Transition from n_{50} to actual air exchange dependent on climatic conditions

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Abstract. The knowledge of the air flow and air exchange in the building is critical both on the design and operation stage of the building. Infiltration of air interferes with the mechanical ventilation and determines the proper functioning of the natural ventilation system, still commonly used in the standard buildings. The building airtightness can be described by n_{50} parameter, however it does not specify the real air exchange in natural conditions. According to the simple procedure of the standard EN ISO 13789, factor n_{50} may be easily converted to the monthly averaged air change rate. However, it is difficult to accept the same value of air change rate in any month of a year, as it is often done in the certification procedures. More precise, climate dependent conversion procedures have been elaborated in USA, but they were developed for the specific local building technology and local climate conditions. This paper presents the results of the preliminary measurements conducted in a single family house in Poland, built in a heavy-weight technology. The real air exchange rate was measured in various climatic conditions by means of gas tracing method, with CO₂ as the tracer gas, in order to prove a relationship between the enhanced procedure and the external conditions. Acceptable agreement between the results of the measurement and model calculations was obtained. Based on the preliminary results, the authors determined the more realistic influence of the enhanced algorithm on the ventilation energy demand. The use of the simplified model resulted in case of the analyzed object in 15% overestimation of the ventilation thermal losses.

1 Introduction

Due to the increasing concerns regarding building energy demand, reduction of energy losses related to ventilation is one of the main targets in the designing process. However ventilation cannot be analyzed without influence of infiltration. This uncontrolled and unintentional airflows affects significantly total volume of exchanged air and energy losses.

The knowledge of the air flow and air exchange in the building is an indispensable source of information both on the design and operation stage of the building. Infiltration of air determines the proper functioning of the gravitational ventilation system, the most common in the existing Polish buildings.

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Infiltration is a nonlinear phenomenon dependent on the quality of external building shell as well as its environment and driving forces. It is driven by the pressure difference caused by the weather dependent terms: wind speed and direction and temperature difference. The weather independent characteristic of a building shell can be partially quantified (measured n_{50} value) by the fan pressurization method [1] in the artificial conditions. The real air exchange through the building envelope can be determined with a gas tracing method. However, this measurement is complicated and the results are strongly related to the momentary external climatic conditions. The exact calculation of infiltration for a building based on the n_{50} parameter is currently beyond practical capabilities, therefore approximate methods must always be used [1]. The simplest procedure of transition from n_{50} to estimated air change rate, included in the European standard EN ISO 13789 [2], is not related to any climate parameters or e.g. local building exposure to wind. The more advanced algorithm, elaborated by Sherman [1], was based on the extremely wide research but is related to American climate and mostly the lightweight building technology. That is why the authors of the paper have begun research, the purpose of which is to check whether the method proposed by Sherman, hereinafter referred to as the enhanced approach, makes sense in the other technical and climatic conditions. The second goal is to assess to what extent a more accurate method of determining infiltration affects the building's energy performance.

2 Measurement of building airtightness and air infiltration

The building airtightness (air leaks in the building envelope) affects the infiltration and can be described by n_{50} parameter, indicating the volume of air being exchanged through the building envelope during one hour at a pressure difference of 50 Pa between indoor and outdoor environments. The most popular method of building airtightness evaluation is currently the pressure method (blower-door method), according to the standard EN 9972 [3]. It allows to assess tightness of the outer building envelope in the artificially created conditions of a considerable pressure difference between the interior and the building's external environment. It is a form of the envelope quality diagnostics, but the assessment of the actual air exchange in a building, especially with gravitational ventilation system and under real climatic conditions, is still unknown.

The actual air exchange in natural conditions can be measured using gas tracer concentration decay method standardized in EN ISO 12569 [4]. The practical aspects and problems connected with the tracer gas concentration decay method were discussed in [5,6]. This method is based on the analysis of the rate of decay of tracer gas concentration in the internal air. Carbon dioxide is one of the natural compounds of atmospheric air that can be used also as a tracer gas. Measurement technique with CO_2 as a tracer gas was described in [7,8,9,10,11,12]. The Rotronic meters have been used to measure: CO_2 concentration within the range of 0 to 5000 ppm with the accuracy of 30 ppm + 5% of sensor indication and the temperature with an accuracy of up to 0.3K.

Despite the simple physical principle of this method, it is not easy to achieve the high precision of measurements due to the problems with uniform mixing of tracer gas and air in a multi-room apartment or building.

