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Article

Performance Analysis of the Demand-Based Ventilation in a Nordic Apartment Building

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Featured Application: The paper assesses the ventilation system performance of a modern Finnish building with kitchen boosting and proposes a new design concept which addresses changes to the overall design approach for the future apartment residential building with high airtightness level in Finland.

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. However, in practice, it has been found that the system does not work as desired. The focus of the paper was to present the simulation results from a case building equipped with a ventilation system that is commonly used in Finland. In the analysis, the airflow rates are calculated for the room, apartment, and air handling unit (AHU) levels for various ventilation mode scenarios. 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. The calculated pressure difference for future buildings with high airtightness were at the warning level of 40 Pa below atmospheric level. The kitchen hood exhaust system showed a 28% lower airflow rate in certain scenarios. A new solution to guarantee the designed airflow rates was proposed and assessed. The new solution consists of replacing the apartment level flow control damper and a new balancing method for the kitchen hood exhaust branch. The proposed design was able to stay within 10% of the designed airflow rates in all operation modes.

Keywords: ventilation; demand-based ventilation; apartment building; kitchen boosting; Nordic climate

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1. Introduction

The general purpose of residential ventilation is to provide a sufficient amount of fresh and clean air to the occupants with an acceptable level of energy consumption [1]. The air quality and airflow rate parameters are introduced in the building codes or recommendations for different regions and countries of Europe. Energy recommendations are presented in the Energy performance of buildings directive with levels of Energy Performance Certification [2]. Most building codes of Central and Northern Europe countries require a minimum air change rate for the whole building and define airflow rates concerning the floor area and room type [3]. Other countries, such as France and Switzerland, only define the overall dwelling airflow rate concerning the floor area. Overall, the minimum air change rate is 0.3 1/h, with an average of 0.5 1/h and a maximum of 1.5 1/h. The building codes of some countries, such as Switzerland, specify the indoor air quality by introducing limits for the CO_2 concentration [4]. In Finland, recommendations toward the ventilation and building construction of the residential building stock are given by the Ministry of Environment [5–7], requiring the minimum airflow rate to be set at 0.5 1/h.

In Finland, residential buildings account for 85% of the building stock. Detached houses represent 75.6%, attached houses 5.4% and blocks of flats 4% of this number. However, the blocks of flats account for around one-third of the total floor area of all residential buildings, and buildings with four floors or more host approximately 1.3 million occupants. The ventilation systems of the buildings have a direct relation to their construction years [8]. The majority of the buildings from the 1970–1990s are equipped with mechanical exhaust ventilation. In new apartment buildings, balanced mechanical ventilation with heat recovery is the standard solution. Natural ventilation solutions have not been used in apartment buildings in Finland in recent decades because of the energy requirements [9], although they are still quite common in single-family houses.

To improve the energy efficiency in the existing buildings, retrofitting is required. The optimal solution for the building retrofit depends on the existing ventilation system and climate conditions [10]. In old buildings with low thermal insulation and poor airtightness, the energy efficiency of the building envelope, together with an improved ventilation heat recovery, should be considered to meet the current European requirements for energy efficiency [11]. The standard ways for a retrofit are to replace the original ventilation system with balanced mechanical ventilation or to implement a heat pump together with exhaust airflow energy recovery [10,12,13]. Mechanical exhaust systems equipped with heat pump heat recovery and ventilation radiators are common solutions e.g., in Sweden [14,15]. A retrofit with the installation of centralized balanced mechanical ventilation is often feasible but complicated for an old apartment building, so decentralized air handling units for apartments are preferable.

New buildings are equipped with mechanical balanced systems with modern automation systems. The most common solutions are constant air volume balanced systems. Some ventilation systems have several operation modes with variable airflow rates, providing purging features based on the dwelling occupancy level using the variable-air-volume (VAV) system design [16]. VAV ventilation, previously utilized mainly in the office, commercial and public buildings is now also used in residential buildings with various decentralized and semi-centralized solutions despite their higher initial cost compared to standard constant air volume (CAV) systems [17].

However, the ventilation systems should be able to precisely control the indoor climate or otherwise the target values of indoor temperature or CO_2 concentration may not be fulfilled [18,19]. This creates a demand to control the airflow rate in the apartments, so nowadays, the majority of demand-based (DB) ventilation systems have two airflow rates (high and low). The most common control strategies are based on relative humidity, occupancy, CO_2 level or total volatile organic compounds (TVOC) level control [3,20]. Humidity-based control systems are usually introduced in bathrooms [21]. In Denmark, the ventilation system is sometimes controlled at the apartment level by the occupant presence and CO_2 level [22,23]. This strategy gives a significant energy saving potential and improved indoor air quality in the occupied apartments. However, in certain conditions, it could lead to unacceptable volatile organic compounds (VOC) levels or create an undesired imbalance of supply and exhaust airflow rates with more than 10% difference due to the inaccurate airflow control either at the local or air handling unit (AHU) level [16,24,25]. Centralized demand-based systems with the combined control strategy of CO_2, TVOC and humidity are often proposed and simulated in studies. Their energy efficiency and overall performance are good, but we still have limited measured case studies where the benefits of demand-based systems are demonstrated [26].

In Finland, most newly built apartment buildings are equipped with demand-based mechanical balanced ventilation with a heat recovery of at least 67% efficiency [27]. 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 cooking gas, as it is the primary source of indoor pollutants in modern residential buildings. Cooking processes account for around 54% of particle matter (PM) and 53% of personal exposure to ultrafine particles [28]. PM exposure is directly linked to respiratory and cardiovascular health issues [29]. 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 reduction in the bathroom exhaust is not possible due to the minimum required airflow rate of 10 L/s, and hence the apartment supply airflow is increased instead [27].

