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Performance indicators for facilities operation and maintenance (Part 1): systematic classification and mapping

Structured abstract

Purpose
The study reported in this paper (Part 1 of 2) aims to classify and map, in a systematic manner and from a facilities management (FM) perspective, the performance indicators that are applicable to evaluating facilities operation and maintenance (O&M) in commercial buildings.

Methodology/approach
Forming part of a multi-stage research project, the applicable performance indicators that had been identified from an extensive literature review were consolidated and defined. Based on a phase-hierarchy (P-H) model - a fundamental classification framework comprising three phases of facilities services delivery and three hierarchical FM levels, the indicators were systematically classified, and a map showing their distribution along the phase and hierarchy dimensions was obtained.

Findings
The P-H model enabled systematic classification of the 71 applicable indicators. Mapping the indicators with the model showed that more indicators concern the input or output phase of facilities services delivery. Indicators at the strategic level, which have a wide span of control, are small in quantity, compared to the large number of indicators at the operational level.

Research implications
The P-H model, which proves useful for classifying performance indicators for facilities in commercial buildings, may be applied to similar research on other types of buildings or infrastructures.

Practical implications
The way in which the performance indicators were classified and the mapping result of the indicators are useful reference for different levels of FM practitioners.

Originality/value
This paper illustrates a novel attempt that made use of the P-H model to classify O&M performance indicators.

Paper type
Research paper

Keywords
Assessment, commercial properties, facilities, KPI, maintenance, performance

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Introduction

Facility management (FM) is a multi-disciplinary profession that covers a range of core competencies (International Facility Management Association, 2016). Besides the "soft" FM services such as cleaning, catering etc., operations and maintenance (O&M) is an essential, "hard" element of FM. Involving different kinds of engineering facilities, the knowledge and skills needed for carrying out O&M works span across various trades (air-conditioning and ventilation, electrical, fire services, etc.) and natures, e.g. budgeting and cost control, energy and environmental management, to name but a few (Lai, 2010).

In some specific environments, e.g. an industrial building installed with a manufacturing plant, operations and maintenance are two separate functions undertaken by different groups of personnel (Mobley, 2014). For facilities in other types of buildings such as residential or commercial buildings, operations (e.g. checking the running condition of a water pump) and maintenance (e.g. replacement of a defective pump bearing) are typically carried out by the same team of personnel, collectively called as O&M team or simply maintenance team (Lai, 2017).

Many commercial buildings, especially those in metropolises like Hong Kong, are large-scale complexes or skyscrapers (e.g. the 108-storey International Commercial Centre) equipped with engineering facilities including, for example, high-speed lifts, active fire protection devices and automated air-conditioning systems. The need for looking after such sophisticated facilities in a massive development often justifies the establishment of a dedicated O&M team, which typically comprises three levels of practitioners (Lai, 2017): strategic (e.g. Head of Technical Services), tactical (e.g. Maintenance Manager) and operational (e.g. Technician). In order to make the facilities perform to the satisfaction of their users, the practitioners need to measure and monitor the performance of O&M services provided for the facilities. For this purpose, it is essential to use appropriate key performance indicators (KPIs).

Over the years, various attempts have been made to establish KPIs for FM. For example, Hinks and McNay (1999) used the Delphi method to solicit expert opinions, from which 23 KPIs were identified. Through a literature search and a survey on FM professionals, Lavy *et al.* (2010) identified 35 facilities performance indicators. Further effort, later, was made to derive and categorize core indicators for assessing facilities performance (Lavy *et al.* 2014a; 2014b).

The provisions of facilities and factors such as user type and demand on facilities services, in fact, vary between different types of buildings. Therefore, a set of generic KPIs would not suit all building types. Whereas performance indicators have been commonly used to evaluate the effectiveness of FM, there has been limited knowledge on how to systematically classify performance indicators from an FM perspective. Without such fundamental information, it is difficult, if not impossible, to credibly assess the performance of facilities.

As such, a research study was initiated. Aimed at devising a credible scheme for evaluating the performance of engineering facilities in commercial buildings, the study was carried out in four stages. At the beginning of the study, a state-of-the-art review on performance evaluation for engineering facilities in buildings was done (Lai and Man, 2017). The subsequent tasks completed for the first stage of the study and the corresponding results obtained from further

analysis of the initial findings published in Man et al. (2013) and Man and Lai (2013; 2014) are presented in two parts: the current paper (Part 1) and the next one (Part 2).

Reported in the ensuing section is the research method of the study, which covers an outline of the four stages of work of the study, and the model and relevant management principles used to classify performance indicators with respect to the phase of facilities services delivery and the level of an FM organization. After showing the definitions and formulas of the indicators that are applicable to evaluating the performance of engineering facilities, the analysis made in classifying the indicators and discussions on the analysed findings are presented. Finally, the conclusions drawn from the results of Part 1 are given.

Method - classification model and principles

As depicted in Lai and Man (2017), the whole of the study consists of four stages of work:

- Stage 1: Identify applicable performance indicators, classify the indicators and shortlist them for use.
- Stage 2: Investigate the usefulness of the selected KPIs and form a framework for the intended evaluation scheme.
- Stage 3: Determine importance weights of the KPIs and establish the evaluation scheme.
- Stage 4: Determine performance levels of facilities and validate the applicability of the scheme.

Before identifying and classify performance indicators for use in evaluating specifically the performance of engineering facilities in commercial buildings (i.e. Stage 1), it is essential to understand the delivery process of facilities services in the real world. According to the performance evaluation schema presented in Lai and Man (2017), the performance of facilities services can be gauged by measurement (e.g. measuring the indoor air quality of a building), perception (e.g. gauging the users' perceived levels of satisfaction with the facilities) or a combination of measurement and perception. In addition, a phase-hierarchy (P-H) model, which integrates two essential performance evaluation dimensions, has been developed for classifying performance indicators. The first dimension covers the different phases (input, process and output) of facilities services delivery, and the second refers to the hierarchical levels (operational, tactical and strategic) of an FM organization.

