The Applicability of Probabilistic Calculation Methods in Building Thermal Technology and Energetics

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Abstract: - The paper deals with the possibilities of using probabilistic calculation methods for the assessment of structures in building thermal technology and energetics. The subject is particularly the performance of individual probabilistic calculation methods that can be used for this purpose and their basic principles. Following are then examples of these calculations used in practice.

Key-Words: - probability calculation methods, building thermal technology, energetics, condensation, surface temperature, solar systems, solar gains

1 Introduction

All the buildings and their structures has to meet the requirements of their technical characteristics and safety, in accordance with legislative regulations of the state. These requirements include especially mechanical resistance and stability of structures, fire safety and other criteria directly related to the protection of human life or health. Very important and actually increasingly rated aspect is also energy saving and thermal protection of buildings. These requirements are more specifically stated in the relevant standardized rules. Normative regulations and requirements mainly lead to improving the energy performance of buildings and to ensure the comfort of indoor environment. Some of these requirements are emerging in the form of reliability criteria. Very good example of this type of requirement is the risk of condensation and mold growth on the surface of building structures. To assess the reliability of the structure there is usually used standard deterministically defined procedure which is in accordance with relevant standards. It means that all the input variables are modelled as constants, where there are expressed average values of material characteristics or boundary conditions. However, if it is possible to define the function of reliability criteria is convenient to use probabilistic calculation methods to evaluate the structure. Using these calculation methods it is possible to achieve more accurate results and in particular to evaluate the construction using realistic parameters, which are obtained by long-term measurements, e.g. real temperature and relative humidity.

2 Probabilistic Calculation methods

With this type of calculation methods, it is possible to determine the probability of so-called structural damages. Primarily, these methods were developed to use them in the field of building mechanics, where the variability of input variables may affect the result of calculation very significantly. However, we don´t have to speak about a failure of structure just in terms of structure disruption in connection with its static or mechanical function and stability, but it is possible to talk generally about the failure within the meaning of violation of any standard requirement. The advantage of this type of methods in comparison with deterministic methods is evaluation of building construction in variable input conditions. Due to this fact the reliability of each structure can be qualitatively better assessed. As a very convenient it seems to be their use also in thermal technology, energetics and evaluation of building services [6].

The number of methods which use probabilistic calculation is actually relatively high. Primarily they can be divided into four basic groups, which are as follows:

- simulation methods,
- approximation methods,
- numerical methods,
- advanced methods of probabilistic calculations.

The most widespread group are the simulation methods. This paper show selected examples of practical calculations using simulation and numerical methods of probabilistic calculation.

2.1 Method Based on Numerical Integration of Monte Carlo

The most commonly used simulation method is the classic Monte Carlo simulation. This is the method where they are carried out repeated simulations of reliability function. It is a numerical simulation, which uses the generation of (pseudo)random numbers, reflecting the behavior of the random variable. To increase the accuracy of the result of calculation it is necessary to carry out a large number of simulations. This method is easy to apply, but its disadvantage is the impossibility of application to complex problems precisely because of the need of many simulations. Monte Carlo simulations are applied, for example, in the probabilistic method SBRA [1] (Simulation Based Reliability Assessment). SBRA probabilistic method was applied e.g. into Software Anthill. It is the user-friendly software, which has been developed in the Czech Republic where is fairly widespread.

2.2 Direct (Numerical) Methods

The method Direct Optimized Probabilistic Calculation – hereinafter referred as “DOProC method”, solves probabilistic tasks without using any numerical simulation techniques. It has been developed since 2002 and its theoretical background has been published e.g. in [3]. It is an alternative to simulation SBRA.

The calculation procedure of the DOProC method is unlike to simulation methods unequivocally given by pre-described algorithm. Therefore, there is not used simulation technique. DOProC method is implemented in software product ProbCalc [1]. This software is developed since 2004 at the VSB - TU Ostrava. The advantage of this method is its accuracy, which can be influenced only by numerical error.

3 Possibility of Using Probabilistic Calculation

The probabilistic calculation can be used in cases where it is possible to clearly define the so-called *reliability function*. Criteria of reliability of building structures are usually defined by the appropriate normative regulations. However, there also can be used general physical relations.

3.1 Reliability Function

The basic prerequisite for the possibility of application of probabilistic assessment is the existence of reliability function or its generation. Generally it is expressed as:

$$RF = S - R \geq 0 \qquad (1)$$

Where S is effect of influence,
R structure reliability (limit state).

If the reliability function is not met, it means that the effect of influence S is higher than its reliability R, the failure occurs. Then the result of calculation expresses the probability of structure failure. Graphical representation of this state is shown in figure 1.

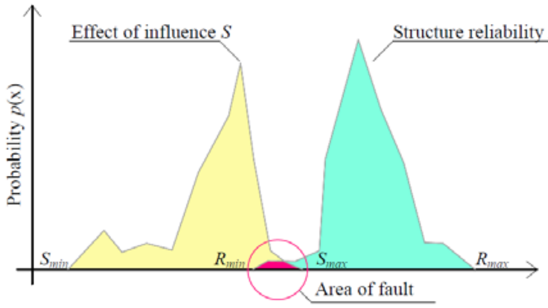


Fig. 1 Curves of probability of influenced effect S and structure reliability R showing the area of the possible occurrence of faults

3.2 Input variables

As it was mentioned above, significant advantage of probability calculation is the possibility to take into account the variability of input variables. This phenomenon is very significant in building thermal technology assessment. Variability of input data can be expressed e.g. in form of histograms. Input variables are obtained by long-term measurements or it can be defined mathematically.

