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Risk management of windows performance

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Abstract

Glazed windows have a long history and good practice has been established. Nevertheless, failures still occur. This is usually the case when the systemic approach to the design change was not adopted.

Risk management technique based on systemic approach is proposed as a tool supporting the choice of design/retrofitting strategy. The failures concerning windows are categorized. Many problems encountered today with windows are related to the destructive action of moisture. The qualitative and quantitative approach to system failure based on risk analysis theory is described and the examples concerning condensation on glaze pane of windows are provided.

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Keywords: windows; building; system; reliability; risk management.

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1. Introduction

Glazed windows date back to the Roman times. Around 100CE they began to appear in Alexandria, and gradually spread over the Empire. Hence, they have a long history and good practice has been established. But failures still occur. They are partly due to poor understanding of the physical phenomena and partly to the unexpected results of applying newer technology. Certain design changes, aiming at achieving improvement in one performance aspect, can have unexpected and not studied negative effects on another aspect. This is usually the case when the system approach to the design change is not adopted. For example in eighties to improve the energy efficiency of buildings the design promoted small area of windows sometimes not adequate to deep spaces.

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2. Reliability of windows – systemic approach

Window is a part of a façade which is a component of the building/environment system described in [1]. The main function of the system is to ensure comfort and health of inhabitants. Because the system failure leads to a functional failure, they can be analysed from the user perspective [2]. Windows face the demands concerning

- Provision of:
  - sufficient access of natural light,
  - an attractive aesthetics,
  - linking to outdoors,
  - security,
  - energy, when glass is used as an energy system (collecting and producing).
- Protection against the impact from environment through:
  - thermal insulation,
  - sound insulation,
  - durability – keeping form, strength and functions through varying interior-exterior climate conditions during specified time,
  - shelter against wind and rain,
  - safeguards against pollutants.

The reliability of a window performance depends on the design concept and its implementation. Applying reliability science that is concerned with the mechanisms and events leading to the object's failure seems adequate.

Reliability is defined as the ability of a system to operate (to perform within specified limits) under designated conditions for a specified period of time. Unreliability means probability of failure. It could be illustrated as in Fig. 2, where the reliable operation is assumed when a relative humidity φ is within the interval (0,R). Hence, reliability is expressed by the integral of pdf (probability density function) of φ over that interval and the probability of failure P_f (expressed by the shaded area in Fig. 2) is a complement to reliability, it means P_f=1-Reliability.

When coping with failures four major reliability tasks are involved in the analysis: design reliability, system reliability, inherent reliability and field reliability that can be defined as:

- *Design reliability* – reliability evaluated at the design stage (on the product level). It responds to the knowledge about the uncertainty and variability coupled to the significant variables and theirs interconnections. It includes also uncertainties related to the quality of modeling tools and the level of expert-knowledge applied.
- *System reliability* – sort of design reliability related to various levels of system analysis.
- *Inherent reliability* - reliability of a produced object that depends on the variation of quality. It deals with the effect of the manufacturing process of materials and components.
- *Field reliability* - reliability based on actual performance. It depends on many sources of failure like workmanship, aging, as well as difficult to post-evaluate overstresses coming from the local environment.

3. Risk management for design/retrofitting tasks

The procedure of a decision making about the design/retrofitting strategy is a case for application of risk management techniques [3]. According to ISO 31000, a *risk management process* is one that systematically applies management policies, procedures, and practices to a set of activities intended to establish the context, communicate and consult with stakeholders, and identify, analyze, evaluate, treat, monitor, and review risk**.** Risk management can be then a useful tool to cope with failures by decreasing the object/system vulnerability to hazards and eventually preventing or reducing property damage. A general framework of risk management for design/retrofitting of buildings is proposed. It includes a probabilistic part that finds the proper context of application (Fig. 1).

Risk is treated as a function of the systemic context, probability of failure, and the adverse consequences of failure. The components of risk analysis and management shown in Fig. 1 can be treated as optional depending on the character of the task and possibilities and constraints of decision making.

