Key Performance Indicators for maintenance of hospital buildings

Igal M. Shohet
Department of Civil Engineering and National Building Research Institute
Technion – Israel Institute of Technology, Haifa 32000 ISRAEL
E-mail: ishohet@tx.technion.ac.il

Abstract: *Maintenance management of hospital buildings is one of the more complex issues in the field of maintenance. The performance and operation of hospital buildings are affected by numerous factors. These include hospital occupancy relative to standard occupancy, age of buildings, and building surroundings. The purpose of this research was to quantify the effects of users, building characteristics and systems on the buildings' performance and maintenance. The following factors were investigated:*

1. *Overall performance of the building: A Building Performance Indicator (BPI), based on systematic performance and maintenance rating scales, was used to monitor the building's performance.*
2. *Age of the building: A high correlation was found, using a Life Cycle Cost analysis, between maintenance expenditures and the age of a hospital building.*
3. *Building's level of occupancy: The maintenance labor inputs of two identical hospitalization wards with different occupancy levels were compared over a period of 3 years. The results showed that maintenance labor inputs for the higher occupancy ward (133% of the standard) were 22% higher than for the other ward.*
4. *Level of labor outsourcing: The financial benefits of outsourcing maintenance activities were investigated through a field survey. Facilities with high occupancy levels and frequent breakdowns were compared with facilities with standard occupancy levels that practice preventive maintenance extensively. It was found that for standard occupancy facilities, outsourcing of maintenance resulted in a saving of 8% of the overall maintenance expenditure. For facilities with high occupancy levels, use of in-house labor resulted in a 6% decrease in maintenance expenditures.*

The coefficients and diagrams developed were integrated into 4 Key Performance Indicators for Hospital Buildings. The model was examined in 6 Case studies one of which is presented.

Keywords: Facility Management, Key Performance Indicators (KPI), Maintenance, Outsourcing, Performance.

Introduction

Maintenance management of hospital buildings is one of the more complex issues in the field of maintenance. Contributing to this are the great complexity of hospitalization buildings, the high criticality of hospital mechanical and electrical systems, and the shortage of maintenance budgets. Moreover, the performance and operation of hospital buildings are affected by numerous factors. These include hospital occupancy relative to planned occupancy, age of buildings, building surroundings, managerial resources invested, and labor sources for execution of maintenance (in-house provision vs. outsourcing). The objective of this research was to develop a model for the prediction of the performance and operational costs of hospital buildings. The study examined the effect of the above-mentioned factors on the performance and maintenance costs of buildings, as a basis for the development of Key Performance Indicators.

Background

Building maintenance is gaining a central role in the construction activity worldwide. In Britain, for example, building maintenance activities have reached a level of 50% of all annual construction activities (Baldry, 2002). Many researchers are involved in the prediction of maintenance costs for various types of buildings (Domberger and Jensen, 1997; Underwood and Alshawi, 1999). Many studies indicate that the performance and maintenance of a building are influenced by a large number of factors, including the age of the building, labor sources, and the type of the building (Neely and Neathamer, 1991; Atkin and Brooks, 2000). Nevertheless, a need exists for the development of models that integrate building performance into asset management and budgeting of management and maintenance activities (McDougall and Hinks, 2000).

Methodology

The methodology of this study included gathering of data from hospital engineering departments, statistical comparative analyses, and quantitative analyses of maintenance costs under various conditions based on previous empirical studies (Shohet, 1999). In addition, case study analyses for the examination of the Key Performance Indicators developed on the basis of the various coefficients were performed. This paper focuses on three parameters that influence hospital building performance and maintenance, namely the age of the building, the building's occupancy level, and the available labor sources. Performance analysis of the buildings was based on the Building Performance Indicator (BPI).

Statistical Findings

A model was developed for the overall maintenance management of hospitalization buildings based on indicators of performance, budgeting and resource allocation. The basis for the development of the model was a field survey of 17 major hospitals in Israel and a statistical analysis of the survey data. Subsequently, four Key Performance Indicators were developed, based on the research findings and on the development of budgeting and performance coefficients for hospitalization buildings. The indicators were validated and tested using case studies at 6 hospitals.