In terms of building physics are the most significant variables especially boundary conditions, that affect the construction. The examples of histograms expressing the variability of input data are shown in figure 2 and figure 3. To express input variables there can be used parametric or non-parametric distribution. In case when it is possible to measure input data objectively and that there exist a sufficient amount of input data, it is appropriate to use non-parametric distribution. It means direct use of measured data. Otherwise, there can be advantageously used parametric distribution, where the input data are replaced by curve which suitably characterizes the characteristics of particular variable. Figures which are shown below are demonstrating the possibility of expressing the variability of data used in probabilistic calculation.

Figure 2 shows the histogram of input variable with parametric distribution. For the example there is given histogram of relative humidity of interior air. Distribution is based on the assumption that the design internal moisture for residential buildings is 50% in this case according to CSN 73 0540. However, it can be assumed that the humidity continuously fluctuates around this value with a certain degree. This effect is best expressed by the Gaussian curve, which was used in the formation of the histogram of internal moisture.

Figure 3 expresses the histogram of variable with non-parametric distribution. Specifically it is the thermal conductivity of the material (cellulose), where the data was obtained by measuring at the accredited laboratory. This histogram is a typical example of possibility how to use specific characteristics of building material for thermal-technical calculations. Both histograms were created in software HistAn which is one of computational software modules of ProbCalc.

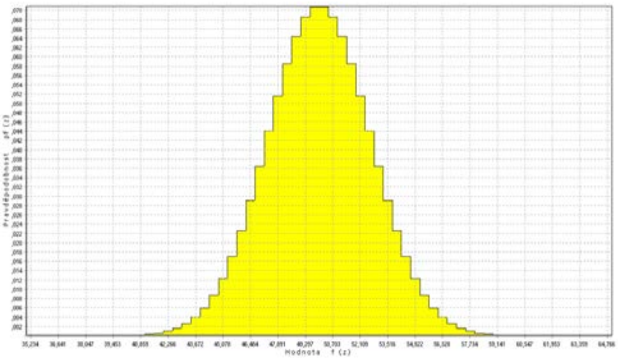


Fig. 2 Histogram of relative humidity of indoor air *RH* [%] - normal parametric distribution

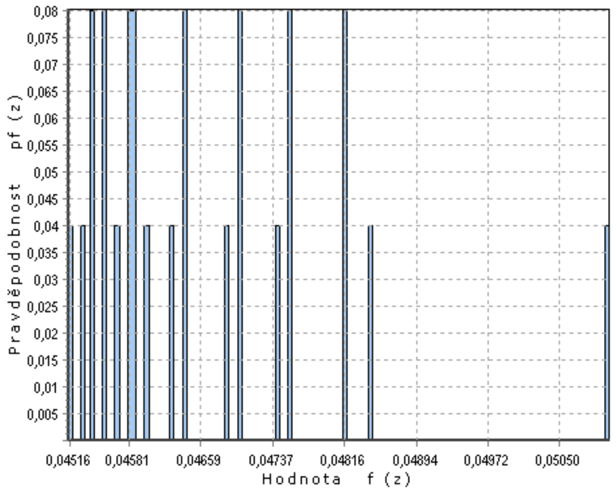


Fig. 3 Histogram of cellulose thermal conductivity λ [W/(mK)] - nonparametric discrete distributions

Variables entering into the probabilistic calculation may often be statistically dependent, as a typical example we can use physical parameters of environment. This dependence can be taken into account when calculating the probability by using a 2D histogram. Example of this type of histogram is shown on figure 4, where there is expressed the dependence between relative humidity of interior air φ_i [%] and temperature of interior air θ_{ai} [°C]. The result of its use is that the probabilistic calculation consequently does not occur with random combinations of input data, but with the actual interdependent environment parameters. The disadvantage of expressing the dependence between the input variables is limited computational power of software and the inability to use a larger number of collected data, or the data must be pre-adjusted appropriately.

4 Example of Using Probabilistic Calculation in Building Thermal Technology

This calculation method is advantageously usable especially for evaluating the thermal [4] and humidity characteristics of structures which exhibit significant variability of input variables and boundary conditions in the calculation.

4.1 Temperature factor at the internal surface of structure

One of the areas where the DOProC method can be successfully used is also a probabilistic reliability assessment of water vapor condensation on the building structures surface.

Sufficiently high temperature of structure surface θ_{si} and low relative humidity of the indoor air $\varphi_{i,r}$ are the main factors that ensure the prevention of condensation of water vapor on the surface of structure and thus it precludes subsequent mold growth [9,12]. This problem occurs especially with older buildings which are not thermally insulated and the temperature of their inner surface still remains low. Another problematic category consists of reconstructed building, where the replacement of windows and insulation of the building envelope causes the increase of surface temperature on the one hand, but at the same time it is eliminated natural air exchange inside the building and this fact leads to an increase of dew point temperature, which is caused by higher interior relative air humidity [11]. The solution for constructions of new houses is therefore designing of peripheral structures with sufficient thermal and technical parameters and then the ventilation of excess humidity has to be ensured.

