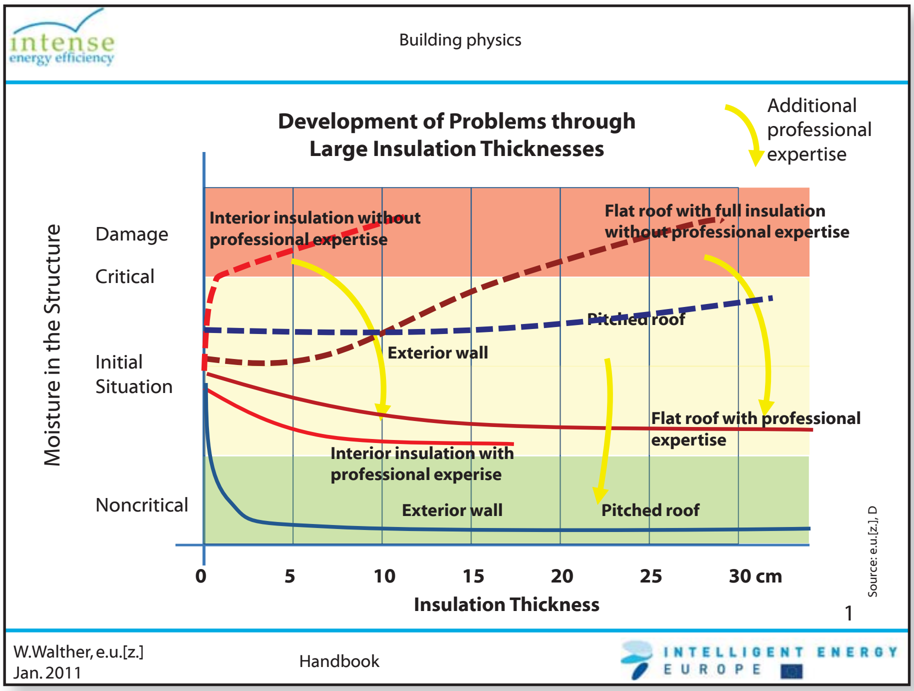


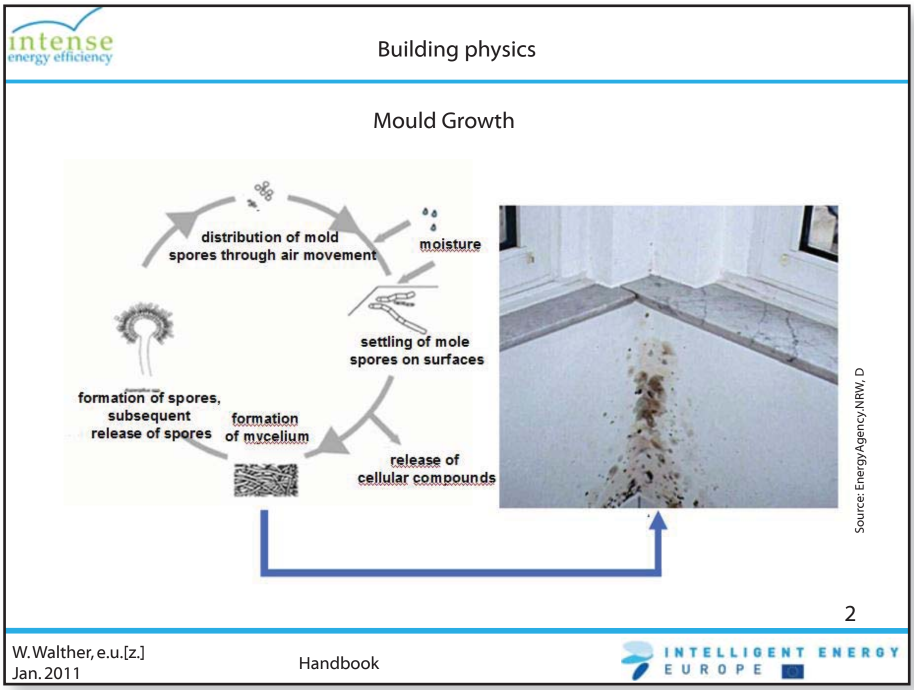
Despite large insulation thicknesses, the building envelope of the passive house can be implemented without any risks. However, this requires professional expertise with regard to mould prevention, thermal bridges, diffusion, and airtightness of the building envelope. The large insulation thicknesses of the building envelope differ in their impact on the moisture behaviour within the various structural components.

Exterior insulation and basement ceiling insulation cause the least problems. Exterior walls and pitched roofs in all systems of solid construction, wood construction, wood product boards, insulating materials, and exterior plasters are extremely durable. They can be installed in such a way that the structure remains dry and damage free. The only risk is in providing insufficient airtightness. The issue of airtightness has therefore gained special importance in building physics.

In the case of flat roofs, which cannot be ventilated because of their large insulation thickness, damage often occurs due to improperly dimensioned vapour retarders and the lack of airtightness. Professional expertise is very important in these cases.

As far as interior insulation is concerned, many critical issues need to be addressed that otherwise can easily result in damage, unless professional expertise is applied. The example of interior insulation is well suited to discuss the problems associated with thermal bridges, diffusion, and airtightness of the building envelope and how they can be avoided by installing the materials properly.

