AN INVESTIGATION ON THE LIGHTING SYSTEMS
OF THE MANUFACTURING FLOOR
IN ELECTRONICS INDUSTRY

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ABSTRACT

AN INVESTIGATION ON THE
LIGHTING SYSTEM OF THE MANUFACTURING FLOOR
IN ELECTRONICS INDUSTRY

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Required illumination levels in an electronics manufacturing facility were studied in order to provide feedback for architects and engineers. The study was carried out for the production floor of an electronics company in Ankara.

The space considered was a Printed Circuit Board Assembly (PCBA) and Surface Mount Device (SMD) production department. The selected area was subdivided into different areas according to required illumination levels for each year. These levels were determined according to the specific work types over the total area according to each individual department. Data compiled by the field survey was analyzed and evaluated for investigating the relation of the potential effectiveness of the lighting systems regarding time, together with illumination levels needed for specific work areas. Changes in the sizes of areas needing various illuminance levels over past years were analyzed. It was found that there had been a decrease in the total required illumination levels.

Keywords: Electronics Industry, Manufacturing Floor, Task Lighting, General Lighting

ÖZ

ELEKTRONİK SANAYİİNDE
ÜRETİM ALANLARININ AYDINLATMA SİSTEMLERİ ÜZERİNE
BİR ARAŞTIRMA

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Bu çalışmada, bir elektronik üretim binasındaki aydınlatma ihtiyacının binanın yapılışından günümüze kadar geçen sure içerisindeki değişimi incelenmiş; böylece mimarlara ve mühendislere geri besleme sağlaması hedeflenmiştir. Araştırma Ankara'da bulunan bir firmanın elektronik üretim binasında gerçekleştirilmiştir. Çalışma alanı olarak Baskı Devre Kartı (BDK) ve Yüzey Monte Cihaz (YMC) bölümlerini içeren bir üretim holü seçilmiştir. Seçilen çalışma alanı her yıl için belirlenen aydınlatma ihtiyaçlarının seviyesine göre alt bölgelere ayrılmıştır. Aydınlatma ihtiyaçlarının seviyeleri, yapılan işlerin niteliğine göre her bir çalışma alanında ayrı ayrı belirlenmiştir. Toplanan veriler; aydınlatma sistemlerinin potansiyel etkinliğinin zamanla değişiminin, seçilen alanlarda gereksinim duyulan aydınlatma seviyeleri ile ilişkisini belirlemek maksadı ile analiz edilmiş ve değerlendirilmiştir. Farklı aydınlatma seviyelerine gereksinim duyulan çalışma alanlarının büyüklüklerinin geçmiş yıllardaki değişimi analiz edilmiştir. İstatistiksel çalışma neticesinde, ihtiyaç duyulan toplam aydınlatma seviyelerinde belirgin bir azalma tespit edilmiştir.

Anahtar Terimler: Elektronik Sanayii, Üretim Holü, Lokal Aydınlatma, Genel Aydınlatma

To My Father

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Finally, the author wishes to express her deepest thanks to her family, friends and co-workers for their enduring love and support, which gave her the inspiration to complete this study.

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LIST OF ABBREVIATIONS

ASHRAE	: American Society of Heating, Refrigerating and Air-Conditioning Engineers
CIBSE	: Chartered Institution of Building Services Engineers
CIE	: Commission Internationale de l'Eclairage
FGL	: Fördergemeinschaft Gutes Licht
IES	: Illuminating Engineering Society
IESNA	: Illuminating Engineering Society of North America
PCBA	: Printed Circuit Board Assembly
SMD	: Surface Mount Device

LIST OF NOMENCLATURE

E_n : Nominal illuminance
LC : Light colour
LLD : Lamp lumen depreciation
LDD : Luminaire dirt depreciation
BF : Ballast factor
RSDD : Room surface dirt depreciation for interiors
CR : Colour rendering
QC : Quality class
ww : warm white
nw : neutral white
dw : daylight white
Φ : Luminous flux (lumen)
E : Specified average illuminance (lux)
A : Surface area of the room (m2)
UF : Utilization Factor
MF : Maintenance Factor
Φ_n : Nominal lamp flux per luminaire (lumen)
l : Length of the room (m)
w : Width of the room (m)
h : Height or vertical distance between the luminaires and the working plane (m)
N : Required number of luminaires

CHAPTER 1

INTRODUCTION

In this chapter are first presented, under respective sub-headings, the argument for and objectives of the study being reported on herein. Again under a dedicated sub-heading, it continues with a brief overview of the general procedure followed in its conduct and ends with a succinct description of what is covered in each of the remaining chapters, under the sub-heading titled “Disposition”.

1.1 Argument

A very large amount of experience and expertise is needed to successfully design a high-quality, low-cost building which is practical for industrial processes as well as being a sympathetic environment for the employees. Yet, what makes it particularly challenging is that it should be capable of continually adopting to changing work patterns.

Faced with growth, downsizing, or reorganizations, or faced with the creation of new operations and the need for different spatial relationships among employees, the users or owners of the facility should be able to change its interior configuration, tear down some walls and put up others and rearrange work stations and files. Sometimes a more comprehensive retrofit is undertaken and changes include early replacement of electrical or communications systems, HVAC controls, human safety and security systems, lighting, elevators and even exterior cladding. The users of the facility want to continue operations with as little disruption as possible during the course of any project. In reality, the most reputed buildings turned out to be short-lived or disappointingly inflexible because of unpredictable and evolving requirements, although they were designed to be flexible. As DARLEY (2003) states, the new industrial æsthetic of ‘cool boxes’ was an image, rather than a reality.

In order to take these changes into account, flexible adjustment of the technical equipment must be enabled, depending on the work, the process, the production and the function involved. In addition, securing production is given absolute priority, as the development/manufacturing of products is not possible without sufficient production-dependent provisioning. In this vein LOFTNESS, HARTKOPF, LEE, SHANKAVARAM & AZIZ (2001) summarize the key features as 'support on-going organizational and technological dynamics in appropriate physical, environmental, and organizational settings to enhance individual and collective performance and human health, comfort, and motivation'. MERCHANT (2000) bears this out by the statement: "Develop and apply the technology that will support the user, rather than that where the user will have to support the technology".

The electronics industry embodies a complex task-specific facility which is critically dependent on rapid technological innovation. Changes in the technology of equipment used also produces a number of fields and consequent shifts in work patterns which depends on interdisciplinary teams rather than on a departmentalized organizational structure. The processes are therefore carried on in large single-storey sheds which consist of undivided spaces with a great number of employees. There are also automatic and semi-automatic machines in these spaces arranged as production lines according to the capability of the company in regard to technological trends.

In today's high-tech world, the human eye plays a crucial role in supervising and controlling industrial processes. It supplies more than 80% of all the information we receive about our immediate surroundings, where light plays a central role in the design of a visual environment: The architecture, the users and the objects are all made visible by way of this phenomenon.

On the other hand, the manufacturing industry, with robotics and laser-operated and computer-programmed machinery, operates in unrelentingly clean, even sterile, windowless conditions, so artificial lighting is a major consumer of primary energy. As the cost of materials are relatively small compared to other industrial sectors power consumed to operate lighting systems represents a significant portion of that used in the whole manufacturing process. Lighting of the manufacturing floor in this industry therefore seems to be one of the most important aspects of concern in terms of both running and maintenance costs, if not in those of initial installation in an indirect way; it embodies the concept of flexibility.

Energy and resource-saving measures and environmentally responsible policies will increasingly determine the design and construction of industrial buildings. 'Advanced lighting design', 'Advanced lighting technologies', and 'Sensors and controls' technologies offer both energy and non-energy benefits; ranging from reduced environmental impact to improved productivity.

Arguments against such building systems are: a) the time it can take to develop it, and b) its development costs. In most cases such systems can hardly be implemented because they are at present economically inefficient. On the other hand, past experience suggests that new materials and products are likely to reduce the relative costs of these details in the future, making their use increasingly advantageous. Also, as learned from experience, certain design details clearly have demonstrated their value as tools for enhancing flexibility or adaptability.

It has been a widely-accepted idea that a good general lighting system makes it possible to change the location of machinery without rearranging the lighting, and also permits full utilization of floor space. General lighting therefore has been accepted as a reasonable lighting technique in the name of flexibility. However, the consistency of general lighting and architectural modularity should be examined not only in terms of space utilization, but also in those of functionality, æsthetics, cost and technology.

Although general lighting is considered to be the best solution for achieving flexibility in question, task lighting seems to be a very effective alternative technique. For detailed or close work, supplemental task lighting close to the work surface makes sense, to optimize energy use and to give workers personal control for adjusting their lighting to meet specific requirements. Relying on the general ambient lighting system to provide adequate light for demanding tasks will result in higher energy costs and less comfortable working conditions. Therefore more extensive attention should be paid to design a flexible and effective lighting scheme.

The aim of this study was to examine an electronics manufacturing building over its 23 past years of use. The examination was made based on the evolution of the whole structure, including number of workers and machines, utilization of work spaces *etc*. The illumination levels with respect to the working areas were considered in detail.

1.2 Objectives

Four basic objectives were defined for the study. These can be briefly defined as follows:-

a) To evoke an awareness about the importance of lighting schemes used in industrial areas among the professionals such as architects and electrical engineers,
b) To explain the most important aspects of task lighting technique and give an insight about its effects from a few point of views,
c) To examine the long-period effects of general lighting structures on electronics industry based on a real-life example,
d) To provide a guide for future researchers who are interested in lighting techniques in industrial areas and are also concerned with the flexibility issues.

1.3 Procedure

A general survey was first conducted on the facilities of the largest electronics industries in Ankara. The main concern here was to find one such facility in which the most recent technology is used and therefore a continuing modification in the work areas is inevitable.

A sample space was then defined for the quantitative aspects of the study. This was a Printed Circuit Board Assembly (PCBA) and Surface Mount Device (SMD) production department in an electronics manufacturing building. This particular building was selected because many different tasks were likely to occur on the same floor. In addition, it was one where general lighting was the preferred solution.

Next, a detailed investigation was made on the retrofit and renovation projects for this building that has been conducted since it was constructed. Also, the new automatic or semi-automatic machines, integrated into the manufacturing process in time noted to obtain the proportions of functions with different lighting requirements, which was considered to be an analogue indicator for the potential effectiveness of lighting.

Lastly, an imaginary lighting system was proposed as an alternative for the general lighting system, based on required illumination levels. Using data compiled on working areas for each specific required illumination level, the diversity of different illumination levels was examined and the total number of luminaires for each individual illumination level were calculated. Correlation and regression analyses were then conducted to determine whether or not there was a linear relationship between these illumination levels.

1.4 Disposition

The study consists of five chapters, of which this introduction is the first. In the second chapter is given a summary of literature surveyed on the general characteristics and criteria of lighting; on lighting aspects pertinent to electronics industrial areas and on examples from existing industrial buildings.

In the third chapter is described the study material and the method used in data collection and its analysis. Relevant elements on the effectiveness of lighting systems evaluated through analyses of variance.

In the fourth chapter are presented the results of the study, together with a discussion of these in terms of its objectives and the relevant aspects described in the literature.

The final chapter, the conclusion, summarizes the findings of the study and offers some recommendations for future researchers.

CHAPTER 2

LITERATURE SURVEY

A total of 66 sources were covered in this survey. Owing to the nature of the subject matter and of the investigation itself, these necessarily encompassed marked diversity, ranging from reports dealing directly with the issue at hand to those on background and methodology. Certain others, on the other hand, were used merely as sources of quantitative or descriptive inputs, such as normative values for the performance and physical properties of subject matter. To maintain clarity of relevance in the face of such diversity, they have thus been ordered under four sections-each embodying a number of pertinent sub-sections-in the following summary as: 1) reports on general aspects of the electronics industry; 2) reports on attributes of the manufacturing floor environment; 3) reports on the interaction of occupant and environment; 4) reports on the interaction of workplace dynamics and environment; and 5) reports on methodology. Since many of these sources were involved in more than one domain, individually quoting how many were cited under each did not seem to be meaningful here.

2.1 Reports on General Aspects of the Electronics Industry

What follows is a selective iteration from the relatively large number of sources on this particular aspect, as it was considered to have only a marginal bearing on the study proper.

In the electronics industry, visual tasks range from work on subminiature assemblies to the construction of generator sets the size of houses. According to GRAEDEL & GREENVILLE (2005) there are four distinct steps involved in electronic product manufacture, each with many sub steps. These are as follows:

1. Manufacture of integrated circuits (the "chip").

2. Manufacture of the printed wiring (or circuit) board (PWB / PCB).
3. Mounting of chips and components on the PWB to form an electronic circuit pack.
4. Assembly of circuit packs and other components to make the finished product.

To quote from another source, as stated by FORDERGEMEINSCHAFT GUTES LICHT (FGL, 2002) in electronics industry, interiors and workplace layouts are therefore extremely diverse, offering no common denominators for production room and workplace lighting planning. Hence every application requires individual appraisal.

2.2 Reports on Attributes of the Manufacturing Floor Environment

The greatest number of sources belonged to this domain. The most salient of these have been cited below under three discrete sub-headings, as: reports on the physical attributes of manufacturing floors, reports on the ambient attributes of manufacturing floors and reports on attributes of manufacturing floor occupants.

2.2.1 Reports on the physical attributes of manufacturing floors

When tracing the earlier transition in the architecture of industry, both ADAM, HAUSMANN & JUTTNER (2004) and DARLEY (2003) point out that the implementation of media, particularly when they are more user-friendly; the heightened demands with regard to communication both within the enterprise and in society as a whole; the minimization of emissions, new technologies, materials, construction methods; and expanded means of travel and transport require new designs.

DUNHAM (1948) very early on emphasized the necessity for designing manufacturing floors as to be most open, unobstructed floor spaces, and even provision for expansion, but also planning scientifically incorporation with engineers, operators, and architects as stated by MALLICK & GAUDREAU (1951). Defining scientific planning as a function of the production process, GRUBE (1971) proposes a classification system where a distinction can be made between processes following a linear, circular or horse-shoe shaped alignment, so it is possible to determine with relative accuracy the direction in which extensions, major or minor, should take place and additional processes might be added, without hindering the operation of the plant during construction. The decision about the possibility of future extensions by square standard bays, or by flexible super-units where all the processes are accommodated within a neutral structural system, also where it is functionally possible to introduce an identical construction system or a uniform column spaces is described as one of the architectural tasks.

As claimed in this source, in the case of plants strictly orientated production lines, major extensions will take the form of parallel replicas of entire lines; many new plans accordingly provide for parallel ribbons (stores, production, administration, staff welfare) so that minor extensions can be carried out simultaneously by extending these ribbons. The weak points of standardized concept of factory construction as the repetition is deliberately broken for emphasis, as at entrances, and the auxiliary buildings, powerhouses, and so forth, WANKS (1951) very early on emphasized the necessity for dividing these features for increased efficiency in manufacturing area. Along the same lines, CAPLAN (1988) argues that separating the services from a building's usable space, identifying the services very accessible, also organizing the building so, it does not have to close when the services are being renewed, together with the increased proportion of usable space inside.

While on these grounds the choice of the right material and structural form can generally conceded to be obsolete in a very short time, MILLS (1951) points out changes in public opinion, fashion or general practice. Along the same lines, CHERRY (1972) argues when evaluated on a discounted cash-flow basis, these systems generally did not warrant the additional expense, although give useful options for rearranging functions, pointing out that routine renovation and rehabilitation have been most effective approach to taking advantage of most of the 'architectural and mechanical changing occurring due to new technology'.

Commenting on the scientific merit of such early studies, the study carried out from Building Research Board of the National Research Council (NRCS, 1993) in order to delay or minimize the impact of facility obsolescence recommend that, make flexibility an explicit design goal and make appropriate use of design details or integrated building systems that enhance flexibility or adaptability, where post-occupancy evaluation (POE), yield an assessment of how well a facility's performance matches the design optima and user's need, is a valuable aid in programming. Recommended design details to enhance flexibility are:

1. *Unconstrained Interior Space*, imposed by structural or service subsystems or by site characteristics, with increased floor load capacities, that enhance

responsiveness to changes,

2. *Accessible Service Areas*, organized-segregated plans with raised access flooring and interstitial ceiling space and access to switches and other control devices,
3. *Modularity*, separation of major user areas in to "zones" served by independent mechanical and electrical component with changeable, movable and demountable enclosure and partitioning systems,
4. *Shell Space*, allowing for expansion by constructing "extra" structure, foundation, and unfinished enclosed spaces

On the other hand, as ADAM, *et al.* (2004) states that increasing mechanization of production brings the need to resolve networked problem intellectually in order to convert complex processes into an electronic sequence of instruction where one feels best and can be most creative. With these changes in the concept of work together energy and resource saving measures that multi-storey buildings (ratio of the skin area to the conditioned net surface, floor areas of varying sizes and of varying shapes – balance between systematizing and differentiation) have become popular again.

Another classification made by ADAM, *et al.* (2004), three main requirements influences the design of flexible multi-storey buildings are (intelligent) *open systems*, *resource-optimized conditioning* and *industrial manufacturing*. On the basis of posits by authors, global interconnectedness of manufacturing process, all buildings will be industrially produced individual parts that are mono-functional, and if the individual building components are adapted on the basis of a precise system of order so that even the connecting details of the individual building components are standardized, then an exchange of components is possible and they can be re-used elsewhere. Among the many issues addressed are the semiconductor lighting material LED, innovative glass industry, composite material systems, light-weight materials and computer-supported control technology like in the article by BURKHARDT (2003) pointing out optimized construction process through the rational (pre-) fabrication of semi-finished products and through the use of construction machines and assembly methods, hence the evolution especially energy technologies will change the buildings of the future in much the same way as earlier innovations did some eighty years ago.

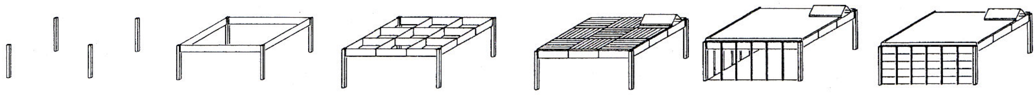


Figure 2.1. Resource-conserving production and sustainable uses of system components by prefabrication-MAXI steel construction system (ADAM et al. 2004).

In a modular approach, ADAM, *et al.* (2004) classification according to construction systems in order to understand the connections on a super ordinate level, citing Fritz Haller MAXI steel construction system, summarized in Table 2.1., includes the model 'ARMILLA' for the modular coordination and the cooperative design of the technical systems (conduit system level) of building, with a square grid of 1.20 m adapted to MIDI steel construction system.

Table 2.1. The ADAM, HAUSMAN & JUTTNER (2004) classification according to construction systems.

