Design and calculation of the internal roof drain system structure in terms of thermal protection and moisture condensation

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Abstract. A field survey of roof structures of several administrative buildings in the temperate climatic zone showed the presence of condensate in the zone of the internal drain. The fact of overmoistening of the roof structure raises doubts about the operability of the roof aerators installed on these coatings, designed to remove condensate from the roof layers. The inefficiency of using roof aerators can be explained by the process of condensed moisture freezing in the structure during the cold season thus cannot be removed by aeration. Two types of structures of the internal roof drain system used in construction from the point of view of condensate formation are revealed. The difference between the types is the degree of water vapor permeability of the junction layer between the pipe and the coating plate. An impermeable solution can be made by mounting a steel flange at the junction of the pipe and the coating plate. The vapor-permeable solution is made in the form of a simple sealing of the gap with polyurethane foam or other permeable materials. A calculated analysis of the temperature fields and the humidity conditions of the two types of internal roof drain structures showed that the use of polyurethane foam or its analogs in the gap is not enough to protect the roof structure from condensation. This solution leads to condensation inside the structure at positive outside temperatures (less than 2 °C). The design with steel flange at the junction of the pipe and the coating plate is free from these drawbacks and can be used at lower outdoor temperatures.

Keywords: enclosing structures, humidity conditions, condensation, water vapor, drain system, convection.

1 Introduction
For the correct execution of the internal roof drain system, the participation of three specialists is necessary:
• An architect - to determine the location of water intake funnels, slopes and roofing materials;
• Drainage specialist – to determine the type of funnel, drain cross-sections, etc.;
• Heating engineer to provide thermal protection and protection against condensation and frost.

In practice calculations of possible condensate formation in the internal roof drain construction units are not carried out. Typical construction is carried out according to the Set of rules 30.13330.2012 “Domestic water supply and drainage systems in buildings”. Thus the design comes down to calculating the drainage capacity, their number, location, minimum roof slopes, etc. The moisture content of materials affects their thermal conductivity and, ultimately, the effectiveness of thermal protection [1–4]. One of the main causes of moisture in addition to precipitation is moisture condensation. Condensation can occur due to neglect of vapor permeation processes through the layers of materials. In this regard, the authors indicate the need for an experimental assessment of the vapor permeability of building materials and their absorption [5–7]. The lack of individual accounting of operation thermophysical features of the internal drainage unit in practice leads to the penetration of water vapor from the room into the layers of the roof structure and, as a result, soaking of the roofing layers with condensed moisture. Examples of consequences are shown in the photo, Figure 1.
Figure 1. Water vapor condensation on the pipe itself and on the surface of the coating plate.

In the photo you can see condensate formation both on the pipe itself and on the surface of the coating plate. According to observations, the amount of flowing condensed moisture can reach 8–10 liters per day. It is worth noting that the dismantling of the specified roof of the administrative building showed complete tightness from the ingress of atmospheric moisture. It is also significant to note that the presence of roof aerator structures did not solve the problem of drying the roof. The presence of water is explained by the fact that the condensed moisture inside the roof freezes at low outside temperatures and by the time the thaw sets in, it melts and drains into the room in large quantities.

Despite a large number of studies on the temperature and humidity of enclosing structures [8–12], the vast majority of studies on the design of internal roof drain systems are devoted to their organization and streamflow calculations [13–15], as well as to thermal efficiency of the roof itself [16–17]. Less attention is paid to the issue of condensation process, namely, the issues of the effectiveness of roof aerators or deflectors are studied, as well as waterproofing and insulating properties of membranes [18–19]. However, these studies do not completely take into account the fact that the condensate inside the roof will turn into ice in the cold season and cannot be removed by aerators. The presence of impermeable membranes prevents construction materials from drying out. For this reason, it is clear that the roof structure must be designed individually, depending on the severity of the climate, based on the requirements of limitation or the complete exclusion of condensation.

Typical design units from the point of view of thermal engineering calculations are reduced to a regulatory framework such as Set of rules 230.132580.2015 “Building enclosing structures. Thermal heterogeneity characteristics”. In the appendix of the document, there is one solution of the unit that corresponds to the drainpipe, namely, a scheme of the passage of the tube bundle through the combined roofing is given. However, this solution is not a generalized scheme for the entire variety of drains types and does not reveal the problems of possible condensation process. There is also no methodology for calculating such structural units for buildings heat protection in the current regulatory literature. According to Set of Rules 50.13330, thermal protection issues are solved for structural elements in which there is no intensive convection or transport of matter as it happens in a drain pipe. Convection processes are constantly taking place in the internal pipe in the cold season it means that the warm air is transferred from the premises outside the building. This circumstance will significantly affect the temperature fields in this unit, as well as the amount of heat loss, etc. Thus, it becomes obvious that this problem requires scientific development.

2 Materials and Methods
2.1 Analysis of design solutions of the internal roof drain structures
Analysis of various types of structures of the internal roof drain allows distinguishing two types of constructive solutions in terms of condensation processes, Figure 2.
It turned out that the difference between these two types is in the vapor permeability of the zone where the drainpipe adjoins the cover plate. Figure 2a shows the first type of structure, where the junction between the floor slab and the insulation layer is permeable to water vapor. In this assembly, the gap is made of vapor-permeable polyurethane foam. The arrows indicate the possible diffusion path of water vapor from the room to the roofing layers. Figure 2b shows the second type of structure, where the junction of the drainpipe to the cover plate is impermeable to water vapor due to the use of a steel flange. Based on these considerations, these two cases were taken as a basis when analyzing their temperature and humidity operating conditions.