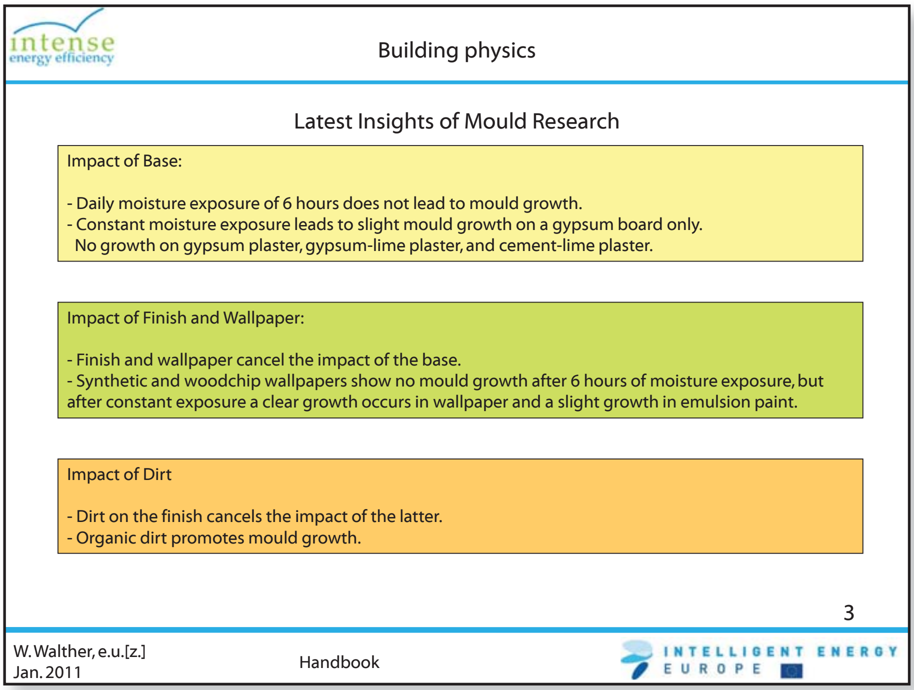
All efforts concerning the proper installation of materials focuses on avoiding moisture in the structure and thus mould growth.



Mould-like fungi belong to the microorganisms. They reproduce by producing numerous spores, which are ubiquitous. When appropriate climate conditions are provided, spores mature and form a mycelium. Food intake, metabolism, and reproduction take place there. Food consists of carbon and water. Carbon can be found in such materials as paint, adhesives, wallpapers, wood, etc., but also in fibers, dust, soap remnants. After a certain time period, fruit bodies grow from the mycelium, and the mould becomes visible. Then the fruit bodies produce spores that are dispersed through indoor air.

The photo to the right shows an outer corner with obvious mould growth. The growing conditions are reached only in the lower corner, and they are rather clearly defined. In the wall area away from the corner, the conditions are not reached and no fruit bodies are formed.

Mould growth is directly linked with indoor air humidity and surface temperature. The lower the surface temperature of the wall, the higher the moisture level in the surface of the building component. Mould spores are natural allergens. After repeated contact, they can trigger allergies in susceptible people.



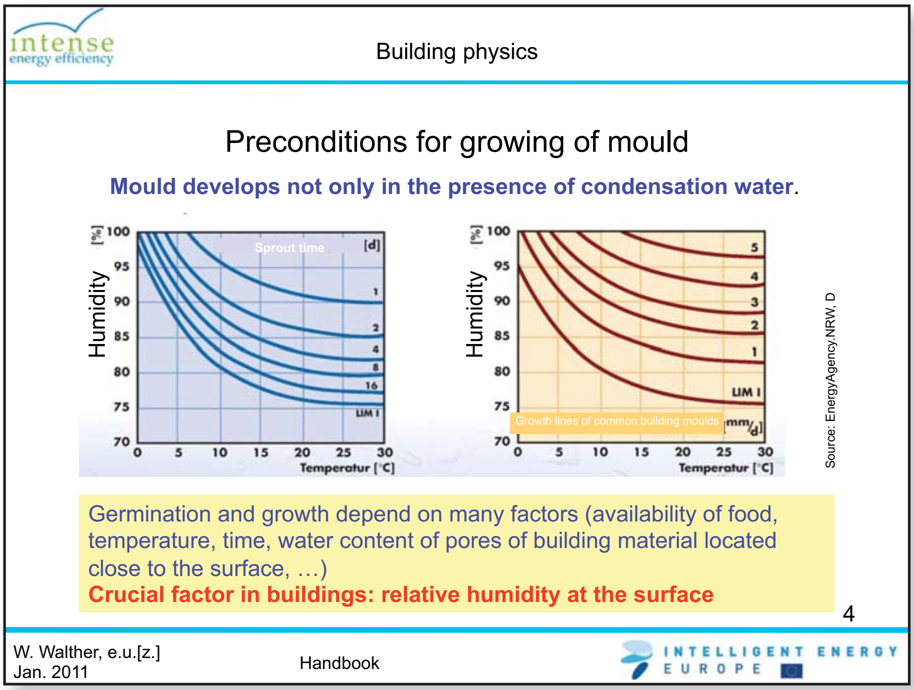
In order to avoid mold growth in buildings, we need to know its growing conditions.