3 Models of infiltration based on the tightness measure n_{50}

The diagnostics of the building's external shell under the conditions of artificially generated pressure difference is relatively easy and quick to perform. In many European countries, it becomes nowadays a standard building survey. The measurement of real air exchange rate

is more difficult, time-consuming and strongly related to the momentary climatic conditions. Hence, attempts have been made for a long time to determine the accurate relationship between both methods. The simplest, widely known relation is the Kronvall and Persilly infiltration model [13,14]. It states that the mean annual infiltration rate can be obtained by dividing n_{50} value by the numerical coefficient equal to 20. As mentioned above, this model was applied in the standard EN ISO 13789 [2]. However, this kind of approach is a significant simplification, due to the assumption, that infiltration rate is the same in any month of the year, no matter what are the momentary climate indicators. Sherman at Lawrence Berkley Laboratory worked out the more accurate model replacing numerical coefficient 20 with a parameter N , that is called leakage infiltration ratio, and equal to $N = 14 / s$, where s - specific infiltration is a function of wind speed and external air temperature [1]. The value of leakage infiltration ratio N is different for the various regions of the country, depending on the local climate indicators. N value can be determined on annual or monthly basis. When discussing air leaks through the external envelope, a factor q_{E50} may be used, that is the specific leakage rate per the building envelope area or q_{F50} that refers leakage to floor area. However, the only basis for the transition to the real air infiltration rate in the considered simplified procedures is n_{50} value.

4 Results of the measurements and discussion

The analysed single family house, Figure 1a, built in 2017, is located in the village Zielonki, in the neighbourhood of Cracow. It is one story building with the unconditioned attic space.

Fig. 1. a) tested single family house in Zielonki, b) blower-door set mounted in the entrance door

The external walls are made of ceramic blocs with 5 cm insulation of expanded polystyrene. The attic floor is a reinforced concrete slab, insulated with 15 cm of expanded polystyrene. The wooden windows are double glazed with low emissivity coating and argon filled glazing. The window frames are sealed with the rubber gaskets. The windows are embedded in walls in a standard way, using the assembly PU foam. In the house there is a natural ventilation system with the two ventilation ducts, 18 cm x 18 cm each, located in the kitchen and in the bathroom. Ventilated volume of building is 230 m³. The applied climatic data (average monthly wind speed and average monthly temperature) for Cracow Balice (the nearest meteorological station).

The measurements of the building tightness (blower-door test, Figure 1b) and air exchange rate were carried out in the different periods and climatic conditions. Air exchange rate was measured with the gas tracer method using three detectors located in the three different parts of the tested building (one in the leaving room, one in the kitchen and one in the bedroom). The specific airflow rates were calculated separately for each day

using two point decay method. The measurements with gas tracer method were repeated for five times. The obtained results are presented in Table 1. In this method, it is not necessary to measure the pressure difference between the environment and building interior.

Table 1. Results of the measurements by means of tracer gas decay method

Date	Specific airflow rate N[1/n]	External temperature [°C]	Wind speed [m/s]
24.07.2018	0.029	26	3-4
25.07.2018	0.031	28	2-4
03.08.2018	0.011	27	1-0.5
29.01.2019	0.096	-4	1-1.5
17.02.2019	0.102	6	5-7

The measured values of the actual air exchange in the building are very low and do not meet the required hygienic requirements. The maximum measured air change rate occurred in February and was equal to 23 m³/h (0.102 of the ventilated volume 230 m³), while the hygienic requirements for this building (2 adults and 2 children) can be estimated as 100 m³/h. It may be expected that the average air quality in this building is also quite low. The instantaneous value of the air exchange depends on the pressure difference induced by temperature difference and wind action. In this situation, the degree of building protection against wind and wind direction must also have a significant, but very difficult to determine, impact on the result.

The blowerdoor test was conducted on 13 of October 2018 using two methods, as suggested in standard [3], with the closed (method B) and opened (method A) ventilation ducts. Results of these measurements: method A, $n_{50} = 3.47$ 1/h, method B, $n_{50} = 1.85$ 1/h. In the further analysis the lower value of n_{50} was used as it describes only the building shell infiltration without influence of ventilation system. The specific leakage rate per the building envelope area was equal to 1.26 m³/(m²h).

The above information enabled calculation of the total ventilation air change and the related energy demand in two different ways and in the variable external climatic conditions.

According to the simplified (Persilly) model, used in the European standard [2], the air exchange rate n , based on the measured value of n_{50} , is equal to 0.0925 1/h. The same value is taken in this model for each month of the year, Figure 2 (the orange bars). This nonphysical approach will not be the subject of comparisons with the test results.

