SOFTWARE FOR RELIABILITY TESTING OF THERMOMECHANICAL INSTALLATIONS

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Abstract:

The aim of this paper is to present the application of Auto Desk software: Revit on Heating, Ventilation and Air condition building installation systems. Determining the reliability of a number of components that are installed also plays an important role in the design of such systems. In this context, the authors developed software for determining the probability of rendering system components using probability theory. An overview of the application of this software as well as the Revit program is given in the paper. The software package was applied to establish the failure of individual components of the thermo technical installation in a larger complex of buildings. Characteristic of this analysis is that the probability of failure of each component weighs zero, while the number of components weighs infinity. The software package was developed for various probability analyzes that are accessed through several different probability distributions. This analysis can be applied to different industries. The need for failure analysis in thermo technical has arisen within the theory of system reliability and is useful for companies engaged in the maintenance of thermo technical installations and fire protection systems of larger residential and business complexes. The paper presents the specifics of the installation on the one hand, as well as the software package that was applied to solve specific tasks, where the Poisson probability distribution is established as appropriate.

Keywords:

HVAC systems, Revit, Poisson distribution, Reliability, Probability analyses.

INTRODUCTION

The analysis considered in the paper is applied to Heating, Ventilation and Air condition (HVAC) systems in residential and business complexes. However, the HVAC system's pipe network in buildings is highly branched and contains pipes of different diameters. This means that the water and therefore the heat are distributed unevenly, and some consumers get more heat than others. The consumers farthest from the pump are supplied with too little heat, and those nearest the pump get too much. As soon as one room occupant turns on the heat, another area of the building will inevitably get less heat. It means that the water is distributed in the optimal way. With hydraulic balancing, all components in the hydraulic system are matched and balanced, ensuring that energy is distributed evenly throughout the system.

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Some of the components exposed to a higher risk of failure and necessary for reliable operation of the system are: Valves, filters and thermostats. To create a balanced hydraulic system with standard control valves, you first need to determine the design flow rates and calculate the pressure losses across the whole hydraulic network. Then you'll determine the valve type, size, and proper flow coefficient. HVAC valves are such components without which we cannot control flow in pipes. Valves are needed for every media whether it is water, gas, air or any other liquid. The thermostat is the control for the entire HVAC system in your home or office. Most people are familiar with this part of their HVAC system as they've used it before. This small appliance is situated on a wall at the most used level of your home or office. You can use it to set the desired temperature for the room. Many people have upgraded to what are known as smart thermostats. These allow you to control the thermostat from anywhere you have an internet connection and they're fully programmable. An HVAC filter is a filter that is used in a heating, ventilation and air conditioning system. The filter increases the efficiency and longevity of the HVAC system by protecting it from dust and airborne particles. It is therefore an integral, yet often overlooked part of the system. In addition to protecting the HVAC system from damage, some HVAC filters are designed to improve the quality of the interior air. In order to check the reliability of each key component of the system Poisson distribution was to be applied and establish the most probable number of them being malfunctioned.

2. RELATED WORK

Description of the aim explored in the paper is based on the references based on the HVAC itself as well as on the optimisation process represented by the distribution of probability of reliability of the system components. In the papers [1] and [2] authors have made focus on design layout in order to improve the reliability of each HVAC system component. The goal of such analysis is minimizing the repetitive process of system. In these papers graphical visualization of the reached progress in the Building Information Modelling (BIM) model is presented. Authors have presented optimizing the construction process by which they allow an immediate and intuitive understanding of the status of a construction project. In the paper [3], the primary purpose of the authors is to present the way of data collection in order to increase the effectiveness of the database by increasing the quantity and quality of the information through facility reliability/availability assessments. However, only forming of databases is presented without probability analyzes and without mathematical methodologies in order the process will be optimized. On such way production failure could be minimized and estimation of the reduction of the time associated with various systems or subsystems could be realized. In paper [4] authors present all the technical information related to an efficient design proving the benefits and necessity of the requirement. This paper presents a complete design of a Heating Ventilation Air Conditioning (HVAC) system for battery rooms using modern components and techniques to achieve a cost effective design. In paper [5] authors give practical example of BIM which assumes total amount of components to be installed by a certain task on-site in order to estimate reliable way for duration of the task itself.

