In-situ and laboratory airtightness tests of structural insulated panels (SIPs) assemblies

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ABSTRACT

One of the main factors influencing building airtightness is the construction typology. As building environmental performance requirements raise so does the prevalence of less conventional envelope construction systems as modular structural insulated panels (SIPs) buildings.

In this paper, the airtightness performance of a constructive solution based on SIPs was evaluated. Airtightness tests were performed on the laboratory according to the EN 12114-2000 methodology. One complete exterior wall assembly and another one with the inclusion of a window were tested to determine their performance as an effective air barrier. The impact of the window framing in the overall resistance to air leakage was also determined. Additionally, the airtightness of a dwelling using these SIPs was measured during the construction phase and after commissioning. The objective was not only the assessment of the ACH50 difference between the two stages, but also the comparison with previously tested conventional envelopes on the same climate.

Laboratory and field test data resulted in mismatching values. Workmanship and unforeseen leakage paths were found to be the main contributors to these findings. Moreover, the case study displayed a superior airtightness performance when compared to heavy type construction solutions, common amongst the Portuguese building stock. Additional work is needed to identify and quantify envelope airpaths in order to properly design lightweight buildings solutions.

KEYWORDS

Airtightness, SIPs

1 INTRODUCTION

One of the main factors influencing building airtightness is the construction typology. The growing demand on the environmental performance of buildings has inspired the development of new envelope construction systems such as modular structural insulated panels (SIPs). SIPs are commonly composed by a thermally insulating core material skinned by structural sidings, among others, wood or metal based, and may include internal reinforcement. When reinforcement is included, the panels are of the closed box type, otherwise they represent sandwich type panels. SIPs can be applied in roofs, ceilings and floors, internal and external walls and claddings. These uses are dependent on the panels contribution to the loadbearing capacity of the building, which not all types are designed for.

In a building, human well-being and safety, construction materials durability and energy related issues are greatly dependent on the relationship between the ventilation strategy and the air permeability of its envelope. Air flow patterns, ventilation rates and heating/cooling loads are among the variables highly dependent on the building level of airtightness. On account of the Energy Performance of Buildings Directive (EPBD) application, as conduction through building components is being progressively addressed, the convective heat transfers gain more relative importance on the energy demand of buildings. Addressing airtightness is therefore a main issue for Europe's ambition of a correct implementation of the nearly zero energy buildings (nZEB) strategy.

In the European Technical Approval Guideline (ETAG) 16 (EOTA 2003), on self-supporting composite lightweight panels, and in the ETAG 19 (EOTA 2004), on prefabricated wood-based loadbearing stressed skin panels, the Essential Requirements (ER) address air permeability assessment. Issues regarding energy economy, cold draughts and the risks of water vapour condensation inside the envelope assembly are emphasized. As most issues are cross referenced between different ERs the guidelines express that the properties should be addressed under the most important one. Additionally, quantified mandatory national building regulations on air permeability in European countries are not widespread. Most of the existing ones address whole building airtightness and do not mandate the evaluation of separate building parts. By virtue of these considerations it is not uncommon for the performance of the air permeability of these panels to not be determined in the European Technical Approval (ETA) of a panel product.

As buildings become more complex and occupants more demanding, there is an obvious trend for smart design, supervised workmanship and materials durability, especially in the design of buildings envelope systems. In the particular case of SIPs, the critical air paths occur on joints between panels and joints between panels and other components (Kalamees 2007). Air permeability at these paths allows for moisture deposit in the insultation layer (Langmans, Klein, and Roels 2012), negatively impacting the panel serviceability. In chamber tests of wind barrier materials impact on panel joints permeability reductions by 96% and over were found in comparison with a situation without any sealing method (Relander et al. 2011). These tests occurred at a 50 Pa pressure difference with the studied assemblies ranged from gypsum boards and horizontally and vertically rolled wind barrier sheets. Prefabricated timber frame building envelope joints were assessed both in laboratory conditions and in already built houses (Kalamees, Alev, and Pärnalaas 2017). Results were found to be largely different from the laboratory to in situ case studies. Causes were related to workmanship on joint site sealing and the presence of other leakage pathways not studied. Additionally, self-adhesive tape seemed to be the best solution for improving the airtightness levels of the joints. The laboratory measurements in this study followed the EN 12114 (CEN 2000a) standard procedure. Another study on the airtightness properties of wood frame houses (Langmans et al. 2010) investigated the performance in different construction stages. Alongside field measurements, laboratory tests underwent on specimens of the building envelope in order to investigate possible local air leakage paths. Laboratory tests found that air permeability at material level is independent of the moisture content for as long as it does not exceed acceptable limits. Still on in situ measurements the presence of moisture content in the wind barrier reduced the overall airtightness performance by up to 30%. It was highlighted that workmanship is the most decisive source of error. Along with it, the unforeseen leakage paths were ascribed as the main influencers for the mismatching air permeability results between laboratory and in situ measurements.

