Methods and Materials for an Airtight Building

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ABSTRACT

This paper summarizes projects that deal with important requirements for achieving an airtight building. The major themes are: (1) problem areas with respect to airtightness, (2) how to find leaky areas and improve their airtightness, (3) good and airtight solutions, and (4) durability of airtight layers and joints.

First, critical details for airtightness are identified and analyzed. Poor airtightness is often caused by lack of consideration of airtight details in the design phase, by poor workmanship, or by lack of understanding of airtightness during construction. The consequences of poor airtightness are described.

Second, different methods of searching for air leaks are investigated and evaluated. Searching for leaks during the construction phase is a good way of improving airtightness, since the airtight layers are more accessible during erection of the building than when the building is completed.

Third, several buildings with very good measured airtightness are investigated in order to provide airtight solutions to designers and builders. A number of important details and designs are collected and presented to the building industry.

INTRODUCTION

Interest in airtightness has increased in Sweden over the last ten years. One reason for this is the increasing focus on energy use and passive houses[1]. Airtightness is linked to energy use in different ways, depending on whether the air passes through the building envelope or between different parts of the interior of the building.

If air leaks (uncontrolled) into the building envelope, the performance of the insulation can be degraded, which can lead to cold inner surfaces. Cold surfaces, such as floors, can result in a need to increase the indoor temperature to compensate for increased discomfort due to radiational losses and, thus, to an increase in energy use. In addition, if the building is not airtight, the ventilation rate may be increased, particularly in windy or cold weather.

Apart from energy, there are other reasons for having airtight buildings. If humid air is allowed into the building envelope, this can lead to high moisture conditions and, as a result, to mold, deterioration, and increased emissions. Figure 1 shows an interior roof surface with mold growth due to humid air.

Another reason for having good airtightness is that it is a prerequisite for correct performance of the building's ventilation system. Without an airtight envelope, it is difficult to filter the air, to stop gas or particle transport inside the building and through the building envelope, or to ensure an adequate ventilation rate in all parts of a building (particularly in windy weather). Critical parts of a building envelope are presented in Sandberg and Sikander (2005). The leakage pathways are illustrated in Figure 2. In addition to the leakage pathways

1. Passive houses are buildings, in which a comfortable temperature in winter as well as in summer can be achieved with only minimal energy consumption. Different countries have different requirements for passive houses.

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Figure 1 *Mold growth in a cold attic.*

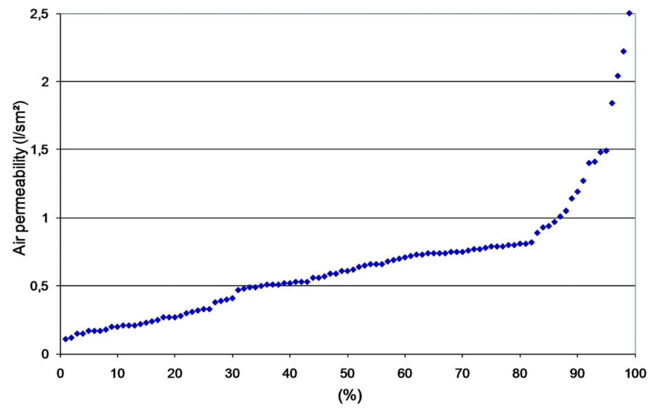

Figure 3 *Airtightness in 100 Swedish buildings (Svensson 2009).*

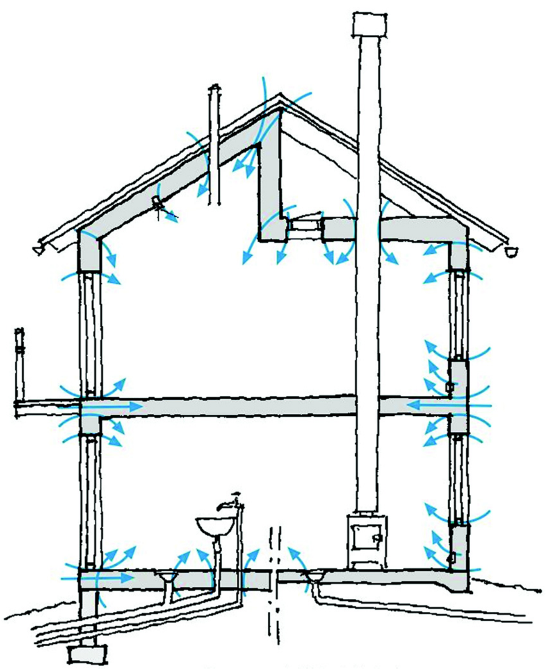

Figure 2 *Common air leakages in a building envelope (Eric Werner AB).*

shown in the figure, there is also air leakage through joints in the air barrier.

