Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 11 (60) No.1 - 2018

RESEARCHES REGARDING THE USE OF PREDICTIVE RELIABILITY STUDIES TO PERFECTING THE CALCULUS AND THE DESIGN OF GREENHOUSES LOCATED ON THE ROOF OF BUILDINGS

Eduard C. BADIU[1] **Gheorghe BRĂTUCU**[1]
Daniel C. COŞARCĂ[1]

Abstract: *The paper proposes and demonstrates the possibility of using predictive reliability studies for the improvement of sizing calculations and the design of greenhouses located on the roofs of buildings. Starting from a well-established rooftop greenhouse model, its structural and logical reliability schemes are compiled, and then the predictive reliability of the components and the assembly is calculated using the exponential distribution time law, where the failure rate is constant. Based on the use of the accepted data in the speciality literature, are calculated the values of the predictive reliability of the greenhouse over time intervals, and by analyzing them, intervenes on the safety coefficients used in the sizing calculations.*

Key words: *rooftop, predictive reliability, estimated calculations*

1. Introduction

Reliability is the probability that any equipment, in this case a roofed greenhouse, will perform its specific functions without failures for a specified period of time under specified working conditions. In recent decades, reliability has become a technical condition, a parameter in product design, manufacture and exploitation, and one of the basic issues of current technology [1].

The bases of the reliability of any product are set into the elaboration period, when the structure is established and dimensioned. In the design it is necessary to choose the materials correctly, to determine the maximum loads, to assess the durability of the product, to make an orientative calculation of reliability, to foresee the likely appearance and the nature of the falls, as well as the measures for their

[1] Department for Engineering and Management in Food and Tourism, *Transilvania* University of Brașov, Castelului Street no. 148, Brasov 500014, Romania;
Correspondence: Gheorghe Brătucu; e-mail: gh.bratucu@unitbv.ro.

prevention or removal. The reliability of this stage in the product life, in this case the roofed greenhouse, is called preliminary (predictive or projected).

Reliability is ensured in the manufacturing process by the correct choice of the materials of the semi-finished products, the processing processes and the technological equipment, by observing the cutting regimes, by ensuring a fitting in which the adjustments in the joints are within the prescribed limits. Also, the control on each operation and the final one must be executed with the required requirement, and the SDVs that ensure the interchangeability and the correctness of the execution are checked as often as possible. Gearing on sub-assemblies and finishing must be done with great responsibility, so that any malfunctions are highlighted before the product is delivered to the customer. On the basis of experimental tests in the conditions closest to those in operation, a number of experimental (or manufacturing) reliability indicators can be appreciated.

Reliability is maintained by using appropriate methods of preservation, commissioning and, in particular, the way in which the technical equipment is used (in this case the roof greenhouse), thus understanding the methods and periodicity of the technical status checks, the quality of the maintenance and technical revisions and, in particular, the quality of the repairs. The reliability of this stage in the life of technical equipment is called operational reliability (effective at the beneficiary) [5].

By estimating the predictive reliability of a greenhouse, it is understood that predictions are made on the value of the reliability indicators of the strength structure or the greenhouse units that are projected, based on previous experience, relative to the behavior of similar greenhouses.

Regarding the predictable reliability of the greenhouses placed on the roofs, the following considerations are required:

- The predictive reliability analysis can be a basic tool in designing roof greenhouses on the one hand to predict their performance in terms of reliability and on the other to optimize the design of the greenhouses, in the sense of ensuring a certain level of reliability. The importance of designing the predictive analysis of the reliability of these greenhouses is justified by the fact that 40 ... 80% of their reliability is determined by the quality of the project;
- Operational reliability of greenhouses is generally lower than their predictive or experimental reliability. To a great extent, the "loss" of the reliability of the greenhouses placed on the roofs is due to the variability of the manufacturing and installation process;
- Another source of differences between predictive and operational reliability is the conditions of use of the respective greenhouses. From this point of view it is necessary to take these factors into account in the calculation of the predictive reliability by means of environmental coefficients;
- Whereas the predictive reliability is estimated at the greenhouse design stage, there is a tendency to impose the predicted parameters as quality specifications. Predictable reliability indicators provide only an indicative value of greenhouse performance, the significance of which should be considered as such, in the formalization of its specifications;

- The calculation of predictive reliability is of crucial importance in the design of complex equipment security, for which a failure is a critical phenomenon (nuclear power plants, flight equipment etc.), the greenhouses placed on the roofs can be included in the vicinity of this category;
- The predictive reliability analysis addresses the period of normal operation of these greenhouses, where the failures are of a random nature with a relatively constant and stable rate. For this reason, most of the predictive reliability estimates are based on the exponential distribution pattern, with a constant failure rate.