To meet energy efficiency demands, the minimum airtightness for a new apartment building should be 1.0 1/h at 50 Pa difference over the building envelope [26]. In future passive buildings, it is assumed that airtightness will be improved up to 0.5 1/h. 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 [30].

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. The novelty of the paper comes from the performance analysis of the demand-based mechanical balanced ventilation system with kitchen exhaust boosting, implemented in the apartment building with a high airtightness level. This type of system, unlike common modern ventilation systems, has not been assessed or simulated. To close the research gap, the kitchen boost system performance was analyzed concerning various operation conditions. The airflow balance at the room, zone and AHU levels, and the pressure difference over building envelope were calculated, and suggestions for further advancement 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.

2. Materials and Methods

2.1. Building Description

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, 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.

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. Supply airflow rates are chosen according to occupancy, room type or floor area, whichever value is higher. 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 apartment floor area for the studio, two-, three- and four-room apartments are 32.5 m^2, 41.3 m^2, 64.5 m^2, and 87 m^2, respectively.

The kitchen hood has two operating modes: normal with 8 L/s and boosting with 25 L/s. In the boosting mode in the two-, three- and four-room apartments, the increased airflow in the kitchen hood is compensated by decreasing the exhaust airflow rate in the bathroom and toilet by closing one of the exhaust air valves. In the studio, the supply airflow rate is increased by opening an additional supply diffuser to compensate for the additional kitchen exhaust airflow rate needed in boosting mode. The exhaust airflow rate of studio bathrooms cannot be reduced due to the minimum required airflow rate demand, shown in Figure 2.

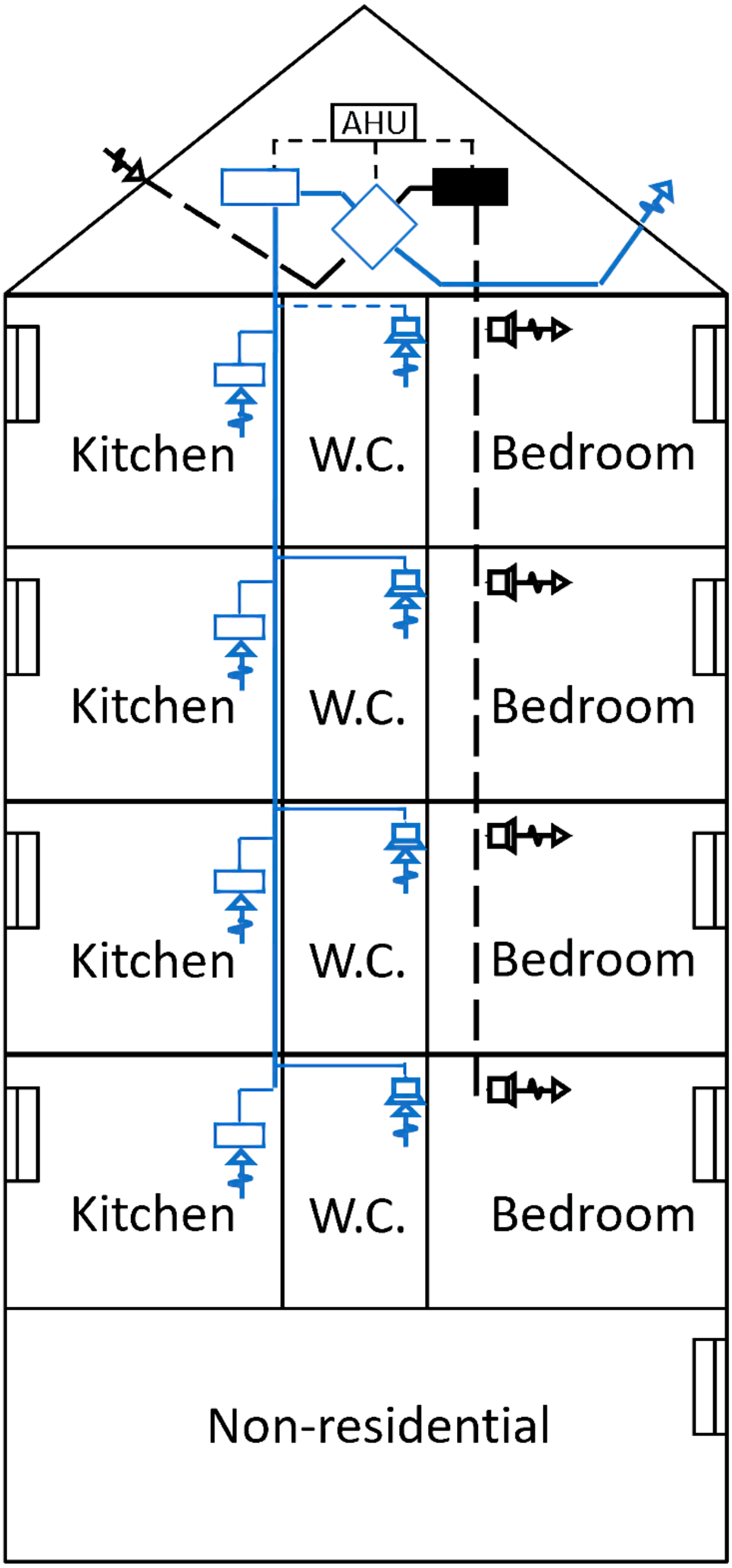


Figure 1. Scheme of the ventilation system in the case building. AHU: Air Handling Unit.