As mentioned, the field survey included 17 hospitals and was performed in the course of 2000-2001 in reference to the budgetary year 1999. The average built area of the hospitals in the survey was approximately 80,000 sq m. The average number of patient beds per hospital was 660 and the average number of beds per 1,000 sq m. built area was 8.25. The average annual maintenance budget per hospital was about $3,000,000, i.e. approximately $37.2 per sq m. per year. The average Reinstatement Value was calculated according to the final invoices of several projects and was equal to $1678 per sq m., i.e. the average actual annual maintenance budget amounted to 2.22% of the average Reinstatement Value. A parallel analysis of the required annual cost of maintenance, based on the standard life cycles of 10 of the buildings' main systems, revealed that the average annual maintenance budget, required to maintain a hospitalization building at a high state of performance, was 3.23% of the average Reinstatement Value, i.e. $54.2 per sq m.

per year. The implication of these two last data is that the actual average annual maintenance budget equals approximately 70% of the optimal value.

Coefficients and Measures of Budgeting and Maintenance Performance

The statistical analyses examined the following aspects:

- The effect of various labor sources mixes (outsourcing vs. in-house provision) on the annual maintenance expenditures of hospital buildings.
- The effect of the occupancy level of hospitalization wards on their maintenance costs.
- The effect of the building's age on the annual maintenance costs.

Findings and Results

Outsourcing vs. In-house Personnel

An examination of the proportion of maintenance works performed by outsourcing (contractors and external firms) versus in-house provision shows that hospitals can be divided into two different categories: (1) High-occupancy hospitals (over 10 patient beds per 1,000 sq m.); and (2) Hospitals with standard, or lower, levels of occupancy (up to 10 patient beds per 1,000 sq m.). The analysis compared total work expenditures and divided them into two categories of labor sources: in-house provision, and outsourcing. Figure 1 presents a regression analysis of the relationship between outsourcing (Y-axis) and in-house provision (X-axis) of maintenance work in standard- or low-occupancy hospitals. The regression analysis shows that, when hospital occupancy level is standard or lower, outsourcing results in a saving of approximately 8% (R^2=0.89). On the other hand, when hospital occupancy levels are higher than planned, as seen in Figure 2, the use of in-house provision leads to a 6% saving in maintenance expenditures (R^2=0.98). These finding are explained by the fact that under high occupancy conditions the deterioration of some of the hospital building systems is accelerated and a high availability of maintenance workers is required for the execution of breakdown maintenance. Therefore, under such conditions, the employment of in-house personnel offers opportunity for savings. This conclusion differs from that of previous studies on the subject (Australian Industry Commission, 1996), and is more complex. At occupancy levels that are standard or lower, there is indeed an advantage and saving in the employment of a manpower mix in which the majority of the maintenance workers are external personnel. On the other hand, under high occupancy conditions, there is a clear advantage to a manpower mix in which the majority of personnel are in-house maintenance workers.

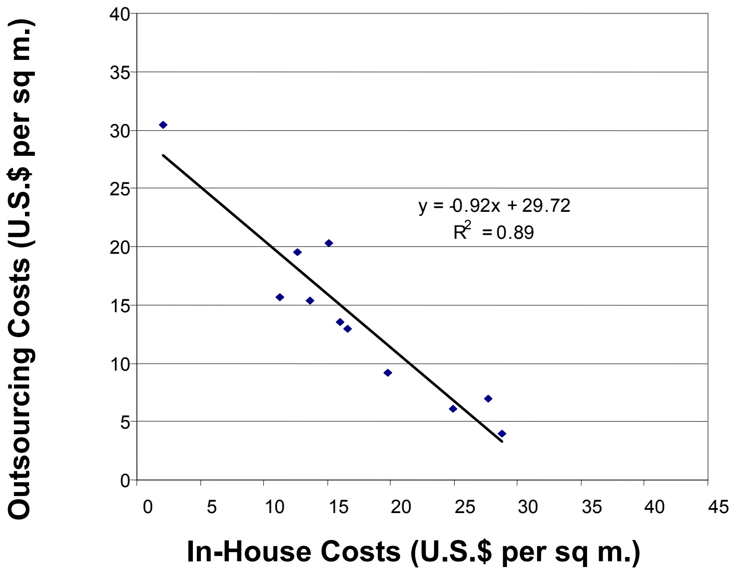

Figure 1: Annual labor expenditures per sq m.: Outsourcing vs. In-House Provision – Low level of occupancy

