Research Opportunities In Maintenance Of Office Building Services Systems

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Purpose

The purpose of this study is to highlight special characteristics of building services systems and investigate how practitioners view reliability and maintenance. These characteristics include energy-hungry services systems, operating modes, maintenance types, the relationship between procurement costs and maintenance costs. The practitioners' viewpoints on reliability and maintenance are explored through a workshop. The authors wish to draw the attention of researchers in the reliability and maintenance community and furthermore emphasise the difference between building services systems and systems in industries other than construction.

Objectives

- Highlight special characteristics of building services systems in terms of maintenance.
- Confirm the main concerns of building services practitioners, on the application of reliability and maintenance methods between construction and other industries.

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Practical implications

The gap between academia and practitioners should be bridged through better understanding each other's needs. Accurately estimating the ratio between procurement and maintenance costs is needed from a whole life costing perspective.

Originality/value

This paper is a good reference for building designers, facility managers and maintenance staff of building services systems. It also offers reliability researchers references on special characteristics of building services systems.

Keywords: Maintenance, Reliability, Building services systems, HVAC (Heating, Ventilation, Air-conditioning)

Paper type: Research paper

Introduction

Building service systems encompass mechanical, electrical, security, safety, information and communication systems, among others. The systems are installed to support the required business functions of the building, here office buildings are mainly focused, and the needs of the occupiers. It is therefore essential that maintenance be carried out with minimal interruption to this, whilst still meeting the users' needs, either through reliability or maintainability to optimise whole life cost. The ability of the building service systems to continually perform interactively is of vital importance to the operational requirements.

Reliability defines the ability of an item to perform its required functions under stated conditions for a specified period of time. It is an essential factor used in assessing the performance of building services systems. Systems with poor reliability can directly or indirectly affect health, security and safety, as well as business continuity, whereas systems with high reliability may offer opportunities for less maintenance.

This paper investigates the following two important issues:

1. Special characteristics in maintaining building services systems, and
2. How practitioners view reliability and maintenance of building services systems from several aspects.

Building services systems have their own special characteristics that differ from other systems such as production lines. Such characteristics include energy-hungry systems, maintenance types, operating mode, and types of maintenance needs.

Depending on the equipment type, the ownership cost over the life cycle span may vary from ten to one hundred times the acquisition cost (Dhillon, 1989). To optimise total performance, lifecycle cost should be taken into consideration and carefully analysed at each stage of equipment life, from cradle to grave. This paper also highlights the importance of estimating the ratio on the basis of a dataset of acquisition costs and maintenance costs of HVAC (Heating, Ventilation, Air-conditioning) systems.

It is known that there is a gap between academic researchers' knowledge and practitioners' application in the reliability and maintenance community. There is a need for academia to understand practitioners' views on some important issues. This paper therefore lists nine questions and practitioners' answers to these questions.

It is also noticed that, in reliability journals, most of the maintenance models have been developed by very good mathematicians, but often with limited knowledge of maintenance. From a practical point of view, most of the models have been a fiasco and they are seldom used in practical maintenance management (Dekker, 1996). We hope that this paper can be helpful to academic researchers to gain a more in-depth understanding of the practice of building services systems and further bridge the gap between academia and practitioners.

Special characteristics

In this section, special characteristics of building services systems from a maintenance perspective are listed.

Energy and building services systems

Buildings are responsible for a large percentage of all national energy consumption. Table 1 shows statistics of energy consumption in buildings. According to the table, the main energy consumptions in both commercial and residential buildings are heating, lighting and cooling, which can be controlled by HVAC and lighting systems.

End Use	Residential	Commercial
Space heating	6.7	2.0
Space cooling	1.5	1.1
Water heating	2.7	0.9
Refrigerator/Freezer	1.7	0.6
Lighting	1.1	3.8
Cooking	0.6	-
Clothes dryers	0.6	-
Colour TVs	0.8	-
Ventilation/Furnaces	0.4	0.6
Office equipment	-	1.4
Miscellaneous	3.0	4.9
Total	19.0	15.2

Table 1: Energy consumption in buildings (Source: Interlaboratory Working Group, 2000)

Improper operation and maintenance of building services systems can lead to unnecessary energy consumption, tenant complaints, poor indoor air quality and even environmental damage. Most HVAC systems can be retrofitted to improve reliability, reduce energy consumption and meet new environmental standards.