Airtightness can be defined as air permeability at 50 Pa, q_{50} m^3/(h·m^2) or L/(s·m^2) (EN 13829 2000). This air permeability is the air leakage rate per envelope area at a reference pressure differential of 50 Pa across the building envelope. Currently, there is no requirement for a maximum permissible value of air permeability for Swedish buildings. In the Swedish specification for passive houses, the maximum permeability for a passive house is 0.3 L/(s·m^2). Previously, Sweden had a maximum requirement for air permeability of 0.8 L/(s·m^2). In order to find out the existing permeability of newly constructed Swedish buildings, air permeability data has been collected for 100 buildings (Svensson and Hägerhed-Engman 2009). The study includes apartment buildings (individual apartments are measured), schools, single-family residential houses, and wooden and concrete structures. As seen in Figure 3, values range from 0.11 to 2.5 L/(s·m^2). Many buildings are in the range of 0.8 L/(s·m^2) (former Swedish requirement). Passive houses and the buildings with high airtightness performance requirements all have an air permeability of less than 0.3 L/(s·m^2).

This is the situation in Sweden today. The work described in this paper aims at supporting the construction of airtight buildings. In several joint projects with SP Technical Research Institute of Sweden and Chalmers University of Technology, the Convection Group has worked with airtightness, air movement, building envelopes, and related issues for the last ten years or so (Figure 4). Sandberg et al. (2007a, 2007b) describe the consequences (both physical and economic) of poor airtightness. The projects described in this paper aim to demonstrate a method of finding the air leakage paths during the construction phase (Sikander et al. 2008) and to show examples of good airtight designs (Wahlgren 2010). The airtightness work is continued with, for example, work on durability.

FINDING AIR LEAKAGES

There are many steps to be taken to ensure an airtight building. The airtightness of a building needs to be considered in all stages of a building project. A quality-assurance system for airtightness is described in Knight et al. (2003) with

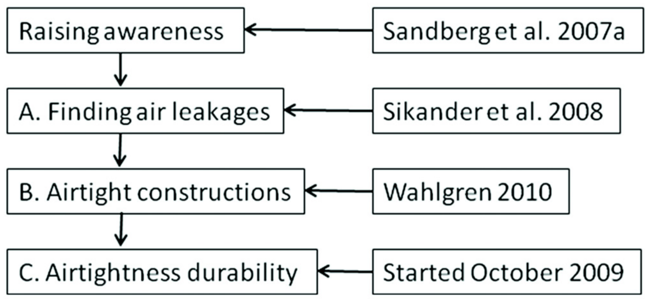

Figure 4 *Example of projects aiming at improving building airtightness.*

instructions for several phases, including air leakage pathway determination (ASTM E1186 2009). Wray et al. (2002) bring together methods to evaluate the building envelope, including airtightness and searching for air leaks.

A methodology to easily detect air leakages before a building is completed has been formulated. The idea of the methodology has been to find an easy-to-use method to be used by construction workers at the building site following straightforward written instructions. The equipment and instruments should also be easy to use and to obtain (buy or rent).

In order to develop such a method, the following steps were taken: an inventory of possible ways of detecting and measuring air leakage, interviews with airtightness test engineers in order to select good methods, and field testing of the different methods. After a first round of testing, the construction workers were interviewed and improvements of the method were made. A second round of testing and evaluation was also made.

The resulting method is intended for use before the interior finishes are in place so that improvement of the air barrier can easily be made. The method is described below.

INSTRUCTIONS FOR DETECTING AIR LEAKAGES AT AN EARLY CONSTRUCTION STAGE

The Purpose of Detecting Air Leakages

The purpose of detecting air leakages at an early stage of construction is to find and address any weak spots in the airtightness of the building envelope. These instructions are not intended to provide a measured value of the airtightness; Airtightness measurements must be made in accordance with the requirements of EN 13829 (2000) or ASTM E779 (2003).