As the P-H model in Figure 1 shows, performance indicators can be classified with respect to the phase dimension (horizontally) or the hierarchy dimension (vertically). Thus, there are nine possible classes of performance indicators: input-operational (I, O); input-tactical (I, T); input-strategic (I, S); process-operational (P, O); process-tactical (P, T); process-strategic (P, S); output-operational (U, O); output-tactical (U, T); and output-strategic (U, S).

"Insert Figure 1 here"

In practice, frontline staff at the operational level of an FM organisation are tasked with indispensable minutiae, while senior staff at the strategic level mostly focus on top management issues. Those at the middle level, typically some managers, are crucial links between the strategic and operational levels (Alexander, 1996; Atkin and Brooks, 2014). The managerial span of control, which is the widest at the strategic level, declines to become moderate at the tactical level and narrow at the operational level (Figure 2). This principle, on the contrary, reverses when it comes to the number of indicators to be used by the three levels of staff in evaluating FM performance. Instead of a large number of indicators that are

applicable to measuring operational FM performance, a smaller number of performance indicators are desirable for use by managers at the tactical level (Lai and Yik, 2006). Too many performance indicators, if adopted, will demand too much measurement and monitoring effort, outweighing the benefits obtainable from performance evaluation. In order to be manageable by those at the overseeing, strategic level, the number of performance indicators needs to be further minimised.

"Insert Figure 2 here"

After the identification of the applicable performance indicators from the literature (Lai and Man, 2017), the definitions of the indicators were consolidated. Then, each of the indicators was classified according to the P-H model. The classification results so obtained were used to prepare a mapping matrix that comprises the phase and hierarchy dimensions of FM.

Applicable performance indicators

The above-mentioned literature review had identified a total of 71 performance indicators as applicable to evaluating the performance of O&M services. Such indicators are composed of six in the physical group, 22 in the financial group, 30 in the technical group, six in the environmental group, and seven in the health, safety and legal group.

With reference to the review findings, further effort was made to summarise and refine the representations of the indicators; where applicable, the formulas for calculating the indicators were also defined. Table 1 shows the definitions and formulas pertaining to the six physical performance indicators. The counterparts of the two largest groups - financial and technical performance indicators - are summarized in Tables 2 and 3 respectively. In the environmental group, there are six performance indicators and their definitions/formulas are listed in Table 4. Shown in Table 5 are the definitions/formulas of the seven indicators that reflect health, safety and legal performance.

"Insert Table 1 here"

"Insert Table 2 here"

"Insert Table 3 here"

"Insert Table 4 here"

"Insert Table 5 here"

Analysis and Discussion

Physical performance indicators

Based on the P-H model (Figure 1), the identified performance indicators were classified. For the physical performance indicators, their classification results are summarized in Table 6.

"Insert Table 6 here"

Thermal comfort (P1), which hinges on parameters including air temperature, air speed and humidity, indicates users' satisfaction with the thermal environment served by a heating, ventilation and air-conditioning (HVAC) system. Visual comfort (P2) in an indoor environment such as a commercial building reflects how well the artificial lighting installation has served the building occupants. In the exterior zone of the building, daylighting harvesting and control facilities also play a vital role in visual comfort performance. Aural comfort (P3) is a result of the environmental noise perceived by the occupants, which is dependent not only on the sound power level generated from the operation of noise-generating facilities (e.g. ventilation fans and water pumps) but also how well such facilities are maintained and the extent of acoustic treatments (e.g. silencer, sound absorption device) provided for noise mitigation. The presence of respirable suspended particulates, gases (e.g. carbon dioxide, ozone, volatile organic compounds) and airborne bacteria, etc. affects the air quality of an indoor environment. The performance of air purification and disinfection facilities, therefore, is crucial to indoor air quality (P4).

The above four indicators share the same property – they represent the output performance of the O&M services provided for the respective engineering facilities. Ensuring that such facilities perform to the required levels is the duty of operational staff, e.g. engineering technicians. Meanwhile, staff at the tactical level (e.g. technical managers) are responsible for monitoring the performance levels of these physical parameters (P1 to P4). As a result, they are classified as physical indicators that reflect the performance at the output phase of facilities services delivery, which is useful for tactical and operational staff.

Both of the remaining two physical performance indicators, namely percentage users dissatisfied (P5) and number of users' complaints per year (P6), can reflect the level to which the building users are disappointed with the performance of the physical indoor environment. Such disappointments may be due to underperformance in one or some of the preceding four physical parameters (P1 to P4). Thus, P5 and P6 belong to the same group – output phase. These two indicators are particularly required for staff at the tactical level as they need to handle complaints on the physical facilities performance while at the same time having to deal with grievance of any disgruntled users.

Financial performance indicators

Resources used for financing O&M works can be represented by actual costs within budgeted costs (F4) or direct maintenance cost (F5) (see Table 7). Energy used for building operations can be measured, in normalized terms, as energy expenditure per building area (F16) or energy expenditure per person (F17). This group of performance indicators gauges the amounts of monetary or energy resources input, which are essential information for FM staff at the strategic or tactical level.

"Insert Table 7 here"

A similar group of performance indicators, also measuring input resources, comprises O&M cost per building area (F13), total safety and security expenditure (F18), security expenditure per building area (F19), and security expenditure per person (F20). This group of indicators, slightly different from the preceding four indictors (F4, F5, F16 and F17) that can help tactical staff who look after technical matters (maintenance and energy use), is particularly useful to the senior management who oversee the overall building O&M cost as well as expenditures on soft FM functions including safety and security.

