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PREDICTION COST MAINTENANCE MODEL OF OFFICE BUILDING BASED ON CONDITION-BASED MAINTENANCE

PREDYKCYJNO-KOSZTOWY MODEL KONSERWACJI BUDYNKU BIUROWEGO OPARTY O UTRZYMANIE ZALEŻNE OD BIEŻĄCEGO STANU TECHNICZNEGO (CBM)

Building maintenance costs are continuously increasing as a result of poor maintenance. Consequently, there is an urgent need to develop solutions to reduce the maintenance costs. Various studies demonstrated that the characteristics of condition-based maintenance are directly related to the cost performance. Thus, this paper seeks to establish the relationships between the characteristics of condition-based maintenance and the cost performance. The researcher then developed a regression model for maintenance planning and prediction. The study adopted a mix method approach that includes questionnaire survey, interview, and case study. The findings highlighted the reliability of maintenance data and information as the most significant characteristic of condition-based maintenance. Consequently, the study concluded that the planning and the application of the condition-based maintenance strategy should consider its significant characteristics and make reference to the resulting prediction model. Furthermore, the study recommended measures to improve the significant characteristics and the cost performance in practice.

***Keywords**: characteristics, condition-based maintenance, cost performance, office building, Malaysia.*

Koszty konserwacji budynków nieustannie rosną ze względu na nieodpowiednią konserwację. Z tej racji, niezbędne jest wypracowanie rozwiązań obniżających koszty konserwacji. Różne badania wykazały, iż charakterystyki utrzymania urządzeń zależnie od ich bieżącego stanu technicznego (condition-based maintenance, CBM) są bezpośrednio powiązane z wydajnością kosztu. Niniejszy artykuł stara się więc ustalić związek pomiędzy charakterystykami utrzymania budynków zależnie od ich bieżącego stanu technicznego a wydajnością kosztu. Następnie opracowano model regresji dla planowania konserwacji jak i predykcji. W badaniach użyto metody mieszanej łączącej badania kwestionariuszowe, wywiad oraz studium przypadku. Rezultaty podkreśliły, iż wiarygodność danych z konserwacji i informacji to najbardziej istotne charakterystyki CBM. W konsekwencji, wnioski z badań sugerują, iż planowanie i wdrożenie strategii utrzymania w zależności od bieżącego stanu technicznego powinno brać pod uwagę jej istotne charakterystyki i odwoływać się do wynikającego z niej modelu predykcji. Ponadto, praca zawiera zalecenia jakimi środkami można w praktyce poprawić istotne charakterystyki i wydajność kosztu.

***Słowa kluczowe**: charakterystyki, utrzymanie zależne od bieżącego stanu technicznego (CBM), wydajność kosztu, budynek biurowy, Malezja.*

1. Introduction

Building maintenance is the combination of technical and administrative actions to ensure the items and elements of a building are of an acceptable standard to perform their required functions. Generally, building maintenance is divided into planned maintenance and unplanned maintenance under BS3811 [25]. Planned maintenance is the predetermined tasks that are well organised and performed in advance so as to reduce or to prevent any damages to the components or items. It is subdivided into scheduled maintenance and condition-based maintenance. On the other hand, unplanned maintenance is carried out in the event of contingency maintenance without any predetermined plan after failure or damage was detected. It is subdivided into corrective maintenance and emergency maintenance [1].

Moreover, planned maintenance should be the major activity in building maintenance compared to unplanned maintenance. Otherwise, unplanned maintenance will result in frequent breakdown or downtime, and subsequently, high maintenance cost for repair and replacement works [7]. Thus, condition-based maintenance, as a strategy of planned maintenance, should be recommended to achieve the optimal maintenance expenditure.

This paper aims to establish the relationship between the characteristics and the performance through inferential analysis; then, to develop a regression model for prediction purpose. Taking into cognizance of the advantages and disadvantages of condition-based maintenance, this paper focuses on the characteristics of condition-based maintenance towards maintenance performance as shown in Figure 1.

