Moisture Behavior of Building Insulation Materials and Good Building Practices

Hannu-Petteri Mattila
Paroc Group Oy

Abstract

The moisture behavior of building insulation materials was evaluated in an experimental laboratory study. The study included stone and glass wool, EPS, PIR, phenolic foam and cellulose insulations, and measured the moisture binding properties of these materials with different mechanisms as well as the recovery of initial material properties after drying. All the examined insulation materials absorb water when exposed to moisture, although with significant differences in wetting and drying capacities. Moisture absorbed in insulations always has some degree of adverse effect on both thermal insulation capacity and surrounding structures. It is important to secure a continuous dry chain with appropriate protection of building materials, allowing drainage of structural moisture by designing structures with drying towards the exterior. For instance, the drying of concrete structures can be sped up by using diffusion-open building insulation materials. A tight vapor barrier again will efficiently prevent water vapor diffusion from the interior into structures during the service life of a building. Wet building materials, caused for instance by damage, always have to be dried or exchanged regardless of material.

1. Introduction

In recent years, particular attention has been paid to moisture management on building sites during the construction period and also to long-term practical moisture properties of structures. In 2016-2017, VTT Expert Services Oy was assigned to conduct an extensive experimental study on the moisture behavior of insulation materials [1]. The comparative study included stone and glass wool, EPS, PIR, phenolic foam and cellulose insulations and measured the materials in terms of hygroscopic properties, water absorption in partial immersion, water absorption by diffusion and capillary water absorption as well as specific properties related to thermal insulation capacity. Also the drying of wet test specimens was monitored. The measurements made under laboratory conditions in principle correspond to the wetting and drying of materials in practical situations.

Moisture can be transmitted into insulation materials or an insulated space in the form of water vapor, liquid water or in solid form as snow. As air always contains water vapor, air movements in the insulated space also transfer water. An appropriate water vapor barrier on the interior surface of the structure prevents moisture transfer from interior air into the insulated space. On the exterior, the insulation layer is protected by roof covering and cladding. Hygroscopic materials bind moisture also from exterior air, which always is in contact with the insulated space. An understanding of water vapor movements is essential for the understanding of vapor condensation behavior and the prevention of uncontrolled condensation [2]. Insulations may be exposed to liquid water for instance during rain or concrete casting in the construction phase, or at a later stage due to construction damage or faults. Also snow can penetrate into insulated spaces by the wind. Moisture accumulation in structures can be prevented by proper protection of building materials and by ensuring that gained structural moisture is dried out by designing structures with drying towards the exterior.

2. Tested materials

Table 1. Material properties [1].

Material	Abbreviation	Density, measured (kg/m^3)	Thermal conductivity at 10 °C, measured (mW/(m*K))
Stone wool, low-density	SW, LD	30	36
Stone wool, high-density	SW, HD	94	35
Glass wool, low-density	GW, LD	14	36
Glass wool, high-density	GW, HD	71	35
PIR	PIR	31	21
EPS	EPS	15	31
Cellulose insulation slab	Cell.	38	40
Phenolic foam	PF	37	19

The general properties of materials used in the VTT study are listed in Table 1. All results presented in this article are as such applicable only for the tested materials. When analyzing the results it is to keep in mind that there may be differences in the properties also within the material groups.

3. Total moisture bound in insulation materials from air and its effects

Moisture from air bound in building materials can be estimated using equilibrium conditions (relative humidity, temperature) determined in accordance with standard EN ISO 12571. The results are presented as so-called moisture sorption curves describing the moisture content in both absorption and desorption conditions, where the equilibrium condition is changed from dry to more moist and vice versa. Figure 1 presents the equilibrium moisture content of the various materials at 75% (absorption) and 98% relative humidity measured at a temperature of 23 °C [1]. The measurement results correspond to conditions where the insulation materials are exposed to air humidity, but are not in contact with liquid water. In Finnish outdoor conditions relative humidity varies from 60-70 percent in summer to approximately 90 percent in winter months. Figure 1 shows the amount of moisture bound in the insulation materials in the first phases of wetting and in extremely high relative humidity.