Method

Establish a negative pressure in a building or part thereof and find the inward leaks of air using one or more of the following instruments: an anemometer, smoke canister or smoke pencil, and/or a thermal imaging camera. Having done this, seal the leaks.

Selecting the Test Area

Decide on the area to be tested (i.e., the area in which a negative pressure is to be established) in order to investigate the airtightness of the building envelope. The area can range from a single room, to an apartment, to an entire building, depending on the size of the test area concerned and the fan capacity. The airtight layer must, of course, have been completed (common with polyethylene film in Sweden). Windows and doors must have been fitted: if the door to a stairwell has not been fitted, the opening can be temporarily sealed.

Equipment

- Polyethylene film
- Tape
- Fan with controllable variable flow. The necessary capacity depends on the size of the building/area and its current airtightness. As an example, a fan with a capacity of 400 L/s should be sufficient for a volume with a floor space of 100 m^2. Fans can be rented from tool rental shops.
- Pressure gauge/ manometer with plastic tubing[2]
- Smoke canisters/smoke pencil[2]
- Anemometer[2]
- Thermal imaging camera[2]

Time Required

To perform early leak detection in, for example, an apartment of about 70 m^2, it can take one person about two hours to set up and remove the equipment, 1–2 hours to trace leaks and seal them, and one hour to evaluate the results and make notes to assist in continued work. This gives a total time of about 4–5 hours for one person, but the work will be easier and more quickly performed if carried out by two people.

Preparations

(Tick off the following points as you proceed.)

- ❑ Make a visual check of the building envelope, paying particular attention to connections, joints, penetrations or any damage to the air barrier, and rectify any obvious defects. If any large leaks are present, it may be difficult to establish and maintain a negative air pressure.
- ❑ Make a visual check of leaks into adjacent spaces and seal as much as possible.
- ❑ Cover and seal air-supply diffusers and exhaust grilles, as well as floor drains and penetrations through walls, floors and ceilings. This can be done temporarily using tape or firmly compressed insulation (see Figure 5 for examples). Plumbing traps should be filled with water.

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2. Choose one or more methods as appropriate.

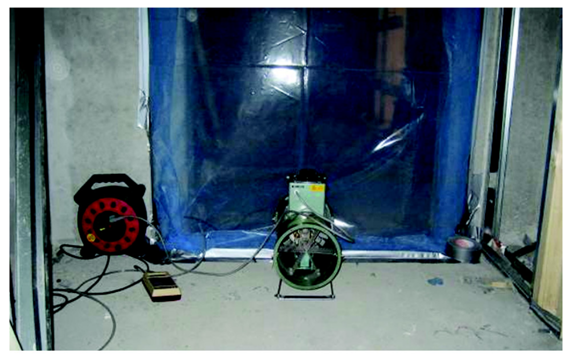
(a) (b) (c)

Figure 5 *(a) The hole around a penetration through a ceiling, (b) sealing around pipes with compressed mineral wool, and (c) a ventilation duct closed by a balloon.*

- ❑ Check that all the equipment is in place and that a power supply is available for the fan inside the test volume.
- ❑ Close all doors and windows to the test volume.

Create a Negative Pressure

- ❑ If the fan does not come with an adjustable door frame and panel material, fit a sheet of polyethylene film (or a board that is somewhat larger than the door opening) to close off a door opening, and seal it all around with tape. If possible, the first choice for this is a door to the exterior. If that is not available, then a door to a stairwell or corridor can be chosen. (If this is done, make sure that the door from the stairwell to the exterior is open.) Remember that ways in and out of the apartment/area can be limited after the film or board has been set up.
- ❑ Make a hole in the film, about 1–2 cm less in diameter than the size of the fan.
- ❑ Install the fan in the opening by pressing it into the hole in the film so that it can suck air out of the apartment (Figure 6). Tape the connection between the fan and the film.
- ❑ Measure the pressure difference between the test area and the exterior, using the pressure gauge. Position the pressure gauge in the test area so that it is not affected by the air to the fan. Connect a plastic tube to the pressure gauge and run it to the exterior, again, well away from the fan. Pass the tube through a hole in the polyethylene film in which the fan is fitted. If the film and fan are in a door to a stairwell, run the hose instead out through a gap in a window, and then tape the gap.
- ❑ Start the fan and adjust its speed to give a pressure difference of 20–30 Pa but not less than 10 Pa. (If a 10 Pa pressure difference cannot be established, there is probably a larger air leak that has been missed that can be sealed.)



