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THE HYGROTHERMAL ASPECTS OF FORMING THE INTERNAL STRUCTURE OF THE ROOF SLOPE

HIGROTERMICZNE ASPEKTY KSZTAŁTOWANIA WEWNĘTRZNEJ STRUKTURY SKOŚNEJ POŁACI DACHU

A b s t r a c t

The system of external, sloping construction barriers protecting the bearing structure and the building's interior from the influence of environment's adverse weather conditions is one of the crucial elements of interior's thermal and acoustic protection. The steep roof effectively protects the interior against rain, snow, and wind. Proper thermal and damp-proof protection of the attic's microclimate space enclosed by the roof plane requires the application of new materials, which permit the system to obtain technical and functional values complying with the contemporary requirements. The roof's plane structure requires the use of multilayered construction barrier functioning as an oblique outer wall.

Keywords: roof, layers, building physics

S t r e s z c z e n i e

System skośnych, zewnętrznych przegród budowlanych, chroniących konstrukcję nośna i wnętrze budynku od wpływu niekorzystnych warunków atmosferycznych otoczenia, jest jednym z istotnych elementów ochrony termicznej i akustycznej wnętrza. Stromy dach skutecznie chroni przed deszczem, śniegiem i wiatrem. Właściwa ochrona cieplna i przeciwwilgociowa, zamkniętej dachem przestrzeni mikroklimatycznej poddasza, wymaga wprowadzania w strukturę połaci dachowej nowych materiałów pozwalających na uzyskiwanie przez ten ustrój wartości techniczno-użytkowych odpowiadających współczesnym wymaganiom. Konstrukcja skośnej połaci dachu wymaga zastosowania wielowarstwowej przegrody pełniącej funkcję pochyłej ściany zewnętrznej.

Słowa kluczowe: dach, warstwy, fizyka budowli

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1. Introduction

The roof plane, functioning as an oblique outer construction barrier, has become an element of the complicated internal structure. It is composed of several layers of properly selected materials installed in a proper sequence. These layers provide thermal insulation, protect the interior as well as the roof structures against wind, external and internal moisture. They also insulate the habitable attic acoustically. This paper attempts to present the possibilities of forming the internal structure of this kind of construction barrier in connection with the hygrothermal processes that take place in it. The exchange of heat, water vapor and condensate between the environments of different temperatures and relative humidity separated by the barrier is a natural process. It is impossible to eliminate it completely. However, the excessive loss of heat from the thermally insulated interior can be significantly reduced by introducing the products and materials which poorly conduct heat in the internal structure of the barrier. The structure of the thermal insulation materials, which are applied today, can be cellular, made of grain, fibers, plates or it can combine those. These are solid substances where empty spaces between particles, fibers or plates are filled with damp air or another gas. The thermal insulation properties of empty spaces in the construction material depend to the great extent on the heat conductivity of the gas filling the pores. The right thermal insulation properties of this group of products can be formed by the porosity of the material. The mechanism of the heat flow in a damp and porous construction material, where it was assumed that no moisture migration occurs, takes place as a result of a few concurrent physical phenomena, including [1]:

- heat conducting through the material's structure, the damp air filling its pores and the capillary water adhered to the pore walls,
- heat convection through the damp air filling its pores,
- heat emission or absorption as a result of the phase transformations of water inside the pores,
- heat transfer through radiation inside the pores.

The description of the phenomena is further complicated with the assumption that water vapor diffuses simultaneously with heat exchange through the structure of a material. It can change its state of aggregation along with the change of temperature on the face of a material or inside it. The roof plane insulating the microclimatic interior can be composed of the following layers:

- windtight or watertight roofing,
- roof bearing construction, functioning as an underlay (sometimes also watertight) and as windtight diaphragm installed from outside,
- system of ventilation gaps,
- layer of thermal insulation,
- diaphragm protecting against wind and adverse effects of the water vapor diffusion,
- barrier`s internal finish.

The rafters are the elements supporting the roof planes with traditional timber framing.