The design target for airtightness of an envelope should not be solely assessed at commissioning stage but also during construction stage if the proposed limits are not to be surpassed (Relander, Holøs, and Thue 2012). A stronger focus on airtightness at design phase could avoid costly operations on corrections on later stages. A study on wood frame low energy houses reports a 20 to 30% reduction on air change rate at 50 Pa (ACH50) from the wind-barrier finishing stage to the commissioning stage (Holøs and Relander 2010). Still, other study (Iordache et al. 2016) points to the fact that even though finishing works normally improve airtightness levels, further works, such as HVAC equipment installation, can compromise the improvements and even increase the air permeability of the envelope in relation to the performance at a previous stage. Although the construction phase measurement is an important reference for the overall building performance it does not serve as insurance that the airtightness can only get improved in subsequent phases of construction. The in-situ measurements followed the EN13829 (CEN 2000b) blower door test method.

The present work pretends to discuss the air permeability performance of a lightweight construction solution. Summarily, the aim of the study is apprehended by the following objectives:

- Assessment of the airtightness offset between the finished wind barrier construction stage and the commissioning stage;
- Comparison of the airtightness performance in laboratory and field application of the SIPs envelope solution.

2 MATERIALS AND METHODS

2.1 Structural insulated panel

The SIP solution evaluated in this paper is composed by metal framing elements, a core of expanded polystyrene (EPS) and oriented strand boards (OSB) sidings. Figure 1 illustrates the composition and the assembly details. The constructive solution includes connection modules that fill the space between the metal frame profiles. At the connection between panels the OSB sidings are theoretically in contact. To ensure the continuity and performance of the construction system all the joints are sealed with a continuous mastic strand both on the exterior and interior side.

A specimen of 360x300 cm^2 was used for the laboratory tests. After the initial assessment, a 55x70 cm^2 side hung window was added to the setup. Figure 2 shows the two laboratory SIPs specimens ready for testing. The interior surface remained unfinished but the exterior one was finished using the same materials used in the in-situ example: magnesium oxide-based boards, with a coating of synthetic mortar reinforced with a fiberglass net. The specimen has an area of 10.8 m^2, 9.6 linear meters of joints between panels and 2.5 linear meters of joints between the SIPs and the window.

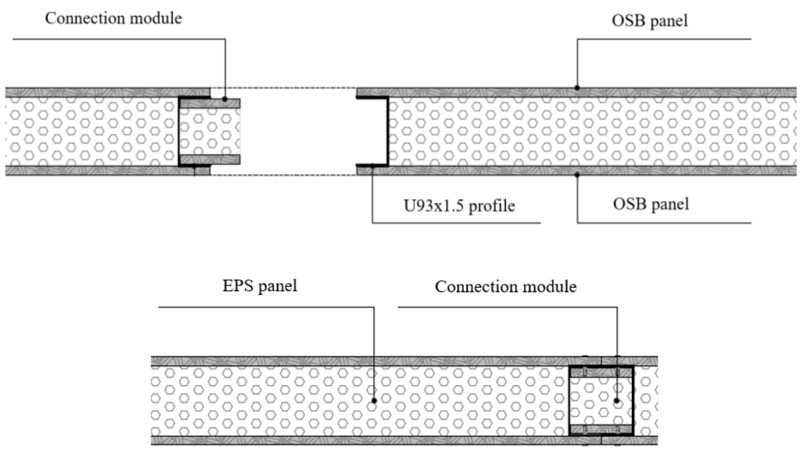

Figure 1: Details of the SIPs assembly.

a) b)

Figure 2: SIP modules tested: a) wall assembly; b) with a side hung window.