Construction System	Used for	Groups of elements	Advantages	Specially developed elements	Suitable for
MAXI Steel	Sigle-storey Large span	Supporting structure (columns and trussed girders) Roof Exterior and interior walls	extend horizontally in all directions disassemble, and interchangeable within the framework of modular arrangement	Foundations Floor Construction Building Services	Production Plants
MIDI Steel - ARMILLA Installation Model	Multi-storey with high density installation	All construction components and their interdependencies with geometric organizations of the conduit systems	Integrate object-specific components or ready made components, easy building service installation to supply useable floor areas with all necessary media over the whole surface without conflicts, to design conduit systems with IT support, to manufacture industrially portions of conduit systems as elements of component systems, to rationalize the assembly, alteration and maintenance of conduit systems.		
MINI Steel	One to two storey Spans of up to 8,40	Supporting structure (columns and girders of cold-formed sheet steel profiles) Floor Roof External walls	extend horizontally in all directions disassemble, and interchangeable within the framework of modular arrangement	Foundations Basement Interior Fittings and Accessories	Wide range of different uses, e.g. Ateliers, offices, schools, sales kiosk, exhibition booths, waiting room, houses
USM Haller Modular Furniture System		Supporting framework Claddings Fittings and Accessories	A "Complete Kit" or "Closed System"*, can be easily disassembled and reassembled in other combinations to form different objects		

* Steel construction systems are open system, because they can only be assembled into a complete building with object-specific construction components.

In this vein, also considered relevant were studies of DIBERARDINIS, BAUM, FIRST, GATWOOD, GRODEN & SETH (1993), HAIN (1995), CROSBIE (2004), and GRIFFIN (2005). These were mainly on the laboratory design rather than factory or manufacturing plant, *per se*, since they were guidelines for the construction of new industrial buildings and also the renovation of old ones, emphasizing the term flexibility. As DARLEY (2003) points out in his book 'Factory', advanced manufacturing technology permitting 'a combination of manufacturing, information technology, design and engineering', replaced the serried ranks of heavy manufacturing premises with the green campuses of biotech and electronics companies, where the contemporary version of the factory, quiet and self-contained, has become a 'laboratory' more likely to be dealing with ideas than heavy metals.

DIBERARDINIS, *et al.* (1993) present a broad overview of reliable design information and area requirements from various experimental science activities and disciplines as well as of methods for their calculations (net-to-gross ratio) and evaluation of schematic plans. CROSBIE (2004) attracts attention especially on 'green' lab buildings, where interventions are generally cosmetic changes within existing rooms, such as repainting, or upgrades within existing rooms, such as new utilities, lighting, ceilings, *etc.*

2.2.2 Reports on the ambient attributes of manufacturing floors

Arguing the interdisciplinary nature of lighting design a combination of applied art and applied science in general and its connection with HVAC and daylight in particular, both BOYCE (2003) and STEIN, REYNOLDS, GRONDZIK & KWOK (2006) cite in evidence compared to the effort that has been put into studying lighting for offices, lighting for industry had been sadly neglected, not lack of importance of lighting for industry, but rather the difficulty in generalizing any conclusions. According to authors, there is a limit to how closely the lighting can be tailored, it is set by many different tasks are likely to occur on the same industrial site, within the same building, on the same production line and, certainly, within the area lit by one 'general lighting' installation. System design approach given by STEIN *et al.* (2006) is reproduced below in Figure 2.2.

Besides lighting level, as in the guidebook by FGL (2002) it is stated that, correct lighting at work premises in trade and industry is only achieved if *luminance distribution, glare limitation, direction of light and modeling, light color and color rendering* are all taken into account to ensure optimum ergonomic lighting. Their order of priority may differ, depending on the type of interior and activity like in the case of electronics industry, subject of the study. Electronics industry lighting needs range from low-level requirements for assembly and welding of large structures to the high levels needed for manufacture of precision mechanical and electronic components such as integrated circuits. The recommendations of lighting design in that industry given by this source are summarized in Table.2.2, following, while the full listing is given in Appendix A, also the list of general advice on lighting for industry the guidance documents published by professional associations like IESNA (2001), CIBSE (2002), *etc.* is given in Appendix B.

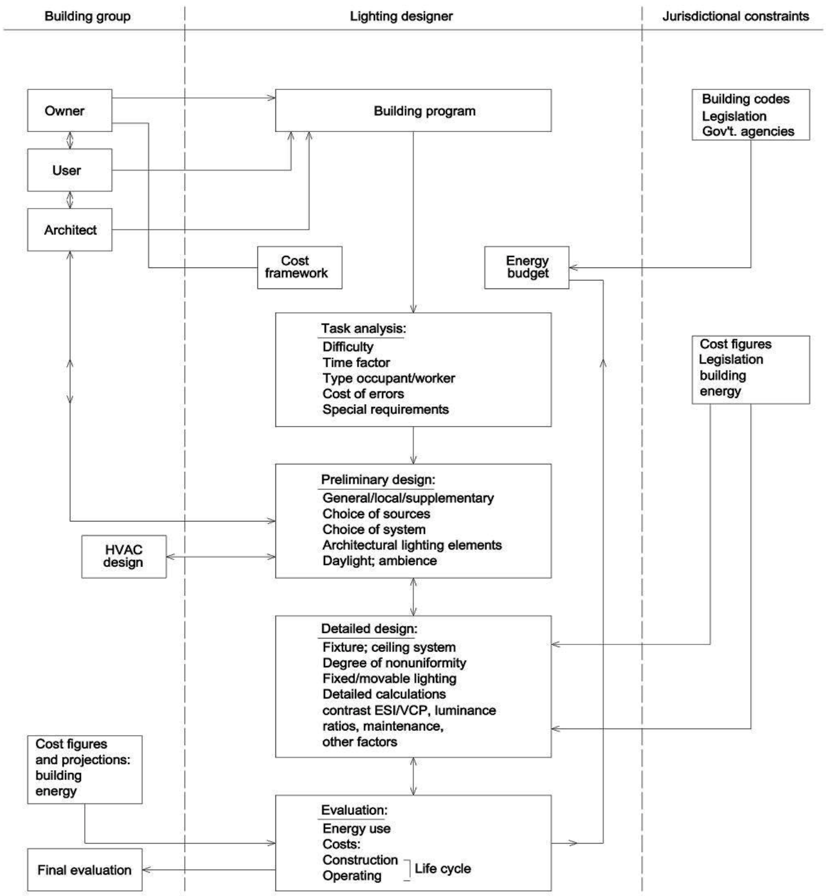


Figure 2.2. Lighting design procedure chart (STEIN *et al.* 2006).

As it is seen from the recommendations, selection of the lighting equipment can be given as an example of the difficulty of lighting design. In the selection of the equipment – light sources (*incandescent filament, fluorescent, and high density discharge lamps*) and luminaires (*direct, semi-direct, general diffuse, semi-indirect, and indirect*) - many variables must be considered. Some of the basic factors are lamp efficacy and life, lumen maintenance, burning hours per start, luminaire efficiency, finish and distribution, brightness and glare control, the accessibility of equipment for maintenance, and the amount of dust and dirt in the air. Noting these variables, CHEN (1990) explains that it is necessary for purpose of comparison to hold some factors constant, which is in industrial lighting usually *mounting height and location*.

It is recommended by CHEN (2000) in high-bay areas by using a few high-wattage sources makes it possible to obtain uniform general illumination, where the work generally presents visual tasks that are not difficult because of large machinery and other objects, they tend to cut off light and cast shadows that makes it difficult to see important vertical and angular surfaces, so broad light distribution is essential. Luminaires with medium and narrow distribution is defined suitable for greater mounting height or closer spacing, while for the areas those are wide in respect to mounting height luminaires with wide distribution. As far as choices of lamps concerned, the use of fluorescent lamps described as limited with the areas its proportions are such that the room cavity ratios are in the range of 1 to 3, only high or extra high output fluorescent in 8ft sizes are recommended. On the other hand, in medium- and low-bay areas seeing tasks are usually more difficult than those encountered in the high-bay areas, so increasing the size and reducing the brightness of the luminaires emphasized to improve visual comfort and the visibility of specular objects.

(a) *Reports on the general lighting in industrial environments*

BOYCE (2003) states that despite the variability faced by the designer of industrial lighting, the objectives of lighting are the same everywhere. These are:

- to facilitate quick and accurate work;
- to contribute to the safety of those doing the work;
- to create a comfortable visual environment.

In order to facilitate quick and accurate work the factors that the designer of general lighting needs to consider are listed by BOYCE (2003) as the locations of working planes, the direction of the light and the spectrum of the light used.

Table 2.2. The recommendations of lighting design in the electronics industry, given by FGL (2002)

	En	LC	CR	QC
Large details with high contrast	300 lux	ww, nw	3	1
Medium-sized details with medium contrasts	500 lux	ww, nw, dw	3	1
Small details with low contrasts	1000 lux	ww, nw, dw	3	1
Very small details with very low contrasts	1500 lux	ww, nw, dw	2A	1

En: Nominal illuminance
LC: Light color
CR: Color rendering
QC: Quality class

As the author continues the locations of the working planes are important in determining the placing and desirable distribution characteristics of the luminaires used in the lighting installation, while the working plane may not be horizontal and there may be more than a single working plane should considered.

According to BOYCE (2000) the directions from which the light comes is important for two reasons: The first is the degree of obstruction and the second is the occurrence of veiling reflections. To minimize shadows casts from obstructions the author recommend to have light incident on a point from many different directions, which ideally can be approached by using a larger number of smaller wattage light sources, by using luminaires with a widespread light distribution, and by having high-reflectance surfaces in the space, that also works to minimize veiling reflections. The other reason is the occurrence of veiling reflections, as stated by CHEN (2000), they are images of high luminance objects, such as a luminaire or a window, superimposed over the task, can decrease task luminance contrast, in which case the visual performance of the task will deteriorate. Figure 2.3 depicted by CHEN (2000) shows that light would reflect into the eyes of the viewer from the "offending zone" and defines the zone of veiling reflection.

The other factor that the designer of the general lighting needs to consider is described by CHEN (2000) as the spectrum of the light used, where color discrimination or color matching is a part of the work process, such as in the printing and textile industries.

Some considerations of the impact of lighting on safety are appropriate in all lighting applications but it is particularly important in industrial situations. This is because of the complex layout of many plants, the hazards associated with some manufacturing processes and the dangers of moving equipment. Minimum illuminances are recommended by IESNA (2000) for safety whenever the space is occupied, ranging from 5 to 54lx depending on the level of hazard but illuminance alone is not enough. Hazardous situations can arise whenever seeing is made difficult by disability glare, strong shadows, and sudden changes in illuminance.

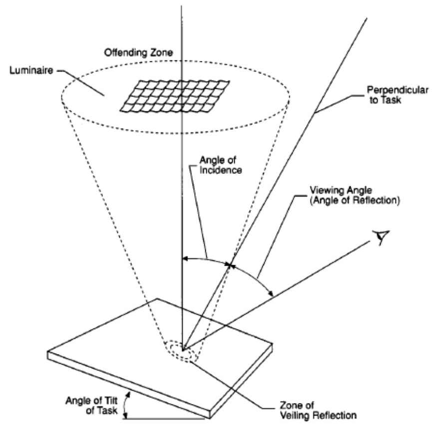


Figure 2.3. Diagram showing "offending zone" and zone of veiling reflection by CHEN (2000)

The design of industrial lighting is too frequently dominated by a desire to maximize lighting system efficacy. As CARLTON (1982) states that this desire is often consummated through a lighting installation which uses the smallest number of luminaires, containing the highest wattage light source, positioned at the widest allowed spacing, and directing most of their light downwards to an assumed horizontal working plane this is a recipe for deep shadows, strong veiling reflections and possibly discomfort glare, as well as inadequate illumination on vertical planes.

While noting whether direct, indirect, or indirect/direct is intended, to provide a low-moderate intensity of light uniformity a space, STEFFY (2001) states 'general lighting' allows for great flexibility in rearranging furnishings and for general circulation throughout a space. Remarking on the variation limit of light level from point to point within the area should be 17% of the selected level, CHEN (2000) also argues a good general lighting system makes it possible to change the location of machinery without rearranging the lighting and also permits full utilization of floor space.

(b) ***Reports on the task lighting in industrial environments***

According to EGAN & OLGYAY (2002) how well we see depends on: ability of the observer, visibility and characteristics of object being observed, and type of task being performed and its context. Visual ability varies from person to person and with age, but most importantly, visual ability can be improved with the repeated performance of the task. Skill at a task increases as the person becomes adept at distinguishing the visual signal from the background, so the primary factors affecting visibility are size of the object, time available to perform task, and luminance of the visual field, contrast between object to be viewed and its immediate surround, as BOYCE (2003) suggest it should always be remembered that it may also be possible to make the task easier by changing the task characteristics.

On the other hand, BOYCE (2003) calls attention that most visual activities are not task-oriented and tend to be general monitoring of the environment. A variety of visual tasks, such as reading, writing, assembling, and various types of visual inspecting and manipulating, are intermixed with our activities. As the visual task becomes more demanding, the lighting conditions become increasingly critical.

CHEN (2000) stipulates combined 'general and local lighting', in this dissertation named as '*task lighting*', as a valuable industrial lighting tool, which is specified for different seeing tasks that require a specific level or quality of light not readily obtained by standard general lighting methods. As BOYCE (2003) states to contribute to the safety of those doing the work the probability of a stroboscopic effect occurring can be reduced by with other ways, by supplementing the general lighting of machinery with task lighting using a light source with inherently small oscillation in light output, such as an incandescent lamp or to facilitate quick and accurate work veiling reflections may also be used to reveal the nature of a surface, in which case they are called highlights, and can be beneficial for the performance of some tasks. If they are beneficial then they are more easily provided by a local lighting installation mounted close to the task.

As reported by GORDON (2003) and STEIN *et al.* (2006) the main distinction was energy-efficient lighting, thus larger values of task illuminance are provided for the workplace while lower values of ambient illuminance are provided for surrounding areas. Continuing, KAMPF (2005) comments that successful lighting design is one which improves visual comfort while saving energy and money, decreasing maintenance, and reducing waste. Citing Semiconductor Industry Association Report (1997), NRCS (1999) points out that, excluding capital and construction expenditures, the electric bill can be the largest or second largest expense item, representing 25 to 40 percent of facility's operating budget.

Of further note is the study by LOFTNESS *et al.* (2001) which noted that the introduction of an ambient lighting system-often indirect for shadowless spatial reconfiguration-in conjunction with task lights, can significantly reduce office lighting energy demand, reduce the air conditioning load, and provide light levels that are better matched to today's diverse work activities. On a more tangible stand in this vein are the several examples of such places given by WOODROOF (2001), one of which is high intensity task lights installed on fork trucks for use in rarely occupied warehouses, so entire warehouse's lighting can be turned off or reduced, saving a large amount of energy and also money.

Localized and task lighting can take many different forms and serve many different purposes. The most common forms are described by BOYCE (2003) as the fixed luminaire that provides additional illuminance in a localized work area and the adjustable task luminaire that allows the worker to have some control over the lighting of the task. Fixed localized lighting is common where the work area is in shadow. Adjustable task lighting is common where the tasks to be done are much more visually difficult than average. For large-scale manufacture, localized lighting can be moveable, consisting of luminaires mounted on a wheeled frame, so that lighting can be moved into position when work demands it. Fixed localized lighting rarely does more than provide a higher illuminance. Adjustable task lighting also does this, but in addition, allows some modification of the distribution of light falling on the task.

As STEELCASE (2000) points out, these split task and ambient systems should have user control of task light location, density, and on/off switching. The author continues, each workstation should have a minimum of one or two task lights, they should be relocatable by the user to match work-surface configuration and use, they should have adjustable arm/directional control of the light distribution, and there should be occupancy sensors for automatic shutdown when the workstation is unoccupied.

(c) ***Reports on visual inspection***

One type of local lighting that can take many different forms, each form being designed for a particular function, is lighting for visual inspection. EGAN *et al.* (2002) defines visual inspection work involves detection, recognition, and identification. According to authors threshold studies examine the minimum light level needed to detect, recognize, or identify visual tasks under various conditions of contrast, brightness, and time. In real-world situations, acceptable conditions for ease of seeing often involve detection or search well above threshold levels.

BOYCE (2003) states that studies of eye movements made while searching for defects in products have revealed a common pattern of fixation and saccade, where the observer goes through a series of fixation pauses with rapid saccadic eye movements between them. Citing MEGAW & RICHARDSON (1979), the author bears out observations of this sort illustrate that the search pattern made by experienced inspectors is often systematic rather than random, the search pattern being based on the inspector's expectations about where the defects are likely to occur.

As described in the same source, lighting cannot provide a clear definition of a defect for the inspector, although it can sometimes be designed to reveal the visual characteristics that define a defect, once that definition is available. What lighting can always be designed to do is to enhance the probability of off-axis, *i.e.* the peripheral visual field, detection of a defect. For a uniform field, where any departure from uniformity is a defect, the probability of off-axis detection can be related to the visibility of the defect. For searching uniform, empty fields, it is the visibility of the defect off-axis that determines the search time. BOYCE (2003) summarize that situation: as the defect size increases, which will make it more visible, the search time decreases.

However, BOYCE (2003) concludes for many inspection tasks, the defect appears not in a uniform, empty field but in a cluttered field, i.e. one which many different items are present. High visibility is not enough to guarantee high conspicuity. For high conspicuity, the defect should differ from the other items in the field on as many dimensions as possible. The differences in color give a much larger effective visual detection lobe than do differences in shape.

Many of the lighting techniques used for visual inspection are aimed at either increasing the visual size or luminance contrast of the defect, either by casting shadows or by using specular reflections. FAULKNER & MURPHY (1973) list 17 different methods of lighting for inspection. Their methods can be classified into three types;

- Those that rely on the distribution of light,
- Those that rely on some special physical property of the light emitted that interacts with the material being inspected, e.g. ultraviolet radiation for detecting the presence of some types of impurities in a product;
- And those that call for the projection of a regular image onto or through the material being studied.

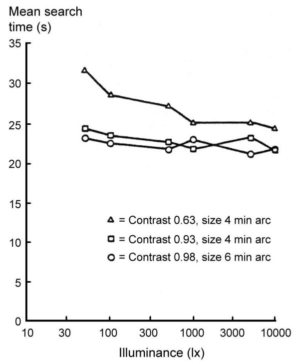


Figure 2.4. Mean search times for locating a specified two-digit number from a random array of 100 such numbers, plotted against illuminance, for numbers of three different size and contrast combinations (MUCK & BODMANN, 1961).