Another group of financial indicators, mainly useful to technical staff at the tactical level, consists of 12 indicators that measure the input performance of O&M works. Those that can represent the proportions of money spent out of the total O&M cost are percentage of personnel cost (F1), percentage of subcontractor cost (F2), and percentage of contractor cost (F3). Indicators F6 to F12, namely breakdown severity, equipment replacement value, maintenance stock turnover, percentage of maintenance material cost, percentage of corrective maintenance cost, percentage of preventive maintenance cost, and percentage of condition based maintenance cost, measure various input maintenance resources (see Table 2). The remaining two input performance indicators, O&M cost per capacity of installation (F14) and cost of equipment added or replaced (F15), are needed for technical managers who look after engineering facilities.

Associated with the output phase of facilities services delivery, building income per building area (F21) is an indicator of great interest to the seniors who care about revenue from rental paid by commercial tenants. Serving a similar performance indication function is the final indicator - total rentable value of the building (F22).

Technical performance indicators

The largest category of indicators, related to maintenance tasks or equipment installed in buildings, measures the technical performance of O&M works (Table 8). Indicators that involve measurement of parameters in both the input and output phases of facilities services delivery are number of completed work orders per staff (T12) and efficiency of facilities (T29). These two indicators, capable of assessing maintenance manpower efficiency and how efficient the facilities are operated, are useful information for tactical and operational staff.

"Insert Table 8 here"

Several more indicators that are useful at the tactical or operational level include preventive maintenance ratio (T6), percentage of corrective (reactive) work (T7), percentage of preventive (proactive) work (T8), percentage of condition based maintenance work (T9), number of man hours per capacity of installation (T11), area maintained per maintenance staff (T13), corrective maintenance time (T20), and preventive maintenance time (T21). The measurements required for this group of indicators, when compared with those for T12 and T29, are more straightforward because only some input technical performance parameters are involved. Whereas gross floor area under safety and security patrol (T30) is also an input performance indicator, its use is mainly for staff at the tactical level rather than the operational level.

There are a dozen indicators that can facilitate tactical or operational staff to evaluate the technical performance during the process of facilities services delivery. The first batch of such indicators embraces percentage of improvement work (T10), which is a measure of the ratio between man hours used and man hours available. The rest of the indicators consist of two subgroups; the first being those that measure the amount of maintenance requests or work orders, namely: quality of scheduling (T14), schedule realization rate (T15), schedule compliance (T16), work order turnover (T17), backlog size (T18), urgent repair request index (T19), and failure/breakdown frequency (T25). The second subgroup contains four indicators that measure maintenance and/or breakdown periods, and they are: response time for maintenance (T22), percentage compliance with required response time (T23), mean time between failures (T26), and mean time to repair (T27).

A further group of indicators reflecting how well the O&M processes are performed, which is similar to the foregoing group yet particularly needed for technical managers at the tactical level, comprises five indicators: work request response rate (T1), scheduling intensity (T2), manpower utilization rate (T3), manpower efficiency (T4), and manpower utilization index (T5). They measure the amounts of maintenance requests, work orders and man hours.

The final two technical indicators are common in that they gauge the output performance of O&M works. Number of maintenance induced interruptions (T24) is useful for showing how well the maintenance works are executed. Availability (T28), whose calculations involve T26 and T27 in the previous group of indicators, can help tactical and operational staff understand the eventual performance of O&M processes.

Environmental performance indicators

The first batch of environmental performance indicators, representing effort made in the input phase of facilities services delivery, are useful to tactical FM staff (Table 9). Common to all such three indicators, they show whether audits or assessments have been carried out for environmental management purposes. Energy audit, if properly conducted for a building, will reveal energy management opportunities for reducing energy use (Electrical and Mechanical Services Department, 2007). E4 serves as an indicator for such an energy audit. Likewise, a carbon audit can identify greenhouse gas (GHG) emitting activities and the amounts of GHGs so emitted (Lai et al., 2012). Whether a carbon audit has been conducted is indicated by E5. Building environmental performance assessments, which are more comprehensive than energy or carbon audits, typically cover a wide range of environment-related aspects (Man et al., 2012). Indicator E6 is to show whether such environmental assessments have been conducted.

"Insert Table 9 here"

Different from the above group of indicators, the final three environmental performance indicators reflect facilities' performance in the output phase. Indicator E1 is an index that reflects the eventual amount of energy use normalized on the basis of the building's gross floor area. E2, also an indicator of energy use, is calculated on a per capita basis. E3 is an even more embracive indicator that counts not only energy use but also resources used under scopes 1 to 3 of the GHG Protocol (Lai, 2014).

Health, safety and legal performance indicators

This group of indicators is critical and, by the term 'legal performance', it means the performance in compliance with relevant legal requirements. Unlike the preceding four categories of indicators, the health, safety and legal performance indicators are homogeneous in that they all represent certain performance outputs of facilities services (Table 10). Such indicators, reflecting the consequences of poor facilities' performance, are useful to practitioners at the tactical level as well as senior management at the strategic level.

"Insert Table 10 here"

The first indicator, H1, measures the number of accidents arising from improper building operations or maintenance work. If such accidents are of a serious nature, legal claims from the suffered parties will be resulted (H2). For cases where compensations are needed to settle

the claims, the severity of which can be gauged by the number of such cases (H3) or the amount of compensation paid (H4).

For cases caused by health and safety problems, before they are escalated to legal disputes or if such cases do not lead to severe consequences, there will be complaints from the affected users. The number of such complaints (H5) is an output performance indicator of the relevant facilities. Apart from users, FM staff may also suffer from the health and safety problems. The number of their lost work days (H6) due to work-related injuries is another output performance indicator. The final indicator, H7, can also measure the level of output performance of certain O&M works. The spread of avian influenza (also known as bird flu), which is an example of specific diseases, could be attributed to unsatisfactory cleaning or disinfection service (Lai and Hui, 2006).

