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Development of a Systematic Approach for the Assessment of Adhesive Tape Suitability to Ensure Airtightness

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Abstract: Ensuring the tightness of buildings using self-adhesive tapes is one of the cost-effective, efficient, and reliable solutions. There is a lack of research, standards, and methodologies for construction adhesive tape, especially for assessing the functional properties of the tape after ageing. The aim of this work is to evaluate the tightness of different building surfaces and adhesive tape systems by conducting artificial ageing. It was found that adhesive tapes with an acrylic adhesive base ensured a fully sealed system. In all cases, tapes applied to surfaces such as plywood, gypsum plasterboard, cement-bonded particle board, plastered cement-bonded particle board, and plastic board provided sufficient sealing. The air permeability of the tapes on the OSB was two to seven times higher than that of the defined sealed system with other surfaces. In most cases, air permeability increased on OSB, gypsum plasterboard, and plastered cement-bonded particle board after ageing. The least problematic surface is the plastic board. In all tested cases, adequate sealing was observed after ageing, with only three of all tested tapes not providing sufficient bonding strength.

Keywords: adhesive tape; construction surface; air permeability; artificial ageing

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1. Introduction

As global energy consumption increases, there is a growing demand for energy savings strategies. Energy consumption in public buildings has drastically increased over the past decade. This is crucial not only due to rising electricity prices but also due to increasing environmental awareness. Trends show that the importance of energy-efficient buildings will increase in the future. One of the most significant examples is the EU Energy Performance of Buildings Directive, which fundamentally increases energy planning and building energy efficiency requirements. One way to adhere to stricter rules of energy consumption is the requirement for airtightness. Research results show that simple modification strategies, such as window glazing, air tightness, and insulation, can reduce energy consumption by an average of 33% [1,2].

In recent decades, more attention has been paid to increasing the thermal resistance of building components, significantly elevating the relative importance of air tightness for overall building energy losses. The construction industry demands practical information on the tightness of individual structural elements and building envelopes [3]. The issues related to the current search for construction solutions that ensure tightness and the determination of changes in tightness over time are relevant [4–6].

Airtightness is considered to be an important factor at all levels of the building envelope, i.e., at the level of the whole building envelope and at the level of components and materials. The tightness of building envelopes is a decisive factor in achieving energetically efficient and durable buildings. However, there is still a lack of knowledge on how to create sealed building details at both the design and implementation levels. There is very little scientific literature on the tightness of joints in airtight buildings. In the European system, there is a lack of classification systems or operational property requirements specifically for the tightness of building components, joints, or sealing materials [7]. The authors argue that in many studies on the tightness of building joints, important factors are often overlooked, such as the properties of sealing materials, material ageing, or unevenness of the construction surface.

In recent years, interest in the construction industry in the use of adhesive tapes to make the building envelope more airtight and robust has increased rapidly. With the growing demand for energy efficiency in buildings, national construction authorities are strengthening building requirements to mitigate future climate impacts and adapt to them. The research results also indicate that traditional solutions can be further improved by using modern foil materials together with sealing tapes [8,9].

When ensuring the tightness of wooden frame structures, the use of adhesive tapes is the most promising solution. To assess the levels of a building's tightness during the design stage, a larger database with various joint, material and production combinations is needed. The use of air-impermeable adhesive tapes is one of the most reliable and robust solutions for window sealing, as airflow indices are measured where the adhesive tape was used. Field measurements have shown that the levels of airflow through the joint between the window and the external wall are one of the most typical leakage points. Gaps in thermal bridges in doors and windows are also a significant part of a building's energy consumption for heating; therefore, long-term tightness must be guaranteed. A common European or international standard is required to officially establish all the requirements (adhesive properties, long-term durability, resistance to tearing, elongation, etc.) when airtight adhesive tapes are used for building tightness levels. However, such requirements are still lacking, and there is a shortage of comprehensive scientific research with practical recommendations [10–12].

Typical airflow locations included the joint between the ceiling and the floor with the external wall, the joints of the separating walls with the external wall and the roof, the penetration points of electrical and plumbing installations through air barrier systems, the leak around and through windows and doors, the joints of windows with walls, the external window and door deformation parts and inaccurately sealed joints and gaps [13,14].

When constructing with cross-laminated timber (CLT) panels, the airtightness of the external walls depends on the initial moisture content of the CLT panel; the higher the material, the lower the airtightness [15]. It is suggested that one measure to meet the tightness requirements of buildings constructed from CLT is to use adhesive sealing tapes for the sealing of CLT elements in joints [16]. Linden et al. found that the airtightness of joints sealed with tapes depends on the type of structural foundation; in the case of a cross joint, water impermeability is quite poor, and mechanically induced artificial ageing had no significant impact on both air and water tightness [17]. The problem area of the building is the openings, where a rigid sealing tape designed to seal joints between panels may not be suitable [18].

A comprehensive review of the wide variety of adhesive tapes has shown significant differences in their adhesive properties, which should be evaluated depending on the application of the tape [19]. Research has shown that factors such as the addition of different amounts of dye pigments [20] and the modification of pressure-sensitive adhesives with talc [21] also contribute to the changes in the functional properties of self-adhesive tapes. To ensure tightness, construction adhesive tapes used for sealing must adhere well to any surface, achieving this by applying low pressure and minimal contact time. The surface has an impact on the tightness and a significant effect on the adhesive strength of the adhesive tapes. Research has found that adhesive tapes adhere best to plywood, orientated strand boards (OSB), and cement particle boards. The surface also affects the resistance of the tape to peeling, with an influence greater than ageing [22–24].

In both new construction and renovation projects, adhesive tapes are widely used to seal building envelopes and create energy-efficient structures. When it comes to sealing with adhesive tapes, the issue of their long-term durability often arises. It is crucial to reliably predict whether these tapes are durable. During the study, it was found that the adhesion of tapes deteriorates with ageing, which reduces resistance to shear and peeling. This applies to both resistance to peeling and shear, both before ageing and after, but varies from substrate to substrate after ageing [25]. Tests under natural and artificial ageing conditions also showed that the properties of the tapes may change due to climatic factors, and the tightness can be compromised. Environmental degradation affects the airtightness of pressure-sensitive adhesive exterior housing tapes on plywood. It was observed that resistance to peeling indicates better changes occurring in the tape due to ageing than shear strength [26].

Accelerated ageing procedures are proposed for adhesive tapes used indoors and outdoors. To assess whether the tapes meet the operational requirements for the entire building's lifespan, durable testing methods are required. However, reliable testing methods and evaluation procedures for construction tapes are lacking. This study aimed to evaluate testing and assessment methods for the longevity of tapes, forming the basis for further improvement of existing methods. The study also emphasises the need for further analysis to better understand the chemical and mechanical properties of adhesive tapes, the bonding of adhesive tapes to various substrates, degradation processes and reliable methods for predicting operational lifespan. Thus, the analysis demonstrated that research on sealing adhesive tapes is important and relevant [27].

Unlike internal barriers, external air barrier systems can be affected by harsh weather conditions; outdoor conditions can impact the longevity of sealed joints. The study emphasises joints bonded with tape, which was installed correctly. Further research is recommended to investigate the effect of weather conditions on the durability of imperfectly bonded joints. Suggested parameters to be investigated in future studies include the pressure of the tape during installation, exposure to dusty and wet surfaces, and the use of primers. In addition, it is recommended that combinations of different types of plate and tape are used and a statistical analysis with an increased sample size for each test is used [28].

Another objective of the study was to assess how building tightness changes over time and how sealing materials function over an expected 50-year lifespan. Laboratory tests on various products with accelerated ageing were conducted, and an evaluation of older existing buildings was analysed. The study was carried out in a temporary facility with a lightweight wooden structure and various sealing products. The results obtained indicated that most of the products still maintained their functionality after accelerated ageing; however, some products significantly lost their ability to seal air through the building envelope. The selected tape products passed durability tests on smaller samples but were not airtight in tests conducted in spaces with larger joints. This may suggest the need to review tape testing methods, as well as tape application methods [29]. Thus, analysis of the scientific literature revealed that ensuring building tightness is a current issue that must be addressed in the context of longevity. One cost-effective, efficient, and reliable solution is to ensure tightness using adhesive tapes. However, the analysis of scientific literature showed a lack of research, standards, and methodologies for construction adhesive tape, especially the absence of relevant studies that evaluated the functional properties of adhesive tapes after the ageing process. Therefore, artificial ageing studies remain highly relevant in this case, allowing the prediction of the quality of adhesive tapes after a certain period of use. The aim of this work is to evaluate the tightness of different building surfaces and adhesive tape systems after artificial ageing.

