Airtightness test of single-family building and calculation result of the energy need for heating in Polish conditions

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Abstract. The article presents results of air permeability measurements carried out for envelopes of two entire typical single-family residential buildings and separately for envelopes of garages and residential zones of these buildings. The effect of taking into account separate air permeability measurements of building zones on the calculation results of infiltration heat losses and on the energy need for heating is analysed. The calculation results obtained in this way are then compared to calculation results obtained in the case of air permeability measurements of the entire building envelope.

1 Introduction

Heat losses have a significant influence on the results of the energy calculations for a building. Due to the high requirements of thermal insulation of the building envelope, ventilation heat losses become more and more important. They can be divided into two parts; losses resulting from ventilation and losses from infiltration. Heat losses resulting from the aforementioned air flows particularly depend on the type of building ventilation system and the airtightness of the building envelope. In single-family buildings, with increasingly popular mechanical supply and exhaust ventilation with heat recovery, the contribution of infiltration heat losses increases. Ventilation air flows are simple to determine. In contrast, infiltration air flows depend on both the building's properties (mainly the airtightness of the building envelope) as well as on external conditions (outdoor air temperature, wind speed and direction). For these reasons, they are difficult to determine. A review of methods for determining infiltration air flows is given by way of example in [1].

Methods for determining infiltrating air flow rate used in energy calculations in Poland are based on the results of building air permeability measurements [2]. The national regulations are based on the European standard [3]. Therefore, the Polish regulations limit the permissible air permeability of the building envelope [4]. The parameter used to

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characterize the building's tightness is n_{50} – ratio of measured air flow rate across the building envelope (at indoor-outdoor pressure difference of 50 Pa) to internal volume of the building. In Poland, it is recommended not to exceed n_{50} = 1.5 h^{-1} for a building with mechanical ventilation or air conditioning, and n_{50} = 3.0 h^{-1} for a building with stack or hybrid ventilation [4]. However, due to Polish regulations, air permeability measurements are not obligatory.

The issue of airtightness in relation to the energy calculation of a building was considered in [5–7].

For calculations of the energy need for heating, a building should be divided into zones [2, 3]. This division results mainly from different internal air temperatures and various heating and ventilation systems. Moreover, according to Polish law [2], it is possible to calculate the energy need of only part of the building (for example, for an energy performance certificate for that part of the building). However, the standard n_{50} values are given only for entire buildings envelopes [1, 2, 5, 8]. For this reason, the question was asked: whether the n_{50} of the entire building or separate n_{50} of each building zone should be taken into account for calculating the energy need for building heating? The calculation methods presented in [2, 3, 8] do not indicate the necessity to differentiate the results of air permeability for particular building zones.

According to the above-described requirements, a single-family building with a garage should be divided into a residential zone and a garage zone with a significantly lower internal temperature. In the case of a building divided into zones with different internal temperatures, the influence of different air permeability of particular zones can affect the calculations (according to the methods presented in [2, 3]) of the energy need for building heating. Therefore, an attempt was made to show the impact of the method of performing and taking into account the airtightness tests on the result of calculations of infiltration heat losses and energy need for heating.

2 Airtightness tests of analysed buildings

Air permeability measurements were carried out for two single-family houses with a built-in garage (called building 1 and building 2). Tests for each building were done in three variants:

B1, B2 – for the entire building,
R1, R2 – for the residential zone after closing the door between zones,
G1, G2 – for the garage zone after closing the door between zones.

2.1 Description of the tested buildings

Building 1 - a single-family, detached, two-story house without a basement and with a non-usable attic. The building has mechanical supply and exhaust ventilation with heat recovery. In addition, a wood-burning fireplace is installed in the building. The building is shielded from the north and from the east, while the southern and western facades are exposed.

