APPLICATION OF MULTI DIMENSIONAL DIAGNOSIS SYSTEM OR P DIAGRAM IN BUILDING DESIGN

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ABSTRACT

Current building design is heavily influenced by design of experiment approach where the analysis is based on computation of factor by factor for evaluation of variability in product characteristics. The outcome of the analysis is not focused on performance during operation. A method such as Robust Engineering (RE) approach in manufacturing has been shown to improve the product's engineered quality and performance. The RE approach focuses on the interaction of control and uncontrolled factors using a multidimensional diagnosis system. It focuses on stabilizing product characteristics for better performance during operation. The aim of this research is to assess the potential of applying the multidimensional diagnosis system in building design. The luminaires design was selected as an example in this study. The control and uncontrolled factors are developed based on brainstorming sessions with experts. The analysis uses the orthogonal array to execute a balanced design. This paper proposed an approach that is more efficient using energy thinking and interaction of control and un-control factors of luminaires design. The main advantage using this approach compared to the conventioanal approach is that it utilises the technical information to optimize the design. It produces a robust design that is less sensitive to variation during operation.

Keywords— multidimensional diagnosis system, building design process, design management, robust building design

1. INTRODUCTION

Current building design is heavily influenced by design of experiment approach where the analysis is based on computation of factor by factor for evaluation of variability in product characteristics. The analysis tries to meet all safety and regulation requirements. While pressure to speed up production in terms of design and construction requirement increases, the clients also expect high-quality designs. Focusing on meeting the requirement usually does not produce a quality design as most of the design outcomes might not interact well with the user. Building design process is a sequential and linear progression process. The process follows the sequence shown in Figure 1. The process starts with an identification of requirements from the project owner which represents the customer attributes. These attributes, will then be translated into technical requirements for the development of design concepts. The next process is the identification of design parameters which will be the basis of acceptance of the design. The evaluation is conducted using the code of practices or design method which usually consists of analysis of control factors. Control factors satisfy the basic needs of the building. It is found that the analysis has low interaction between the user and the design element or between the control factors and uncontrolled factors [1].

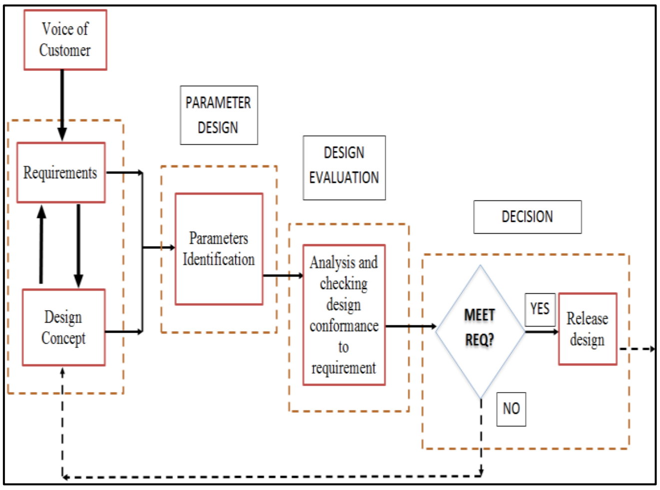


Figure 1. Current flow of building design process

The current design outcome relies on the designers' experiences and lessons learned from previous projects [2]–[4]. Clients are rarely involved in the design process as their interaction is only during technical discussion. As a result, the clients do not have sufficient information to make an informed decision during the design stage. To improve designs, a structured approach that focuses on meeting users' expectation in terms of maintenance-related considerations is highlighted. A study by [5], [6] proposed formulating a holistic method which focuses on building performance while in use in addition to focusing on meeting the current code of practice and client's needs. This can be achieved by formulating an efficient and effective method that considers the interaction of control factors with the uncontrolled factors in the analysis. The importance of designer's competency along with efficient and effective methods is stressed by [7], [8]; to enable informed decisions during the design stage.

