Implementation of airtight constructions and joints in residential buildings

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SUMMARY:
Airtightness is mainly a property of the building and not the structure. The basic recommendation is that air barriers must be continuous between adjacent structures and sealed around the supplementary construction elements and penetrations. A critical stage in achieving an airtight building is the quality of work at the construction site. Careful designing does not help if the solutions are unfeasible or difficult to execute and therefore are not realized at the site. Updated information of how to ensure building envelope's airtightness with constructional details has not been available in Finland. As a part of the research project "Airtightness, indoor climate and energy efficiency of residential buildings" the department of Civil Engineering at Tampere University of Technology decided to publish a guide book of airtight constructions and joints. This paper presents the development work and structure of the guide book and also some recommended solutions for airtight constructions as presented in the guide book. The objective of this part of the research project is to give practical instructions to designers and other construction professionals of how to achieve sufficiently airtight buildings for Finnish climatic conditions.

1. Introduction

1.1 Airtightness of residential buildings in Finland

In recent years the research group of Building Physics at the department of Civil Engineering at Tampere University of Technology has conducted two major research projects which were concerning airtightness of residential buildings in Finland. During the first study, "Moisture-proof healthy detached house", TUT and the HVAC-laboratory at Helsinki University of Technology measured the airtightness of 100 timber-framed dwellings. In the second research project, "Airtightness, indoor climate and energy efficiency of residential buildings", the participants measured the airtightness of heavyweight single-family houses and apartments. Measured buildings were for the most part recently constructed so the result describes quite well the situation in Finland today. The results of these measurements revealed that most Finnish single-family houses do not reach the n_{50}-value recommended in the National Building Code of Finland. The recommended value of building envelope's airtightness, in respect of the functioning of the ventilation system, should be close to the value of n_{50}= 1,0 1/h (RakMK C3). The n_{50}-value 1,0 1/h means that one volume of air in the building is flowing through the building envelope in an hour when the pressure difference between the inside and outside air is 50 Pa.

The average n_{50}-value measured from 100 single-family timber-framed houses was 3,9 1/h. The mean value of log-houses was 6,0 1/h, measured from 20 houses, and the average n_{50}-value of other heavyweight single-family houses was 2,3 1/h. The group of other heavyweight houses consisted of 10 houses built from blocks of autoclaved aerated concrete (AAC), 10 houses of lightweight aggregate concrete (LWAC), 10 brick houses (of these 5 were calsium silicate and 5 burnt clay bricks), 10 houses built from shuttering concrete blocks and 10 concrete element houses. The average measured n_{50}-value of apartments was 1,5 1/h, consisted of data from 57 apartments. (Korpi, et al. 2007). Generally apartments were tighter than single-family houses and block, masonry and concrete element houses achieved better n_{50}-values than timber-framed or log houses. During the measurements it was also discovered that it is possible to achieve an airtight building with an n_{50}-value around 1,0 1/h with all construction types. This requires that both the designing of details as well as the work at the site are executed carefully. Because there was no up-to-date information available of how to achieve this, TUT decided to publish a guide book of how to design and execute airtight constructions and joints in residential building envelopes.

1.2 Benefits of building envelope's airtightness

Previously there has been a widespread belief in Finland that airtight buildings incur unsatisfactory indoor climate or moisture damages to the structures. One reason to this belief is the so-called "bottle-house" from the 1970's. These houses might have been airtight but they lacked adequate ventilation or had severe structural defects. Almost all new residential buildings in Finland have mechanical ventilation so the indoor climate is better controlled and easily adjustable. The knowledge on hygrothermal performance of structures has also improved. On this account, there is an explanation about the advantages and correct functioning of airtight constructions in the beginning of the guide book.

Uncontrolled exfiltration of humid indoor air through the building envelope can also inflict on a major local moisture accumulation to constructions. This can then create moisture problems such as mould or decay of timber structures. Air leakage from outside especially through the floor structures can also introduce airborne pollutants or radon gas into the indoor air.

Airtightness can affect on building's heat energy consumption. It has been suggested that for a detached house in a sheltered suburban area in the climate conditions of Helsinki the increase of one unit of the building leakage value n_{50} can give a rise to an increase of approximately 6% in the heat energy consumption of the zones and the ventilation system and the increase in total heat energy consumption is about 4% (Jokisalo, et al. 2007). Also infiltration can deteriorate the indoor climate by creating the feeling of draught, which is usually compensated by an increase of the indoor temperature.