2. Thermal insulation

In pitched roofs above habitable attics, the thermal insulation material is placed inside the roof planes. The application of material solution is considered effective as long as it complies with the requirements in that respect imposed by the provisions regarding the thermal insulation of buildings [2]. At present, the heat transmission ratio U for insulated roof planes should not exceed 0.25 $W/m^2 K$. It is expected that in 2020 that ratio can reach in Poland 0.12÷0.15 $W/m^2 K$. Consequently, the thermal insulation in the roofs providing protection for habitable attics, can be installed above the system of rafters, between rafters; filling the empty spaces their full height or partly their height, under the rafter. Future stricter regulations on thermal insulation of buildings shall result in the necessity of a more popular application of solutions including the use of mixed insulation systems in design practice, such as above and in between rafters or in between and under rafters. The thermal insulation should be placed in the roof plane in such a way as to provide for its ventilation.

3. Ventilation of the roof

The design mistakes and imperfections in the roof plane workmanship result in some amount of air and water vapor that can penetrate through gaps. The exchange of air and water vapor through the materials of the barrier will grow along with the increase in porosity of their internal structure. As a result of differences in pressure, caused by wind or the differences in air density around the building as well as in ventilation gaps (thermal uplift), the air filling them is in constant motion. The motion of the air in ventilation gaps intensifies the convective heat exchange. Furthermore, it provides for the water vapor, condensation water and moisture of the building shell to escape from the roof plane.

4. Ventilation air ducts

The roof ventilation is greatly affected by its construction and properties of the materials of breathable roof underlay. The roof with a layer of thermal insulation should be protected against rain water, snow or condensation water that gathers on the inside surface of roofing and which can penetrate through the roofing gaps. The condensate also forms when the water vapor diffusing through the structure of the barrier reaches the state of complete saturation. The ventilation of the roof also alleviates the effects of excessive roof overheating caused by the absorption of direct and diffuse solar radiation. The most effective method of elimination of excessive moisture of the internal structure of the barrier is the removal of the excess of water vapor and condensate by its efficient ventilation. The air flowing through the ventilation gaps carries out the excess of moisture. Drying its interior, it improves the thermal insulation of the structure. The most susceptible places in the barrier are considered to be those where a lot of condensation water can gather as a result of insufficient airing. The ventilation of a thermally insulated pitched roof is composed of a system of air gaps below the roofing layer. Two basic solutions of such a ventilation are applied in design practice [3, 4]:

– one-gap ventilation, where the water vapor and the condensate together are carried out of the roof with air through one gap located between counterbattens and the underlay membrane installed directly on insulation,
– two-gap ventilation, which is applied with underlay foil or membrane of low vapor permeability or a layer of waterproof barrier installed on rigid roofing.

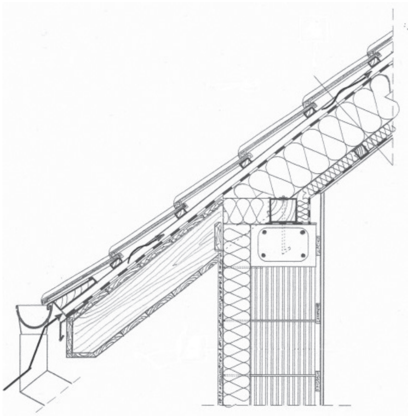
The lower ventilation gap dries the thermal insulation and the timber structure of the roof. The upper one provides an escape passage for the water, which in the form of volatile snow and slanting rain with wind got under the roofing. It also provides a passage for the condensate forming under the roofing. The roof plane with poor windtightness does not eliminate the exchange of air that takes place between the surrounding and the space under the roofing. The air is exchanged here through joints between the elements of roofing, which are not tight on the whole roof plane. A tight roofing is most often made of overlapping strips of materials connected with sealing joints or with other tight joints. A tight roofing is installed on a rigid base (e.g. boarding.) In this case the air exchange is minimal. The ventilation gaps function correctly as long as the air filling them can pass through them continuously. The recommended air gap height is at least 3 cm. The height of the ventilation gap can prove insufficient in the case when the insulation material can expand after it was installed. The growing thickness of the fibrous material can fill in the clearance and result in its inefficient ventilation. In pitched roofs, the temperature measured directly in the ventilation ducts can be up to 15 K higher that the temperature of ambient air [4]. When the roofing is not heated with solar energy, the ventilation air can begin to move in the opposite direction, from the roof ridge to the eaves. This is what comes about in the roofs, which are constantly in shade or are oriented to the north. It is also possible at night when the roofing is cooled as a result of heat radiating from its surface. The air gaps of greater height should be installed in the roofs with short ventilation channels or when the roof pitch is low.