There are substantial differences between the examined materials. When analyzing the significance of the differences, it is essential to remember that the basic function of thermal insulation in structures is to reduce thermal conductivity of the structure. High amounts of bound moisture weaken the thermal insulation capacity of materials. For instance, for cellulose insulations literature [3, 4] mentions a 1.5 % increase in thermal conductivity for each moisture percent. Also biological activity and the risk for structural corrosion increase with growing moisture content in materials.

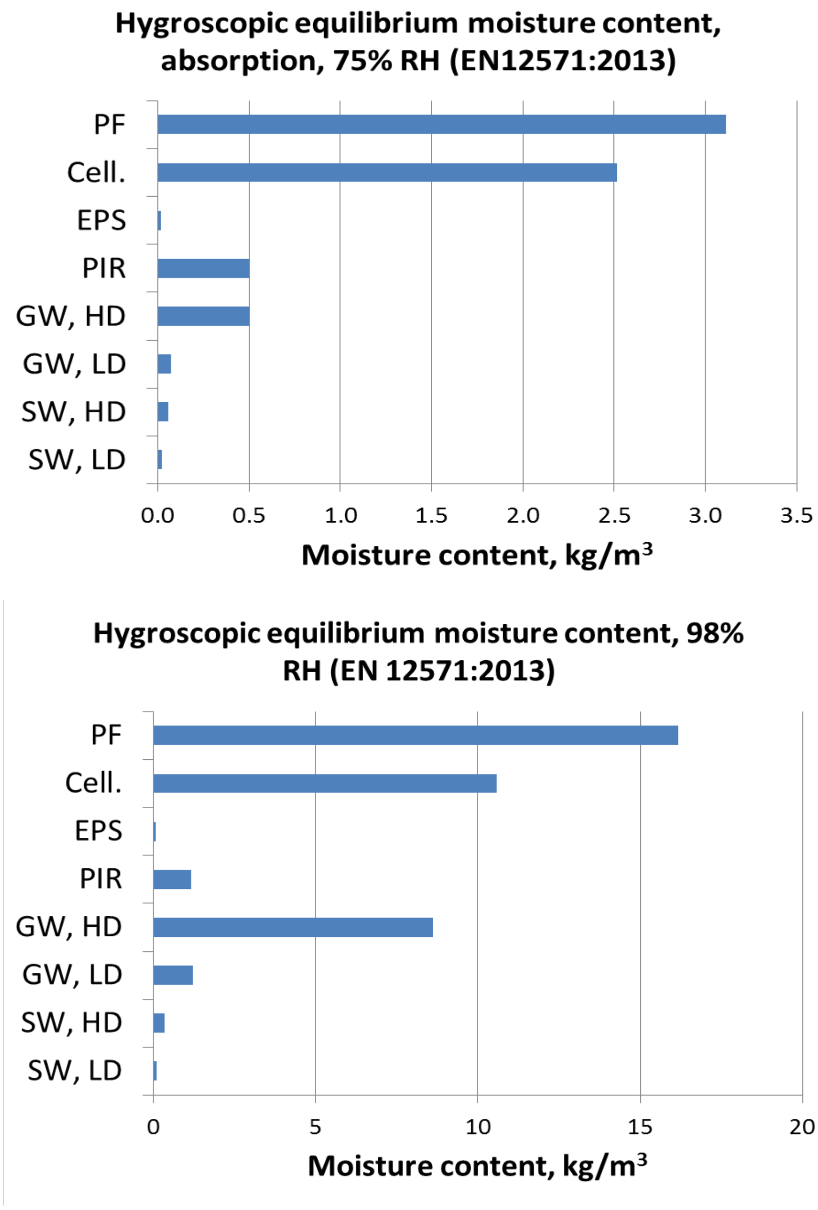

Figure 1. Equilibrium moisture content of materials, calculated based on measurement results in report [1].

4. Wetting and drying of insulations as a function of time

4.1 Partial immersion (EN 12087)

Water absorption in insulations with partial immersion corresponds to, for instance, conditions where an insulation package or insulation installed on a flat roof is exposed to rain.