This example and related research deal with the rating of the temperature factor at the internal surface of the structure which is based on data obtained by measurements in an experimental research center MDSK (Moravian Silesian Energy Cluster) [7]. All the building envelope structures are designed in accordance with the standard requirements for energy efficiency of buildings. Replacing of the internal air is secured mechanically there.

The temperature factor of the internal surface of the structure f_{Rsi} is a proportional expression of the inner surface temperature of structure. Required value is set out in CSN 73 0540-2 as:

$$f_{R_{si}} \geq f_{R_{si,cr}} \tag{2}$$

where $f_{Rsi,cr}$ is the critical temperature factor of the internal structure surface. Then it is determined as:

$$f_{Rsi,cr} = 1 - \frac{237.3 + 2.1 \cdot \theta_{ai}}{\theta_{ai} - \theta_e} \cdot \frac{1}{1.1 - 17.269 \Big/ ln\left(\frac{\varphi_i + \Delta\varphi_i}{\varphi_{si,cr}}\right)} \tag{3}$$

where θ_{ai} is a design temperature of the indoor air for desired use of the building (20 °C), θ_e design temperature of outside air during winter (-15 °C), φ_i design relative humidity of indoor air (50%), $\Delta\varphi_i$ safety supplement for moisture in accordance with CSN EN ISO 13788 (5%).

Actual value of the temperature factor of internal structure surface is then depending on the temperatures of surrounding environment and on the inner surface temperature. The dependence is:

$$f_{R_{si}} = \frac{\theta_{si} - \theta_e}{\theta_{ai} - \theta_e}. \tag{4}$$

4.1.1 Input variables used for calculation

All the input variables are in relevant legislation expressed by their deterministic design values. However, in the case of values characterizing the properties of the internal environment they are significantly influenced by the way of use of the building and design values can differ significantly. Similarly, in case of outside air temperature, which is expressed as a single number and therefore do not characterize its actual course during the period under review. For this reason, all the input variables were expressed in the form of shortened probability histograms with nonparametric (empirical) probability distributions for the assessment of selected structure. These histograms were prepared on basis of actual measured data [1], which was obtained by measuring in winter period. The risk of structural failure due to surface condensation of water vapor can therefore be assessed under real conditions in a given climatic area.

Figure 4 shows the histogram of the measured outdoor temperature values. In red area there are shown temperatures below freezing, i.e. lower than 0 °C. The minimum measured value during this period was -15.3 °C, maximum then 15.6 °C.

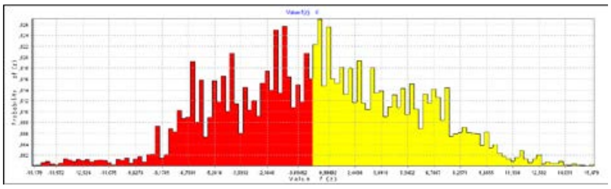


Fig. 4 Histogram of exterior temperatures measured during the period under review, Ostrava (CZ)

Table 1: Correlation coefficients expressing the statistical dependence between characteristics of indoor environment

Statistically dependent pairs of input variables	Pearson's correlation coefficient	Spearman's rank correlation coefficient
θ_{ai} - θ_{si}	0.981123	0.976205
θ_{ai} - φ_i	-0.649787	-0.497204
φ_i - θ_{si}	-0.67117	-0.504349

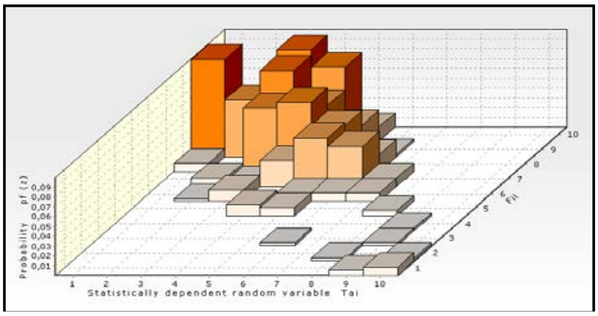


Fig. 5 Output from HistAn2D software: the double histogram expressing the statistical dependence of θ_{ai} and φ_i

Variables characterizing internal environment, i.e. indoor air temperature, surface temperature of structure and the relative humidity of indoor air are mutually statistically dependent. For this reason, there was used 3D software HistAn 3D [2] where there was constructed three-dimensional histogram expressing their mutual statistical dependence, which was also used for the actual probability calculation. Figure 5 expresses the dependence between these temperatures and relative air humidity. Statistical dependence of input random variables can also be expressed by correlation coefficients, which are shown in Table 1. From these statistical dependencies of input random variables it is clear that their influence should not be ignored primarily in calculation. Therefore, the actual probability calculation is performed in two variants. In a first variant, the input variables are considered as statistically dependent, then, in the second variant they input into the calculation independently. One of the aims of this paper is also to determine the extent to which statistical dependence affects the resulting probability of failure.

4.1.2 Calculation model

To determine the resulting failure probability of the building envelope structure based on heat-moisture conditions there were used ProbCalc software [5], which uses the above-mentioned DOProC method.