The most widely applicable aspect of lighting which aids visual inspection was examined by MUCK & BODMANN (1961) the illuminance on the search area. Figure 2.4 shows how increasing illuminance leads to shorter search times, particularly for small-size, low-contrast targets.

On the other hand, BOYCE (2003) calls attention to the fact that the effect of increasing illuminance is merely to decrease the contrast or effective visual size of the defects or to produce confusing visual information in the search area, so that visual inspection performance will be worse with higher illuminances. An early example of this was the WYATT & LANGDON (1932) examination, as shown in Figure 2.5. The authors goes on to note that as the important point here is onset of lighting almost certainly increased the illuminance on the task but this caused a worsening of performance because of reflected glare from the brass caps of the cartridge cases and the cases were less uniformly lit. Thus, in this case, the increased illuminance was provided in such a way that the defects became more difficult to see. These results demonstrate the need to understand the whole impact of a lighting installation on visual search, rather than just one part, the illuminance.

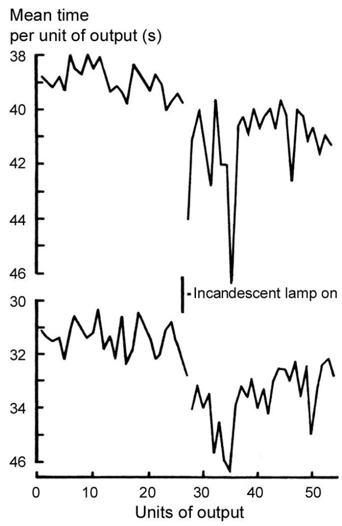


Figure 2.5. Mean time taken by two workers to inspect and pack cartons of 25 shotgun cartridges before and after an incandescent lamp was switched on (WYATT & LANGDON, 1932).

According to BOYCE (2003) to design appropriate lighting, it is necessary to understand the physics of the situation. Whenever visual inspection lighting is under consideration, it is necessary to have a clear understanding of the physical nature of the defect and how it interacts with light, and the constraints imposed by the conditions in which the inspector works. Simply providing more light, without thinking about the consequences for the visibility and conspicuity of the defect, may make visual inspection more difficult. It is also necessary to consider the consequences of lighting to make it easier to detect one type of defect for the ability to detect other types of defect.

Finally, as REYNOLDS, KARPALA, CLARKE & HAGENLERS (1993) states that, it is necessary to appreciate that visual inspection by humans may not be the only possibility. Remarking on automated inspection is possible for many simple, repetitive inspection tasks and is steadily increasing in sophistication the main advantage of automated inspection is that the detection criterion is clear and automated inspectors do not become bored and inattentive.

2.2.3 Reports on attributes of manufacturing floor occupants

It was the middle of the last century when the specifications published by the British Lighting Council (BLC, 1962) stipulate the visibility of essential detail must have an effect on the speed and accuracy of not only purely manual processes, but also of any automatic processes in which human supervision and control plays a part. On this point, BLC (1962) call attention to the fact that every industrial product at some stage or other undergoes inspection where acceptance or rejection usually depends on vision. Modern machine tools, robotics and laser technology taking the place of people in manufacturing facility, but people remain still a part of the process was also explained later by DARLEY (2003) who, in perhaps more colorful terms, had called it '*Group technology*' and had described it as the teams of workers took full responsibility for the entire process. As SMITH (1998) points out, a firm's "resources" are not limited to the raw materials of an assembly line. Along the same line, noting that the greatest resource of a company is its personnel, BURKHARDT (2003) stipulate that in today's united entity of work, *the skilled trade of the future* will be the experimental field for industrial production.

It was seen that alterations in the face and pace of work, brings new ergonomic and spatial design thinking, where it is necessary for the workers in industry to determine the sensible and necessary *amount and the type of communication*. As STEIN *et al.* (2006) state that, concentrated pools of light in an overall low-ambient light space effectively isolate the illuminated areas from each other, this can be used to advantage in work where it is desired to define individual 'territories' in a single large space.

The task illuminance can be provided at the appropriate level, while the access and circulation lighting can usually be at a lower illuminance level, provided that the contrast is not too great. As an aside, GLIGOR (2003) points out that, rapid spatial changes in illuminances around the task area may lead to visual stress and discomfort, where the ratio of work surface luminance to the luminance of large surfaces farther away, such as ceilings, walls and machinery, should be no greater than 10:1, and no less than 1:10.

Of further note is the study by SAGAWA & TAKAHASHI (2001) which showed that as the eye ages, the transmittance of the lens decreases, particularly at the short-wavelength end of the visible spectrum this will lead to a reduced sensitivity in this wavelength region for older people. Commenting on the scientific merit of such studies, both BOMMEL, BELD & OOYEN (2002) and WOODROOF (2001) define good lighting on the task and in the workplace for optimal task performance, especially taking into consideration the progressively aging workforce. What are so in this regard, the authors continues most workers prefer lighting systems designed with task lighting because it is flexible and allows individual control. What they then cite as modular task lighting which would allow older workers to increase their light levels on specific tasks.

Table 2.3. Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors. (IES Lighting Handbook, Application Volume, 1993)

Type of Activity	**Illuminance Category**	**Range of Illuminances**		**Reference Work-Plane**
		Lux	**Footcandles**	
Public spaces with dark surroundings	A	20-30-50	02.03.2005	General lighting throughout spaces
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10	
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20	
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50	Illuminance on task
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100	
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500	Illuminance on task, obtained by a combination of general and local (supplementary lighting)
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000	
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000	

Table 2.4. Weighting Factors for Selecting Specific Illuminance Within Ranges A, B, and C. (IES Lighting Handbook, Application Volume, 1993)

Occupant and Room Characteristics*	Weighting Factor		
	-1	0	1
Workers' age (average)	Under 40	40 to 55	Over 55
Average room reflectance	>70%	30 to 70%	<30%

Note: The table is used for assessing weighting factors in rooms where a task is not involved.
1. Assign the appropriate weighting factor for each characteristic.
2. Add the two weights; refer to Table 2.3, Categories A through C:
a. If the algebraic sum is -1 or -2, use the lowest range value.
b. If the algebraic sum is 0, use the middle range value.
c. If the algebraic sum is +1 or +2, use the highest range value.
* To obtain average room reflectance: determine the areas of ceiling, walls, and floor; add the three to establish room surface area; determine the proportion of each surface area to the total; multiply each proportion by the pertinent surface reflectance

Table 2.5. Weighting Factors for Selecting Specific Illuminance Within Ranges D through I. (IES Lighting Handbook, Application Volume, 1993)

Task or Worker Characteristics	Weighting Factor		
	-1	0	1
Workers' age (average)	Under 40	40 to 55	Over 55
Speed or accuracy*	Not important	Important	Critical
Reflectance of task background, %	>70%	30 to 70%	<30%

Note: Weighting factors are based upon worker and task information
1. Assign the appropriate weighting factor for each characteristic.
2. Add the two weights; refer to Table 2.3., Categories D through I:
a. If the algebraic sum is -2 or -3, use the lowest range value.
b. If the algebraic sum is -1, 0, or +1, use the middle range value.
c. If the algebraic sum is +2 or +3, use the highest range value.
*Evaluation of speed and accuracy requires that time limitations, the effect of error on safety, quality, and cost, *etc.* be considered. For example, leisure reading imposes no restrictions on time, and errors are seldom costly or unsafe. Reading engineering drawings or a micrometer requires accuracy and, sometimes, speed. properly positioning material in a press or mill can impose demands on safety, accuracy, and time.

On this point citing IES Lighting Handbook (1993), CHEN (2000) call attention to the new methods for calculating the recommended illuminance level for a given task. As CHEN (2000) point out in their book, a more comprehensive investigation of required illuminance is to be performed where the average age of workers, the importance of speed and accuracy, and the reflectance of task background should be considered. Ergo, the weighting factors, shown in Table 2.4. and Table 2.5., devised by this author to depict the interaction of these factors.

2.3 Reports on the Interaction of Occupant and Environment

The most salient of the sources have been cited below under to discrete sub-headings, as: reports on the role of employee and reports on the role of employer.

2.3.1 Reports on the role of employee

Citing the results of the long-term study of Massachusetts Institute of Technology (MIT) established that 80% of all innovative thought results from personal communication, ADAM *et al.* (2004) call attention the importance of architecture, which supplies the preconditions for patterns of movement, of encounter and of avoidance. As BEAN (2004) states that, where working zones are clearly defined and access ways are fixed, then the use of different types of luminaries to define these areas can give a *sense of orientation and organization* which adds to the satisfaction of employees with their environment. In this vein FLYNN, SPENCER, MARTYNIUK & HENDRICK (1992) very early emphasized lighting, in addition to influencing providing task visibility, also influences *motivation, orientation, mood, social interaction and well-being*.

ADAM *et al.* (2004) further stipulated that as an architectural feature lighting, which makes the volumes brought into being by the limitation of the space recognizable from the inside and from the outside, the available space should be divided up in such a way that rooms or areas for individual, concentrated work are juxtaposed with spaces devoted to communication, so that direct, face-to-face communication can take place between the right people at the right time. The same author goes further in this vein ideally, an independent, responsible employee should have a certain degree of control over the amount of communication and seclusion that he or she requires where individual performance is determined by the degree to which it is interconnected and the exchange of knowledge-free, direct, or unplanned-between staff and departments too, as in a network structure, the number of connections is much higher than the number of participants.

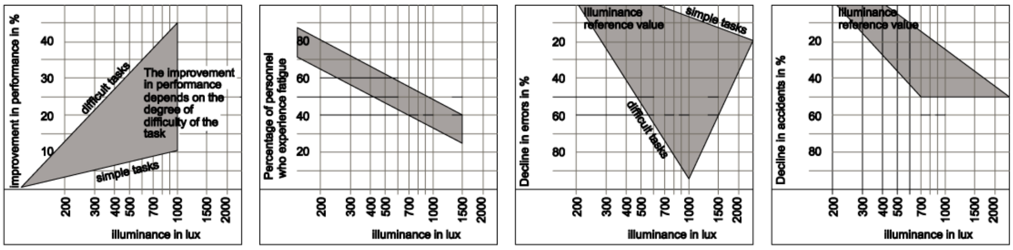
What was considered also noteworthy were the reports on the role played by dominant lighting pattern in regard to physiological effects. A design consideration defined by STEIN *et al.* (2006) points out that the impression of room length and width can be emphasized by the direction of lines of lighting; and even wall wash of light can also be used to shorten and widen a hallway or corridor that STEFFY (2001) bears this out by visual attraction is beneficial physiologically by offering eye rests establishing visually distant focal points onto which employees viewing hardcopy and computer screens can gaze from time to time.

On this point, both REA (2005) and SMITH (1998) emphasize in their works the visual system combined with a flexible body provides employees the ability to adjust their posture in response to the available light, so inadequate lighting conditions tend to be more physical by employees–sore necks, aching backs which lead to increased break time, sick time, or just slightly less overall productivity.

The environment affects performance, health and efficiency. Improving the work environment enables employees to perform at their best. This situation is described by JUSLEN, WOUTERS & TENNER (2006), and SMITH (1998) as a critical environmental cycle in industrial ecology: the healthy workplace results in a healthy environment, enhances productivity, reduces waste pollution, and, in turn, maintains a healthy workplace. Ergo, the scatter plots for higher quality of light versus improvements depicted in Figure 2.6., below.

2.3.2 Reports on the role of employer

Noting that the electronics industry is critically dependent on rapid technological innovation, and it is beginning to apply similar efforts to meet environmental challenges, the report of NRCS (1993) explains that the cleaner production of industrial processes is applied to reduce the uses of resources and energy. On this point the authors call attention the use of metrics for decision making within the industry is generally driven by regulation, one exception is efforts to reduce energy and water use, which generally result from a desire to lower operating cost.



(a) (b) (c) (d)

Figure 2.6. The positive impact of light in industry

(a) Improvement in performance as a result of higher quality of lighting; (b) Lower incidence of fatigue as a result of higher quality of lighting; (c) Fewer errors as a result of higher quality of lighting; (d) Fewer accidents as a result of higher quality of lighting (FGL, 2002).

Arguing the entire lighting design must be accomplished efficiently in terms of capital and energy resources, the former determined principally by life-cycle costs and the latter by resource-energy usage and operating-energy costs, STEIN, *et al.* (2006) note two fundamentally different approaches to reducing lighting operating costs, first one is reducing hours of use by switching off or dimming lights, second is minimizing the lighting load by using efficient lamps and fittings and designing to the correct light levels, which addresses attention to task and ambient lighting.

This aspect is to a certain extent confirmed by CHEN (1990) when noting that in view of high energy cost, considerations of operating cost often outweigh the initial cost, but life-cycle costing is often the best way to measure lighting cost. As an aside, ADAM *et al.* (2004) states in typical production plants, about two thirds of the construction costs are for finishing and building services engineering, while only about a third goes on the load-bearing structure and construction, where industrial buildings with a high installation density are buildings in which a wide variety of technical installations are required in great quantity.

What is so in this regard SMITH, CAPEHART & ROHRER (2007) stipulates whether for modification, retrofit, or new design, consideration should be given to the spectrum of high-efficiency lamps and luminaires that are available; high-pressure sodium lamps are finding increasing acceptance for industrial use, with savings of nearly a factor of five compared to incandescent lamps given as an example.

In addition to high quality design and the use of efficient lighting technologies, KREITH, de ALMEIDA & JOHNSON (2007) states commissioning and maintenance of lighting systems play important roles in maximizing energy saving. Defined by CHADDERTON (2007) as a critical factor, a planned maintenance schedule will include regular cleaning of light fittings and the lamp to ensure the most efficient use of electricity. Of further note is the phased replacement of lamps which maintains design performance and avoids breakdown. Continuing, the author comments that in air-conditioned buildings the lamps operates at a lower temperature, which prolongs its service and maximizes light output. Noting that if maintenance is neglected or conditions of use are more demanding than anticipated during design, NRCS (1993) point out that performance deterioration may proceed more rapidly than expected, as clarified by KREITH, *et al.* (2007) in a very clean environment luminaire dirt is estimated to reduce light output over a period of 3 years by 10%-20% depending upon the type of luminaire used where in a very dirty environment light output can be reduced by 50% in a less than 2 years.

Of further note is the study by GRIFFIN (2005) which showed that the maintenance of a task lighting system is much easier than any other systems. The author continues to say as a subset of increasing source efficacy, task lighting techniques involve improving the efficiency of lighting in an entire workplace, by replacing and relocating lighting systems.

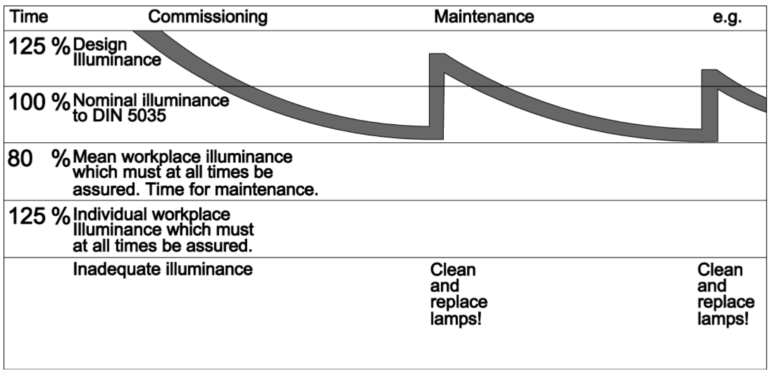


Figure 2.7. Lighting system maintenance according to the illuminance of a lighting system diminishes with time.

Arguing that changes in technology are not inevitable; in the long term they are desirable, because the new systems and services offer enhanced performance to the facilities, users, and owners, NRCS (1993) points out rising expectations can effectively shorten the lifetime of a facility, where accommodating rising expectations often has been costly, but failing to accommodate change is costly as well, that can impose heavy burdens on their owners and users. What is so in this regard, the author continuous to say, often these modifications are especially costly because the designs of older structures are not adapted easily to new systems, finishes, and interior layouts; therefore, a more adaptive lighting system would be capable of accommodating these changes much easier cited as a basic concern.

2.4 Reports on the Interaction of Workplace Dynamics and Environment

Defined by both BEARD (2001), and GYULA (1998) including not only certain high-technology solutions, but also integrated control systems of services, so different from the high-tech or advanced building, the term 'intelligent or smart building' originated in North America around 1980s as a consequence of the growth of information technology and its increased use in building, which fallows the beginning of the 'design-built' movement, the authors accentuate designing and building these structures need specialized efforts.

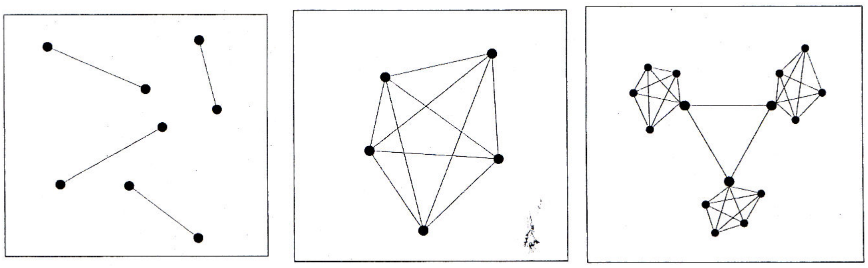
Citing the report released from ACEEE in October 2000 of a study they did in conjunction with staff from Lawrence Berkeley Laboratories (LBL), where they identified 175 emerging energy-efficient technologies, and honed this list down to 32 technologies that had a high likelihood of success and a high energy savings, SMITH *et al*. (2007) call attention three of them was 'advanced lighting design, advanced lighting technologies, and sensors and controls, given in Table 2.6., noting that many of the technologies have important nonenergy benefits, ranging from reduced environmental impact to improved productivity. In his individual work, undertook a review of then-current major trends of manufacturing begins with digital computer technology to thereby, MERCHANT (2000) bears this by this statement: "Develop and apply the technology that it will support the user, rather than, that the user will have to support the technology".

Arguing that in the medium term, energy and resource-saving measures and environmentally responsible policies will increasingly determine the design and construction of industrial buildings, both ADAM *et al.* (2004) and KREITH, *et al.* (2007) stipulate flexible adjustment of the technical equipment to take these changes into account must be enabled, depending on the work, the process, the production and the function involved and securing production is given absolute priority, as the development/manufacturing of products is not possible without sufficient production-dependent provisioning.

Table 2.6. Technologies with High Energy Savings and a High Likelihood of Success by SMITH *et al.* (2007)

Technology Next Steps	Code	Total Energy Savings	Likelihood of Success	Recommended Next Steps
Advanced lighting technologies	Lighting-1	High	High	Dissem., demo
Sensors and controls	Other-5	High	High	R&D, demo, dissem.
Advanced lighting design	Lighting-2	High	Medium	Dissem., demo

In this vein LOFTNESS *et al.* (2001) summarize the key features as 'support on-going organizational and technological dynamics in appropriate physical, environmental, and organizational settings to enhance individual and collective performance and human health, comfort, and motivation'.