2. Materials and Methods

2.1. Type of Adhesive Tape

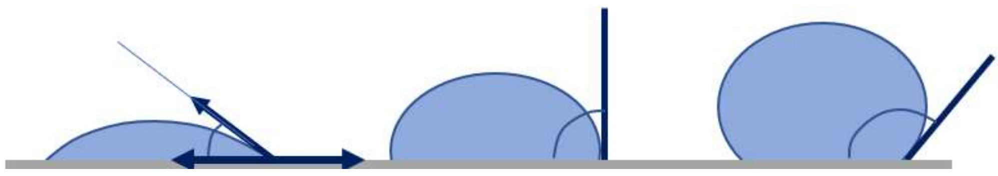
The adhesive tapes used in the experiments are presented in Table 1.

Table 1. Structure and main properties of the investigated adhesive tapes.

Code	Backing	Adhesive	Thickness µm	Application Area
NWac_73	non-woven	acrylic	730	Covering window and door joints from the outside.
FRMac_39	film with reinforcement mesh	acrylic	390	For permanent wind-tight bonding of component layers outdoors.
NWac_84	non-woven	acrylic	840	Covering window and door joints from the inside.
PAac_38	paper	acrylic	380	Continuous protective barrier against air and water infiltration.
PAac_45	paper	acrylic	450	For sealing overlaps and damage repair for underlays and air/vapour control layers.
NWac_78	non-woven	acrylic	780	Interconnecting facade films, repairing film damage.
MPAac_37	metallic paper	acrylic	370	Interconnecting metallised films, repairing film damage.
NWac_57	non-woven	acrylic	570	Sealing windows, doors and any penetrations in the external structure of the building. Can be used to adhere vapour barrier membranes to the wall structure.
FRMac_37	film with reinforcement mesh	acrylic	370	Sealing joints between vapour barrier membranes and skylights, pipes and roof structures.
NWac_56	non-woven	acrylic	560	Sealing joints between vapour barrier membranes, windows, doors, wooden sills, and concrete floors.
NWRMac_63	non-woven with reinforcement mesh	acrylic	630	Sealing of window and door joints from the outside.
FRMac_38	film with reinforcement mesh	acrylic	380	Sealing of seams in the installation of windproof sheets.
FRMac_36	film with reinforcement mesh	acrylic	360	External wind and hydro insulation using the installation of metal sheet joints and connections from other adjacent parts of the building with the installation of windproof sheet joints.

2.2. Contact Angle Measurement

Identification of the water contact (wetting) angle is used to determine whether the surface of solid materials is hydrophilic, hydrophobic or highly hydrophobic. The surface is considered hydrophilic when the water contact angle is less than 90° (Figure 1), hydrophobic when the water contact angle is greater than 90° and highly hydrophobic when the water contact angle is greater than 150° [30]. Surfaces with water contact ranging from 10° to 90° are termed semi-hydrophilic [31,32].



(**a**) (**b**) (**c**)

Figure 1. Water contact angle on solid surfaces: (**a**) Θ < 90°, (**b**) Θ = 90°, (**c**) Θ > 90°.

The free energy of the test surfaces was determined using the sessile drop method. This measurement method is based on measuring the contact (wettability) angle between the liquid and solid surface, allowing the assessment of the solid surface wettability. The water contact angle serves as a measure of surface wettability and can be determined based on Young's equation [33–35]. Young's equation describes the relationship between surface tension forces, that is, surface energy:

$$\cos\theta = \gamma\ SV - \gamma\ SL/\gamma\ LV \quad (1)$$

where cos θ is the contact angle, γ SL, γ SV, and γ LV represent the interfacial tension of solid, liquid and solid/liquid surfaces, respectively.

For each group of samples at different surface locations, five water droplets were dispensed, and the average water contact angle value was calculated for each group. The coefficient of variation did not exceed 8%.

2.3. Air Permeability Test

The air permeability measurements of the samples were carried out based on the practice of measuring the tightness of buildings, where the measurement results are given at a pressure difference of 50 Pa between the inside and outside of the building. Pressure caused by artificially blowing doors determines the movement of air through the cracks in building structures from the zone of higher to lower air pressure. Air permeability was determined according to the EN 9053-1 standard [36]. A sealed cylindrical vessel was created for measuring changes in the air permeability of the samples (Figure 2), in which an increased pressure of 50 Pa was also created, thus simulating air movement conditions corresponding to natural measurements of building tightness. Rings with different types of construction material and equipped with a 100 × 2 mm perforation were sequentially mounted on the vessel and sealed with the adhesive tape selected for investigation. Air flow passing was measured with the electronic flow meter Veri-Flow 500; the pressure was increased with a Retrotec DM32 gauge.

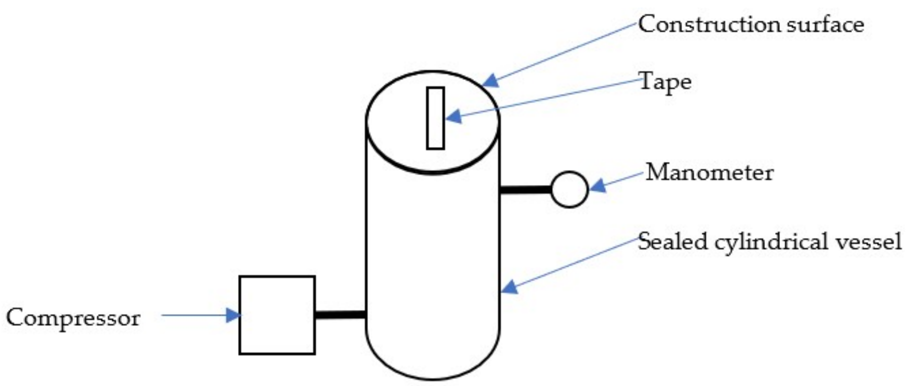


Figure 2. Air permeability test setup.

The air permeability test is carried out by introducing an additional airflow into the cylindrical vessel, creating an increased pressure, which is recorded by a micromanometer

(DM32, Retrotec, Everson, WA, USA). Between the sides of the cylindrical vessel, where the test object is mounted, a pressure difference is created. Air begins to move through the perforations and leaks to the lower pressure side until steady airflow is established, which is recorded by the instrument. Subsequently, the sample is placed in the ageing chamber and after the ageing cycles, the air permeability test is repeated, determining the dynamic changes in air permeability. For each group of samples at different surface locations, three samples were dispersed, and the average air permeability value was calculated for each group. The coefficient of variation did not exceed 10%.

Several locations of air leakage can be distinguished: (1) the construction material used as the base for the adhesive bonding of sealing tapes. The construction material itself may exhibit certain air permeability, influencing the final result value; (2) the adhesion of the sealing tape to the construction material.

2.4. Adhesion Test

The peel adhesion of tapes is determined according to the EN ISO 29862-1 standard method (peeling at a 180° angle to the surface) [37]. The tapes were peeled from plywood, OSB, gypsum plasterboard, cement-bonded particle board, plastered cement-bonded particle board, and plastic board. The test was carried out using a Zwick/Roell Z010 device (Zwick/Roell, Ulm, Germany) with a crosshead speed of 5 mm/s. Peel adhesion was calculated as the average force obtained by peeling a 24 mm wide tape specimen over its entire length (150 mm), excluding the first 25 mm from the start of peeling. The arithmetic mean of peel adhesion was calculated for five samples, and the coefficient of variation did not exceed 10%. The test was conducted under conditions of (23 ± 1) °C temperature and (50 ± 5)% relative humidity. Before tape adhesion, the surface was cleaned with acetone, and the tapes were adhered using a 2 kg roller. Cutting and pressing against the surface did not exceed 30 s.

2.5. Experimental Design

Air permeability and peel adhesion were determined before and after the artificial ageing of the samples, simulating the effects of moisture, heat, and cold. One ageing cycle, lasting 48 h, consisted of the following:

- Seven hours of heating at +5 °C temperature, with a relative humidity (RH) of 96–100%;
- Five hours of cooling at −10 °C (with an additional 0.5 h for cooling deactivation for rearrangement);
- Heating at different temperatures and humidity levels. 18 h + 31 °C (RH = 45–50%), 10 h +39 °C (RH = 25–30%), 7.5 h +49 °C (RH = 15–20%).

