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Improving Occupants' Satisfaction with Effective Maintenance Management of HVAC System in Office Buildings

Cheong Peng Au-Yong *
PhD Candidate
Faculty of Built Environment,
University of Malaya,
50603 Kuala Lumpur, Malaysia.
Email Address: auyongcp@um.edu.my
Telephone No.: +6017-2731281
Fax No.: +603-79675713

Azlan Shah Ali
Associate Professor
Faculty of Built Environment,
University of Malaya,
50603 Kuala Lumpur, Malaysia.
Email Address: asafab@um.edu.my

Faizah Ahmad
Associate Professor
Faculty of Built Environment,
University of Malaya,
50603 Kuala Lumpur, Malaysia.
Email Address: faiz@um.edu.my

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Abstract

Office buildings are equipped with HVAC system to provide a comfortable working environment. However, the level of the occupants' productivity and comfort is highly influenced by the reliability of HVAC system's service. Thus, the proper maintenance of HVAC system is necessary to ensure the smooth operations of an organisation. This paper seeks to investigate the maintenance characteristics of HVAC system that affect occupants' satisfaction and subsequently establish a relationship between the characteristics and occupants' satisfaction through questionnaire surveys and interviews; and finally develop a regression model for prediction purpose. The findings reveal that the maintenance characteristics which influence occupants' satisfaction include the skill and knowledge of manager, skill and knowledge of labourer, quality of spare parts and materials, as well as the response level towards failure and downtime. The study concludes that an effective communication platform which involves all key participants in the maintenance activities should be developed by the management to improve the maintenance outcomes.

Keywords: HVAC system; office building; maintenance characteristics; occupations' satisfaction; participants' involvement

1. Introduction

The heat, ventilation and air conditioning (HVAC) system is a system that provides proper ventilation and air circulation in a building. A central HVAC system may serve one or more spaces within the building. The HVAC system comprises of two main sections, which are in-building section and out-building section. All the main components of HVAC system perform their own function. A central HVAC system consists of [1]:

(a) Chilled water plants (chillers) complete with cooling towers
(b) Water distribution systems which consist of pumps and insulated steel pipes
(c) Air handling units
(d) Air distribution systems consisting of insulated ducts, fans, dampers and air terminals

(e) Electrical distribution systems
(f) Control systems

Central HVAC system is widely used in large buildings, such as office buildings, commercial buildings and shopping complexes. This is due to the advantages of the system. The central HVAC system allows major components to be isolated in a mechanical room. Thus, the maintenance personnel are able to perform the maintenance tasks without interrupting the daily activity within the building or its functions. Moreover, the isolation of components helps to reduce noise and enhances the building in terms of its aesthetic value.

According to Kwak et al. [2], the service reliability of the HVAC system highly relates to the level of the occupants' productivity and comfort. Suttell [3] supported that heating and cooling system is necessary for a building. A building without a heating and cooling system would be inhabitable. Furthermore, indoor air quality is a significant determinant of healthy life and human's well being, because human spend up to 80% of their lifetime in indoor area [4].

However, improper operation or failure of the HVAC system may lead to poor ventilation which in turn caused Sick Building Syndrome (SBS). SBS develops when the indoor air contaminants build up, and subsequently resulting in poor health and low productivity [5]. The symptoms of illness related to SBS include eye, nose and throat irritation; skin allergy; mental fatigue; headache and difficulty in concentration [4,6]. Norhidayah et al. [4] further demonstrated that the failure to respond to the problem of poor indoor air quality can bring the disastrous impacts towards human health.

In fact, inefficient operation and maintenance of the HVAC system can cause energy wastage, customer complaints, poor indoor air quality and even environmental damage [7]. Thus, the maintenance of the HVAC system must be planned and carried out effectively to ensure the satisfaction of the occupants towards the system and service. Consequently, this paper seeks to identify and investigate the maintenance characteristics of HVAC system that affect the occupants' satisfaction.

2. Maintenance of HVAC System

Generally, the manufacturers recommend the maintenance requirements and the operating environment to the users. Wu et al. [8] highlighted four types of maintenance program for HVAC system which includes:

(a) Test and inspection
(b) Scheduled maintenance
(c) Condition-based maintenance
(d) Corrective maintenance

In order to plan, organise and execute the maintenance program appropriately, it is vital to understand the components and functions of a particular system. Chandrashekaran and Gopalakrishnan [9] demonstrated that the most important HVAC components are the chillers, cooling tower, air handling unit, compressor and pump. Thus, the maintenance of a HVAC system should focus on these essential components to enhance the performance and the cost effectiveness of the system.

Since the HVAC system is centralised, it may affect the entire building when a failure occurs in any of its component. For example, the cooling of condensed water cannot be done if the chillers breakdowns and hence the entire system cannot convert the hot air into cool air. Furthermore, the maintenance of the central HVAC system is more complicated and difficult because of the system's size and complexity. Hence, to minimise the HVAC system downtime, corrective maintenance shall be replaced with appropriate preventive maintenance strategies.

As argued by Wu et al. [8], most maintenance programs of building systems are developed based on the HVAC maintenance program. Thus, the HVAC system is selected as the scope of study in this paper. In addition, Lavy [10] demonstrated that HVAC system is the largest and most expensive component in a building. A high cost of maintenance is required to retain the conditions of the HVAC system without affecting maintenance performance.

3. Research Design

This research adopted the mixed method approach that was adopted by Ali [11] and Nik Mat [12] to study maintenance-related topics. The approach comprises of

literature review, questionnaire survey, semi-structured interview, and case study. This approach allows the researchers to address more complicated research questions and achieve higher reliability and validity of the research [13]. The research was divided into stages and conducted sequentially (see Figure 1).