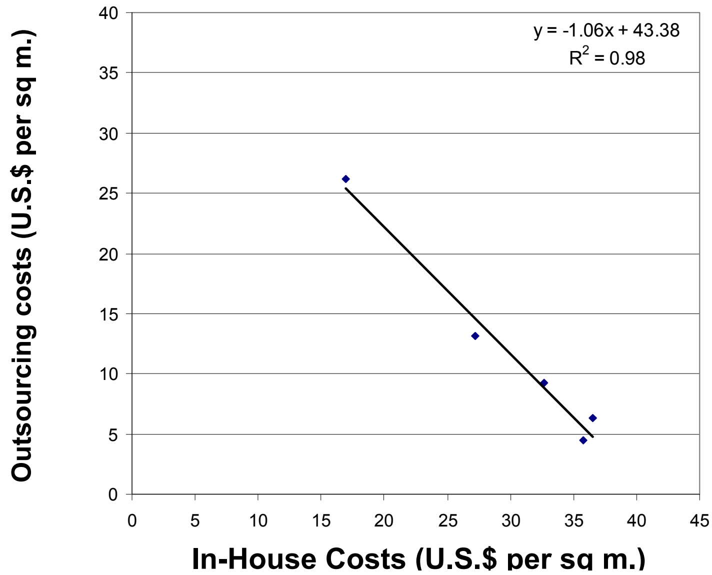

Figure 2: Annual labor expenditures per sqm.: Outsourcing vs. In-House provision – High level of Occupancy

Effect of Occupancy Level on Annual Maintenance Expenditure of Hospitalization Buildings

The effect of the occupancy level on the deterioration rate and annual maintenance results was examined in two ways:

a) Two identical hospitalization wards located in the same hospitalization building were compared. One ward had an occupancy level of 133% of the standard occupancy rate (13.3 beds per 1,000 sq m.), while the other ward, the control ward, was an identical ward located in the same building and had an occupancy level of 10 patient beds per 1,000 sq m., which is the planned occupancy rate for such wards. Table 1 presents a comparison of the maintenance inputs for both wards over a period of three years. The comparison indicates that average labor inputs for the over-populated ward were 22.3% higher than for the control ward (standard occupancy conditions).

b) Maintenance costs for high and low occupancy rates (up to 133% and as low as 80% of the standard occupancy, respectively) were estimated by quantifying annual maintenance costs according to the life cycles of building components under accelerated deterioration conditions as opposed to moderate deterioration conditions.

The analysis for accelerated deterioration conditions was based on previous findings, which showed a 25% increase in the replacement rate of finishing components and various building systems. The calculation for moderate deterioration conditions was based on a moderate replacement rate of interior finishing components and some of the electro-mechanical systems. It is emphasized that for certain systems no decrease in maintenance expenditures was seen, since the analysis was based on preventive maintenance only. We assumed that maintenance of certain systems, such as Elevators and Fire Extinguishing & Detection, would not decrease because inspection and replacement activities would continue to be executed even under moderate deterioration conditions.

Our analysis showed that the predicted saving, as a result of moderate deterioration under low occupancy conditions, is but 5%. By comparison, according to the same analysis, it was found that maintenance expenditures would increase by about 20.0% for high-occupancy condition and accelerated deterioration of finishing components and electro-mechanical systems. This figure is very similar to that found in the labor input analysis (22.3%), so that both results are reinforced.