(a) (b) (c)

Figure 2.8. Systems of varying complexity

(a) Simple, unintegrated systems; (b) complex systems with undifferentiated integration. Any change in a subsystem always affects the whole system; (c) complex systems with differentiated integration. Subsystems can be changed to a certain extent without a negative effect on the functional efficiency of the whole system (ADAM *et al.* 2004).

While in an earlier study, TU (1997) has revealed statically significant relationships between organizational workplace dynamics and building infrastructural flexibility for delivering the appropriate environmental and technical quality in offices. The percentage of work surfaces whose light levels are below the average acceptable light level correlates with the degree of space configuration change, the provision of task light fixtures, and workspace size, as depicted by the scatter plot of Figure 2.9., is below.

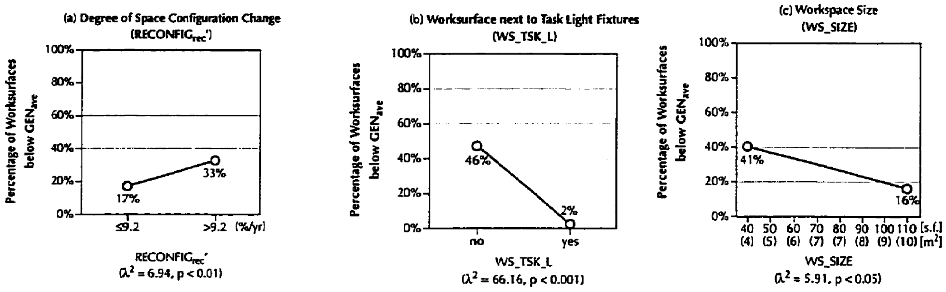


Figure 2.9. Scatter plot for the percentage of work surfaces whose light levels are below the average acceptable light level correlates with (a) the degree of space configuration change; (b) the provision of task light fixtures; and (c) workspace size, as determined (TU, 1997)

Of further note is the study by TU & LOFTNESS (1998) which showed a number of major spatial changes, creating new demands on the workplace–the buildings, infrastructures, and interior systems- as a result of the commitment to worldwide growing organizational reengineering and the reevaluation of buildings that support the "dynamic" organization, as follows:

- Workstations are getting smaller (64 ft^2 is now generous)
- Occupant densities are going up (3% a year at least)
- Partitions are coming down (from 80-64" to 52-42")
- The walls are also coming down (from 30% closed to none?)
- Teaming spaces are proliferating (growing from 3-15% of gross ft^2)
- Floor plates are getting bigger (growing from 10.000 ft^2 to over 60.000ft^2)
- Workspace ownership is under negotiation (free address, hoteling increases)
- Abandoned shopping malls and warehouses will do?
- And, if less than 20% could have a window, why not take it from all?

This was carried further by the studies by LOFTNESS *et al.* (2001), in which focus was dynamic, user-based infrastructure practice in building diagnostics in order to predict its pathology of pretended flexible structures.

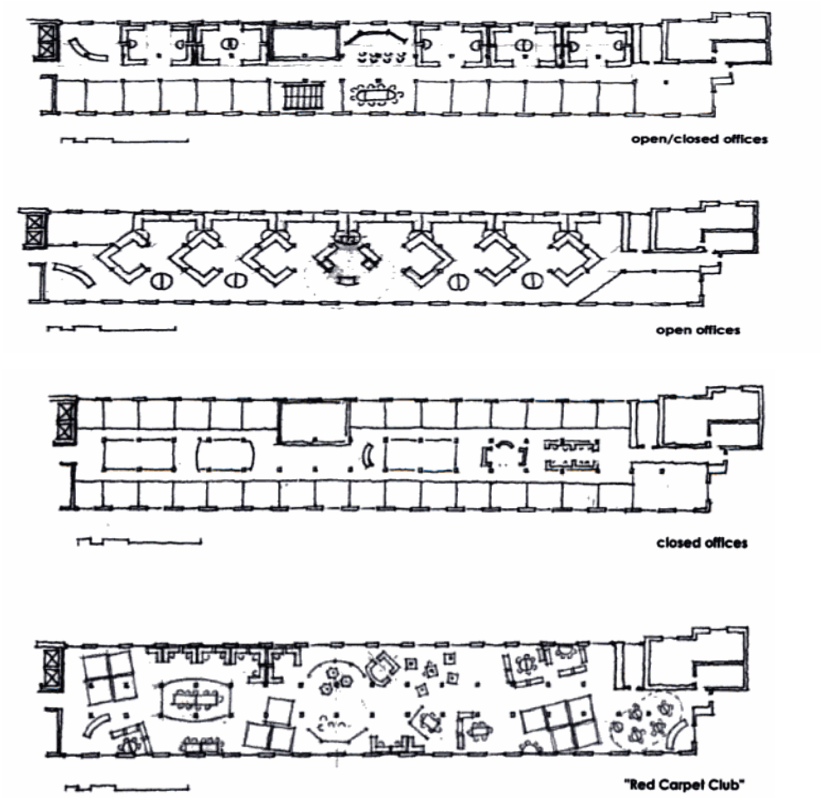


Figure 2.10. Adaptable workplace laboratory generated multiple workgroup layouts (Loftness *et al.*, 1996)

As claimed in this source, existing building infrastructures are so inflexible that they are incapable of accommodating the rapidly changing organizational and technological requirements for buildings today. Concomitantly are redefined and reproduced in Figure 2.11., the basic features of '*flexible grid- flexible density- flexible closure*' building subsystems, that permit each individual to set the location and density of HVAC, lighting, telecommunications and furniture, and the level of workspace enclosure, with the concept of the '*grids*' establish the overall level of capacitance available to support the working group or neighborhood (fresh air, cooling, power, and network capacitance) and the '*nodes*' or user interfaces, must be flexible in terms of location, requiring accessible and expandable vertical service with collaborative horizontal plenum. Being more detailed, the comparison of today and future needs is summarized below in Table 2.7.

Noting changes in such design precepts LOFTNESS *et al.* (2001) comments lighting systems in the intelligent building should fully address the demands of the dynamic organization for:

- Organizational/spatial flexibility (continuous organizational change without waste)
- Functional flexibility (changing tasks and work tools without visual discomfort)
- Technological flexibility (changing desktop/multimedia technologies without visual discomfort
- Healthy, motivational work environments.

Table 2.7. Seven basic infrastructures every occupant / workstation needs individually recommended by LOFTNESS *et al.* (2001)

PAST / TODAY ?	TODAY ? / FUTURE
Variable air supply, dependent on thermal demand	Fresh air
Blanket supply of cooling, large zones for fifteen people (average)	Temperature control
Uniform, high-level lighting	Lighting control
Rare daylight and view, isolation from outdoors	Daylight and view, reduced isolation from outdoors
Rare working quiet and prvacy control	Privacy and working quiet
One data connection, nonrelocatable; two power connections, nonrelocatable; one voice connection; nonrelocatable	Network access to multiple data, power, voice connections
Precomputer furniture, non-ergonomic; unmeasured indoor pollutant sources	Ergonomic furniture and environmentally appropriate finishes

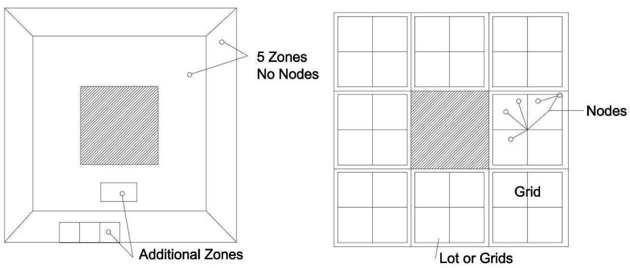


Figure 2.11. Existing service/utility vs. concept of grid and nodes by LOFTNESS et al., (1996)

It was nevertheless reported by ATKINSON, DENVER, McMAHON & CLEAR (2008) a number of innovative design approaches supported by lighting components and systems illustrate the next generation of 'smart lighting systems'. Semiconductor lighting material LED, which requires little energy, does not become particularly hot, requires almost no maintenance and can attain up to 100.000 operating hours discussed in detail by CHIPALKATTI (2002), manually or photoelectrically switched from transparent to translucent electrochrominc glazing and automatically respondable to light intensity and dims transparency to a predetermined level photochromic glazing reported by STEFFY (2001), addressable lights from a computer terminal or by a handheld device with sensors examined by LEE & AGHAJAN (http://peec.stanford.edu/buildings/research; accessed:2009) based on occupancy reasoning, permanent supplementary artificial lighting of interiors (PSALI) system defined by CHADDERTON (2007) in which the heat generated by permanent lighting can be extracted from the luminaire by passing the ventilation extract air through it, and then supplying this heated air to perimeter rooms in winter are only a part of them. In this vein, LOFTNESS *et al.* (2001) summarize the design approaches; thus:-

- Effective daylight utilization with controllable electric lighting interfaces, which is the subject of numerous publications, prescribed was critical to attracting and retaining the high-tech worker,
- Separate Task Lighting from Ambient Lighting, discussed in detail in section 2.2.2,
- Reconfigurable Lighting with Plug-and-Play Fixtures, prescribed was reconfigurable ceiling lights where density and location can be changed by the occupant or in-house staff, since the pigtail connections-male-female plugs-allow fixtures to be added or subtracted from any circuit and its corresponding light switch. Acoustic ceiling tiles interchangeable with lightweight light fixtures to enable the simple relocation of fixtures along with each desk or room configuration given as an example.

Track lights also offer this level of plug-and-play flexibility that supports high-voltage and low-voltage fixtures for plug-and-play uplighting, downlighting, and accent lighting. With this grid of service, the nodes–or light fixtures-can be purchased on a just-in-time basis and continuously reconfigured to support organizational, functional, or technological changes.

- Continuous Change in Lighting Zone Size and Control, redefined was supplying advanced electronic ballasts for each fixture will support a variety of control options, from individual on/off switches to timers, occupancy sensors, daylight/photocell readers, lamp depreciation controllers, and/or peak load shedding strategies. The most critical reason for individually ballasted fixtures-with smart ballasts is the ability to continuously change control strategies to match spatial and functional changes, that is redefine the size and shape of control zones and their digital / infrared switches to accommodate continuous spatial and organizational change.

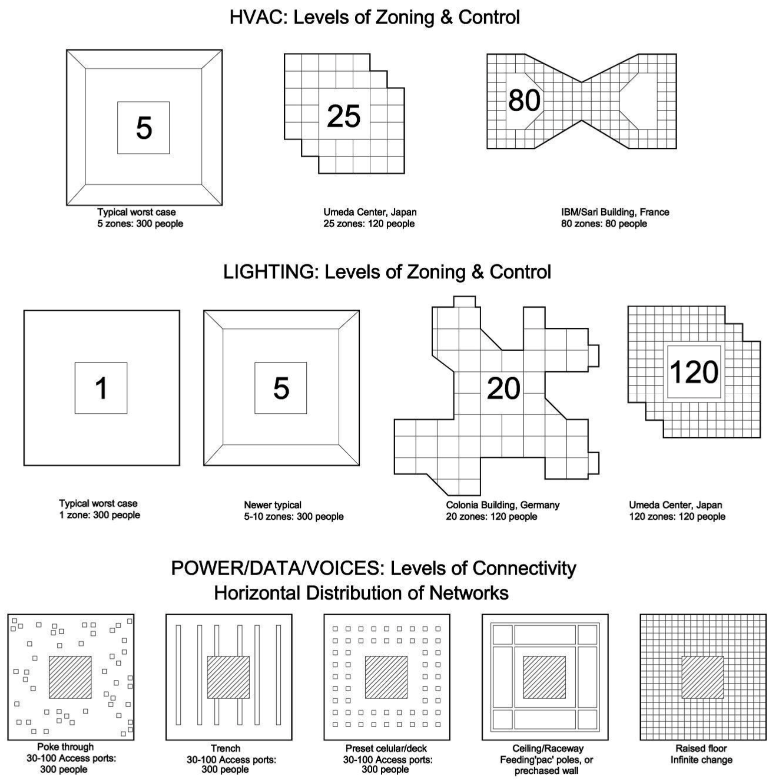


Figure 2.12. HVAC, Lighting, Power/data/voice: Levels of zoning and control (Loftness *et al.*, 2001).

The design of a control scheme for an occupied space described by CHADDERTON (2007), it may include a minimum number of luminaires, which are switched on from a time switch or by the occupant to provide safe access. Groups of luminaires that are near windows may be controlled from local photocell detectors to ensure that the perimeter lighting remains off as long as possible. The internal parts of the space may be operated from automatic presence detectors. Data on the length of operation of each lighting unit can be transmitted to the computer-based building management system so that real-time usage and electric power consumption can be reduced. Timed-off controllers avoid lights left on excessively after working hours and when nobody is present.

Once the appropriate modular, relocatable, and user-based infrastructures are provided, the continuous recreation of workstations or workgroups can be achieved with assurance of thermal comfort, lighting quality, and connectivity, these will support individual comfort and productivity, organizational flexibility, technological adaptability, and environmental sustainability ensuring effective individuality as well as collaborative work.

While all the studies mentioned so far dealt with the subject on the basis of design approaches, the work by HARTKOPF (1992) was unique in that it points out attention to the numerous roles of facility manager in the user-controlled intelligent building: in preventive maintenance; in feedback to owners, designers, and manufacturers; and in the development of expert systems for building management.

2.5 Reports on Methodology

Under this section are collected calculation methods given in the literature for obtaining quantitative values on aspects pertinent to the subject domain. They are presented below under 2 sub-sections; namely: methods for calculating required luminaries, and correlation and regression analyses.

(a) *Methods for calculating required luminaries*

According to PHILIPS (2008) required number of luminaires for a specified illumination level is calculated as follows;

Luminous flux (Φ) is calculated by the following formula:

$$\Phi = \frac{E \times A}{\Phi_n \times UF \times MF} \tag{2.1}$$

where Φ is luminous flux (lumen), E is specified average illuminance-lighting level (lux), A is surface area of the room (m^2), UF is utilization factor, MF is maintenance factor and Φ_n is nominal lamp flux per luminaire (lumen).

In this calculation, the maintenance factor (MF) is composed of lamp lumen maintenance factor (LLMF), lamp survival factor (LSF), luminaire maintenance factor (LMF) and room surface maintenance factor (RSMF).

The Utilization Factor of a lighting installation represents the percentage of the luminous flux of the lamp which reaches the working plane in a room. The UF is dependent on the light distribution, the luminaire efficiency, the reflection of ceiling, walls and floor of the room and the room index. To obtain UF value Reduced Working Plane Utilization Factor Table in Appendix C is used.

The room index k represents the geometrical ratio of the room, and expressed as:

$$k = \frac{lw}{h(l+w)} \tag{2.2}$$

where l is the length of the room (m), w is the width of the room (m) and h height or vertical distance between the luminaires and the working plane (m).

Nominal lamp flux per luminaire (Φ_n) is calculated as follows:

$$\Phi_n = (number\ of\ lamps) \times \left(\frac{lm}{lamp} \right) \tag{2.3}$$

Number of luminaires is calculated by the following formula:

$$N = \frac{\Phi}{\Phi_n} \tag{2.4}$$

where N is required number of luminaries, Φ luminous flux (lumen) and Φ_n nominal lamp flux per luminaire (lumen).

(b) ***Reports on Correlation and regression analyse***

According to BREYFOGLE (1999) a statistics that can describe the strength of a linear relationship between two variables is the sample correlation coefficient (r). Defining that the denominator is not zero and that both x and y are random variables or observed values, DÜZGÜNEŞ & ELİAS-ÖZKAN (2006) goes on to the state that:-

a) -1 ≤ r ≤ 1;
b) r ≥ 0 if y tends to increase as x increases and r ≤ 0 if y tends to decrease as x increases;
c) the stronger the linear relationship between x and y, the closer r is to ±1 and the weaker the linear relationship between x and y, the closer r is to 0.

Noting that correlation only measures association, BREYFOGLE (1999) notes that regression methods are useful to develop quantitative variable relationships that are useful for prediction. For this relationship the independent variable is x, while the dependent variable is y, where the dependent variable in the regression equation is modeled as a function of the independent variables, corresponding parameters ("constants"), and an error term. The author continues to say that as all data points do not typically fall exactly on the regression model line the error term is treated as a random variable and represents unexplained variation in the dependent variable. Parameters are estimated to give a "best fit" of the data. Most commonly, the best fit is evaluated by using the least squares method, but other criteria have also been used.

CHAPTER 3

MATERIAL AND METHOD

In this chapter there are two subsections, namely, the material and the method. They are associated with the description of the study and evaluation of statistical analysis of various elements. Material consists of physical facilities of the production building and nature of the data obtained. The sampling procedure, data collection and evaluation were included in Method.

3.1 Material

The study was carried out in an Electronics Manufacturing Building located in Ankara. Materials were Material Preparation, Cable Harnessing, Electromechanical Assembly, Printed Circuit Board and SMD Assemblies, Board Test, Final Test and Production Engineering departments; and automatic and semi-automatic machines which are used during the electronic production process.

Others were the plans of the selected area obtained from the maintenance department including all the modifications since the building was constructed.

3.1.1 Physical Facilities

The subject building is a part of a multi-product defence electronics company that introduces state-of-the-art equipment and systems solutions for both military and professional applications.

The building was constructed in 1987 and general lighting has been used since that time. More specifically;

- General service lighting is provided by continuous rows of 4x36 watt cold-white fluorescent lamps with plain reflectors, where
  Height for luminaire to ceiling (ceiling cavity h_{cc}) is 200 cm,
  Distance from luminaire to the work plane (room cavity h_{rc}) is 330 cm,
  Distance between the work planes to the floor (floor cavity h_{fc}) is 80 cm.

All of these distances were determined by the system designers for specific purposes of the process, regardless of the machine types that had been used. In other words, no matter what types of machines were used (automatic or semi-automatic) all of these values have been kept constant for the whole lifetime of the building.

- Emergency lighting is provided by eight unit of 2x50 watt fluorescent lamps for use when the power supply for the normal lighting fails,
- Also internally illuminated exit signs are provided for each exit door and emergency exit door.