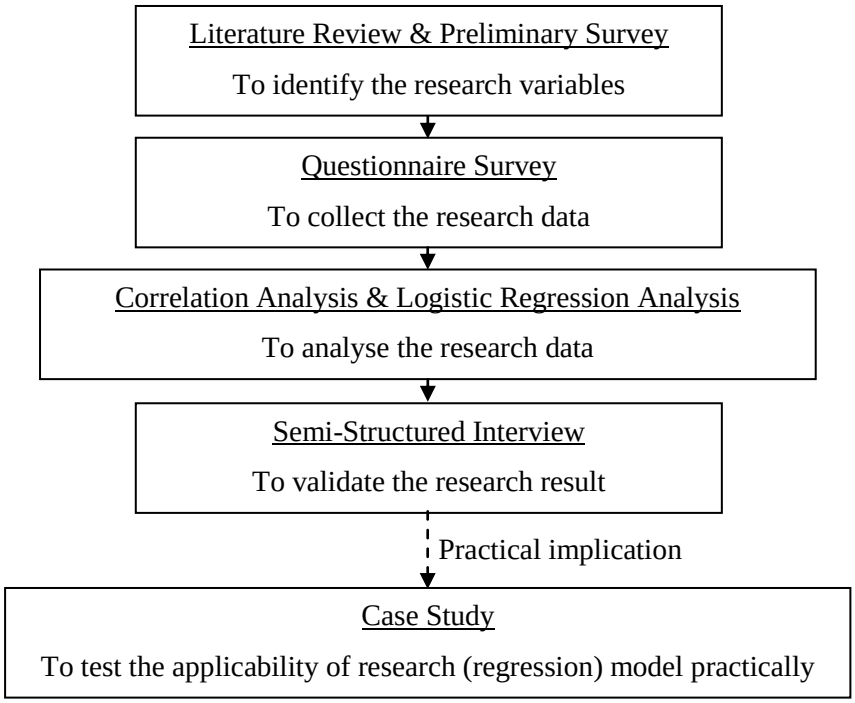

Figure 1: Overall research flow

Firstly, the features of the maintenance system of HVAC system were identified through literature reviews and preliminary survey. Subsequently, close-ended questionnaires were drafted in five-point Likert scale and multiple choices based on the findings of literature and preliminary survey. The questionnaires were developed with reference to the research of Ali [14]. It covered three sections, namely the respondent's particular, maintenance characteristics of the HVAC system, and occupants' satisfaction level (see Appendix).

Secondly, the simple random sampling method was adopted in the questionnaire survey to identify the relevant respondents who have been or are currently involved in the management of office building maintenance. This method ensures the accuracy of the sample by selecting the respondents at random and all elements in the population are considered [15]. Population criteria included building requirements, which were high-rise office buildings (7-storey and above) located in Klang Valley, Malaysia and

must be completed more than two years. Overall, 398 office buildings met the criteria and hence, the figure was determined as the research population. A set of the questionnaires were sent out to each building from the research population and 120 sets of valid questionnaires were returned, which gave a return rate of 30 percent. The respondents were maintenance management personnel working in different office buildings. 83 percent of the respondents were building managers, building supervisors and executives specialising in the planning and execution of maintenance management activities (see Figure 2). Meanwhile, 86 percent of the respondents had more than 5 years of working experience in the maintenance management field (see Figure 3). Hence, the collected data was considerably reliable and accurate.