The predictive analysis is based on previous experience on the testing or operation of identical or similar components under identical or similar conditions to the equipment under consideration.

2. Material and Method

The object of predictive reliability research is a typical greenhouse pattern located on the roof of a building like the one in Figure 1 produced by the North American company Nexus Corporation.

Fig. 1. *Types of greenhouses produced by Nexus Corporation USA [9]*

The calculation of the predictable reliability of a roofed greenhouse requires the following steps [8]:

- Establishing the functional model of the greenhouse;
- Establishing its reliability scheme;
- Determination of possible constraints and / or similarity coefficients;
- Assessing the predictive reliability of the greenhouse.

The functional model represents a schematic of the structure of the analyzed seed, i.e. the principle scheme or the block diagram of the greenhouse operation. This model should play the best way of interconnecting the elements of the greenhouse. For example, Figure 2 shows the structural-functional model of a greenhouse located on the roof of a building, as in Figure 1, in which the notations have the following meanings: 1 -metal roof liner; 2 - connecting elements (screws etc.) between the floor reinforcement and the basic profile of the metal structure of the greenhouse; 3 - basic profile of the metallic structure of the greenhouse; 4 - connecting elements (screws, welding lines, etc.) between the base profile and the metallic structure of the greenhouse; 5 - metallic structure of greenhouse; 6 - bills fixed to the metal structure for supporting the glass doors and windows; 7 - the windows and doors of the greenhouse; 8 - elements for fixing the transparent materials of the roof and the side walls on the metal structure of the greenhouse; 9 - transparent materials of the roof and the side walls of the greenhouse. In a more detailed representation each profile of the metallic structure of the greenhouse could be included in its structural-functional scheme.

Fig. 2. *The structural-functional model of a greenhouse located on the roof of a building*

It is noted that the structural-functional elements of the greenhouse whose model is shown in Figure 1 are connected in series.

The reliability scheme is the structural-functional-logical scheme of the greenhouse, which highlights the effect of the behavior of each structural element on the overall greenhouse behavior from the point of view of reliability. The logical reliability scheme allows for a logical follow-up of how faults of component parts lead to the failure of the greenhouse. Figure 3 presents the logic scheme of greenhouse reliability whose functional model is shown in Figure 2.

In principle, the notations are similar to those in Figure 2, with the following additions: 2^{I}, 2^{II}, 2^{III} etc. represents all the connecting elements between the metal reinforcement of the floor and the basic profile of the greenhouse; 4^{I}, 4^{II}, 4^{III} etc. - all the connecting elements between the basic profile and the metallic structure of the greenhouse; 7^{I}, 7^{II}, 7^{III} etc. - all glass doors and windows; ^{8I}, 8^{II}, 8^{III} etc. - all the elements of fixing the transparent materials of the roof and the side walls on the metal structure of the greenhouse; 9^{I} - transparent roof material; 9^{II} - transparent material of the side walls of the greenhouse.

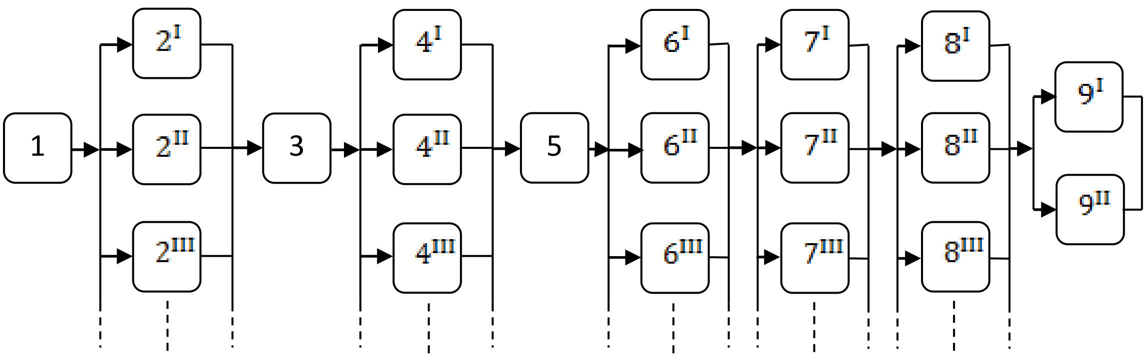

Fig. 3. *The logical scheme of greenhouse reliability whose functional model is shown in Figure 3*

It is found that in the logic scheme of greenhouse reliability of Figure 3, the links between the component elements form a mixed system, i.e. a combination of serially connected elements and parallel-linked elements.