The in-situ case study corresponds to a single floor modular dwelling built in the north region of Portugal. The slab is of reinforced concrete. The rest of the structure is made of the SIPs. As referred before, an additional exterior cover of magnesium oxide-based boards was added to the SIPs and covered by a synthetic mortar reinforced with a fiberglass net. On the interior side, a plasterboard finishing was applied. The roof is composed of the same SIPs with an additional liquid waterproofing layer on the exterior surface. All the exterior openings, with the exception of the entrance door, are double glazed side hung aluminium frames. There are mechanical exhausts in the bathrooms and kitchen and grilles for fresh air admission in the living room and in the laundry.
Table 1 presents the dwelling relevant geometric properties.

Table 1: Modular home geometric properties

Floor area [m^2]	**Volume [m^3]**	**Envelope area [m^2]**	**SIPs – windows joints length [m]**	**Internal SIPs joints length [m]**
103.0	319.3	322.0	64.0	329.5

2.2 Laboratory tests

The laboratory tests were carried out according to the procedure described in EN12114-2000. The test starts by imposing three pressure pulses at the maximum pressure difference, followed by increasing levels of pressure up to a maximum of 1000 Pa, both for negative and positive pressures. At each step of the process the corresponding airflow is measured. The pressure differences used in the tests were 50, 100, 180, 320, 560 e 1000 Pa.
To assess the test chamber effect the specimen with no window was first measured as-built and after measurement was made with tape sealed internal joints. The difference between the two flow volumes totals the air flow across the specimen itself. The same method was used to assess the permeability of the specimen containing the window.
The measurements were performed with temperatures ranging between 15 and 16 ºC and relative humidity between 55 and 60%. An integrated electromechanical system was used to control, measure and record the data of the tests. The pressure transducer records a minimum

of 50 Pa pressure difference with an accuracy of ±5 Pa. The accuracies of the flowmeter and the anemometer are ±0.05 l/min and ±0.05 m/s, respectively.

2.3 In-situ tests

In the in-situ case study, the airtightness measurements occurred during the construction stage and at commissioning. The tests were performed with the blower door Retrotec1000 model (Figure 3), following the procedure described in the standard EN13829-2000.

Figure 3: Blower door setup for in-situ airtightness measurement

In the measurement carried out at construction stage, the whole envelope was already assembled and the exterior coating was already applied. Nevertheless, the connection between the window frame and the interior plasterboards was not completely sealed. Additionally, no other penetrating elements in the exterior walls, such as the electrical ones, were installed. At construction stage, only method B of the EN 13829 was addressed. At commissioning stage, both methods A and B were applied.

3 RESULTS AND DISCUSSION

Figure 4 portrays the permeability of the specimens with and without window for linear meter of internal joints. The left graph displays pressurization measurements. Depressurization data can be found in the right graph.. The contribution of the internal SIPs joints to the airtightness is 0.0048 $m^3/(h.m)$ at 50 Pa of pressure difference. This result is approximately 30% below the average contribution found by previous authors for both horizontal and vertical joints (Newell and Newell 2011). The inclusion of a window to the setup increases the airflow volume to 0.0113 $m^3/(h.m)$ at 50 Pa. This is partially justified by the window frame permeability. The different geometry of the SIPs-window joints in comparison with the internal SIPs joints is another factor to take into account on the permeability differences between the specimens. Still, the results show a good performance throughout the range of studied pressure differences, never exceeding the DIN 4108-2 limit. This proves the reliability of the envelope system on creating airtight environments with no further addiction of sealing elements.