Since the beginning of 2008 energy efficiency certificates are required from all new buildings. With the new regulations it is possible to use good airtightness as a compensation for lower U-values in certain structures. This is enabled by the calculation of the buildings heat losses. The n_{50}-value used in reference calculation is 4,0 1/h and if the buildings actual n_{50}-value is lower than this, the compensation is possible. (RakMK D3.) This option is significant for example to massive log external walls which do not meet the required U-values with commonly used thicknesses. Of course, it is not recommended to minimize the thermal insulation thickness in all cases. The main objective is that new buildings reach a better energy efficiency class than the one suggested by the reference calculation.

2. Development of the guide book

As a part of the research project "Airtightness, indoor climate and energy efficiency of residential buildings" the department of Civil Engineering at Tampere University of Technology decided to publish a guide book of airtight constructions and joints, which is focused on typical Finnish constructions. Solutions were developed by a group of researchers from different fields of engineering. The participants were professionals in structural engineering, building physics, renovation, fire safety or site practice. The group had several meetings during 2006-2008 in which the designs were first developed and then revised. Solutions have also been commented by the construction industry professionals in the executive group of the research project.

The guide presents both detailed plan drawings for the designers and working instructions for the construction site. The examples are planned for concrete element, block, masonry, wood-framed and log structures. The guide book concentrates on residential single-family houses but the solutions can be adapted to other buildings as well. The details are planned so that their scope is as wide as possible. It was not practical to take into account all different variations so the recommendations should be modified to specific end-use applications by the designer of the building. Although the air barrier in the structure is often functioning as a moisture-barrier too, the publication does not concern the hygrothermal performance of structures.

3. Design recommendations

3.1 General

Airtightness is mainly a property of the building and not the structure. The basic demand is that air barrier should remain continuous in structural joints e.g. the junction between the external wall and roof structure. The sealing of joints to supplementary construction elements, such as windows, should also be well planned and executed. Typical places of air leakages in Finnish residential buildings are around and through windows and doors, in the junction of roof structure or intermediate floor with the external wall as well as penetrations through the air barrier system (Kalamees et al. 2007). Penetrations can be for example electric wall sockets or chimneys and air pipes. At some cases it has been evident that the basic structure of a window or door itself can also incur an air leakage. The airtightness of these structures should be a target for development to the manufacturers.

In some constructions the main air barrier is a separate layer such as a plastic or paper based foil or a plaster coating. The first one is common in layered timber-framed structures and the latter is used with permeable block constructions e.g. LWAC. With timber-framed constructions the air barrier is most commonly also used as a vapour barrier and it is therefore located near the internal surface. Because the guide book does not cover the hygrothermal performance of the structures we only use the term air barrier instead of vapour barrier.

Some structural elements, e.g. concrete elements and AAC blocks, are functioning as an air barrier without a separate layer. However, with these structures the joints to adjacent elements or blocks and penetration seals should also be carefully executed to achieve an airtight building envelope. Similarly massive log walls do not have a separate air barrier layer. Therefore the gap between the logs must be sealed with joint strips and the shape of the log profile and corner details should be carefully considered. Log structures also tend to sag after construction, which should be considered with joint detailing. Also other recommended solutions should endure the life expectancy.

3.2 External walls, roofs and base-floors

In timber-framed external walls the air barrier is usually a foil of plastic or paper-based product. The use of thicker rigid polystyrene or polyurethane thermal insulation boards has also been suggested. The advantage of these boards is relatively easy jointing and sealing with polyurethane foam. The board can also be regarded as a part of thermal insulation which may thin down the required construction thickness. The foil air barrier can be located slightly deeper inside the thermal insulation layer (FIG 1, left), this enables concealed electric wiring behind the interior board and easier assembly of electric wall sockets without piercing the air barrier. The assembly space is equally recommended with rigid thermal insulation board air barriers (FIG 1, right). Depending on other constructional details, e.g. the thermal insulation material, the air barrier must have adequate water vapour resistance for ensuring the hygrothermal performance of the wall structure.