Total selected area was 2836 m^2 and all of this space is functionally organized for the use of different departments, to manufacture various kinds of printed circuit board assemblies, modules, cable assemblies, interconnection cables, coils, transformers, to perform the mechanical assembly and carry out their relevant test operations. General work-flow diagram in this specific production building is represented in the following chart:

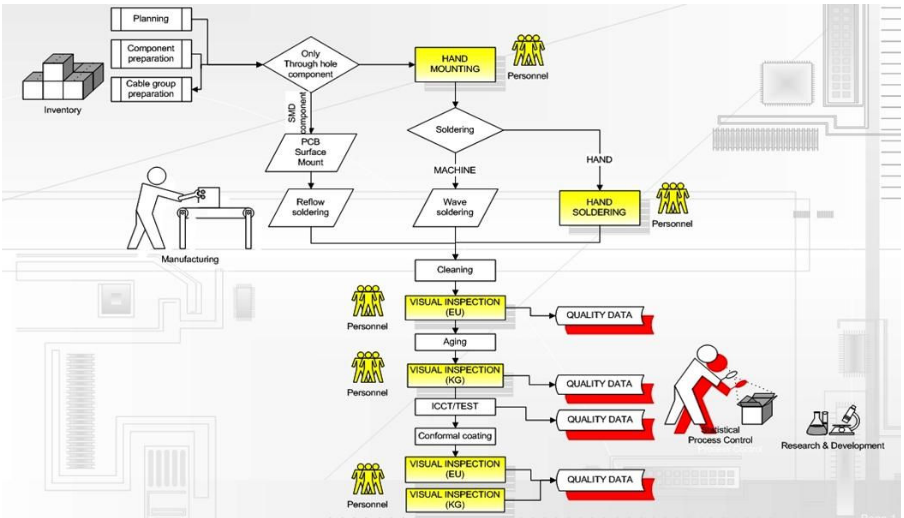


Figure 3.1. General work-flow diagram in subject building.

The basic work definitions of each individual department are explained in the following sections.

a) Production Engineering Department

Main function of the Production Engineering Department is logistically supporting all the production activities. For this purpose; documentation, catalog library, tool shop services are provided, training activities are planned and organized, expense materials (adhesives, solders, chemicals, etc.), cables, spare parts, production equipment, tools and hand tools requirements are determined, planned, ordered and purchased through this department. Also, company wide production management system (e.g. MANMAN) related activities are coordinated; all the required information for this system are collected, generated data are controlled and entered to the system. Performance reports are prepared and published; besides Production Engineering department maintains stock control activities.

b) Material Preparation Department

At Material Preparation Department, kitted components, mechanical parts, cables and other parts of the work orders are processed, before their assembly operations. Component leads are cut, bent and preformed; all cables including coaxial ones are cut and stripped according to their required lengths by utilizing automatic and semi-automatic cable cut & strip machines. Painting and marking operations of equipment front panels, displays and knobs are also made in Material Preparation department by using semi-automatic dispensers.

c) Cable Harnessing Department

Cable assemblies that are used inside modules and/or equipment and equipment interconnection cables are produced in Cable Harnessing Department. All the cutting and stripping operations of cables to manufacture assembly cables, coaxial cables and semi-rigid cable assemblies are carried out by precise semi-automatic cable cut-and-strip machines. Besides continuity test of some of the cable assemblies and interconnection cables are automatically accomplished by using cable harness test system.

d) Electromechanical Assembly Department

Finished PCBA's, cable assemblies, mechanical and electromechanical parts are assembled into modules, semi-finished products and final products in Electromechanical

Assembly Department. Most of the military equipment are designed to be immersible up to a specific depth of water level, their water tightness test are also carried out in this department.

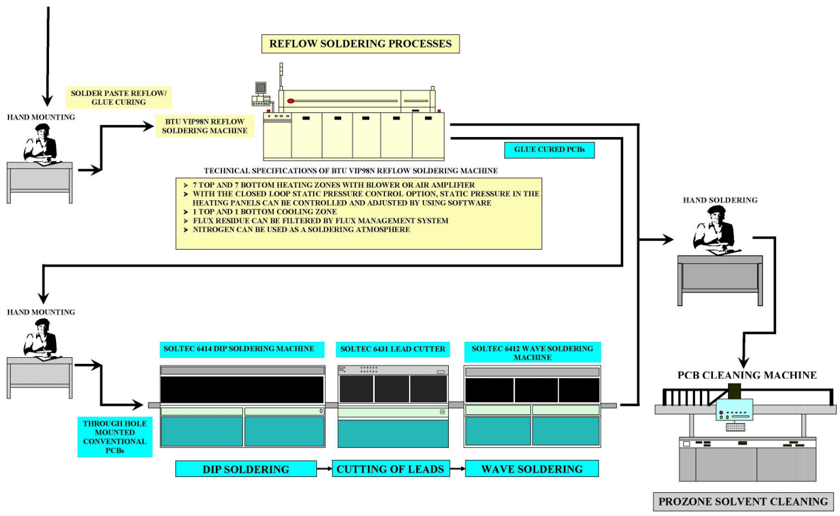


Figure 3.2. Work-flow diagram for reflow soldering processes.

e) Printed Circuit Board and SMD Assemblies Department

In Printed Circuit Board Assembly and SMD Production departments, the most critical processes of electronic production such as manual and semi-automatic insertion of through hole radial, axial and odd shaped components to PCB's, automatically pick and placement of SMD components, screen printing of solder paste or adhesive, manual, wave and reflow soldering, cleaning and visual inspection operations are carried out.

f) Test Department

Manufacturing techniques for modern electronic hardware consists of hundreds of different operations and processes through which many of the defects can be detected by use of visual inspections, in-circuit tests (component level), functional tests (board and module level) and other conventional quality assurance procedures. A small percentage of latent defects remains undetected by obvious means and if not removed in the production phase, will eventually manifest as early life failure during product usage. In order to find latent defects, all the PCBA's are aged (a process or series of processes in which environmental stimuli, such as rapid thermal cycling and random vibration are applied to electronic items) in a Temperature Chamber before test operations.

Afterwards, in the test departments all the PCBA's are tested and defective PCBA's (if there exists) are repaired, then all the boards are transferred to the next operation. Repair and non-conformity data of every independent operation are collected and reported using Statistical Process Control (SPC) programs; hence the processes are monitored and improved continuously for a more efficient production.

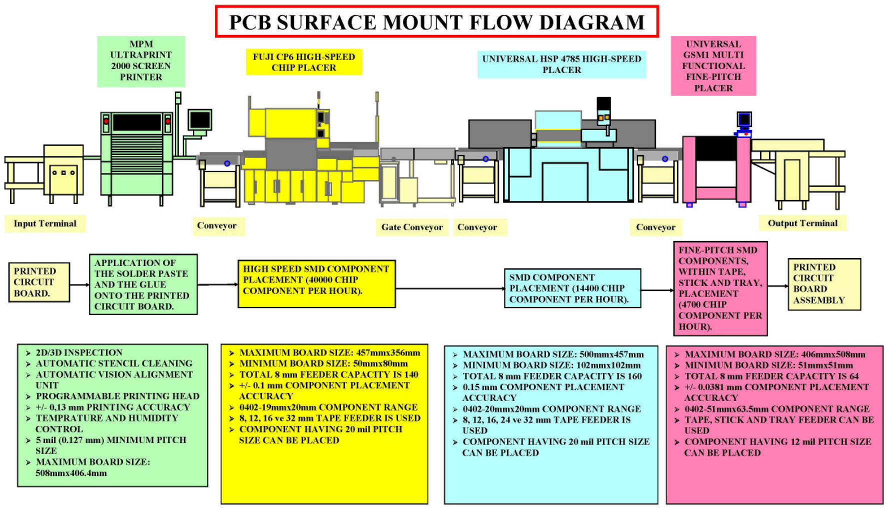


Figure 3.3. PCB surface mount flow diagram.

3.1.2 Nature of Data

Data in this study includes the required illumination levels which were classified in three groups. The classification was made as a result of the discussions that were held with the production engineers working in production building.

a) 1000 lux

Illumination level of 1000 lux is used for visual inspection part of the whole process. This can be after the cleaning phase of PCBA's, where all the assembled boards are visually inspected according to the company's workmanship standards and non-conformities are reworked, then their transactions to next operation steps are done; or between two successive machines that are working on the same assembly where the assembly is inspected before the next operation. Some of the devices used for visual inspection have on-board lamps which gives a very high illumination level for the inspector. Because of the need for a pre-determined contrast level between the work plane and the ambient lighting level, the illumination level of 1000 lux is very appropriate.

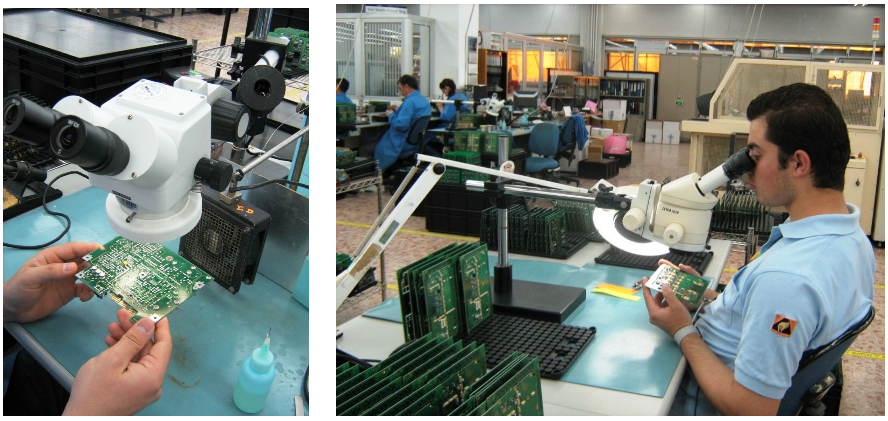


Figure 3.4. Visual inspection.

In addition to visual inspection, 1000 lux illumination level is required for assembling processes used for the production of conventional military devices, for which it is not possible to use a machine. This type of devices can always be in production process because of the recurring customer needs. Moreover, 1000 lux illumination level is required in the SMD production departments in which there has always been a need for some of the components to be mounted by hand.

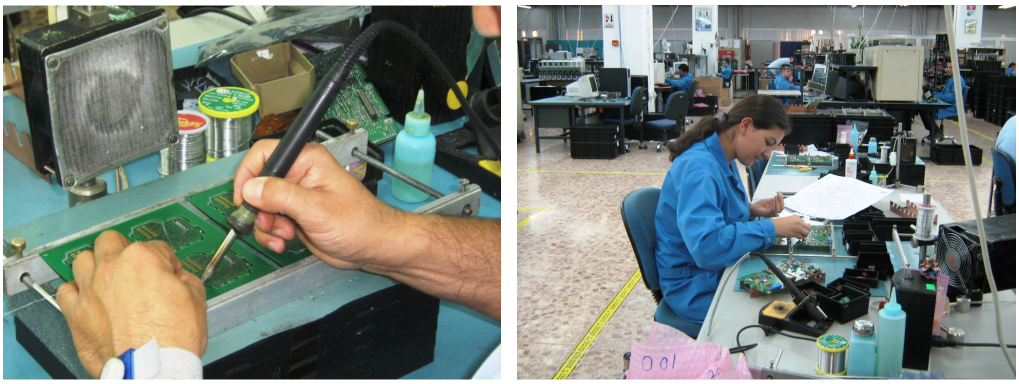


Figure 3.5. Hand soldering and hand mounting.

b) 500 lux

Illumination level of 500 lux is needed generally for the workspace areas of the building where most of the activities are conducted using a table and a PC.

For example in Production Engineering Department; all of the engineers use a PC as a tool to manage their works. In addition to this department, there are many engineers working in the departments other than Production Engineering, like test department. They also need a single PC to manage their test procedures. Therefore an illumination level of 500 lux is enough for this type of areas.

Furthermore there are a group of workers who are occupied with documentation process for a great part of their workflow process. 500 lux is a very appropriate illumination level for these people as well.

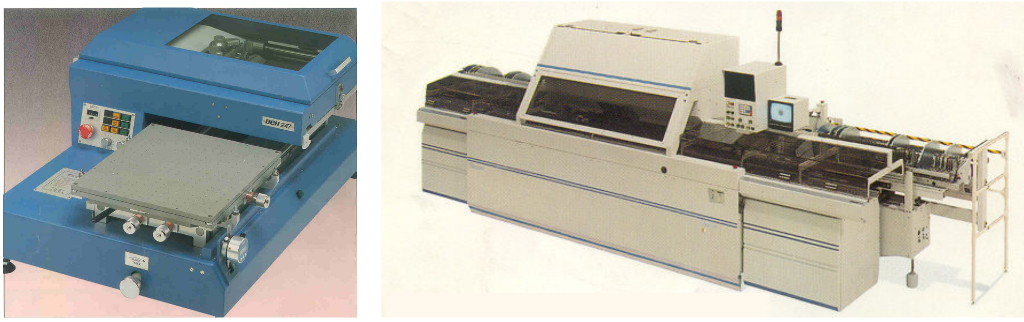
As the last example, can be given the workers whose responsibility is to program and run the production machines. Specifically, they manage these operations from a remote PC terminal; therefore this part of the process can be cited in this group.

c) 300 lux

The demand to meet today's electronic assembly production requirements forced the company to invest almost in every year for automatic or semi-automatic production machines. There are many reasons behind this trend; namely the need for faster and more precise production, the technological trends to use SMD components extensively to meet the increased production lot sizes, a demand for miniaturization of products, the respect and sensitivity to the environment. The machines are used almost in all departments of the production process.

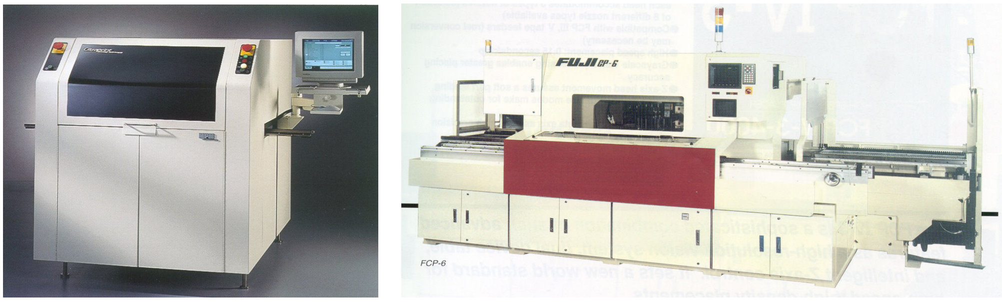
For example at Material Preparation Department, automatic and semi-automatic cable cut-and-strip machines, semi-automatic dispensers for painting and marking operations are used. In Cable Harnessing Department, precise semi-automatic cable cut-and-strip machines, and automatic cable harness test system.

In PCBA and SMD Production departments, automatic precise fine-pitch pick and placement machines, fast chip shooters, screen printing machines and semi-automatic light guided through hole component insertion equipment, and effective reflow soldering machines are used.



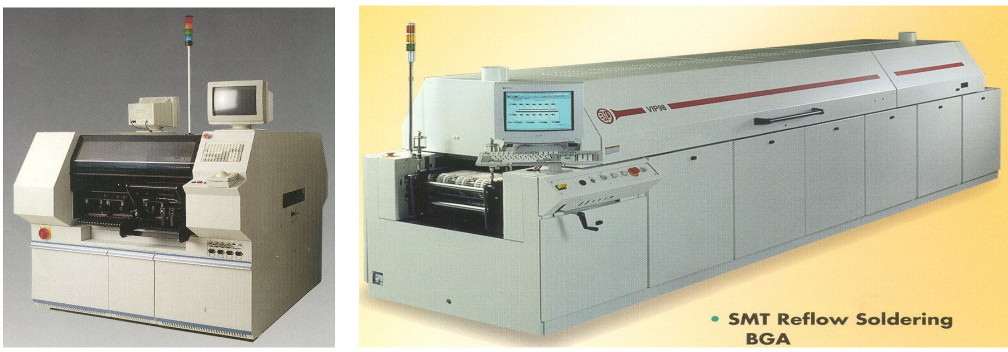
(a) (b)

Figure 3.6. (a) DEK 247 Semi-automatic dispenser (b) Universal 4785 HSP high-speed placer



(a) (b)

Figure 3.7. (a) MPM Ultraprint 2020 screen printer (b) Fuji CP-6 high-speed chip placer



(a) (b)

Figure 3.8. (a) Universal 4681 GSM1 multi functional fine-pitch placer (b) BTU forced-convection reflow soldering machine.

Ozone friendly automatic semi-aqueous board cleaning systems are used for the control purpose of the effectiveness of the cleaning process, an ionic contamination test equipment is used and conformity of the contamination level on the board surface to the standards is tested in the sample base.

In Test Department, Automated Board Test Systems are designed and built for computer automated operation, and operator’s role on test station performance is minimized by using such test stations.

In addition to the work spaces that employ automatic or semi-automatic machines; the circulation areas need an illumination level of 300 lux as well. Therefore circulation areas should also be cited in this group.

3.2 Method

Several steps of statistical analyses were followed to accomplish the study, namely, a sampling procedure, data compilation and evaluation.

3.2.1 The Sampling Procedure

First of all, a general survey was conducted among the biggest electronics industrial buildings in Ankara. The main concern was to find a place in which the most recent technology is used and therefore a continuing modification on the working areas is inevitable.

Then, a sample space was defined for the quantitative aspects of the study. This was an electronics manufacturing building. This particular building was selected because many different tasks are likely to occur on the same industrial building also general lighting is the preferred solution as it is the most practical system in coping with several different requirements economically.

The field survey was carried out in three main steps. First of all, structure and modification plans were obtained from the Construction and Maintenance Department of the company. Secondly, the detailed information about the building including the technical details about the machines were gathered from the engineers working in that production building. Lastly, purchasing dates of the machines were gathered from the Purchasing Department of the company.

The sampling procedure was based on the required illumination levels of specific working areas over the past years. For each year, a different illumination distribution is required and data is composed of these illumination levels.

3.2.2 Data Compilation

Data Compilation process had several steps which are summarized below:

The plans showing the modifications of this building were obtained from the Construction and Maintenance Department of the company. These plans were cross-checked with the departments to make sure that those changes had really been applied.

Information about the purchasing dates of the production machines was obtained, from the Purchasing Department of the company. Detailed information was gathered about the machines those had been purchased, from the departments using them.

Personnel occupation densities of the selected area were obtained for the whole period.

Using the information above; the selected area was subdivided into different areas according to the required illumination levels for each year. Required illumination levels were determined considering the specific work types over the total area according to each individual department defined previously.

The subdivision process mentioned above was represented on an empty architectural plan of this building. This step was repeated for each year.

Using these plans, areas were measured for each specific illumination level and these data were tabulated.

Table 3.1. Data on required illumination levels and total number of workers.