Building 2 - a single-family, detached, two-story house without a basement, with a non-usable attic over a garage. The building has mechanical supply and exhaust ventilation with heat recovery and a ground heat exchanger. In addition, a wood-burning fireplace is installed in the building. Additionally, stack ventilation ducts are used for the attic and storeroom. The building has moderate shielding from the north, east, and west, while the southern facade is exposed. The surfaces and volumes of particular zones of both buildings are given in Tab. 1.

Table 1. Parameters of the investigated buildings.

Parameter	**Values**	
Object	Building 1	Building 2
The building's internal volume (no attic), m^3	768.0	587.3
Internal volume of the residential zone - without a garage (no attic), m^3	641.0	490.9
Internal volume of the garage zone, m^3	127.0	96.4
The building floor area (without attic), m^2	308.7	244.2
Floor area of the residential zone - without a garage (no attic), m^2	268.8	213.6
Floor area of the garage zone, m^2	39.9	29.0

2.2 Method and conditions of tests

According to regulation [1], the air permeability measurement of a building should be carried out in accordance with the standard [9]. It should be noted that this standard has been withdrawn and replaced by the standard [10]. Since the standard [10] does not have a Polish language version, the norm [9] should be used in Poland. However, there are no significant differences between the norms [9] and [10] in the method of determining the n_{50}.

Airtightness was tested by blower door, produced by Retrotec, type EU5101 (accuracy of air flow measurement +/- 5%). The research was carried out after the buildings were prepared in accordance with [9] and [10]. The air intake for supplying outside air to the fireplace, air intake and outlet of the ventilation system, fireplace chimney, endings of stack ducts from the storeroom and attic (in building 2), and ventilation slot in the garage door (in building 2) were sealed. The internal doors in the zone under test were open. Siphons were flooded or sealed. Windows and external doors were closed. The window trick vents in the roof windows were closed or sealed.

The fan-pressurization method described in standards [9, 10] is intended to characterize the air permeability of the building envelope or part of building. Both documents are intended for the measurements of single-zone buildings. Many multi-zone buildings can be treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones [9, 10].

The tightness tests were carried out separately for each zone in the two-zone buildings. In contrast to the method described in the standards [9, 10], the tightness tests were performed using a differential method (described below) adopted only for the two-zone building. This approach did not require the use of an additional fan to create a counter-pressure in the adjacent zone.

The adopted differential method assumes the air flow scheme during the airtightness test presented in Fig. 1. It was assumed that the measured air leakage rate of the entire building envelope $\dot{V}_b^m$ is equal to the sum of air leakage rates across external barriers of the residential $\dot{V}_r$ and garage $\dot{V}_g$ zones. Without counter-pressure in the adjacent zone, the measured air leakage rate of the zone (for the residential $\dot{V}_r^m$ and garage $\dot{V}_g^m$ zones) is the sum of the air leakage rate across external barriers of the zone ($\dot{V}_r$ and $\dot{V}_g$ respectively) and the air leakage rate between zones $\dot{V}_z$. It was assumed that the air leakage rate value $\dot{V}_z$ is the same during measurements for each zone. Therefore, to eliminate the effect of air flow between zones $\dot{V}_z$ from the results of air leakage rate measurements carried out separately for zones, the following method of correction was applied.

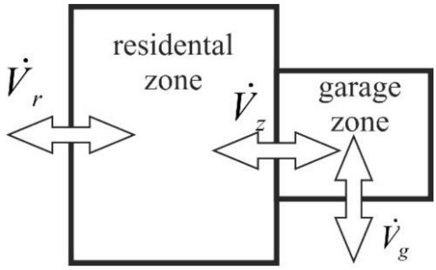

Fig. 1. The assumed model of air flow in the building for the differential method.