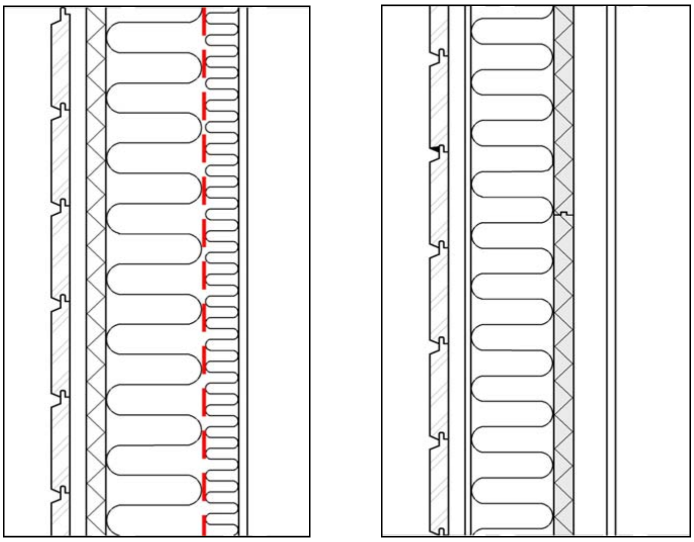

FIG 1. Air barrier in timber-framed external wall constructions. On the left plastic or paper based foil, on the right rigid thermal insulation board. Structure is from left to right: external cladding and ventilation gap, wind shield board, thermal insulation, air barrier, installation gap and interior board.

When the air barrier layer is also the vapour barrier the internal thermal insulation (FIG 1, left) should be installed only after the high moisture load work phases such as concrete pourings are done. The vapour barrier must not be taken too close to the exterior surface. Otherwise there is a risk of moisture condensation. A general rule is that ¾ of the insulation thickness should be on the outside of the vapour barrier (Vinha J. 2007).

When plastic or paper-based foil is used as the air barrier the adjacent foils should be overlapped (> 150 mm) and compressed together or taped with a product that has adequate long-term durability for the extensions to stay airtight. The first alternative, overlapping and compression with wooden lath, is presented in figure 2. This is the recommendation for the external wall structure presented in FIG 1, left. The maximum limit between fixing screws is 300 mm so the compression is continuous. The recommendation for overlapping and compression or taping is equally valid for plastic or paper-based foil air barriers in roof structures. In horizontal constructions the air barrier foil must be adequately supported from below so that the weight of the thermal insulation does not cause damage to the foil. If possible, both the taping and compression can be used simultaneously to ensure the tightness of the extension in horizontal structures.

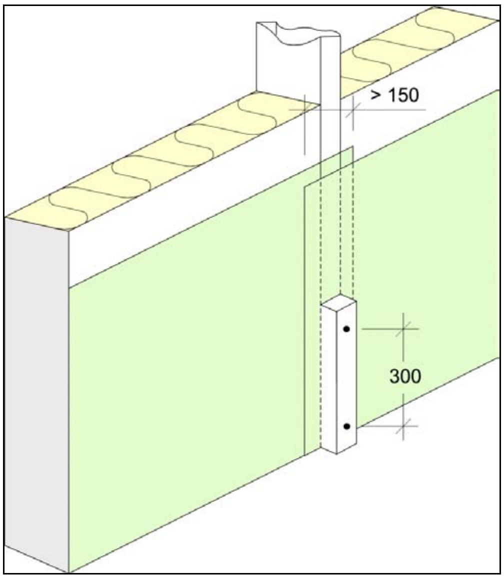

FIG 2. Plastic or paper-based foil air barrier's extension in timber-framed external wall construction.

Some block wall structures need a separate air barrier layer because the blocks themselves are air permeable. The layer is usually a plaster coating in the internal surface. Plastering should in these cases extend continuous the whole wall height and also behind suspended ceilings etc.

As a roof structure concrete or AAC elements are rare in residential single-family houses but as mentioned before they are in themselves airtight. The most critical places for air leakage are joints with external walls, seams between elements and penetrations e.g. chimney junction.

Base-floors can consist of a concrete slab (slab-on-ground or crawl-space construction) or timber beams and boards (crawl-space). Generally a concrete slab is in itself airtight but poorly sealed penetrations can cause air leaks. In timber-framed base-floors the boards are usually also the air barrier. The most critical air leakage is usually the junction between base-floor and external wall, which often is also a thermal bridge (Kalamees et al. 2007). An air leak along the floor can cause a feeling of draught and act as an entrance route for radon gas or airborne pollutants to the indoor air.