Year	Number of Workers	1000lux (m^2)	500lux (m^2)	300lux (m^2)
1987	746	1679	694	463
1988	668	1679	694	463
1989	621	1589	677	570
1990	440	1493	773	570
1991	351	1467	799	570
1992	421	1407	799	630
1993	365	1407	799	630
1994	360	1347	799	690
1995	316	1347	799	690
1996	309	1347	799	690
1997	384	1333	873	630
1998	394	1293	873	670
1999	401	1293	873	670
2000	376	1253	913	670
2001	304	1213	913	710
2002	291	1199	925	712
2003	253	1165	925	746
2004	203	1007	934	895
2005	201	965	934	937
2006	182	924	940	972
2007	220	813	948	1075
2008	229	813	948	1075
2009	217	813	948	1075

Table 3.2. Data for automatic and semi-automatic machine

	Automatic or Semi-automatic Machine	Width	Length	Area	Start Date	End Date
Printed Circuit Board and SMD Assemblies Department	Wave-soldering machine	2,50	22,00	55,00	1987	1989
	Wave-soldering machine	2,00	18,40	36,80	1989	2009
	Wave-soldering machine	1,90	6,60	12,54	1998	2009
	PCB Cleaning machine	2,00	4,00	8,00	1987	1991
	PCB Cleaning machine	1,60	6,80	10,88	1991	2009
	Reflow soldering machine	4,00	5,60	22,40	1989	2009
	SMD Machine pick & place	4,50	4,50	20,25	1989	1996
	SMD Machine pick & place	4,00	4,00	16,00	1992	1998
	SMD Machine pick & place	4,00	11,50	46,00	1996	2009
	Screen printer	4,00	4,20	16,80	1996	2009
	High speed chip placer	4,00	4,00	16,00	2009	2009
	High speed chip placer	4,00	4,00	16,00	2009	2009
	High speed chip placer	4,00	4,00	16,00	2009	2009
	High speed chip placer	4,00	4,00	16,00	2009	2009
	Fine pitch & placer	4,00	4,00	16,00	1998	2009
	X-RAY Inspection	4,00	4,00	16,00	2008	2009
	Optic Inspection	4,00	4,00	16,00	2007	2009
	Aging Cabinet	4,50	7,50	33,75	2000	2009
	Aging Cabinet	2,00	2,00	4,00	1988	2009
Test Department	ICCT (In-circuit test)	8,00	9,20	73,60	1989	2009
	Flying Probe	4,00	5,00	20,00	2009	2009
	Test System	1,00	2,00	2,00	2006	2009
	Test System	1,00	2,00	2,00	2006	2009
	Test System	1,00	2,00	2,00	2006	2009
	Test System	1,00	2,00	2,00	2006	2009
	Test System	1,00	2,00	2,00	2006	2009
	Robot Test System	4,00	4,00	16,00	2003	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Faraday Cabinet	2,00	2,00	4,00	1987	2009
	Aging Cabinet	2,80	2,80	7,84	1987	2008
	Aging Cabinet	2,80	2,80	7,84	1987	2008
	Aging Cabinet	2,80	2,80	7,84	1987	2009
	Aging Cabinet	2,80	2,80	7,84	1987	2009
	Aging Cabinet	2,00	2,00	4,00	1987	2009
	Aging Cabinet	2,00	2,00	4,00	1987	2008
PED	Kardex	5,00	8,00	40,00	1993	2009

3.2.3 Data Evaluation

Data compiled by the field survey was analyzed and evaluated for investigating the relation of the potential effectiveness of the lighting systems regarding time together with illumination levels needed for specific working areas.

The change in the sizes of the areas that needs various illuminance levels over past years was analyzed using graphically. The changes can be seen in the following graphs.

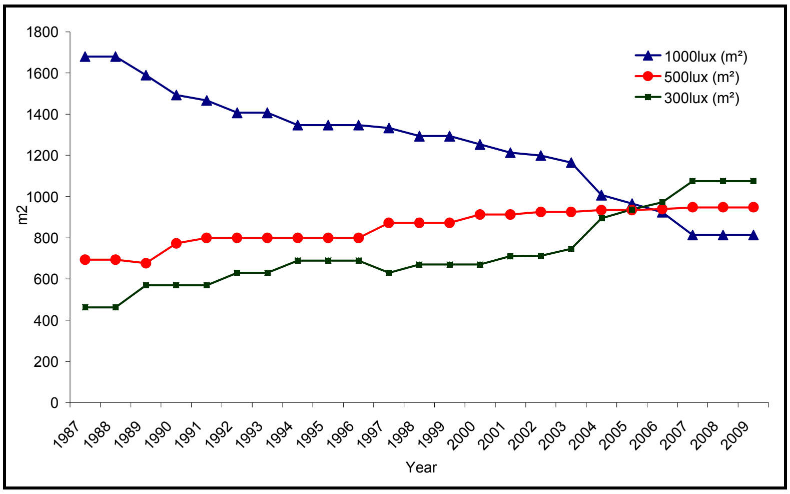


Figure 3.9. Changes in sizes of areas needing illuminance level of 1000 lux, 500 lux and 300 lux over past years.

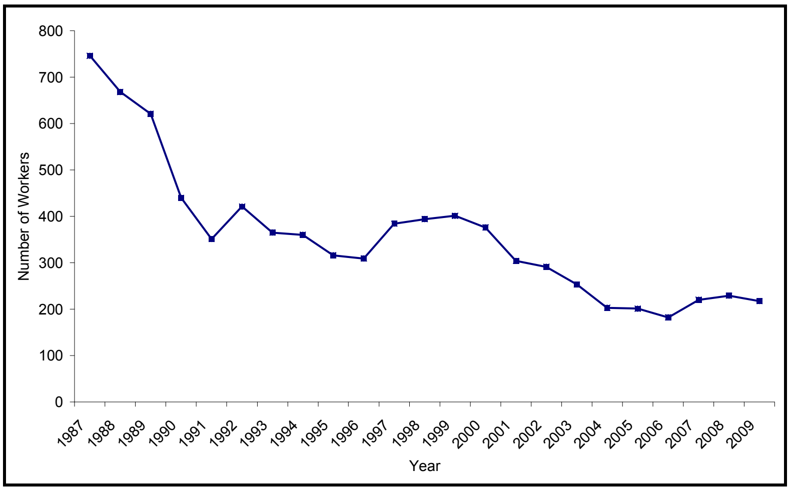


Figure 3.10. Changes in occupant population of the selected area over past years.

3.2.4 Calculation of Required Luminaires

Although the building has a lighting system composed of the same type of lamps and a constant illumination level over all of the working areas, an imaginary lighting system was assumed to be built and the calculations was based on the required illumination levels for specific working areas for the past 23 years of use. The required numbers of luminaires for a specified illumination level are calculated as follows:

Luminous flux (Φ) corresponding to the illuminance levels of 1000, 500 or 300 lux is calculated by the equation 2.1. In this calculation, the maintenance factor (MF) was assumed to be 1, because required maintenance is executed in a regular and periodic manner.

Applying equation 2.2 for the dimensions of the subject building, where *l* is 70m, *w* is 40.5 m, and *h* is 3.3 m, the room index found to be:

$$k = 7{,}78$$

In Table C.1, the highlighted column was chosen taking the pollution and usage factors into account. Then, by interpolation between the points of 7 and 8, the corresponding UF value was found to be;

$$UF = 0.61$$

Next, nominal lamp flux per luminaire (Φ_n) was calculated by the equation 2.3 as follows:

= 4 x 3250 lm (Philips TLD Xtreme Super 80 36W/840, Cold white)

= 13000 lm

Using the values above, Φ values for each average illuminance-lighting level (1000, 500 and 300 lux) were calculated.

Lastly, required number of 4x36W luminaires according to required illumination levels were calculated by equation 2.4 and tabulated as given below:

Table 3.3. Comparison of number of 4x36W luminaires for each required illumination level versus a constant 1000 lux illumination.

Year	Number of luminaires				
	Available Total	Required Illumination Level			
		1000 lux	500 lux	300 lux	Required Total
1987	358	212	22	9	243
1988	358	212	22	9	243
1989	358	201	22	11	234
1990	358	189	25	11	225
1991	358	185	26	11	222
1992	358	178	26	12	216
1993	358	178	26	12	216
1994	358	170	26	14	210
1995	358	170	26	14	210
1996	358	170	26	14	210
1997	358	169	28	12	209
1998	358	164	28	13	205
1999	358	164	28	13	205
2000	358	159	29	13	201
2001	358	153	29	14	196
2002	358	152	30	14	196
2003	358	147	30	15	192
2004	358	127	30	17	174
2005	358	122	30	18	170
2006	358	117	30	19	166
2007	358	103	30	21	154
2008	358	103	30	21	154
2009	358	103	30	21	154

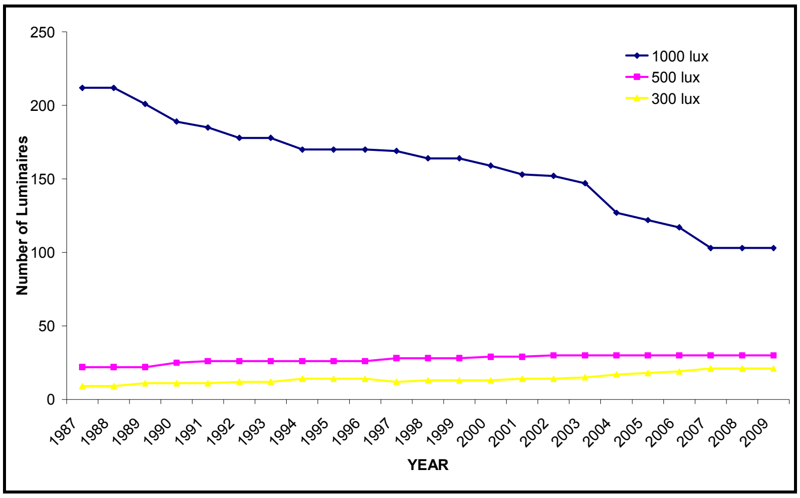


Figure 3.11. The changes in the required number of luminaires for different illumination levels over the past years.

3.2.5 Correlation and Regression Analyses

In the analyse here, three variables are employed. Based on the required number of luminaires for three different illumination levels, these variables are the number of each within the total number of luminaires for a specific workplace on the electronics manufacturing floor. The dependent variable is the number of 1000 lux luminaries whereas independent variables are those for 300 and 500 lux ones.

In the model of regression analysis; the following equation is applied for our specific case:

$$y = a + bx \tag{3.5}$$

In this equation, a is a constant and b is a variable. y represents the dependent variable and x represents the independent variables.

Student's t-test was applied at the end of this analysis to assure that the regression model is reasonable.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter are presented the results obtained from graphical analyse according to past years and required illumination levels together with a discussion of these according to literature and objectives.

4.1. Results

In order to extract a possible correlation between the number of luminaires for different illumination levels, data set was examined and plotted below. Figure 3.11 shows the changes in the values of luminaires for different illumination levels (1000, 500 and 300 lux), presented in a way to show the relation between 1000 lux and 500 lux; and 1000 lux and 300 lux.

In order to examine the effect of the number of luminaires at 300 and 500 lux on that for 1000 lux, correlation coefficients (r) were calculated and tabulated as below:

Table 4.1. Correlation coefficients of number of luminaires of 300, 500 or 1000 lux.

r	**300 lux**	**500 lux**	**1000 lux**
300 lux	1.00	0.95	-0.99
500 lux	0.95	1.00	-0.99
1000 lux	-0.99	-0.99	1.00

The number of luminaires at 300, 500 or 1000 lux are denoted as "300 lux", "500 lux" or "1000 lux" in the Table 4.1., above. To be seen from the correlation table, there is a strong negative correlation between the numbers of 1000 lux luminaires and 300 lux luminaires. The same relation is observed between 1000 lux luminaires and 500 lux luminaires as well.

In the regression analyse here, it was assumed that the dependent variable is the number of luminaires for 1000 lux and the independent variables are the number of luminaires for 300 and 500 lux. Our purpose was to extract a linear relationship, if exists, between the dependent variable and the independent ones. The hypotheses are defined as below:

H_0 : There is no linear relationship between the number of luminaires for 1000 lux and the number of luminaires for 500 lux and 300 lux.

H_1 : There is a linear relationship between the number of luminaires for 1000 lux and the number of luminaires for 500 lux and 300 lux.

Table 4.2. Results of Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	360.24	5.89		61.21	0.00
500 Lux	-3.96	0.29	-0.33	-13.48	0.00
300 Lux	-6.55	0.22	-0.72	-29.5	0.00

Table 4.3. Results of Regression Analyse

	Sum of Squares	df	Mean Square	F	Sig.
Regression	23,875.4	2	11,937.7	2,209.17	0.00
Residual	108.07	20	5.4		
Total	23,983.48	22	0		

Table 4.4. Results of Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.998	0.995	0.995	2.325

According to the results above, the following regression model is obtained:

$$y = 360.24 + \left(-3.96 \times X_{500}\right) + \left(-6.55 \times X_{300}\right) \qquad (4.1)$$

Where

y : Number of luminaires for 1000 lux

X_{500} : Number of luminaires for 500 lux

X_{300} : Number of luminaires for 300 lux

Regression Analysis results according to the equations above for the 1000 lux illumination level showed that the significance value is less than 0.05. Hence, there is a significant statistical decrease in the of number of luminaires for 1000 lux by the increase in number of luminaires for 300 or 500 lux. Moreover, this decrease can be explained to be resulted from the independent variable to a level of 99.5%.

The production capacity of the building was assumed to be constant for the past years. The occupant population and the equipment density was given in the previous figures.

Required illumination levels for this specific working area were much less than the overall general lighting scheme in place. While the required illumination level of 1000 lux decreases, 500 and 300 lux levels increased over the past years. Thus, it can be said that the total required illumination level of this specific building has decreased.

It was found that there is a meaningful relation between the number of luminaires for different illumination levels. Specifically, there was a statistically significant decrease in the number of 1000 lux luminaires according to the increase in these values for 300 and 500 lux. Since required illumination levels and number of luminaires are derived from the specific related working area types, results can therefore be interpreted according to these changes in the building. The result of the regression analysis can be interpreted in the following manner also: The working areas required for hand mounting, visual inspection and similar applications that needs an intense level of illumination decrease by increases in areas allocated for production equipment or office areas, where most of the activities are conducted using a table and a PC.

It was observed that the occupant population in the selected area decreased over the past years. This decrease can be correlated with the increase in the number and allocated area of production equipment. In other words, occupant population and allocated area of the production equipment were seen to be inversely proportional to each other.

4.2. Discussion

In this study, results could not be compared with the other studies of previous researches; because there was no such research related to the lighting schemes of electronics manufacturing buildings that proposes alternative lighting schemes for evolving production processes. However, the approach was very similar to the one of TU (1997) who made surveys that have revealed statically significant relationships between organizational workplace dynamics and building infrastructural flexibility for delivering the appropriate environmental and technical quality in offices. We were concentrated on the lighting schemes specifically to point out the relation between required illumination levels and the nature of the building in the sense of workplace types.

Results may guide further designers and researchers in following ways:

- In any electronics manufacturing building, or any structure which has similar evolving dynamics, the lighting schemes should be considered more carefully in the design phase.
- Total work spaces can be divided into zones and different lighting schemes can be employed for different areas at the design phase. By this way, there can be obtained more efficient lighting structures.

Although this study was carried out in only one electronics manufacturing building, it was demonstrated that changes in needs for illumination levels by the elapsed time seems to be common for any similar structure.

- It should be investigated whether or not it is possible to apply automated control of an existing general lighting structure. This control can be strengthened by the aid of state-of-the-art sensors to determine the exact need of illumination level for a specific work place.
- Further studies should be carried out to design smart lighting systems at the design phase of the building.

In this specific study it was seen that a general lighting structure had been capable of serving satisfactory illumination levels for this specific building’s workflow process.

However, it was observed that there had been a decrease on the total required illumination levels, as a result of the examined data. This decrease is so obvious that even at the end of the first year of the building, the required illumination level dropped by a remarkable amount.

Professionals, architects and electrical engineers therefore should become aware of the requirements on the illumination levels of a building and apply more intelligent solutions in lighting design. In addition, the reasons behind the need for intelligent solutions in lighting design, one of which was stated in this study, should be considered in more detail in order to achieve more efficient and economic lighting solutions.

CHAPTER 5

CONCLUSION

The lighting system in an industrial building has many different effects. It affects the health and mood of the workers, and therefore productivity. The efficiency of the overall system depends heavily on the effectiveness of the lighting system whose cost is the most remarkable one among all lifetime cost. In addition, its effects on environment have been proved to be extremely important.

The visual requirements for industrial work can show great variations. While some industrial work requires the extraction of countless visual information, typically involving the detection and identification of fine detail and fine differences in color, other types of industrial work require different forms of visual information, for example, shape and texture rather than detail and color. On the other hand, some other types of industrial work can be done with very little or no visual information. The materials from which visual information has to be extracted can be matte or specular in reflection; also the information can occur on many different planes, and the material containing the information can be moving or stationary. Moreover, the nature of the process may impose constraints on the type of lighting that can be used (e.g. where obstruction is extensive and where the atmosphere is hazardous, corrosive, or just plain dirty). The most suitable lighting condition is highly dependent on the context.

In spite of this variability, the objectives of industrial lighting are the same everywhere. These objectives are: to facilitate quick and accurate work, to contribute to the safety of the people doing the work and to create a comfortable visual environment. In order to apply these principles to an industry, an understanding of the information that needs to be obtained to do the work, where it is likely to be found and the constraints imposed by the application should be understood. Once this information is collected the necessary amount, distribution, and spectrum of light delivered can be determined.

Many industrial lighting systems are designed with a general/localized/task lighting approach. The localized lighting is employed where activity is intense (e.g. on an assembly line), and the task lighting is employed where tasks are critical and difficult. One form of task lighting that needs special care is lighting for visual inspection.

The best lighting conditions for visual inspection are very specific for each situation and this variability is the major problem. The performance of a visual search task is likely to be improved by a lighting system that increases the effective visual size, luminance contrast, or color difference of the item being sought. The same effect can be seen by a lighting system that makes the visual system more sensitive to differences in visual size, luminance contrast, or color differences. However, the specifics of such lighting depend critically on the area to be searched, what that area contains, and the luminous and color characteristics of the items in the area, including the defect. Finally, it is important that the complete visual inspection task involves a great deal more than just the ability to see the defect. Inspection is often done at a set speed, which limits the time available for searching, and once the defect has been detected there comes the decision as to what to do about it, a decision that is influenced by social, organizational, and psychological factors. Lighting has a part to play in visual inspection but it is a limited one. Other factors, such as, the time allowed to inspect the item and the manner of presentation, are also important.