Retrofitting strategies can include redesigning of the whole structure or only substitution of a component or changing of a material. The solutions can be the emergency short time solutions or the fundamental ones. The consequences over time should be traced. Systems approach makes possible to create a holistic view of the hazards and the consequences associated with design/retrofitting inputs [1]. The key variables should be identified. The questions arise: Is it possible, in relation to the addressed performance, to decompose the system into separate subsystems? Which aggregation level is the most proper one in the context of specific objective? What are the significant interconnections between variables? A qualitative and quantitative approach help to answer these questions.

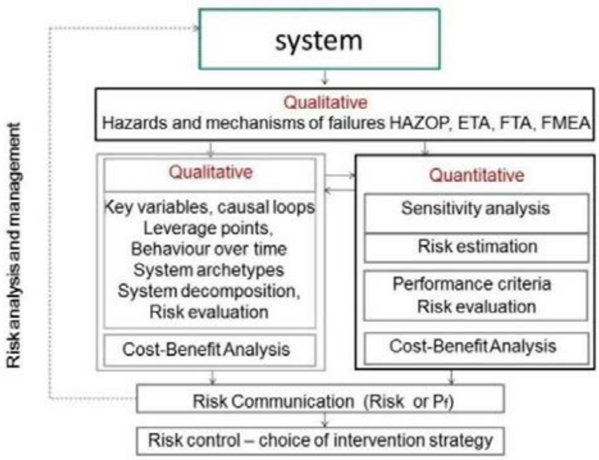

Fig. 1. Risk management procedure that could be applied for design/retrofitting tasks.

First stage - Qualitative description – Systems thinking for qualitative risk analysis includes definition of the problem, description of the mechanisms of failure, identification of the key variables and relationships amongst them, analysis of the behaviour over time, recognition of the system archetypes (behavioural patterns associated to the specific structure), and the identification of the leverage points - the sensitive points in a system's structure where a solution element can be applied. Deductive and inductive methods like Fault Tree Analysis and Event Tree Analysis are used for qualitative risk assessment that may seek to identify alternative scenarios for the risk outcome, the possible implications of these scenarios etc.

Second stage - Quantitative description – It includes mathematical descriptions, computer simulations, probabilistic risk assessment, reliability analysis etc. For risk/reliability studies of building serviceability, probabilistic characteristics of a variable representing a building performance aspect should be evaluated. To achieve this, a model is applied based on the significant input variables. The qualitative procedure addressing the whole system leads to the decomposition suggestion, which could be examined by the quantitative sensitivity analysis. Risk evaluation studies based on the criteria for satisfactory performance leads to the establishment of probability of failure and/or reliability concerning selected performance aspects.

Generally, both stages of the analysis can lead to developing of the intervention strategies and to theirs implementation in case when the cost-benefit analysis gives acceptable results and risk communication leads to acceptance of the proposed solution. If not, the feedback loop leads to redesign of the building system.

4. Risk management of windows performance

Window with the structural and environmental context is treated as a subsystem of a building/environment system. Risk reduction can be accomplished by decreasing the expected loss from a particular type of a hazardous event. This can be done by reducing the likelihood of an event (*risk prevention* or *risk elimination*), by reducing the expected loss if the event happens (*risk mitigation*), or both. Mitigations measures can have pro-active character but also can be implemented to cope with adverse effects of hazardous events.

The reliability problems with windows refer to those described in chapter 2 and could be categorized as follows:

1. Design failures (for the new and retrofitted objects)
2. Durability failures
3. Manufacturing failures (defects)

4. Installation failures
5. System failures resulting from the application of a window in a specific building/environment system

4.1 Qualitative analysis

The problems encountered with windows depend on their construction (product level), its interaction with the façade (component level) and the whole building and its nearest environment (whole system level). In Table 1 some failures are listed, together with the explanation of their roots, physical consequences, functional consequences, and suggested remedies based on qualitative evaluation of the problems. They refer to the presented in chapter 4 classification of failures (1-5). The examples given below are based also on [5,6,7].

Table 1. Windows – examples of failures.