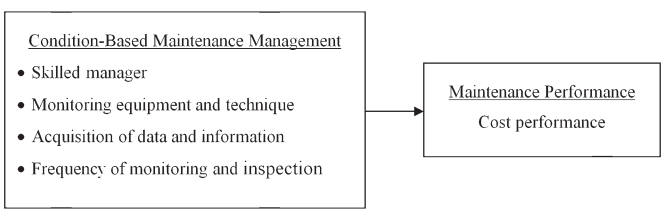

Fig. 1. Relationship between characteristics of condition-based maintenance and maintenance performance

2. High-Rise Office Building

In Malaysia, high-rise building is defined as building of more than 7 storeys (or the top floor of the building is more than 60 feet) [8]. This definition is in accordance with the Uniform Building By-Laws 1984. Despite the increasing concerns on the maintenance of buildings in Malaysia, there are few researches on the facilities and maintenance management of high rise office building.

Office buildings usually have their own maintenance management teams managed by the maintenance or the building managers to preserve the conditions of the buildings [30]. Generally, the services provided by the building managers in office buildings are cleaning, landscaping, general maintenance, lighting, heating, ventilating and air conditioning (HVAC), lift or escalator, mechanical and electrical, sanitary and plumbing, access, signage, parking and others [22]. These services are significant for office buildings as they provide functions, safety, health and comfort to the building users in daily activities.

However, building satisfaction surveys indicated that most building users were not satisfied with the building services [30]. The building users' dissatisfaction was mainly due to issues such as lack of maintenance staff, lack of expertise, lack of tools and technology, insufficient allocations and inappropriate maintenance strategies. These issues are more evident in medium-sized high-rise office building, which is equipped with more sophisticated systems, such as fire detection and protection systems, central heating, ventilating and air conditioning system, escalators and others [15].

Therefore, this study focuses on the issue related to the building users' dissatisfaction in high-rise office buildings through the examination of the characteristics of condition-based maintenance strategy towards maintenance performance.

3. Characteristics of Condition-Based Maintenance

Condition-based maintenance is defined as the maintenance initiated as a result of knowledge of the condition or significant deterioration of an item or component through continuous monitoring and routine inspection to minimise the total cost of repairs [11, 12, 17, 19, 25]. This maintenance strategy is aimed to minimise the total maintenance cost by collecting and gathering the condition data of the building systems, especially those critical components. However, the maintenance strategy might not be applicable to all building systems or assets in terms of the availability of such maintenance technology and cost effectiveness [17]. The characteristics of condition-based maintenance toward maintenance performance are stated below:

3.1. Skilled Manager

This maintenance strategy requires vigorous analysis on the data and information of systems condition and reliability, as well as financial maintenance data. Meanwhile, building managers must have proper understanding on the failure modes and rates, asset criticality, and other significant factors while implementing condition-based maintenance [11]. In order to perform condition-based maintenance effectively, there must be qualified maintenance personnel with related experience, skill and knowledge. High level of training is required for the supervisors and technicians to carry out the maintenance works include condition monitoring, routine inspection, as well as repair and replacement [6, 27]. In this circumstance, skilled manager should be able to provide or conduct training session for the maintenance personnel improve their skill and knowledge. Thus, satisfactory level of skill and knowledge of manager is required to ensure the success of the maintenance strategy.

3.2. Monitoring Equipment and Technique

According to Edward et al. [10], there is a wide range of techniques to examine the condition of specific items or assets, such as oil analysis, vibration monitoring, thermography and so on. Specific measuring and monitoring equipments are required by expertise to perform the maintenance tasks. The tools might be complicated and costly for an organisation [6]. Due to the technical complexity of building systems and the level of sophistication of monitoring tools increases, the maintenance management must be able to train and develop the skill of maintenance personnel for adaptation of new maintenance technology. Therefore, the criteria that should be taken into consideration for condition-based maintenance include:

- Availability of monitoring equipment and technique.
- Capability to adopt the monitoring technology.

3.3. Acquisition of Data and Information

Bevilacqua and Braglia [5] argued that the data and information acquisition systems are the necessary applications to perform condition-based maintenance. The documentation and record of information are essential to ensure the reliability of information about the conditions and remaining lifetime of system components. Ali [2] further explained that the conditions of buildings and systems must be considered to allocate adequate maintenance cost. Thus, the maintenance personnel should acquire the data and information regarding the conditions of building system components. In order to achieve the success of condition-based maintenance, the reliability of data and information regarding system conditions must be taken into consideration.