It is important to target the proper light level to avoid underlighting, or overlighting when designing a work area. Overlighting not only wastes energy, but can reduce light quality, cause glare, increase error rates and strain employees' vision. Overlit spaces can have their lighting reduced by delamping or by installing reduced-output electronic ballasts and reduced-output lamps which automatically lower lamp operating levels. Simply delamping an area and adding reflectors tends to concentrate lighting directly downward, reducing the uniformity of light while reducing glare. This option is best used in combination with low-energy, task-specific lighting as it results in an overall loss of lighting. Industrial applications such as assembly work, inspection, and machine operations are likely candidates for delamping and task lighting solutions.

Light levels can be influenced by the desired reductions in error rates, by the age of the employee, by speed, accuracy, visual contrast needs and other factors. It is important to fit the light quality and color to the task.

This study dealt with the lighting systems used in the electronics production departments of electronics industry companies. Statistical part of the study was carried out in an electronics production building of an electronics company, in Ankara, Turkey. It was concentrated on the required illumination levels evolving in time, compared to the actual constant levels in order to provide feedback for architects and engineers from the effectiveness and efficiency points of view. According to the results of the examined data, it was found that there is a decrease on the total required illumination levels. Moreover, statistical correlations were observed between specific illuminance levels which are derived from the different working areas calculated for each year of the life-time of the subject building.

If following studies, including various similar buildings of other companies were done, similarities between the evolving needs for illumination for similar buildings would have been concluded. Other further studies may be related with electronics production buildings other than the subject building, to relate the similar results on the changing needs for illumination. Moreover, it may be investigated whether or not it is possible to design intelligent lighting systems that are capable of serving the changing needs of this type of structures.

This study demonstrated the tendency of required illumination levels in the lifetime of a production building by collecting data related to the required illumination levels. These results will be used by professionals who are interested in evaluating the effectiveness of their designs after they are in use. As it is expected, awareness about the effectiveness of the lighting systems should be constructed among those.

Once the correct light levels have been determined, the proper technology can be matched to the needs of the task and of the worker. In addition, people heading management and maintenance departments of similar buildings will become aware of these results. Those people may try to apply different approaches for more intelligent lighting systems. They will therefore concentrate on evaluating the changes in the need for illumination levels, and make the required modifications for more efficient and economic lighting systems.

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APPENDIX A

LUMINAIRE ARRANGEMENT AND TYPES OF LUMINAIRES IN THE ELECTRONICS INDUSTRY

Table A.1. Luminaire Arrangement and Types of Luminaires in the Electronics Industry according to FGL (2002)

		Luminaire arrangement and types of luminaire
Large details with high contrast	cable production, coating and impregnation of coils, assembly of large machines, galvanizing, simple assembly work, winding coils and armatures with heavy-duty wire.	Normal general-service lighting. In interiors with low to medium-high ceilings: continuous rows of luminaires for single fluorescent lamps. In high bays: specular reflector luminaires for fluorescent lamps or high-pressure lamps. At winding machines, stroboscopic effects must be avoided.
Medium-sized details with medium contrasts	assembly of telephone sets and small motors, winding of coils and armatures with medium-duty wire.	Workplace-oriented general service lighting provided by continuous rows of wide-angle or asymmetrical single-lamp specular reflector or plain reflector luminaires with louver enclosures. For ceiling illumination, it is advisable to use slotted or open-top luminaires to reduce reflected glare. In very dusty interiors, enclosed luminaires with specular optical controllers are recommended.
Small details with low contrasts	assembly of radio and television sets, production of fine wire-wound coils and safety fuses, regulating, inspection and calibrating operations.	Normal general-service lighting (1000 lux) provided by continuous rows of luminaires mounted parallel or perpendicular to assembly lines (depending on the main line of vision), General-service lighting (500 lux) provided by continuous rows of luminaires with supplementary continuous rows of low-level workplace-oriented luminaires. This solution provides more than 1000 lux at workplaces. Care should be taken to ensure that luminaires are shielded from eye contact.
Very small details with very low contrasts	micro-assembly of electronic components and subminiature parts.	General-service lighting (500-1000 lux) provided by continuous rows of plain or specular reflector luminaires with louver enclosures. Additional directional workplace lighting should be provided to raise illuminance to 1500-2000 lux and improve conditions for three-dimensional vision. For visual inspections of solder connections in printed circuits, light should be diffuse and as uniform as possible. Here, large-surface luminaires with opalescent enclosures should be used.

APPENDIX B

LIGHTING ISSUES REFERENCES

Table B.1. Lighting Issues References

Lighting issues	References	Website address
Quality / quantity	Illuminating Engineering Society of North America (IESNA)	http://www.iesna.org/
Product safety	Underwriters Laboratories (UL)	http://www.ul.com
Energy	American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)	http://www.ashrae.org/
	California Energy Commission (CEC)	http://www.energy.ca.gov/title24/index.html
Life safety	Building Officials and Code Administration (BOCA)	http://www.bocai.org/boca_codes.htm
Installation	National Electric Code (NEC)	http://www.nfpa.org/Codes/index.html
	National Electrical Contractors Association (NECA)	http://www.necanet.org/
Disposal	US EPA	http://www.epa.gov/epahome/rules.html#codified
	State agency	[references available on EPA website]
Document searches	National Standards Systems Network (NSSN)	http://www.nssn.org/
	Global Engineering Documents	http://global.ihsicom/

APPENDIX C

THE UTILIZATION FACTOR TABLE

Table C.1. Reduced working plane utilization factor table (Philips, 2008)

Room Index k	REFLECTANCES (%) FOR CEILING WALLS & WORKING PLANE										
	0,8				0,5				0,3		CEILING
	0,5		0,3		0,5		0,3		0,1	0,3	WALL
	0,3	0,1	0,3	0,1	0,3	0,1	0,3	0,1	0,3	0,1	FLOOR
	Utilisation Factor (UF)										
0,6	0.24	0,23	0,18	0,18	0,20	0,19	0,15	0,15	0,12	0,15	
0,8	0,31	0,29	0,24	0,23	0,25	0,24	0,20	0,19	0,16	0,17	
1	0,36	0,33	0,29	0,28	0,29	0,28	0,24	0,23	0,20	0,20	
1,25	0,41	0,38	0,34	0,32	0,33	0,31	0,28	0,27	0,24	0,24	
1,5	0,45	0,41	0,38	0,36	0,36	0,34	0,32	0,30	0,27	0,26	
2	0,51	0,46	0,45	0,41	0,41	0,38	0,37	0,35	0,31	0,30	
2,5	0,56	0,49	0,5	0,45	0,45	0,41	0,41	0,38	0,35	0,34	
3	0,59	0,52	0,54	0,48	0,47	0,43	0,43	0,40	0,38	0,36	
4	0,63	0,55	0,58	0,51	0,50	0,46	0,47	0,44	0,41	0,39	
5	0,66	0,57	0,62	0,54	0,53	0,48	0,50	0,46	0,44	0,40	
6	0,70	0,60	0,66	0,57	0,56	0,51	0,54	0,49	0,47	0,42	
7	0,73	0,62	0,7	0,6	0,59	0,53	0,57	0,52	0,50	0,44	
8	0,77	0,65	0,74	0,63	0,62	0,56	0,61	0,55	0,53	0,46	
9	0,80	0,67	0,78	0,66	0,65	0,58	0,64	0,58	0,56	0,48	