In manufacturing, improvement in terms of product design, construction and assembly has been realised by utilizing an efficient production philosophy. The manufacturing, product development approach has gained improvement in terms of product design and has become the main reference to learn from and applied in the construction industry. A method such as the Robust Engineering (RE) approach in manufacturing has been shown to improve the product's engineered quality and performance. RE focuses on the interaction of control and un-control factors using the multidimensional diagnosis system or the P diagram as a planning tool to execute a much efficient and effective analysis. One of the most important considerations in RE is stabilising the product characteristic performance, which is the ability to identify the problems affecting a product while in operation[9]–[11].

2. AIM AND OBJECTIVES

The aim of this research is to assess the potential of applying the multidimensional diagnosis system or the P diagram in building design. The luminaires design was selected as an example in this study. The flow of the processes conducted in this study is as follows,

- Identify the control and uncontrolled factors for a building design element (luminaires design).
- Develop the multidimensional diagnosis system or P diagram for the design of luminaires requirement.
- Develop the proposed orthogonal array for luminaires design analysis.

3. COMPONENT OF MULTIDIMENSIONAL SYSTEM OR P DIAGRAM FOR BUILDING DESIGN

All man-made engineering systems use energy transformations to convert input energy into specific, intended output responses in delivering specific results sought by clients. Figure 2 is the multidimensional diagnosis system which captures the interaction affecting the product. In every engineered system, there exist some forms of ideal relationship between the input signal (M) and the output (y). Robust design seeks to attain this ideal state referred to as the design's ideal function. The planning stage needs a multidimensional diagnosis system where the control variables are considered as design space in which all the control variables are identified as controlling the design. The control variables are any design boundaries of a system that allow an engineer to specify nominal values and preserve cost effectively. The input signal, expected output and noise where the client uses the space for interaction between control variables and noise factors are evaluated to improve performance. The noise or uncontrolled factors comprise of three types, namely environment (client's usage condition, temperature, humidity, surrounding subsystem), ageing or wear (change of property over time, effect of cycling, deterioration over time, the durability of a subsystem) and manufacturing variability (variability within tolerances, assembly variation, batch to batch variation, piece to piece variation) [3–5]. Achieving robustness is to take advantage of the interaction between design space and client space usage at the upstream stage of product development [3].

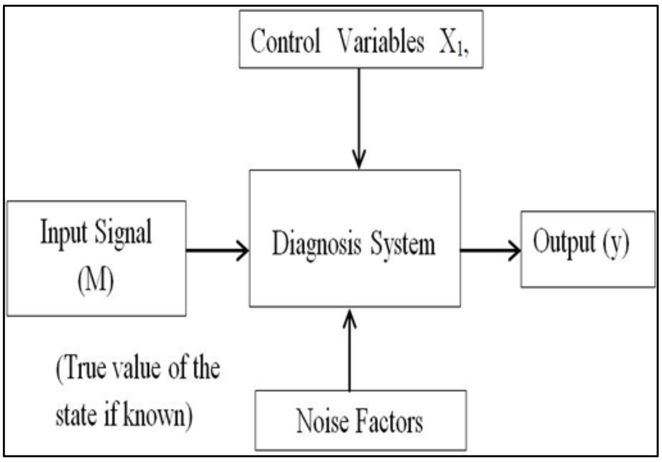


Figure 2. Multidimensional diagnosis system [10]