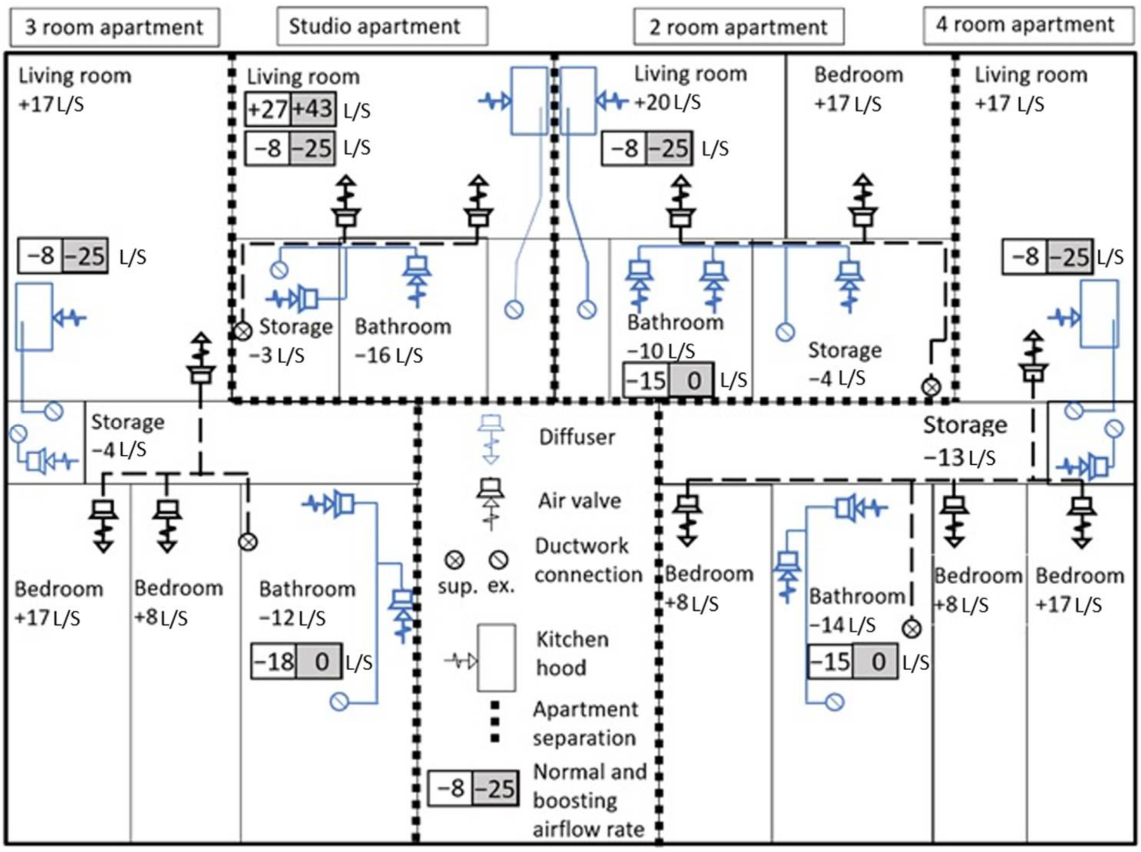


Figure 2. Airflow rate of rooms in differently sized apartments on one floor during normal and boosting modes.

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 2 and 3. 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, controlled by adjusting the speed of the fans.

At the apartment level, the boosting technology is introduced in two ways: apartment airflow increment and borrowing. In the studios, the total airflow rate (both supply and exhaust) is increased by 30% in the boosting mode. 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 the two, three and four-room apartments. The boosting exhaust airflow of the kitchen range hood is compensated by reducing the bathroom exhaust. In the bathroom branch, the damper is closed when the boosting mode is activated, and opened in the normal mode.

The characteristics of components of the ventilation system of the apartment and branch levels are presented in Tables 1 and 2. The ducts are the same size as the corresponding components. The k-values are presented for each component in the normal operation mode to represent its resistance characteristics in accordance with Equation (1). The airflow rate values are based on the commissioning documentation of the case study building and are equal for the supply and exhaust sides. The kitchen hoods have two k-values, one for normal mode and the other for boosting, and these values are identical for each hood. The balancing dampers have one fixed k-value and are adjusted to the normal mode.

