is compensated by reducing the bathroom exhaust. The damper is closed in the bathroom branch when the boosting mode is activated and opened in the normal mode, shown in Figure 2.

The ventilation ductwork is designed so that apartments connected to the same staircase are served by a single air handling unit (AHU). In that AHU's serving area, the ductwork has separate control zones. Each control zone has the same set of apartments on 4 different floors, shown in Figures 1 and 2. The apartments located above and below each other are identical and have joint branches of exhaust and supply ventilation ducts. The AHU maintains a constant static pressure in the exhaust (140 Pa) and supply (110 Pa) ventilation plenums, that is controlled by adjusting the fans' speed.

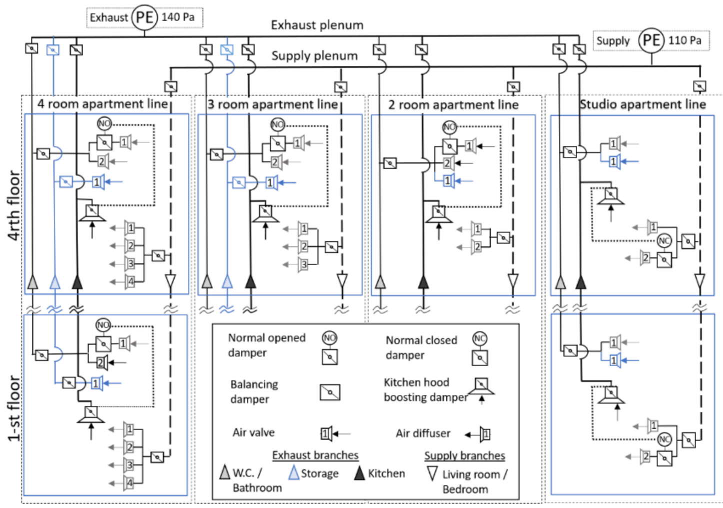


Figure 2. The topology of ductwork in the apartment zones, and the locations of the control and balancing dampers, supply diffusers and exhaust units (valves and hoods) in the apartments.

Simulation model

The performance of the ventilation system was analyzed by using the ductwork topology presented in Figure 2. The ductwork was modelled, and the airflow distribution was simulated using a HIT Balance tool[4]. The ideal control of the constant static pressure in the supply and exhaust plenums was assumed. Ductwork is assumed to be ideal without leakages. The other possible local resistances e.g. apartment control dampers are presented as an additional pressure loss to the branch. The principles for calculating the pressure drops are assumed accordingly[5]. The physical properties, components and settings are according to building documentation.

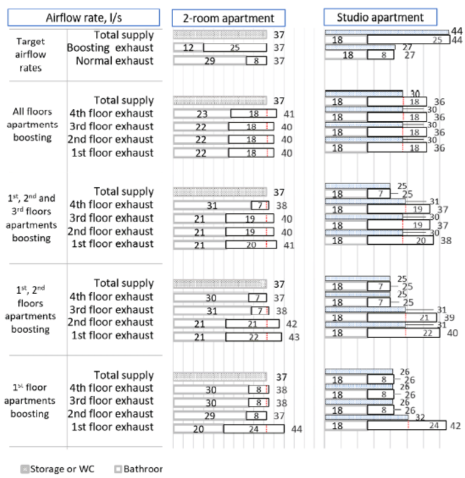
The equitation to evaluate the effect of airtightness on the pressure difference over the building envelope was used accordingly[6,7]. An airtightness level is presented by infiltration air change rate at a pressure difference of 50 Pa. The levels are 2.5 1/h that represents an old Finnish apartment building. Then, 1/h was selected to represent the airtightness of the current target level of building code, and 0.5 1/h was selected to represent airtight and energy-efficient buildings.

RESULTS

The standard solution was simulated and compared to the proposed improved design. The apartment, branch and AHU airflow rates and patterns were analyzed. The improved design was implemented by replacing the one-position balancing dampers with two-position ones and adjusting the airflow rates utilizing a specific balancing strategy. The improved solution showed significantly better matching of the supply and exhaust airflow rates with the design values.

Performance of Standard Demand-Based Ventilation System

The simulation assesses the airflow rates and airflow balance at room and apartment levels as a function of the number of apartments with kitchen boosting active. Figure 3 represents the target and simulated exhaust and supply airflow rates for apartments and zones in different boosting scenarios concerning each boosting type: studio for apartment airflow increment and two-room apartment for borrowing strategy. The results are assessed concerning two main criteria: balance of the apartment supply and exhaust airflow rates and the ability to follow room airflow demand in the boosting mode.



Apartment Type	Studio apartment	2-roon apartment
2.5 1/h	−4.4 Pa	−1.6 Pa
1 1/h	−15.4 Pa	−5.5 Pa
0.5 1/h	−39.8 Pa	−15.4 Pa

Figure 3. Airflow rates of the different sizes of apartments when a different number of apartments are boosting on the left, pressure difference in the apartments with different airtightness levels on the right

The target airflow rate in two-room apartments should be constant in normal and boosting modes. However, the simulation shows that an imbalance exists between the apartment supply and exhaust. The worst-case scenario of apartment airflow rate imbalance occurs with the one-floor boosting case. The bathroom exhaust airflow rate is 8 l/s higher, which leads to a 7 l/s difference in the apartment level supply and exhaust airflow rates. The worst-case scenario for airflow demand redistribution happens when all the floors are boosting. The kitchen airflow rate, in this case, is 7 l/s lower than the target in each apartment. The trend is also the same in the other boosting cases as bathroom exhaust airflow rates are higher, and the kitchen hood airflow rates are lower than target values.