Probabilistic reliability assessment of water vapor condensation on the building structures surface could be based on reliability function analysis, which is possible to defined e.g. in form (as in [10]):

$$RF_{(\mathbf{X})} = f_{R_{si}} - f_{R_{si,cr}} \tag{5}$$

where **X** is the vector of random input variables. Then can be expressed reliability criterion in the form:

$$f_{R_{si,cr}} \leq f_{R_{si}} \rightarrow f_{R_{si}} - f_{R_{si,cr}} \geq 0 \rightarrow RF_{(\mathbf{X})} \geq 0\,. \tag{6}$$

Failure to comply with condition (6) is a negative in terms of reliability, i.e. fault condition, when the temperature factor of the internal structural surface is less than its critical value. By performing an analysis of the reliability function (5) can then obtain the probability of failure P_f:

$$P_f = P\left(RF_{(\mathbf{X})} < 0\right) = P\left(f_{R_{si}} - f_{R_{si,cr}} < 0\right). \tag{7}$$

Any non-zero value of failure probability represents a potential threat to the structure in terms of surface water vapor condensation and subsequent mold growth.

4.1.3 Calculation results

In the first calculation, where the input variables describing the state of the internal environment of the building were used as mutually statistically dependent, the probability of failure was set as zero with a minimum value of the reliability function of 0.146538. From this result it is obvious that, on the basis of the measured data and performed probabilistic calculation, a fault of structure should not occur. The calculation result is obvious from Figure 6. Then, in the second computing model, there are the input variables defined as mutually independent and they have been characterized by individual histograms using directly measured values. In this case, the probability of failure is also determined as 0 with a minimum value of reliability function 0.110967. As in the previous case, also from this probability (Fig. 7) it is clear that the risk of structural damage is minimized in real conditions. Comparison of both results of these simulations points to the fact that if the interdependence of input variables is considered, the resulting probability of structural failure is lower. If the input variables are considered as statistically independent the calculation result is more conservative.

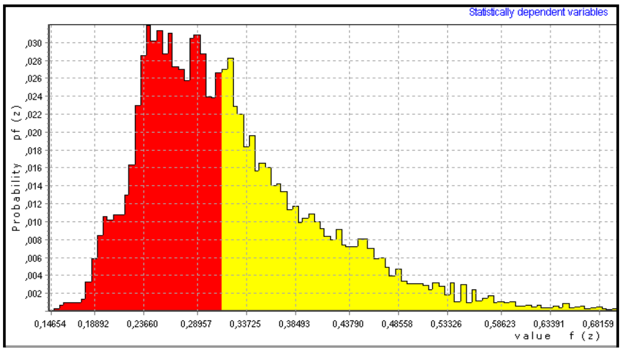


Fig. 6: Histogram of reliability function (5): statistically dependent input variables
(range 0.15 to 0.68, median 0.310760) (5)

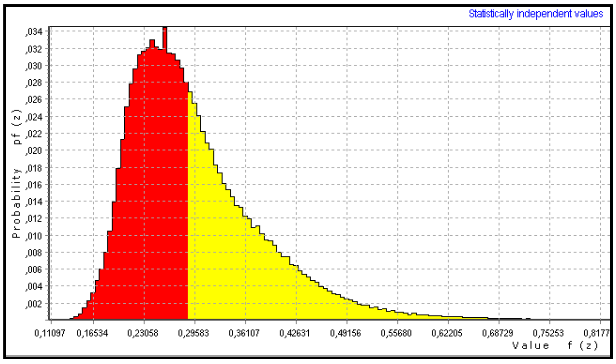


Fig. 7: Histogram of reliability function (5): statistically independent input variables
(range 0.11 to 0.82, median 0.284952)

5 Example of Using Probabilistic Calculation in Energetics

In the following part of article there is shown an example of probabilistic calculation which is used to determine the optimal number of solar thermal collectors, with regard to the actual usefulness of solar energy.

5.1 Design of solar system

Calculation and the subsequent design are dependent on a number of input variables, which are usually presented as constants. Data, which these constants are determined from, are not current often. Another issue is their significant variability depending on the specific climatic and environmental conditions in the monitored area. Individual values involved in the calculation are detailed below.

5.1.1 Solar energy

Average annual value of radiant flux of solar energy which reaches the earth surface is called the *solar constant* and its value is equal to G_{SC}=1367 W/m^2. This radiant power is not constant over time, but it varies depending on an Earth-Sun distance (the movement of the earth in an elliptical orbit). Passage of light through the atmosphere leads to its scattering and solar radiant flux decomposes into two components - diffuse and direct. The total solar irradiance G [W/m^2] is then the sum of these two values. This unit is variable in range of 100 – 1000 W/m^2 and its actual value is directly depending on cloudiness and pollution. For this example of calculation there are used values for mountain areas.