Mapping the indicators

For all the above indicators, each of them was mapped with respect to the FM phase and hierarchy dimensions of the P-H model (Figure 1), and the results are shown in Table 11. On the whole, a small number of indicators were found at the strategic level: eight for the input phase and nine for the output phase. Yet, these indicators have a wide span of control in performance management (Figure 2). No indicator at the strategic level is for the process phase of facilities services delivery, nor is there any strategic indicator applicable to more than one of the three phases.

"Insert Table 11 here"

At the tactical level, 30 indicators are for the input phase while 20 indicators are for the output phase. The total number of indicators at the tactical level (67), when compared with that of the strategic level (17), is significantly larger. This result matches with the principle illustrated by the pyramid in Figure 2. The same principle, however, seems unable to predict the amount of indicators at the operational level. As the results show, the number of operational indicators is not large: 10 for the input phase, 12 for the process phase and eight for the output phase. In fact, the list of operational indicators could be expanded if, for instance, those in the technical group (e.g. "(T11) number of man hours per capacity of installation"; see Table 8) were subdivided to become trade-specific indicators. Note that for O&M works, there are typically 16 trades, e.g. air-conditioning and ventilation, electrical, etc. (Lai, 2017).

Involving both the input and output phases of facilities services delivery, "(T12) number of completed work orders per staff" and "(T29) efficiency of facilities" are applicable to more than one hierarchy level: tactical and operational. Concerning the input phase, indicators F4, F5, F16 and F17 are the indicators that are applicable to both the strategic and tactical levels, while several other indicators (T6-T9, T11-T13, T20, T21 and T29) are applicable to both the tactical and operational levels. In the output phase, indicators H1-H7 are applicable to both the strategic and tactical levels, while several other indicators (P1-P4, T12, T24, T28 and T29) are applicable to both the tactical and operational levels. Across these two levels, there are several other process indicators: T10, T14-19, T22, T23 and T25-T27.

Conclusions

A total of 71 indicators, which had been identified from the literature to be applicable to evaluating the performance of engineering facilities in commercial buildings, were clearly

defined and consolidated. In theory, it is possible to use these indicators for performance evaluation purposes, but the time taken to use all of them, in reality, would be considerable. Apart from time constraint, whether there are other factors that may hamper the adoption of the indicators in practice are yet to be explored.

When categorized by their nature, the indicators fall into five groups. Whereas the majority of the indicators belong to the financial and technical groups, it does not necessarily mean that the indicators of the other three groups (physical; environmental; and health, safety and legal) are less useful. As different indicators may carry different weights in evaluating the performance of facilities, it is necessary to conduct further research to find out how such weights could be determined.

The P-H model, comprising three phases (input, process and output) of facilities services delivery and three hierarchical levels (strategic, tactical and operational) of FM, was built upon the important management principles. As illustrated above, the model is fundamental to the systematic classification of the indicators. Mapping the indicators with the model showed that the number of indicators distributed along the hierarchy dimension generally matches with that anticipated in principle: indicators at the top (strategic) level, which have a wide span of control in managing facilities, are small in quantity, while the number of operational performance indicators is large given that there are multiple trades of facilities.

Whereas the focus of the above study is facilities operation and maintenance, the approach of the study may be taken in future studies to identify performance indicators for the other core competence areas of FM. The P-H model, in particular, is useful for researchers who need to classify performance indicators for facilities.

The above-mentioned mapping result, which reveals the applicability of the performance indicators with respect to the three phases of facilities services delivery, is useful for FM practitioners. But because an effective performance evaluation necessitates the use of an optimal number of practicable indicators, the subsequent task of the study, as will be reported in the next article (i.e. Part 2), was to shortlist the identified indicators to become KPIs.

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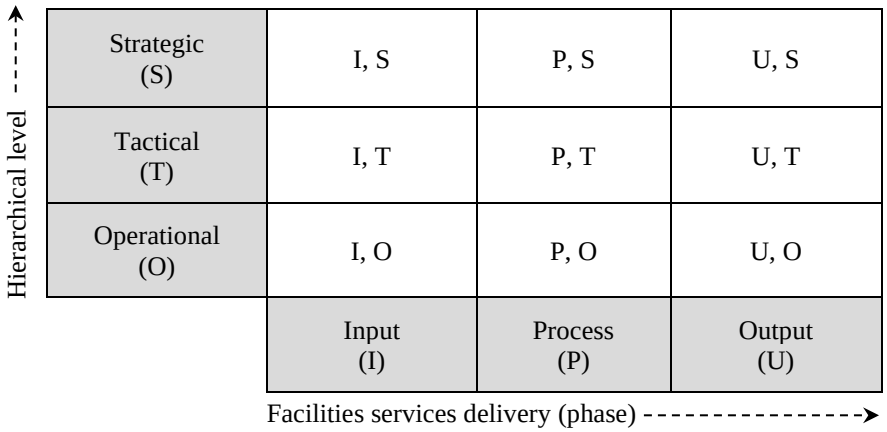