5. Protection of the roof against moisture caused by changing weather conditions

Water in various forms is always present in both environments separated by a roof. This is why the internal structure of a roof can be damp from outside or from inside. The protection of a roof on the inside then comes down to eliminating or reducing the effects of moisture on the materials or products built into it. The critical levels of moisture, resulting in the excessive condensation depositing inside an element, are destructive for the material. They also deteriorate its thermal properties. The critical levels of moisture can occur when:
– the material of good sorptive properties is subject to moisture caused by rain water blown into the structure from a side of waterproof roofing,
– the relative humidity of air in contact with the layer of the material of low temperature reaches the value of complete saturation,
– the beginning of the in-depth condensation process takes place near the layer made of material which does not demonstrate sorptive properties, which results in the deposition of condensate on the surface of that layer,
– the material of the layer, which can absorb water, is in an environment whose temperature reaches the level at which the in-depth condensation process begins.

In such a case, empty spaces in the internal structure of the material filled earlier with air and water vapor are also filled with condensation water. Consequently, the following layers protecting the inside of the structure against moisture should be built into the roof:
– waterproof or watertight roofing system,
– underlay or waterproof barrier,
– vapor barrier.

a)



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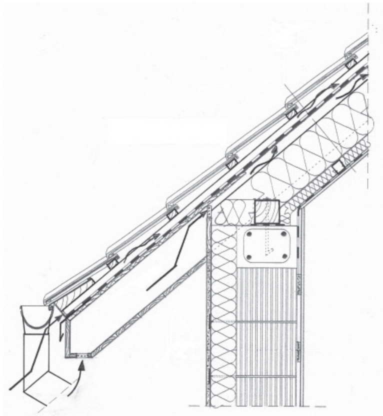

c)

Ill. 1. A roof with thermal insulation and: a) one ventilation gap, b) two ventilation gaps, c) two ventilation gaps and a rigid roofing (by author)

6. Roofing foils and membranes

Every thermally insulated pitched roof requires measures protecting its interior against rain water, snow, and dust blown from the roofing as well as against air penetration and the effects which can be caused by the water vapor diffusing through the barrier. In adverse thermal conditions, it changes into condensate. Excessive moisture is destructive to built-in materials and it reduces their thermal performance. The elements of the structure protecting the roofing and thermal insulation include roofing foils and membranes. The lack of breathable roof underlay as well as vapor barrier and windtight foil can result in a more intensive exchange of air; also through the porous material of the barrier. Consequently, the convective exchange in the heat and water vapor transmission process will be greater.

Roofing foils and membranes vary in their internal structure and technical properties. Their water vapor permeability is especially important. Due to that material's feature, roofing foils and membranes can be divided into three subgroups:
– vapor-proof foils of very high diffusion resistance,
– foils and membranes of low vapor permeability,
– membranes of high vapor permeability.

The first of those subgroups includes traditional vapor-proof foils, which block the supply of water vapor to the layers protected by a vapor barrier – primarily to the layer of thermal insulation. The products from each of those subgroups are built into the roof plane in different places. The proper structure of other layers and their materials enables a foil or membrane to perform effectively.

7. Breathable roofing underlays

An underlay should be placed from the external side of a building under its roofing system. Breathable foils and membranes can feature different technical properties. Their desired material properties are however, always closely connected with their position in the internal roof structure. The technical properties of the breathable roofing underlay are determined among others by the roof ventilation system. The parameters specifying the basic technical properties of breathable foils and membranes include: vapor permeability, resistance to water penetration, grammage (areal weight), resistance to longitudinal, lateral, and nail tear, fire resistance, resistance to UV radiation, the range of admissible use temperatures. Furthermore, when the producers present the characteristic features of foils or membranes, they additionally describe where they can be used [5].

The foils and membranes with low vapor permeability can be applied where there is a ventilation gap designed above a layer of thermal insulation. In such cases, there is an additional ventilation gap between an underlay and the bottom of the roofing system.