(a)

Figure 6 *(a) The fan and pressure gauge fitted in a door opening to a stairwell and (b) sealing around a door.*

- ❑ Check that the pressure difference and direction of airflow are correct by slightly opening a door or window. Air should flow in through the gap. Close the door/window after checking.

(a) (b) (c)

Figure 7 *Leak tracing using (a) a thermal imaging camera, (b) an anemometer, and (b) smoke.*

Identify the Positions of Leaks/Positions for Improvements

There are often problems with air leaks around window and door openings, joints, connections to floors, ceilings or intermediate walls, and around duct and pipe penetrations. Typical weak points are shown in Figure 2.

- ❑ Get a rough idea of the position and size of possible leaks by using your hand after starting the fan.
- ❑ Find the positions of leaks using smoke, an anemometer, or a thermal imaging camera (Figure 7). Read their instructions carefully for more detailed descriptions of how to use them. When you find a leak, take the necessary steps to reduce it or eliminate it entirely.

Thermal imaging camera. If the outdoor temperature is at least 5°C colder than indoors (and preferably 10°C), a thermal imaging camera can be used to find leaks. In some cases, you may be forced to raise the temperature in the test area for at least twelve hours before carrying out the tests, in order to create a greater temperature difference. However, as air leaks can be confused with thermal bridges, the camera should be complemented by an anemometer.

Anemometer. Place the anemometer carefully next to the position where you found an air leak with your hand and/or where you suspect that there might be a leak. Make sure that it is aligned so that any air currents flow through it. All detected leaks shall be completely sealed since it can be difficult to interpret the results and determine the consequences of a leak.

Smoke canister/smoke pencil. Use the smoke canister or smoke pencil in accordance with its manufacturer's instructions. Some types of smoke must not be inhaled, so read any warning texts. Puff smoke carefully towards the position where you found an air leak with your hand and/or where you suspect that there might be a leak. It is sometimes more suitable to use smoke for detecting leaks if the pressure in the building is positive, so that air is pushed out through the leaks. In such a case, reverse the direction of the fan.

- ❑ Turn off the fan and seal all leaks.
- ❑ Repeat the inspection by turning on the fan again (positive or negative pressure as appropriate). No air leaks should now be apparent.
- ❑ Fill out an inspection report form. This will provide feedback from the inspection, which will help work or inspections in other apartments, etc., in order to achieve good airtightness.

If necessary, repeat the inspections in several test areas/apartments.

INSPECTION REPORT FORM FOR AIR LEAKAGE DETECTION

Date:

Performed by:

Test area:

(Area, building, or apartment)

Results:

(Describe the leaks that were found and, if possible, why they occurred.)

Corrective actions:

(Describe the corrective actions that were taken and also those that remain to be done.)

Feedback:

(List any corrective actions etc. that should be carried out in other locations, apartments, or buildings. State whether leak detection should be performed in other locations, apartments, or buildings, and pass the information on to those concerned.)

This method is part of the work to facilitate the construction of airtight buildings. Another challenge, when it comes to ensuring airtightness, is the design of the details and the construction. This is investigated in the section "Good Examples of Airtight Details and Designs" below.

GOOD EXAMPLES OF AIRTIGHT DETAILS AND DESIGNS

This work is necessitated by the difficulties that designers and contractors have in ensuring airtight building envelopes. Previous projects found that airtightness was seldom given proper consideration, and also highlighted a major need for information on airtightness in general, its importance, and how an airtight building envelope can be achieved. The client has a great influence on the airtightness of a building through the formulation of requirements, and it is the responsibility of the designer and contractor to fulfill these requirements. Knight et al. (2001) describe a quality assurance program for the air barrier, divided into the different construction phases.

Our project aims at assisting designers and contractors to fulfill the owner's or developer's airtightness requirements. Particular care is taken to describe airtight details and constructions. The following steps have been made to select airtight details.

