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Using Thermography to Locate Air Leakages through the envelope of a Building in the summer season

Abstract

The article presents how to use thermography to locate leakages through the air envelope of three selected single-family houses. Identification of air leakage was possible using differential analysis of thermal images recorded during a pressure test of the buildings as thermovision sequences. This enabled the detection of leakages through envelopes of the buildings at small summer internal and external temperature differences from 2 to 5°C.

Keywords: Termography, envelope air-leakness, airtightness test.

1. Introduction

Air-tightness of a building envelope is very important because of energy consumption for heating. Achieving adequate standards in energy-efficient and passive buildings may be practically impossible, because of the large non-tightness of the building envelope [2]. Buildings with low-energy demand, having low heat loss through the envelope and a heat recovery system from ventilation air can consume a lot of energy to heat the air infiltrating through leakages. Moreover, cold air, flowing through the bulkheads and openings of internal installations, adversely affects the recuperation system efficiency by reducing heat recovery from exhaust air from the building. These factors affect the growth of energy consumption for heating and ventilation.

The requirements contained in the Technical Specifications (TS) 2014 [3] applicable in Poland prescribe keeping tightness of connections between partitions or their parts and installation openings. There is no requirement for air leakage tests of the building envelope, only a recommendation. According to the recommendation, after the execution of construction, buildings should be subjected to tightness tests. The regulation sets out the recommended number of air changes not exceeding $n_{50} < 3.0$ 1/h for buildings with gravity and hybrid ventilation and $n_{50} < 1.5$ 1/h for air-conditioned buildings or buildings with mechanical ventilation. In the case of low-energy buildings or buildings built according to NF40 and NF15 standards (passive buildings), these requirements are even stricter and are respectively, $n_{50} < 1.0$ 1/h $n_{50} < 0.6$ 1/h [2]. The requirement of testing the envelope tightness after completion of the building works is imposed by the National Fund for Environmental Protection and Water Management (NFOŚiGW), if its construction was financed from the funds for subsidies to loans for building energy-efficient homes in the NF40 and NF15 standards. Then, carrying out a pressure test, it is verified whether the requirements for the tightness of the envelope are met in accordance with the provisions of one of the above standards.

2. Description

The most common leakages in buildings are shown in Figure 1. These are connections of building envelope, sealed connections as well as all kinds of mains connections, openings, electrical outlets.

It is the best to check tightness of buildings when they are in the so-called closed-in condition with ready internal installations. It is then possible to perform an initial assessment of tightness before handing buildings for use. This makes removal of leakages easier and less costly. Leak testing may be performed by two methods: pressurized, using a fan [1] or using a tracer gas. Currently, the most commonly used is the pressure method. It is possible to visually localize leakages using smoke generators or thermal imaging cameras during pressure tests.

The disadvantage of locating leakages using smoke generators or the so-called "smoke pen" is the necessity to produce smoke in the locations of anticipated leakages or to release smoke at the whole tested area. The greater the experience of performers of the test, the more leakages can be localized using this method. Thermographic imaging does not have these disadvantages, but it is necessary in this case to fulfill certain conditions, in which the measurement makes sense.

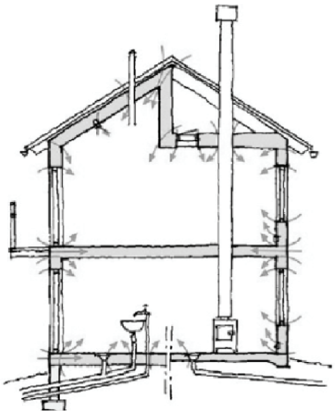

Fig. 1. Most common locations of air leakages (outflow of air) in buildings

From the viewpoint of thermography measurement conditions, periods of lower outdoor air temperatures are preferred as they allow achieving a temperature difference of more than 10°C. Mostly these are the months of late autumn to early spring when buildings are heated. With an high-sensitivity infrared camera, however, below 40 mK (NETD), it is possible to localize air leakages even during the summer at a temperature difference from 2 to 5°C. The smaller temperature difference is also important due to the differential pressure at zero flow, which can't be higher than 5 Pa before and after the leak test. This condition practically can't be met in larger objects, with a large temperature difference and large wind power.