3. AIM OF RESEARCH

In this paper the HVAC building system is analyzed. Graphic representation of the mechanical installation model system was done in the Auto Desk software package: Revit program, Fig.1. Complet duct system with all its components could be designed and locate the main critical points, as well as major conflikt points caused by ducts intersection. Great number of fiting parts have dominant role in HVAC building instalation. Among them, three considered elements were selected as representative having in mind their mass application in the HVAC building system. These selected elements are: valves, filters and thermostats.

In order to create a balanced hydronic system with standard control valves, it is neccessery to determine the design of flow rates and calculate the pressure losses across the whole hydronic network. Then it is to be determined the valve type and size, proper flow coefficient, to define type of filters as well as of thermostats.

Statistical analysis is applied to each of the key components listed above. By such analysis it was possible to establish the mathematical expectation of each component failure. Based on this data, it is calculated the probability that more components, than allowed number of them, will be malfunctioned in relation to the total number of each of them. In the paper is presented the methodology, as well as application of software based on it and realized by authors of the paper in order to calculate the reliability of population consisted of 1500 valves, 1000 filters and 500 thermostats.

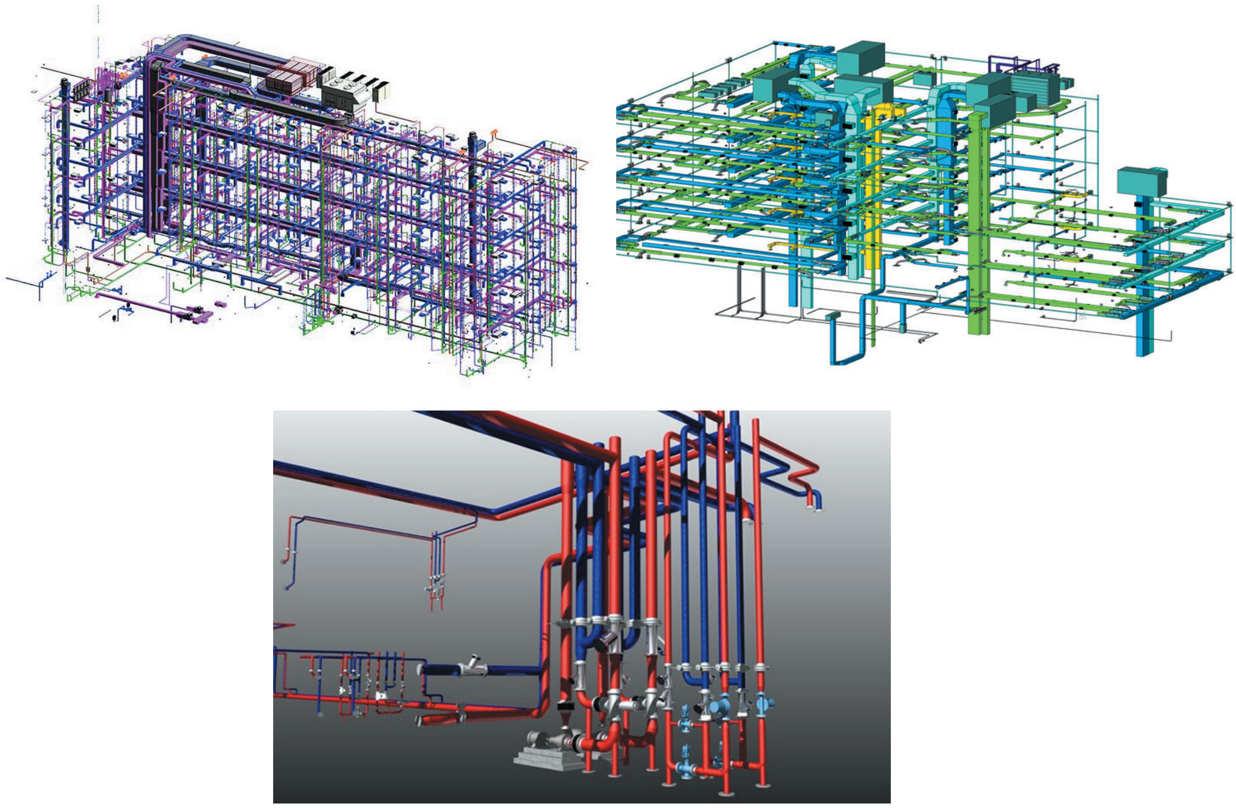


Figure 1 – Overview of Mechanical and plumbing installations in Revit

The probability of arbitrarily selected valve sample is 0.1%. The probability of arbitrarily selected filter sample is 0.5%, and the probability of an arbitrarily selected thermostat sample is 0.1%. The assessment of mathematical expectation of the number of the malfunctioned parts of each component individually is established.