1. Literature reviews.
2. Collection of laboratory measurements of the airtightness of designs; selection of good details.
3. Interviews with airtightness test engineers, designers, and contractors.
4. Evaluation of successful building projects that have resulted in airtight buildings. In this study, most of the selected good examples are from buildings with a measured air permeability of 0.3 $L/(s \cdot m^2)$ @ 50 Pa or better. A majority of these are even better than 0.2 $L/(s \cdot m^2)$ @ 50 Pa.
5. Report with airtight details, sealing methods, and constructions. Some other factors that have been identified as important to the building airtightness are also described, such as information at the building site.

The collection of good examples of airtight details and designs (Wahlgren 2010) is divided into critical parts according to

- joints in air barrier sheet materials
- wall-to-floor connection
- wall-to-ceiling connection
- wall-to-window connection
- service penetrations

In Sweden, many low-energy houses are highly insulated wooden constructions (or lightweight steel joists), and the airtight layer is a polyethylene film placed on the inside of the construction. Only a small amount of the pressure difference occurs over the exterior wind protection (board or paper). The details shown here are some principal examples for buildings with air barriers made of polyethylene film. The details and designs for joints in air barrier sheet materials and wall-to-floor (or ceiling) connections are shown.

Joints in Flexible Air Barriers

There are several measures that can help to ensure high performance with an air barrier made of polyethylene film.

1. Minimise the number of service penetrations.
2. Make sure that the joints in the polyethylene film overlap two joists, as shown in Figure 8. The polyethylene film should preferably be placed between two solid layers (mineral wool is sufficient), so that the joint is compressed over its entire length.
3. The polyethylene film joints should be placed in line with the joists if possible. If it is not possible to have an overlap of two joists, the overlap should be at least 200 mm. The joints can be clamped, taped, or secured with double-sided adhesive material, such as mastic or butyl rubber strip (Figures 9, 10, and 11, respectively). When adhesion is needed, care should be taken so that the polyethylene film is clean and not folded. In addition, the durability of the sealing materials must be considered. A clamped joint can lose its airtightness when wooden joists dry. Consequently, combining a clamped joint with a flexible or double adhesive material ensures a good result.
4. Use double layers of polyethylene film to improve airtightness.
5. Use extra-thick polyethylene film (0.4 instead of 0.2 mm). This is particularly important when there is a risk of damaging the polyethylene film.
6. Protect the polyethylene film during the construction phase. If the sheet is damaged, it must be repaired by first surrounding the damaged part with tape and then adding an extra piece of polyethylene film over the damage. The overlap must be at least 100 mm in all directions (Figure 12).
7. Finally, the polyethylene film should be recessed into the construction when possible (see Figure 13). This way, the number of service penetrations is minimized and the polyethylene film is also protected. Care should be taken to ensure that the polyethylene film (and vapor barrier) is

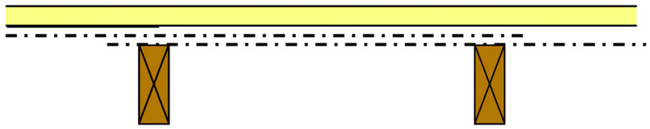


Figure 8 *Two polyethylene films overlap over two joists.*

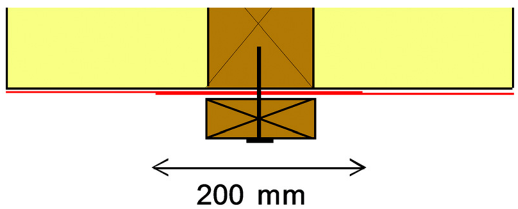


Figure 9 *Clamped overlap.*

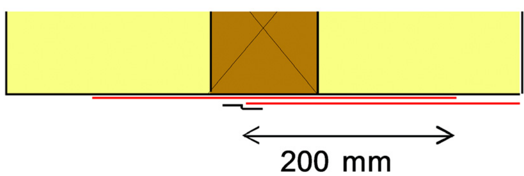


Figure 10 *Taped overlap.*

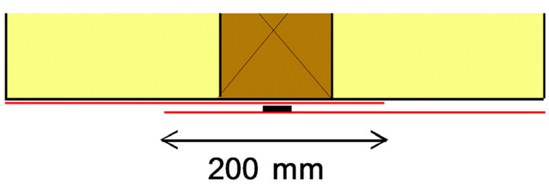


Figure 11 *Butyl rubber strip.*

not located too close to the cold side of the structure, as this can result in moisture damage. Recessing the polyethylene film is common in exterior walls and is also a good idea for roofs.

