Degradation of wooden products used in non-ventilated flat roofs

P Juras
Faculty of Civil Engineering, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovakia

E-mail address: peter.juras@uniza.sk

Abstract. In the recent years, the amount of flat roofs with load bearing structure from wood in Slovakia increases. This is caused by the costs and the effort to maximize the speed of built. Using the wood rafter in the flat roofs cause problem of using an organic material between two vapor tight layers, from interior a vapor barrier and from outside the roofing membrane. Additional, also oriented strand boards are also used instead of wooden boards. These are used either in condensations zones of the roofs or direct under the roofing membrane. This creates degradation of the material because of use in the humid environment in very short time. This paper briefly describes the state-of-art situation in Slovakia with some examples from the buildings and the numerical evaluation of the problem.

1. Introduction
Use of wood in different products increases in the building sector in Slovakia every year. It is caused by various factors, such as the speed of the construction, or the energy efficient buildings, where the timber framed buildings have a more subtle building envelope in comparison to the traditional masonry wall with ETICS or masonry from insulated bricks.

To avoid a wet process, some civil engineers decide to use the lightweight load carrying structure made of wood, instead of the concrete slab. This causes several problems, because the hydrothermal regime of flat roof differs from the regime of pitched roof and the same composition cannot be just used in both types.

Figure 1. Flat roof with wooden rafters and OSB under the PVC roofing membrane. Total degradation of OSB caused by the condensed vapor [3].

Figure 2. Wet OSB (caused by the condensed vapor under PVC membrane) [3].
In this paper, some examples and the hydrothermal regime of selected roof, which is nowadays unfortunately used in more variants in Slovakia, are shown.

2. State of the art and Oriented strand boards
Use of wooden products in the non-ventilated flat roof is more obvious because of using the oriented strand board (OSB) in these roofs as a cheap alternative instead of other materials. OSB is a material with favorable mechanical properties which make it particularly suitable for load-bearing applications in constructions [1]. It is now more popular than plywood, commanding 66% of the structural panel market [1]. OSB is a type of engineered wood similar to particle board, formed by adding adhesives and then compressing layers of wood strands (flakes) in specific orientations. It was invented by Armin Elmendorf in California in 1963 [2]. OSB may have a rough and variegated surface with the individual strips of around 2.5 cm×15 cm, lying unevenly across each other, and it is produced in a variety of types and thicknesses. There are also five classes for use in different environment. Most used is the OSB 3 type, which should be suitable for use in load-bearing boards for use in humid conditions.

OSB boards are usually used in two positions depending on the type of the flat roofs:
- as a layer under the roof membrane (figure 1 and 2),
- as a layer on the top of rafters, with thermal insulation on top of each other (figure 3 and 4).

In both positions, its use is not recommended, because in the first case, the roofing membrane has usually a high vapor resistance, and in case of daily temperature changes, the water vapor condenses at the bottom of membrane and the surface of OSB starts to rot (figure 1, 2). In a short time period, during the normal maintenance of roof, the worker can break through into the thermal insulation.

In second case, the roof composition consists of two layers of thermal insulation, one is above the OSB, second is bellow, between the rafters. The idea, in which the roof is constructed is that in the first stage, normal flat roof composition is realized on the OSB, starting with the vapor barrier, thermal insulation and ending with roofing membrane. In second stage, in order to achieve the higher thermal resistance, additional thermal insulation is added from bottom between the rafters and another vapor barrier is added with the ceiling from gypsum board (figure 5). Usually, for lower thermal insulation is used the cheapest option, which is a spray applied polyurethane foam (PUR). This has high vapor resistance and also high water retention. Insulation also in short time becomes wet and the water starts to flow in the interior of building between the joint of the gypsum boards (figure 5 and 6). This caused the total deterioration of the OSB (figure 7 and 8) and also the rafters, but they last longer, because of their bigger dimensions and also the fact, that the massive wood has higher resistance than the OSB. High vapor amount and change of the wet/dry state increases the speed of deterioration of the boards. The glue cannot hold the strands together.
Figures 1, 2, 5, 6 are collected by the worker for the company producing the roofing membranes as results of the warranty claims, that the roof is not waterproof and has a leak. The reality showed almost every time a problem within the roof composition and the membrane was waterproof.