3.4. Frequency of Monitoring and Inspection

Condition-based maintenance can only be implemented with proper system monitoring and inspection. Tsang [28] found that the frequency of inspection must be determined, either the components are monitored continuously or inspection is performed with fixed interval, so that action can be taken in time to prevent the failures or breakdowns occur. The maintenance personnel need to identify an optimal frequency or interval of inspection to avoid over-inspection or under-inspection. Then, Hameed et al. [16] demonstrated that planning of appropriate maintenance activities prior to failure and maintenance cost is greatly influenced by the ability to monitor and inspect the condition of systems. Thus, it is necessary to identify the optimal frequency of monitoring and inspection, so that condition-based maintenance can improve the performance in term of cost-effectiveness.

4. Maintenance Performance

The development of performance measurement in management aims to improve the quality and service, as well as to meet cost parameters [4]. The measurement of maintenance performance is an assessment that helps to identify the strengths and weaknesses of the maintenance activities. In addition, the result of performance measurement indicates the effectiveness of the existing strategy. Consequently, the management team is able to plan and make appropriate decision for future maintenance strategy [13].

The measurement of performance can be obtained through the level of success or failure in terms of schedule, cost and functionality [18, 26]. Acknowledging that the rising maintenance cost is one of the major concerns of the industry and public, this study chose cost performance as the dependent variable. The cost or expenditure for building maintenance is often used in measuring the performance of buildings. The maintenance performance is calculated using the variance of actual expenditure and planned cost for building maintenance activities [2]. However, accuracy of planned cost reflects the credibility of maintenance performance. Therefore, it is vital for top management to identify the planned maintenance cost at the planning stage.

For the purpose of this study, a comparison between the actual and the planned cost was made to identify the level of maintenance

performance. For example, maintenance performance of a building system is deemed below expectation when the actual expenditure for maintenance tasks exceeds the planned cost. In contrast, high performance level is achieved when the total expenditure is below the planned cost for maintenance works.

5. Research Methodology

This research adopted a mixed method approach that was adopted by Ali [3] and Nik Mat [23] to study maintenance-related topics. The approach comprises literature review, questionnaire survey, semi-structured interviews, and case study. This approach allows researchers to address more complicated research questions and achieve higher reliability and validity of the research [29]. The research was divided into stages and conducted sequentially. Firstly, the characteristics of condition-based maintenance were identified through literature reviews and subsequently; questionnaires were drafted.

Secondly, simple random sampling was adopted in the questionnaire survey to identify the relevant respondents who have been or were involved in office building maintenance management during the period of this research. This method ensures the sample accuracy by selecting the respondents at random and by considering all elements in the population[24]. Population criteria included building requirements, which were high-rise office buildings (7-storey and above) located in Klang Valley, Malaysia and must have been completed for more than two years. 338 (research population) sets of the questionnaire were sent out by post and 100 sets were returned, which gave a return rate of 30 percent. The respondents were maintenance management staff working in the office buildings (see Figure 2). Based on the data obtained during the survey, some of the respondents, included in the category of "others", were either managing directors of a property management firm, or mechanical and electrical engineers. 85 percent of the respondents were building manager, building supervisor and executive specialising in the planning and the execution of maintenance management activities. They are considerably expert in the planning and implementation of maintenance strategies, and thus able to provide accurate and reliable answers towards the questions.

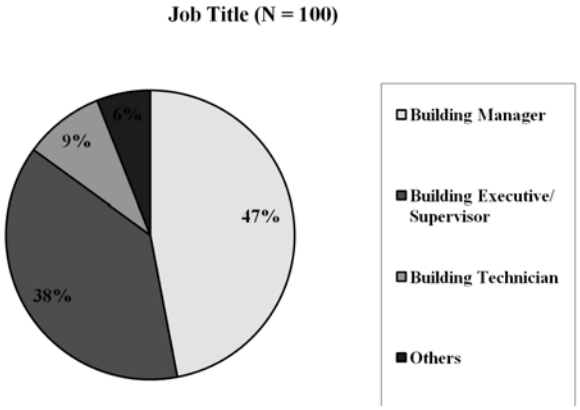

Fig. 2. Respondents' Profile

Subsequently, the survey result was converted and analysed through Statistical Package for Social Science (SPSS) software. Reliability analysis was conducted for the condition-based maintenance characteristics variables to enhance the reliability of the data. The purpose of this analysis was to check the consistency of the scale of data [20]. Cronbach's alpha test showed a coefficient of 0.888. A coefficient of more than 0.70 indicates good reliability.