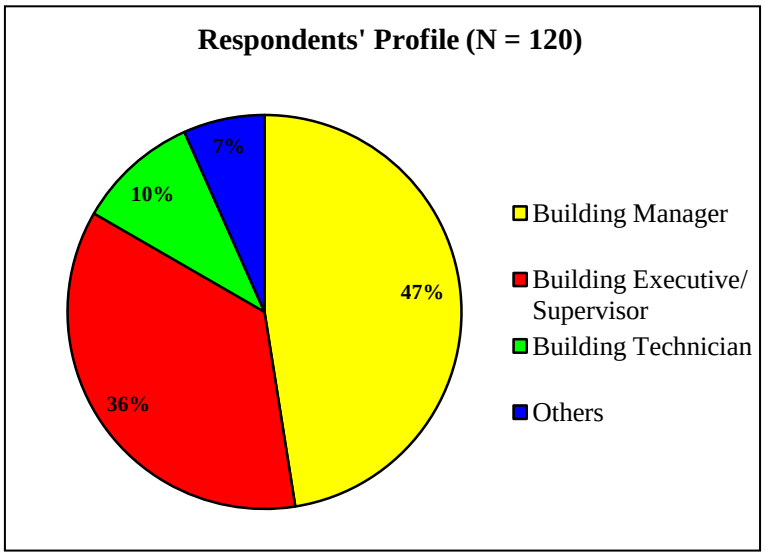

Figure 2: Respondents' profile

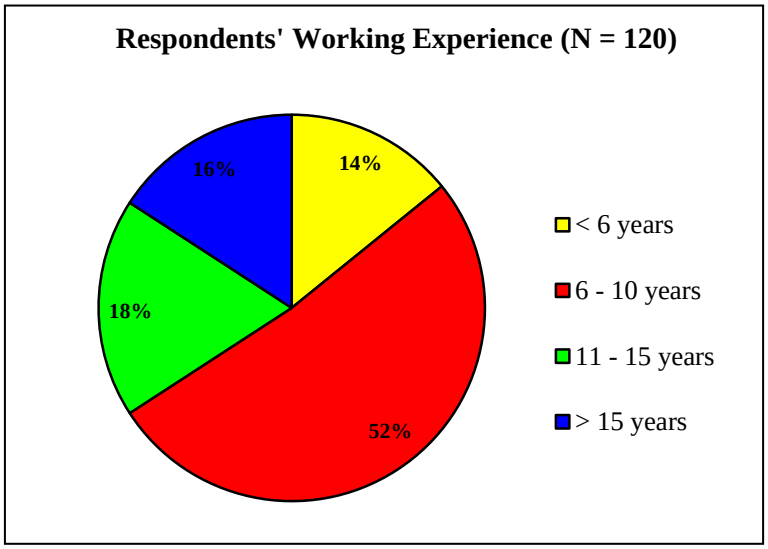

Figure 3: Respondents' working experience

Reliability analysis was conducted for the variable of maintenance characteristic to enhance the reliability of the data. The purpose of this analysis was to check the consistency of the scale of data [16]. The Cronbach's alpha coefficient test shows the coefficient for the maintenance characteristics was 0.755. Coefficient of more than 0.70 indicates good reliability.

A correlation test was used to measure the relationship between the maintenance characteristics and occupants' satisfaction through Statistical Package for Social Science (SPSS) [17]. The Spearman rank-order correlation was employed for analysis. It is suitable to analyse either or both variables are ordinal [18].

Subsequently, this study used the binary logistic regression to produce the prediction model for occupants' satisfaction. Whereby, the probability of an event can be measured by using logistic regression [19]. Basically, logistic regression function is as follow:

$$\boldsymbol{Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon}$$

Where,

Z = latent variable

$X_1, X_2, ... , X_k$ = independent variables

β_0 = constant

$\beta_1, \beta_2, ... , \beta_k$ = change in Y for a change of one unit in $X_1, X_2, ... , X_k$ respectively

ε = error term

Z value is transformed using a link function to obtain the probability of the event occurring. In this research, the link function to obtain the probability of occupants' satisfaction is stated below:

$$\textbf{P [occupants' satisfaction]} = \boldsymbol{e^z/1+e^z}, \text{ the value is between 0 and 1.}$$

In order to validate the questionnaire results, building managers with more than five years of experiences in office building maintenance were interviewed. The interviewees were selected from the questionnaire respondents who fulfil the requirements. Semi-structured interviews were conducted to obtain further details and understandings about the maintenance characteristics toward occupants' satisfaction.

For example, one of the interview questions was "*Does the level of labourer skill and knowledge significantly influence the occupants' satisfaction? How it influences the occupants' satisfaction?*" The interview allows the researcher to explore and uncover the respondents' views in detail [20].

76 respondents were identified as meeting the interviewee's requirement, however, only 15 of them agreed to participate in the interview session. The answers provided by the participants reached a saturation after twelve (12) of them were interviewed, where the answers given by the participants were similar and predictable without new information [11]. Nevertheless, the interview session was carried on until all fifteen (15) participants were interviewed. Unlike the questionnaire survey, the interviewees were required to answer the interview questions and provide further explanation of maintenance characteristics toward occupants' satisfaction.

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 building is accommodated with centralised air-conditioning system. The purpose of the case study was to test the applicability of the developed regression model. Relevant information about the significant predictors was collected. The data was applied into the regression model for calculation of the probability of occupants' satisfaction. Consequently, the probability was compared to the exact scenario of the office building.

4. Findings and Discussion

Eight main maintenance characteristics of the HVAC system were identified through the literature review and preliminary survey. They are [21]:

(a) Skilled labourer [22-27]
(b) Spare parts and materials [22,28-32]
(c) Predetermined maintenance interval [27,30,33-36]
(d) Failure and maintenance downtime [7,9,37-40]
(e) Skilled manager [23,25,41]
(f) Maintenance equipment and technique [23,42-45]
(g) Maintenance data and information [34,38,46-49]

(h) Monitoring and inspection [2,34,46,50-52]

Table 1: Correlation between maintenance characteristics and occupants' satisfaction

Maintenance Characteristics	**Occupants' Satisfaction**	
	Correlation Coefficient	Significance Value
Skill and knowledge of labourer	**.634****	.000
Number of labourer	**.192***	.035
Stock of spare parts and materials	-.108	.239
Quality of spare parts and materials	**.608****	.000
Length of predetermined maintenance interval	.020	.830
Response towards failure and downtime	**.617****	.000
Skill and knowledge of manager	**.697****	.000
Availability of maintenance equipment and technique	.152	.099
Capability to adopt maintenance equipment and technique	**.553****	.000
Accuracy of maintenance data and information	**.589****	000
Frequency of monitoring and inspection	**.189***	.039

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

The eleven independent variables were extended from the maintenance characteristics and analysed using correlation analysis as shown in Table 1. Indeed, higher concern towards the maintenance characteristics is likely to raise the occupants' satisfaction. Therefore, positive correlation between the maintenance characteristics and occupants' satisfaction was expected in the outcome of the analysis. Basically, a correlation coefficient of less than 0.3 points to a weak relationship; a coefficient of 0.3 to 0.5 denotes a moderate relationship; and a correlation coefficient of 0.5 or more points to a strong relationship between two variables [53,54]. However, SPSS determines significantly correlated variables with the significance value of 0.05 or below. Of the eleven independent variables, the following eight variables are significantly correlated to the occupants' satisfaction:

(a) Skill and knowledge of labourer
(b) Number of labourers
(c) Quality of spare parts and materials
(d) Response towards failure and downtime
(e) Skill and knowledge of manager
(f) Capability to adopt maintenance equipment and technique