3.3 Joints and penetrations

With slab-on-ground structures the most effective way to obstruct air leakage and at the same time the radon gas from entering the indoor air is to use elastic (SBS modified) bitumen felt strip in the joint. There are multiple possibilities for mounting the felt and the best one for each case depends on the foundation structure as well as the external wall structure. If the foundation wall and external wall are sufficiently airtight or their tightness has been otherwise assured the elastic bitumen felt strip can be attached to the foundation wall and folded under the concrete slab (FIG 3, left (2)). It should be noticed that in this example the plaster coating extends to the whole height of the block wall structure in both surfaces and so it ensures the airtightness of the wall structure. The gap between the wall and the slab is sealed with polyurethane foam or putty (1). With timber-framed external walls the felt may extend under the longitudinal timber at the bottom of the wall structure to hinder capillary flow from foundation wall to the timber structure (FIG 3, right (2)). In this picture the air barrier foil of the external wall is folded under the slab (1) which of course is possible only when the wall is erected prior to casting of the concrete slab.

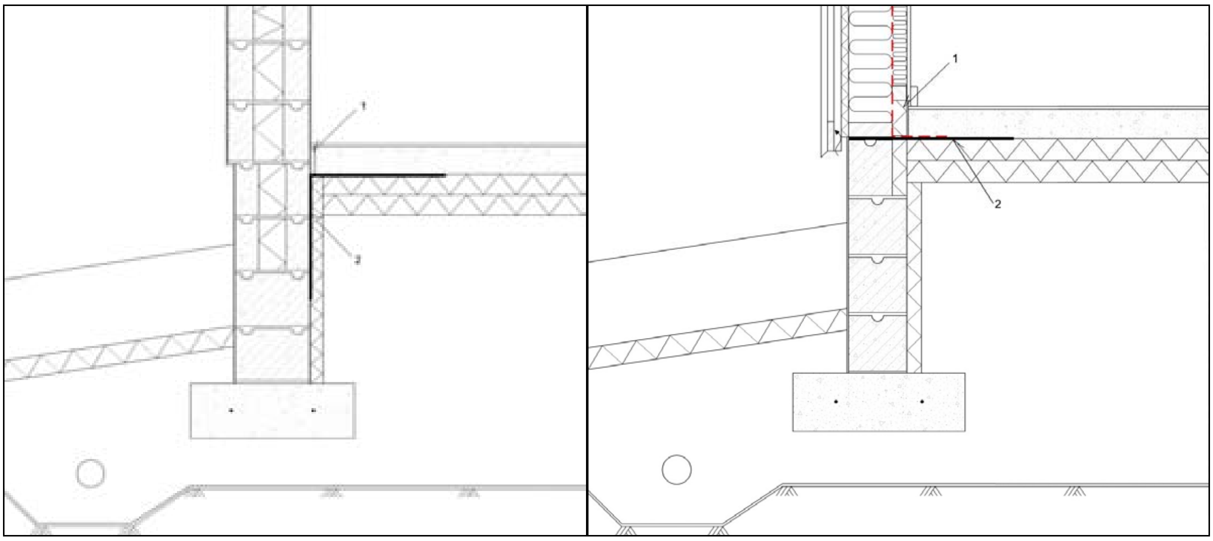

FIG 3. Examples of airtight junctions between a slab-on-ground structure and external wall.

Timber-framed roof structures with plastic or paper based foil air barriers are very common in Finnish single-family houses even when the external walls are made of blocks or bricks. With timber-framed external walls it is possible to overlap the joining air barrier foils (FIG 4, left (2)) and then compress them with a wooden lath and dense screw fixation (1). When the wall structure does not have a separate air barrier foil the junction is more difficult to execute (FIG 4, right). One possibility is to compress the air barrier of the roof structure between the longitudinal timber on the top of the block wall and suspending lath (2). The gap between the longitudinal timber to which the roof truss is attached to and the block wall is then sealed with polyurethane foam or putty (1). These examples are a combination of different sealing methods and demand a certain working order. Therefore it is very important to give good instructions for the execution to the site.