A correlation test was suitable to measure the relationship between the characteristics of maintenance strategy [9]. It helped to indicate the influence of the maintenance characteristics on the maintenance expenditure. This was performed through the SPSS software. The Pearson product-moment correlation was employed for the analysis. The correlation test was calculated using the following formula:

$$r = \frac{\sum (x-\bar{x}) \times (y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \quad (1)$$

Where,

$(x-\bar{x})$ = the deviation of variable X from its mean;

$(y-\bar{y})$ = the deviation of variable Y from its mean.

The findings on the relationships between condition-based maintenance characteristics and cost performance were used as the basis for the prediction of maintenance performance. The predicted value of a dependent variable from the value of an independent variable is called regression [14]. In this study, there were more than one significant independent variables identified. Thus, a multiple linear regression was used to analyse the collective and the separate contributions of two or more independent variables to the variation of the dependent variable. The multiple linear regression is formulated as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon \quad (2)$$

Where,

Y is the dependent variable (Y = maintenance expenditure variance)

X_1, X_2, ..., X_k are the independent variables (X_1 = skill and knowledge of manager; X_2 = availability of monitoring equipment and technique; X_3 = capability to adopt the monitoring technology...)

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k$ is the deterministic portion of the model

β_i determines the contribution of the independent variable X_i

ε is the random error

In order to validate the questionnaire results, building managers were interviewed at the third stage. In the interview sessions, the interviewees were required to answer the interview questions and to provide further explanation about the implementation of the maintenance strategy. Thus, the building manager with more than five years' experiences and expertise in office building maintenance was the minimum requirement as the interview respondent. The interviewees were selected from the questionnaire respondents who fulfil the requirement. 76 respondents who met the requirement were identified. However, only 15 of them agreed to participate in the interview session. Semi-structured interviews were conducted to obtain further details and understandings about the significant characteristics of condition-based maintenance determined through the correlation analysis. For example, one of the interview questions was *"Does the level of manager skill and knowledge significantly influence the cost performance? How does it influence the cost performance?"* This type of interview allows the researcher to explore and uncover the respondents' views in detail [21].

Then, a case study was carried out on a 27-storey office building located in Kuala Lumpur. The building is thirteen years old, with total floor area of 324,000 square feet, privately owned and managed under the in-house maintenance and management team. The purpose of the case study was to test the applicability of the developed regression model. Relevant information about the significant predictor was collected. The data was applied into the regression model for calculation of the ratio of maintenance expenditure variance. Consequently, the ratio was compared to the exact scenario of the office building.

6. Finding and Discussions

6.1. Relationship between Characteristics of Condition-Based Maintenance and Cost Performance

The findings revealed the relationship between characteristics of condition-based maintenance and cost performance as shown in Table 1. The dependent variable of this study was cost performance, which was determined by maintenance expenditure variance whilst the independent variables were the five variables discussed earlier. SPSS considers variables with the significance value of 0.05 or below to be significantly correlated. Four out of the identified five independent variables were determined to be significantly correlated to the maintenance expenditure variance. The variables are as follows:

- Skill and knowledge of manager
- Availability of monitoring equipment and technique
- Capability to adopt the monitoring technology
- Reliability of maintenance data and information

Table 1. Correlation between characteristics of condition-based maintenance and maintenance cost performance

Characteristic	Maintenance Expenditure Variance
Skilled Manager-Skill and Knowledge	-.276**
Equipment and Technique-Availability	-.350**
Equipment and Technique-Capability to Adopt	-.240*
Acquisition of Data-Reliability	-.394**
Monitoring and Inspection-Frequency	-.138