The occupancy coefficient was therefore determined to be 1.22 (according to actual labor input measurements) under maximal occupancy conditions of 133%, and 0.95 (according to expenditure analysis) for minimal occupancy conditions of 80%. Figure 3 presents the change in the occupancy coefficient as a function of the occupancy rate, according to a simplified model which assumes the existence of a linear relationship between the occupancy coefficient and the occupancy rate under standard conditions (100% occupancy) and under extreme conditions of high and low occupancies.

In-depth research must be conducted on this issue in order to formulate a more complex and accurate model, such as, for instance, the gray line that represents the second order change of the occupancy coefficient.

Ward	Occupancy Level (No. of beds per 1,000 sq m.)			Average Annual Maintenance Labor Input (hours)	S.D.
	Standard	Actual	Occupancy Rate (%)		
1	10.0	13.3	133	836.2	108.2
2	10.0	10.0	100	683.6	55.5

Table 1: Annual maintenance labor input (in hours) per hospital ward for high- and standard-occupancy levels

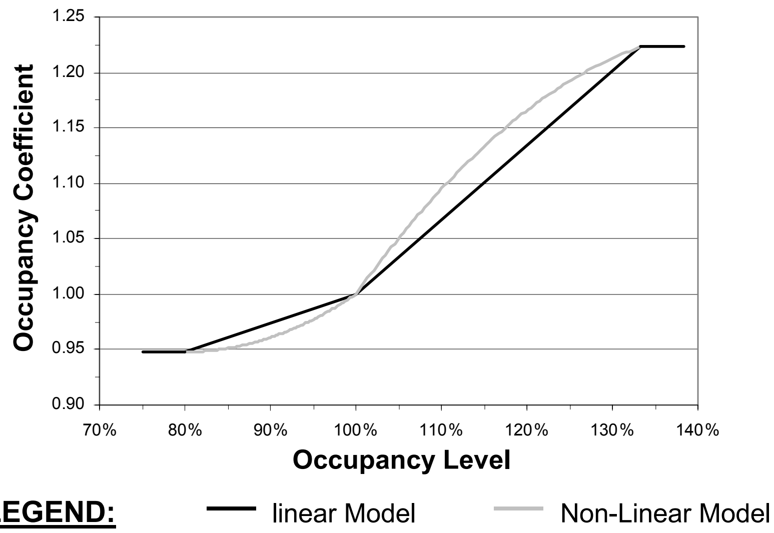

Figure 3: Occupancy coefficient (for annual maintenance expenditure) for different levels of occupancy

The Effect of the Building's Age on Annual Maintenance Expenditure

The effect of the building's age was examined by an analysis of the annual maintenance costs according to the life cycles of building components, as identified in surveys of energy and construction companies in Israel, and according to additional literary sources (Building Services Component Life Manual, 2002).

Annual maintenance costs were determined according to the ongoing cost of maintenance of the building's various components, and the replacement cost of components at the end of their life cycle. An analysis of annual maintenance costs revealed a great deal of fluctuation from year to year, due to the accumulation of a high number of replacements during several specific years (for example years nos. 20, 25, and so on).

In order to curb such fluctuations, the building's Age Coefficient (AC_y) was calculated according to the value of the moving average (over a period of 10 years) of the ratio of annual maintenance costs for year *y* to the average annual maintenance cost for the building's entire life cycle ($54.2). Figure 4 and Table 2 present the analysis results. Age Coefficients range between 0.55 for the first decade to 1.32 for the third and fourth decades. This expresses a high rate of replacement in Decades 3 and 4 compared to a low rate of replacements in the first decade.

The coefficient demonstrates the problematic character of maintenance budgeting of complex buildings, such as hospitalization buildings, and the need to investigate this issue in a systematic, quantitative, and scientific manner. This diagram reveals that the development of a maintenance budget must be tracked continuously and the budgeting examined both for each specific year and in relation to the building's performance.