(g) Accuracy of maintenance data and information
(h) Frequency of monitoring and inspection

Building clients and users demand that the maintenance labourers provide good quality of work at all time. Poor labourers' skill and knowledge is one of the main barriers in executing an effective maintenance management [25]. The result stated that the level of labourer skill and knowledge is significantly correlated to the occupants' satisfaction. When the maintenance labourers fail to maintain the HVAC systems above the acceptable standard, the daily activities of building occupants can be affected. Therefore, they will be complaining on the poorly skilled labourers that lead to the occurrence of uncomfortable working environment. In order to ensure that the maintenance labourers possess relevant skill and knowledge, the qualification of potential labourers must be identified upon employment [24]. One of the interviewees acknowledged the importance of labourers' qualification and revealed that:

"...we always require the minimum qualification and working experience when employing the building technicians."

Then, the Spearman's rank correlation coefficient detected significant correlation between the number of labourers and occupants' satisfaction. However, large amount of budget allocation is required for hiring greater number of labourers [23]. Ali et al. [22] suggested employing minimum but optimum labourer with acceptable qualification standard as one of the measures to minimise maintenance cost. The result of analysis did not match the literature contents. In addition, it was denied by most of the respondents, who argued that the number of labourer should be minimum but sufficient to perform the maintenance tasks effectively. One interviewee mentioned that:

"...due to budget restriction, the clients will not spend extra money to hire extra workers."

According to the correlation analysis result, the quality of spare parts and materials is significantly correlated to the occupants' satisfaction. Quality of spare parts and materials always has an impact towards maintenance performance. Good quality spare parts and materials ensure the building systems to operate effectively without affecting the activities of building users [22]. In contrast, poor quality spare parts and

materials will lead to more defects and increases the frequency of breakdown [32]. Hence, the quality of spare parts and materials must be considered to prolong the system lifespan and enhance its operation. An example was quoted from one of the interviewees:

> "...good quality parts may need to be replaced once in 2 years. On the other hand, poor quality parts may need to be replaced every 6 months. So, good quality parts reduce maintenance need. They save time and cost, as well as minimise possibilities of defect."

Furthermore, the response towards failure and downtime was found to be significantly correlated to the occupants' satisfaction. Failure and downtime involve the time required for detection, repair or replacement and restarting the system, thus the unavailability of services and facilities [38]. Generally, most of the office buildings are solely dependent on the HVAC system to provide air circulation and ventilation. Failure of the system will critically jeopardise the indoor air quality and hence affect the working environment [7]. Therefore, the interviewees expressed that immediate response to the failure and downtime of HVAC system is always requested by the building users. One of the interviewees extended further impact of HVAC system failure towards the organisations in the building:

> "...extensive downtime may affect the image or reputation of organisation. For example, the customers of the organisation will be frustrated when they visit to the office with poor working environment."

The result further demonstrated that the level of managerial skill and knowledge is significantly correlated to the occupants' satisfaction. Ellis [41] demonstrated that the introduction of maintenance strategies without a skilled manager is unlikely to achieve the result. For example, a skilled manager should be capable in obtaining appropriate maintenance data and analysis, as well as providing training to produce disciplined and knowledgeable maintenance staff. Therefore, the support from skilled manager is highly required to plan, manage, organise, supervise, and monitor the implementation of the maintenance strategies in different aspects. Some interviewees validated that a skilful and experienced building manager is usually able to provide the service as required by the clients and users, above satisfactory level. He ensures

all the maintenance tasks run smoothly and accordingly to prevent failure, additional expenditure and downtime. For instance, an interviewee said that:

> "...one of the most important aspects in maintenance management is that a manager must be able to solve the complaints raised up by the clients or users."

In building maintenance, some specific equipments such as scanning equipment, are required by experts to perform such technologies and techniques. This might be complicated and costly for an organisation [23]. Due to the increase in the technical complexity of the HVAC systems and the level of sophistication of the tools, Veldman et al. [44] argued that the need for training to use and operate the tools also increases. This implied that the maintenance personnel should be able to adapt to the new tools and technologies accordingly through proper training. The correlation analysis result revealed that the capability to adopt maintenance equipment and technique is significantly correlated to the occupants' satisfaction. Most of the interviewees revealed that the building clients and occupants expect proper maintenance works to be performed using appropriate tools and equipments. An interviewee further explained that:

> "...if we are not capable to utilise the equipment and technique, it will just be a waste of money and time, yet it will affect the system quality. We know how advanced and expensive is the infrared camera, but when no one understands the way of using it, it is just nothing."

The documentation of maintenance data and information is essential to ensure the accuracy and reliability of information about the maintenance records, conditions and remaining lifetime of system components. In order to obtain and maintain accurate information, appropriate documentation is required [46]. Qingfeng et al. [48] explained that effectiveness of planning and implementation of maintenance tasks is highly dependent on the accuracy of maintenance data. The analysis result showed that accuracy of maintenance data and information is significantly correlated to the occupants' satisfaction. Accurate maintenance data lead to precise identification of the maintenance task, thus help to enhance the quality of system operation as well as optimise the utilisation of time and resources. Few interviewees commented that:

> "...accurate and reliable maintenance data improves the process of maintenance and its outcome, hence fulfilling the requirement of clients and users. As such, they will not complain on the provided maintenance service."

> "...it is important to provide accurate data for implementation of a specific maintenance task without any hidden threat or problem that might cost more for additional remedial work."

