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THE RAINWATER FROM THE ROOFS OF BUILDINGS IN THE SYSTEM OF STORMWATER MANAGEMENT

This paper analyzed the design guidelines drainage of rain roofs of buildings, recommended for different systems. There was a wide divergence of recommendations given by different types of manufacturing systems. They referred it to the guidance relating to the determination of the maximum rainfall, taking into account the characteristics of the rainy region's in Poland and the probability of occurrence of such rain. In the paper the conclusive rainfall for the region have been recommended. The importance of the correct determination of rainfall drainage system sizing and proper management of stormwater runoff from urbanized areas. An accurate determination of the flow of rain water ensures the safety of buildings, allows reducing the costs of fresh water and the costs of paying for the removal of rainwater.
Keywords: **drainage system, rainfall water, roof drainage, water management.**

Introduction. Rainwater or thaw water in urban agglomerations runs off on the surface of construction facilities and across the ground to reservoirs, or natural or artificial watercourses, connected with the surface water drainage systems, or get absorbed into the soil. Finally, such water may be discharged to surface water by means of the conduits of rainfall water or general sewage systems, after their pre-treatment.

The management of rainfall water runoff is contained in the selection of construction and technological, organisational and legal solutions undertaken at the stage of planning, designing and maintenance of the facilities collecting, storing and discharging rainfall water or thaw water in the settlement units. The scope of management also covers defining of the implementation methods of the solutions adopted, including, in particular, the acquisition of financial resources necessary for their execution [1].

Rainwater management refers to, among others, issues:

• designing rainwater systems providing protection against unwanted ambient splashing rainwater;

• the collection and use of rainwater;
• enabling operational cost reduction through the use of rainwater;
• reduction of fees rainwater from the area of real estate.

Recently, the climate warming effect has been observed. Specialists have not reached any consensus in relation to the assessment of this phenomenon so far, however, the fact of climate change is obvious. As a result of the growth of the average annual temperature of the globe, water circulation in the global hydrological circuit has been intensified, causing the manifestation of extreme weather phenomena (storms, hurricanes, etc.). In connection with the increasing value of the precipitation volatility coefficient and the frequency incidence ratio of convective type of clouding, the growing intensity of rainfall and increased frequency of extreme precipitation should be expected. Such phenomena may result in damages in construction in urbanised areas (flows, overflows and floods) [2]. This problem encourages launching of precautionary measures aimed at mitigation of the adverse effects of such phenomena. It is even more important in view of the fact that the constructed sewage systems should ensure efficient performance in the perspective of up to 2100 [3], and these aspects should be also taken into account in the rainfall water runoff management. The problem refers to all components of the drainage system, including the roof drainage systems of buildings.

Systems designed for rainfall water drainage make an inherent element of equipment of buildings and various facilities of urban infrastructure. In case of buildings, precipitation water accumulating on roof surfaces may be discharged by an external or internal drainage system. In the external, gravitational system, water flows to the gutters running along the roof edges, being subsequently taken over by the downpipes fixed to the elevation of the building. In the internal system water accumulates in roof dip trays or basins, from where it is captured by roof inlets directing it to the rainwater drainage system. Internal drainage systems may be of gravitational or vacuum nature, the latter operating under the conditions of negative pressure developing in the conduits. The external system is recommended for buildings of up to five floor height [4], with vertical dimensions reaching up to ~15 m above the terrain level. On the other hand, the internal systems may be used both in low and high buildings and they practically represent the only feasible solution in facilities with large surfaces of flat roofs.

While adjusting the method of managing rainwater collected from buildings and their surroundings, the principle of sustainable water management should be applied. The optimum management method of uncontaminated rainwater discharged from real property is its temporary storage, followed by usage on the area of the real property. The connected drainage system may contain special reservoirs from which the rainwater is used for residential purposes following the adequate pre–treatment. Such systems may be used in residential buildings, public utility buildings or industrial facilities where many technological processes do not require potable water. The retention and slow infiltration into the ground is also recommended, or direct absorption by the ground. Such measures allow for retaining water in the basins, which is particularly important in urbanised areas where hardening of the surface and accelerated runoff of rainwater occurs.