In the figure above, the term "base" refers to materials that are newly installed or free of dirt. Surfaces of alkaline materials provide poor growing conditions.

A "constant moisture exposure" is equivalent to rel. air humidity levels above 80% air humidity.

Any finish contains "organic" compounds as a basic food source for mould growth. Fungicides in surface treatment systems have a "fungicidal" effect, which in most cases lasts only for a short period of time. Some months later, the active ingredient will have diffused into the indoor air.

Mould growth often occurs in locations where considerably more dust layers have accumulated. This is often the case on materials with great surface roughness or in hard-to-reach areas such as corners and edges. Mould growth, however, is also observed on smooth surfaces when the surface is a food source (soap remnants, oil film, aromatic substances).



Mould germination and growth rate depend on the temperature, but especially on the relative humidity of the surface of a given material. To be safe from mold growth, relative humidity levels need to be at least below about 75%. At temperatures of about 10 °C, the growth conditions are achieved at 80% r.h. (see graph).

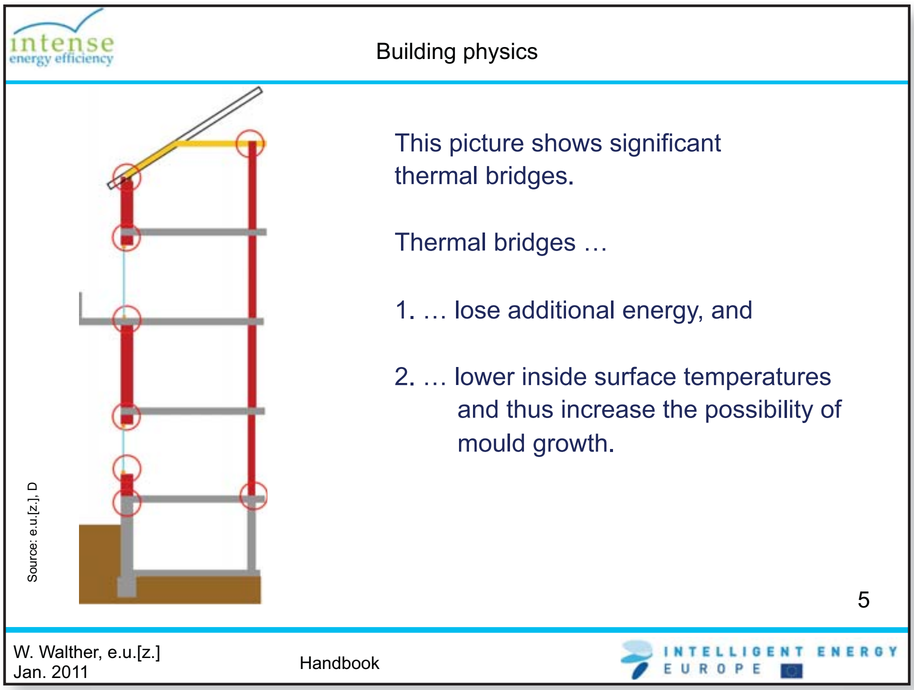
The mold growth remains dormant when the climate conditions are dry. Whenever (again) the growing conditions are reached, mould continues to grow. Owing to this special feature of mould, it can take very long before the mould becomes "visible."

Short-term moisture peaks are not an issue. Favorable growing conditions must be reached for more than 3 h/day in order that mould continues to grow.

At a given indoor temperature and relative air humidity of e.g. 20°C and 50% r.h., air humidity levels will be higher than 80% r.h when temperature levels fall below 12.6 °C.

The causes of mould and how to avoid them can be broken down into 6 topics.

1. Increase of Wall Temperature: exterior insulation, interior insulation, continuous heating. Do not allow rooms to become cool. Do not place furniture in front of outside walls.
2. Promote Low-Moisture Conditions: Ventilate for short periods of time and with open windows. Turn on ventilation system. Use space dehumidifier.
3. Prevent Moisture Sources: Do not dry laundry indoors. Cover aquarium (hamster instead of fish). Take a shower away from home. Cook with lids on pots (eat out). Cacti instead of palm trees.
4. Reduce Building Moisture: Protect construction site from rain. Do not use water-absorbing materials.
5. Ensure Airtightness of Building Envelope: Prevent leaks in membranes (especially in roof area). Seal around penetrations through membranes.
6. Miscellaneous: Use anti-mould finish. "Create" alkaline surfaces.