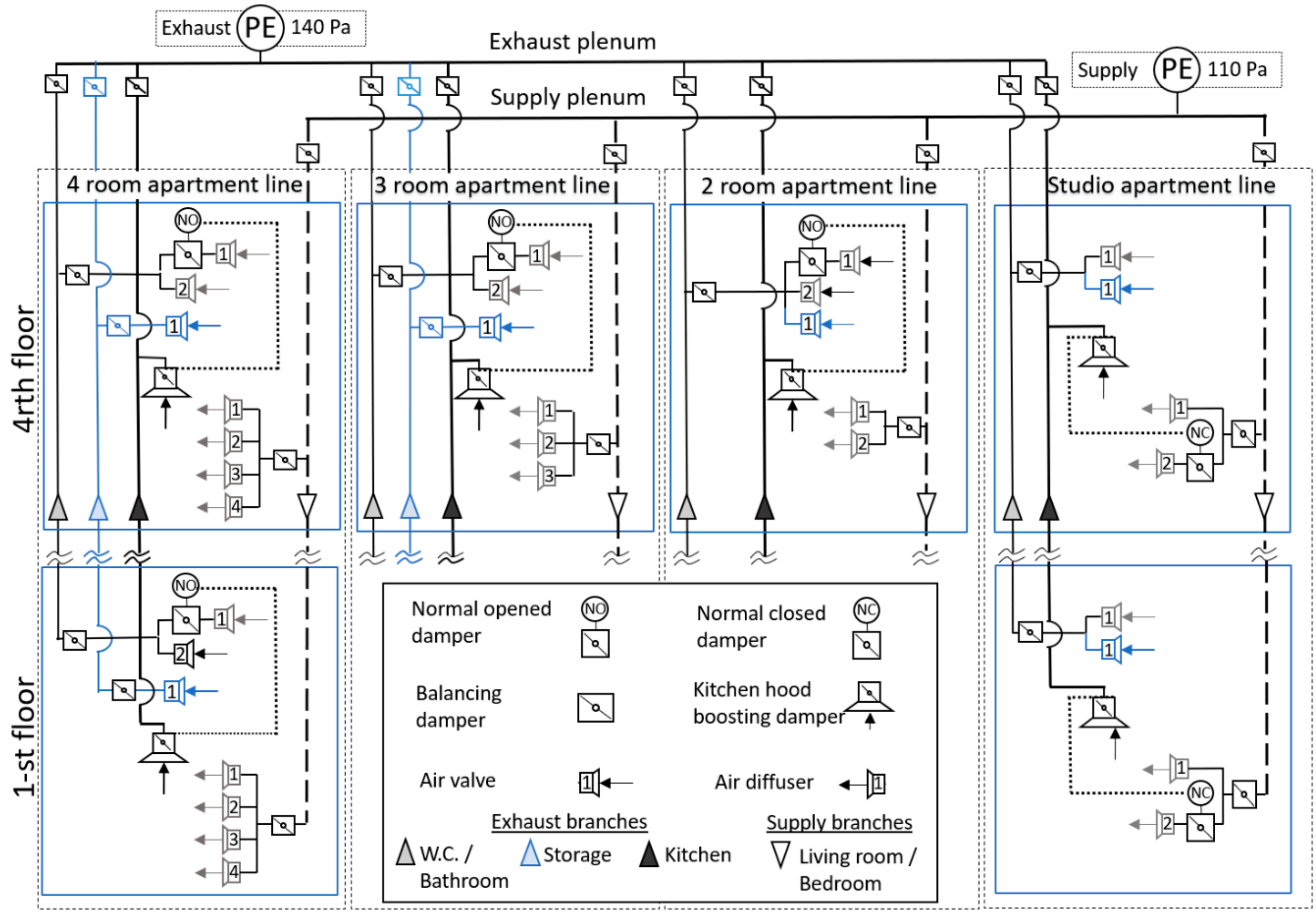


Figure 3. The topology of ductwork in the apartment zones, and the locations of the control and balancing dampers, supply diffusers and exhaust units (valves and hoods) in the apartments.

Table 1. Airflow rates, k-values and the sizes of the main ductwork of the different size of apartment branches.

Room Type	Component	4-Room Apartment				3-Room Ap.				2-Room Ap.				Studio Ap.			
		Size, mm	Airflow, L/s		K-Value	Size, mm	Airflow, L/s		K-Value	Size, mm	Airflow, L/s		K-Value	Size, mm	Airflow, L/s		K-Value
			N [1]	B [2]			N	B			N	B			N	B	
Bathroom	Air valve, 1	Ø125	15	0	3.35	Ø125	18	0	4.24	Ø125	15	0	3.00	Ø125	16	16	3.06
	Air valve, 2	Ø125	14	14	2.86	Ø125	12	12	2.45	Ø100	10	10	1.96	Ø100	3	3	0.57
Storage or W.C.	Air valve, 1	Ø125	13	13	2.91	Ø100	4	4	0.73	Ø100	4	4	0.73				
Kitchen	Range hood	Ø125	8	25	0.73 [3] 2.44 [4]	Ø125	8	25	0.73 [3] 2.44 [4]	Ø125	8	25	0.73 [3] 2.44 [4]	Ø125	8	25	0.73 [3] 2.44 [4]
Living/bed-room	Diffuser, 1	Ø125	17	17	4.91	Ø125	17	17	4.12	Ø125	20	20	4.85	Ø125	27	27	4.77
	Diffuser, 2	Ø125	17	17	4.54	Ø125	17	17	4.12	Ø125	17	17	4.37	Ø125	0	16	3.01
	Diffuser, 3	Ø100	8	8	2.41	Ø100	8	8	2.00								
	Diffuser, 4	Ø100	8	8	1.71												

[1] N—normal airflow rate, [2] B—boosting airflow rate, [3] 0.73—kitchen hood normal mode k-value, [4] 2.44—kitchen hood boosting mode k-value.

Table 2. Airflow rates of the branch-level balancing damper, k values and ductwork sizes.

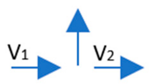
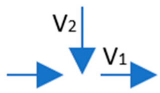
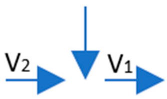
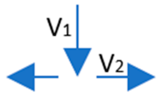
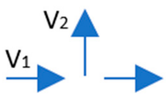
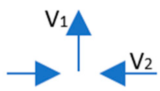
Room Type	4-Room Apartment				3-Room Ap.				2-Room Ap.				Studio Ap.			
	Size, mm	Airflow, L/s		K-Value	Size, mm	Airflow, L/s		K-Value	Size, mm	Airflow, L/s		K-Value	Size, mm	Airflow, L/s		K-Value
		N [1]	B [2]			N	B			N	B			N	B	
Bathroom	Ø250	116	56	25.94	Ø250	120	48	26.83	Ø200	116	56	36.68	Ø200	76	76	17.00
Storage or W.C.	Ø125	52	52	11.63	Ø125	16	16	2.92								
Kitchen	Ø200	32	100	7.16	Ø200	32	100	7.16	Ø200	32	100	7.16	Ø200	32	100	7.16
Living/bed-room	Ø250	200	200	57.74	Ø250	168	168	43.38	Ø200	148	148	33.10	Ø200	108	176	34.15

[1] N—normal airflow rate, [2] B—boosting airflow rate.