It was assumed that the air flow between zones can be estimated with the following equation:

$$\dot{V}_z = \frac{\left(\dot{V}_r^m + \dot{V}_g^m\right) - \dot{V}_b^m}{2} \tag{1}$$

The corrected air leakage rate across the external barriers of the garage zone was determined as: `

$$\dot{V}_g = \dot{V}_g^m - \dot{V}_z \tag{2}$$

On the other hand, the corrected air leakage rate across the external barriers of the residential zone was determined as:

$$\dot{V}_r = \dot{V}_r^m - \dot{V}_z \tag{3}$$

The measured air leakage rate of the entire building envelope does not need correction, hence $\dot{V}_b = \dot{V}_b^m$.

2.3 Analysis of measurements results

The results of the airtightness tests on the analysed buildings are presented in Table 2. The results after the correction described in point 2.2 are shown in Table 3.

Table 2. The results of airtightness tests of buildings 1 and 2 before the correction.

Parameter/Building zone	Entire building 'b'	Residential zone 'r'	Garage zone 'g'
***n_{50}*, measured air change rate at indoor-outdoor pressure difference 50 Pa, h^{-1}**	**Building 1**		
	3.55	2.99	9.80
	Building 2		
	2.69	2.07	11.99
$\dot{V}_{50}$, air flow rate across building envelope at indoor-outdoor pressure difference 50 Pa, m^3/h	**Building 1**		
	2 730	1 915	1 245
	Building 2		
	1 580	1 016	1 156

Table 3. Corrected results of airtightness tests of buildings 1 and 2.

Parameter/ Building zone	Entire building 'b'	Residential zone 'r'	Garage zone 'g'
	Building 1		
n_{50}, corrected air change rate at indoor-outdoor pressure difference 50 Pa, h^{-1}	3.55	2.65	8.11
	Building 2		
	2.69	1.47	8.91
	Building 1		
$\dot{V}_{50}$, corrected air flow rate across building envelope at indoor-outdoor pressure difference 50 Pa, m^3/h	2 730	1 700	1 030
	Building 2		
	1 580	720	860

In the case of both analysed buildings, the results of the airtightness test indicate a much larger permeability of the garage zone than the residential zone. This regularity seems to result mainly from the lower airtightness of garage gates in relation to windows and doors. The observed property was the main reason for analysing whether such a difference in the airtightness of zones with different internal temperatures can significantly impact on calculation results of infiltration heat losses and heating energy need.

3 Analysis of the influence of separate results of zone airtightness tests on the results of energy calculations

The examined objects were treated as typical examples of single-family buildings. The airtightness test relates to the building envelope, so the impact of the ventilation system used in the tested building was considered as of little significance. Therefore, despite the fact that the analysed buildings are equipped with mechanical supply and exhaust ventilation, a similar ratio of the airtightness test results for particular zones can also be expected in buildings with natural ventilation.

The infiltration air flows were determined by the method imposed by the Polish regulations on the energy certification of buildings. For natural ventilation, regulation [4] gives the following relationship:

$$\dot{V}_{inf} = \frac{0.05 \cdot n_{50} \cdot V}{3600} \tag{4}$$

where V is the volume of the building. In the case of mechanical ventilation, the average additional air flow $\dot{V}_x$ infiltrating during fans operation, Regulation [4] requires calculation according to the method given in the standard [3]:

$$\dot{V}_x = \frac{V \cdot n_{50} \cdot e}{1 + \frac{f}{e}\left(\frac{\dot{V}_1 - \dot{V}_2}{V \cdot n_{50}}\right)^2} \tag{5}$$

where $\dot{V}_1$, $\dot{V}_2$ are the supply and exhaust air flows of the ventilation system, while e, f are coefficients depending on the building wind shielding (for one exposed façade: no shielding e = 0.03; moderate shielding e = 0.02; heavy shielding e = 0.01; for more than one exposed façade: no shielding e = 0.10; moderate shielding e = 0.07; heavy shielding e = 0.04).

For both analysed buildings, the infiltration air flows were calculated in two variants:

A) assuming the same n_{50} value for both building zones based on an airtightness test of the entire building envelope,
B) assuming different n_{50} values for each building zone (after correction) based on separate airtightness tests of building zones.