The reliability of some systems can be strongly related to energy consumption of building services systems. For example, data centres and telecommunications switching rooms, known as central offices, provide mission-critical support to the daily operations of all kinds of organizations. Because even a few minutes of downtime can jeopardize an organization’s operations significantly, data centres and central offices must be highly reliable. But these spaces also consume high percentage of total energy of buildings; sometimes as high as 75 percent of energy. Thermal management is really the biggest issue for such places, as high temperature can be a major cause of equipment failure in the centres and central offices. It is very apparent that the mandate to reduce risk of equipment failure results in high energy costs for space cooling systems. This poses a challenge to researchers in the reliability community on introducing algorithms to balance energy consumption and equipment reliability.

Operating Modes

Building services systems, for example HVAC systems, may be installed while a building is being constructed. They are not usually used until the building is completed and commissioned. The time from the installation to the commissioning (or dormant state) may be several years, which is not a short time period. In addition to construction, buildings can also be left in a dormant state if the owner cannot find someone to occupy the building. For example, a construction company has such a building where the services have been installed and commissioned, but during the handover period, the client refused to accept the curtain walling and this has had to be replaced. Throughout this period the systems have not been in use.

Unlike other products that are usually put into use after they are sold, the building services products at a dormant the following conditions could apply:

- The products can age and deteriorate and they can therefore fail to function when they are put into use at commissioning time;
- No inspection or maintenance is conducted.

Hence, impact of the dormant (out of use) state to the reliability of building services systems should be taken into consideration when maintenance regimes are developed. However, due to a lack of failure data for systems in the dormant periods, developing optimal maintenance policies can be a challenge.

It should also be noted that some building services systems may be operated intermittently. For example, a boiler system in a building is working with various loads. It might be switched off during the summer, partially loaded in a mild winter and fully loaded in a cold winter. The failure rates of the boiler in different loads can be different; there are at least three operating modes: idle, partial load and full load in this example. Hence, properly recommending maintenance regimes are important to ensure a level of availability of the system.

Reliability-based maintenance and performance-based maintenance

In the reliability literature, maintenance is defined as

> "…any activity intended to retain a functional unit in, or to restore it to, a state in which it can perform its required function."[2]

Here, the required function is specified by the manufacturer of the equipment. Such maintenance is hereafter called Reliability-based Maintenance (RbM), as the intention of the maintenance is to improve the reliability of maintained systems. An RbM activity is carried out for the purpose of improving the reliability of systems to be maintained, and it is only based on the consideration of how well the specified required function is performed. Therefore corrective maintenance or preventive maintenance may be carried out with various scenarios.

However, building services systems may perfectly perform its required function as defined by the manufacturer but maintenance is still needed in order to meet the users' requirements. For example, a ventilation system supplies fresh air to, and removes stale air from a space. The ventilation system may become contaminated if it is not cleaned and maintained and as a consequence it could spread airborne contamination. Another example is a cooling tower that may become contaminated and therefore the whole cooling system may fail to function properly, possibly leading to the development of the organisms that cause Legionnaire's disease. Cleaning is a form of maintenance but sometimes this is not conducted to improve reliability, for example cleaning for safety, authentic and sanitary reasons is required on the product. The maintenance for this sort of failure is not associated with the reliability defined by the

[2] British Standard, 1993

manufacturer. This sort of maintenance is health and safety based maintenance (HSbM), as the intention of such maintenance is to ensure the health and safety of people.

External environmental factors, for example, the degree of cleanliness of the operating environment of a ventilation system and operating time are two key factors that may impact on the failure pattern of a building services system. Usually, a manufacturer mainly considers the failure pattern based on the intrinsic factors that a system has. It is unlikely to investigate all of the possible operating environments in which a system may work. The real failure rate of a system can be given by $r(t) = r_e(t) + r_i(t)$. Here, $r_e(t)$ represents the failure rate of the system incurred by the external environmental factors, called Extrinsic Failure Rate. $r_i(t)$ represents the failure rate of the system due to factors such as the improper design of the manufacturer and operational misuse of the system, called Intrinsic Failure Rate.

In reliability literature, preventive maintenance policies are developed on the basis of two factors: failure patterns and costs, such as business losses and costs on preventive maintenance. On developing an optimal preventive maintenance policy for building services systems, both the failure patterns and costs may be associated with more factors such as health and safety.

The failure patterns that need to be considered may include an intrinsic failure rate, external environmental factors and dormant states. An HSbM is employed to rectify the failure state of a system caused by external environmental factors whereas an RbM action is responsible for the failure caused by intrinsic factors. Maintenance policies should be developed based on a consideration of both the external environmental factors and the intrinsic factors, or failure rate $r(t)$, instead of only the intrinsic failures. As for the costs, apart from costs such as business losses and cost on preventive maintenance, more factors such as health and safety, environmental, economic, operational and company reputation, should also be considered.