The aforementioned measures enabling the reduction of tap water consumption, are classified as cost-saving and ecologically–friendly solutions. The problem of rainwater management has recently started to be particularly significant in view of implementation of a fee for rainwater discharge from real properties in some regions. The fee, sometimes referred to as the "rainfall tax" is introduced on the basis of statutory provisions [5]. The level of the fee for the discharge of rainwater usually depends on the area of the roof, the plot, and sometimes also on the forecast precipitation quantity. Accordingly, similar to designing of the drainage water system and elements used for rainfall water recuperation, it is necessary to adopt reliable environmental parameters describing the rainfall and the technical parameters of various elements of the rainfall drainage system.

Performance of external drainage systems. The altitude limitations concerning the application of external drainage are associated with the maintenance conditions and physical phenomena which may lead to a number of undesired processes affecting the sustainability of the facility. The particularly hazardous factors include:

- overfilling of gutters during intensive precipitation, with the consequent overflowing and dampness of hoods, external walls and other elements by rainfall water running off in disorganised manner; in addition, dampness and blurring of the building surroundings may occur, as well as washout of the band at the foundation walls, etc.
- freezing of water in gutters and downpipes, occurring in autumn and winter periods during fluctuations of air temperature within a day, as a result of which the throughput is reduced, or even blocking of the system may occur; in such cases, flooding by water may also occur (originating from the melting snow or ice) and damping of external elements of buildings may take place; moreover, the water freezing in the drainage system may cause its unsealing or other impairments;
- impairment of elements of the system as a result of combined effects

of several external factors, such as wind, temperature volatility and sun radiation intensity, chemical and mechanic contaminants, hail falls or snowfall.

The internal systems of rainfall water drainage from the roofs are not exposed to the majority of the aforementioned adverse effects which accompany the external systems, due to their incorporation into the roof surface and running of the conduits discharging water inside the building, thus, across the area protected against direct impact of external factors.

It is assumed that downpipes of the gravitational systems, both internal and external, irrespective of the rainfall intensity, operate properly when they are partially filled in with water. Such a performance of the downpipes may be only provided by the adequate adjustment of the gutter and downpipe throughput, so that the inlet of the downpipe remains unflooded during the water flow along the gutter or a draining tray. In other case, if the water stream covers the inlet to the vertical duct, the uneven (pulsating) flow appears. Water moves through the downpipes in the so–called water jams, separated by air bubbles. The air bubbles are occasionally interrupted, causing the vibration of the pipe. The vibration is not recommended since it is the factor which may damage the downpipes: on the joints, in the points of fixing to the wall, and in case of steel pipes, the protective coating may be interrupted, which consequently fosters the development of corrosion.

Guidelines on designing the external drainage system of a roof. The principle of the drainage system design is based on the relevant adjustment of the meteorological and hydrological parameters of the local rainfall to the hydraulic capacity of individual components of the drainage.

The individual steps of the designing process may be contained in the following points:

1. Defining of the so–called equivalent drained roof surface – *EPD*, which should also include, besides roof surface, other surfaces from which the rainfall water will be collected. This may comprise surfaces of elbow walls, attics and other elements protruding above the roof surface. The calculations are usually simplified, taking only roof dimensions into account. The *EPD* value is then equal to the roof surface, at the surface slope of $\leq 10^{o}$, and for slopes $> 10^{o}$ it is determined according to the formula:

$$\boldsymbol{EPD = L(W + \frac{H}{2}),\ m^2} \quad \text{or} \quad \boldsymbol{EPD = L\frac{H}{\sin\alpha},\ m^2} \qquad (1)$$

where $\boldsymbol{W}$ – width of the roof surface plan (with the slope towards the gutter), m; $\boldsymbol{H}$ – hight of the roof surface, m; $\boldsymbol{L}$ – length of the roof surface, $\boldsymbol{m}$; α – slope of the roof surface, ^{o}.

2. Determining of the concentration of inflow of rainfall water

collected from the $EPD - Q_d$

$$\boldsymbol{Q_d = \psi \cdot EPD \frac{q_m}{10000}, dm^3 / s} \quad , \tag{2}$$

where $\boldsymbol{\psi}$ – coefficient of surface runoff; usually in the range of $0.8 \div 1.0$; $\boldsymbol{q_m}$ – intensity of measurable rain, $dm^3/(s{\cdot}ha)$.

3. The selection of dimensions (diameters, cross–sections) of gutters and downpipes as well as location of downpipes (distance between inlets), arising from their throughput, is usually performed on the basis of specifications presented in tables.