Main goal of research is application of Revit software on HVAC thermo - technical installation, globally, and realize high level of reliability all its components.

The methodology and software for the inspection of reliability, presented in this paper, are applicable to a different number of considered samples and different probability of failure of each of them in different branch of industry.

4. MATHEMATICAL MODEL FOR EXPLORING OD RELIABILITY OF HVAC KEY COMPONENTS

The mathematical model for process optimization is based on the application of the event probability distribution. In that sense, the establishment of the probability of failure of system components is realized with the support of probability distribution models and statistics as well as with software support. The appropriate distribution for the analysis is Poisson's, and the basic settings of the method are given below. The basic premise for the application of this distribution is a very large number of samples and a very small probability of events, malfunctions, concrete components. For that reason, we start from the binomial distribution, which is based on combinations of realization: k times and non-realizations: $(n\text{-}k)$ times in n attempts. The probability of occurrence of the event is: p and non-realization: q. Probability that the event will be realized in n attempts is:

This binomial distribution, (1), tends to exponential:

$$P_{binomna} = \binom{n}{k} p^k q^{n-k} /_{k=1, n\to\infty, p\to 0} \to P_{eksponencijalna} = e^{-\lambda}\frac{\lambda^k}{k!} /_{k=1} = e^{-\lambda}\cdot\lambda, \text{fig.2.} \quad (2)$$

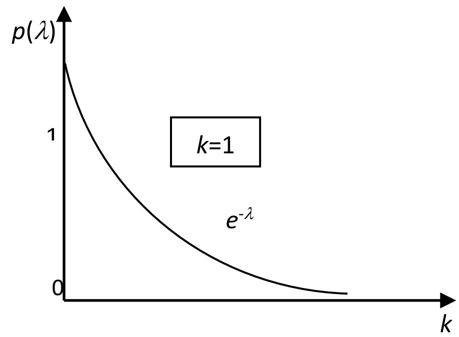


Figure 2 – Exponential distribution of probability

$$B(n,p) = P\{S_n = k\} = \binom{n}{k} p^k q^{n-k}; k = 0....n, \text{ where} \quad (1)$$

$$\binom{n}{k} = \frac{n\cdot(n-1)\cdot....\cdot(n-k+1)}{k!}$$ - represents number of combinations.

It is valid:

$$n\to\infty, p\to 0, q\to 1, \lambda = n\cdot p, k = 1. \quad (3)$$

However, when: $k > 1$ in (3), the exponential distribution shifts to Poisson distribution, fig. 3, (Siméon Denis Poisson, 1781 - 1840), on which the papers: [6] and [7] are based on. This distribution is in the form of:

$$P\{A_k\} = e^{-\lambda}\frac{\lambda^k}{k!} \quad (4)$$

Distribution (4), [8] and [9], is characterized by: n and k, $0 < k < 20$. Here λ refers to the mathematically expected number of samples in which the failure occurred.

In this case, k, fig. 3, refers to the characteristic number of samples. This number is the limit and great amount of probability is expected to be that the sum of malfunctions of particular part will not be greater than imposed. The aim is to establish the probability that the number of samples, in particular, of defective components will be higher than the limit. Two conditions are imposed:

- the probability that the number of samples is greater than the limit must not be significant, greater than allowed,
- if the limit number of samples is greater than 20, a number significantly less than the total number of samples, the premise of adopting the Poisson distribution as valid is not applicable.

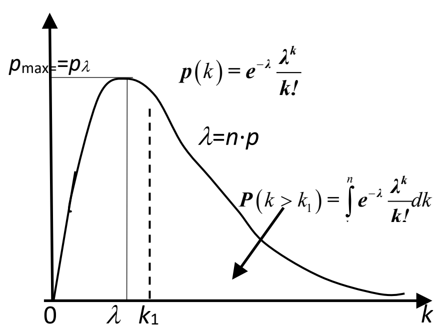


Figure 3 – Poisson distribution of probability

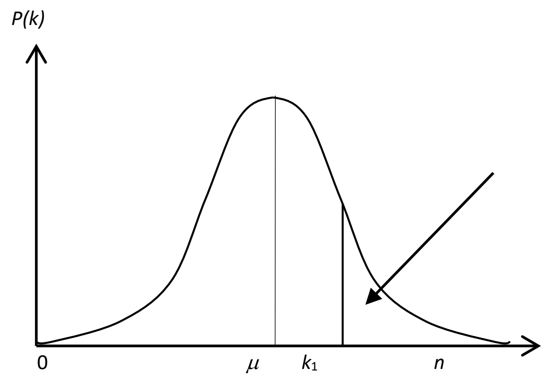


Figure 4 – Gaussian distribution of probability

In that case, another distribution from the family of Γ distributions, [10], is adopted, most often Gaussian, [11], fig. 4, in the form of:

$$P\{S_n = k\} = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(k-\mu)^2}{2\times\sigma^2}} . \qquad (5)$$

Characteristics of this distribution are:

$$n \to \infty,\ \mu \approx n \cdot p, \text{k>20} \qquad (6)$$

but not the imposed condition from previous: $p \to 0$. Here, μ represents assessment of mathematical expectation for the limit number of realizations: k in n attempts. Parameter σ represents deviation of the distribution.

In any probabilistic analysis, the premise is that it is appropriate that the risk of accepting the assumed distribution be up to 5%. Testing of the premise is realized by Pearson x^2 test, [7], by x^2 distribution, fig. 5.

Expression for x^2 is in the form:

$$\chi^2 = \begin{cases} \dfrac{x^{\frac{k}{2}-1} \times e^{\frac{x}{2}}}{2^{\frac{k}{2}} \times \Gamma\left(\dfrac{k}{2}\right)}, x \geq 0 \\ 0, \quad x < 0 \end{cases} ,$$

$$\Gamma\left(\frac{k}{2}\right) = \int_{x=0}^{x\to\infty} x^{\frac{k}{2}} \cdot e^{-x} dx = \left(\frac{k}{2} - 1\right)! k \in \{C\}. \ (7)$$

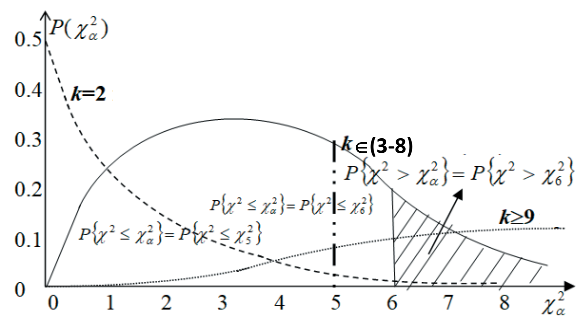
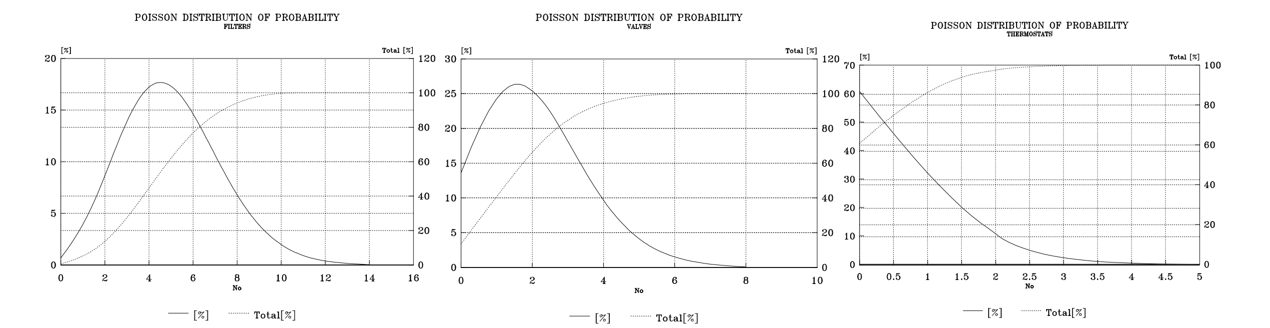


Figure 5 - x^2 distribution

5. RESULTS HAVING ACHIEVED BY SOFTWARE: "POISSON" APPLIED TO MATHEMATICAL MODEL FOR EXPLORATION OF RELIABILITY OF KEY COMPONENTS OF HVAC INSTALLATION

In order to explore the reliability of mechanical and plumbing installations authors of this paper have developed the software: "POISSON" for establishing the percentage of malfunctions of the key components of the system. Software used for analysis is based on Poisson's, fig. 3, Gaussian, fig. 4, and x^2 distribution, fig. 5, as key ones as well as on the others but which are not applied to this analysis. x^2 distribution, (7), is applied to testing the premise that adopted distribution is appropriate for analysis. Software is realized in QBASIC program language, while graphic presentation is realized in Harvard graphics. Results of analyzes are presented by diagrams which represents distributions and cumulative curves of the number of sum of defective key components of the system depending to malfunction of the particular part, fig. 6.



a.) b.) c.)