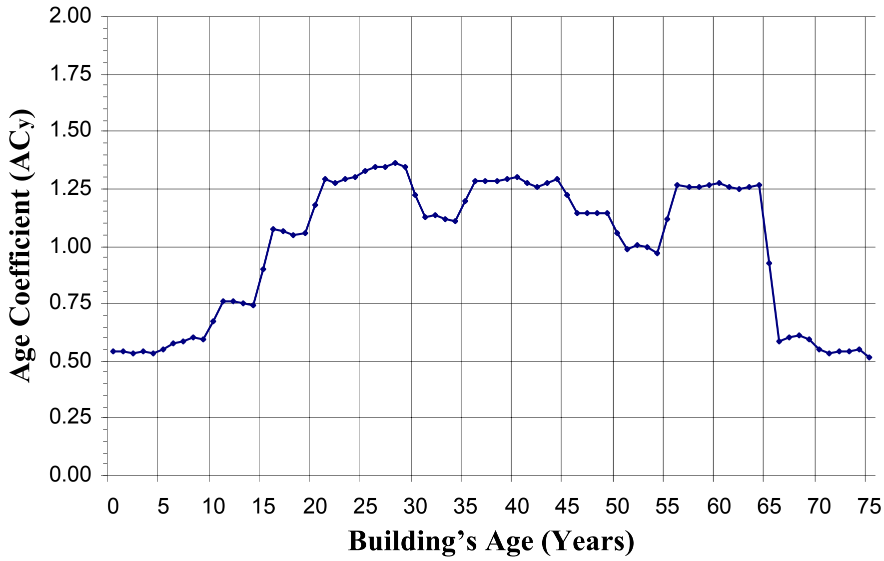

Figure 4: Age Coefficient (Ac_y) vs. age of building

Age of Building [Years]	**Age Coefficient AC_y**
5	0.55
10	0.67
15	0.90
20	1.18
25	1.33
30	1.22
35	1.20
40	1.30
45	1.22
50	1.05

Table 2: Age Coefficients for hospitalizing buildings of various ages

Summary of findings regarding influence parameters

Research findings reveal that the three parameters examined have a fundamental effect on the performance of the buildings studies, as well as on the maintenance costs. The influence of the above-mentioned factors must, therefore, be quantified into a comprehensive model that will relate the facility's characteristics to its performance and predicted costs. This study assumes the existence of a linear correlation between the level of performance and the level of maintenance expenditure.

The age of the building (or the average age of a larger building complex) has a substantial effect, which is expressed in values that are up to 45% lower than average for the first decade, and up to 32% higher than average for the third and fourth decades. The effect of the building's age must, therefore, be quantified for use in any quantitative model that addresses maintenance budgeting and control.

Occupancy of the building also has a significant, albeit more moderate, influence on the annual maintenance expenditure. A statistical and quantitative analysis of the high occupancy levels of hospitalization buildings revealed consistent results indicative of a 20-22% increase in annual maintenance expenditure. On the other hand, under low occupancy conditions, savings are not symmetrical, but rather much more modest, and amount to only 5%.

Sources of labor have an additional effect that might have a restraining impact on the annual maintenance expenditure. It was found that by exchanging in-house labor with outsourced labor under low-occupancy conditions an 8% saving may be obtained by, while under high-occupancy conditions (when a significant increase in costs occurs) a saving of 6% can be created by use of in-house personnel.

In order to examine the above-mentioned findings, a comprehensive model was developed, in which the various coefficients investigated in the analysis and formulation of maintenance policies in large hospitals are manifested.

Comprehensive model for hospital maintenance management

The hospital campus management model is implemented via four Key Performance Indicators, as follows:

1. The physical-functional state of the building – Building Performance Indicator (BPI);
2. Manpower Sources Diagram (MSD);
3. Maintenance Efficiency Indicator (MEI);
4. Managerial Span of Control (MSC).

Following is a concise description of these four indicators:

<u>The Building Performance Indicator</u> of a hospital comprises the following 10 building systems: Skeleton, Envelope, Finishing Components, Electrical System, Water & Sanitation System, Elevators, HVAC, Fire Extinguishing & Detection, Communications & Low-Voltage, and Medical Gases. Each system is made up of its basic components. For example, the building's Skeleton comprises basic units, such

as columns, beams, walls and ceilings. Each system is analyzed on a performance/ maintenance scale that covers three main aspects: (1) Suitability of the components to their intended use; (2) Past malfunction and failures; and (3) Preventive maintenance. Each system is graded on a 0-100 scale, and this score is integrated into the Performance Indicator according to the proportional weight of the system in the hospitalization building's life cycle. The indicator reflects the hospital building's performance as described by the four categories: good to very good (BPI>80); satisfactory-marginal (70<BPI≤80); deteriorating (60<BPI≤70); and run-down/dangerous (BPI≤60). The Indicator is described in detail in another paper (Shohet, 2002).