A pressure test carried out in accordance with the standard [1] is about creating negative pressure or pressure between the internal and external environment of the building. It is recommended to generate pressure in the range of 10 Pa to 50 Pa, using a differential fan. Basing on the amount of air flowing through the fan, at an assumed differential pressure, surface and cubic of the tested zone, it is possible to calculate air change and the permeability of the envelope along with a unit flux leakage. The resulting n_{50} factor, characterizing the tightness of the envelope [3], determines the number of air changes in ventilated area in the building per an hour at differential pressure of 50 Pa. Values related to the n_{50} factor include air permeability q_{50} and unit stream of air leakage w_{50}. They are determined by dividing the stream of air leakage through the building envelope surface, respectively, by the envelope area and the net floor area. These factors are used in the requirements, e.g. in the USA, Canada, Sweden, France and England

Three single-family buildings were subjected to pressure tests. Two of them were made using traditional technology with masonry walls and a habitable attic with a purlin-and-collar-tie type roof truss. The third building was made of logs covered with clapboards and did not have a habitable attic. The tests were conducted using the Blower Door set by Retrotec (Fig. 2).

Leakage tests were carried out from June to late August. Results of the pressure tests (Fig. 3) show the dependence of the air stream flowing through the fan on the pressure difference.

Fig. 2. An installed system for leak testing using the Blower Door method - a view from the outside and from the inside of the building

Leakage testing was performed according to the B method, as described in the standard [1], with all inlets sealed, for the building to respond to the change in the pressure as one zone. In addition, the flow of outside air into the fireplace was closed (building 1) and spaces in the door of tiled stoves, supplying air to fireplaces, were sealed with tape (building 3).

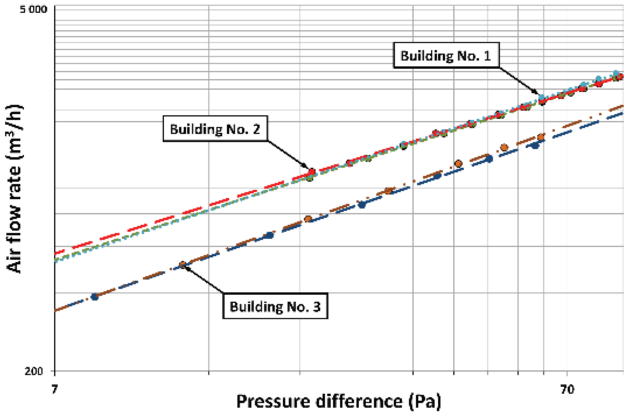

Fig. 3. Pressure difference depending on the adjusted amount of air flowing through the fan

Leakage tests of the selected buildings were performed in under and overpressure generated by a fan, values from 10 to 70 Pa, increments of 10 Pa.

Tab. 1. Data on buildings and leak test results

No.	Useful floor area	Ventilated cubic capacity of building	Number of air changes per hour at 50 Pa n_{50}	Air permeability at 50 Pa q_{50}	Unit stream of air leakage w_{50}
	m^2	m^3	1/h	$m^3/(h \cdot m^2)$	$m^3/(h \cdot m^2)$
1	79.24	144.48	7.60	5.36	19.20
2	180.80	442.20	3.03	4.27	7.42
3	70.40	177.10	10.55	7.96	26.59

Analyzing the results (Table 1), great diversity of the levels of tightness in three buildings can be observed. This depends largely on the design, construction of the envelope and the quality of execution. The impact of these factors is confirmed by tests carried out on existing domestic and foreign building [4], [5].

Flir SC660 thermal imaging camera was used for the localization of air leakages. The camera produces thermal images with a resolution of 640 × 480 pixels. Thermal sensitivity of the camera is 30 mK (NETD). For the performance of thermal images a lens with focal length f = 19 mm and FOV = 45°×34° was used to enable the observation of a large area.

To locate any leakages of air in external walls, during leakage testing at negative pressure, thermal imaging sequences of partitions were recorded from the inside of the building, to be processed later on. The processing consisted of images of thermographic differences between two thermograms - a reference one prepared at the beginning of registration and one selected from a sequence prepared during the leak test. Thus, the differential thermogram (in the right of Figures 4, 6, 8, 9, 11) shows temperature differences between the pixels of the frame recorded during the test in relation to the frame of reference recorded before the test.

In the case of building 1, leakages resulted mainly from the poor condition of windows (no gaskets in warped sashes) and being mounted in the outer wall (Fig. 4).

Leakages visible on the thermogram of a skylight in the attic (Fig.6) were due to a lack of continuity in impermeable vapor barriers.