Connections

Polyethylene film is often secured to ceilings or floors by clamping. This should be complemented by a flexible and airtight seal, such as a rubber strip, extruded polyethene, or a sealing strip or double-sided adhesive strip. This applies to both light and massive structures using polyethylene film as the seal. A flexible seal is recommended for timber structures, as shrinkage of the wood due to drying can result in loss of connection

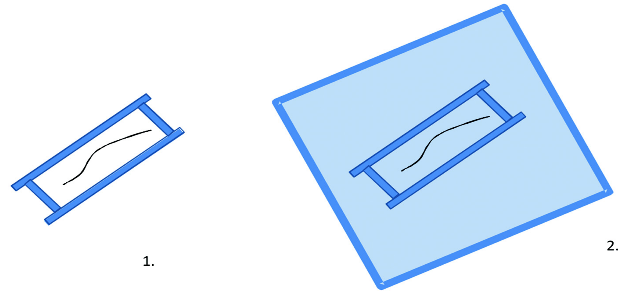


Figure 12 *Damaged polyethylene film must be repaired in two stages.*

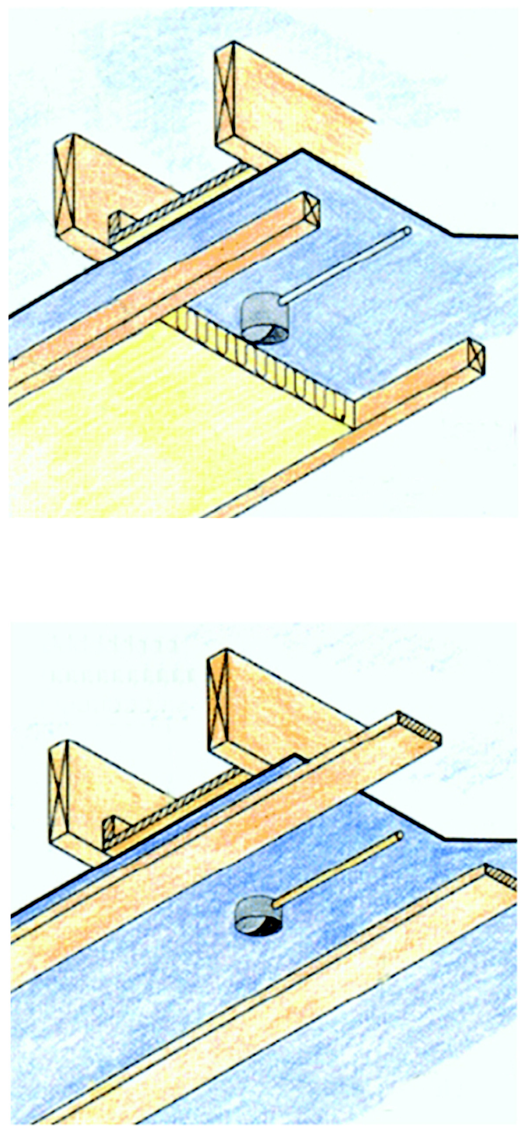


Figure 13 *A gap for the services is created by recessing the air barrier (Byg-Erfa 1997).*

pressure on the polyethylene film. Where the sheet is connected to a concrete slab, the surface of the concrete must be smooth and clean. A flexible sill seal should be applied between foundation slabs and bottom plates, as it can take up any gaps and, therefore, prevent air leakage. This means that a sill seal is intended not only to protect against moisture but also to ensure airtightness. A sill seal should, therefore, be used not only for wooden sills but also for steel joists.

As previously mentioned, the specific properties of the materials to be used must be considered so as to ensure adequate durability and that the materials do not adversely affect each other. If tape, mastic, or double-sided adhesive tape are used, care must be taken to ensure that all surfaces are thoroughly cleaned and that correct adhesive behavior is ensured with respect to the material to which the tape etc. is to bond.

Figures 14–18 show methods of connection between lightweight and massive structures together with an example of a connection in a lightweight structure (Figure 19).