Figure 1 The phase-hierarchy (P-H) model for classifying performance indicators

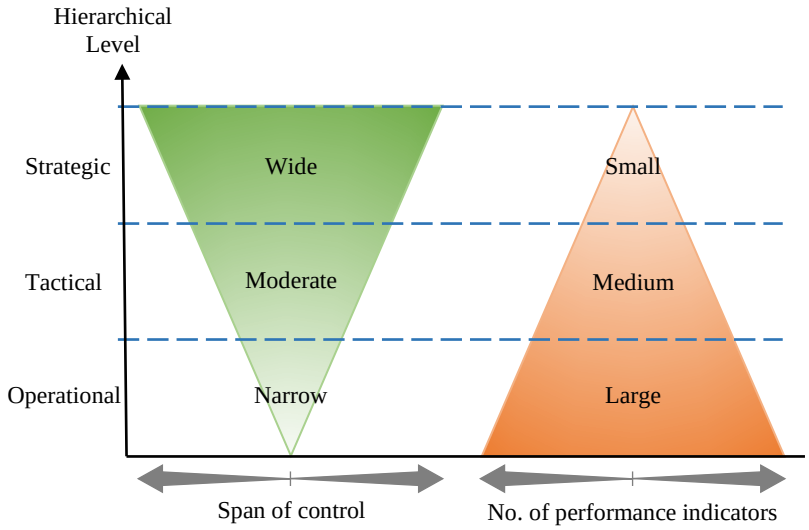

Figure 2 Span of control and number of performance indicators

Table 1 Physical performance indictors

Indicator	**Definition/formula**
(P1) Thermal comfort	Thermal comfort is where there is broad satisfaction with the thermal environment i.e. most people are neither too hot nor too cold. Main parameters that influence the perception of thermal comfort are: air temperature, mean radiant temperature, relative air speed and humidity. For more technical details/formulas, see American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (2013).
(P2) Visual comfort	Visual comfort concerns about good lighting design that considers both the quantity and quality of light, and improvements to these can make an important contribution to improved visual performance. Factors relating to quantity include: illuminance and distribution of light. Factors relating to quality include: colour, contrast, modelling and glare. Other factors that affect visual comfort are: non-uniformity, veiling reflections and highlights, shadows and flicker. For more technical details/formulas, see Chartered Institution of Building Services Engineers (2006).
(P3) Aural comfort	The main requirement for acoustic comfort is for a sufficiently 'quiet' environment to enable tasks to be carried out comfortably and without distraction, i.e. with no unwanted sounds or vibration. Sound is a vibration or pressure wave that moves through a suitable medium such as air or structure at a frequency and intensity that can be detected by the human ear. For more technical details/formulas, see Chartered Institution of Building Services Engineers (2006).
(P4) Indoor air quality	Indoor air quality parameters include: room temperature, relative humidity, air movement, carbon dioxide (CO_2), carbon monoxide (CO), respirable suspended particulates (PM_{10}), nitrogen dioxide (NO_2), ozone (O_3), formaldehyde (HCHO), total volatile organic compounds (TVOC), radon (Rn) and airborne bacteria. For more technical details/formulas, see American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (2007).
(P5) Percentage users dissatisfied	Ratio (in percentage) of the number of users in a customer survey (for the assessment period) who indicated their dissatisfaction with the physical indoor environment of the building to the number of users who responded to the survey. Formula: $\frac{Number\ of\ users\ dissatisfied}{Number\ of\ users} \times 100\%$
(P6) Number of users' complaints per year	Number of complaints lodged by the building users over the assessment period (year).

Sources (on top of the above-stated): Chan and Chan (2004); Lai and Yik (2006); Lavy et al. (2010); Leung et al. (2005); Loosemore and Hsin (2001); Lützkendorf and Lorenz (2006); Parida and Chattopadhyay (2007); The Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group (2003).

Table 2 Financial performance indicators

Indicator	Definition/formula
(F1) Percentage of personnel cost	Ratio (in percentage) of the total cost of personnel engaged in maintenance to the total cost of maintenance works over the assessment period. Formula: $\frac{Total\ staff\ cost}{Total\ maintenance\ cost} \times 100\%$
(F2) Percentage of subcontractor cost	Ratio (in percentage) of the expenditure on subcontracted maintenance works to the total cost of maintenance works over the assessment period. Formula: $\frac{Expenditure\ on\ subcontracting}{Total\ maintenance\ cost} \times 100\%$
(F3) Percentage of contractor cost	Ratio (in percentage) of the sum of contractor invoices billed for their maintenance activities spent on the facilities to the total cost of maintenance works over the assessment period. Formula: $\frac{Total\ contractor\ cost}{Total\ maintenance\ cost} \times 100\%$
(F4) Actual costs within budgeted costs	Ratio (in percentage) of the total maintenance cost actually expended to the total maintenance budget over the assessment period. Formula: $\frac{Annual\ actual\ costs}{Annual\ budgeted\ costs} \times 100\%$
(F5) Direct maintenance cost	Total sum of labour and material costs directly expended on maintenance works for the facilities over the assessment period. Formula: $Labour\ cost + material\ cost$
(F6) Breakdown severity	Ratio of the cost of breakdowns to the direct maintenance cost over the assessment period. Formula: $\frac{Breakdown\ cost}{Direct\ maintenance\ cost}$
(F7) Equipment replacement value	Estimated amount of capital that would be required to procure the equipment over the assessment period.
(F8) Maintenance stock turnover	Ratio of the cost of maintenance materials used to the cost of materials in stock over the assessment period. Formula: $\frac{Cost\ of\ materials\ used}{Cost\ of\ materials\ in\ stock}$
(F9) Percentage of maintenance material cost	Ratio (in percentage) of the total cost of maintenance materials to the total cost of maintenance works over the assessment period. Formula: $\frac{Total\ cost\ of\ maintenance\ materials}{Total\ maintenance\ cost} \times 100\%$
(F10) Percentage of corrective maintenance cost	Ratio (in percentage) of the expenditure on corrective maintenance works to the total cost of maintenance works over the assessment period. Formula: $\frac{Corrective\ maintenance\ cost}{Total\ maintenance\ cost} \times 100\%$
(F11) Percentage of preventive maintenance cost	Ratio (in percentage) of the expenditure on preventive maintenance works to the total cost of maintenance works over the assessment period. Formula: $\frac{Preventive\ maintenance\ cost}{Total\ maintenance\ cost} \times 100\%$
(F12) Percentage of condition based maintenance cost	Ratio (in percentage) of the expenditure on condition based maintenance works to the total cost of maintenance works over the assessment period. Formula: $\frac{Condition\ based\ maintenance\ cost}{Total\ maintenance\ cost} \times 100\%$
(F13) O&M cost per building area	Ratio of the cost expended on O&M works during the assessment period to the total building area. Formula: $\frac{O\&M\ cost}{Building\ area}$
(F14) O&M cost per capacity of installation	Ratio of the cost expended on O&M works during the assessment period to the capacity of the respective installation. Formula: $\frac{O\&M\ cost}{Capacity\ of\ installation}$