In addition, the frequency of monitoring and inspection was found to be significantly correlated to the occupants' satisfaction. In fact, the downtime of a system can be reduced by increasing maintenance personnel care in condition monitoring [52]. Lo and Choi [51] and Jardine et al. [34] demonstrated that for optimum monitoring of HVAC system, inspections should preferably be executed at regular intervals in order to select the most cost-effective method for maintenance action and to minimise the risk and hazards to the building users. Hameed et al. [46] supported that planning of appropriate maintenance activities prior to failure is greatly influenced by the ability to monitor and inspect the condition of systems. All interviewees acknowledged that regular inspection on the HVAC systems is one of the unavoidable tasks. Optimal frequency of inspection allows the technicians to detect abnormal system condition effectively. Defective parts can be replaced to prevent further damage, and ensures the system operates smoothly without disruption from damage. One of the interviewees mentioned that:

> "...inspection should be carried out as frequent as possible to detect and rectify the defective component as soon as possible."

One of the important criteria to improve maintenance performance is proper management of spare parts and materials. Basically, management of spare parts and materials includes the study of spare part needs, efficiency of spare parts reordering, level of stocks of spare parts, and storage of spare parts [24]. Although positive correlation between the maintenance characteristics and the occupants' satisfaction was expected in this study, the analysis result indicated a negative correlation between the stock of spare parts and materials and the occupants' satisfaction. Most of the interviewees clarified that there is limited or even no storage space provided for storage of spare parts and materials. Thus, the stock-up of spare parts and materials is

not practised by the management in office buildings. To address the issue of unavailability of spare parts and materials, an interviewee commented that:

> "...we don't keep stock of spare parts and materials, but we always have various panel suppliers to provide us the spare parts and materials in the shortest time with reasonable cost."

4.1 Developing the Regression Model

In order to validate the correlation analysis result and to determine the significant predictors of the occupants' satisfaction, logistic regression analysis was conducted using the eleven independent variables as the predictors. The analysis includes all the significant predictors (with significant value of less than 0.05) in and excludes all the insignificant predictors (with significant value of more than 0.05) from the regression model. In the analysis, occupants' satisfaction was coded with the value of 0 and 1. Whereby, "not satisfied" and "satisfied" were labelled as 0 and 1 respectively.

Table 2: Variables in the equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	ManagerSkill	1.628	.269	36.742	1	.000	5.095
	Constant	-5.114	.925	30.570	1	.000	.006
Step 2[b]	LabourerSkill	1.202	.293	16.877	1	.000	3.327
	ManagerSkill	1.511	.316	22.926	1	.000	4.531
	Constant	-8.481	1.563	29.439	1	.000	.000
Step 3[c]	LabourerSkill	1.488	.390	14.548	1	.000	4.427
	PartQuality	1.194	.327	13.343	1	.000	3.302
	ManagerSkill	1.328	.344	14.916	1	.000	3.774
	Constant	-12.451	2.479	25.231	1	.000	.000
Step 4[d]	LabourerSkill	1.444	.422	11.705	1	.001	4.240
	PartQuality	1.254	.368	11.587	1	.001	3.504
	DowntimeResponse	1.048	.389	7.263	1	.007	2.852
	ManagerSkill	.887	.364	5.929	1	.015	2.428
	Constant	-14.648	3.031	23.348	1	.000	.000

a. Variable(s) entered on step 1: ManagerSkill.
b. Variable(s) entered on step 2: LabourerSkill.
c. Variable(s) entered on step 3: PartQuality.
d. Variable(s) entered on step 4: DowntimeResponse.

By using forward stepwise method, SPSS produced four steps (see Table 2) to include the predictors that significantly contributed to the logistic regression model. Step 1 revealed the skill and knowledge of manager significantly predicting the odds of occupants' satisfaction with $X^2 = 71.00$, $p < .05$. Then, Step 2 computed the skill and

knowledge of labour with $X^2 = 22.93$, $p < .05$. After that, Step 3 indicated the quality of spare parts and materials significantly predicting the probability of occupants' satisfaction with $X^2 = 18.09$, $p < .05$. Lastly, Step 4 figured out the response towards failure and downtime with $X^2 = 8.84$, $p < .05$. Therefore, there are four independent variables significantly predicting whether or not the occupants are satisfied with the maintenance management ($X^2 = 120.86$, $p < .05$).

In this case, 85.0% of the variance in occupants' satisfaction could be predicted from the skill and knowledge of manager (SKM), skill and knowledge of labour (SKL), quality of spare parts and materials (QSM), and response towards failure and downtime (RFD). Furthermore, the p-value for Hosmer-Lemeshow goodness of fit was 0.552, which was more than 0.05. Thus, the model adequately fit the data. Then, the logistic regression equation was produced as follows (see Table 2):

$$\boldsymbol{Z = -14.648 + 0.887\ SKM + 1.444\ SKL + 1.254\ QSM + 1.048\ RFD}$$

The value of the predictors was quantified from 1 to 5 that represented "very low degree of concern" to "very high degree of concern" respectively. Then, the value could be inserted to the equation in order to obtain the probability of occupants' satisfaction. Therefore, the skill and knowledge of manager, the skill and knowledge of labourer, quality of spare parts and materials, as well as the response towards failure and downtime are the significant maintenance characteristics that influencing probability of occupants' satisfaction. A high level of concern towards these characteristics is likely to increase the probability of occupants' satisfaction towards the HVAC system.

4.2 Testing the Applicability of the Regression Model in Practical

Case study on a selected office building was carried out to collect the data about the four significant predictors. The criteria to be concerned about these predictors were tabulated in Table 3. Level of concern towards each predictor could be reflected by four criteria respectively. Concern on four criteria would contribute to the score of 5; while none would contribute to the score of 1.