The total duration, intensity, and sequence of the climatic factors were selected according to statistical climatological data for the average latitudinal climate zones [38]. Twenty cycles of artificial ageing were performed during this investigation. A Feutron® KPK 200 Type 3423/16 (Feutron, Langenwetzendorf, Germany) climate chamber was used for ageing.

For each surface, before and after ageing, groups of three test samples were prepared for the air permeability test, and groups of five samples were prepared for the peel adhesion test. The test sample consists of an adhesive tape glued to each panel selected for testing. Such a 'tape-board' system was prepared for each tape selected for investigation, as well as for sample ageing. The test sample consists of each adhesive tape glued on each tape of panel. The standard deviation and coefficient of variation of the test samples from each group were calculated by statistical processing.

3. Results and Discussion

To justify the relevance of sealing measures, evaluate the air permeability threshold characteristics of building envelopes, and assess the quantity of these envelopes in the total area of the building envelopes, a comprehensive analysis of 188 buildings in Lithuania was conducted. For the analysis, various-purpose buildings' projects developed from 2015 to 2021 were examined:

- Residential buildings (1 to 2 apartments)—117 units, average area 160 m^2;
- multi-residential buildings—27 units, average area 2.340 m^2;
- public-purpose buildings—32 units, average area 3.070 m^2;
- industrial, storage and manufacturing buildings—12 units, with an average area of 4320 m^2.

After performing a statistical analysis of the envelopes of these buildings, the dominant envelopes were identified, along with the respective areas they occupy in the overall building envelope. Additionally, the lengths of the key envelope junctions were calculated. It should be noted that the specific areas of the building envelopes and junction lengths can vary, so the information provided below is indicative, showing only a certain trend in the distribution of the building envelopes in newly constructed buildings.

Analysis of building envelopes for residential buildings (1 to 2 apartments) revealed that the average maximum area in such buildings is found in wall envelopes, which constitute approximately 37% of the total envelope area (approximately 200 m^2). Average roof and floor areas account for approximately 27% and 20%, respectively. The remaining envelopes—windows, doors, canopies, and coverings above unheated spaces or exterior surfaces—make up the other 16%. Furthermore, after performing an analysis of various junctions in the envelope of residential buildings (1 to 2 apartments), it was determined that the highest number of junctions occurs in window openings (approximately 92 m) and wall-to-roof junctions (approximately 60 m). Floor-to-wall junctions make up about 42 m, and the remaining junctions, primarily around windows, doors, and gate openings (Figure 3a), are about 48 m in length.

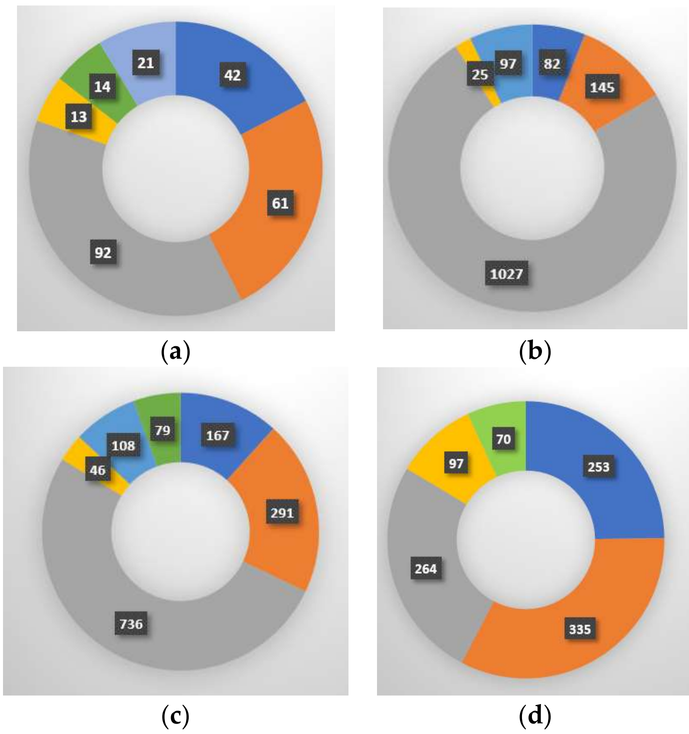


Figure 3. Average length of the joints of the different envelopes in the analysed buildings: (**a**) residential (1–2 apartment) buildings; (**b**) residential (multi-unit) buildings; (**c**) public buildings; (**d**) industrial, storage and manufacturing buildings, where —floor/wall, —wall/roof, —window opening, —door opening, —gate opening, —wall/floor.

The analysis of envelope junctions in residential (multi-unit) buildings revealed that the average maximum area in such buildings is found in wall envelopes, which constitute approximately 42% of the total envelope area (about 1.330 m^2). Average roof and floor areas account for approximately 18% and 13%, respectively. The remaining envelopes—windows, doors, canopies, and coverings above unheated spaces or exterior surfaces—make up 27%. Furthermore, after conducting an analysis of various envelope junctions in residential (multi-unit) buildings, it was determined that the highest number of junctions occurs in window openings (approximately 1.030 m), and wall-to-roof junctions are only about 145 m (Figure 3b).

In public-purpose buildings, the average maximum area is found in the roofs (about 32% of the total envelope area, approximately 1.635 m^2). Average areas of walls and floors account for approximately 26% and 28%, respectively. The remaining envelopes—windows, doors, gates and coverings above unheated spaces or exterior surfaces—make up about 14%. After analysing various envelope junctions in public-purpose buildings, it was found that the highest number of junctions occurs in window openings (about 740 m), and wall-to-roof junctions are approximately 290 m (Figure 3c).

The analysis of envelope junctions in industrial, storage, and manufacturing buildings showed that the average maximum area in such buildings is found in roofs (about 39% of the total envelope area) and floors (about 38% of the total envelope area). Average wall areas constitute approximately 20%, while the remaining envelope elements, windows, doors, and gates combined make up a mere 3%. The analysis of envelope junctions in industrial, storage, and manufacturing buildings revealed that the highest number of junctions occurs in wall-to-roof junctions (about 335 m), floor-to-wall junctions (about 253 m), and window openings (about 264 m) (Figure 3d).

Thus, analysis of the building envelope makes it possible to predict the predominance of the building envelope in buildings of different types of use while at the same time highlighting the importance of the choice of materials to ensure the tightness of the envelope. Therefore, to evaluate diverse and different construction joints, a range of construction surfaces was selected, including plywood, OSB, gypsum plasterboard, cement-bonded particle board, plastered cement-bonded particle board, and plastic.

First, the water contact angle with the surface, a measure describing the relationship between surface adhesion forces, i.e., surface energy, was determined. When the water contact angle is >90°, the surface is hydrophobic, and when the angle ranges from 10° to 90° surface is semi-hydrophilic. In the examined case (Table 2), two construction surfaces, OSB and cement-bonded particle board, are hydrophobic. Plywood, gypsum plasterboard, plastic board, and plastered cement-bonded particle board surfaces are semi-hydrophilic.

Table 2. Water contact angle with construction surfaces, in degrees.

Characteristics \ Surface	Plywood	OSB	Gypsum Plasterboard	Cement-Bonded Particle Board	Plastered Cement-Bonded Particle Board	Plastic Board
Water contact angle with the surface, °	76	108	78	91	66	63
Thickness, mm	8.0 *	15.0 *	12.5 *	8.0 *	10–12	6.0 *
Density, kg/m^3	600 *	620 *	680 *	1350 *	1800	1390 *

* provided by the manufacturers.