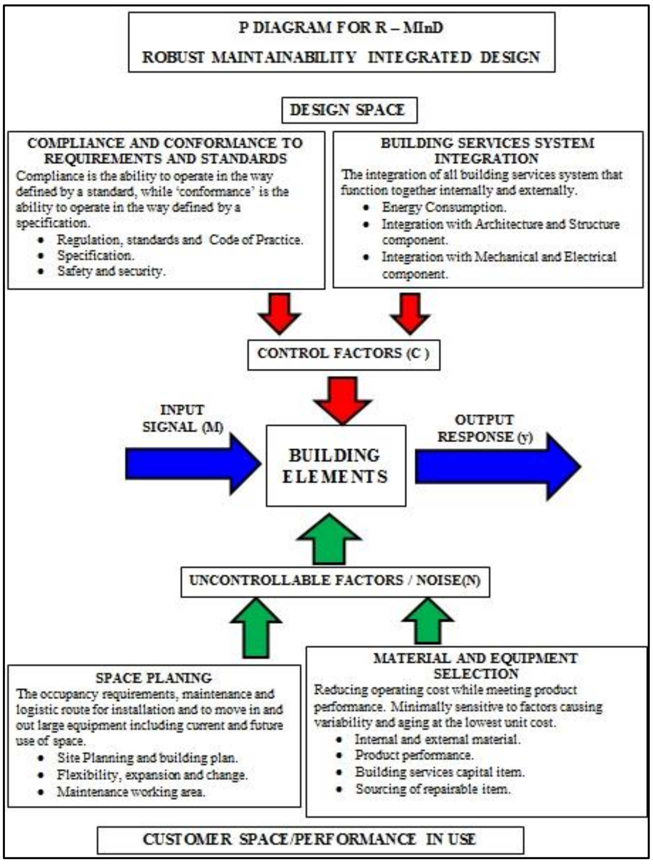


Figure 3. Multidimensional diagnosis system for building design [12]

To improve building performance, an efficient design method is needed. The method must be able to stabilize the variation that will occur during construction and during operation. It must focus on building performance with high engineered quality [6]. Variations will occur at operational level and the design must stabilize the product from these variations for robust outcome. As suggested by [12] the factors that are considered by designers using multidimensional diagnosis system is shown in Figure 3. The uncontrolled factors consist of space planning, material selection, and equipment selection, while the control factors are the conformance to regulation and standards and building system integration services. The uncontrolled factors or noise is due to ageing and manufacturing variability. All of these interact with the control factors where typically the control factors for design space, comply and conform to the requirements and standards and the supply chain support.

The space planning refers to user's environment noise (client's usage, temperature, humidity, surrounding subsystem). Optimising use of space refers to space planning in design stage where the analysis and design of spatial and occupancy requirements, maintenance and logistic route for installation and moving in and out of large equipment including, but not limited to space layouts and final planning are carried out. In the context of product design, the main goal of material selection is to minimize cost while meeting product performance goals. The control factors involve system integration where it brings together the component subsystems into one system and ensuring that the subsystems function together as a system. All design elements must comply with standards and regulations.

4. DESIGN EXAMPLE OF LUMINAIRE REQUIREMENT OF A ROOM IN BUILDING DESIGN

In this section, an example will be discussed to illustrate the thought process and steps utilized to formulate the multidimensional diagnosis system or the P diagram for luminaires design. The study will focus on the development of the input signal, output response, control and uncontrolled factors for luminaires design. Detailed computation of the signal to noise ratio will not be presented.

4.1. Current Design Approach

Currently the design procedures for luminaries of a room utilise a step by step computation with certain considerations. Figure 4 is the sample calculation format which consists of the following steps:

- Step 1. Selection of material and configuration
- Step 2. Selection of coefficient of utilization
- Step 3. Selection of light loss factors
- Step 4. Total light loss factor computation

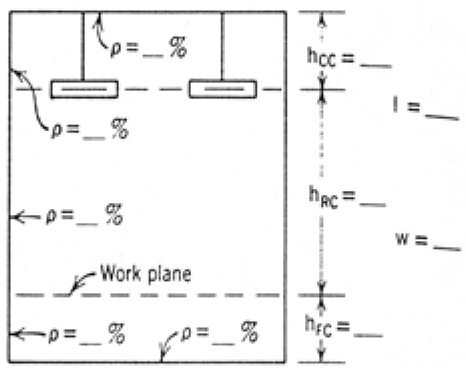
From Figure 4, item 1 is the project identification. Item 2 to 7 are the proposed material selection. Item 8 to 12 is the selection of the coefficient of utilisation mostly based on information provided by the manufacturer. Item 13 to 21 is the selection of light loss factors based on standard formulae computation. Information used in the computation is based on the control factors. In assisting the design, spreadsheet as in Figure 5 was used for computation of various configurations and selection made was based on the number of luminaires and Lux (foot-candle) provided.