APPENDIX D

ARCHITECTURAL DRAWINGS OF MANUFACTURING FLOOR IN THE STUDY SAMPLE

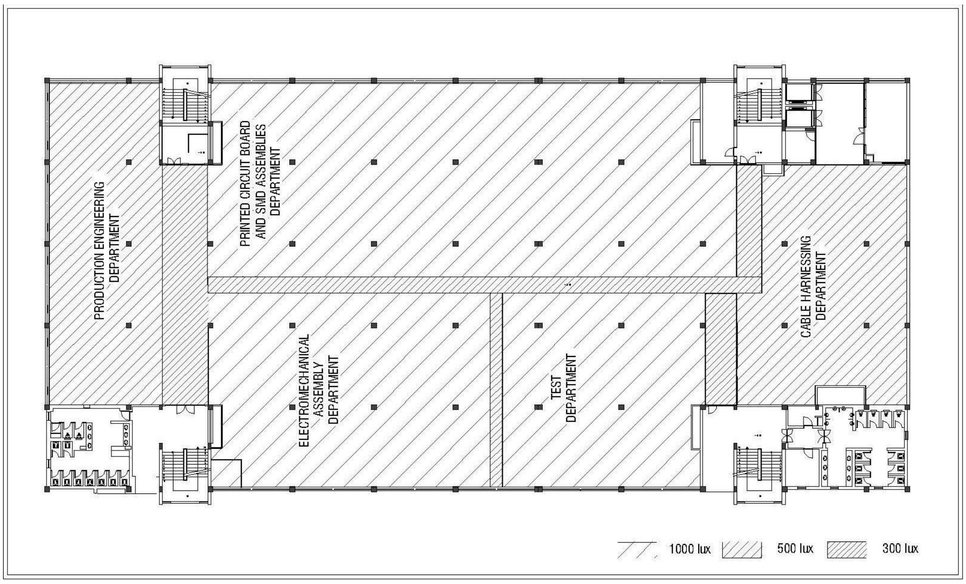

Figure D.1. Occupancy of the Manufacturing Floor between the years 1987-1988

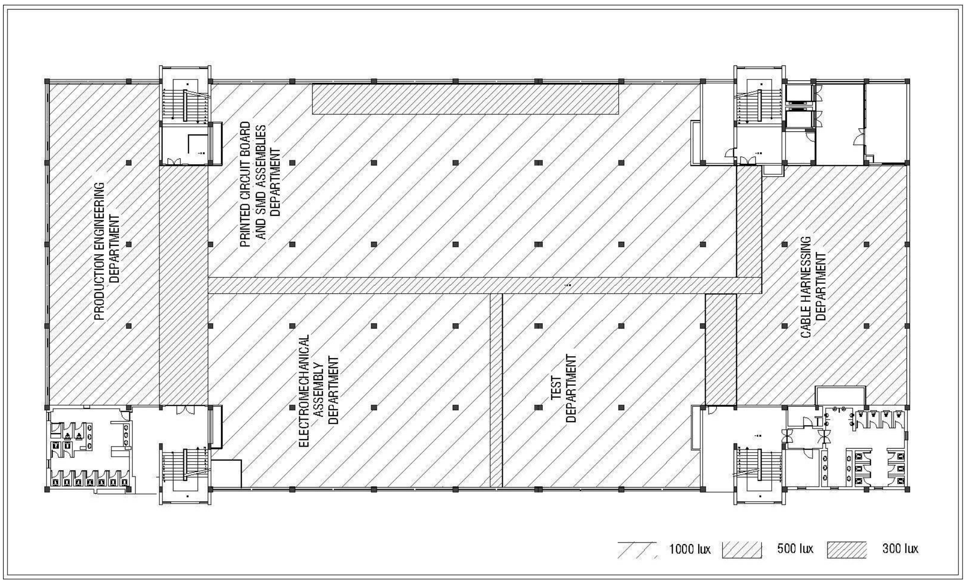

Figure D.2. Occupancy of the Manufacturing Floor in 1989

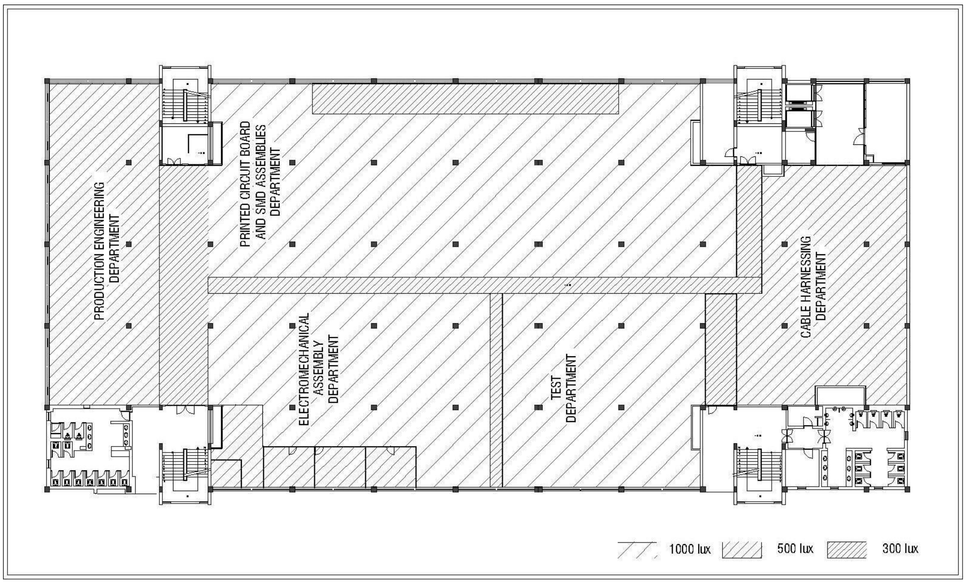

Figure D.3. Occupancy of the Manufacturing Floor in 1990

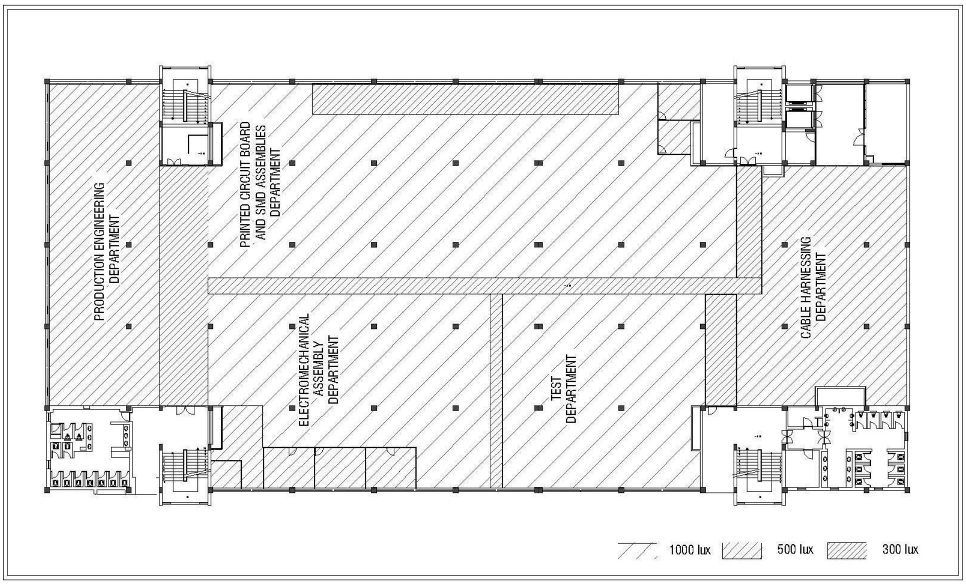

Figure D.4. Occupancy of the Manufacturing Floor in 1991

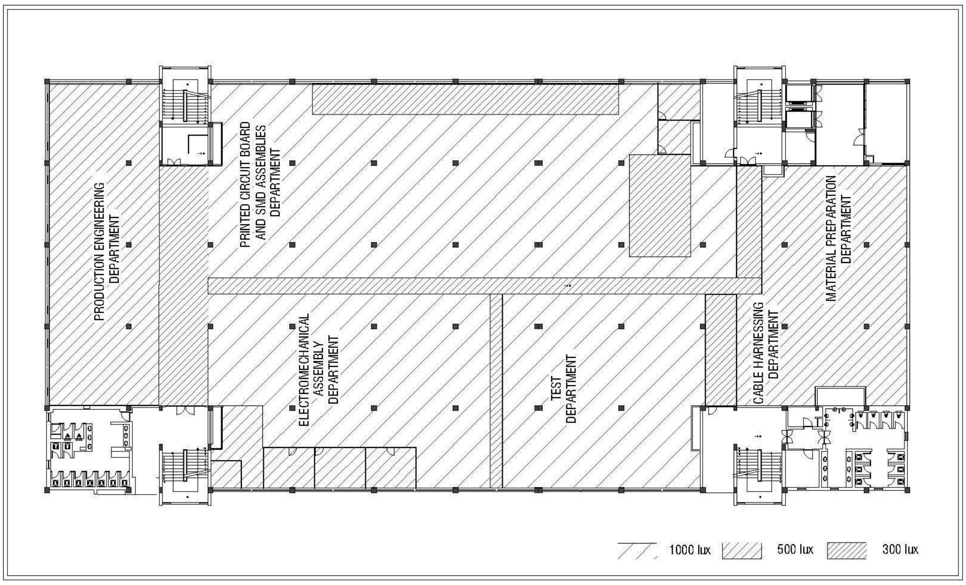

Figure D.5. Occupancy of the Manufacturing Floor between the years 1992-1993

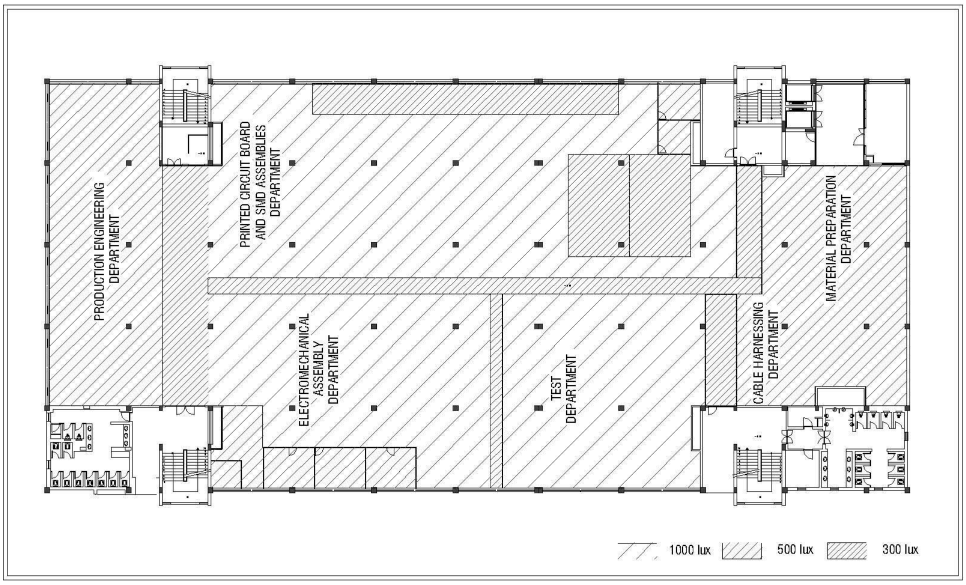

Figure D.6. Occupancy of the Manufacturing Floor between the years 1994-1996

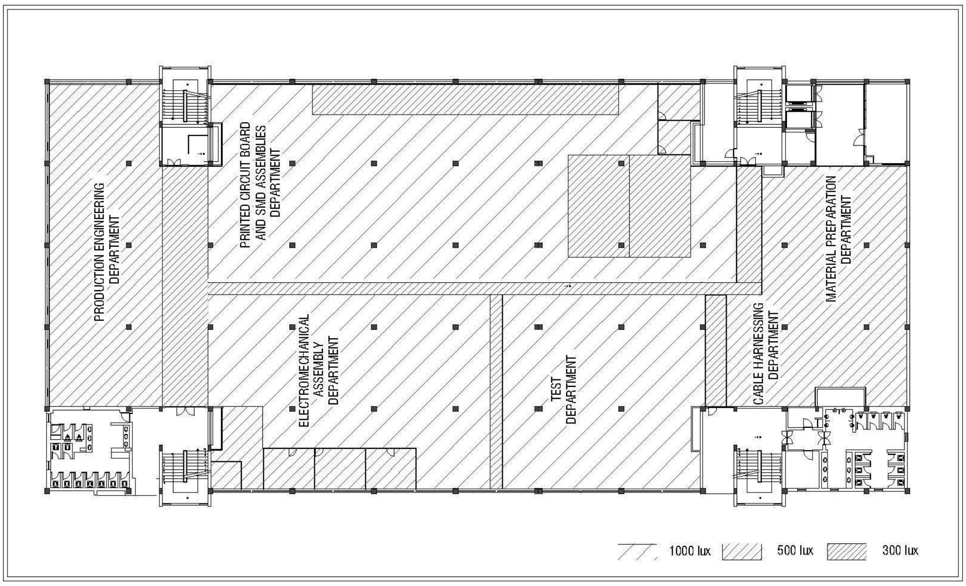

Figure D.7. Occupancy of the Manufacturing Floor in 1997

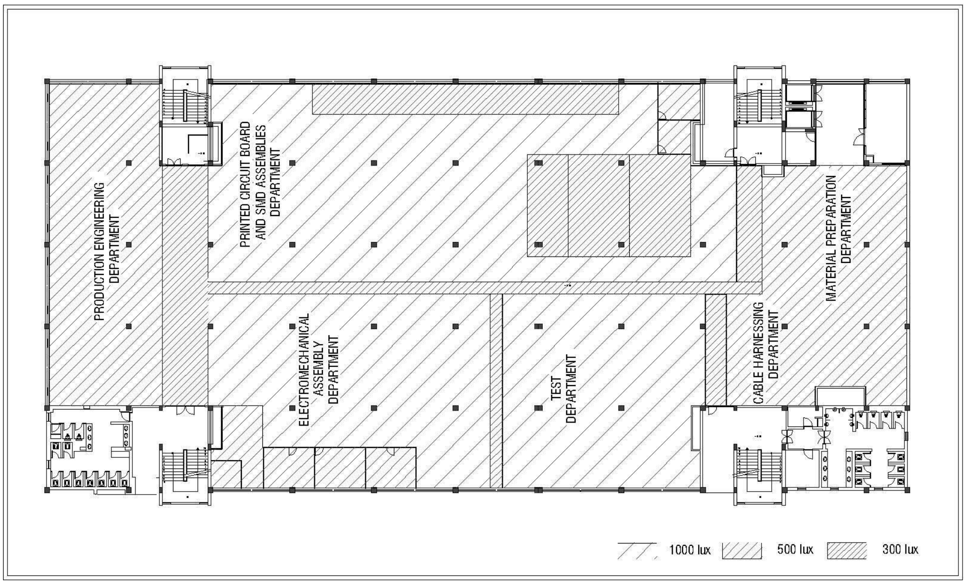

Figure D.8. Occupancy of the Manufacturing Floor between the years 1998-1999

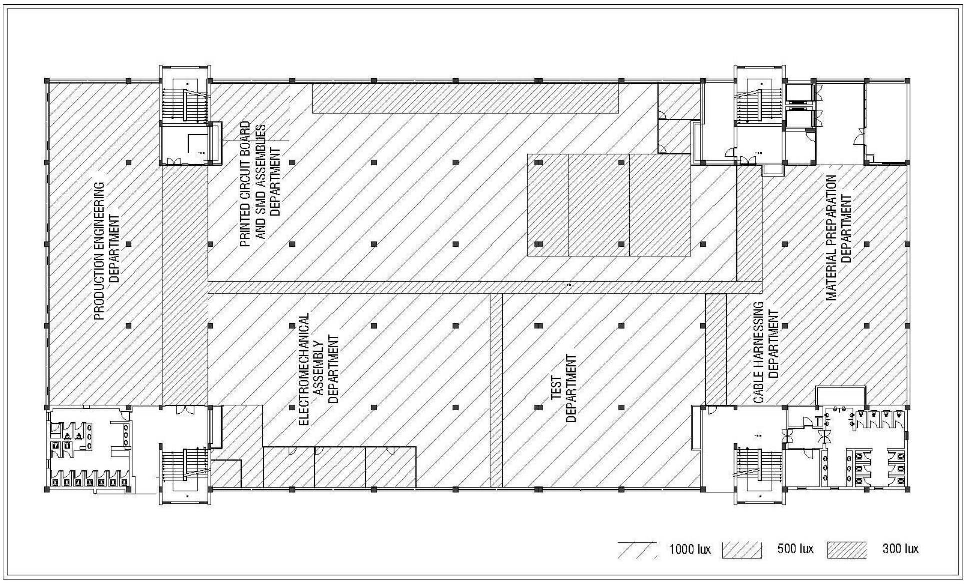

Figure D.9. Occupancy of the Manufacturing Floor in 2000

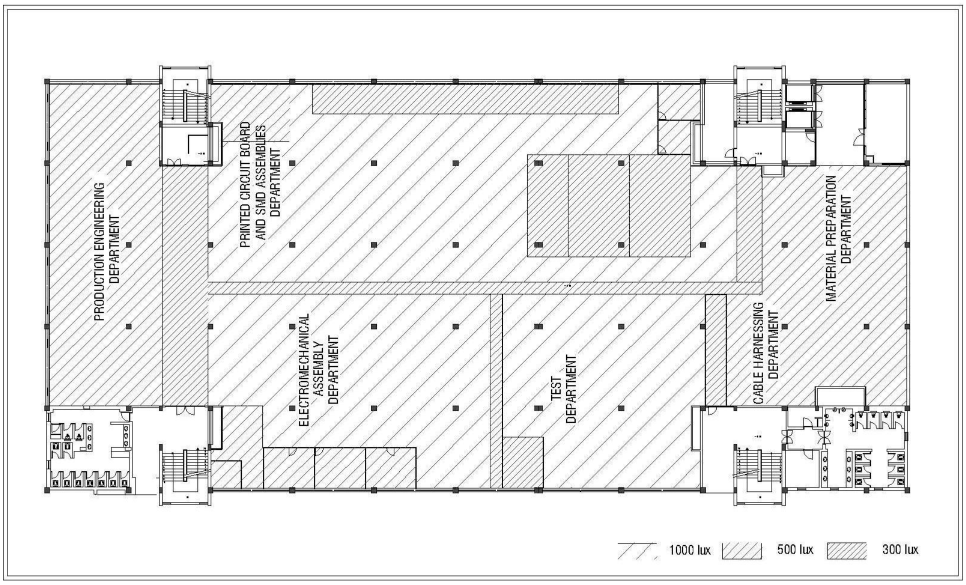

Figure D.10. Occupancy of the Manufacturing Floor in 2001

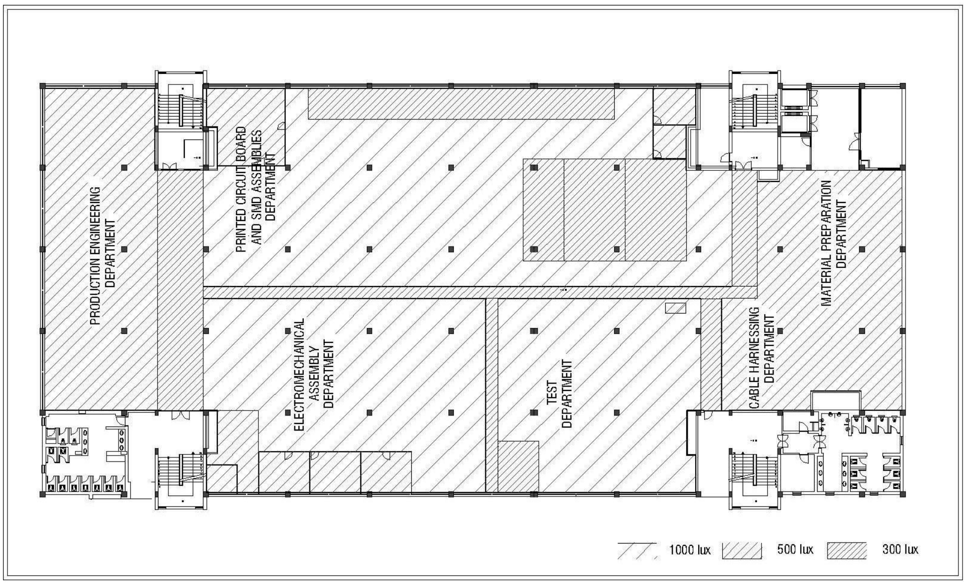

Figure D.11. Occupancy of the Manufacturing Floor in 2002

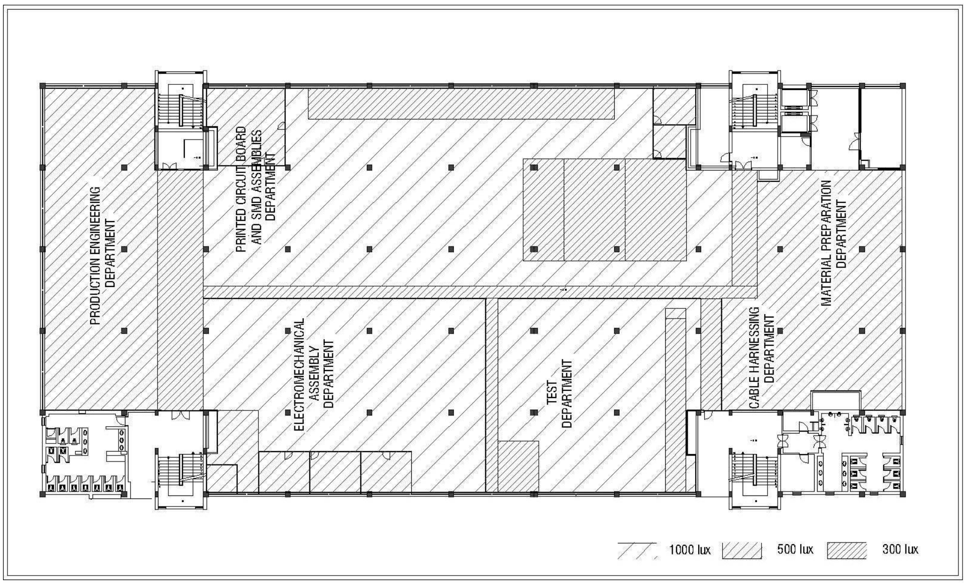

Figure D.12. Occupancy of the Manufacturing Floor in 2003

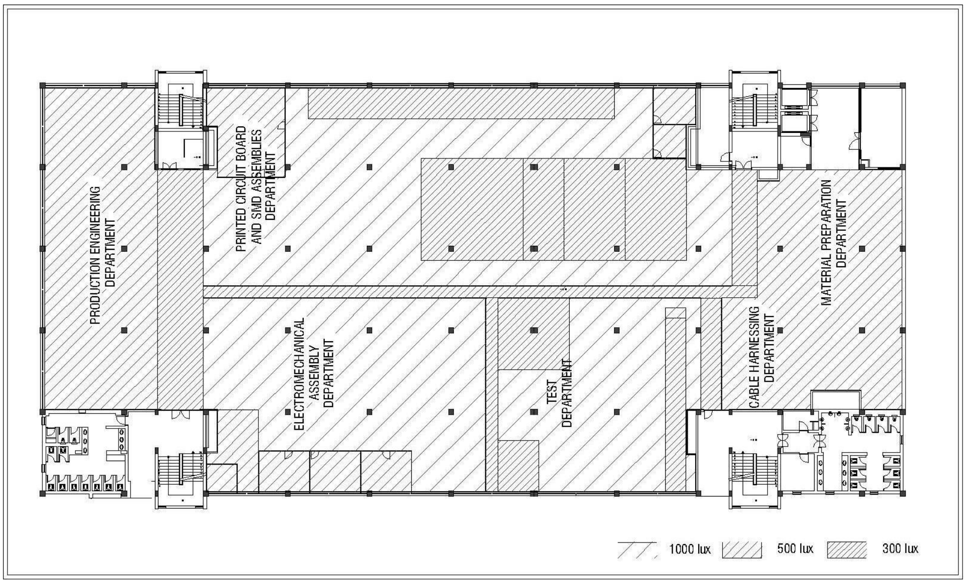

Figure D.13. Occupancy of the Manufacturing Floor in 2004

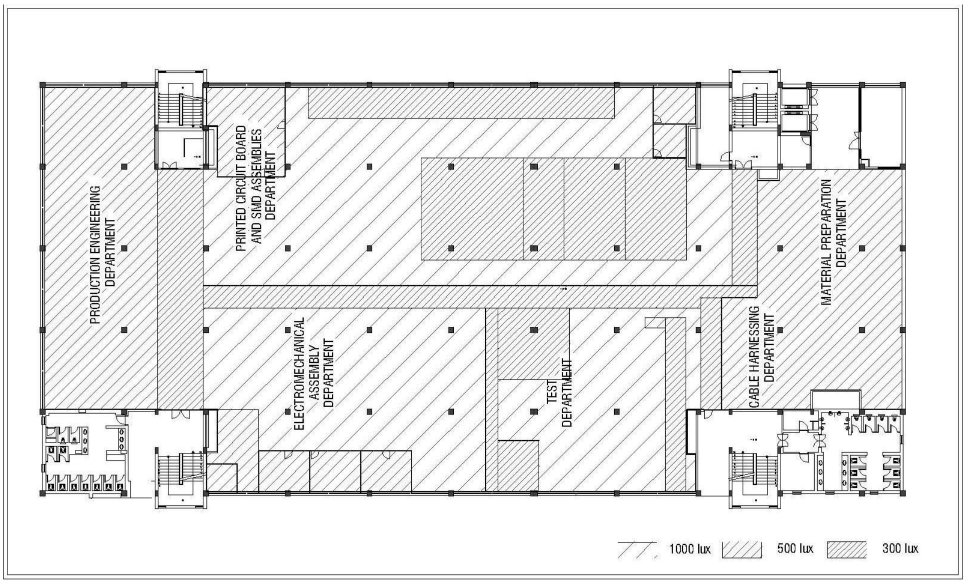

Figure D.14. Occupancy of the Manufacturing Floor in 2005

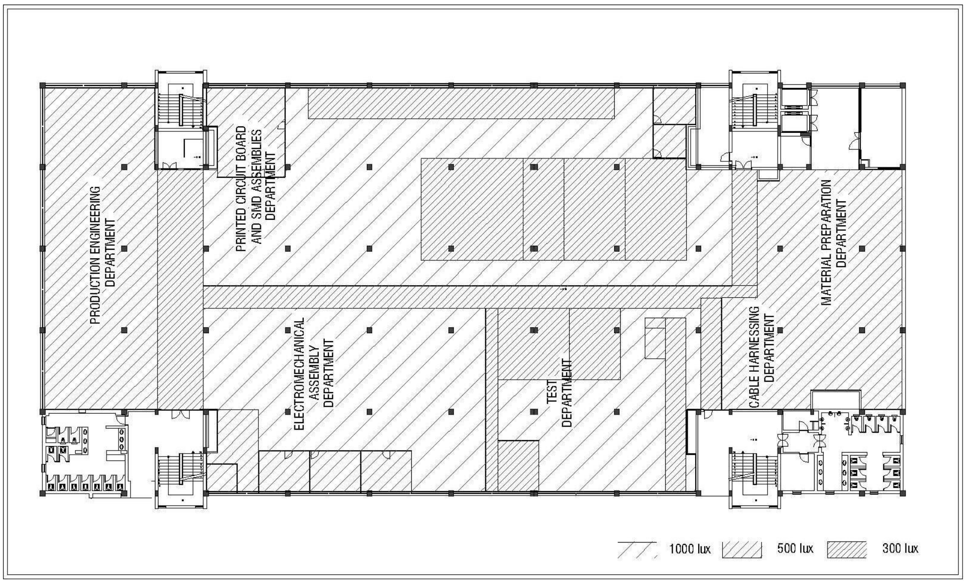

Figure D.15. Occupancy of the Manufacturing Floor in 2006

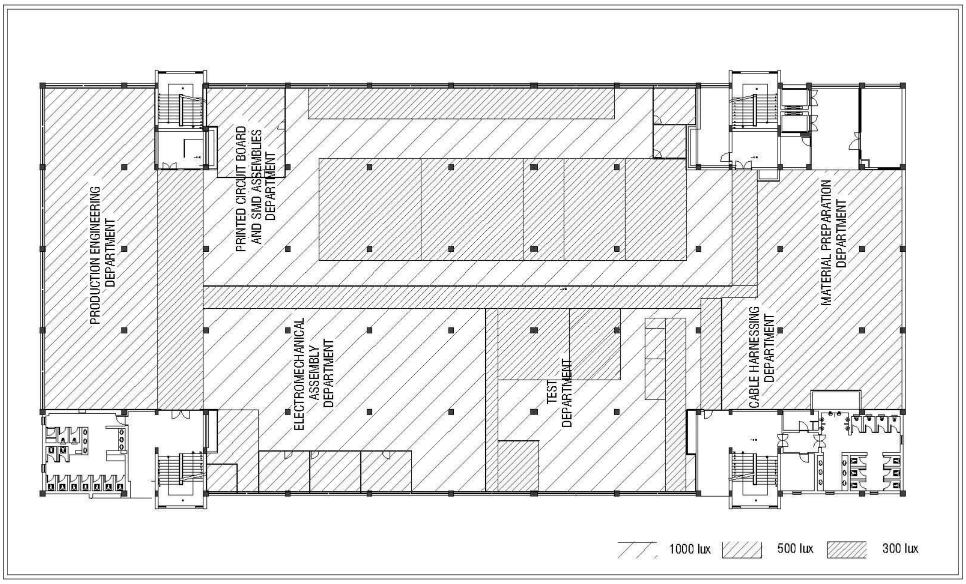

Figure D.16. Occupancy of the Manufacturing Floor between the years 2007-2009