(F15) Cost of equipment added or replaced	Cost expended on adding or replacing equipment over the assessment period.
(F16) Energy expenditure per building area	Ratio of the energy cost during the assessment period to the total building area. Formula: $\frac{Energy\ expenditure}{Building\ area}$
(F17) Energy expenditure per person	Ratio of the energy cost to the average number of building occupants over the assessment period. Formula: $\frac{Energy\ expenditure}{Number\ of\ occupants}$
(F18) Total safety and security expenditure	Total expenditure on safety and security services over the assessment period.
(F19) Security expenditure per building area	Ratio of the expenditure on security service during the assessment period to the total building area. Formula: $\frac{Security\ expenditure}{Building\ area}$
(F20) Security expenditure per person	Ratio of the expenditure on security service to the average number of building occupants over the assessment period. Formula: $\frac{Security\ expenditure}{Number\ of\ occupants}$
(F21) Building income per building area	Ratio of the total building income during the assessment period to total building area. Formula: $\frac{Building\ income}{Building\ area}$
(F22) Total rentable value of the building	Total amount of rent obtained during the assessment period from the area of the building for which rent can be charged.

Sources: British Standards Institution (2007); Hinks and McNay (1999); Ho et al. (2000); Hong Kong Quality Assurance Agency (2012); Lai and Yik (2006); Loosemore and Hsin (2001); Muchiri et al. (2011); Tsang et al. (1999).

Table 3 Technical performance indictors

Indicator	**Definition/formula**
(T1) Work request response rate	Ratio of the number of work requests remaining in "request" status for less than 5 days to the total number of work orders done over the assessment period. Formula: $\frac{Work\ requests\ (<5\ days)}{Total\ work\ done} \times 100\%$
(T2) Scheduling intensity	Ratio of the amount of scheduled maintenance man hours to the amount of maintenance man hours available over the assessment period. Formula: $\frac{Scheduled\ man\ hours}{Man\ hours\ available} \times 100\%$
(T3) Manpower utilization rate	Ratio of the amount of maintenance man hours used to the amount of maintenance man hours available over the assessment period. Formula: $\frac{Man\ hours\ used}{Man\ hours\ available} \times 100\%$
(T4) Manpower efficiency	Ratio of the amount of man hours allocated to maintenance tasks to the amount of maintenance man hours used over the assessment period. Formula: $\frac{Man\ hours\ allocated}{Man\ hours\ used} \times 100\%$
(T5) Manpower utilization index	Ratio of the amount of man hours used for maintenance works to the amount of man hours available for maintenance works over the assessment period. Formula: $\frac{Man\ hours\ used\ for\ maintenance\ works}{Man\ hours\ available\ for\ maintenance\ works}$
(T6) Preventive maintenance ratio	Ratio of the amount of man hours used for preventive maintenance works to the amount of man hours used for corrective maintenance works over the assessment period. Formula: $\frac{Man\ hours\ used\ for\ preventive\ maintenance}{Man\ hours\ used\ for\ corrective\ maintenance}$
(T7) Percentage of corrective (reactive) work	Ratio (in percentage) of the amount of man hours used for corrective maintenance works to the total amount of maintenance man hours over the assessment period. Formula: $\frac{Corrective\ maintenance\ man\ hours}{Total\ maintenance\ man\ hours} \times 100\%$
(T8) Percentage of preventive (proactive) work	Ratio (in percentage) of the amount of man hours used for preventive maintenance works to the total amount of maintenance man hours over the assessment period. Formula: $\frac{Preventive\ maintenance\ man\ hours}{Total\ maintenance\ man\ hours} \times 100\%$
(T9) Percentage of condition based maintenance work	Ratio (in percentage) of the amount of man hours used for condition based maintenance works to the total amount of maintenance man hours over the assessment period. Formula: $\frac{Condition\ based\ maintenance\ man\ hours}{Total\ maintenance\ man\ hours} \times 100\%$
(T10) Percentage of improvement work	Ratio (in percentage) of the amount of man hours used for improvement works to the total amount of maintenance man hours available over the assessment period. Formula: $\frac{Man\ hours\ used\ for\ improvement\ works}{Total\ maintenance\ man\ hours\ available} \times 100\%$
(T11) Number of man hours per capacity of installation	Ratio of the amount of maintenance man hours used to the capacity of the respective installation over the assessment period. Formula: $\frac{Maintenance\ man\ hours\ used}{Capacity\ of\ installation}$
(T12) Number of completed work orders per staff	Ratio of the number of maintenance work orders completed to the average number of maintenance staff over the assessment period. Formula:

	$\frac{Number\ of\ work\ orders\ completed}{Number\ of\ maintenance\ staff}$
(T13) Area maintained per maintenance staff	Ratio of the area maintained to the average number of maintenance staff over the assessment period. Formula: $\frac{Area\ maintained}{Number\ of\ staff}$
(T14) Quality of scheduling	Ratio of the number of maintenance work orders with delayed execution to the total number of maintenance work orders over the assessment period. Formula: $\frac{Number\ of\ work\ orders\ with\ delayed\ execution}{Total\ number\ of\ work\ orders} \times 100\%$
(T15) Schedule realization rate	Ratio of the number of maintenance work orders (with scheduled date earlier or equal to late finished date) to the total number of maintenance work orders over the assessment period. Formula: $\frac{Number\ of\ work\ orders\ (scheduled\ date\ earlier\ or\ equal\ to\ late\ finished\ date)}{Total\ number\ of\ work\ orders} \times 100\%$
(T16) Schedule compliance	Ratio of the number of maintenance work orders completed in the scheduled period (before late finished date) to the total number of maintenance work orders over the assessment period. Formula: $\frac{Number\ of\ work\ orders\ completed\ (before\ late\ finished\ date)}{Total\ number\ of\ work\ orders} \times 100\%$
(T17) Work order turnover	Ratio of the number of maintenance tasks completed to the number of maintenance tasks received over the assessment period. Formula: $\frac{Number\ of\ tasks\ completed}{Number\ of\ tasks\ received}$
(T18) Backlog size	Ratio of the number of overdue maintenance tasks to the number of maintenance tasks received over the assessment period. Formula: $\frac{Number\ of\ overdue\ tasks}{Number\ of\ tasks\ received}$
(T19) Urgent repair request index (URI)	Ratio of the number of urgent repair requests (UR) to the total number of urgent repair requests and general repair requests (GR) over the assessment period. Formula: $\frac{UR}{UR + GR}$
(T20) Corrective maintenance time	Amount of time needed for carrying out corrective maintenance works over the assessment period.
(T21) Preventive maintenance time	Amount of time needed for carrying out preventive maintenance works over the assessment period.
(T22) Response time for maintenance	Amount of time needed for maintenance staff to respond to maintenance work requests over the assessment period.
(T23) Percentage compliance with required response time	Ratio (in percentage) of the number of maintenance work requests responded within the specified response time limit to the total number of maintenance work requests over the assessment period. Formula: $\frac{Number\ of\ work\ requests\ (responded\ in\ time)}{Total\ number\ of\ work\ requests} \times 100\%$
(T24) Number of maintenance induced interruptions	Number of interruptions on the normal operations due to the execution of maintenance works.
(T25) Failure/breakdown frequency	Number of failures/breakdowns over the assessment period.
(T26) Mean time between failures (MTBF)	Ratio of the total time during which the facilities are performing their required functions to the number of failures over the assessment period. Formula: $\frac{Total\ operating\ time}{Number\ of\ failures}$

(T27) Mean time to repair (MTTR)	Ratio of the total time to restoration (during which the facilities are in downstate) to the number of failures over the assessment period. Formula: $\frac{Total\ time\ to\ restoration}{Number\ of\ failures}$
(T28) Availability	Ratio of uptime of facilities to the sum of their uptime and downtime over the assessment period. Formula: $\frac{Uptime}{Uptime + Downtime}$
(T29) Efficiency of facilities	Ratio of power output of facilities to their power input over the assessment period. Formula: $\frac{Power\ output}{Power\ input}$
(T30) Gross floor area under safety and security patrol	Gross floor area of the building provided with safety and security patrol services.

Sources: British Standards Institution (2007); Campbell (1995); Chan et al. (2001); Electrical and Mechanical Services Department (2009); Hinks and McNay (1999); Ho et al. (2000); Lai and Yik (2006); Loosemore and Hsin (2001); Lützkendorf and Lorenz (2006); Muchiri et al. (2011); Parida and Chattopadhyay (2007); Róka-Madarász (2011); Tsang et al. (1999).

Table 4 Environmental performance indictors

Indicator	**Definition/formula**
(E1) Energy use index	Ratio of the total annual equivalent energy consumption to the total internal floor area of the building. Formula: $\frac{Total\ annual\ equivalent\ energy\ consumption}{Total\ internal\ floor\ area}$
(E2) Energy consumption per person	Ratio of the total annual equivalent energy consumption to the average number of building occupants. Formula: $\frac{Total\ annual\ equivalent\ energy\ consumption}{Number\ of\ occupants}$
(E3) Greenhouse gas emission per building area	Ratio of the total amount of greenhouse gas emission during the assessment period to the building area. Formula: $\frac{Total\ greenhouse\ gas\ emission}{Building\ area}$
(E4) Conduction of energy audit	It refers to having an energy audit conducted during the assessment period. (Energy audit is an inspection and analysis for the assessment of the energy needs and efficiency of a building or buildings.)
(E5) Conduction of carbon audit	It refers to having a carbon audit conducted during the assessment period (Carbon audit is an inspection and analysis for the assessment of the total set of greenhouse gas emissions caused by a building or buildings.)
(E6) Conduction of environmental assessment	It refers to having an environment assessment conducted during the assessment period. (Environment assessment is an assessment of the environmental consequences (positive and negative) of a plan, policy, program, or actual projects prior to the decision to move forward with the proposed action.)

Sources: BEAM Society Limited (2016); BRE Global Limited (2016); Chan et al. (2001); Electrical and Mechanical Services Department (2007; 2012a; 2012b); Electrical and Mechanical Services Department and Environmental Protection Department (2010); Ho et al. (2000); Hong Kong Quality Assurance Agency (2012); Lavy et al. (2010); Loosemore and Hsin (2001); U.S. Green Building Council (2016); Varcoe (1996).

Table 5 Health, safety and legal performance indictors

Indicator	**Definition/formula**
(H1) Number of accidents per year	Number of accidents (injuries or casualties) arising from underperformance of facilities over the assessment period (year).
(H2) Number of legal cases per year	Number of legal cases arising from underperformance of facilities over the assessment period (year).
(H3) Number of compensation cases per year	Number of cases (arising from underperformance of facilities) where the injured parties are compensated over the assessment period (year).
(H4) Amount of compensation paid per year	Amount of compensation paid to the injured parties (arising from underperformance of facilities) over the assessment period (year).
(H5) Number of health and safety complaints per year	Number of complaints lodged by the building users on health and safety issues arising from underperformance of facilities over the assessment period (year).
(H6) Number of lost work days per year	Number of days off due to work-related illness/injuries (arising from underperformance of facilities) over the assessment period (year).
(H7) Number of incidents of specific diseases per year	Number of incidents of specific diseases (certified by doctors) over the assessment period (year).