In the face of an extensive selection of construction adhesive tapes, it is often challenging to predict how these construction tapes will fulfil their primary purpose, i.e., ensuring system tightness. The impact of the water contact angle with the surface on the key characteristic of the system—tightness—was evaluated for the investigated adhesive tapes and various construction surfaces (Figure 4). In all examined cases, a strong linear dependence was identified between the water contact angle of the construction surface and the air permeability. In the context of the study, all adhesive tapes with an acrylic adhesive base ensured a completely airtight system, regardless of the adhesive tape backing, i.e., non-woven material, paper backing or film. In all cases, adhesive tapes applied on plywood, gypsum plasterboard, cement-bonded particle board, plastered cement-bonded particle board, and plastic board provided a sufficient system seal. As is known, the essential functional components of the tapes used for sealing structural joints are the tape backing and the adhesive, the purpose of which is to ensure a tight, flexible, and reliable adhesion of the tape to the constructional surfaces. In the production of construction self-adhesive tapes, adhesives are usually used, which do not undergo any physical or chemical transformation during the glueing process. Long-term connection to the construction surface, which ensures the tightness of the structure, is achieved by pressing the tape onto the panel during a short contact time. It is significant that synthetic polymers are used for the production of adhesives (acrylic in the case of the tapes selected for the research), which provide the functional properties corresponding to the intended purpose of the adhesive tapes. The adhesive is tacky at room temperature and immediately and permanently adheres to the substrate to form a reliable bond [39–41].

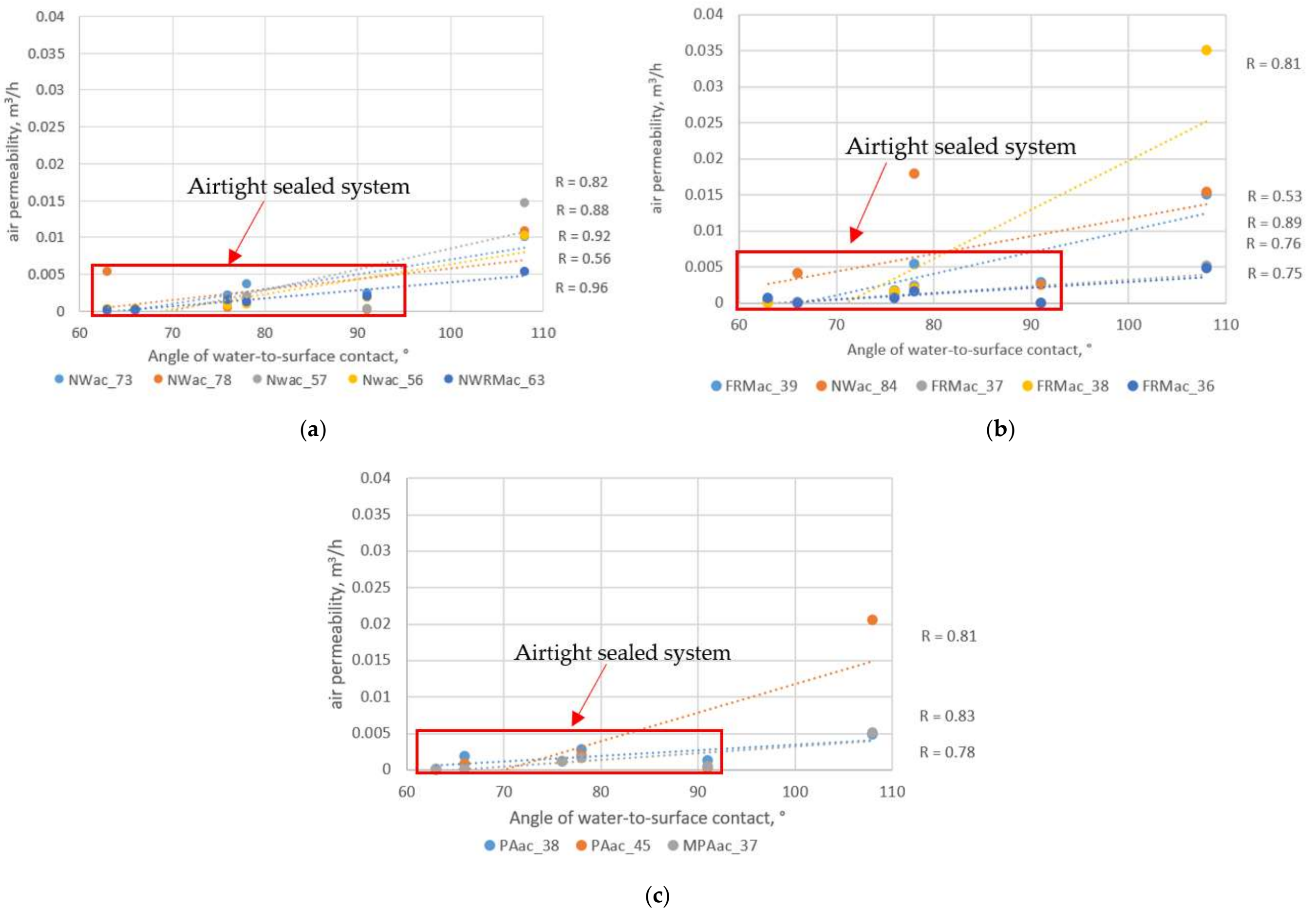


Figure 4. Dependency of system air permeability on the water contact angle with the construction surface: (**a**) tapes with a nonwoven backing, (**b**) tapes with a film backing, and (**c**) tapes with a paper backing.

Slightly different results were obtained when conducting the airtightness test on OSB. In this case, the air permeability was found to be from two to seven times higher than in the defined airtight system with other surfaces. Oriented chipboard (OSB) consists of wood chips of various sizes and thicknesses glued together, but the surface of these boards is not completely smooth. Therefore, when glueing sealing tapes on them, in almost all cases, micro-cracks are formed between different parts of the panel surface. It should also be noted that the tightness measurements of the OSB panel showed that these panels are not absolutely airtight, and a small amount of air permeability was observed through the panel alone. Due to the reasons listed above, the air permeability through the sealing tapes that were glued on the OSB panels was higher compared to other surfaces.

The adhesive tapes on construction surfaces system must perform their function over an extended period, as buildings are typically designed for long-term use. For this purpose, air permeability was determined after the ageing of systems (tapes adhered to the test surface) in this study, involving 20 cycles.

According to the results, it was observed that different construction surfaces yield varying initial air permeability. The lowest air permeability was achieved by applying adhesive tapes to plywood (Figure 5a) and cement-bonded particle board (Figure 5d). Additionally, in most cases, it was found that air permeability on plastic board (Figure 5f) was also very low, indicating effective insulation by the adhesive tapes. Evaluating the results obtained on plastered cement-bonded particle board, it was concluded that the applied tapes effectively insulated this particular surface. In all the cases discussed, air permeability did not exceed 0.005 m^3/h. Analysing the results on the gypsum plasterboard, it was identified that only in one case the air permeability exceeded this threshold, reaching ~0.017 m^3/h. In all other instances, air permeability did not exceed 0.005 m^3/h. Slightly different results were obtained when the tapes were applied to OSB (Figure 5b). In this case, a noticeable increase in air permeability compared to other tested surfaces was observed. Therefore, adhesive tapes with acrylic adhesives do not exhibit good sealing properties when sealing OSB constructions (the OSB itself). In most cases, higher permeability on OSB was noted for adhesive tapes with a non-woven material base. In this case, it is recommended that PAac_38, MPAac_37, FRMac_37, NWRMac_63, and FRMac_36 tapes are used, as their air permeability was approximately 0.005 m^3/h. However, all tapes are quite different, and no characteristic suitable tapes were identified for OSB. Therefore, it is recommended that more extensive studies are conducted with a broader assortment of adhesive tapes in this case.

Examining the results after 20 cycles of ageing, it was found that in most cases, ageing led to an increase in air permeability. On plywood, cement-bonded particle board and plastic board, air permeability increased but remained within insignificant limits and did not exceed 0.005 m^3/h. Hence, it can be asserted that the tested adhesive tapes are suitable for these surfaces and maintain good airtightness properties in the system with construction surfaces after ageing. Slightly different results were obtained on OSB, gypsum plasterboard, and plastered cement-bonded particleboard. Analysing the air permeability of the system—adhesive tapes and OSB system after ageing cycles, it was observed that, in all cases, air permeability increased after ageing. In some cases, such as using tapes NWac_78, MPAac_37, NWac_57, NWac_56, NWRMac_63 and FRMac_36, air permeability doubled after ageing. The gypsum plasterboard surface also stands out, as after ageing cycles, the air permeability of the four tapes increased several times. Therefore, it is not recommended to use adhesive tapes NWac_73, FRMac_39, NWac_84 and MPAac_37 with gypsum plasterboard surfaces, as the long-term effectiveness of these systems in preventing air leakage significantly diminishes. It was also found that the tape system with a plastered cement-bonded particle board may undergo changes after ageing. In this case, the air permeability of tapes NWac_73, FRMac_39, PAac_38 and NWRMac_63 increased several to several dozen times after ageing. Thus, these tapes on plastered cement-bonded particle boards may not ensure a proper seal.