Kind of failure	Design details contributing to failure	Mechanism of failure	Physical description of failure	Functional description of failure	Mitigation of risk of failure by changed system design
1	Secondary double glazing by additional frame attached to the inner side of an existing single-glazed window frame	Reduces the temperature of the inner surface of the original single glazing while normal room air is closed in a gap between glazing that leads to condensation (inside a window)	Water drops on the inner glazing	Decreased aesthetics Decreased access of day light	Efficiently sealing both the original and the secondary glazing and providing a moisture absorbent within the air gap
2	Wooden frame	Weathering, deteriorating, Interstitial condensation	Fungal decay on the frame Physical damage	Decreased aesthetics	Preservation treatment wood coatings, using impermeable vapour barrier paint on the interior surface and permeable paint on the exterior surfaces
3	Glazing that has not been cut strictly square and has snags, with metal frames	Thermal movement for an aluminium frame is much higher than for glass causing stress through the frame in cold weather	Glass fracture	Decreased thermal security, access of day lighting aesthetics	Quality control of glazing
4	Component assembly of the window	Bad workmanship of installation	Cracks, discontinuity of gaskets	Poor sound insulation of the building facade	Quality control of workmanship, education
5	Exposure of a window to sun radiation	Electromagnetic waves come through the glass and after absorption by material are converted to heat	Increased heat gain	Overheating	Applying reflective film, solar shading devices
5	Exposure of a window to wind	Wind cooling Wind noise is caused by air passing through or over orifices Wind pressure	Increased heat loss Noise (whining) Increased air infiltration	Decreased thermal comfort Deterioration of comfort draft	Adding storm sashes Applying weather strip, also for exclusion of draught and noise
5	Exposure of a window to driving rain	Wind driven rain is pushed to the façade causing enhanced moisture penetration	Frame deterioration (Fungal decay,..)	Decreased aesthetics	Adding storm sashes Applying weather strip Limit exposure, ensure construction easy to dry

4.2 Quantitative analysis

The Table 1 contains the qualitative description of the problems and their consequences. The quantitative evaluation can be carried out using calculation models. For example for the problem of condensation on interior surface of glass pane of low insulated window or condensation on exterior of glass pane of well insulated window (3-glass with low U-value) [4] deterministic models given in literature [8,9] can be used. However to evaluate the risk of condensation in terms of probability, the stochastic character of climatic conditions and probabilistic risk assessment model could be applied [10] as shown in Fig. 2. The chosen construction solution is then evaluated in the context of random environmental load relevant to the building location. Greatly facilitated distribution of products across different geographic zones can sometimes lead to system failure. Those can occur, when products developed and applied in one climatic/cultural environment are being used in a radically different environment. Climatic conditions, local context, building technology, level of occupation and users habits all play roll. The example has been calculated to show the quantitative input for the management of risk of condensation on the inner surface of window. It is based on the probabilistic model presented in [10]. The model is shown in Fig. 2. It gives the assessment of the probability of condensation on the glass pane of the window (described by parameters b,c,d) for chosen climatic and using conditions (the temperature T_{out} and T_{in}, the moisture content ν_{out} for Luleå city in Sweden and the relatively high moisture production G). The results of calculation of reliability and probability of failure for the 2 alternative U-values of windows are given in Fig. 2 and Table 2.

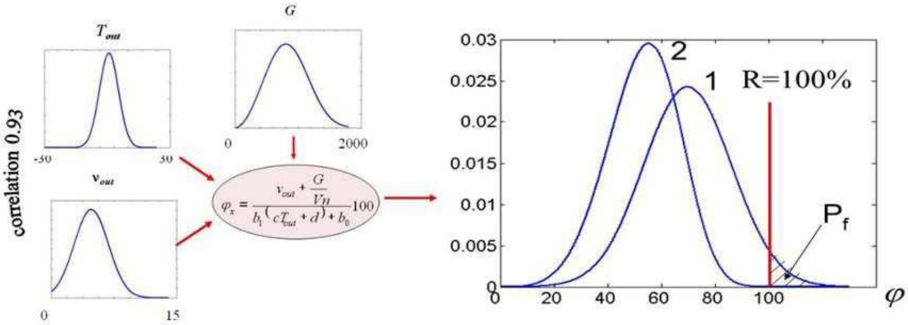

Fig. 2. Modelling flow for probabilistic approximation of the probability density function of the surface relative humidity φ [10] together with the results of analysis of the 2 cases described in Table 2.