The analysis of the design recommendations collected from the technical data of several producers or distributors of drainage systems on the territory of Poland, shows significant and unexplained discrepancies of the indications concerning maximum EPD_{max} drained surfaces. For the analysis, the guidelines related to the selection of the following drainage systems were adopted: Hunter, Galeco, Gamrat, Kanion–Wavin, Marley, Plastmo, Plastmo-Plastal i Raiko. In case of gutters, the maximum recommended EPD_{max} values were compared to the corresponding dimensions of gutter diameters (semi–circular or with a similar cross–section) of the analysed drainage systems. These recommendations are usually diversified in terms of water inlet to the downpipe from one direction, i.e. the location of the downpipe in the vicinity of the edge of the drained roof surface and inflow from two directions, i.e. next to the location of the downpipe in the middle zone of the drained surface. Therefore, to specifications are presented in the form of charts, for a single direction inflow (Fig. 1) and for a double direction inflow (Fig. 2). Comparison of the guidelines of various producers related to the selection of the gutter diameter to the drained roof surface indicates very high dispersion of the EPD_{max}value, exceeding even 100%.

In case of the guidelines concerning the adjustment of the downpipe diameter to the drained roof surface, the comparison was also made for two situations: the first one – inflow to the downpipe from a single direction (Fig. 3), the second one – inflow from two sides (Fig. 4).

Comparison of the guidelines on the selection of downpipes indicates even higher dispersion of the EPD_{max} value than in case of gutters. This refers, in particular, to the case of water inflow to the downpipe from a single side. For example, for a pipe diameter of 9 *cm* (single side inflow), guidelines recommending the application of pipes of this size from 50 to almost 250 m^2 EPD_{max}, and from 116 to 355 m^2 EPD_{max}, for double-sided inflow, can be found.

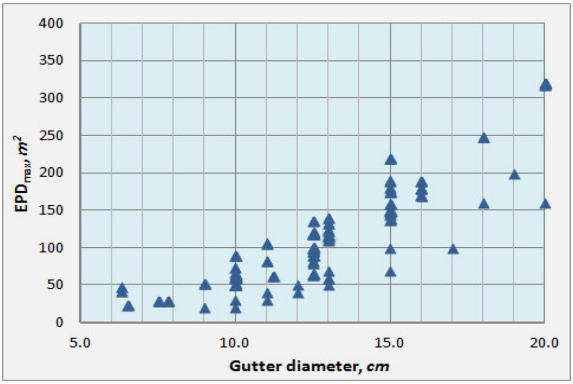

Fig. 1. The value EPD_{max} dependence on the gutter diameter at the water inflow to the downpipe from one direction, according to the guidelines of various manufacturers of drainage systems

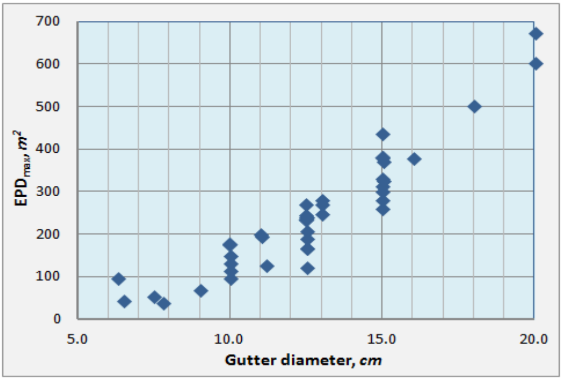

Fig. 2. The value EPD_{max} dependence on the gutter diameter at the water inflow to the downpipe from two sides, according to the guidelines of various manufacturers of drainage systems

Such a significant discrepancy in the EPD_{max} values referred to in the guidelines, depending on the diameter of a gutter or a downpipe, may result from assuming of various drainage system load with the value of measurable rain intensity q_m in the calculations. Although, on the other hand, in several cases, the value of measurable rain intensity of 75 *mm/h* is provided in the guidelines, which corresponds to the rainfall of intensity $q_m = 208\ dm^3/(s \cdot ha)$. At this point, it should be noted that standards [4, 6] recommend adopting $q_m \geq 300\ dm^3/(s \cdot ha)$ value for the calculation of rainfall water drainage, thus, much higher that indicated before.