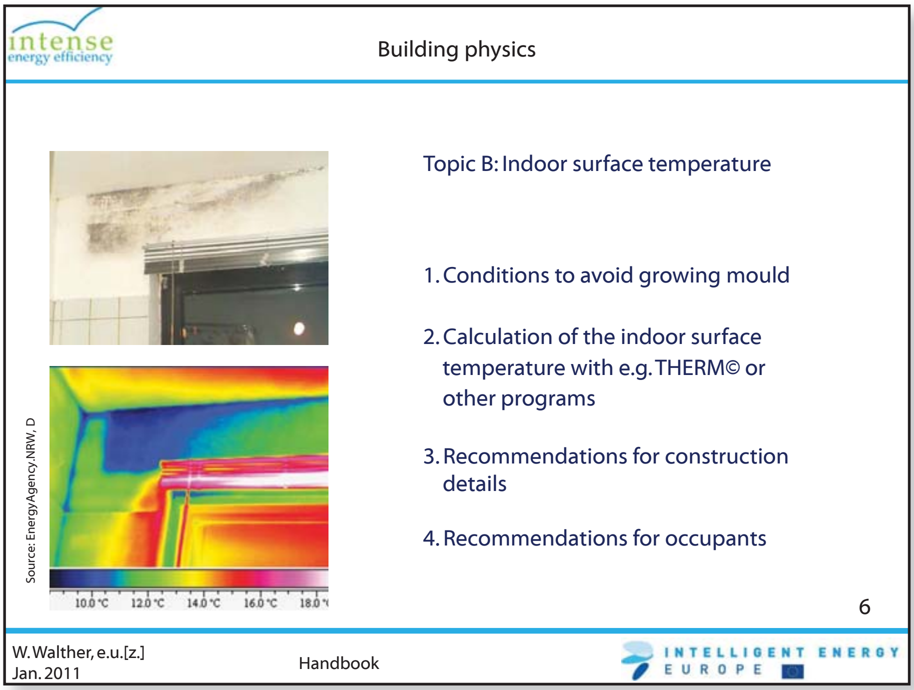
There are two reasons why we have to calculate and avoid thermal bridges. The additional energy requirement can be about 10-20 kWh/m^2.The inside surface temperature can be less than 12°C.

The building envelope of a passive house needs to be designed and installed in such a way that the impact of all thermal bridges are kept as minimal as possible. For a passive house this means: There are (almost) no thermal bridges!

Thermal bridges are avoided by covering all areas where building components are connected to each other with additional insulation, by not installing cantilevers (balconies), and by using load-bearing materials with minimal thermal conductivity (lambda < 0.13 W/mK).

Facts

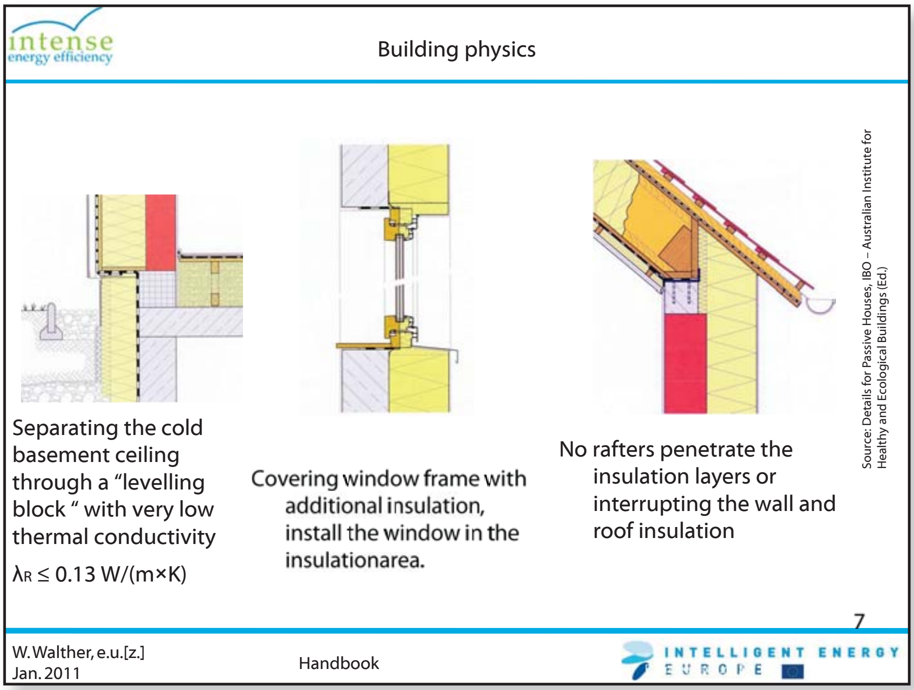
- In new construction it is easy to prevent thermal bridges.
- Exterior insulation eliminates a wide range of thermal bridges.
- Remaining thermal bridges in exterior insulation as well as interior insulation are acceptable concerning energy savings.
- Energy retrofitting of existing buildings is economically feasible despite the thermal bridges.



The two images show the same situation; the top one is taken with a normal camera and the bottom one with a thermal imaging camera.

The thermographic image shows in the temperature legend from green to blue an area of ca. 11°C ± 0.5°C.

It is interesting to note here that mould grows within a very small temperature range or not. More about this in the module "Avoiding Mould".