Figure 6 – Distributions and cumulative curves of the number of sum of defective valves, filters and thermostats depending to malfunction of the particular part

On fig. 6 is clearly visible that graphic of probability distribution character moves from the shape similarly appropriate to Gaussian distribution, (5), fig. 6 a, over Poisson distribution character, (4), fig. 6 b, to exponential, (2), fig. 6 c. Such shifting from symmetrical graphic shape to exponential one is depending on parameters: n, p and λ, according to (3) and (6). It is to be established the percentage that the number of malfunctioned samples of each component being tested greater then the number of malfunctioned samples that has imposed to be minimal. Such percentage depending to malfunction of each component as well to the imposed number of failed number of samples allowed to be minimal is presented by diagrams, fig. 7. Total number of samples per component, taken in research, is equal to 1500, 1000 and 500 unites, referring to each components.

Results of the analysis realized by software are given below.

Poisson distribution of Probability
VALVES

Probability of particular valve malfunction: 0.2 [%]

Probability that number of malfunction parts is greater then 4 is 38[%]

Poisson distribution of Probability
FILTERS

Probability of particular filter malfunction is 0.4 [%]

Probability that number of malfunction parts is greater then 5 is 22 [%]

Poisson distribution of Probability
THERMOSTATS

Probability of particular valve malfunction is 1[%]

Probability that number of malfunction parts is greater then 4 is 55 [%]

6. CONCLUSION

The paper presents a model of installation in buildings realised in the Revit program and gives a concrete example of the analysis of the HVAC system components. Primary role of this software is design of installations as well as defining and locating conflict points on them. The other contribution is presentation of the results have got by applying software: “POISSON” realised by authors.

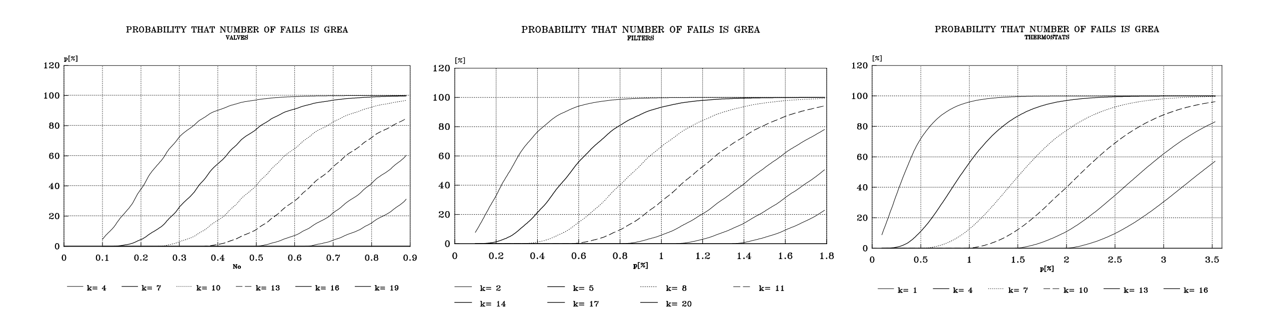


Figure 7 – Percentage of failed valves, filters and thermostats depending to the limit number of the parts allowed to be malfunctioned and to the dysfunction of the particular key component

Last mentioned software is yoked with software for graphic presentation: Harvard Graphics what integrally result the analysis of reliability of the whole installation. Building Information Modelling assumes complete design with calculation of the reliability each crucial component.

Graphics presented on the figures above demonstrate the specifics of the software "POISSON" which is convenient to calculate the probability of wide range different populations. What more, it is considered for each premise for probability analysis to be tested by Pearson x^2 test. On such way it is possible to consider the results of probability analysis has been applied, as adequate and to accept them for calculations that follow. Software: "POISSON" is proved by a lot of analysis, firstly Gaussian, Poisson, and on family of Erlang distributions on the field of Queuing theory, [12]. The specific of the paper is integration of Revit software, POISSON software and Harvard Graphics as complete unit giving relevant results for Building Information Modelling and reliability calculation.

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