5.1.2 The amount of solar energy and sunshine hours

Very important value for the design of solar collectors is theoretically possible daily dose of total solar irradiance $H_{T,day,teor}$ [MJ/m^{2}a], which is determined by integrating the total solar irradiance of earth area from sunrise to sunset.

$$H_{T,day,teor} = \int_{\tau_1}^{\tau_2} G_t d\tau \qquad (8)$$

This value is tabulated in the literature, but it is only valid in bright sunny days. However, during the day, it becomes more important the diffuse radiation $H_{T,day,dif}$ [MJ/m^{2}a]. The real dose of irradiation $H_{T,day,}$ [MJ/m^{2}a] can be expressed by the relationship (9). The relative amount of sunshine τ_r [-] then by equation (10).

$$H_{T,day} = \tau_r \cdot H_{T,day,teor} + (1-\tau_r) \cdot H_{T,day.,dif} \qquad (9)$$

$$\tau_r = \frac{\tau_{real}}{\tau_{teor}} \qquad (10)$$

The value τ_{real} is the real time of sunshine, which was obtained by measurements from the meteorological station. Theoretical time of sunshine τ_{teor} is calculated from declination δ for characteristic days of each month. This value is shown in table 2.

Table 2: Used tabulated values

Month	$H_{T,day,teor}$ [kWh/m^{2}day]	$H_{T,day,dif}$ [kWh/m^{2}day]	$G_{T,m}$ [W/m^2]	τ_{teor} [h]	$t_{e,s}$ [°C]
1	5,35	0,31	636	8,26	-3.5
2	6,59	0,44	674	10,12	-3.6
3	7,93	0,66	676	12,00	-1.7
4	8,73	0,87	646	13,90	1.7
5	8,97	1,06	589	15,70	6.6
6	8,83	1,22	549	16,34	9.6
7	8,80	1,18	562	15,70	11.6
8	8,57	1,04	602	13,90	11.9
9	8,03	0,80	647	12,00	9.7
10	6,97	0,54	665	10,12	5.5
11	5,67	0,36	640	8,26	0.9
12	4,86	0,27	612	7,85	-2.0

5.1.3 Selection of solar collector

In this theoretical case it was chosen a flat selective collector. It´s parameters are described in table 3 below. Also the real orientation and slope of is not known, so for the calculation there are used idealized values – the slope of 45° and azimuth 0° (the direct South).

Table 3: Technical data of selected collector

Efficiency with zero temperature gradient η_0	0,854	-
Linear coefficient of heat lose a_1	3,37	W/m^{2}K
Quadratic coefficient of heat lose a_2	0,01	W/m^{2}K^2
The area of absorber	2,373	m^2
Weight	49,2	kg
Glazing thickness	4	mm
Maximum working pressure	10	bar
Thickness of insulation	60	mm
Maximum working temperature	120	°C

5.1.4 Efficiency of solar collector

The middle efficiency of solar collector η_k during the day is determined as:

$$\eta_k = \eta_0 - a_1 \cdot \left(\frac{t_{k,m} - t_{e,s}}{G_{t,m}}\right) - a_2 \frac{(t_{k,m} - t_{e,s})^2}{G_{t,m}} \qquad (11)$$

The average temperature $t_{k,m}$ of heat transfer fluid in the solar system during all the day is 40 ° C (set for solar coverage of 35 - 70%). Average temperature at the time of sunshine $t_{e,s}$ is given in table 2.

5.1.5 Theoretical gains of solar collectors

Theoretical heat gains in month $Q_{k,u}$ [kWh/month] are set as:

$$Q_{k,u} = 0.9 \cdot \eta_k \cdot A_k \cdot n \cdot H_{T,day} \cdot (1-p) \cdot D \qquad (12)$$

Where: p=0,1 is heat lose coefficient of solar system

A_k	area of one collector
n	number of collectors
D	number of days in month

5.1.6 Demand of heat for hot water

As an evaluated object for the purpose of this article it was chosen mountain chalet with capacity of 90 persons in restaurant and 12 for accommodation. The proposal of mean daily hot water needs is based on calorimetric equation (13) its results are shown in Table 4.

$$Q_{HV} = \frac{V_{HV,day} \cdot \rho \cdot c \cdot (t_{HV} - t_{CV})}{3.6 \cdot 10^6} \qquad (13)$$

The total heat demand for hot water preparation must also contain heat loss of tray. For central tray without circulation is the heat loss determined as z = 0.15.

$$Q_{p,c} = (1 + z) \cdot Q_{HV} \qquad (14)$$

Table 4: calculation of hot water need

-	Number of units	Hot water need per unit [l/day]	Total hot water need [l/day]
Accommodation capacity	12	35	420
Restaurant capacity	90	15	1350
Totally			1770

Table 5: calculation of total heat demand for hot water preparation

Temperature of cold water	10	°C
Temperature of hot water	55	°C
Density ρ	1000	kg/m^3
Specific heat capacity c	4184	J/kg·K
Q_{HV}	92,57	kWh/day
$Q_{p,c}$	106,45	kWh/day

5.1.7 Solar coverage of heat demand for hot water preparation

The solar coverage is the ratio between the total usable gains of solar system $Q_{ss,u}$ and the overall heat demand for water heating Q_{pc}.

$$f = \frac{Q_{ss,u}}{Q_{p,c}} \qquad (14)$$

In the case of design of solar collectors just for hot water preparation it is ideal to choose the solar coverage of 60%. When the solar coverage increases, on the other hand, the specific solar gains decrease. This effect leads to oversizing of all the system. Then it is necessary to solve the problem with solar surpluses in summer period. In this case there will be also rated 100% coverage.