In the studios, the apartment total airflow rate should be increased in the boosting mode. However, the simulation shows that neither supply nor exhaust airflow rates reach the target values. The worst-case scenarios are the same as in the larger apartments. Maximum apartment disbalance is around 10 l/s, and the kitchen hood airflow rate is 7 l/s lower than the target in boosting mode. The supply airflow is unable to reach the design values and is lower than the exhaust. The difference between the target and simulated kitchen hood airflow rates becomes higher when more floors are boosting.

Imbalance in a mechanical ventilation system may lead to pressure differences over the building envelope. The acceptable level of negative pressure in residential buildings was assumed to be −10 Pa, and −30 Pa was set as a warning level[8]. Two-room apartments had an unacceptable pressure level at an airtightnesses of 0.5 1/h and better, and studios exceeded the acceptable pressure level in new buildings and had a warning trend in future buildings with a pressure difference of around 40 Pa.

Performance with the Improved Design Concept

The standard ventilation system design analysis shows a satisfactory operation in the normal mode and a significant imbalance of the supply and exhaust airflow rates in the apartments in the boosting mode. The origins of the practical issues in the supply branches of studios and two-room apartments are the same. The control system does not adjust the k-value of the components in the boosting mode, resulting in too high or too low apartment branch resistances, respectively.

In Figure 4, a proposed solution is presented. If only the dampers are replaced with two-position ones, but the balancing strategy is standard, then this design fails to match the target values due to the decrement of the airflow rate of kitchen hood while more apartments are boosting. As a result, it is causing an ineffective performance of kitchen hoods and hence system imbalance. The combined solution with a damper replacement and modified balancing strategy shows the ability to maintain the airflow rate values within 10% of the target value. The maximum supply and exhaust imbalance on the apartment level is around 10%.

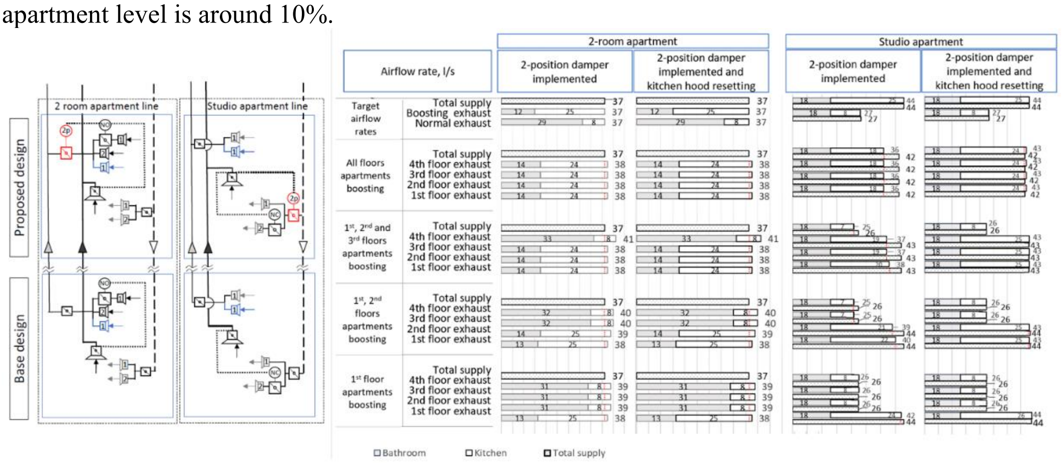


Figure 4. Apartment airflow rate control schemes in the standard design and proposed improved concept on the left, airflow rates of the 2-room and studio apartments in boosting and normal modes with two-position dampers installed and with two positions dampers and an improved balancing method on the right

The two-position dampers are set to have different k-values for normal mode and boosting mode. The k-value for normal mode is obtained for all apartments in the branch simultaneously. The k-value for boosting is then obtained with only one apartment in the branch boosting and the rest in normal mode. The branch-level damper settings are presented by a k-value obtained when all apartments in the branch are in boosting mode. The kitchen hood has two settings for the k-value as well. The k-value for the normal mode is obtained when all hoods in the branch are in the normal mode. The k-value for boosting is obtained with only one apartment in the branch boosting, and the same value is used in every hood in the branch.

CONCLUSION

In Nordic Europe, energy efficiency requirements and a cold climate led to the utilization of balanced mechanical ventilation with heat recovery in apartment buildings. Starting from 2018, the building code requires to boost the airflow rate in the kitchen during cooking mode. This paper assesses the performance of the centralized demand-based ventilation system with kitchen airflow rate boosting in a modern Finnish apartment building with high airtight envelope. Based on the conducted simulation, the standard design is unable to reach the design values in the boosting mode with increased airflow rates. A new apartment airflow control device design and a new balancing strategy were proposed to improve the performance. The concept addresses changes to the overall design approach for the future apartment residential building with high airtightness level in Finland. With the improved design, the performance of the ventilation system enhanced significantly, and the maximum difference of apartment supply and exhaust airflow rates were under 10%.

Acknowledgements: The authors would like to thank Panu Mustakallio from the Halton Group for providing the Hit Balance toolset and technical support for the simulation.

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