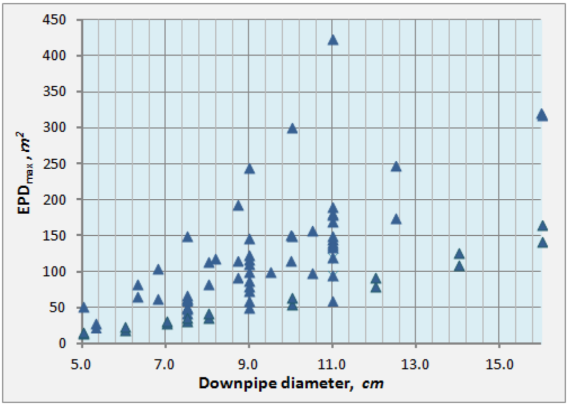

Fig. 3. The value EPD_{max} dependence on the downpipe diameter at the water inflow to the downpipe from one direction, according to the guidelines of various manufacturers of drainage systems

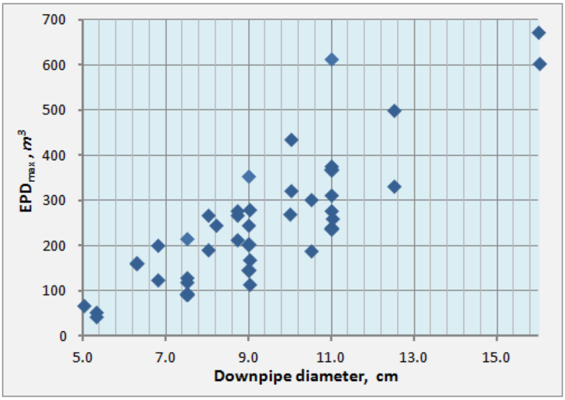

Fig. 4. The value EPD_{max} dependence on the downpipe diameter at the water inflow to the downpipe from two directions, according to the guidelines of various manufacturers of drainage systems

The runoff ratio and the slope of roof surface may have some impact on the differences in the EPD_{max} values in various drainage systems, however, theses factors should not result in 3÷5 – fold discrepancy in the equivalent value of the drained roof surface. The inaccurate consideration of the longitudinal slope of the gutters seems to be more important, as well as various speed of water flow on the inlet to downpipes and, as a consequence, the expenditure of the flow on the pipe inlet. Unfortunately, the guidelines under discussion do not take the slope of gutter arrangement into account while determining EPD_{max}. It seems that it is a significant drawback of the guidelines analysed, which may lead to irrational selection of the system elements and, as a result, to the ineffective performance of the drainage systems of roofs of the buildings.

Intensity of measurable rain. Due to the fact that the drainage systems should ensure fast discharge of the rainfall water in order to protect the building and its surroundings against being flooded with water, the heavy rainfall, i.e. occurring within a short period of time, appearing with a specific probability, should be taken into account. Rain with short duration is accepted to the calculations since this type of precipitation shows the highest intensity at the initial stage when the runoff of rainfall water is at the level posing the risk of flooding to the building elements. As a rule, the intensity of rain easing in the period of 5 minutes is adopted for the calculations.

An important parameter determining the intensity of measurable rain is the adopted probability of its ceasing. Parallel to the decreasing probability of the rainfall ceasing, the protection of the system increases in terms of exceeding the assumed intensity of the rainfall. The probability of 1% indicates the possibility of recurrence of the rain of the intensity assumed, thus, the possibility of its exceeding, once in 100 years, whereas the probability of 100% indicates the possibility of the rain recurrence once a year, consequently, the possibility to exceed its intensity in the following year. The probability expresses how many times per century the assumed rain intensity may be exceeded, thus, it defines the level of the drainage system protection against the activity without overload. In the external roof drainage, usually the probability of 50% is accepted, i.e. the repeatability of the rainfall once in two years. German standards [7] assume a similar level of probability for external drainage systems, however, for internal drainage systems, creating potentially higher risk for the facility and conditions of its maintenance, they assume probability of 1% (rainfall once in 100 years).

The relationship for determining of the measurable rain intensity for the territory of Poland, commonly quoted in various types of guides, is Błaszczyk's formula,

$$\boldsymbol{q_m = A \cdot C^{0,333}\, t^{-0,667}\ ,\ dm^3 /(s \cdot ha)}\ , \qquad (3)$$

where $\boldsymbol{A}$ – parameter dependent on the value of the average annual sum of rainfall (at the average annual total rainfall equal to 600 *mm*, A = 470); $\boldsymbol{C}$ – frequency of a single exceeding of the specific rain intensity, years; $\boldsymbol{t}$ – duration of the rainfall, min.