5.2 Input variables for the calculation

5.2.1 Histograms of used variables

This calculation includes totally 8 variables which were described in theoretical part – chapter 5.1. They are listed in the following table. Also there is described the type of used distribution, minimum and maximum values that characterize these variables.

Table 6: Input variables

Sign.	Variable name	Type of distribution	Min.	Max.
1	Overall heat demand for water heating Q_{pc}	Normal parametric distribution	60	150
2	Number of days in month D	Nonparametric discrete distribution	28	31
3	Theoretically possible daily dose of total solar irradiance $H_{T,day,teor}$	Nonparametric discrete distribution	4.8	8.8
4	Dose of diffuse radiation $H_{T,day,dif}$	Nonparametric discrete distribution	0.27	1.17
5	Real time of sunshine τ_{real}	Nonparametric discrete distribution	21.8	308.2
6	Theoretical time of sunshine τ_{teor}	Nonparametric discrete distribution	7.9	16.1
7	Median of total solar radiation $\mathrm{G_{T,m}}$	Nonparametric discrete distribution	550	675
8	Mean temperature at the time of sunshine $\mathrm{t_{e,s}}$	Nonparametric discrete distribution	-3.5	11.6

The input values used for creating histograms no. 2-4 and 6-8 are the data obtained from the literature. For each month there is given one value and based on this there are created histograms with nonparametric type of distribution, where each value has the probability of 1/12 = 0.083. The input data for histogram no. 5 are meteorological data obtained in meteorological station in the locality where the object is really situated. Creation of histogram no. 1 was described in chapter 5.1.6. All the used histograms which are shown below were created in software HistAn [ ].