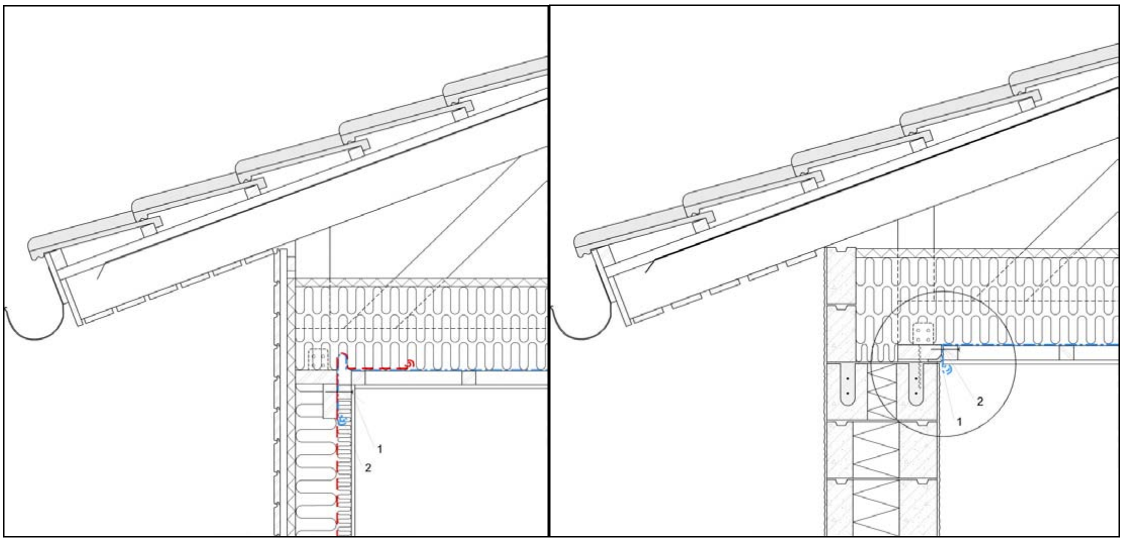

FIG 4. Examples of airtight junctions between a wood-framed roof structure and external wall.

In wood-framed external walls with foil air barrier the junction of the intermediate floor often creates a discontinuity to airtightness. The problem can be avoided by using a rigid plastic thermal insulation board between the intermediate floor beams (FIG 5, (1)). The board is fixed with polyurethane foam to the wall structures above and below and also to the beams. The air barrier foils are again compressed with dense screw fixation (2). The detail is actually easier to execute in practise as the traditional way of folding the foils around the beam-ends.

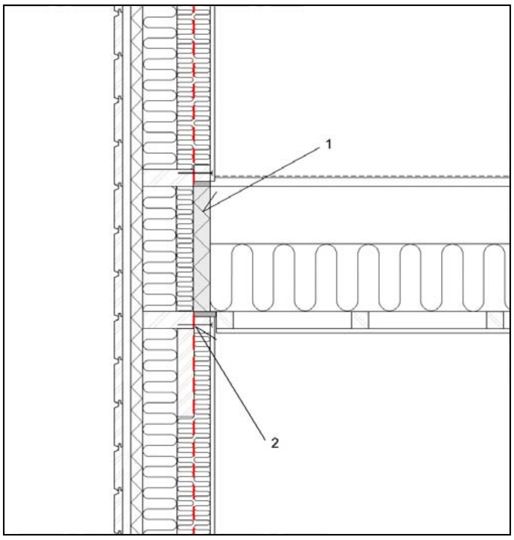

FIG 5. Example of continuous air barrier in a timber-framed external wall at the junction of an intermediate floor.

The details presented above are only an example of the recommendations in the guide book. In addition to these junctions and their modifications to other construction materials, the guide book has examples for window and door joints, chimney and ventilation pipe penetrations and some specific details for designing structures of spaces with high moisture exertion such as steam rooms.

4. Implementation of airtight building envelopes

The most critical stage of achieving an airtight building is at the construction site. The benefits of an airtight building envelope should be evident to the workers as well as the supervisors at the site so the motivation for careful execution of details is present at all times. Thoughtfully designed details will not be efficient if they are not executed correctly. Even though the details planned for airtight structures are often somewhat different from custom and sometimes even slightly more demanding the designer must ensure that they are feasible or they will not be realized at the site. Most of the airtight details are combinations of different sealing methods so the work phases and their order need to be clearly instructed.

Detail planning that concentrates on airtightness is at the moment uncommon in residential buildings. If we wish to improve the airtightness of new buildings the detailing should be done by professional designers. By improving the airtightness of the building envelope we also improve the energy efficiency and indoor air quality of residential buildings and avoid local moisture damages to structures.

5. Conclusions

The objective of this part of the research project “Airtightness, indoor climate and energy efficiency of residential buildings” is to give practical instructions to designers and other construction professionals of how to achieve sufficiently airtight building envelopes for Finnish climatic conditions. For this purpose, the department of Civil Engineering at Tampere University of Technology decided to publish a guide book of implementation of airtight constructions and joints. The guide book is scheduled to be published in the autumn of 2008. It is expected to raise knowledge of the importance of building envelope’s airtightness relative to the correct functioning of structures, the energy efficiency of the building and achievement of good indoor air quality.

6. Acknowledgements

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