2.2. Simulation Model

The performance of the ventilation system was analyzed by using the ductwork topology presented in Figure 2. The physical properties, components and settings are described in Tables 2 and 3. The ductwork was modelled, and the airflow distribution was simulated by using a HIT Balance tool, which is a tailored version of the simulation tool MagiCAD [31]. The ideal control of the constant static pressure in the supply and exhaust plenums was assumed. Ductwork is assumed to be ideal without leakages. In Equation (1), the exponent was assumed to be 0.5, according to most HVAC parts manufacturer documentation recommendations [31]. 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 given below, along with the used equations [31,32].

Table 3. Pressure drop equations for T connections.

	$\left[0.4408\cdot\left(\frac{v_2}{v_1}\right)^2 - 0.7619\cdot\frac{v_2}{v_1} + 0.3785\right]\cdot 0.6\cdot v_1^2$		$1.07\cdot\left[0.8 + 0.4\cdot\left(0.4\cdot\left(\frac{v_2}{v_1} - 0.5\right)\right)^{1.5}\right]\cdot 0.6\cdot v_1^2$
	$0.2\cdot\left(\frac{v_2}{v_1}\right)^{-0.76}\cdot 0.6\cdot v_1^2$		$\left[0.7\cdot\left(\frac{v_2}{v_1}\right)^2 + 0.4\cdot\frac{v_2}{v_1} - 0.4\right]\cdot 0.6\cdot v_1^2$
	$1.07\cdot\left[0.8 + 0.4\cdot\left(0.4\cdot\left(\frac{v_2}{v_1} - 0.5\right)\right)^{1.5}\right]\cdot 0.6\cdot v_1^2$		$\left(0.56\cdot\frac{v_2}{v_1} + 0.6\right)\cdot 0.6\cdot v_1^2$

K-values for the components of the system were taken from the manufacturer data for designed airflows. The following equation was used for the volumetric airflow rate:

$$q_v = k\cdot\sqrt{\Delta p}, \tag{1}$$

where q_v—volumetric airflow rate, Δp—component pressure drop.

The resistance coefficient for the duct was calculated with:

$$\frac{1}{\sqrt{\lambda}} = -2\cdot\lg\left(\frac{k}{d\cdot 3.71} + \frac{2.51}{Re\cdot\sqrt{\lambda}}\right) \tag{2}$$

where d—roughness number, Re—Reynolds number, λ—friction coefficient.

The duct pressure drop equation for 90° circular bends was obtained from:

$$\Delta p = 0.32\cdot v^{1.8} \tag{3}$$

where $v$flow velocity.

For a 45° bend, the values were divided by 2 and for 30° by 3.

The pressure drops of the different T-connection sections of the supply and exhaust ductwork systems are presented in Table 3.

2.3. Airtightness

Equation (2) was used to evaluate the effect of airtightness on the pressure difference over the building envelope [33]. An airtightness level is presented by infiltration air change rate at 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 highly energy-efficient buildings.

The pressure difference was calculated from known airtightness levels, represented above by the airflow rate required to maintain pressure difference of 50 Pa:

$$q_{v50} = C \cdot \Delta p_{50}^{n}, \quad (4)$$

where q_{v50}—is the airflow rate required to maintain a pressure difference Δp 50 Pa (m^3/h), C—flow coefficient (m^3/(h·Pa)), Δp_{50}^{n}—50 Pa pressure difference between outdoor and indoor air, n—exponent:

$$n_{50} = q_{v50}/V, \quad (5)$$

where n_{50}—air change rate at 50 Pa (1/h), and V—the inner volume of the measured building (m^3).

3. 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 standard design is described in Figures 2 and 3. 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.

3.1. Performance of Standard Demand-Based Ventilation System

The simulation assesses the airflow rates and airflow balance at room, apartment, branch and AHU levels as a function of the number of apartments with kitchen boosting active. Figure 4 represents the target and simulated exhaust and supply airflow rates for apartments and zones in different boosting scenarios. Figure 5 illustrates the airflow rates at the AHU level concerning each apartment type. The scenarios are selected by the number of boosting apartments in each type. These scenarios represent 25, 50, 75 and 100% boosting modes of the ventilation system with one, two, three and four floors boosting simultaneously. 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. For one-, two- and three-room apartments, it is required to reduce the bathroom exhaust airflow rate in the boosting mode. For the studio, the supply airflow rate in the living room is increased instead.