![Figure 5. Wet surface of the polyurethane foam. Water drops on the vapor barrier [3].](image5.png)  ![Figure 6. Collected water from the condense in foam [3].](image6.png)

3. Case study of the roof
To investigate the hydrothermal regime of such kind of roof, one representative roof for this article was chosen. The composition of this roof is shown in figure 9, and pictures from its observation are presented in figures 3 - 5 and 8. The roof survey was conducted almost after 2 years of construction of the building. Building was 3 family, two story house. Construction of the roof was as described before, in two stages, starting with wooden rafters and OSB on it. Usual problem is the fact that sometimes when the roofing workers started the work, the OSB was wet from the rain. In this case, the vapor barrier was used from foil and not the bitumen type, which should be melted to the surface and the board will be dried.

![Figure 7. View at oriented strand board after removing the sprayed thermal insulation. Growth mold and rot degradation.](image7.png)  ![Figure 8. Totally degraded OSB, removed with bare hands after nearly 2 years after construction.](image8.png)

If the roof was left with the first stage, it would work flawlessly as a simple flat roof with vapor barrier. Using the foil/plastic vapor barrier has problematic seams, so the real vapor resistance of the layer can vary. During conducting the roof survey, samples of materials for gravimetric measurement were taken. Measured water contents are stated in table 1.
Very high water content was measured in almost all layers, but especially in the PU foam. During the survey it was found out that the roof membrane was watertight, so the measured water content was not caused by the leak of rainwater.

**Table 1.** Gravimetric measurement results.

| Material               | Water content [%] |
|------------------------|-------------------|
| Geotextile             | 45.9              |
| EPS polystyrene        | 18.9              |
| EPS polystyrene        | 1.1               |
| OSB                    | 40.25             |
| Polyurethane foam      | 380               |
| Gypsum board           | 14.1              |

**4. Calculation according to the Slovak standard in the software Teplo**

In this paper, only a mandatory calculation of water vapor condensation for the roof was made, in order to find out, if this theoretical model based on the Glaser model shows potential problem of this kind of roof, or the more advanced method should be used. For the condensation calculation, two methods can be used, either the one described in the STN 73 0540-2 [4], which is season made, or the one from STN EN ISO 13788 [5], which is monthly based. There are two conditions to be fulfilled:
amount of condensed vapour \(M_{\text{condensed}}\) is less than 0.1 kg/(m\(^2\)a) and the difference between condensed and evaporated \(M_{\text{evaporated}}\) water vapor is positive.

Calculations were made in the Svoboda's software Teplo in version 2017.3 [6]. Monthly calculation of the roof is in figure 10. During the cold season of the year, water condenses in the roof, during summer some of this water content dries, but there is more condensed water than evaporated, so the roof does not fulfil the conditions and has to be considered as wrong.

![Figure 10. Composition of flat roof used for the numerical calculation.](image)

Parameters of used materials in the roof are summarized in the table 2. Because of various boundary conditions and some uncertain material properties, more cases were calculated: higher indoor relative humidity (60 instead of 50%), without middle or bottom vapor barrier, possible perforation of vapor barriers (lowered vapor diffusion resistance factor), more efficient bottom vapor layer and wet OSB layer as starting condition. All variants and results of the calculations are summarized in table 3.

Because this calculation of condensation does not reflect the ability of some organic materials to deteriorate caused by the moisture, there is analyze table (table 4), which shows number of days of the year in which the material was in some area of relative air humidity. Each material, if is exposed long enough to some specific relative humidity, is going to reach equilibrium with its sorption curve. Especially for wooden materials, high water content can cause the mold growth, rot etc.

5. Results and discussion
Results of the gravimetric measurement in table 1 show very high water content in the OSB board and the foam thermal insulation. Such a high water content caused the total degradation of the board and the polyurethane foam was completely wet.

Calculated hydrothermal cases are summarized in table 3. Simple method of calculation according to the STN 73 0540-2 showed good results in all cases, the flat roof compositions works. According to the monthly method from STN EN ISO 13788, some considered cases show a negative balance, but in some cases neither standard calculation showed possible problems.

The probable risks with non-ventilated flat roofs showed the result table 4.
Table 2. Material properties.

| Layer                  | Thickness $d$ [m] | Thermal conductivity $\lambda$ [W/(m·K)] | Vapor diffusion resistance factor $\mu$ [-] |
|------------------------|-------------------|------------------------------------------|------------------------------------------|
| Gypsum board           | 0.0125            | 0.270                                    | 17.0                                     |
| Vapor barrier lower    | 0.0002            | 0.350                                    | 600 000.0                                |
| Air gap                | 0.120             | 0.750                                    | 0.08                                     |
| Polyurethane foam      | 0.250             | 0.025                                    | 72.5                                     |
| OSB                    | 0.032             | 0.130                                    | 50.0                                     |
| Vapor barrier middle   | 0.0002            | 0.300                                    | 500 000.0                                |
| EPS 150                | 0.090             | 0.035                                    | 50.0                                     |
| mPVC membrane          | 0.0015            | 0.350                                    | 24 000.0                                 |