A breathable roofing underlay of high vapor permeability can be applied directly on a layer of thermal insulation. With such a solution only one ventilation gap can be used above an underlay and the layer of thermal insulation can be placed on the full height of the rafters, thus it can be much thicker. The multilayered breathable foils, commonly known as membranes, among others control the processes connected with the diffusion and condensation of water vapor as well as with the deposition of condensate under the roofing. These diaphragms are made of several layers fused together. Their internal structure is composed of a network of properly formed channels. Water vapor passes smoothly through such a material and the water stops on its surface. Breathable foils with several layers demonstrate high mechanical strength. They are also resistant to low and high temperatures. Breathable membranes, which are used as waterproof underlays, enable small amounts of rain water to penetrate under the roof or condensate on the internal surface of the roof. They also provide a windtight barrier. The new generation breathable membranes are produced with the use of ultrasound layer fusion. A large amount of energy supplied to the place where the layers contact provides for a durable and precisely manufactured bond. The use of special bond template enhances the tear resistance of the membrane. The membranes produced with that method are mechanically strong and flexible as well as resistant to aging. The micropores which provide for the membrane high vapor permeability are uniformly passable allover its whole surface.

8. Vapor barriers

The thermal insulation of the roof is protected from the inside with a vapor barrier. Preventing or significantly slowing down the diffusion of water vapor, it minimizes the influence of adverse effects, which can be caused by condensation of that vapor in the layer of insulation. When choosing the type of vapor barrier, one should pay special attention to technical characteristics of the other layers of the roofing. The effects of the sequence in which the layers are installed in the barrier should also be considered. It is especially important whether the suggested system of layers and materials in the layers will be tight or open to diffusion. The efficiency of the structure is also affected by the ventilation of the roof. At present, on the market of building materials there are available vapor barriers with new technical characteristics which prevent or slow down the process of diffusion of water vapor in winter [5, 6]. They also allow for drying out the inside of the barrier in summer as there are high temperatures outside of the habitable attic. A good example of such a barrier is a vapor barrier which actively reacts to the diffusion of water vapor. Water vapor penetrates through such a vapor barrier and thermal insulation open to diffusion outside only in such an amount, which can pass through the structure of the breathable underlay. In such a case the breathing underlay is installed directly on the insulation layer.

Another type of a new generation vapor barrier is the one, which apart from preventing the diffusion of water vapor in winter allows for guiding water vapor inside from the barriers in the summer. Its internal structure allows for so called reverse diffusion in which water vapor passes continuously in the direction from the roofing heated in the summer to its colder parts located near the thermally insulated interior. The reverse diffusion would be impossible if there was a traditional vapor barrier with a very high diffusion resistance on the colder side of the interior in summer. Such a solution would cause condensation in the place of contact between thermal insulation and traditional vapor barrier. It can prove especially dangerous when rain water gets inside the roof or water from condensation deposits there.

Still another type of a new vapor barrier is a membrane with a polyamide layer which actively reacts to humidity changes in relation to air which is on both sides of the vapor barrier. Due to the reversible changes taking place in the polyamide, its diffusion resistance is active and it can change the direction in which water vapor flows in winter and in summer. As a result of such characteristics of the barrier the polyamide vapor barrier causes it to dry inward in summer.

9. Conclusions

The structure with ventilation gaps above thermal insulation still seems to be an efficient solution for habitable attics. The air gap, which allows for ventilating the thermal insulation from the top enables the water penetrating the structure through a perforated waterproof layer to escape. It also enables the water vapor, which condenses from the air in the ventilation gap or in the thermal insulation layer to escape. Furthermore, it drives off the initial moisture in the building shell and hot air in the ventilation gap in hot summer. The roofs with a ventilation gap seem to be a more reliable solution when the vapor barrier is not installed carefully or its type is selected incorrectly. The system of sloping construction barriers transferring heat and water vapor should be hard to penetrate for the air. It regards the internal structure of the materials of barriers and joints between individual elements as well as installation penetrations. When the air movement through the barriers is too intensive, it contributes to excessive convective heat loss. Too tight systems of external construction barriers can however, result in a significant deterioration of the microclimate of the insulated interior because the tighter the structure, the greater the threat of interior moisture. Currently, the reason of that problem seems to be the lack of ventilation or its defective operation. Additional threat of moisture on the barrier is created by the warm ventilation air with a ot of water vapor, which can condense under adverse thermal conditions. The breathable roofing membranes open to diffusion and modern active vapor barriers with varied functions facilitate driving off moisture from inside the structure. The underlay, which does not prevent the diffusion of water vapor, facilitates the diffusion exchange in the reverse direction. The stream of diffusing water vapor is then directed from hot roofing to a colder room.

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