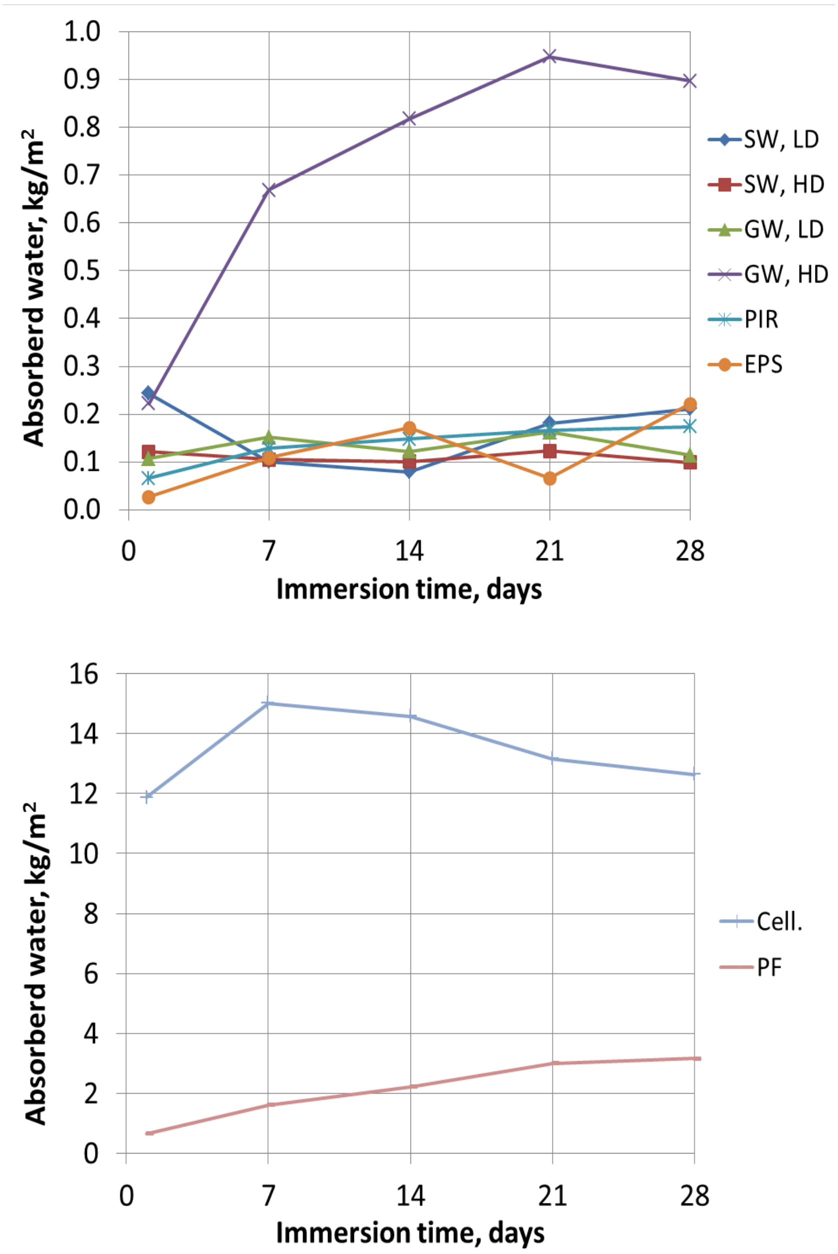

Figure 2. Water absorption in insulation materials with partial immersion (EN 12087, method 1) as a function of time [1].