Ratio of maintenance costs over acquisition costs

Evidence shows that the cost for the operation and maintenance of a building system is a significant element of its LCC. Research on the ratio for commercial office buildings has been conducted by researchers (Evans et. al. 1998; Osso, et. al., 1996). Evans et al. (1998) identified the life cost ratio covering construction, maintenance, operating and staff costs. They found that maintenance and building operating costs can be five times construction cost. Studying over a 30 year period, Osso et. al. (1996) showed that initial building costs account for approximately just 2% of the total, while operating and maintenance costs equal 6% and staff costs equal 92%. For a set of HVAC systems, Wu and Clements-Croome (2007a) estimate the following ratios:

- The ratios of maintenance costs to initial costs range from 0.45 to 1.80;
- The ratios of operating and maintenance costs to initial costs are larger than 5 and range from 4.75 to 30.

As the building services systems can vary with different building times, locations and types, it is inferred that the ratios should distribute in a certain interval rather than a fixed constant. However, developing benchmarks for such ratios can help industrialists in estimating lifecycle cost more precisely.

Practitioners' view

At a workshop on reliability of building services systems, 21 industrial practitioners and 3 academic researchers participated. These practitioners were contractors, consultants, and facility managers. These 24 people were divided into 4 groups. 9 questions were prepared for each group to answer. What follows is a list of all of the 9 questions and the answers from each of the 4 groups; the analysis was based upon our knowledge and understanding. Readers are encouraged to draw their own conclusions on the basis of the question and answers.

Question 1: How do you define reliability for the construction elements?

Answers: The ways to define reliability for the construction elements are to determine criticality of elements to meet the following conditions:

- Business needs;
- Statutory regulations;
- Robust management (might be congruence-based);
- To determine reliability from client brief by breaking down into a systems reliability model.

Analysis: It can be seen from the above answer, that the practitioners defined reliability mainly from business needs and a technical perspective, as both statutory regulations and robust management are essential for smooth operation of the business, while the last condition is a technical issue.

Question 2: How do you determine the initial reliability requirement from the briefing?

Answers: The initial reliability requirement from the briefing should be determined by considering the core business needs supplied by manufacturers, insurers and standards. The ways to do that are:

- To set reliability criteria for elements and systems;
- To analyse each individual system's reliability, then break down into each construction element's reliability.

Analysis: The practitioners might use reliability block diagrams to achieve their requirement. We can also assume that some other tools such as event trees, fault trees and FMECA (Failure Modes, Effects, and Criticality Analysis) are used for practitioners' daily work.

Question 3: How do you determine the achievement of the reliability requirement?

Answers: The ways to determine the achievement of the reliability requirement include:

- Test on commission – operation to meet design parameters;
- Data analysis based on reliability data collected.

Further action may be taken to feedback failures to the manufacturers Designers to improve the system reliability.

Analysis: Reliability validation is a time-consuming and data-oriented work. The optimal approach to validating the achievement of the reliability requirement is to estimate reliability of the objects on the basis of analysing of reliability data collected for in-service systems. However, this task is very time-consuming as less failure occurs and the data collection is not only a pure technical issue, it is also an administrative burden.

Question 4: Reliability predictions are related problems. What are they, and how can they be solved?

Answers: Reliability prediction is hard to conduct, because of the following reasons:

- Item reliability may also dependents upon installation factors;
- Change of use profiles;
- Poor communication;
- Lack of data, and inaccurate reliability data from manufacturers.

We should overcome the above mentioned shortcomings via the following means:

- To redefine reliability for a new environment;
- Effective training;
- Manage installation;
- Improve communications;
- Sign contracts for reliability (option) or warranty (extended);
- To look at the remaining life of services systems before decision making.

Analysis: Due to changes in installation, usages, loads and lack of reliability data, reliability prediction proves hard from a practitioners' viewpoint. To overcome these shortcomings, time and effort are needed from various people who might directly or indirectly be associated with the building services systems. However, it seems difficult to estimate the remaining life of services systems as various data - including operating time, environmental data, failure data, and maintenance quality - might be needed.

Question 5: How do you determine the frequency of preventive maintenance?

Answers: The following information can be used to determine the frequency of preventive maintenance:

- O.E.M. manuals;
- Experience on failures;
- Use of help-desk;
- To collect reliability data on failure for the future use;
- The operating environment.