1. Project Identification : ……………………………………………………………………… ………………………………….
2. Average maintain for illumination ……………………… Lux (footcandle)

Luminaires Data			
3	Manufacturer :	5	Type and No:
4	Catalogue Number:	6	No Per Luminaires:
		7	Total lumen per luminaires:

SELECTION OF COEFFICIENT OF UTILIZATION

8. Fill in the sketch of light



9. Step 2 : Determine cavity ratio by formulae
9a. Room Cavity Ratio, RCR =
9b. Ceiling Cavity Ratio, CCR =
9c. Floor Cavity Ratio, FCR =

10. Step 3 Obtain effectiveness ceiling cavity reflectance From Table 20.3
11. Step 4 Obtain effectiveness floor cavity reflectance From Table 20.3
12. Step 5 Obtain coefficient of utilisation (CU) from manufacturer data

SELECTION OF LIGHT LOSS FACTORS	
Unrecoverable	Recoverable
13. Luminaires ambient temperature	17. Room surface dirt depreciation
14. Voltage of luminaires	18. Lamp lumen depreciation
15. Luminaires surface depreciation	19. Lamp burnout factor
16. Others factors	20. Luminaires dirt depreciation

21. Total Light Loss Factor computation

Figure 4. Design Procedures of Luminairies

No	Ruang	Unit	L	W		Lux	Mounting	Index	Faktor	Faktor	Flux	Jenis lampu	Lumen	Bilangan
							Height	Bilik	Pendaraban	Penyeleng-	Terpasang		lampu	lampu
									Pengguna	garaan				yg. Diperlukan
					A	*Lux*	*Hm*	*A/ [Hm(L+W)]*	*CU*	*MF*	*Lux xA /[CUx MF)]*			*Flux/lumen lampu*
	BANGUNAN PENTADBIRAN													
2.1	**Pejabat Ketua Polis Daerah**													
	Bilik P.A KPD	1	3.80	2.80	11	300	3.2	0.5038	0.34	0.8	11,735	3x36W(F)	7950	1.48
	Bilik KPD	1	4.30	6.80	29	300	3.2	0.8232	0.34	0.8	32,250	3x36W(F)	7950	4.06
	Stor	1	2.80	3.00	8	200	3.2	0.4526	0.34	0.8	6,176	3x36W(F)	7950	0.78
	Tandas	1	1.95	3.70	7	100	3.2	0.3991	0.34	0.8	2,653	1x36W(F)	2650	1.00
	Bilik Mesyuarat KPD	1	4.80	6.50	31	300	3.2	0.8628	0.34	0.8	34,412	3x36W(F)	7950	4.33
	Bilik T/KPD	1	4.80	3.60	17	300	3.2	0.6429	0.34	0.8	19,059	3x36W(F)	7950	2.40
	Bilik Air T/KPD	1	2.00	2.80	6	100	3.2	0.3646	0.34	0.8	2,059	3x36W(F)	7950	0.26
	Ruang Menunggu	1	4.80	4.80	23	300	3.2	0.7500	0.34	0.8	25,412	3x36W(F)	7950	3.20
	Pantri	1	1.80	3.00	5	300	3.2	0.3516	0.34	0.8	5,956	3x36W(F)	7950	0.75
	Tandas KPD	1	1.95	3.70	7	100	3.2	0.3991	0.34	0.8	2,653	1x36W(F)	2650	1.00

Figure 5. An example of the spreadsheet for computation

The procedures are seen to be lacking of three main elements which are:

- Missed opportunity to obtain technical information to optimise the design. Here, the design is only focused on what are the available data. The function of design actually is to obtain this technical information and use that information to optimize the design to be less sensitive towards variation that will occur in building usage.
- No interaction of usage condition with the design element. The usage of the room will be influenced by three uncontrolled factors, namely the usage condition, the material variability and the aging of the material. These uncontrolled factors were not considered thoroughly in the current design approach.
- Lacking the time laden consideration in the analysis.