3. Estimating of the Predictive Reliability

The intuitive estimation of predictive reliability consists of predictions provided by experts in terms of subjective judgments based on past personal experience [6]. Given the profoundly subjective nature of these estimates, the method is only recommended when designing equipment with a pronounced novelty character that can not be appropriate, similarly, to previous experimental results, or when there is no availability for a longer more thorough study. However, the method is useful in designing, for example, in optimizing the selection of expected components for making a whole new greenhouse.

Estimation by extrapolation of predictive reliability is a more consistent method than the intuitive method, based on catalog or experimental data, relative to components or equipments identical or similar to those of rooftops. To take account of the constructional or functional particularities of these greenhouses, the correction / average coefficients are estimated. Estimation of reliability by the extrapolation method is performed according to the statistical model specific to the analyzed seed as well as available data base.

When estimating the predictive reliability in the hypothesis of a statistical model of exponential type, the usual reliability ratios, assuming an exponential model of the time distribution of good behavior of the greenhouse (t), which is the objective of a predictive analysis, are presented in Table 1.

Availability D, if the analysis also relates to the repair of the respective greenhouses, is D= MTBF / (MTBF + MTR), where MTBF is the average of the greenhouse running time, and the MTR is the average repair time (Trouble Removal). It means that at this stage, it is also necessary to predict the repair parameters - the average repair time (MTR), the repair rate (t), the repair function (maintenance) M (t).

For the exponential law of failures manifestation times, the calculation relationships for a part of the reliability indicators are shown in Table 1.

Table 1

Relationships for the calculation of reliability indicators by the exponential law [3]

Function	Calculation relationship
Average time for good operation [m]	$m=\frac{1}{\lambda}$
Intensity of failure (fall rate) [z (t)]	$z(t) = \lambda = \text{const.}$
Reliability function [R (t)]	$R(t)=e^{-\lambda t}$
Function of time offset (Unreliability function) [F (t)]	$F(t)=1-R(t)$

In the case of a series system (Figure 2), the failure rate of the system is given by the relation [2]:

$$\lambda_S = \Pi_{i=1}^{n} \lambda_i, \qquad (1)$$

where:

λ_s represents the failure rate of the system;

λ_i - the defect specific rate to the sub-assemblies / components of the greenhouse. The failure an element provokes in this case the failure of the whole system.

The reliability of the serial system has the expression:

$$R_S(t) = e^{-\lambda_S t}. \quad (2)$$

When connecting the elements in parallel (Fig. 3, in part), the system reliability becomes:

$$R_S(t) = 1 - \prod_{i=1}^{n}\left[1 - e^{-\lambda_i t}\right] \quad (3)$$

In this case, failure of an element does not cause the whole assembly to interrupt, but only the part served by that element.

In the case of the mixed connection (Fig. 3), the reliability of the system becomes:

$$R_s(t) = e^{-\lambda_j t} \cdot \left\{1 - \Pi_{i=1}^{n}\left[1 - e^{-\lambda_i t}\right]\right\}, \quad (4)$$

where: the index *j* refers to the product of the series-linked elements, and the index *i* refers to the elements connected in parallel.

Relationships (2), (3) and (4) are used in the calculation of all reliability indicators, not just the reliability function for which these formulas are explicitly written.

The main aspect in estimating predictive reliability with the Exponential Distribution Law is the failure intensity (drop rate) λ = const.

Table 2 shows the lower, average, and higher values of the constant failure rates λ of the components of the reliability logic scheme of a greenhouse located on the roof of a building, shown in Figure 2.