To assess the thermophysical characteristics of the assembly structure of the internal roof drain, it is necessary to determine the distribution of temperature fields under operating conditions, taking into account convection processes. Various authors propose analytical methods for calculating the temperature distribution in construction units with thermotechnical heterogeneity [10, 20], but they do not take into account convection processes and their application is significantly limited by the specific type of inhomogeneity. Therefore, to determine the temperature fields in the structure, it is necessary to use a CFD simulation software package [21].

2.2 Initial data and calculation method

For the selected types of structures (see Figure 2), three-dimensional temperature fields were calculated at standard values of the internal temperature \( t_{\text{int}} = 20 \, ^\circ\text{C} \) and air humidity of the public premises \( (\phi_{\text{int}} = 50 \, \%) \) using the Autodesk CFD software package. For the correct calculation of temperature fields, the convection processes in the pipe were also modeled. The temperature difference between the inner and outer surfaces of the roof is taken according to the climate characteristics of Kazan (Russia) and is set equal to 51 \( ^\circ\text{C} \) (internal air temperature \( t_{\text{int}} = 20 \, ^\circ\text{C} \), external air temperature \( t_{\text{ext}} = -31 \, ^\circ\text{C} \)). The heat transfer coefficients (film coefficient) of the inner and outer surfaces are set as 8.7 and 23 W / (m\(^2\) · \( ^\circ\text{C} \)), respectively. Thermotechnical characteristics of the materials are summarized in table 1.

| Construction Material | Thermal Conductivity (W·m\(^{-1}\)·K\(^{-1}\)) | Vapor Permeability (g/m·h·Pa) |
|-----------------------|---------------------------------|-------------------------------|
| Mineral wool          | 0.044                           | 0.5                           |
| Polyurethane Foam     | 0.045                           | 0.05                          |
| Cement                | 0.93                            | 0.09                          |
| Reinforced Concrete   | 2.04                            | 0.03                          |
| Bitumen               | 0.27                            | 0.008                         |
| PVC                   | 0.19                            | 0.002                         |
| Gravel                | 0.19                            | 0.23                          |
| Steel                 | 58                              | 0                             |
| Technoelast           | 0.27                            | 0.008                         |

![Figure 2](image)
The method of calculating the moisture state of the structure is based on the stationary transfer of water vapor through the structure, which is described both in the regulatory framework of Set of Rules 50.13330 and articles [5–11, 20]. The temperature distribution over the cross section of the structure determines the value of the partial pressure of saturated water vapor $E_i$ in the same sections. Resistance to vapor permeation of the material layers $R$ (m$^2$ h Pa/mg) forms the distribution of the actual partial pressures over the cross-section of the structure $e_i$. The occurrence of condensate is possible at $E_i = e_i$, that is, complete saturation of the air with water vapor.

3 Results and Discussion
A general view of the result of calculating the temperature fields of three-dimensional structural models is shown in Figure 3.

![Figure 3. Temperature fields of the constructions of the internal roof drain system.](image)

It can be seen that due to convection processes, the air temperature in the drainpipe is positive and close to the temperature of the internal air. This process significantly affects the temperature distribution of roof layers, namely the increase in temperature of the layers in the area adjacent to the pipe. The maximum calculated air velocity in the drainpipe of the first and second type at a temperature difference of 51 °C was 1.3 m/s and 2.9 m/s, respectively. Using the obtained temperature fields, the moisture state of the structures was determined. The calculation of humidification in the first type of structure was made by the gap section sealed with mounting foam (section 1-1, Figure 3). That is, the cross-section where water vapor penetrates from the room. It was found that the condensation zone is located between the insulation layer and the waterproofing layer. The equality $E = e_i$, indicating the formation of condensate in section 1-1, is shown in Figure 4. In the design of the second type, condensation is absent due to the presence of an impermeable steel flange.
Using the method of successive approximations, it was determined that the partial pressures $E$ and $e$ in section 1-1 of the structure of the first type begin to converge at an outside temperature of $2.0$ °C, Figure 5. That is, condensation in the construction of the first type begins already at positive outside temperatures.

**Figure 4.** Temperature and Water Vapor Partial Pressure Distribution for Section 1-1 at an external air temperature of -31 °C.

**Figure 5.** Temperature and Water Vapor Partial Pressure Distribution for Section 1-1 at an external air temperature of 2 °C.
4 Conclusions
The main findings of the study are as follows:
- It was revealed that the installed roof aerators do not solve the problem of overmoistening of the studied roof structures. The inefficiency of using roof aerators can be explained by the process of condensed moisture freezing in the structure during the cold season, thus it cannot be removed by aeration;
- It was found that the use of typical drainage units without a steel flange in the area where the pipe adjoins the coating plate can lead to condensation in the roof layers even at positive outside temperatures;
- It is shown that the convection process in the internal drain leads to an increase in the temperature of the roof layers in the zone of their adjacency to the drain pipe. Therefore, the calculation of the temperature and humidity state of the roof structure should take into account convection processes;
- It is shown that the selection of the construction type of the internal roof drain structure must be confirmed by thermal engineering calculation and provide the requirements of protection against overmoistening of the roof with condensed moisture.

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