For the five-minute rain, occurring once in two years, the intensity of the measurable rain according to Błaszczyk's formula is 202 $dm^3/(s\cdot ha)$, which is close to the value of 208 $dm^3/(s\cdot ha)$, corresponding to 75 *mm/h*. However, currently the Błaszczyk's ratio is assessed as imprecisely reflecting the intensity of rainfall for the territory of Poland [7]. The studies of Bogdanowicz and Stachy [8] indicate that the maximum rain intensities for various regions of Poland demonstrate other dependence towards the duration of the rainfall and its intensity, than the relation arising from Błaszczyk's ratio. The equation they propose has the following form

$$q_m = \frac{1000\,[1{,}42\,t^{0{,}333} + a\,(-\ln p)^{0{,}584}\,]}{6\,t}\ ,\ dm^3/(s\cdot ha) \qquad (4)$$

where p – assumed probability of rainfall incidence; a – parameter dependent on the location and duration of rain, for the rain of t = 5÷30 *min*, for a part of the country (except the Sudetes and the Carpathians – for the needs of this article, defined as R 1 rainy area (Fig. 5)), and the time of rain occurrence t = 5÷120 *min*, the relation; and for the north-western rainy region (R 2 rainy region (Fig. 5)), limited approximately by the line Zielona Góra – Poznań – Olsztyn, the relation.

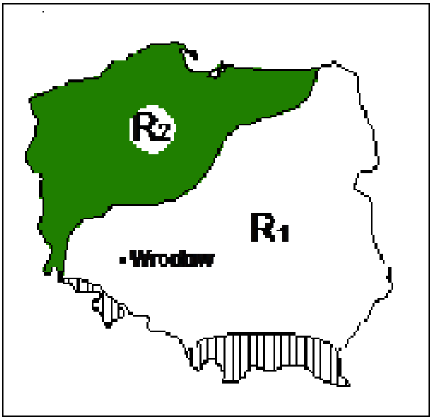

Fig. 5. Division of the country into rainy zones according to [10]

The differentiation of the calculated intensity of rainfall on the territory of Poland is an adequate approach, since it better reflects the real climate conditions in the scope, which can be observed in the maps of rainfall distribution in Poland (Fig. 6).

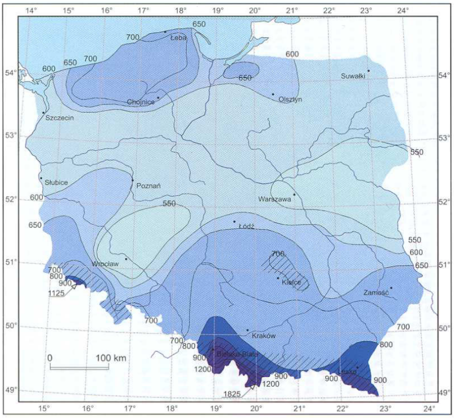

Fig. 6. Average annual level of rainfall in 1996 – 2000 according to [11]

The nature of the dependence of rain intensity on its probability for region I and II, according to the Bogdanowicz-Stachy formula, is illustrated in the chart (Fig. 7). The chart presents the results of calculations of the maximum rain intensity for 50% probability of incidence (rainfall once in 2 years). For zone I it amounts to 276 $dm^3/(s{\cdot}ha)$, and for zone II – to 227 $dm^3/(s{\cdot}ha)$. These values are higher than 202 $dm^3/(s{\cdot}ha)$, the value obtained from the Błaszczyk's formula. Results of calculations of the qm value for the 1% probability (rainfall once in 100 years) have been also included; they are much higher than 300 $dm^3/(s{\cdot}ha)$, the value which is adopted for the dimensioning of the internal rainfall drainage systems.

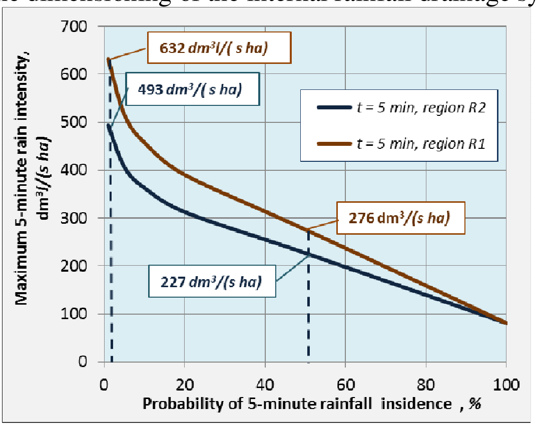

Fig. 7. The dependence of the maximum 5-minute rain intensity on the rainfall probability according to the Bogdanowicz-Stachy formula

Conclusions.