Table 3. Summary of calculated cases.

| case                              | $M_{\text{condensated}}$ | $M_{\text{evaporated}}$ | result | $M_{\text{condensated}}$ | result |
|-----------------------------------|---------------------------|--------------------------|--------|---------------------------|--------|
| real composition                  | 0.0209                    | 0.0592                   | pass   | 0.0344                    | positive |
| increased indoor humidity         | 0.0209                    | 0.0592                   | pass   | 0.0728                    | wet    |
| without middle vapor barrier      | 0.0396                    | 0.0966                   | pass   | 0.0603                    | wet    |
| without bottom vapor barrier      | 0.0237                    | 0.0600                   | pass   | 0.0389                    | positive |
| perforated bottom vapor barrier   | 0.0233                    | 0.0599                   | pass   | 0.0383                    | positive |
| perforated middle vapor barrier   | 0.0392                    | 0.0961                   | pass   | 0.0596                    | wet    |
| better bottom vapor barrier       | 0.0006                    | 0.0534                   | pass   | 0.0001                    | positive |
| wet OSB 0.5kg/m$^2$               | 0.0209                    | 0.0592                   | pass   | 0.5344                    | wet    |

Table 4. Number of days and relative humidity’s for individual materials.

| material            | < 60% | 60-70% | 70-80% | 80-90% | > 90% |
|---------------------|-------|--------|--------|--------|-------|
| Gypsum board        | 182   | 121    | 62     | ---    | ---   |
| Vapor barrier lower | 182   | 121    | 62     | ---    | ---   |
| Air gap             | 273   | 92     | ---    | ---    | ---   |
| Polyurethane foam   | ---   | ---    | 153    | 31     | 181   |
| OSB                 | ---   | ---    | 153    | 31     | 181   |
| Vapor barrier middle| ---   | ---    | 153    | 31     | 181   |
| EPS 150             | ---   | 92     | 212    | 61     | ---   |
| EPS 150             | ---   | 62     | 91     | 61     | 151   |
| mPVC membrane       | ---   | 62     | 91     | 61     | 151   |

The oriented strand board and the polyurethane foam are whole calculated year in the area of relative humidity above 70%, more than a half of the year above 90%. This represents around 150 kg/m$^3$ of water in the material. The results correlate with the gravimetric measurement results. OSB and polyurethane foam have a very high water content. Problem of such roof composition is a wrong placement of the vapor barrier, which creates two condensation zones. One is under the
roofing membrane and the other one is at the bottom of the middle one. The second one creates condense, which moistens the OSB surface (figure 3). Even if the composition was without the middle vapor barrier, the yearly balance is wet. The calculation will be even worse with use of roofing membrane with higher vapor diffusion resistance, such as FPO (flexible polyolefin) or bitumen membranes.

6. Conclusions
In this paper, problems with use of wooden materials in non-ventilated flat roofs were described, which is unfortunately very often in Slovakia nowadays. Flat roof composition, which was analyzed is based on the real roof, where was conducted roof survey. Results from this survey showed serious problem with this roof in very short time after construction. This is caused by the wrong design of roof and use of wooden layers in composition, where is a very small possibility of drying, because the wood is between two, in this case even among three vapor barriers.

These results were supported by the analysis of water content in selected materials during the annual calculation. In such composition, there are two condensation zones, one under the badly placed middle vapor barrier and second under the roofing membrane. Based on the survey and this analysis it is highly recommended to avoid use of wooden layers, such as OSB in the composition with minimal possibility of drying.

Acknowledgment
The research is supported by the grant project VEGA No. 1/0673/20 and KEGA 032ŽU-4/2018.

References
[1] web <https://en.wikipedia.org/wiki/Oriented_strand_board>
[2] Document US000003164511A (PDF). DEPATISnet. Deutsches Patent- und Markenamt Retrieved 2 May 2016.
[3] Mr. Pavol Krajcovic photo archive from Roof surveys, Fatra Izolfa
[4] Standard STN 730540-2+Z1+Z2: 2019: Thermal protection of buildings. Thermal performance of buildings and components. Part 2. Functional requirements Change 1 and 2
[5] Standard STN EN ISO 13788:2013: Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation. Calculation methods
[6] Svoboda software Teplo 2017.3