Table 3: Criteria of the significant predictors to be concerned

Predictor	Criteria
Skill and knowledge of manager	• Qualification (diploma/degree in relevant field) • Experience • Attending seminar/workshop • Member of professional body
Skill and knowledge of labourer	• Qualification (category of competency: technician/chargeman) • Experience • Attending training/workshop • Positive attitude
Quality of spare parts and materials	• Panel supplier • Tendering process • Approval by client • Warranty
Response towards failure and downtime	• In-house technician • Outsourced contractor/service provider • Immediate response to failure • Avoid maintenance downtime during office hour

The details of criteria concerned by the organisation are tabulated in Table 4. The organisation considered three criteria to assess the maintenance manager and so, scored 4 for skill and knowledge of manager. The management also took into consideration three criteria to assess the maintenance labourer, which scored 4 for skill and knowledge of labourer. They concerned four of the criteria to ensure the quality of spare parts and hence, scored 5 for quality of spare parts and materials. Lastly, they stressed on three criteria in responding failure and downtime, which scored 4 for response towards failure and downtime. After getting all the scores of the predictors, they were inserted into the regression model for calculation of the probability as follow:

$$\boldsymbol{Z = -14.648 + 0.887\ SKM + 1.444\ SKL + 1.254\ QSM + 1.048\ RFD}$$

$$= -14.648 + 0.887\ (4) + 1.444\ (4) + 1.254\ (5) + 1.048\ (4)$$

$$= 5.138$$

Then, $\mathbf{P\ [occupants'\ satisfaction]} = \boldsymbol{e^z/1+e^z}$

$$= e^{5.138}/1+e^{5.138}$$

$$= 0.994$$

Table 4: Details of criteria concerned by the organisation

Predictor	Criteria	Score
Skill and knowledge of manager	• Possess at least a Diploma in Architecture/Building/Civil Engineering/Building Engineering or equivalent qualification • Minimum 5 years working experience in relevant field • Attends seminar/workshop related to facilities management	4
Skill and knowledge of labourer	• Building technician – possess at least a Certificate in Mechanical/Electrical Engineering; building executive/administrative staff – possess at least a Diploma in relevant field • Minimum 1 and 3 years working experience in relevant field for building technician and building executive/administrative staff respectively • Good communication and interpersonal skills, willing to work extra hours	4
Quality of spare parts and materials	• Have a list of panel suppliers/contractors • Tender for the acquisition of spare parts/materials • Acquisition of spare parts/materials is approved by the clients • Select the spare parts/materials under warrantee	5
Response towards failure and downtime	• Employ in-house technician to tackle maintenance issue • Outsource specific maintenance project to contractor/service provider • 24-hours standby technician	4

The previous customer satisfaction survey report prepared by the management of the building was obtained. With reference to the survey report towards the HVAC system, 95 percent of the occupants satisfied with the service of the HVAC system. The high level of satisfaction indicated that no major breakdown occurred, and the negative feedbacks were related to the thermal comfort issues. Good maintenance service promoted the occupancy rate of the building, which was 96%. Thus, the probability of occupants' satisfaction matched to the exact scenario of the occupants' satisfaction towards the HVAC system. As a result, the applicability of the regression model in practical was validated and confirmed.

4.3 Recommendations

The study demonstrated that the involvement of key participants such as the clients, maintenance personnel, and building occupants or users in the maintenance management process is vitally important to enhance the effectiveness of maintenance management and increase the occupants' satisfaction. Recommendations to improve the effectiveness of the maintenance management of a building were discussed in the

interview sessions. The interviewees suggested that providing a communication platform to gather the opinions, comments, needs, and issues of the key participants (clients or organisation, management, tenants, and customers or users) can improve the planning of maintenance strategies accordingly. For instance, it is recommended that meeting between the management and clients should be conducted on a weekly basis, whilst meeting between management, clients and tenants be conducted on a monthly basis. In addition, an online feedback system was proposed as a platform for the customers or users to provide feedback, opinion, or complaint about the services provided in the building at anytime. The online feedback system requires minimal cost whilst organising meeting requires no cost. Therefore, the commitment and participation of the key participants are necessary in effective maintenance management. Participation provides an opportunity to tackle problems through engagement of the key participants, prioritising their concerns and maximising mutual satisfaction [55]. Further study about the participation of the key participants and the provision of an effective communication platform in maintenance management is recommended.

5. Conclusion

This paper emphasised the improvement of maintenance characteristics to reach the desired the occupants' satisfaction level towards the HVAC system. The findings highlighted eight significant characteristics that are significantly correlated with the occupants' satisfaction. They are skill and knowledge of labourer, number of labourer, quality of spare parts and materials, response towards failure and downtime, skill and knowledge of manager, capability to adopt maintenance equipment and technique, accuracy of maintenance data and information, as well as frequency of monitoring and inspection. Then, a prediction model generated through SPSS revealed that the skill and knowledge of manager, skill and knowledge of labourer, quality of spare parts and materials, as well as the response towards failure and downtime are the significant predictors of the occupants' satisfaction. Therefore, the significant maintenance characteristics must be considered in the maintenance of the HVAC system or even other building systems. In practice, the regression model would help the management to predict the maintenance performance as proven through the case study. Furthermore, the management would be able to plan and implement the maintenance characteristics effectively in order to achieve occupants' satisfaction.