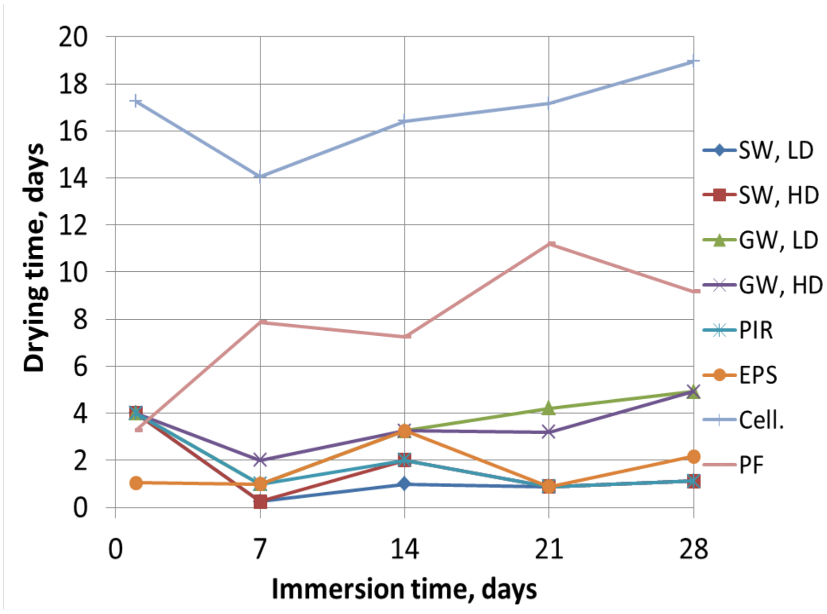

Figure 3. Test specimen drying time after partial immersion test as a function of time [1].

There are substantial differences between the examined insulation materials both in terms of absorbed amount of water (Figure 2) and in drying time back to initial moisture (Figure 3). Stone and glass wool have open-pore structures and water quickly fills the fiber structure, but with the exception of high density glass wool, the amount of absorbed water does no longer increase after seven days. As regards plastic insulations, PIR and EPS behave practically the same way as mineral wool insulations; they absorb moisture somewhat slower, but approximately the corresponding amounts (stone wool, low-density glass wool, PIR and EPS <0.3 kg/m^2, high-density glass wool <1 kg/m^2). Phenolic foam and cellulose insulations accumulate considerably more moisture than the others (phenolic foam up to 3 kg/m^2 and cellulose insulation up to 15 kg/m^2). The measurement results for phenolic foam indicate that 28 days' testing time was not sufficient and that the water absorption might continue. Thus for phenolic foam the test should be renewed with a longer testing period.

After the four-week immersion test stone wool, PIR and EPS were dry after drying at +23 °C and 50 % relative humidity for 1-2 days and glass wool after drying for 5 days. The drying time for phenolic foam was approximately 9 days, whereas cellulose insulation needed 19 days to dry. The significance of time differences would presumably grow if measured in enclosed structures.

The thermal conductivity of the materials was measured both before and after the partial immersion test. Within the measurement accuracy limits, all materials showed a result corresponding to the initial one also after the immersion test. The thermal conductivity of the materials thus returns to its initial level, if the materials can dry out freely and for a sufficiently long time. The dimensional stability of the materials was estimated by comparing percentage changes in test specimen length, width and thickness after the 28 day immersion test. Measured changes in width and length were <±0.1 % (<±4.0 mm). Changes in thickness were below ±2.4 % (<±2.1 mm). In the immersion test only cellulose insulation (-1.6 %) and PIR (-0.7 %) showed shrinkage in thickness. Insulation material shrinkage could weaken the thermal insulation of structures by creating air gaps in the insulation space.

4.2 Capillary water absorption (EN 480-5)

Capillary water absorption into insulation can be a significant wetting mechanism mostly in structures placed directly against ground, where all the tested materials are in general not used. However, Figure 4 shows measurement results for all materials. This property was examined using a measurement method developed especially for measuring capillary water absorption, although the partial immersion method presented in the section above partly measures the corresponding properties. For the insulation materials, the ranking order in terms of absorbed water amount is mainly the same in both tests (Figures 2 and 4). EPS absorbs the lowest amount of water, but with the exception of high-density glass wool, phenolic foam and cellulose insulation, the other materials are on the same level as EPS. It should be noted that phenolic foam insulations are also on the market for floor structures, although this measurement shows that they absorb significant amounts of moisture. Based on the results EPS, high-density stone wool and PIR are in terms of this criterion best suited for applications where capillary water absorption may occur.