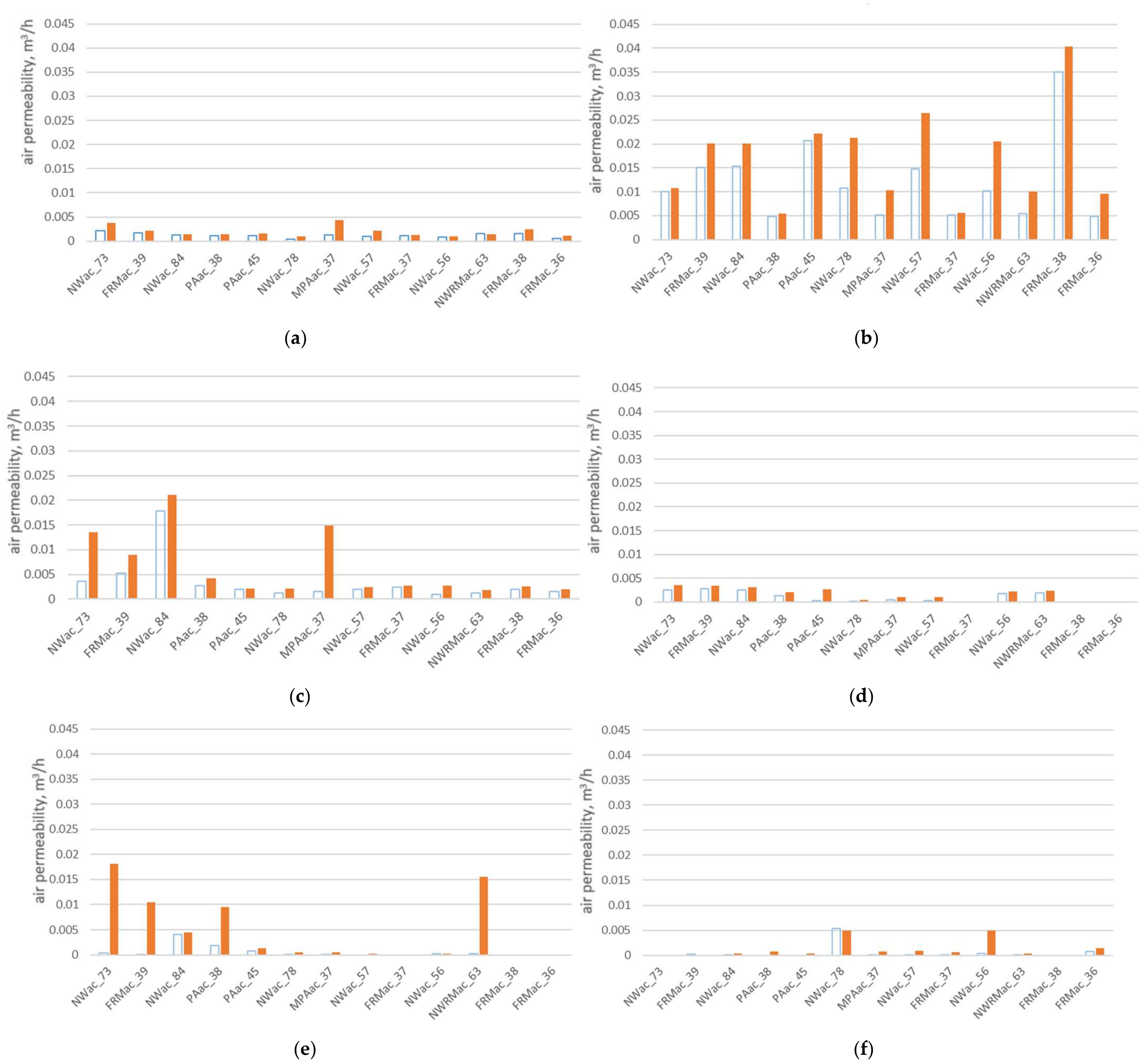
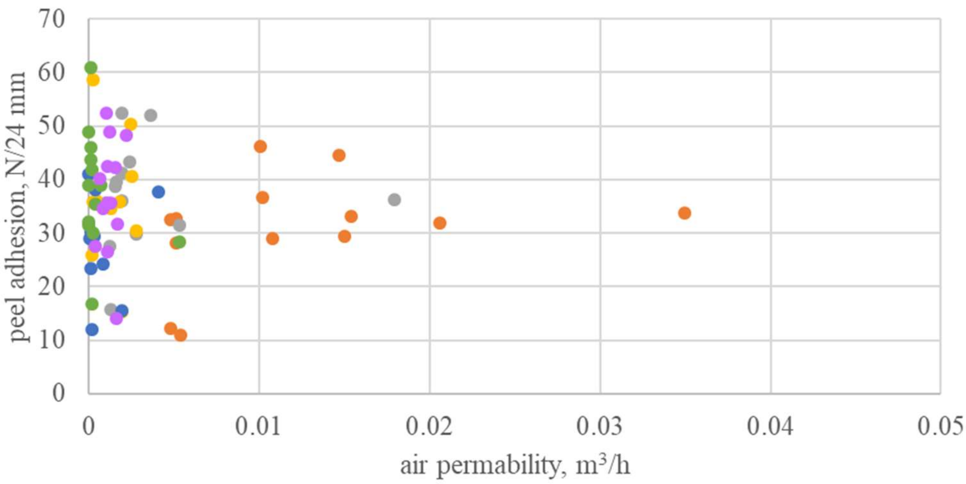
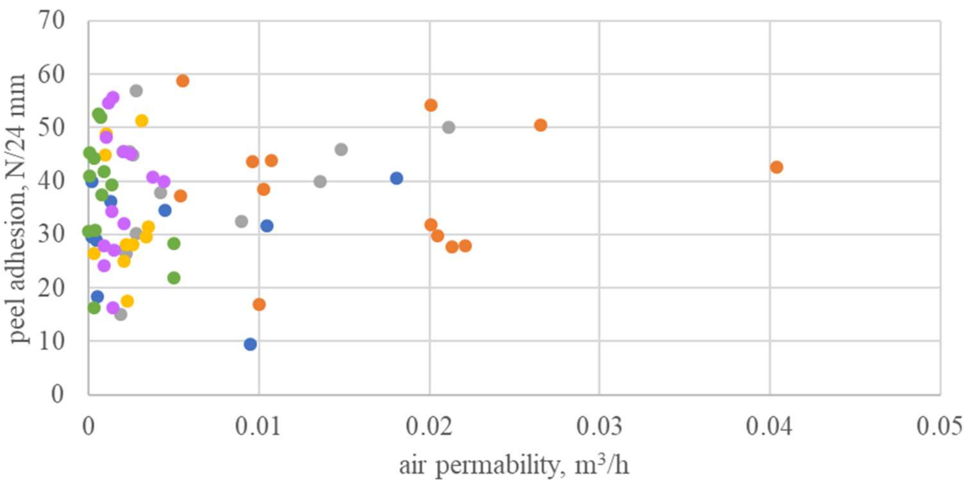


Figure 5. Air permeability of the non-aged ( ) and aged ( ) systems: (**a**) plywood, (**b**) OSB, (**c**) gypsum plasterboard, (**d**) cement-bonded particle board, (**e**) plastered cement-bonded particle board, (**f**) plastic board.

The adhesive bond between the construction tape and the substrate during formation is influenced by the adhesion and cohesion forces. The strength of adhesive bonding is characterised by peel adhesion, i.e., the force required to peel the adhesive tape from the surface to which it is adhered. The results of peel adhesion from different surfaces and the air permeability of the tapes are presented in Figure 6. It is evident that the peel adhesion values for the selected tapes in the study cover a wide range, from 11 N/24 mm (NWRMac_63 on OSB) to 61 N/24 mm (NWac_57 on plastic surfaces). For the non-aged tapes, board system air permeability is in the range of 0.0000–0.0350 m^3/h. A zero value was obtained by sealing a plastic board with many tested tapes, and the maximum value was achieved when the cavity in OSB was sealed with the FRMac_38 tape. Comparing the peel adhesion value from OSB, which reaches 34 N/24 mm, with the average resistance for this group (31 N/24 mm), it was found that the values are close. Conversely, the tape NWRMac_63 has a low air permeability value and the lowest peel adhesion. Therefore, it can be seen that higher or lower peel adhesion does not necessarily determine better or worse air permeability. Peel adhesion is likely relevant when discussing the strength of the bond, the loss of which (radical weakening) will result in the loss of the seal.