Finally, this paper recommended that the management should develop an effective communication platform such as meeting and online feedback system, involving all key participants with commitment and contribution towards the maintenance activities. In the meeting, the clients, tenants and management can discuss, decide and approve the issues or requests about the qualification of manager or labourer, as well as the quality of spare parts. For example, they may decide the minimum qualification of manager and labourer upon employment, or discuss about the working attitude of the existing maintenance personnel. Furthermore, the acquisition of spare parts will be approved by the clients and tenants to ensure the acceptable quality and reasonable cost. Additionally, the online feedback system allows the users to report any failure or maintenance issue at anytime, so that the maintenance personnel are able to respond to the failure without delay.

References

[1] J.H. Buys, E.H. Mathews, Investigation into Capital Costs of HVAC Systems, Building and Environment 40 (2005) 1153-1163.

[2] R.Y. Kwak, A. Takakusagi, J.Y. Sohn, S. Fujii, B.Y. Park, Development of an Optimal Preventive Maintenance Model Based on the Reliability Assessment for Air-Conditioning Facilities in Office Buildings, Building and Environment 39 (2004) 1141-1156.

[3] R. Suttell, Preventive HVAC Maintenance is a Good Investment, The Source for Facilities Decision-Makers: Buildings, Vol. July, UNICCO Intergrated Facilities Services, Newton, 2006.

[4] A. Norhidayah, C.K. Lee, M.K. Azhar, S. Nurulwahida, Indoor Air Quality and Sick Building Syndrome in Three Selected Buildings, Procedia Engineering 53 (2013) 93-98.

[5] A. Smith, M. Pitt, Sustainable Workplaces and Building User Comfort and Satisfaction, Journal of Corporate Real Estate 13 (3) (2011) 144-156.

[6] R. Rooley, Sick Building Syndrome - The Real Facts: What is Known, what can be Done, Facilities 15 (1/2) (1997) 29-33.

[7] S. Wu, K. Neale, M. Williamson, M. Hornby, Research Opportunities in Maintenance of Office Building Services Systems, Journal of Quality in Maintenance Engineering 16 (1) (2010) 23-33.

[8] S. Wu, D. Clements-Croome, V. Fairey, B. Albany, J. Sidhu, D. Desmond, K. Neale, Reliability in the Whole Life Cycle of Building Systems, Engineering, Construction and Architectural Management 13 (2) (2006) 136-153.

[9] A. Chandrashekaran, B. Gopalakrishnan, Maintenance Risk Reduction for Effective Facilities Manangement, Journal of Facilities Management 6 (1) (2008) 52-68.

[10] S. Lavy, Facility Management Practices in Higher Education Buildings, Journal of Facilities Management 6 (4) (2008) 303-315.
[11] A.S. Ali, Integrative Mechanisms in the Design Process of Building Refurbishment Projects, Unpublished Thesis, Universiti Teknologi MARA, 2008.
[12] N.E.M. Nik Mat, Performance Measurement of Office Buildings Maintenance Management, Unpublished Dissertation, University of Malaya, 2009.
[13] R.K. Yin, Case Study Research: Design and Methods, 4th ed., SAGE Publication, Inc, California, 2009.
[14] A.S. Ali, Cost Decision Making in Building Maintenance Practice in Malaysia, Journal of Facilities Management 7 (4) (2009) 298-306.
[15] W.E. Saris, I.N. Gallhofer, Design, Evaluation, and Analysis of Questionnaires for Survey Research, John Wiley & Sons Inc., New Jersey, 2007.
[16] N.L. Leech, K.C. Barrett, G.A. Morgan, IBM SPSS for Intermediate Statistics: Use and Interpretation, 4th ed., Taylor and Francis Group, LLC, New York, 2011.
[17] I. Diamond, J. Jefferies, Beginning Statistics: An Introduction for Social Scientists, SAGE Publications Ltd, London, 2006.
[18] A.M. Graziano, M.L. Raulin, Research Methods: A Process of Inquiry, 7th ed., Pearson Education Inc, Boston, 2010.
[19] Y.P. Chua, Statistik Penyelidikan Lanjutan: Ujian Regresi, Analisa Faktor dan Analisis SEM Buku 5, McGraw-Hill (Malaysia) Sdn. Bhd, Kuala Lumpur, 2009.
[20] C. Marshall, G.B. Rossman, Designing Qualitative Research, 4th ed., Sage Publication, Inc, California, 2006.
[21] C.P. Au-Yong, A.S. Ali, F. Ahmad, Significant Characteristics of Scheduled and Condition-Based Maintenance in Office Building, Journal of Performance of Constructed Facilities (2013).
[22] A.S. Ali, S.N. Kamaruzzaman, R. Sulaiman, C.P. Au Yong, Factors Affecting Housing Maintenance Cost in Malaysia, Journal of Facilities Management 8 (4) (2010) 285-298.
[23] M.C. Carnero, An Evaluation System of the Setting up of Predictive Maintenance Programmes, Reliability Engineering and System Safety 91 (2006) 945-963.
[24] P.D. Groote, Maintenance Performance Analysis: A Practical Approach, Journal of Quality in Maintenance Engineering 1 (2) (1995) 4-24.
[25] J. Kangwa, F. Olubodun, An Investigation into Home Owner Maintenance Awareness, Management and Skill-Knowledge Enhancing Attributes, Structural Survey 21 (2) (2003) 70-78.
[26] J. Lai, F. Yik, P. Jones, Expenditure on Operation and Maintenance Service and Rental Income of Commercial Buildings, Facilities 26 (5/6) (2008) 242-265.