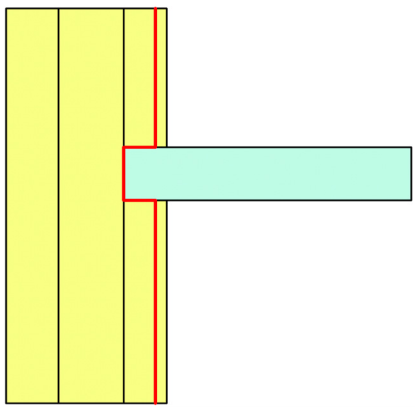


Figure 14 *A lightweight outer wall against a massive floor/ceiling structure. The polyethylene film is run unbroken past the connection.*

Figure 15 *An example of an airtight connection to the floor. The polyethylene film runs behind the services gap, underneath the steel joist (to which flexible bottom plate insulation is adhesively bonded), and is then bonded to the concrete.*

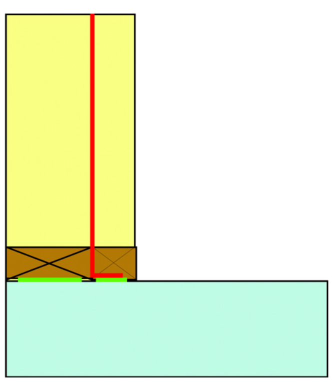


Figure 16 *Connection of a lightweight exterior wall to a concrete floor. The polyethylene film has been secured between the bottom plate and the floor. A rubber strip (green in the diagram) has also been fitted. If the sheet is clamped, the joists must be completely straight and not shrink to stop leaking air, which is why the polyethylene film is also attached to the rubber strip.*

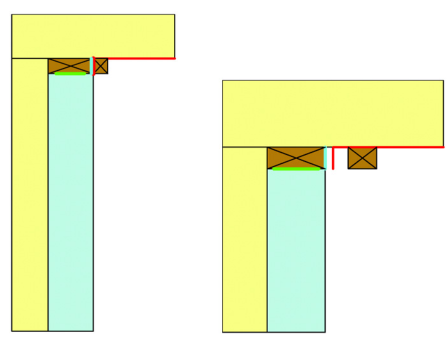


Figure 17 *A massive exterior wall connecting to a lightweight floor/ceiling structure. Here, the seal sheet in the floor/ceiling structure has been adhesively bonded to the joist using a butyl rubber strip. A flexible seal, such as one of rubber, has been fitted between the concrete wall and the joist. (The right-hand part of the figure is an enlarged drawing, with the spaces used only to show the positions of the seals more clearly.)*

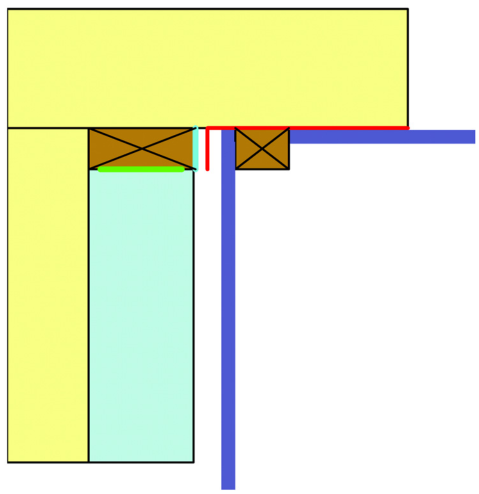


Figure 18 *Same as in Figure 17 but with electrical services installed. The batten has been cut to leave space for the electrical wiring (dark blue) in the corner. The wiring does not penetrate the airtight layer.*

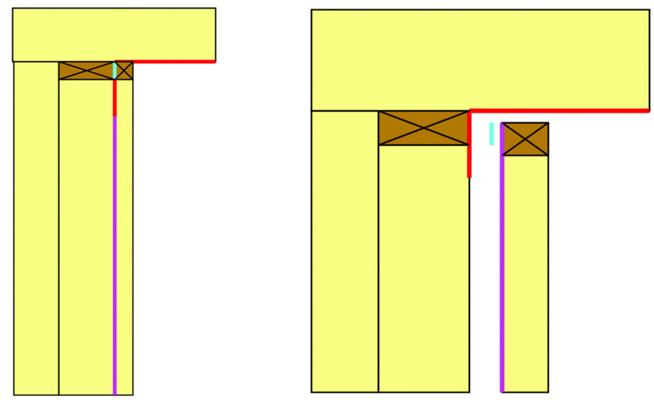


Figure 19 *Connection of a lightweight exterior wall to a lightweight floor/ceiling structure. Red: polyethylene film in the ceiling. Pink: polyethylene film in the wall. Turquoise: butyl rubber strip. (The right-hand part of the diagram is an enlargement.)*