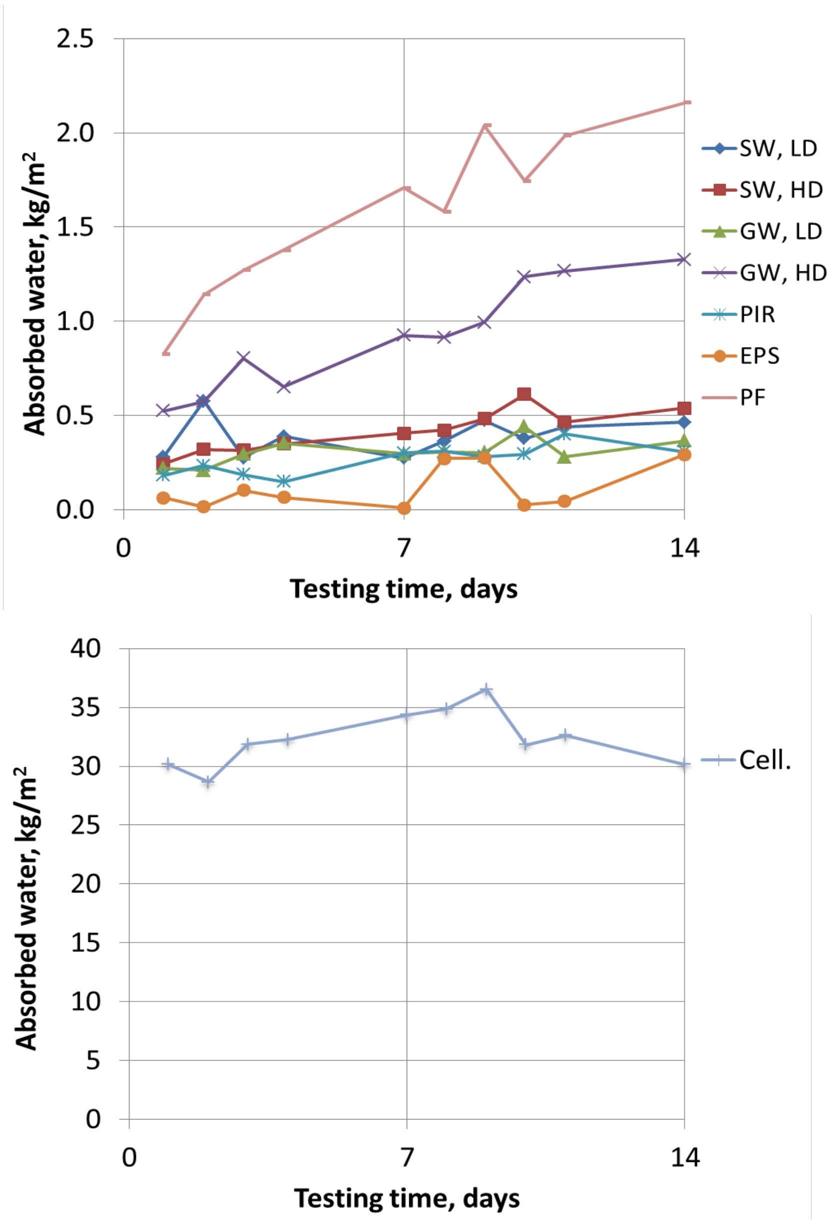

Figure 4. Capillary water absorption into insulation materials (EN 480-5) as a function of time [1].

4.3 Water vapor diffusion (EN 12088)

The partial pressure of interior air water vapor is generally higher than the partial pressure of exterior air water vapor. Consequently, diffusion transfers interior air moisture by the action of pressure from the interior out through the structures. A tight vapor barrier on the interior surface of the structure efficiently prevents the transfer of water vapor into the structure by diffusion. A test conducted in accordance with standard EN 12088 simulates water vapor transfer into insulation materials caused by partial pressure differences by using a heated water basin maintaining a temperature difference of 50 °C across the test specimen.