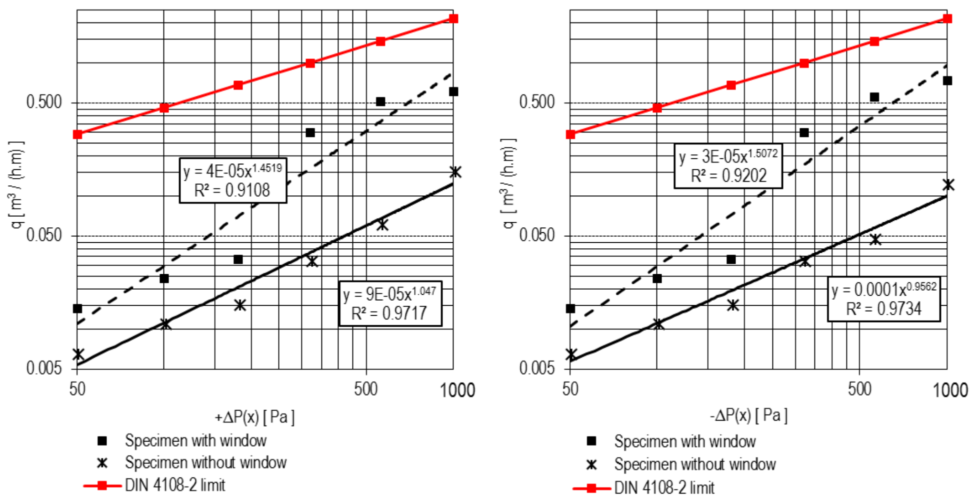

Figure 4: Air flow across joints for the test specimens at positive and negative pressure differentials

Concerning the in-situ tests, Table 3 shows the air change rate across the building envelope at 50 Pa divided by the indoor volume – n_{50} – for the different stages and scenarios under study. A very airtight building was expected after the laboratory experimental results, particularly for method B measurements since the openings are sealed. Nevertheless, even for this situation the n_{50} was 1.55 h^{-1} increasing up to 1.98 h^{-1} when method A is used. This result is in line with findings published in a previous study about wind barriers on wood frame houses (Langmans et al. 2010) where the field measurements largely exceeded the theoretical values found in laboratory. Still, this data contrasts with the results found on reinforced concrete and masonry built flats on a nearby location (Ramos et al. 2015). In that example, the airtightness averaged 6.8 h^{-1}.

Table 3: Air change rates and air permeability at 50 Pa during different building stages of measurements according to EN 13829-2000

Building stage	**n_{50} [h^{-1}]**	**q_{50} [$m^3/(h.m^2)$]**
Construction - method B	2.49	2.47
Commissioning - method A	1.98	1.96
Commissioning - method B	1.55	1.54

Moreover, the results show a 37.8% reduction of the air permeability of the envelope, when measured by method B, from the construction to the commissioning stage. As exterior works were already finished during the construction stage measurement, it can be stated that interior works on the envelope are not negligible for the final airtightness performance. The purpose provided openings contribution is of 0.43 m^3/h at 50 Pa, only 21% of the total air change rate. This differs significantly from other values found in a similar study (Pereira et al. 2014). It is demonstrated that the air renovation is mostly dependent on the infiltration component. Theoretically the infiltration should not be dependent on internal SIPs joints and on joints between SIPs and windows. If the less airtight value estimated on laboratory is considered, the influence never surpasses 1.5 % of the n_{50} measured in situ. Unforeseen leakage paths and workmanship issues are to blame for the results found.

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4 CONCLUSIONS

In this work, the airtightness characterization of a constructive solution based on SIPs was addressed. For that end, both laboratory and in-situ tests were carried out and from the acquired data the following conclusions can be drawn:

- The SIP envelope system complies with the permeability requirements of DIN 4108-2 standard, proving that, in the mild climate of Portugal and in terms of airtightness, this construction system can be an alternative for the traditional heavy construction solutions;
- The effect of workmanship was confirmed as one key factor influencing the airtightness of a building. Airtightness laboratory results are not a reliable estimator for real case scenarios performance and should be perceived as an optimum benchmark for the selection of construction solutions;
- Unforeseen airpaths, and others not studied in the present work, as concrete slab/exterior wall joints, electrical/plumbing/gas facilities, etc. substantially influence the overall airtightness performance.

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