(**a**)



(**b**)

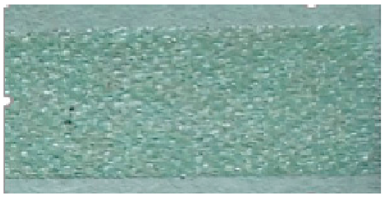
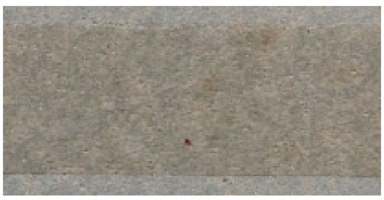
Figure 6. Relationship between peel adhesion and air permeability (**a**)—before ageing, (**b**)—after ageing, ● plywood, ● OSB, ● gypsum plasterboard, ● cement-bonded particle board, ● plastered cement-bonded particle board, ● plastic.

After 20 artificial ageing cycles, the overall peel adhesion interval of all tapes did not change significantly. The difference between initial and aged test samples in each group was less than 13%, but there were significant changes for individual tapes. Discussing significant cases, it is worth mentioning that the peel adhesion of PAac_38 tape from OSB increased almost three times, FRMac_37 tape 1.8 times, NWac_84 from gypsum plasterboard, and OSB 1.6 times. Noteworthy cases of significant peel adhesion were obtained: NWac_73 tape, peeling off from cement-bonded particle board by 37%; NWac_57 tape, peeling off from plastic board by 31%; PAac_38 tape, peeling off from cement-bonded particle board by 28%.

After the ageing of the tape-board system, the air permeability interval extended to 0.0404 m^3/h (FRMac 38/OSB). In almost all surface cases (except plastic), the air permeability values shifted towards higher values. The most significant change in air permeability occurred in the group of plastered cement-bonded particleboard tape systems. When comparing the results of air permeability and peel adhesion for this group, it was found that peel adhesion varied widely from a 39% reduction when peeling off PAac_38 and MPAac_37 tapes to a 49% increase when peeling off PAac_45 tape. Meanwhile, air permeability increased 2 to 5 times. As in the case of non-aged tape-board systems, there is no direct correlation between air permeability and peel strength.

It should be noted that the construction surfaces chosen for the study are resistant to the selected conditions of artificial ageing, taking into account the fact that the service life of the construction materials is many years. The fact that ageing did not significantly affect the surfaces is evident in Table 3.

Table 3. View of test samples of construction surfaces before and after artificial ageing.

Plywood		OSB		Gypsum Plasterboard	
Before Ageing	**After Ageing**	**Before Ageing**	**After Ageing**	**Before Ageing**	**After Ageing**
					
Aged Samples after Tape Removed		**Aged Samples after Tape Removed**		**Aged Samples after Tape Removed**	
					
Cement-Bonded Particle Board		**Plastered Cement-Bonded Particle Board**		**Plastic**	
Before Ageing	**After Ageing**	**Before Ageing**	**After Ageing**	**Before Ageing**	**After Ageing**
					
Aged Samples after Tape Removed		**Aged Samples after Tape Removed**		**Aged Samples after Tape Removed**	
					

Since construction integrity is crucial in a system with construction surfaces, which depends on the ability to maintain proper adhesion between the tape and the surface, the system was subjected to ageing, and the adhesive strength of the adhesive tapes to the substrate was determined. Next, the system's air permeability and adhesion were comprehensively assessed after ageing the entire system.

The comprehensive results presented fully reveal the situation related to the possibilities of using adhesive tapes on different construction surfaces. In this case, it was found that of the 13 tested tapes, 9 are suitable for use on plywood; the remaining four are not recommended for this surface due to inadequate sealing or insufficient adhesion to the substrate (Table 4). The results vividly highlight the challenges with OSB in places where sealing is required. In this case, only two tapes, PAac_38 and FRMac_37, fully meet all requirements, remaining well adhered to the OSB surface even after ageing and ensuring proper sealing. Examining the results on gypsum plasterboard, it is evident that only about half of the tested tapes are recommended for use on this board. The remaining tapes did not meet the requirements for sealing and strength. The system with cement-bonded particle board ensured sufficient sealing in all cases after ageing, but only about half the tapes adhered firmly enough to this surface. When the systems were analysed with plastered cement-bonded particle board, it was found that it was also crucial to select suitable adhesive tapes, as only half of the tested tapes ensured the proper properties of the system. One of the most versatile surfaces in this case, due to its highest density and low porosity, is a plastic board. In all cases, good sealing was achieved after ageing, and only three of all tested tapes did not ensure sufficient adhesion strength.

Table 4. Air permeability and adhesion after ageing the entire system.

Tape \ Surface	Plywood	OSB	Gypsum Plasterboard	Cement-Bonded Particle Board	Plastered Cement-Bonded Particle Board	Plastic Board
NWac_73	black	light grey	light grey	dark grey	light grey	black
FRMac_39	black	white	white	dark grey	light grey	black
NWac_84	black	light grey	light grey	black	black	black
PAac_38	black	black	black	dark grey	white	black
PAac_45	dark grey	white	dark grey	dark grey	black	black
NWac_78	dark grey	white	dark grey	dark grey	dark grey	dark grey
MPAac_37	black	light grey	light grey	black	dark grey	black
NWac_57	black	light grey	black	black	black	black
FRMac_37	black	black	black	black	black	black
NWac_56	light grey	white	black	dark grey	dark grey	dark grey
NWRMac_63	dark grey	white	dark grey	dark grey	white	dark grey
FRMac_38	black	light grey	black	black	black	black
FRMac_36	black	light grey	black	black	black	black

white	Poor surface adhesion and increased air permeability after ageing;
light grey	Adhesion of the tape to the surface, reasonably good after ageing, but air permeability increased;
dark grey	Reasonably good airtightness after ageing but not good enough adhesion to the surface;
black	Good adhesion to the surface after ageing and reasonably good breathability.

When evaluating adhesive tapes, it is essential to highlight the adhesive tape FRMac_37, whose base is a film reinforced with reinforcing threads and the adhesive is acrylic. This film ensured good adhesion strength and sealing on all tested construction surfaces. In this particular study, it stands out as the most versatile adhesive tape, maintaining its properties even after ageing. It is also worth noting adhesive tapes FRMac_38 and FRMac_36, which, in almost all tested cases except for OSB, provided good sealing and adhesion. These tapes also have a base of film reinforced with reinforcing threads, and the adhesive is acrylic. NWac_57 adhesive tape, with a non-woven base, exhibited excellent properties on all surfaces except OSB. Therefore, these tapes can be considered universally suitable for sealing systems on almost all commonly used construction surfaces. In the case of using other adhesive tapes, it is crucial to assess which surface the tape will be applied to, whether it will adhere well to the construction surface and ensure sufficient structural sealing.

For the practical recommendations of this study, three commonly encountered constructions were analysed. Based on the results, the recommended sealing tapes for these constructions are presented in Table 5.

Conducted research, obtained conclusions and provided practical recommendations regarding the proper use of adhesive tapes and their applicability in purposeful constructions will allow to expand the use of tapes for the purpose of increasing the energy efficiency of buildings in both academic and practical aspects.

Table 5. The results of analysis of solutions to ensure tightness of structures.