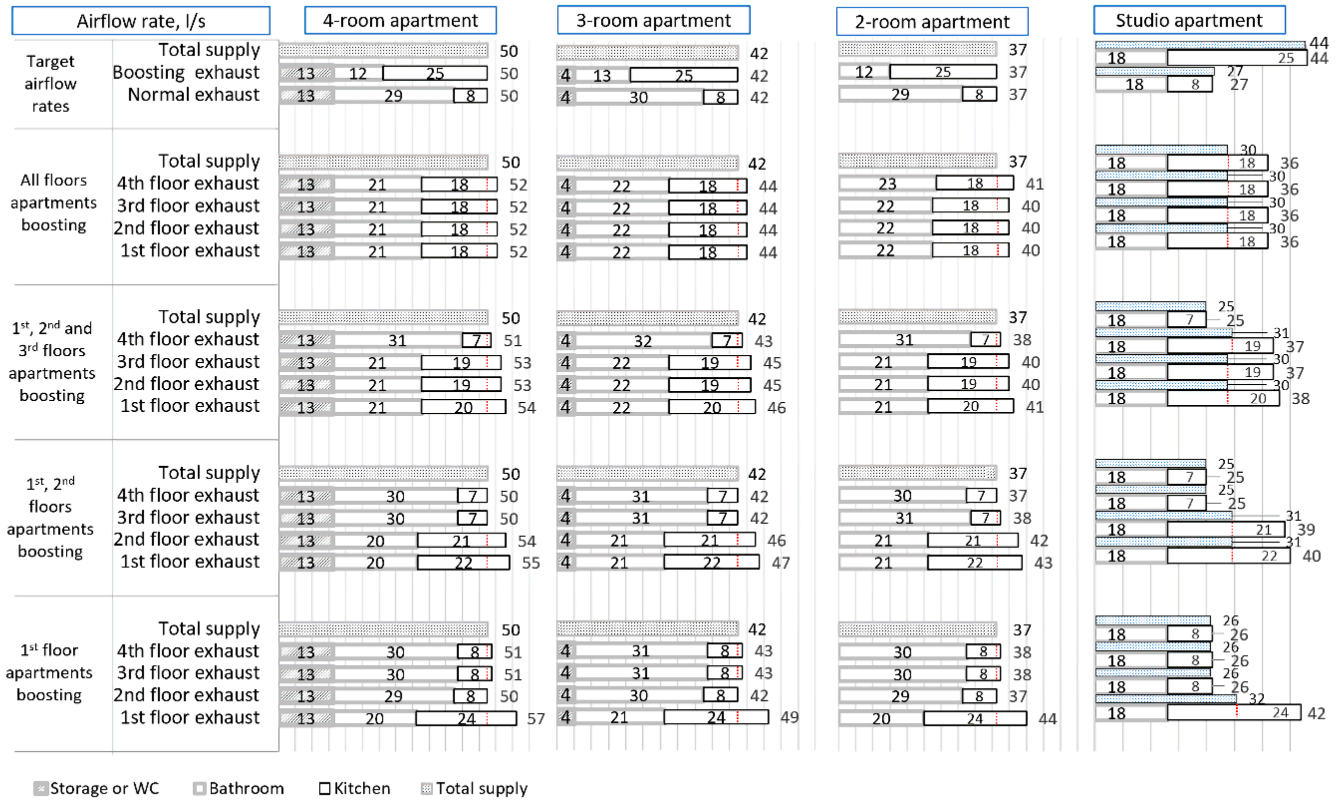


Figure 4. Airflow rates of the different sizes of apartments when a different number of apartments are boosting.

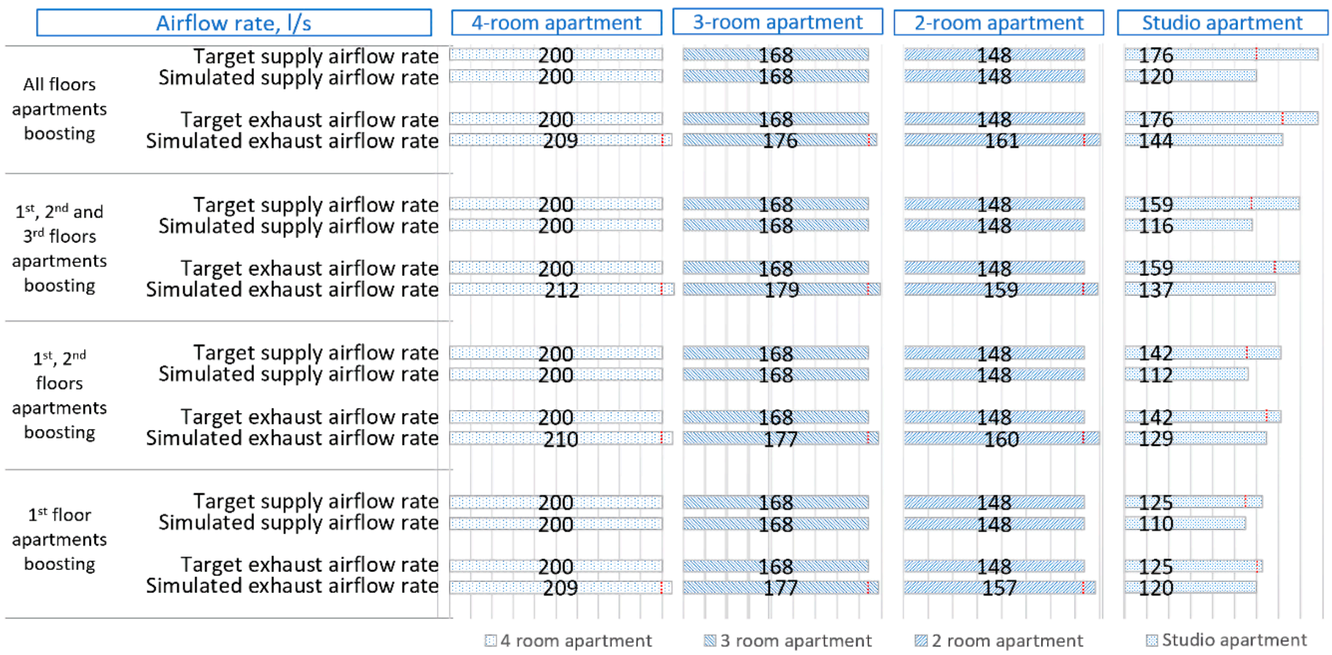


Figure 5. Target and simulated airflow rates at the AHU level when a different number of apartments are boosting.