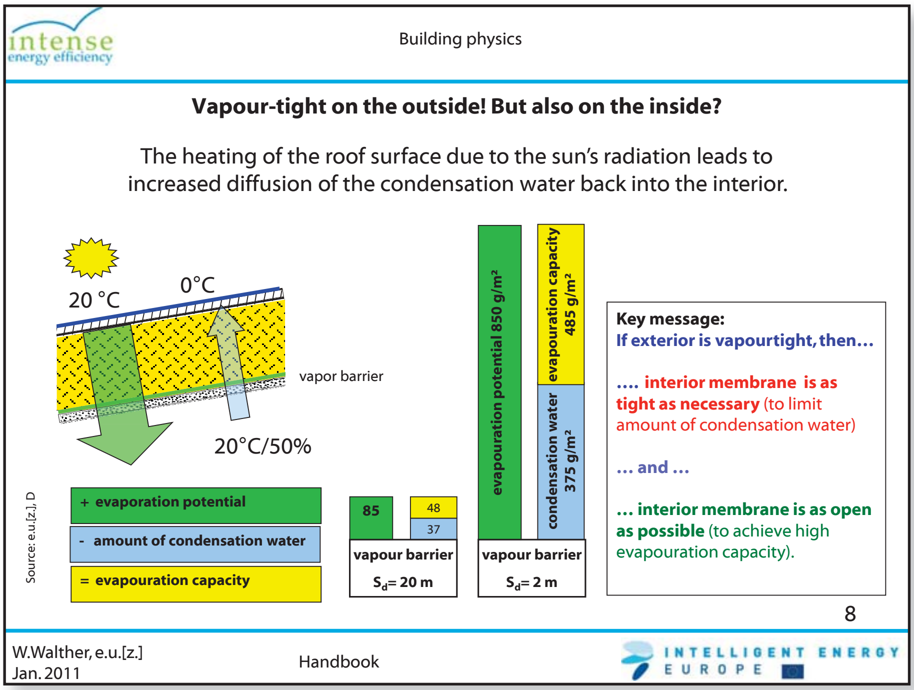


Passive house construction is easy to realize.

- Separating the cold basement ceiling through a "levelling block " with very low thermal conductivity

$\lambda R \leq 0.13$ W/(m×K)

- Covering window frame with additional insulation
- install the window in the insulation area
- No rafters penetrate the insulation layers or interrupting the wall and roof insulation



If structures open to diffusion on the outside, they are free of risk! But if they are vapourtight on the outside?

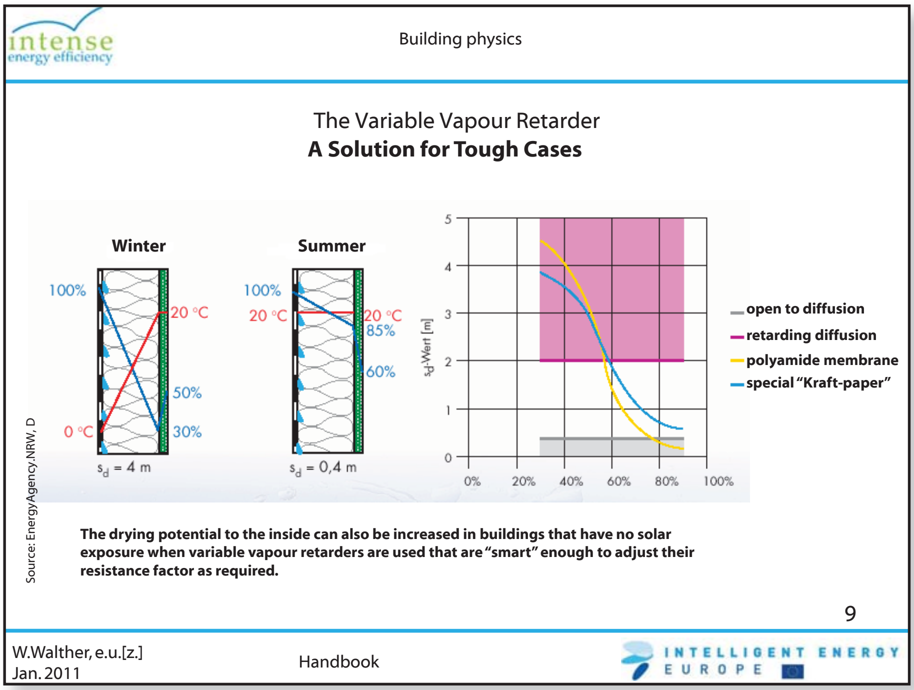
In flat or low-slope roofs without any ventilation between insulation and exterior membrane (watertight bitumen membrane and wood sheathing), condensation water caused by diffusion occurs at the wood sheathing during the winter season. In order to keep this water at a minimum, often an interior vapour barrier with a high resistance factor is chosen.

In the example above, vapour barrier has an sd-value > 20 and the amount of condensation water is only ca. 37 g/m2. At the same time, the possible evapouration potential during "summer" will be very small. Only ca. 85 g/m² can pass through the vapour barrier to the interior during summer.

If a vapour barrier with an sd-value of 2 m instead of 20 m is chosen, the amount of condensation water increases to ca. 365 g/m², but the maximum permissible value has not been exceeded yet (500 g/m² or 5 as mass percentage in wood sheathing). In comparison to choice 1, the potential amount of evapouration with 850 g/m² is higher by a factor of 10 and thus the structure has a higher "evapouration capacity". The structure is more "moisture safe".

If the structure becomes moist because of e.g. leaks and airflow from the inside during winter, this water can now move to the interior "without any problems."