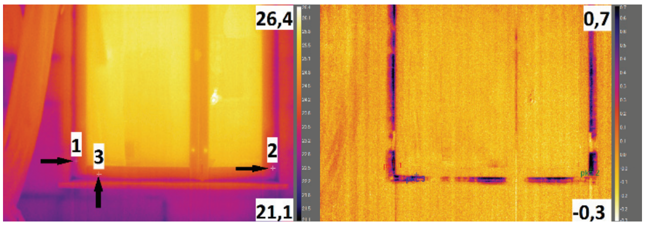

Fig. 4. A window reference and differential thermogram, from a room on the ground floor of Building No. 1 [6]

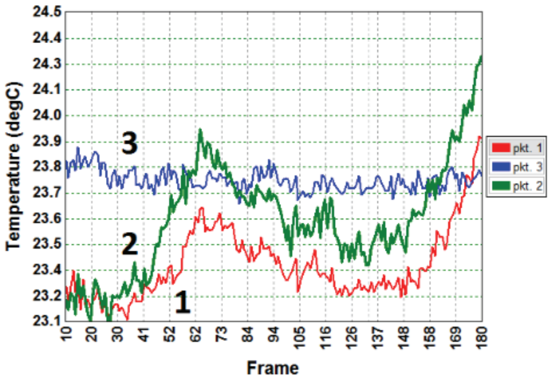

Fig. 5. Temperature pattern at four points around window sashes and on the window frame

Temperature patterns, recorded during the leak test (Fig. 5 and 7) at points located in the area of the leakage, show the rate of response to pressure changes. Outside the leakage zone, temperature remains virtually at the same level.

The fastest temperature increases can be observed when the fan speed is increased to produce another, established in the test, differential pressure – negative pressure increases. Local increases and decreases in temperature during the test result from a temporary increase in vacuum over the required at the given test point. The Blower Door fan temporarily forces a greater pressure difference to then reduce its revolutions and adjust the flow of air to the level required.

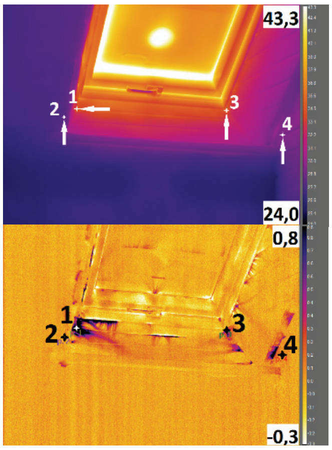

Fig. 6. A roof window reference and differential thermogram, from a room in the attic of building 1 [6]

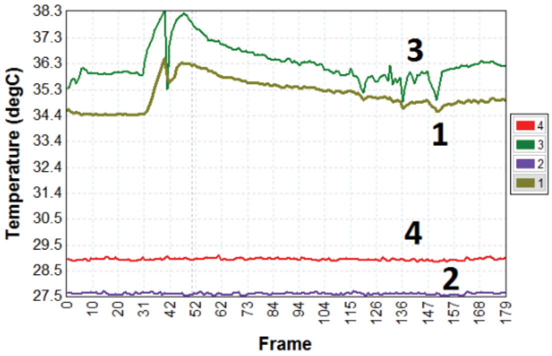

Fig. 7. Temperature pattern at three points in the non-tightness zone of the window fixing points in the roof and at a point outside this zone

In the attic of building 2 (Fig. 8) leakages were evident in the envelope of the roof truss purlins and collars made of boards on the gable wall (point 4), and in the fixing points of the luminaire at the ceiling. The decreased temperature visible on the thermogram of the inner surface of the gable wall results from its structure and the low thermal inertia of the material from the inside of the room. This wall was made of hollow bricks to the level of the sill, while higher, to the level of the ridge, the wall was made of bricks with a thickness of 12 cm, aligned with polystyrene boards from the inside. A wooden load bearing construction was put on such a structure and plasterboards were attached to it. During the test, cooler outside air was flowing in at the connection of the roof and walls, between the load bearing construction and the plasterboards towards the electrical outlet. The cooler air located outside, which penetrate between the plasterboard, with low thermal inertia, and the thermal insulation in the wall, caused a decrease in the surface temperature inside of the building. This decrease occurred after just a minute of generating vacuum. It works as a "ventilation duct" causing a reduction in the surface temperature of the inner wall [7].