The target airflow rate in two-, three- and four-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.

Figure 5 shows that the overall airflow rate at the AHU level is within 10% of the target value. The two-, three- and four-room apartment airflow rate is within 5% with higher exhaust airflow due to the mentioned issues. However, studio supply and exhaust airflow rates are lower by 56 L/s or 32% and 32 L/s or 20% than the target values in all boosting cases, respectively.

Imbalance in a mechanical ventilation system may lead to pressure differences over the building envelope. The more airtight the building is, the higher this pressure difference may become. Three levels of airtightness were chosen to assess and compare the possible resulting negative to atmospheric pressure: 2.5 1/h representing older building stock, 1 1/h representing new buildings, and 0.5 1/h representing future energy-efficient buildings in Finland. To evaluate the meaning of pressure difference over the building envelope, the airflow rate imbalances of the worst scenarios were chosen for each type of apartment. The exponent for Equation 2 was assumed to be 0.74 [34]. The volume was calculated based on the building documentation and the height of the rooms was assumed to be 2.6 m.

Table 4 presents the resulting pressure difference in the apartments with different airtightness level. The acceptable level of negative pressure in residential buildings was assumed to be −10 Pa, and −30 Pa was set as a warning level [12]. The four-room apartments had an acceptable pressure level at any airtightness due to their larger floor area. Two- and three-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.

Table 4. The pressure difference in the apartments with different airtightness levels.

Apartment Type	2.5 1/h	1 1/h	0.5 1/h
Studio apartment	−4.4 Pa	−15.4 Pa	−39.8 Pa
2-room apartment	−1.6 Pa	−5.5 Pa	−15.4 Pa
3-room apartment	−0.9 Pa	−3.3 Pa	−12.7 Pa
4-room apartment	−0.7 Pa	−2.5 Pa	−6.4 Pa

3.2. Performance with the Improved Design Concept

The analysis of the standard ventilation system design 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.

In all apartment types, the kitchen hood exhaust ventilation is unable to provide the designed 25 L/s airflow rate when two or more apartments in the same line are boosting. The range hood has two k-value settings. The principle of the standard balancing strategy is that the boosting mode k-value of the kitchen hood is obtained when only one apartment is boosting in the apartment line.

The origins of the practical issues in the supply branches of studios and two-, three- and four-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 6, a proposed solution is presented. The one-position dampers are replaced with two-position dampers in the exhaust branch of two-, three- and four-room apartments, and the supply branch of studio apartments. 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 that is 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.

The results of applying the new, improved concept are shown in Figure 7. The overall presentation methodology is similar as in Figure 3. In Figure 7, the two-room apartment and studio airflow rates are presented at different operation modes.

The solution where the dampers are replaced with two-position ones but the balancing strategy is the same as in the original 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.

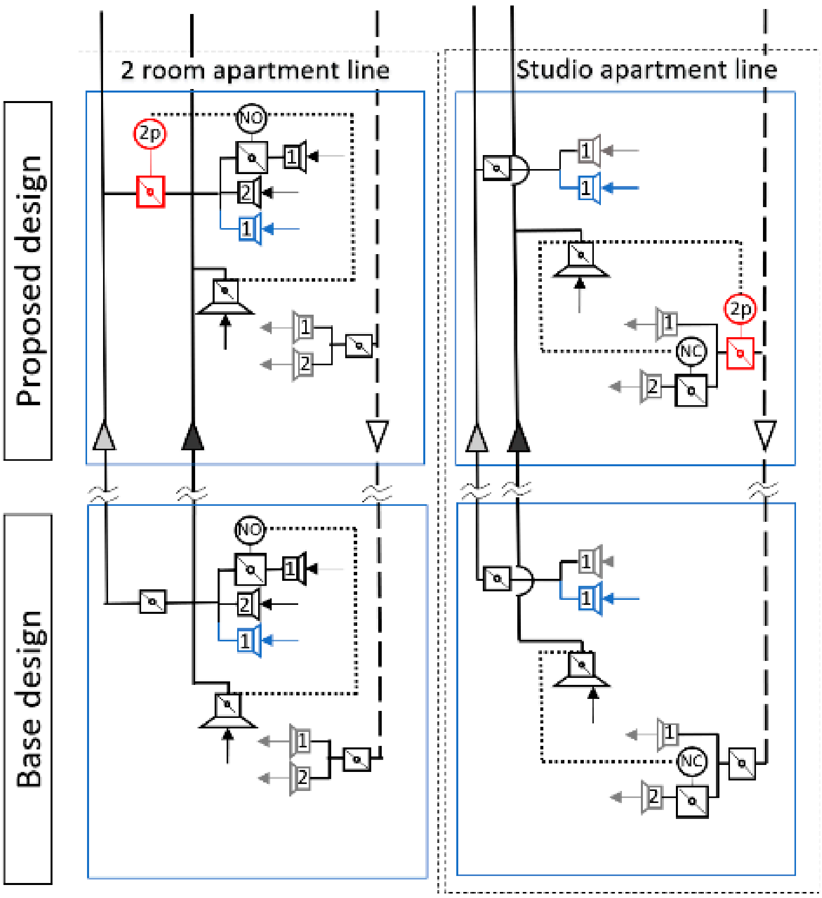


Figure 6. Apartment airflow rate control schemes in the standard design and proposed improved concept.

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%.