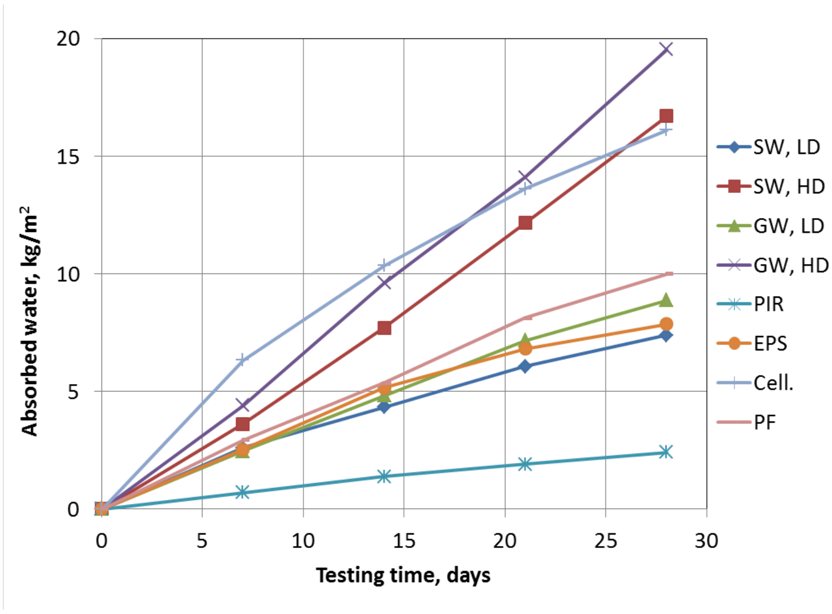

Figure 5. Water absorption into insulation materials by diffusion (12088) as a function of time [1].

The lowest amount of water vapor is transferred by diffusion into PIR insulation, which has a closed-pore structure. EPS insulation, low-density glass and stone wool and phenolic foam are approximately on the same level with each other. The highest amount of moisture is transferred by diffusion into high-density glass and stone wools and cellulose insulation. During the 28 day measurement period the amount of absorbed water grew linearly as a function of time in all materials. Although the study did not include measurements of diffusion resistance coefficients (μ) of the materials, the results are in logical order compared to the table values of the materials [5]. Diffusion-open materials like mineral wools (μ=1) are distinctly on a different level than PIR (μ=160-2000), and the other examined materials lie between these.

5. Practical impact of measurement results

5.1 Practices during construction

The measurement results presented above emphasize the significance of moisture management during construction. All the tested materials absorb moisture by various mechanisms. For instance, insulation packages unprotected from rain on site, or already installed insulations left exposed to rain for longer periods, can lead to unnecessary increase in structural moisture compared to using proper weather protection. Insulation factory packages are not in principle intended to withstand long-term moisture exposure; their main function is mechanical protection of insulation products during transport.

5.2 Structural drying and moisture equilibrium

It is important that moisture accumulated in building materials during construction is dried out as efficiently and quickly as possible. During construction, excess moisture is inevitably always present for instance in concrete structures, where drying can be furthered for instance by using diffusion-open insulation materials [6, 7]. With shorter concrete drying times, also total construction times can in principle be shortened, as the structures can be coated at an earlier stage without increasing the risks for moisture damage.

For structural moisture safety it is essential to examine indoor air, which in general contains a higher amount of absolute moisture. In most cases the partial pressure of indoor air water vapor is higher than the partial pressure of outdoor air water vapor; consequently diffusion transfers indoor air moisture from inside the structure to the outside. In diffusion, the interior wall cladding material plays the key role; it can in principle even out moisture variations in the room. A tight vapor barrier prevents adverse moisture transfer into insulations and other envelope structures. The function of building insulations is not to balance the indoor moisture conditions. In order to achieve a significant effect, insulation materials should in practice be in direct contact with indoor air [8]. Besides, additional moisture always has some degree of adverse effect on thermal insulation performance and surrounding structures.

6. Summary

Water is absorbed by various mechanisms into all insulation materials if exposed to moisture. There are significant differences in the moisture binding and drying capacities of different insulations. To ensure moisture safety in buildings it is important to ensure a continuous dry chain during construction regardless of material. The outermost layers in the roof and external walls of a building should form an adequate weather protection for insulations and load-bearing structures. Using open-pore insulations furthers moisture removal during the construction period, thereby increasing building safety and shortening construction times. In case of damage, wet structures need extensive repair in order to prevent long-term effects regardless of insulation material.

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