[27] D. Pandey, M.S. Kulkarni, P. Vrat, A Model for Optimal Maintenance Interval Incorporating the Cost of Rejections in Manufacturing, Journal of Advances in Management Research 7 (2) (2010) 219-232.
[28] N. De Silva, M. Ranasinghe, Maintainability Risks of Condominiums in Sri Lanka, Journal of Financial Management of Property and Construction 15 (1) (2010) 41-60.
[29] A. Parida, U. Kumar, Maintenance Performance Measurement (MPM): Issues and Challenges, Journal of Quality in Maintenance Engineering 12 (3) (2006) 239-251.
[30] A.H.C. Tsang, Condition-Based Maintenance: Tools and Decision Making Journal of Quality in Maintenance Engineering 1 (3) (1995) 3-17.
[31] F.W.H. Yik, J.H.K. Lai, The Trend of Outsourcing for Building Services Operation and Maintenance in Hong Kong, Facilities 23 (1/2) (2005) 63-72.
[32] A. Zuashkiani, H. Rahmandad, A.K.S. Jardine, Mapping the Dynamics of Overall Equipment Effectiveness to Enhance Asset Management Practices, Journal of Quality in Maintenance Engineering 17 (1) (2011) 74-92.
[33] D.-H. Chen, D.-F. Lin, H.-L. Luo, Effectiveness of Preventative Maintenance Treatments Using Fourteen SPS-3 Sites in Texas, Journal of Performance of Constructed Facilities 17 (3) (2003) 136-143.
[34] A.K.S. Jardine, D. Lin, D. Banjevic, A Review on Machinery Diagnostic and Prognostics Implementing Condition-Based Maintenance, Mechanical Systems and Signal Processing 20 (2006) 1483-1510.
[35] J. Khalil, S.M. Saad, N. Gindy, An integrated cost optimisation maintenance model for industrial equipment, Journal of Quality in Maintenance Engineering 15 (1) (2009) 106-118.
[36] V. Narayan, Effective Maintenance Management: Risk and Reliability Strategies for Optimizing Performance, Industrial Press Inc, New York, 2003.
[37] S. Batun, M. Azizoğlu, Single Machine Scheduling with Preventive Maintenances, International Journal of Production Research 47 (7) (2009) 1753-1771.
[38] M. Bevilacqua, M. Braglia, The Analytic Hierarchy Process Applied to Maintenance Strategy Selection, Reliability Engineering and System Safety 70 (2000) 71-83.
[39] A.C. Marquez, J.N.D. Gupta, Contemporary Maintenance Management: Process, Framework and Supporting Pillars, The International Journal of Management Science 34 (2006) 313-326.
[40] S.K. Yang, A Condition-Based Preventive Maintenance Arrangement for Thermal Power Plants, Electric Power Systems Research 72 (2004) 49-62.
[41] B.A. Ellis, Condition Based Maintenance, The Jethro Project (2008) 1-5.
[42] D.J. Edward, G.D. Holt, F.C. Harris, Predictive Maintenance Techniques and Their Relevance to Construction Plant, Journal of Quality in Maintenance Engineering 4 (1) (1998) 25-37.

[43] L. Mann, A. Saxena, G.M. Knapp, Statistical-Based or Condition-Based Preventive Maintenance?, Journal of Quality in Maintenance Engineering 1 (1) (1995) 46-59.
[44] J. Veldman, W. Klingenberg, H. Wortmann, Managing Condition-Based Maintenance Technology: A Multiple Case Study in the Process Industry, Journal of Quality in Maintenance Engineering 17 (1) (2011) 40-62.
[45] B. Wood, Towards Innovative Building Maintenance, Structural Survey 23 (4) (2005) 291-297.
[46] Z. Hameed, S.H. Ahn, Y.M. Cho, Practical Aspects of a Condition Monitoring System for a Wind Turbine with Emphasis on its Design, System Architecture, Testing and Installation, Renewable Energy 35 (2010) 879-894.
[47] A.A. Irigaray, E. Gilabert, Ubiquitous Computing for Dynamic Condition-Based Maintenance, Journal of Quality in Maintenance Engineering 15 (2) (2009) 151-166.
[48] W. Qingfeng, L. Wenbin, Z. Xin, Y. Jianfeng, Y. Qingbin, Development and Application of Equipment Maintenance and Safety Integrity Management System, Journal of Loss Prevention in the Process Industries 24 (2011) 321-332.
[49] A.H.C. Tsang, W.K. Yeung, A.K.S. Jardine, B.P.K. Leung, Data Management for CBM Optimization, Journal of Quality in Maintenance Engineering 12 (1) (2006) 37-51.
[50] A. Grall, C. Berenguer, L. Dieulle, A Condition-Based Maintenance Policy for Stochastically Deteriorating Systems, Reliability Engineering & System Safety 76 (2002) 167-180.
[51] T.Y. Lo, K.T.W. Choi, Building Defects Diagnosis by Infrared Thermography, Structural Survey 22 (5) (2004) 259-263.
[52] D. Sherwin, A Review of Overall Models for Maintenance Management, Journal of Quality in Maintenance Engineering 6 (3) (2000) 138-164.
[53] C.D. Gray, P.R. Kinnear, IBM SPSS Statistics 19 Made Simple, Pyschology Press, East Sussex, 2012.
[54] M. Saunders, P. Lewis, A. Thornhill, Research Methods for Business Students, 5th ed., Pearson Education Limited, Essex, 2009.
[55] T.H.Y. Li, S.T. Ng, M. Skitmore, Evaluating stakeholder satisfaction during public participation in major infrastructure and construction projects: A fuzzy approach, Automation in Construction 29 (2013) 123-135.