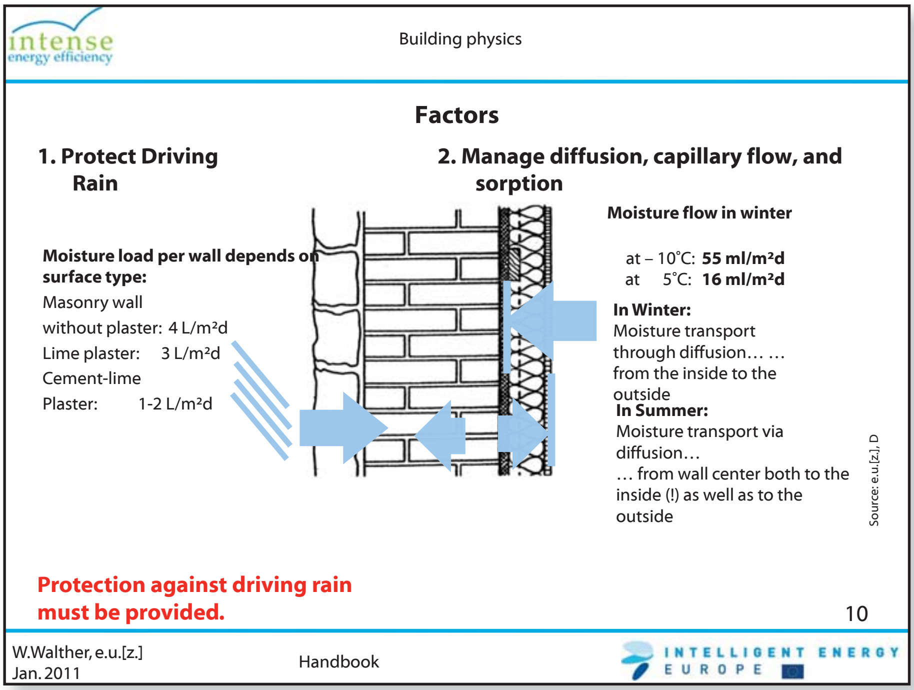
The driving force for the "back diffusion" is the increased surface temperature on the roof caused by the sun's radiation. The moisture of the wood sheathing moves to the cooler side of the structure, that is to the inside, and the structure dries out.



Many building materials have an sd-value independent of relative humidity. They are shown as a horizontal line (color column) in the figure. Wood and wood products, vapour retarder membranes based on paper as well as polyamide membranes and polypropylene liners change their sd-value depending on the relative humidity.

In winter, condensation water occurs at the sealing membrane of a structure with an exterior vapor barrier (left in above figure); the relative humidity is 100% r.h. The temperature increases toward the interior to 20°C in the insulation and the rel. humidity drops to a level of 30% r.h. The sd-value of the vapour retarder responds to the surrounding air humidity (ca. 40% r.h.) with a value of 4 m (yellow curve in graph).

In summer (solar exposure), the water on the now warm side evaporates and increases the air humidity in the insulation and in the wall assembly up to the vapour retarder to 85% r.h. The vapor retarder responds with an sd-value of 0.3 m, letting the water vapour pass through. All vapour retarders up to 0.3 m are considered to be open to diffusion; above this value they are considered to retard diffusion. Only from the sd-value threshold >100 m, they are called vapor barriers.



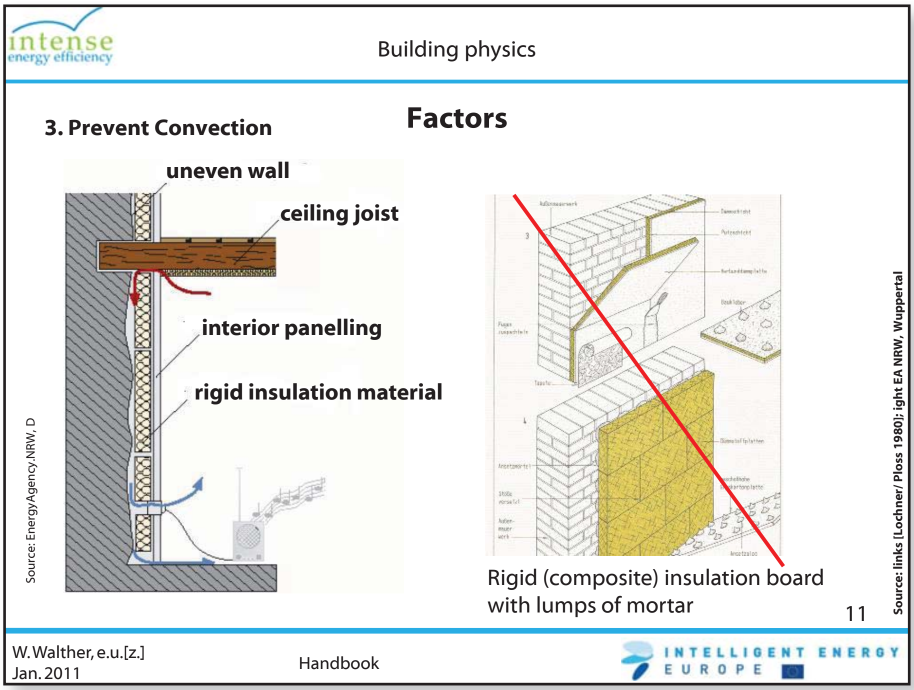
In general the interior insulation of exterior walls increases the moisture content of the exterior wall. Therefore it is important that the exterior wall is protected on the outside against driving rain. Since exterior walls can take up a great deal of rainwater this is a risk for interior insulations.

An important rule: **Protection against driving rain must be provided.**

A look at the exterior wall from the inside:

The interior insulation prevents the solid wall from heating up during winter. The surface temperature of the interior insulation is sufficiently warm to the inside but the solid exterior wall is cold. The water vapour moves from the warm side through the interior insulation to the cold outside. The amount of water vapour is low, and usually an accumulation of moisture in the solid exterior wall does not occur.