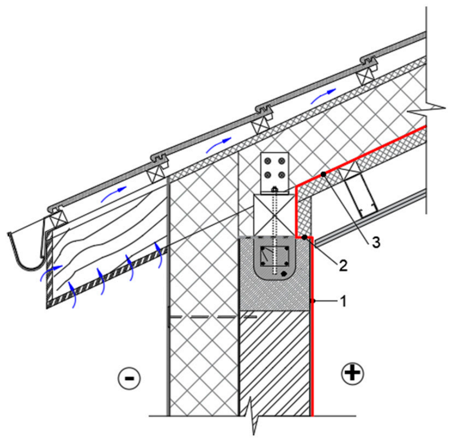
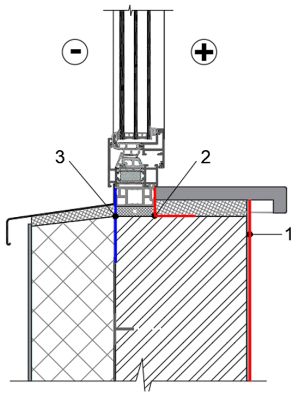
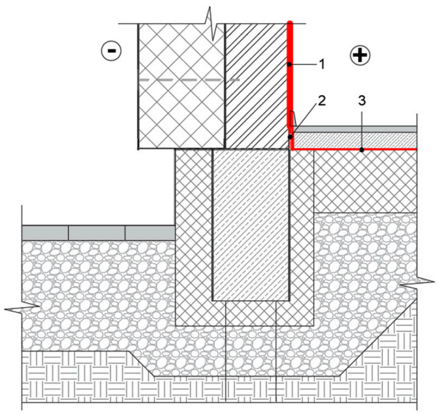
The Tightness of Wall and Roof Construction Junctions	
 1. A layer ensuring the tightness of the wall construction; 2. A layer ensuring the tightness of the junction of wall and roof constructions; 3. A layer ensuring the tightness of the roof construction.	The tightness of the roof construction is ensured by covering the inside surface with a single layer of vapour barrier film. The edges of the film must overlap according to the manufacturer's requirements; overlapped seams are sealed with adhesive sealing tape. In the connection with the wall, the edge of the roof vapour insulation film must be placed on the wall vapour insulation film, and the seam must be sealed with adhesive tape. Heat-insulating panels covered with aluminium foil can also be used to ensure the tightness of the roof structure. The joints can be glued with adhesive aluminium foil tape; there is no need to install complex film systems. For these constructions, considering the potential surfaces to be used, the most suitable adhesive tape in all cases is the tested tape FRMac_37 (after ageing on gypsum plasterboard, cement-bonded particle board, plywood and OSB boards, the air conductivity did not exceed 0.005 m^3/h in all cases, and also after ageing, this tape showed good adhesion to the specified surfaces). Additionally, adhesive tapes NWac_57, FRMac_36, and FRMac_38 are suitable for use in this construction, whereas, on the surfaces used in this construction, sufficiently low air permeability and sufficient adhesion of the tapes to the surface were determined after ageing. The use of other tested tapes in this construction is not recommended.
The Tightness of Wall and Windows or Doors Construction Junctions	
 1. A layer ensuring the tightness of the wall construction; 2. A layer ensuring the tightness of the junction of wall and window or doors from the inside; 3. A layer ensuring the tightness of the junction of wall and window or doors from the outside.	Windows or doors, like other elements crossing the main constructions, must be installed and additionally sealed with sealing materials from the inside and the outside. Sealing works can be performed using sealing foam, tapes or mastics. All investigated surfaces are available in this design. Based on the results presented in Table 4, FRMac_37 was found to be the most suitable for this design, and reasonably good post-aging results were obtained. When evaluating construction surfaces, the following tapes used in the studies can be used: NWac_73, NWac_84, MPAac_37, NWac_57, FRMac_36, and FRMac_38.

Table 5. *Cont.*

The Tightness of Wall and Floor Construction Junctions	
 1. A layer ensuring the tightness of the wall construction; 2. A layer ensuring the tightness of the junction of wall and floor construction; 3. A layer ensuring the tightness of the floor structure (around the entire perimeter of the floor).	The tightness of the floor and wall constructions is ensured by installing the tight layer on wall and floor constructions and connecting these constructions with airtight materials such as tapes or mastics. The tightness of the masonry walls is ensured by installing a single layer of interior decoration (such as plaster). The finishing layer must reach the level of floor and ceiling or roof insulation. The tightness of timber frame constructions is ensured by installing a vapour insulation layer on the inside surfaces, which must be connected to the membranes of other constructions or sealed at the edges with tape. The main sealing works of the floor structure are performed around the perimeter of the floor, sealing the joint between the floor and the wall. Works are performed using mastics and tapes. Regardless of the materials used for the building construction, the air tightness layer must be installed according to the recommendations of the manufacturer. The analysis of the research results has shown that in this construction, given suitable construction surfaces, which in this case can be plywood, OSB, gypsum plasterboard, or cement-bonded particle boards, it is always most appropriate to use the FRMac_37 tape, because the air permeability after ageing did not exceed 0.005 m^3/h, and after ageing it showed a sufficiently strong adhesion to the surfaces. Other suitable tapes for this construction include PAac_38, MPAac_37, NWac_57, FRMac_36, and FRMac_38. Results for other tested tapes on the surfaces of this construction were not as favourable as those of the recommended tapes as they would not ensure the necessary long-term seal.

4. Conclusions

The analysis of various-purpose building envelopes revealed trends in the distribution of envelopes for newly constructed buildings, emphasising the relevance of selecting materials that ensure envelope integrity.

The results showed that in all cases, a strong linear dependence was observed between the water contact angle of the construction surface and the air permeability. All adhesive tapes with an acrylic adhesive base ensured a fully sealed system. In all cases, tapes applied to surfaces such as plywood, gypsum plasterboard, cement-bonded particle board, plastered cement-bonded particle board, and plastic board provided sufficient system sealing. It was also found that the air permeability of the tapes on OSB was 2 to 7 times higher than that in the defined sealed system with other surfaces.

After 20 ageing cycles, the resistance-to-peel interval of tapes remained significantly unchanged, but in most cases, it led to an increase in air permeability. In marginal ranges, air permeability increased on the surfaces of plywood and cement-bonded particle boards. These surfaces were found to be suitable for the tested adhesive tapes and maintain good air impermeability properties after ageing. It has been determined that in most cases, air permeability increased on OSB, gypsum plasterboard, and plastered cement-bonded particle board after ageing.

Following a comprehensive analysis of the results, it was found that on plywood, almost all tested adhesive tapes can be utilised. In this case, out of the 13 tested tapes, the results were only partially satisfactory with four tapes. The most challenging sealing occurs on surfaces where OSB is used. Only two of the tested adhesive tapes proved fully suitable, highlighting the necessity of careful selection when choosing adhesive tapes for OSB surfaces. It was found that approximately half the tested adhesive tapes were suitable for gypsum plasterboard, cement-bonded particle board and plastered cement-bonded particle board. Therefore, when evaluating the problematic nature of these surfaces, it is recommended to carefully choose adhesive tapes that ensure proper sealing. The least problematic surface is plastic board. In all tested cases, adequate sealing was observed after ageing, with only three out of all tested tapes failing to provide sufficient bonding strength.