Fig. 2. Specific air flow rate n according to the enhanced and simplified models

In the enhanced (Sherman) model, the air flow rate depends not only on n_{50} value but also on the temperature difference and wind velocity. In case of the analyzed building and meteorological data of its location, the mean monthly value of n in January is equal to 0.090 1/h, in February 0.087 1/h, in July 0.043 1/h and in August 0.040 1/h (Figure 2, blue bars). The percentage difference between the obtained measurement results (table 1) and the enhanced model is 6% in January, 15% in February, and ca. 30% in July. The very low test result in August (0.011 1/h) is unreliable and was not further considered.

Despite the very small (and therefore error-prone) measured values of air exchange, the measured and the modeled results are similar. The perfect match of the results cannot be expected, the measurements are dependent on the current, strongly variable conditions, while in the computational model the average monthly conditions are assumed. The results of long term measurements of infiltration are not available, but one can try to assess the variability of air change rate based on the results of simulation programs. The infiltration algorithm, used in the Energy Plus program, shows in this climate the monthly variability of infiltration rate of $\pm 30\%$ in January and up to $\pm 44\%$ in July.

Additionally, each building is situated in a different local wind exposure conditions, leakage characteristic and cracks distribution are unique for every building, while the commonly used simplified models do not include any of such factors. The actual difference of pressure is also not taken into account in the this procedure.

Commenting on the results, it can be concluded that the consistency of the obtained results is satisfactory.

To show the impact of the adopted model on the results of energy demand the following calculations have been conducted. Upon the obtained air flow rates from the two different models, ventilation losses in the analyzed house were calculated, Table 2.

Table 2. Specific air flow rate n according to the two different models

	V_{wind} [m/s]	T_i-T_e [K]	n [1/h] Sherman	n [1/h] Persilly	V_{inf} [m3/h] Sherman	V_{inf} [m3/h] Persilly	H_{ve} [W/K] Sherman	H_{ve} [W/K] Persilly	Q_{ve} [kWh] Sherman	Q_{ve} [kWh] Persilly
1	3.08	21.3	0.09	0.09	20.77	20.70	6.92	6.90	109.72	109.35
2	2.51	22.6	0.09	0.09	19.97	20.70	6.66	6.90	101.12	104.79
3	3.04	16.8	0.08	0.09	19.18	20.70	6.39	6.90	79.90	86.24
4	2.39	11.7	0.07	0.09	15.65	20.70	5.22	6.90	43.93	58.13
5	2.2	6.6	0.06	0.09	12.78	20.70	4.26	6.90	20.92	33.88
6	2.49	1.8	0.05	0.09	10.99	20.70	3.66	6.90	4.75	8.94
7	2.05	2.5	0.04	0.09	9.94	20.70	3.31	6.90	6.16	12.83
8	1.8	2.5	0.04	0.09	9.16	20.70	3.05	6.90	5.68	12.83
9	2.28	6.2	0.06	0.09	12.79	20.70	4.26	6.90	19.03	30.80
10	2.31	10.7	0.07	0.09	15.02	20.70	5.01	6.90	39.86	54.93
11	2.66	18.1	0.08	0.09	18.74	20.70	6.25	6.90	81.41	89.92
12	2.92	20.8	0.09	0.09	20.24	20.70	6.75	6.90	104.42	106.78
TOTAL:									616.90	709.43

Air flow rate in case of the Persilly’s model is the same in all the months which results in the constant value of the ventilation heat transfer coefficient H_{ve} . According to the more accurate Sherman’s model the values differ within the year and the heat transfer coefficient is 50% lower during the summer months. The final ventilation losses, being a part of the total energy balance, are ca. 15% lower in case of the enhanced model than in case of the simple approach (decrease from 709.4 kWh/year to 616.9 kWh/year).

5. Conclusions

The authors have attempted to evaluate the two commonly used simple algorithms that link the pressure test results with the actual ventilation rate, but also to assess an energy impact of the two approaches. Air tightness of the external building shell, n_{50} , was measured by means of the blower-door pressure method. The real air exchange rate, n , was measured by means of the gas tracing method in various temperature and wind conditions.

Acceptable agreement between the results of actual air exchange measurements and the monthly mean results of the Sherman model was obtained. The conducted preliminary research confirms the sense of using this algorithm also in Polish conditions and for the different building technology. Taking into account the annual variability of climatic conditions enables estimation of the part of energy losses related to ventilation. The calculated difference between the simplified and the enhanced model reached 15%. The actual energy consumption in this building was not monitored.

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