Table 2. Probability of surface condensation.

Case	U-value W/m^{2}K	$P(\varphi_x \geq R)$ P_f	Number of hours of condensation	$P(\varphi_x < R)$ reliability
1	3.7	0.0370	324	0.9630
2	2.1	0.0004	4	0.9996

Fig. 3. Condensation on the internal gaze pane (photo K. Pietrzyk).

The results for the case 1 shows that about 324 hours of condensation on the inner surface of glaze pane (see Fig. 3) during a year can be expect. For the decision makers, the probability of failure and the following consequences could be accepted or the window should be redesigned. The evaluation of a possible damage in financial terms could proceed the decision. Design applied in case 2 could be considered.

Another example concerns the external condensation on the surface of outer pane of glass of well insulated windows exposed to clear night sky. When the thermal losses of the external glass surface do not balance the radiative cooling, the temperature of cold surface can decrease below the dew point of the surrounding air and the surface condensation occurs. As it is seen in Fig. 4 the condensation is still present for some time in the morning and disappears during the day depending on the climatic conditions (temperature, wind speed, relative humidity) in relation to characteristics of the window.

Fig. 4. Condensation on the external glaze pane of a window (photo K. Pietrzyk).

The functional failure in the form of decreased aesthetics, limited vision through the glass, scattered light in various directions can be listed. The main parameters that are important in the calculation of the probability of occurrence of external condensation are: the U-value of the glazed area, the view factor of radiation, the outdoor, the sky and the indoor temperature, the outdoor and the indoor relative humidity, the wind speed and direction in relation to the position of window. The results of deterministic calculations presented in the report [9] regarding typical year for the Stockholm climate are listed in Table 3, also in terms of probability of occurrence.

Table 3. Probability of surface condensation

Case	U-value W/m^{2}K	View factor	$P(\varphi_x \ge R)$ P_f	No. of hours condensation year (total)	$P(\varphi_x < R)$ reliability	$P(\varphi_x \ge R)$ P_f	No. of hours condensation year(daytime)	$P(\varphi_x < R)$ reliability
1	0.8	0.5	0.064	560	0.936	0.0010	90	0.9990
2	1.0	0.5	0.050	435	0.950	0.0045	39	0.9955
3	0.8	0.4	0.037	320	0.963	0.005	40	0.995

The assessed probability of condensation referring to the building/environment system (see case 1) can be the incitement to introduce the changes in the building environment to limit window exposure to the sky (decreasing probability of condensation) as is calculated for the case 3, or to introduce a window with higher U-value of glazing area of 1.0 (see case 2). The likelihood of the condensation can be also decreased by application of a low emissivity coating reducing surface emissivity of outer glaze pane. The adverse consequences of condensation can be limited by introducing a coating with special hydrophilic properties [11] allowing for formation of the water film that reduce light scattering and improve the view through the window.

5. Conclusions

A system approach for the analysis of the interrelations between structure, its environment and its performance should be applied. System approach makes possible to create a holistic view of the hazards and the consequences associated with design/retrofitting inputs.

The way of system analysis preserving the most important links and influences is a key challenge in evaluating the retrofitting strategies. Classification of failures of windows' performance is introduced referring to different levels of system analysis. Remedies to decrease the risk of malfunction are proposed. As appears from the analysis many failures relate to the interaction between the structure and its environment. The distribution of products across different geographic zones can sometimes lead to system failure. Those can occur, when products developed and applied in one climatic/cultural environment are being used in a radically different environment.

Procedure of a decision making about the design /retrofitting strategy can be treated as a case for application of risk management techniques. The general framework of risk management is proposed. It includes also a probabilistic part that finds the proper context of application. The quantitative approach based on probabilistic approximation of failure could support the decision making concerning the design/renovation strategy.

Acknowledgements

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