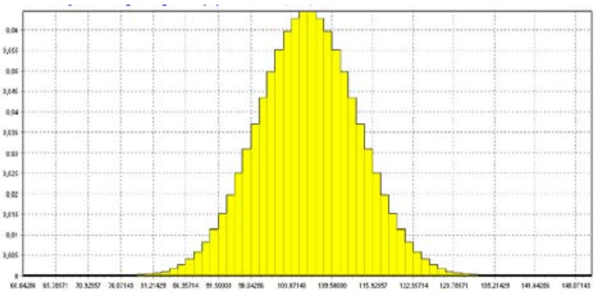


Fig. 8: Histogram 1 – $Q_{p,c}$

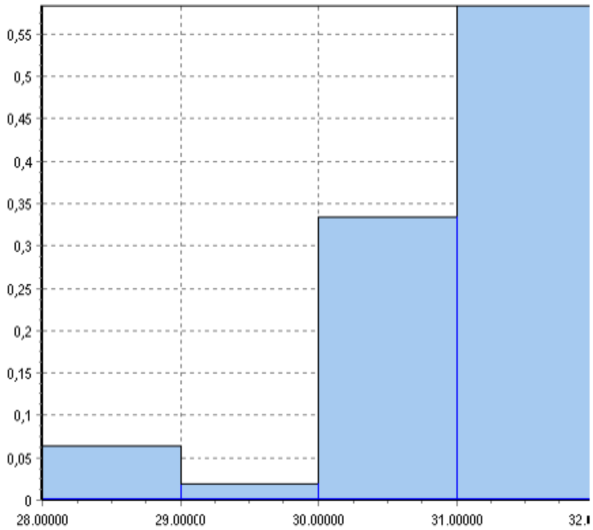


Fig. 9: Histogram 2 – D

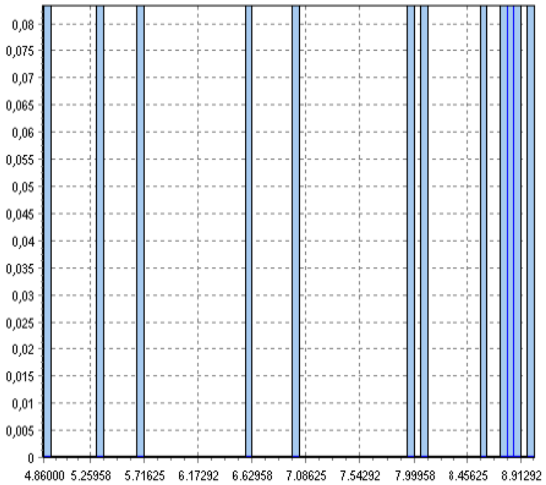


Fig. 10: Histogram 3 – $H_{T,day,teor}$

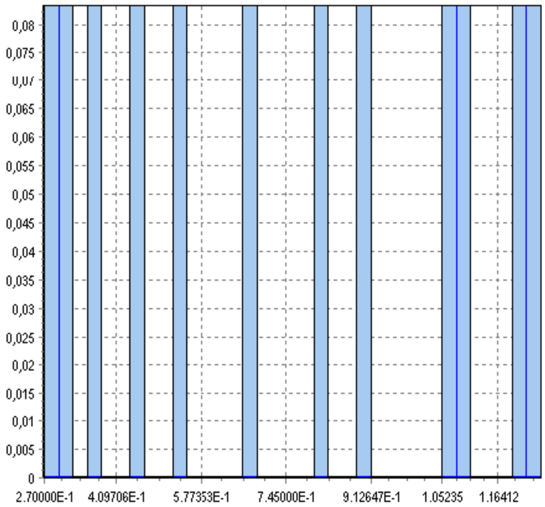


Fig. 11: Histogram 4 – $H_{T,day,dif}$

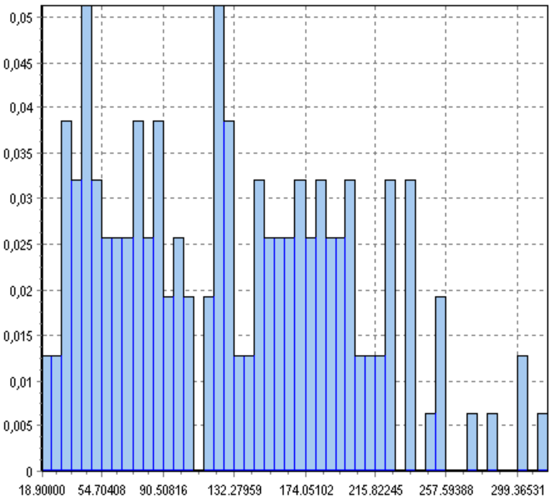


Fig. 12: Histogram 5 – τ_{real}

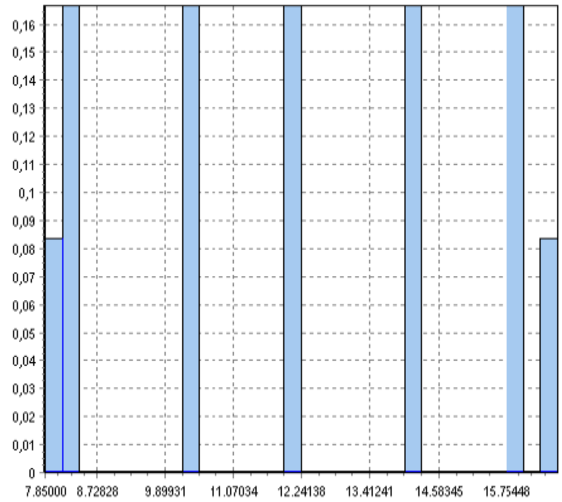


Fig. 13: Histogram 6 – τ_{teor}

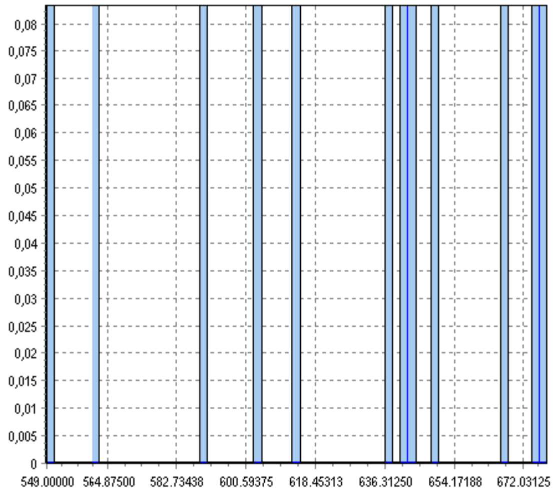


Fig. 14: Histogram 7 – G_{tm}

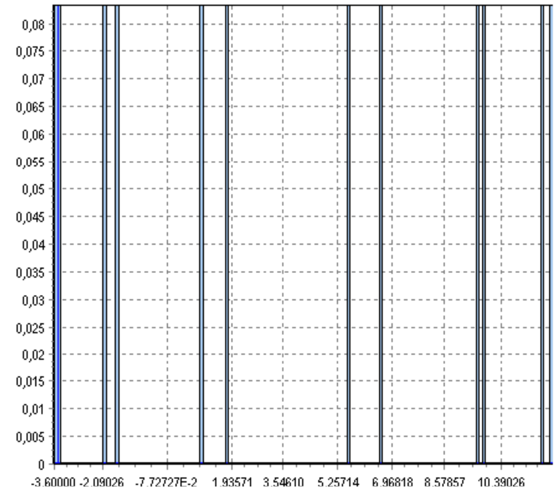


Fig. 15: Histogram 8 – t_{es}

5.2.2 Deterministic values

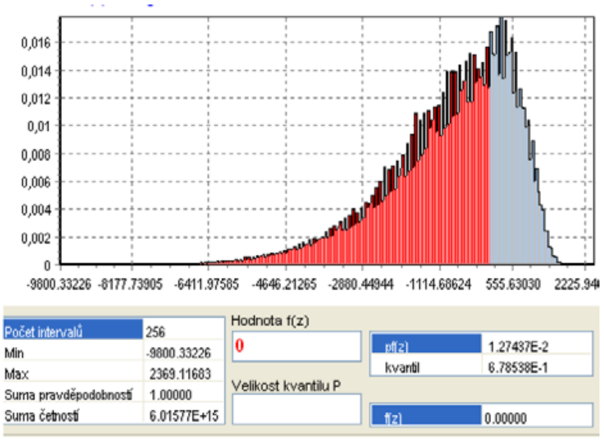
The calculation of solar system also contains several primary values, which were entered as constants into the computational model. There is their summary in the table 7.