Table 2

Indicative values of constant failure intensities of components of the logical reliability scheme of a greenhouse located on the roof of a building [3], [7]

No. crt.	Elements of the schematic diagram of the greenhouse structure	Inferior limit, $x10^{-6}$/h	Mediate, $x10^{-6}$/h	Upper limit, $x10^{-6}$/h
1.	Metal fitting of the roof floor	0.004	0.011	0.022
2.	Connecting elements (screws etc.) between the reinforcement of the floor and the basic profile of the metallic structure of the greenhouse	0.97	29	49.5
3.	The basic profile of the metal structure of the greenhouse	0.05	0.25	0.55
4.	Connecting elements (screws, welding lines, etc.) between the base profile and the metallic structure of the greenhouse	0.90	32	45
5.	Metallic structure of the greenhouse	0.09	0.22	0.42
6.	Hinges fixed to the metallic structure to support the greenhouse doors and windows	1.12	2.5	12
7.	The greenhouse doors and windows	0.88	3.44	7.75
8.	Connecting elements of the transparent roof and side wall materials on the metallic structure of the greenhouse	0.65	1.625	2.60
9.	Transparent material of the glass roof	7.55	25.88	65.55
10.	Transparent material of the side walls of the greenhouse	5.35	17.20	27.32

Table 3 presents the calculation of the reliability function R (t) for the component parts of the logic scheme of reliability of the greenhouse located on the roof, using the time interval *Δt.* Determination of the failure interval size *Δt (i)* is done using the relation (5) [4]:

$$\Delta t = \frac{t_{max} - t_{min}}{1 + 3{,}3 \lg \sum n_i}, \quad (5)$$

where: t_{max} and t_{min} represent the moments of manifestation of the last and first fall of an element, in hours, and n_i the number of falls recorded on that element. If considered t_{max} = 5000 *h*, t_{min} = 500 *h*, n_i = 150 results Δt = 550 *h*. Simplified was the same number of time intervals for calculating the predictive reliability of all the elements of the reliability scheme. In Table 3, numbers 1 to 10 represent the elements of the roof greenhouse logic scheme, as specified in Table 2. The reference time t for calculations is the half of each time interval determined by relation (5). Referring to the schemes of Figures 2 and 3, in which the transparent materials of the roof and of the lateral vertical walls are considered to have identical functions, noting together at position 9, in the effective calculation of the predictive reliability presented in Table 3 it was not possible to disregard the real differences between the materials of the two types of surfaces, occupying positions 9^{I} and 9^{II}.

The calculated predictive reliability values presented in Table 3 allow many more interpretations, such as:

- For the 10th structural components of the roof greenhouse, the reliability varies differently over the 5000 hours of surveillance;
- The best reliability (probability of being in the correct operating condition) is found in the metal reinforcement of the roof floor of the building on which the greenhouse is located, namely 0.999949;
- The weakest reliability behaviors are found in the connecting elements (screws, welding lines, etc.) between the basic profile and the metal structure of the greenhouse (0.861052), the connecting elements (screws, etc.) between the floor reinforcement and the profile the basic metallic structure of the greenhouse (0,873214) and the transparent roofing material of the greenhouse (0.886044);
- The predictive reliability of the greenhouse on the roof is much lower than its components (their product), so after 5,000 hours it is reduced to 0.592035;
- It should be noted that the safe elements in the predictive reliability calculation model presented in Table 2 are only the average values of the constant failure rate, while the 5000 hours surveillance interval and the number of falls (150) represent only possible values.

When using the literature data, the constraints imposed for each set of data can apply, because most of the existing data is extracted from the general tables. In this context the environmental coefficient k_M is applied environmental and thus relations (2) and (3) become:

- for the serial system:

$$R_S(t) = e^{-k_M \lambda_S t} \quad (6)$$

- and for the parallel:

$$R_S(t) = 1 - \prod_{i=1}^{n} \left[1 - e^{-k_M \lambda_i t} \right] \quad (7)$$

Table 3

Values of predictive reliability $R(t) = e^{-\lambda t}$ *for the components of the greenhouse reliability system, specified in Figures 2 and 3*