Manpower Sources Diagram – This diagram presents the manpower source mix (internal and external sources) and enables identification of the optimal manpower mix that will enable maximal labor utilization.

Maintenance Efficiency Indicator – This indicator expresses the cost of maintenance per performance unit (BPI). Two indicators are incorporated into this indicator, namely the budgetary Age Coefficient for the building (ACy) and the Building Occupancy Coefficient (OC), described previously. Equation 1 yields the Maintenance Efficiency Indicator:

$$MEI = \frac{AME}{ACy} * \frac{1}{BPI} * \frac{1}{OC} \qquad (1)$$

Where MEI is the Maintenance Efficiency Indicator, AME is the actual Annual Maintenance Expenditure (in $/sq m.), ACy is the Age Coefficient for year y, BPI is the monitored Building Performance Index, and OC is the Occupancy Coefficient.
Values of this indicator range from 0 and up. For a hospitalization building, values lower than 0.4 indicate a shortage of resources and/or efficient execution of maintenance. Values between 0.4 and 0.6 mean that resources are reasonably utilized, while values higher than 0.6 indicate a surplus of resources or inefficient utilization of resources relative to the building's performance.

Managerial Span of Control – This indicator reflects the number of employees subordinate to the maintenance managers and principal engineer, The MSC helps identify a shortage or surplus in managerial resources as well as an overload on the managerial level.

It is noted that the implementation and analysis of all four indicators must be carried out simultaneously. Analysis of only part of the indicators might create a partial and misleading view of the situation.

Case Study

As mentioned, six detailed case studies were performed, and one of the more interesting of them is presented below.

Hospital Characteristics

The hospital analyzed in the case study had approximately 1,000 patient beds, with an average of 9.3 beds per 1,000 sq m. built area. This gave a resultant occupancy coefficient of 0.98. The annual maintenance budget for 1999 was $4,420,000, i.e. $38.50 per sq m. The distribution of the maintenance budget among its three main components shows that 49.9% was spent on the execution of work by external manpower sources (outsourcing), 39.4% of the budget was designated towards in-house provision, and 10.7% was designated towards materials and spare parts. The average age of the hospital buildings was 23, and thus the Age Coefficient for the campus was 1.31, due to the fact that the hospital was in its third decade during which many electro-mechanical systems and finishing components are due to be replaced. The analysis of the hospital's performance-maintenance state using the BPI led to a score of 66.1, indicating that the hospital was in a condition of deterioration. This low ranking was mainly the result of the low performance of finishing components, which indeed are not vital to the functioning of the hospital, but nonetheless constitute 35% of the BPI. On the other hand, the Medical Gases, Fire Extinguishing & Detection, Elevator, and Water & Sanitation systems were found to be in "good to very good" condition.

An analysis of the maintenance organizational structure revealed that the Principal Engineer's Span of Control was 3, but the number of subordinates on the Maintenance Manager level reached 7, a high and marginal value, which if reduced, could improve maintenance efficiency.

Analysis using hospital Key Performance Indicators

The annual maintenance budget of the hospital examined was $38.5/sq m. (approximately 2.3% of the Reinstatement Value). This, together with the average Age Coefficient for the campus (1.31) and the Occupancy Coefficient (0.98) resulted in a Maintenance Efficiency Indicator (MEI) of 0.45. This value is in the low range of 0.4-0.6, which is a reasonable range for the operation of hospitals in Israel.
Such a value is indicative of a satisfactory utilization of maintenance resources, but at the same time points to a significant shortage of resources, as was evident from the performance of the hospital. It may therefore be concluded that the performance reflects the level of resources invested in the hospital, its relatively old age, and its standard level of occupancy. The hospital's deteriorated condition can be improved by an increase in resource allocation.