For both variants, infiltration heat losses for building zone $\dot{Q}_{inf}^{b}$, residential zone $\dot{Q}_{inf}^{r}$ and garage zone $\dot{Q}_{inf}^{g}$ were calculated. The heat losses were determined based on the following assumptions:

- average internal temperature in the residential zone: 20.4°C,
- average internal temperature in the garage zone (building 1 - garage, boiler room, storeroom, building 2 – garage): 8.1°C,
- average external temperature during the heating season: 5.2°C,
- design ventilation air flow for the residential zone: 195 m^3/h,
- design ventilation air flow for the garage zone, ensuring the exchange rate 0.3 h^{-1}.

The air flow infiltrating through the entire building envelope is equal to the sum of the air flows infiltrating from the outside environment to the residential and garage zones.

Air infiltrating into the garage zone can:

- case 1 - exfiltrate completely and directly to the outside environment,
- case 2 - infiltrate completely into the residential zone,
- case 3 - partially infiltrate into the residential zone and partially exfiltrate directly to the outside environment.

It is obvious that in case 2, taking separate n_{50} values into account does not affect the energy need for heating, because finally the entire infiltrating air flow is heated to a higher temperature in the residential zone. The influence of separate n_{50} values for each zone is expected for case 1. Therefore, the results presented below are valid only for case 1. Case 3 would give results lying between cases 1 and 2.

Figures 2 and 3 present the ratio of heat loss results obtained in variants B and A. Results assume different values of shielding coefficients *e*, *f* and different ventilation systems: natural and mechanical. For the calculations with mechanical ventilation, in the residential zone – supply and exhaust ventilation with heat recovery, and in the garage zone – exhaust ventilation were assumed. Mechanical ventilation system in the residential zone was analysed with balanced and imbalanced air flows (difference between air supply and exhaust was assumed equal +50 m^3/h or -50 m^3/h – for both situations equation (5) gives the same results – Figures 2 and 3).

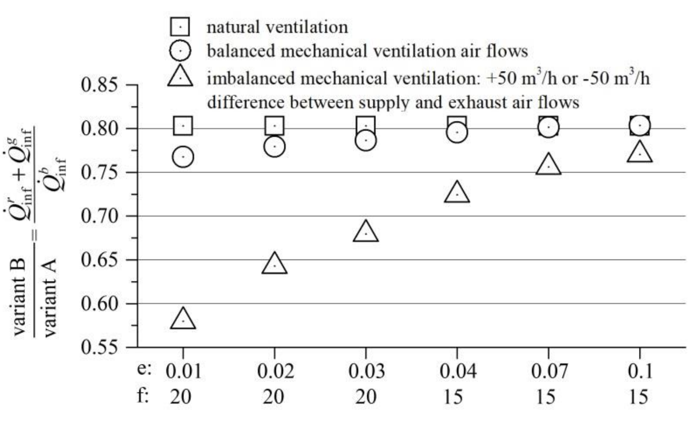

Fig. 2. Calculation results of infiltration heat losses (variant B to A ratio) for building 1.

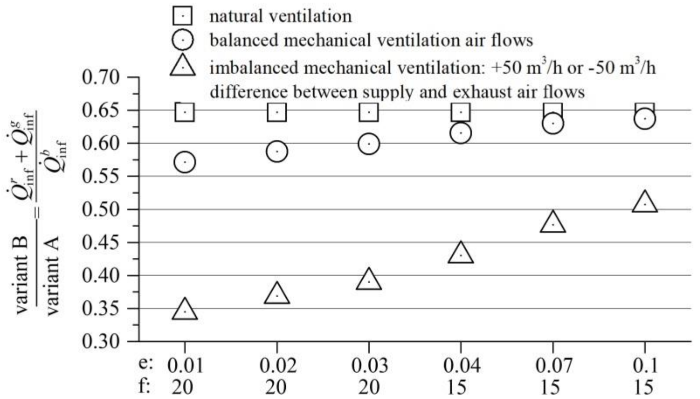

Fig. 3. Calculation results of infiltration heat losses (variant B to A ratio) for building 2.