Sources: Building Services Research and Information Association (2011); Health and Safety Executive (2017); Lavy et al. (2010); Parida and Chattopadhyay (2007).

Table 6 Classified performance indicators (physical)

Phase	Level	Performance indicator
Output	Tactical, operational	Thermal comfort (P1); Visual comfort (P2); Aural comfort (P3); Indoor air quality (P4)
Output	Tactical	Percentage users dissatisfied (P5); Number of users' complaints per year (P6)

Table 7 Classified performance indicators (financial)

Phase	Level	Performance indicator
Input	Strategic, tactical	Actual costs within budgeted costs (F4); Direct maintenance cost (F5); Energy expenditure per building area (F16); Energy expenditure per person (F17)
Input	Strategic	O&M cost per building area (F13); Total safety and security expenditure (F18); Security expenditure per building area (F19); Security expenditure per person (F20)
Input	Tactical	Percentage of personnel cost (F1); Percentage of subcontractor cost (F2); Percentage of contractor cost (F3); Breakdown severity (F6); Equipment replacement value (F7); Maintenance stock turnover (F8); Percentage of maintenance material cost (F9); Percentage of corrective maintenance cost (F10); Percentage of preventive maintenance cost (F11); Percentage of condition based maintenance cost (F12); O&M cost per capacity of installation (F14); Cost of equipment added or replaced (F15)
Output	Strategic	Building income per building area (F21); Total rentable value of the building (F22)

Table 8 Classified performance indicators (technical)

Phase	Level	Performance indicator
Input, output	Tactical, operational	Number of completed work orders per staff (T12); Efficiency of facilities (T29)
Input	Tactical, operational	Preventive maintenance ratio (T6); Percentage of corrective (reactive) work (T7); Percentage of preventive (proactive) work (T8); Percentage of condition based maintenance work (T9); Number of man hours per capacity of installation (T11); Area maintained per maintenance staff (T13); Corrective maintenance time (T20); Preventive maintenance time (T21)
Input	Tactical	Gross floor area under safety and security patrol (T30)
Process	Tactical, operational	Percentage of improvement work (T10); Quality of scheduling (T14); Schedule realization rate (T15); Schedule compliance (T16); Work order turnover (T17); Backlog size (T18); Urgent repair request index (T19); Response time for maintenance (T22); Percentage compliance with required response time (T23); Failure/breakdown frequency (T25); Mean time between failures (T26); Mean time to repair (T27)
Process	Tactical	Work request response rate (T1); Scheduling intensity (T2); Manpower utilization rate (T3); Manpower efficiency (T4); Manpower utilization index (T5)
Output	Tactical, operational	Number of maintenance induced interruptions (T24); Availability (T28)

Table 9 Classified performance indicators (environmental)

Phase	Level	Performance indicator
Input	Tactical	Conduction of energy audit (E4); Conduction of carbon audit (E5); Conduction of environmental assessment (E6)
Output	Tactical	Energy use index (E1); Energy consumption per person (E2); Greenhouse gas emission per building area (E3)

Table 10 Classified performance indicators (health, safety and legal)

Phase	Level	Performance indicator
Output	Strategic, tactical	Number of accidents per year (H1); Number of legal cases per year (H2); Number of compensation cases per year (H3); Amount of compensation paid per year (H4); Number of health and safety complaints per year (H5); Number of lost work days per year (H6); Number of incidents of specific diseases per year (H7)

Table 11 Mapping of the applicable indicators

Phase / Level	Input	Process	Output	More than one phase
Strategic	**8** (*F4, F5*, F13, *F16, F17*, F18, F19, F20)	**0** -	**9** (F21, F22, *H1, H2, H3, H4, H5, H6, H7*)	**0** -
Tactical	**30** (E4, E5, E6, F1, F2, F3, *F4, F5*, F6, F7, F8, F9, F10, F11, F12, F14, F15, *F16, F17, T6, T7, T8, T9, T11*, *T12**, *T13, T20, T21*, *T29**, T30)	**17** (T1, T2, T3, T4, T5, *T10, T14, T15, T16, T17, T18, T19, T22, T23, T25, T26, T27*)	**20** (E1, E2, E3, *P1, P2, P3, P4*, P5, P6, *T12**, *T24, T28, T29*, H1, H2, H3, H4, H5, H6, H7*)	**2** (*T12**, *T29**)
Operational	**10** (*T6, T7, T8, T9, T11, T12**, *T13, T20, T21*, *T29**)	**12** (*T10, T14, T15, T16, T17, T18, T19, T22, T23, T25, T26, T27*)	**8** (*P1, P2, P3, P4*, *T12**, *T24, T28, T29**)	**2** (*T12**, *T29**)
More than one level	**14** (*F4, F5, F16, F17, T6, T7, T8, T9, T11, T12**,*T13, T20, T21*, *T29**)	**12** (*T10, T14, T15, T16, T17, T18, T19, T22, T23, T25, T26, T27*)	**15** (*P1, P2, P3, P4, H1, H2, H3, H4, H5, H6, H7, T12**, *T24, T28, T29**)	

Notes:
1. **Boldfaced numbers** denote quantities of indicators in the respective phase-level classes.
2. *Italicised texts* denote indicators applicable to more than one hierarchy level.
3. * denotes indicator involving both the input and output phases, applicable to more than one hierarchy level.