Figure 5 presents the current condition of the hospital. The X-axis represents the performance level according to the BPI, and the Y-axis represents the total maintenance budgetary increase per sq m. Zero increase (horizontal line at y=0) represents the current budgetary level of $38.5/sq m. In addition, the figure presents two alternatives for improvement of hospital performance by investing additional resources.

Alternative 1 proposes to elevate the hospital's performance to a level of BPI=70 while maintaining the present level of efficiency (MEI=0.45) by increasing the performance of some of the building's systems to a minimum of P_n=70.

In Alternative 2, the performance of all building systems is improved to a level of P_n=70 which will lead to BPI=74.

At the same time, an appropriate labor source mix may be found using a Manpower Sources Diagram for each of the two alternatives.

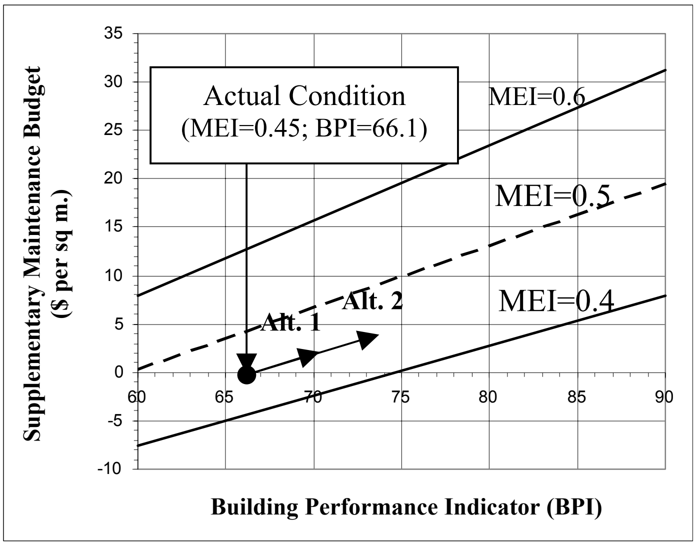

Figure 5: Supplementary Maintenance Budget vs. Building Performance Indicator (BPI) for various levels of resource utilization (MEI)

Summary of Case Study and Conclusions

1. The Building Performance Indicator (BPI), the Maintenance Efficiency Indicator (MEI) and the Managerial Span of Control (MSC) enable the identification of the hospital's state of performance, and an analysis of its budgeting level.

2. Factors, such as the building's age and level of occupancy, have significant influence and are manifested in the building's performance. Thus, they must find expression in the budgeting of maintenance operations.

3. The Indicators afford a wide perspective in the examination of the maintenance issue. Aspects covered by the Indicators include performance, budget per sq m., manpower mix, maintenance management, age of buildings, and occupancy level of hospitalization wards.

Summary and Conclusions

This paper examined the effects of three factors on the performance and maintenance of hospital buildings. All of the factors investigated were found to have a significant effect, which enables, but also necessitates, their inclusion in a quantitative model for the management of hospital buildings. An analysis of the building's age revealed that, over the course of time, maintenance requirements are characterized by a great deal of fluctuation (between +33% to –45% of the multi-year average value). Therefore, there is a need for the development of a managerial-quantitative model to address this issue. Furthermore, it was found that occupancy exerts a considerable effect on the deterioration of the building and its systems. This effect ranges from +22% at very high occupancy levels to -5% at low occupancy levels. Manpower sources exerted the least influence and their effect was not conclusive.

The coefficients developed in the study were integrated into a model for the analysis of the performance and maintenance state of hospitalization buildings. Examination of the model, using sample case studies, revealed that it is possible to accurately diagnose the state of maintenance, as well as the suitability of the maintenance budget to the current performance, as opposed to the expected performance.

Nevertheless, our study indicates that continued research is required to refine the effect of the building's occupancy on the rate of deterioration and of the building's surroundings on its maintenance.

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