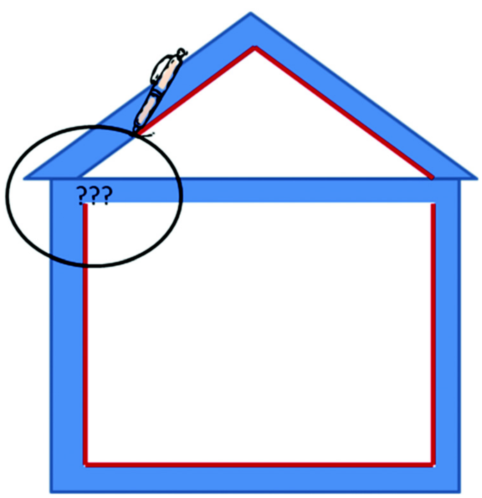


Figure 20 *Identify the continuous air barrier.*

ADDITIONAL MEASURES TO INCREASE AIRTIGHTNESS PERFORMANCE

In addition to construction details, other valuable knowledge has been gathered in the project.

First, when designing the building envelope, it is important to identify where the air barrier is (Figure 20). This is important in particular when it comes to connections between components. Questions to be answered are: where is the air barrier, how are the materials put together, and where should the joints be?

Second, describe the connections and joints. Unusual or difficult details deserve extra attention. Examine the design. Are there any difficult details? Can they be improved?

Third, raising awareness of the importance of airtightness issues during the construction phase is essential for good airtightness. Information, education, and training can be provided in many different ways. When visiting building sites/ projects where the airtightness was good, many different ways of communicating information and education were presented.

One project had an ambitious program that started with a demonstration building. In this first building, different wall designs were built and examined in order to choose the best design with respect to energy, airtightness, and workmanship, and courses for the construction workers were held. Each worker attended courses for 1.5 days in total. They also aimed to include the same workers for all the buildings in the project. The airtightness was tested using the fan pressurization method in each apartment in this project. One person was responsible for the pressurization tests, but each construction worker attended at least one test, which also included searching for air leakages.

Another project sent a number of construction workers, project managers. and the site manager on a course where they built a test wall that included a window. The construction workers who had participated were later responsible for the air barrier work and also took part in fan pressurization tests.

Information transfer can also be in the form of visits to good and airtight projects or to lectures by construction workers who have previous experience building airtight houses. An important part of education, when it comes to airtightness, is knowledge feedback. The designer can visit the building site when the building is almost finished and get feedback on the practicality of the designs and of air leakage data. There is wide variation in the level of knowledge of airtightness, so written or oral knowledge transfer to and within different groups involved in a building project is of great importance.

A fourth measure to improve airtightness is to perform air leakage diagnostics (as previously described), to measure the air permeability, and to specify a required level of airtightness. When air leakage investigation is performed continuously during a building project (for example, for each apartment), new knowledge is gained each time, and improvements in the construction and in work methods can be made.

FUTURE WORK

Our airtightness work is continued in two parts. One part concerns the durability of the airtightness details. The aim is to show how the airtightness changes over time and to show good and durable details and assemblies. Laboratory testing of materials and material combinations subjected to ageing will be made. Different material combinations require different types of ageing: this will be simulated by such means as heating, moisture, or presence of alkalis (for materials in contact with concrete). Sealing performance after ageing will be evaluated by such means as tensile testing, stiffness measurement, or pressure testing (i.e., testing air leakage). Large-scale testing is also included; buildings that have not been airtightness tested within 20 years will be tested and evaluated.

The second part of our continued airtightness work concerns the quality assurance program for the air barrier. A method is being developed with the aim to assist all those involved in the construction sector, and particularly contractor companies, to ensure that buildings meet the functional requirements that have been specified. Properly formulated functional requirements and a construction process that includes quality assurance will improve the conditions for ensuring delivery of an airtight building.

ACKNOWLEDGMENTS

The work has been financed by the Swedish Energy Agency, by the Development Fund of the Swedish Construction Industry (SBUF), and is supported by FoU-väst (part of the Swedish Construction Federation), which is greatly appreciated.

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