No. comp. / Δt	λ **x10^-6**	275	825	1375	1925	2475	3025	3575	4125	4675
1.	0.011	0.999997	0.999991	0.999985	0.999978	0.999973	0.999967	0.999961	0.999955	0.999949
2.	0.29	0.992057	0.976359	0.960910	0.944334	0.930740	0.916013	0.901518	0.887253	0.873214
3.	0.25	0.999931	0.999794	0.999656	0.999506	0.999381	0.999244	0.999107	0.998969	0.998832
4.	32	0.991239	0.973945	0.956954	0.938756	0.923855	0.907738	0.891901	0.876341	0.861052
5.	0.22	0.999940	0.999819	0.999698	0.999566	0.999456	0.999335	0.999214	0.999093	0.998972
6.	2.5	0.999313	0.997940	0.996568	0.995075	0.993832	0.992466	0.991102	0.989740	0.988381
7.	3.44	0.999054	0.997166	0.995281	0.993229	0.991522	0.989648	0.987777	0.985910	0.984047
8.	1625	0.999553	0.998660	0.997768	0.996796	0.995986	0.995096	0.994207	0.993319	0.992432
9^{I}.	25.88	0.992908	0.978875	0.965041	0.950171	0.937955	0.924699	0.911630	0.898746	0.886044
9^{II}.	17.20	0.995281	0.985910	0.976627	0.966601	0.958323	0.949300	0.940362	0.931508	0.922738
$R_s(t)$	-	0.969636	0.911646	0.857124	0.801357	0.757667	0.712353	0.669750	0.629695	0.592035

For the mechanical components for the mechanical components of some technical equipment, the environmental factor k_M is shown in Table 4.

Table 4

Values of the k_M *coefficient for several areas of use [7]*

Areas of use	k_M
Laboratory	1,0
Stationary equipment	16
Shipbuilding	28
Car vehicles	36
CF rolling stock	50
Aviation	120...160
The teleghid projectiles	280
Rockets	700

Table 5

The values of the predictable reliability of the roof greenhouse, calculated on the components and on the whole, on the estimated timeframes, taking into account the environmental coefficient k_M = 25

No.crt/ Δt	275	825	1375	1925	2475	3025	3575	4125	4675
1.	0.999924	0.999773	0.999622	0.999471	0.999320	0.999168	0.999017	0.998866	0.998715
2.	0.992057	0.976359	0.960910	0.945705	0.930740	0.916013	0.901518	0.887253	0.873214
3.	0.999931	0.999794	0.999656	0.999519	0.999381	0.999244	0.999107	0.998969	0.998832
4.	0.991239	0.973945	0.956954	0.940259	0.923855	0.907738	0.891901	0.876341	0.861052
5.	0.999940	0.999819	0.999698	0.999577	0.999456	0.999335	0.999214	0.999093	0.998972
6.	0.999313	0.997940	0.996568	0.995199	0.993832	0.992466	0.991102	0.989740	0.988381
7.	0.999054	0.997166	0.995281	0.993400	0.991522	0.989648	0.987777	0.985910	0.984047
8.	0.999553	0.998660	0.997768	0.996877	0.995986	0.995096	0.994207	0.993319	0.992432
9^{I}.	0.992908	0.978875	0.965041	0.951402	0.937955	0.924699	0.911630	0.898746	0.886044
9^{II}.	0.995281	0.985910	0.976627	0.967432	0.958323	0.999168	0.940362	0.931508	0.922738
$R_s(t)$	0.969565	0.911447	0.856812	0.805453	0.757172	0.749799	0.669118	0.629010	0.591305

Greenhouses located on the roof can be considered, to a certain extent, stationary equipment, for which k_M = 16. In fact, the greenhouses on the roofs are exposed to important wind and weather demands, which is why we recommend the value k_M = 25. In this case, the values of the predictive reliability function $R(t) = e^{-k_M \lambda t}$ for the components of the greenhouse reliability system specified in Figure 2 are those shown in Table 5.

4. Conclusions

If a comparison is made between the values of the predictive reliability of the structural elements of greenhouses or of a greenhouse considered as a system, presented in Table 3 and those presented in Table 5, where the correction of the drop rate with the environmental coefficient is k_M = 25, it is noted a reduction of these values, which implies a more prudent approach in the design calculations of roof greenhouses for the rate of failures provided by the literature.

The great advantage of using the predictive reliability study for the calculus and design of the mechanical structures, including greenhouses located on the roofs of buildings, consists in the possibility of correlating the behavior of their components in exploitation, so that by observing the specific preventive maintenance activities it is possible to avoid accidental failures occurring at random times, which can cause serious physical or financial damage to the greenhouses.

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