***. Correlation is significant at the 0.01 level (2-tailed)*

**. Correlation is significant at the 0.05 level (2-tailed)*

In condition-based maintenance, skilful and knowledgeable maintenance manager is needed for allocating appropriate manpower, providing training, monitoring the system conditions, as well as supervising the execution of inspection and maintenance works. The analysis result as shown in Table 1 stated that the level of manager skill and knowledge was significantly correlated to the maintenance expenditure variance. Condition-based maintenance is meant to prevent system failure by monitoring the system condition and restoring the system to its required standard before failure occurs. When a manager does not have sufficient skill and knowledge to adopt the condition-based maintenance effectively, defects and failures are likely to occur. Thus, additional maintenance cost will be required for the repair works. As a result, the exact maintenance expenditure varies from the planned maintenance expenditure. Meanwhile, the analysis result was supported by majority of the interviewees, who demonstrated that skilful manager is able to ensure the optimal workforce, tools and parts allocated for each maintenance task at minimal cost.

Additionally, the availability of condition monitoring technology may help to improve the maintenance outcome. It was found that the availability of equipment and technique significantly correlated to the maintenance expenditure variance (see Table 1). Since Tsang [28] mentioned that the availability of reliable monitoring and inspection technology is one of the factors to be concerned in condition-based maintenance, the selection of monitoring equipment and technique must be suitable for the monitoring and inspection of building systems. Furthermore, most of the interviewees noted that the condition of building system can be easily tracked and monitored by having appropriate equipment and technique. Therefore, the probability of system failure is minimised. The maintenance expenditure variance is prevented as well because emergency repair cost is reduced.

Meanwhile, specific monitoring and inspection tools and equipment require the expertise to operate and use them in condition-based maintenance. The capability to adopt equipment and technique was found to be significantly correlated to the maintenance expenditure variance (see Table 1). According to Carnero [6], it is complicated and costly for an organisation to acquire the condition monitoring tools and technology. If yet, the maintenance personnel are not capable to utilise those tools and technology, more maintenance issues may occur. Then, additional maintenance cost will be needed to solve the problems. Therefore, the exact maintenance expenditure varies from the planned one. In fact, the interview results proved that capable to adopt and utilise monitoring equipment and technique is compulsory for predicting and remedying system defects.

Furthermore, system condition data and information is one of the most important aspects to be considered in condition-based maintenance. In this maintenance strategy, the maintenance tasks such as replacement works are implemented when the parts are almost end of their lifetime by referring to the condition data. The reliability of data and information was found to be significantly correlated to the maintenance expenditure variance (see Table 1). The primary aim of condition-based maintenance is to prevent failure occurs by monitoring the condition of building systems. Basically, emergency repair cost will not be allocated in planning stage of this maintenance strategy. Some interviewees revealed that reliable condition data can indicate the need of maintenance accurately. This will help to enhance the quality of system operation, as well as utilise the resources and time. Oppositely, when the obtained system condition data is not reliable and accurate, the occurrence of sudden breakdown may not able to be avoided. As a result, additional maintenance expenditure is required for the repair work and it varies from the planned maintenance expenditure.

6.2. Regression Model of Maintenance Cost Performance

Since there were four characteristics found to be significantly correlated to the cost performance, the predictors of maintenance expenditure variance (MEV) included skill and knowledge of manager (SKM), availability of monitoring equipment and technique (AET), capability to adopt monitoring technology (CAT), as well as reliability of maintenance data and information (RDI). The regression model for the research was produced as follows (see also Table 2):

Model 1 (Enter Method)

$$MEV = 6.686 - 0.162\ SKM - 0.392\ AET + 0.272\ CAT - 0.513\ RDI \quad (3)$$

Coefficient of multiple regression, $R^2 = 0.186$ (18.6%)

However, the analysis result determined that three predictors were not significant with p-value of more than 0.05. So, another regression model that eliminated the non-significant predictors was developed as follows (see also Table 3). This model was determined appropriate and accurate to estimate the maintenance expenditure variance.

Model 2 (Stepwise Method)

$$MEV = 6.281 - 0.665\ RDI \quad (4)$$

Coefficient of multiple regression, $R^2 = 0.148$ (14.8%)

In order to ensure that the regression models were not violated, the validity of the regression models was checked. Data tabulated in Table 2 and Table 3 had proven that there was no problem of multicollinearity for Model 1 and Model 2 respectively. Whereby, the tolerance value should not be less than 0.1 and variance inflation factor, VIF should not be greater than 10.