The effect of considering the separate n_{50} values in the calculation of energy need for heating is analysed below. For building 1 for all variants, the energy need for heating (respectively $\dot{Q}^b_{H,nd}$, $\dot{Q}^r_{H,nd}$, $\dot{Q}^g_{H,nd}$) was calculated in accordance with the methodology presented in [2, 3]. Figure 4 presents the ratio of the calculation results from variant B to variant A.

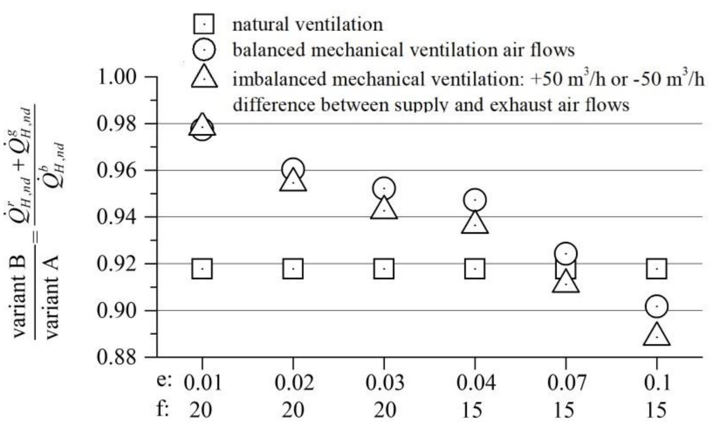

Fig. 4. Calculation results of the energy need for heating (variant B to A ratio) for building 1.

The presented analysis shows that variant B in relation to variant A causes significant changes in the results of calculations of infiltration heat losses. In the case of mechanical ventilation, the changes increase with the building's higher wind shielding and with higher imbalance of the mechanical ventilation system air flows.

Moreover, considering the separate n_{50} values for both zones changes the results of calculations of the energy need for heating (for the analysed case, the reduction of $\dot{Q}_{H,nd}$ was close to 12%). In the case of mechanical ventilation, the changes decrease with the building's higher wind shielding and with higher imbalance of the mechanical ventilation system air flows.

4 Conclusions

- In both analysed buildings, there were significant differences between the airtightness of the residential zone and the garage zone. The result of the airtightness test of the garage zone (n_{50} after proposed correction 8.91 h^{-1} and 8.11 h^{-1}) is several times higher than for the residential zone (n_{50} after proposed correction 2.65 h^{-1} and 1.47 h^{-1}).

- The presented analysis is valid because it shows that this difference significantly influences the calculation result of the energy need for heating. Implementation of separate n_{50} for the analysed case changes this result by up to 12%.
- The presented results concern an extreme situation, when the entire air flow infiltrating to the garage zone is exfiltrated directly outside. In this case, the effect of implementing separate airtightness test results is the greatest. However, in the situation when the entire air flow infiltrating the garage zone will flow to the residential zone with a higher temperature, this influence should not occur.
- Therefore, it was assessed that separate results of airtightness tests for each zone should be taken into account, instead of one common result for the entire building, when the air infiltrating into the garage zone does not enter the residential zone. The more the air infiltrates from the garage zone to the residential area, the more implementing the separate airtightness test results makes less sense.
- Methods presented in [3, 4] do not allow the determination of the direction of air flow infiltrating between zones. If it is not explicitly known (for example, it is not a result of detailed simulations), then separate test results cannot be reliably considered in the calculations of the energy need for heating the building.
- In order to determine the values and directions of flows between zones, for the specific layout and location of the building and the specific ventilation system, dynamic simulations should be performed. They should take into account the impact of wind and thermal buoyancy on the air flow through the building. For this reason, it is worth carrying out this type of simulation as a direct continuation of work on this subject.

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