During summer the effect works the other way around: the water vapour moves from the humid, warm exterior wall through the interior insulation into the indoor space. If there is a vapour barrier on the inside of the interior insulation, there will be a problem. The water vapour can cause moisture in the insulation material and on the vapour barrier. In certain circumstances a vapour barrier can be dangerous.



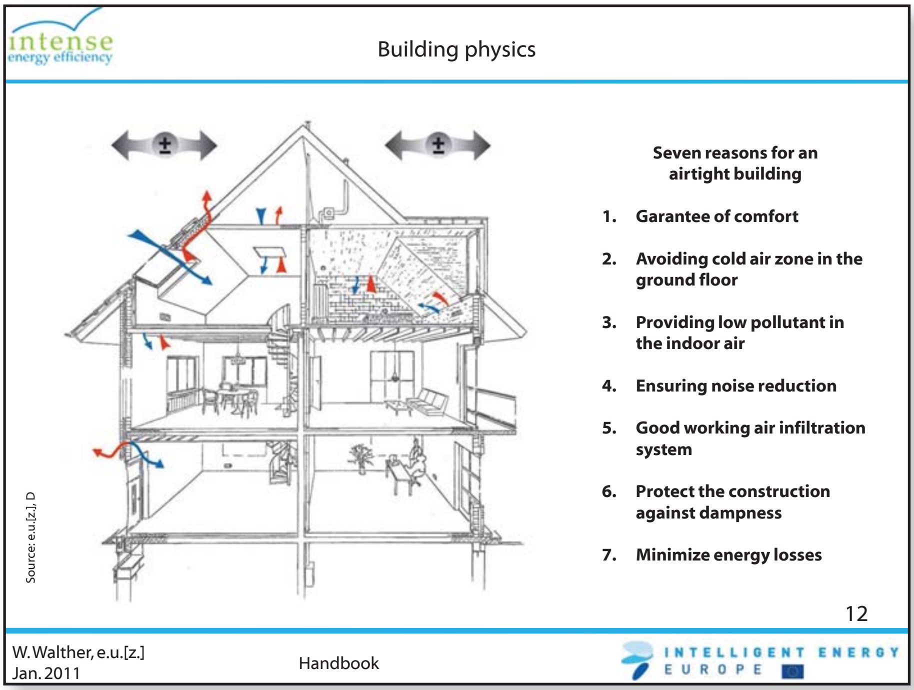
Removal of an old interior insulation made from gypsum board an Polysyrol, 5 cm thickness, shows some areas where mould has grown behind the insulation. The causes are quickly identified.

The interior insulation was attached with lumps of plaster to an uneven wall and leaving a gap. As a result warm (humid) indoor air flowed behind the insulation. The cold cavity becomes moist and mould starts growing. Conclusions for a risk-free insulation:

Avoid cavity between interior insulation and wall - Avoid airflow through a sealing layer.

There are many ways to plan and carry out an interior insulation. Many decision have to be made. Depending on the type of interior insulation system, other preparatory work has to be done and other decisions have to be made.

Remove windowsills - Move radiator unit - Fill recess alcove of radiator unit with solid masonry - Remove wallpaper - Remove plaster? - Remove old paint - Remove gypsum plaster - Improve base, adhesion - Extension of wires - Heating pipes insulated where facing exterior wall - Clarify details of ceiling connection - Clarify details of wall connection



Garantee of comforttableness: Through leakages cold air flows from outside into the building and causes draught. Draught can appear among others at windows and exterior doors but also at sockets.

Cold air zones: Even without the impact of wind, air flows out of the building envelope n the upper stories. Cold outside air flows coeval in the lower building zones. As the cold air is heavier than the inside air it arises a cold air zone at the ground. The effect: cold feet.

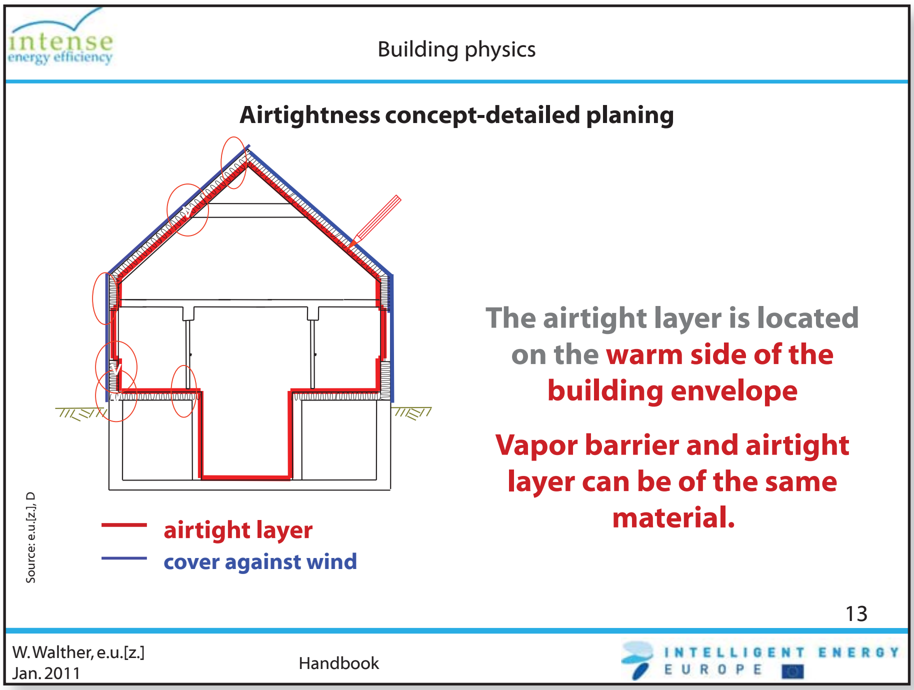
Avoiding pollutant entry: If indoor air flows through cavities in the construction the terms of growth of mildew and micro organism can be supported by the moisture (indoor air condensate in the void).