Table 2. Coefficients[a] – enter method (characteristics of condition-based maintenance toward maintenance expenditure variance)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	6.686	.743		8.999	.000		
	Skilled Manager-Skill and Knowledge	-.162	.240	-.083	-.675	.501	.572	1.748
	Equipment and Technique-Availability	-.392	.218	-.226	-1.800	.075	.544	1.838
	Equipment and Technique-Capability to Adopt	.272	.268	.137	1.014	.313	.472	2.121
	Acquisition of Data-Reliability	-.513	.222	-.297	-2.315	.023	.521	1.919

a. Dependent Variable: Maintenance Expenditure Variance

Table 3. Coefficients[a] – stepwise method (characteristics of condition-based maintenance toward maintenance expenditure variance)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	6.281	.577		10.880	.000		
	Acquisition of Data-Reliability	-.665	.161	-.384	-4.121	.000	1.000	1.000

6.3. Testing the Applicability of the Regression Model in Practical

Since Model 2 was identified as the appropriate model to estimate the cost performance, case study on a selected office building was carried out to collect the data about the reliability of maintenance data and maintenance expenditure variance. Level of concern towards the reliability of maintenance data was reflected by the accuracy of maintenance data (see Table 4); while the maintenance expenditure variance was reflected by the ratio of actual maintenance expenditure to planned maintenance expenditure (see Table 5).

Table 4. Measurement units of the predictor

Accuracy of Maintenance Data, %	Level of Concern towards Reliability of Maintenance Data	Measurement Unit
20% and below	Very low degree	1
21 – 40%	Low degree	2
41 – 60%	Average	3
61 – 80%	High degree	4
81% and above	Very high degree	5

Table 5. Measurement units of the prediction

Maintenance Expenditure Variance (Ratio)	Measurement Unit
0 – 0.80	1
0.81 – 0.90	2
0.91 – 1.00	3
1.01 – 1.10	4
1.11 – 1.20	5
1.21 and above	6

In the case study, the management team of the building had a very high degree of concern towards the reliability of maintenance data. The management ensured 85% of the maintenance data was accurate, getting the measurement unit score of 5. Meanwhile, the actual and planned annual maintenance costs of the building were both 148,000 Malaysian Ringgit. Therefore, the ratio of the maintenance expenditure variance was 1.00, with the measurement unit score of 3.

The measurement unit score of the predictor was inserted in to the regression model for calculation as follows:

$$\begin{aligned} MEV &= 6.281 - 0.665\ RDI \\ &= 6.281 - 0.665\ (5) \\ &= 2.956 \approx 3 \end{aligned}$$

As a result, the prediction of maintenance expenditure variance that was calculated through the regression model matched to the exact scenario of the studied case. So, the applicability of the regression model in practical was validated and confirmed. The result also summarised that very high degree of concern towards the reliability of maintenance data is a must to eliminate the issue of over-budget.

7. Conclusion

The findings revealed that the characteristics of condition-based maintenance directly influenced the cost performance. Therefore, it is important to understand the influences of condition-based maintenance characteristics in the maintenance process, from planning to the outcome of maintenance. Skill and knowledge manager, availability of monitoring equipment and technique, capability to adopt monitoring technology, as well as reliability of maintenance data and information were highlighted as the characteristics that significantly influencing the maintenance performance. Model 2 developed from stepwise regression analysis highlighted reliability of maintenance data and information as the significant predictor in condition-based maintenance strategy. Using the prediction model, practitioners can predict the variance of maintenance expenditure from the level of concern towards the reliability of maintenance data. Thus, they may decide how much of concern towards the reliability of maintenance data is required in order to achieve optimal maintenance expenditure. Several measures were recommended to improve the maintenance characteristics. The measures include provision of training to maintenance personnel, effective communication between maintenance personnel and clients, planning of maintenance interval based on priority of building services and safety level to occupants, and the collaboration with the service providers. In conclusion, it is vital for the building maintenance practitioners to incorporate the identified significant characteristics and measures for improvement in planning and executing condition-based maintenance with optimum maintenance cost performance. Nevertheless, further research should be conducted on measures to improve the maintenance strategy and outcome.

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