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References

1. Salame, T.N.; Sanz, R.; Pascual, S. Airtight duct systems [a simple way of improving a building's energy efficiency without increased investment]. In Proceedings of the 36th AIVC Conference "Effective Ventilation in High Performance Buildings", Madrid, Spain, 23–24 September 2015.
2. El-Darwish, I.; Gomaa, M. Retrofitting strategy for building envelopes to achieve energy efficiency. *Alex. Eng. J.* **2017**, *56*, 579–589. [CrossRef]
3. Van Den Bosschea, N.; Huyghea, W.; Moens, J.; Janssens, A.; Depaepe, M. Airtightness of the window–wall interface in cavity brick walls. *Energy Build.* **2012**, *45*, 32–42. [CrossRef]
4. Novák, J. Assessment of durability of airtightness by means of repeated testing of 4 passive houses. In Proceedings of the 39th AIVC Conference "Smart Ventilation for Buildings", Antibes Juan-Les-Pins, France, 18–19 September 2018.
5. Prignon, M.; Van Moeseke, G. Factors influencing airtightness and airtightness predictive models: A literature review. *Energy Build.* **2017**, *146*, 87–97. [CrossRef]
6. Alev, Ü.; Uus, A.; Kalamees, T. Airtightness improvement solutions for log wall joints. *Energy Procedia* **2017**, *132*, 861–866. [CrossRef]
7. Van Linden, S.; Van Den Bossche, N. Airtightness of sealed building joints: Comparison of performance before and after artificial ageing. *Build. Environ.* **2020**, *180*, 107010. [CrossRef]
8. Johnsen, I.-H.; Andenæs, E.; Gullbrekken, L.; Kvande, T. Vapour resistance of wind barrier tape: Laboratory measurements and hygrothermal performance implications. *J. Build. Phys.* **2022**, *46*, 77–94. [CrossRef]
9. Gullbrekken, L.; Bunkholt, N.S.; Geving, S.; Rüther, P. Air leakage paths in buildings: Typical locations and implications for the air change rate. *E3S Web Conf.* **2020**, *172*, 05010. [CrossRef]
10. Kalamees, T.; Alev, Ü.; Pärnalaas, M. Air leakage levels in timber frame building envelope joints. *Build. Environ.* **2017**, *116*, 121–129. [CrossRef]
11. Li, H.-X.; Zhang, R.; Feng, G.-H.; Huang, K.-L.; Cao, C.-H. The Test and Analysis of Air Tightness for Zero Energy Building in Cold Region. *Procedia Eng.* **2016**, *146*, 239–243.
12. Carrié, F.R.; Jobert, R.; Leprince, V. Contributed Report 14. Methods and techniques for airtight buildings. *Int. Energy Agency* **2012**, 1–36.
13. Šadauskienė, J.; Šeduikytė, L.; Paukštys, V.; Banionis, K.; Gailius, A. The role of air tightness in assessment of building energy performance: Case study of Lithuania. *Energy Sustain. Dev.* **2016**, *32*, 31–39. [CrossRef]
14. Ji, Y.; Duanmu, L. Air-tightness test and air infiltration estimation of anultra-low energy building. *Sci. Technol. Built Environ.* **2017**, *23*, 441–448. [CrossRef]
15. Kukk, V.; Bella, A.; Kers, J.; Kalamees, T. Airtightness of cross-laminated timber envelopes: Influence of moisture content, indoor humidity, orientation, and assembly. *J. Build. Eng.* **2021**, *44*, 102610. [CrossRef]
16. Herms, J.-L. Achieving airtightness and weather protection of CLT buildings. *E3S Web Conf.* **2020**, *172*, 10011. [CrossRef]
17. Linden, S.; Maroy, K.; Steeman, M.; Bossche, N.V. Tape as a means to ensure air- and watertightness of building joints: Experimental assessment. In Proceedings of the 14th International Conference on Durability of Building Materials and Components, Ghent, Belgium, 29–31 May 2017.
18. Bracke, W.; Van Den Bossche, N.; Janssens, A. Airtightness of building penetrations: Air sealing solutions, durability effects and measurement uncertainty. In Proceedings of the 35th AIVC Conference 'Ventilation and Airtightness in Transforming the Building Stock to High Performance', Poznań, Poland, 24—25 September 2014.
19. Bliūdžius, R.; Dobilaitė, V.; Jucienė, M. Investigation of the suitability of adhesive tapes for sealing building structures of various surfaces. *J. Adhes. Sci.* **2024**, *38*, 839–860. [CrossRef]
20. Antosik, A.K.; Mozelweska, K.; Gziut, K. Comparison of Aging Simulation to Real Aging of Silicone Self-adhesives Tapes. *Silicon* **2024**, *16*, 99–104. [CrossRef]
21. Adrian, K.A.; Grajczyk, A.; Półka, M.; Zdanowicz, M.; Halpin, J.; Bartkowiak, M. Influence of talc on the properties of silicone pressure-sensitive adhesives. *Materials* **2024**, *17*, 708. [CrossRef] [PubMed]

22. William, P.; Jacobs, V.; Daniel Dolan, J.; Dillard, D.A.; Ohanehi, D.C. An evaluation of acrylic pressure sensitive adhesive tapes for bonding wood in building construction applications. *J. Adhes. Sci. Technol.* **2012**, *26*, 1349–1381.
23. Jucienė, M.; Dobilaitė, V. Impact of climatic effects and various surfaces on the tack of adhesive tapes for building & construction. *J. Build. Eng.* **2021**, *42*, 102825.
24. Dobilaitė, V.; Jucienė, M.; Banionis, K.; Kumžienė, J.; Paukštys, V.; Stonkuvienė, A.; Miškinis, K. Effect of Artificial Aging of Peel Adhesion of Self-Adhesive Tapes on Different Construction Surfaces. *Appl. Sci.* **2023**, *13*, 8947. [CrossRef]
25. Serrat, C.; Casas, J.R.; Gibert, V. Current Topics and Trends on Durability of Building Materials and Components. In Proceedings of the XV Edition of the International Conference on Durability of Building Materials and Components (DBMC 2020), Barcelona, Spain, 20–23 October 2020.
26. Sletnes, M.; Frank, S. Performance and Durability of Adhesive Tapes for Building Applications. In From Product Documentation to Scientific Knowledge (and Back Again). In Proceedings of the Current Topics and Trends on Durability of Building Materials and Components: XV International Conference on Durability of Building Materials and Components (DBMC) 2020, Barcelona, Spain, 20–23 October 2020.
27. Fufa, S.M.; Labonnote, N.; Frank, S.; Rüther, P.; Jelle, B.P. Durability evaluation of adhesive tapes for building applications. *Constr. Build. Mater.* **2018**, *161*, 528–538. [CrossRef]
28. Langmans, J.; Desta, T.Z.; Alderweireldt, L.; Roels, S. Durability of self-adhesive tapes for exterior air barrier applications: A laboratory investigation. *Int. J. Vent.* **2017**, *16*, 30–41. [CrossRef]
29. Ylmén, P.; Hansén, M.; Romild, J. Durability of air tightness solutions for buildings: Ventilation and airtightness in transforming the building stock to high performance. In Proceedings of the 35th AIVC Conference, 4th TightVent Conference, 2nd Venticool Conference, Poznań, Poland, 24–25 September 2014.
30. Latthe, S.S.; Terashima, C.; Nakata, K.; Fujishima, A. Superhydrophobic surfaces developed by mimicking hierarchical surface morphology of lotus leaf. *Molecules* **2014**, *19*, 4256–4283. [CrossRef] [PubMed]
31. Drelich, J.; Chibowski, E.; Meng, D.D.; Terpilowski, K. Hydrophilic and superhydrophilic surfaces and materials. *Soft Matter* **2011**, *7*, 9804–9828. [CrossRef]
32. Law, K.-Y. Definitions for Hydrophilicity, Hydrophobicity, and Superhydrophobicity: Getting the Basics Right. *J. Phys. Chem. Lett.* **2014**, *5*, 686–688. [CrossRef]
33. Yamaguchi, Y.; Kusudo, H.; Surblys, D.; Omori, T.; Kikugawa, G. Interpretation of Young's equation for a liquid droplet on a flat and smooth solid surface: Mechanical and thermodynamic routes with a simple Lennard-Jones liquid. *J. Chem. Phys.* **2019**, *150*, 044701. [CrossRef] [PubMed]
34. Bonn, D.; Eggers, J.; Indekeu, J.; Meunier, J.; Rolley, E. Wetting and spreading. *Rev. Mod. Phys.* **2009**, *81*, 739–805. [CrossRef]
35. Gao, L.; McCarthy, T.J. Wetting 101°. *Langmuir* **2009**, *25*, 14105–14115. [CrossRef]
36. *ISO 9053-1:2018*; Acoustics—Determination of Airflow Resistance—Part 1: Static Airflow Method. International Organization for Standardization: Geneva, Switzerland, 2018.
37. *ISO 29862:2018*; Self Adhesive Tapes—Determination of Peel Adhesion Properties. International Organization for Standardization: Geneva, Switzerland, 2018.
38. Norvaišienė, R.; Burlingis, A.; Stankevičius, V. *Impact of Acidic Precipitation to Ageing of Painted Facades' Rendering: Monograph*; Technologija: Kaunas, Lithuania, 2006. (In Lithuania)
39. Czech, Z.; Milker, R. Development trends in pressure-sensitive adhesive systems. *Mater. Sci.* **2005**, *23*, 1015–1022.
40. Mapari, S.; Mestry, S.; Mhaske, S.T. Developments in pressure-sensitive adhesives: A review. *Polym. Bull.* **2021**, *78*, 4075–4108. [CrossRef]
41. Takahashi, K.; Shimizu, M.; Inaba, K.; Kishimoto, K.; Inao, Y.; Sugizaki, T. Tack performance of pressure-sensitive adhesive tapes under tensile loading. *Int. J. Adhes. Adhes.* **2013**, *45*, 90–97. [CrossRef]