1. The appropriate management of rainfall water runoff requires a good knowledge of the characteristics of water flow in every section of the drainage system performance. It refers, in particular, to the initial stage, when, depending on the assumptions, the relevant part of water runs off from the real property to the sewage system, and the remaining part is retained for use. In this context, the sustainable rainfall water management should be strived for.

2. The guidelines for designing of roof drainage rainfall water systems used at present, do not take into account the relevant current characteristics of rainfall and the recommendations of manufacturers concerning the dimensioning of the systems indicate an extremely high discrepancy. The design guidelines referring to various systems do not demonstrate consistency in the adjustment of the meteorological and hydrological parameters of rain to the hydraulic parameters of the drainage systems.

3. The significant discrepancy in the design guidelines of various manufacturers of drainage systems seems correlated with the lack of their relationship with the longitudinal slopes of gutter arrangement and the associated gutter expenditure or flow expenditure created at the inlet to the downpipe. The drawback of the guidelines analysed, may lead to irrational selection of the system elements and, as a result, to the ineffective performance of the drainage systems of roofs.

4. For the determining of the maximum rain intensity (measurable intensity) it is recommended to use Bogdanowicz and Stachy formulas instead of Błaszczyk's formula. These relationships reflect the volatility of rainfall characteristics on the territory of Poland more precisely. The calculation values of rainfall intensity for the external drainage systems are different for various regions of the country, and, based on the aforementioned formulas, they amount to $q_{mI} = 276\ dm^3/(s \cdot ha)$ and $q_{mII} = 227\ dm^3/(s \cdot ha)$, respectively.

5. The urban areas demonstrating the specific character of microclimate conditions, including those associated with the rainfall, require special care in adopting the calculation meteorological data and the adjustment of hydraulic parameters of the drainage systems of buildings. This problem may be particularly important in face of implementation of a fee for discharging rainfall water from real property in some cities and a possible waiver of such a fee, as well as the reduction of tap water acquisition costs due to the application of rainfall water recuperation and its use for residential, technological purposes, etc.

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ДОЩОВІ ВОДИ З ДАХУ БУДІВЕЛЬ В СИСТЕМІ УПРАВЛІННЯ ЗЛИВОВИХ СТОКІВ

У статті проаналізовано вимоги щодо проектування відведення дощових вод з дахів будівель, рекомендовані для різних систем. Було відзначено значний розкид рекомендацій, даних різними виробниками. Наведено рекомендації щодо визначення максимального стоку опадів, беручи до уваги характеристики дощових районів в Польщі, і ймовірність виникнення даного дощу. У роботі були рекомендовані розрахункові величини опадів для даних районів. Підкреслено важливість правильного визначення параметрів дренажної системи та належного управління зливовими стоками на міській території. Точне визначення витрати дощової води і подальше її використання забезпечує безпеку будівель, дозволяє знизити витрати по прісній воді і витрати з оплати за відведення до-

щової води.
Ключові слова: **дренажна система, дощові опади, відведення дощових вод з дахів будівель, управління дощовими водами.**

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ДОЖДЕВЫЕ ВОДЫ С КРЫШИ ЗДАНИЙ В СИСТЕМЕ УПРАВЛЕНИЯ ЛИВНЕВЫМИ СТОКАМИ

В статье проанализировано требования по проектированию отвода дождевых вод с крыш зданий, рекомендованные для различных систем. Был отмечен значительный разброс рекомендаций, данных различными производителями. Приведены рекомендации по определению максимального стока осадков, принимая во внимание характеристики дождевых районов в Польше, и вероятность возникновения данного дождя. В работе были рекомендованы расчётные величины осадков для данных районов. Подчеркнуто важность правильного определения параметров дренажной системы и надлежащего управления ливневыми стоками на городской территорий. Точное определение расхода дождевой воды и последующее её использование обеспечивает безопасность зданий, позволяет снизит расходы по пресной воде и расходы по оплате за отвод дождевой воды.
Ключевые слова: **дренажная система, дождевые осадки, отвод дождевых вод с крыш зданий, управление дождевыми водами.**