Table 7: Constants entered into calculation

Sign.	Type	Value	Unit
A_k	Absorber area	2.373	m^2
a_1	Linear coefficient of heat lose	3.37	W/m^2K
a_2	Quadratic coefficient of heat lose	0.01	W/m^2K^2
η_0	Efficiency with zero temperature gradient	0.854	-
p	Correction of thermal gains	0.1	-
t_{km}	Average temperature of heat transfer medium	40	°C
f	Solar coverage factor	0.6	-

5.3 Probabilistic calculation of the coverage of heat demand using DOProC method

For the probabilistic calculation it was used ProbCalc software. It has been preserved the possibility of changes in the number of solar collectors n and also the possibility to change the coefficient of solar coverage f. The calculation was performed for two different variants of solar coverage (RF1 = 60%, RF2 = 100%). All the results are shown in table 7 and graph 1. In figures 16 and 17 there are shown output histograms of reliability function RF1.



Počet intervalů	256
Min	-9800.33226
Max	2369.11683
Suma pravděpodobností	1.00000
Suma četností	6.01577E+15

Hodnota f(z)
0

Velikost kvantilu P

pf(z)	1.27437E-2
kvantil	6.78538E-1

f(z)	0.00000

Fig. 16: histogram of RF1 for n = 24 pcs, ProbCalc software

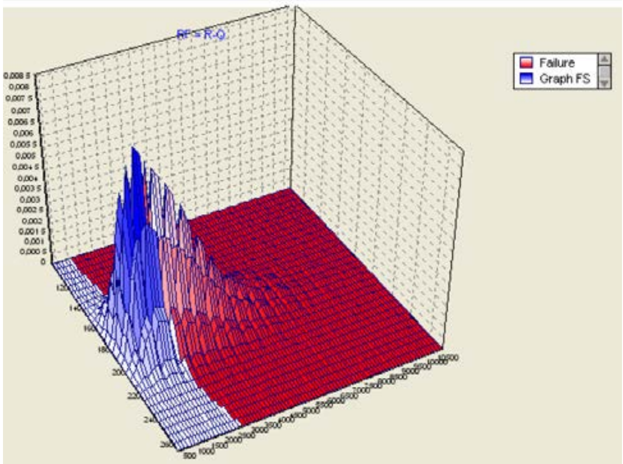
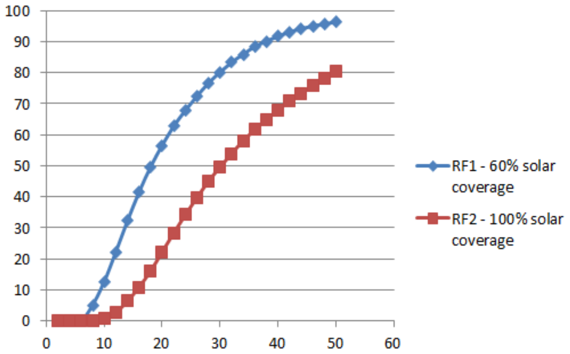


Fig. 17. Spatial histogram of RF1 for 24 pcs of collectors where the red area shows the probability of 60% coverage (Failure)

Table 8: Results of probability function RF1 and RF2 obtained from ProbCalc software

No. of collectors	RF1 (60%)	RF2 (100%)	No. of collectors	RF1 (60%)	RF2 (100%)
2	0	0	26	72.51	39.77
4	0	0	28	76.67	45.02
6	0.08	0	30	80.22	49.62
8	5.02	0	32	83.39	53.97
10	12.73	0.82	34	85.98	58.11
12	22.29	2.84	36	88.45	61.65
14	32.3	6.35	38	90.18	64.92
16	41.5	10.91	40	91.77	68.02
18	49.72	16.11	42	93.14	70.86
20	56.61	22.27	44	94.18	73.36
22	62.85	28.40	46	95.07	75.99
24	67.85	34.24	48	95.76	78.36
			50	96.39	80.38



Graph 1 - probability functions based on the number of solar collectors

5.3.1 Optimal choice of solar collector number

Determination of optimal number of collectors depends on many other factors that can´t be primary taken into account in the calculation. In this case it is possible to expect that solar surpluses can be used to preheat the heating water. In particular, it can be used in summer period, when temperatures of outdoor air can fall very low at night and therefore the chalet need to be heated. Having regards to all these aspects it is possible to determine the optimum number of collectors. The graph 1 shows, that in the area between 22 to 30 panels the growth of probability function is stabilized. Further increasing of collector number leads only to slow growth of the functions of the solar coverage. Based on this simulation as the most optimal number of solar collectors it was set 24 pieces. The probability of 60% coverage is approaching 70%, as it is obvious in table 8.

5.3.2 Advantages and limitation of probabilistic calculation

+ Universality of calculation: a simple change of input histogram allows applicability of calculation to any object and solar system.

+ Calculation based on the elementary data: for creation of the histogram there can be used long-term measurement data obtained directly at the place of the proposed building.

+ Apposite graphical outputs. Based on them it is possible to observe a noticeable variability of rated values and probability functions.

- The input data for the desired amount of hot water may be different during the year.

- It has to be ensured the applicability of the necessary amount of solar collectors with regard to construction system of building.

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6 Conclusion

In the previous paper there were introduced basic probabilistic methods of calculation which can be advantageously used for evaluation of building structures. Their applications are primarily known and widely used in the field of building mechanics, but also they are very effective for application in the field of building physics to ensure the reliability of structure in real design conditions. Also there are described possibilities how to use probability assessment as an optimization tool for design of energetics system.

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