Both concepts are presented to show that issue should be addressed in the complex. In the case study building, the kitchen hood exhaust branch is designed to be capable of providing the required airflow rates in cooking mode. Thus, the most demanding boosting modes have not been taken into account, resulting in the shortage of the airflow rate. The results show that proper airflow balancing is essential even in a well designed ventilation system, and the strategy should be created concerning all possible ventilation system modes.

Furthermore, in general, the system inherited the CAV design with minor changes, presented by local airflow control on the apartment level through on/off dampers. However, this design is capable of changing the airflow rate, the lack of local control results in system airflows imbalance and a lack of ability to adjust the system without replacing components.

The concept for the demand-based ventilation system should be simple and robust to make the balancing of the ventilation system easy. The proposed concept of airflow rate control provides an extensive opportunity to guarantee system performance in all different operation modes. On the other hand, the concept may be implemented in the very late phase of the ventilation system design for a new Finnish apartment building, or it could be easily implemented in the existing building by making relatively simple retrofitting.

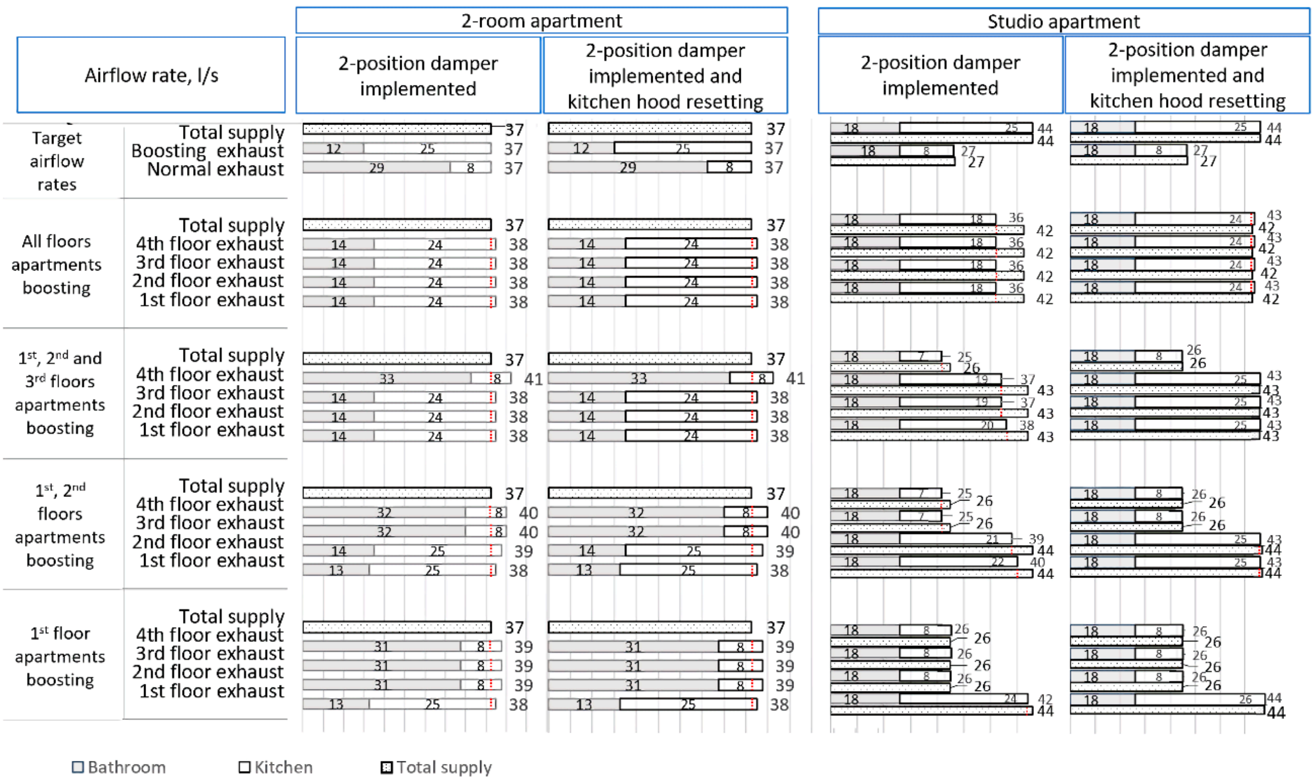


Figure 7. Airflow rates of the 2-room and studio apartments in boosting and normal modes with two position dampers installed and with two positions dampers and an improved balancing method.

4. Conclusions

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 gas as it is the primary source of indoor pollutants in modern residential buildings.

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 airtightness level. In the paper, the performance of the standard design was assessed and analyzed.

Based on the conducted simulation, the standard design is unable to reach the design values in boosting mode with increased airflow rates. The kitchen hood exhaust was 28% lower than the target values in all apartments in the case of simultaneous apartment boosting. The studio apartments have a significant (24 %) exhaust and supply airflow rate imbalance in the boosting mode. The two-, three- and four-room apartments have about 14% higher airflow rates in the exhaust than in the supply, and in the bathroom this difference is 40%. The imbalance of the airflow rates leads to a 15 Pa negative to atmospheric pressure with existing building airtightness levels. In the very energy-efficient building, the pressure difference increased to over −40 Pa.

To improve the performance, a new design of apartment airflow control devices and a new balancing strategy were proposed. 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%. Furthermore, the kitchen hood operation matched the designed values of 25 L/s and provided the required pollutant extraction in the boosting mode. The average error of the standard measuring devices is around 10–15%, which in practice significantly increases the pressure over the building envelope in modern airtight buildings. Thus, this indicates that the accuracy of measuring devices is also required to be improved, and the target of the measurement devices should be 5 % to be able to prevent high pressure differences over the building envelope.

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