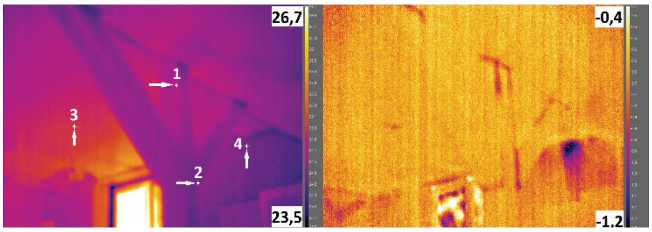

Fig. 8. A reference and differential thermogram from the attic of building 2

In building 3, leakages were found in the joints of the envelope on the ground floor level (Fig. 9) and at the boxes of electrical outlet adapters, socket outlets and switches of the electrical system in plasterboards (Fig. 11). In the kitchen, the biggest leakages occurred after as a result of cracks and subsidence of plain foundation in the corner of the house. This caused a large non-tightness in the ceiling (Fig. 10). Leakages are visible on the surface of the paneling and on the temperature pattern in the profile under the ceiling (Fig. 10).

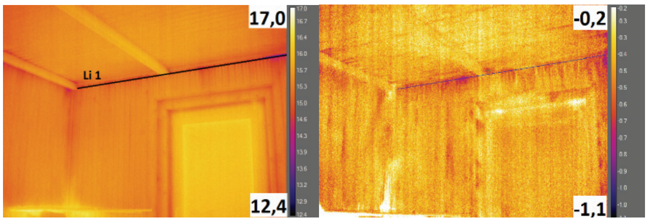

Fig. 9. A corner and window reference and differential thermogram, from the kitchen of building 3

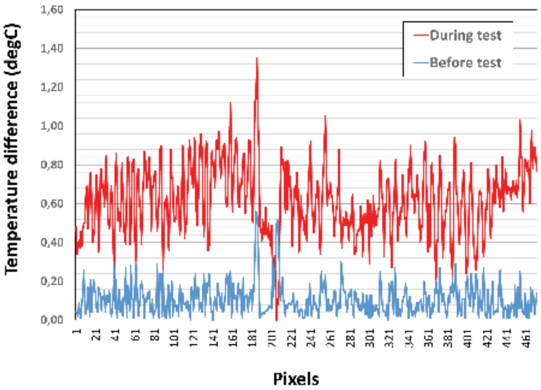

Fig. 10. Temperature pattern at the connection of the roof and exterior walls in the kitchen of building 3, before and during the leak test

The temperature pattern visible at the top of Fig. 10 was recorded during the tightness test at the lower surface of the ceiling. The temperatures in the lower part of the Figure were recorded prior to testing. The visible temperature differences are up to 0.6°C and are due to the connection leakage.

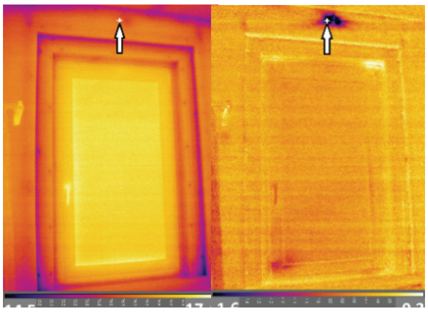

Fig. 11. A window and a wiring junction box reference and differential thermogram, from a room in building 3

Sometimes it is not possible to precisely localize leakages in external envelopes in building. Thermograms can only indicate the entry of outside air into the building, because leakages can be located elsewhere.

3. Conclusions

Achieving high tightness of the building envelope is one of the factors limiting energy consumption for heating. The use of thermography during leak testing is a convenient method. It is more accurate than using smoke and enables the localization of very small air leakages. In the case of thermal imaging method, it is necessary to ensure an adequate difference between indoor and outdoor temperatures and differential pressure.

The recommendations in the PN-EN 13187 [8] standard concerning the minimum differential pressure during leak tests of building envelopes, amounting to 5 Pa, may be insufficient to indicate leakage of air at low temperature differences. The tests carried out by the author on single-family houses show that pressure difference of 50 Pa, necessary for the determination of the value of n_{50} factor is sufficient to localize leakages even at low differential internal and external temperatures, from 2 to 5°C.

To minimize the number of air leakages through the building envelope, the number of openings for electrical installations, sewage, water and ventilation in external and internal walls between the sealed and non-sealed rooms should be minimized. That must be ensured at the design stage of buildings, especially when the given building in to be passive.

4. References

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