4.1. Multidimensional Diagnosis System or the P Diagram for Luminaires Design

For the purpose of this study, focus was given to the planning aspect where the development of the multidimensional diagnosis system is made. The development of the multidimensional diagnosis system or the P diagram is crucial in the planning stage. Brain storming sessions focusing on identifying the control and uncontrolled factors which are essential to the performance and robustness of the luminaries of the required room type were conducted. The brainstorming sessions were based on the following initial questions:

- What information is generated in order to accomplish superior product or process design and meet all requirements simultaneously?
- What should be measured as data in order to generate the best information?
- How should the experimentation be designed?
- How should the data be analysed?
- How is the validity of a result confirmed?

In the planning stage, the steps required for a robust design are:

- Step 1. Define the input signal (M), the output response (y) and the ideal function.
- Step 2. Develop the signal and noise strategies.
- Step 3. Define control factors and level.
- Step 4. Devise the experiment and prepare for the experiment.

Table 1 describes the main issues during maintenance of facilities on luminaires components. The table is based on experience by the building's facility management team in the brainstorming session. Most of key failure mode is due to material and equipment selection. Figure 6 illustrates the outcome of Step 1 and 2. In conventional design the total required illumination is the last item in the design computation. In this approach it is used as the input (the use of technical information to optimized the design) of the signal (M) while the output (y) is the luminosity. These represent the energy thinking as the main criteria of efficient design. The signal factor is a controllable variable to actualize the intention to achieve a robust condition regardless of various room configurations. Step 2 is focused on developing the signal and noise strategies. The control factor consists of room area, a group of the fluorescent lamp and the quality of the lamp. Most of the control factors will remain the same or with a predictable time-based characteristic.

The uncontrolled factors are the factors which might change during operation and causes variations. As an example, the wall painting might change from light to darker colour based on user's preference.

Table 1. Key Issues in maintenance of luminaires component in building

Key Failure mode	*Key Issues*
Loss of light output due to ageing	MES
Loss of gas or vacuum to lamp	MES
High resistance or corrosion at lamp connection	MES
Damage due to poor environment	MES
Wide variations in mains voltage can significantly affect the lives of fluorescent lamps	MES
Optimum lamp replacement cycles are dependent upon both the decline in lighting output and the probability of lamp failure.	MES

MES denote material and equipment selection

The floor finish also might change while in use. Figure 7 describes the level of analysis based on Step 3. The analysis is based on several combinations of usage condition consideration. These combinations represent the interaction of the usage condition. As an example, control factors for level 1 combination is for 540 sq ft room area with T5 fluorescent type. The fluorescents consist of 2 lamps in each group with a total of 10 lamp locations. The uncontrolled factors have two combinations. N1 for example, having the burn out rate of three with carpeted floor finished and dark colour painting with uncovered lamp. By analyzing it with the combination of usage condition the variability of the product characteristics can be identified.

Step 4 is devising the experiment and preparing for the experiment. Control factors A to D (all three level factors) were assigned to a standard orthogonal array L9 (9 x 3 signal level x 2 noise levels). An orthogonal array provides an orthogonal design of the experiment matrix. By assigning factors to the columns of the orthogonal array, the analysis runs will be balanced. The orthogonal array is shown in Table 2. The values in the column A, B, C and D represent the level as in Figure 7. In Table 2, the value in column N1 and N2 for 52, 57 and 59 is the actual data taken in a mock up room or a set of existing data compiled by the manufacturer. It can be seen in this approach the interaction of the technical information is utilised in the design by having a certain combination of the usage condition.