After comparing cost of maintenance and cost of failure, condition monitoring may be applied.

Analysis: In the reliability community, there is considerable research on optimizing preventive maintenance policies (Malik, 1979; Nakagawa, 1988; Wu and Clements-Croome, 2005a; Wu and Clements-Croome, 2005b). Most of them assume that the lifetime distributions are given. However, in reality, this is rarely the case. It proves very hard to optimise preventive maintenance policies for practitioners due to a lack of sufficient failure data, which are used to fit lifetime distributions. The main issues to overcome are data collection on failures and corrective maintenance (Wu, et al, 2006).

Question 6: How do you determine in-service reliability of services systems being maintained?

Answers: The following ways may lead to solutions of determining in-service reliability:

- Wait till it breaks down;
- Use of help desk;

- Find caused effect of failure;
- Analyse against initial brief of design;
- Consider use as "sign-post" to future problems;
- Determine accurate usage;
- Use reliability databases, if any.

Analysis: Data from various sources are needed to determine the in-service reliability. The answers to Question 6 are very similar to those to Question 5. This might be due to a similarity of these two questions.

Question 7: What is the relationship between reliability and the phases of lifecycle?

Answers:

- System reliability is associated with different stages, including: concept design, micro design, macro design, commissioning, operation and disposal stages. At the commission stage, the viewpoint from the commissioning people influences whether reliability is considered or not. At the operation stage, reliability should be considered but this may not be captured. At the disposal stage, if the system (or equipment) will be re-sold its reliability will then be an important factor.
- In order to ensure system performance, monitoring the equipment, sharing information about the equipment, collecting reliability data, and training the relevant people are important features.

Analysis: In the reliability literature, most work on reliability research are dedicate to the design stage in the lifecycle of products; these include reliability design optimisation (Kuo and Prasad, 2000), burn-in policy optimisation (Ebrahimi, 2004; Wu and Clements-Croome, 2007b), and warranty cost optimisation (Blischke et.al. 1994; Wu and Li, 2007). Research in maintenance is another main focus (Malik, 1979; Nakagawa, 1988; Wu and Clements-Croome, 2005a; Wu and Clements-Croome, 2005b). However, less analysis has been conducted for the disposal stage. This might be due to second hand items cost less than brand new items.

Question 8: How to integrate reliability design into lifecycle costing?

Answers:

- From a technical point of view, reliability design should be considered in each stage, for example burn-in stage, in-service stage and wear-out stage in the whole life cycle of a system.
- During conducting design for reliability, there is a balance between cost and performance, for example the following need to be factored into the whole life cost:
    - Training strategy to retain skills performance;
    - Variable technology updates;
    - Business criticality;
    - Customer perception;
    - Budget.

Analysis: Reliability design should be integrated into lifecycle costing. However, such integration should consider various factors such as performance, managerial issues etc.

Question 9: How can academia serve industry better?

Answers:

- Traditionally, industry has not been greatly involved in academic research in developing maintenance strategies;
- There is a lack of communication between industry and academia, industry is sceptical about academia research. Some industry people think that academia research is too focussed on theory and data modelling;
- Industry finds the research on reliability and maintenance to be too fragmented to be fully understood.

A solution to the above-mentioned problems, provided by the industrial practitioners is:

- In order to build communications between industry and academia, more workshops and case studies, handbooks, introductory papers and books, are therefore needed.

Analysis: The gap between academia and industrial practitioners has existed for a long time. This gap is resulted from the fact that academic people usually hope to have their research published, although such research outcome might be unrealistic in practice. On the other hand, practitioners prefer simple tools which can improve the effectiveness and efficiencies of their daily work. Such simple tools have been available for a long time but the practitioners might not know their existence and it is hard for academic researchers to publish 'simple tools'. This is where academia and practice falls down. The gap in the middle is the actual software tool.

If analysing the above answers to the questions, it is found data collection is problematic. Astonishingly, industrial practitioners face the same problem as academic researchers who always complain they do not have sufficient data for their research. How to collect and log various reliability and maintainability related data is a challenge for both academia and industrial practitioners.

Concluding remarks

This paper reviews some special characteristics of building services systems and recalls outputs from a workshop on reliability analysis of building services systems. It shows that a lack of failure data and maintenance data is the main problem from both academic researchers' and industrial practitioner's points of view.

We suggest:

- There exists no fixed cost ratio available to apply to building services systems;
- The analysis of RAMS (Reliability. Availability, Maintainability & Safety) should include duty cycles and the environment;
- Clients of the construction industry would benefit from mandating a LCC to be applied to the build.

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