Noise insulation/protection: Noise protection is only achievable by tight joints and junctions of structural components.

Efficient working Ventilation system: A great advantage of ventilation systems (even simple exhaust-air units) is the constant and predictable air supply, the ventilation inside the building and the air removal. Outside air enters in living rooms and bedrooms (rooms with incoming air) and will transported outside in kitchen, toilet and bathroom (rooms with outgoing air). An airtight building envelope is essential for this, because leakages in the building envelope trouble the susceptible airflow. Air circuits/drifts can cause that some zones are not ventilated.

Protect the construction against dampness: Warm humid air goes into the insulation, condenses at cold zones in the construction and causes damages (dampness)

Minimize energy losses: If the air exchange per hour is - in case of leakage of the building envelope - about 0.3 [1/h] higher, the need for thermal heat will increase in the next 50 years about 15,730 m3 natural gas or liters fuel.



The required airtight envelope should be regarded in the choice of the building construction already in the stage of draft.

Similar to the thermal building envelope this layer must surround the entire heated building zone without any leak or other discontinuity at any building component.

In a multiple family dwelling the airtight layer serves the purpose to separate each apartment of the other and of the stairwell in an airtight way.

In the picture is shown a cross-sectional drawing of a building:

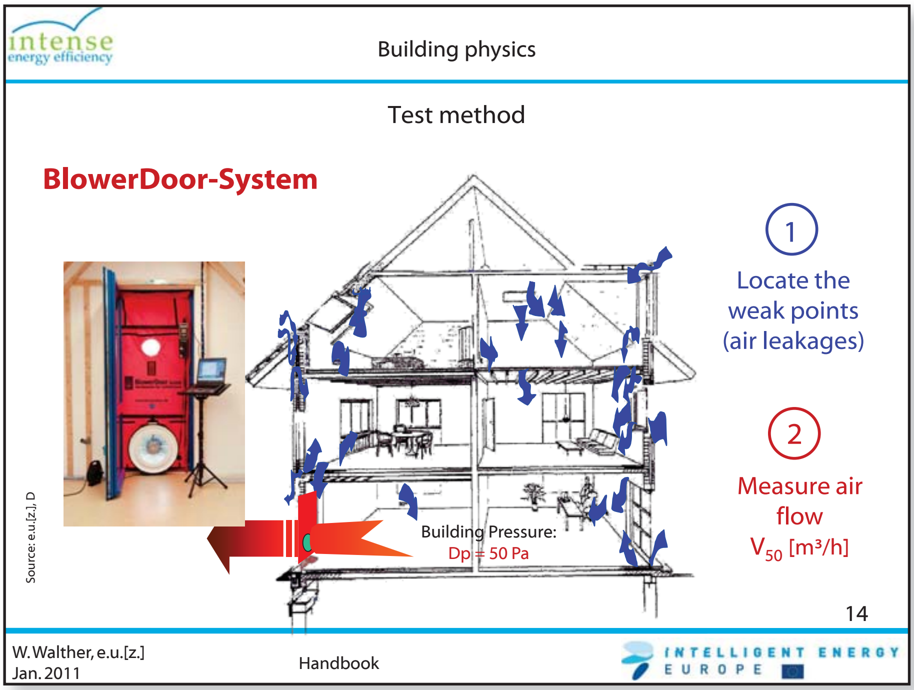
The airtight layer must be build in a way, that it could be drawn as a continuous line without any interruption around all construction components.

The airtight layer corresponds in most cases to the interior plastering of the outer walls and in the roof area to the vapour barrier on the inside.

It is important to lay this membrane in a second level behind the gypsum board.

Thus it is eliminated, that cables and tubular feed through demolish the airtightness.

It should be used suitable materials for building airtight envelopes of notable producers, who offers compatible adhesive tapes and adhesive pulp in cartridges.



We check the quality of the air tight layer with the BlowerDoor system. A fan will be installed in the opening of an external door. With help of an adjustable aluminium frame with a nylon sheet and an opening for the fan, it is possible to fit it tightly in the door frame. Pressure measuring devices are installed to measure the differential pressure between inside and outside as well as the transported airflow rate.

The fan sucks air out of the building until the difference in pressure is 50 Pascal. During the time that the fan runs, air flows through gaps and holes that are in the building envelope. This leakages can easily be located. At the end of the test, the BlowerDoor-System measures the airflow at 50 Pascal and calculates the air change rate per hour. Software evaluates the gained dates and determines the parameters.