The outcomes of the proposed analysis using the multidimensional diagnosis system are as follows:

- The analysis considers the interaction between the control and uncontrolled factors. It reflects the actual performance usage during operation.
- The analysis is focused on stabilizing the product characteristics due to variation which will occur during operation. It includes time laden consideration in the analysis.
- The outcome of the analysis will assist the clients in making an informed decision at the design stage.

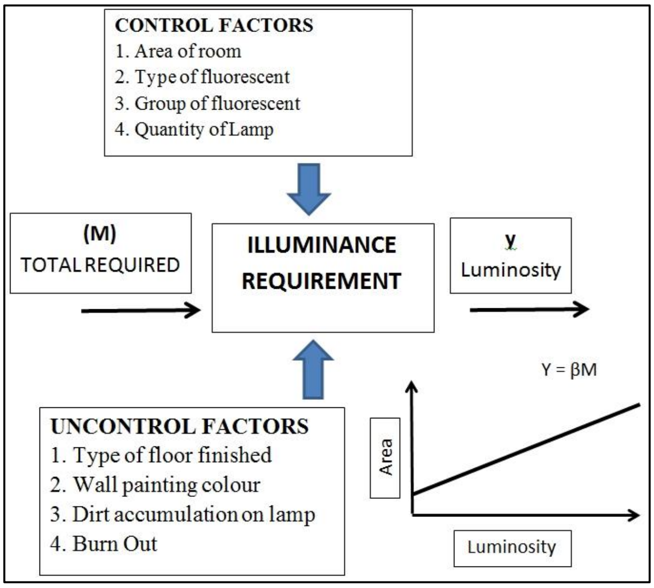


Figure 6. Illuminance multidimensional diagnosis system and ideal function

	FACTORS	Unit	LEVEL 1	LEVEL 2	LEVEL 3
CONTROL FACTORS	A. Area of Room ft2	Sq ft	540	810	1080
	B. Type of fluorescents	Lumen	T5	T8	T12
	C. Group of Lamp	Number	2	3	4
	D. Quantity of Lamp	Number	10	11	12
			N1	**N2**	
UNCONTROLL FACTORS	Burn out		3	1	
	Type of floor finishes		CARPET	GLAZE TILES	
	Wall painting colour		DARK	LIGHT	
	Dirt accumulation on lamp		UNCOVERED	COVERED	
SIGNAL FACTOR	REQUIRED E (FC)	FC	**52**	**57**	**59**

Figure 7. Control, Noise, and Signal Factors and Level

Table 2. Summary of test results combination

Expt No	Control Factors				Uncontrol Factors 52		57		59	
	A	B	C	D	N1	N2	N1	N2	N1	N2
1	540	T5	2	10						
2	540	T8	3	11						
3	540	T12	4	12						
4	810	T5	3	12						
5	810	T8	4	10						
6	810	T12	2	11						
7	1080	T5	4	11						
8	1080	T8	2	12						
9	1080	T12	3	10						

Control factors A, B, C and D and the Uncontrol factors N1 and N2 combination as in Figure 7.

Optimizing building design with time laden consideration such as space planning and, material and equipment selection (also known as maintenance-related considerations) in building operation will produce better design outcome. The user of the building will constantly interact with these maintenance related considerations throughout their design life. Apart from that, building design must also comply with all regulations which are also known as control factors. Maintenance-related considerations need to interact with the control factors and this will ensure better building performance and fulfill the expectation of building owner in terms of ease of operation and acceptable maintenance cost.

5. CONCLUSION

This paper proposed an approach that is more efficient using energy thinking and interaction of control and uncontrolled factors of luminaires design. It utilized the multidimensional diagnosis system or the P diagram. The analysis used the orthogonal array to execute a balanced design. Among the main advantages of using this approach compared to the conventional approach is that it utilises the technical information to optimize the design. These factors has added value to the design and produced a high maintainability design. The interaction also reflects the real operational situation where usage condition might change due to user'spreference or new requirements.

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