Design-Management and Planning for Photovoltaic Cladding Systems within the UK Construction Industry.

An Optimal and Systematic Approach to Procurement and Installation of Building Integrated Photovoltaics – An Agenda for the 21st Century.

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Dedication

This thesis is dedicated to the following:

- The almighty God
- Members of my extended family
- The international Photovoltaic community
- All Photovoltaic technology enthusiast, world-wide.

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My profound gratitude goes to my supervisor Dr. Adrian Pitts and the entire staff of the School of Architecture, The University of Sheffield.

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Abstract

Integrated Definition for Functional Modelling (IDEF) methodology has been used in this research to capture the functional activities and processes as obtained within the UK Construction Industry, conventional Cladding Sector and The Building Integrated Photovoltaic (BIPV) cladding sector. This is hoped, would provide a framework for the optimal re-engineering of the design-management and installation planning of BIPV systems within the UK Construction Industry.

Interest in renewable energy has surged worldwide in the 1990's, despite continuing low International energy prices. The primary reason for this enhancement of interest include impressive technical advancement, environmental pressures, particularly climate change and broader sustainability concerns.

The integration of photovoltaic (PV) technology into the fabric of a building is seen as the most promising application of PV in many industrialised countries because of the design possibilities and the potential benefits of embedded electricity generation, (ETSU (1998(2)).

However, a major factor deterring the take-up of Building Integrated Photovoltaic (BIPV) cladding is the cost. A BIPV cladding system costs approximately £900/m^2, including Balance Of System (BOS) costs.

There are major efforts at R&D and manufacturing process levels to develop PV systems of suitable performance and a reduced overall cost for widespread deployment, Pearsall (1999).

There are substantial on-going researches in the areas of 'Device for solar energy capture', 'Integrated electronics power conditioning' and 'Balance of System' components development. Hitherto, very little has been undertaken in the area of design and installation process development and optimisation. The optimisation of design-management and planning processes, is hoped, would lead to: reduction in installation time, eliminating of non-valued added activities, improved quality and confidence in BIPV installation processes. These are intended to ensuring client satisfaction and also increasing the number of future projects.

The present research is therefore focused on the development of a rational integrated framework for design-management and planning activities for projects involving BIPV work package(s) within the UK construction industry. A proposed innovative design-management model is developed for construction activities aimed at encouraging integration. Optimally lean functions for BIPV installation procedures were determined. The prerequisite of this approach was the use of System Architect / Business Process Re-engineering (SA/BPR)

methodology, which supports IDEF (Integrated DEfinition for Functional) modelling techniques. SA/BPR methodology was used to tackle the arbitrariness in the design-management and planning process that was militate against effective and efficient integration. This research project starts by investigating and analysing the problems associated with existing-design-management processes and systems. The need to review and re-engineer the existing processes is client driven, (Latham (1994), Egan (1998)). The quest to develop an appropriate framework and architecture capable of integrating design, specification, estimation and planning processes, devoid of the arbitrariness found in existing processes and sub-processes is client centred and geared towards raising the aspiration of all those who might be involved with the project.

Evidence suggest that BIPV installation, design-management and planning processes can be more complex than conventional cladding installation. Against this background, a specification has been developed for a proposed 'decision support system/tool', intended to support design-management and planning of a BIPV façade and also system design choices and component selection. This research also contributes to the Best Practice Guide checklist of the design planning and installation of BIPV facades.
A review of the major renewable energy technologies was carried on in the first part of this thesis. Building procurement system and resource management and the UK cladding sector supply chain was dealt with in the second part of this thesis. Existing design-management and planning processes within the UK construction industry is reviewed and re-engineered in the third part of the thesis. Proposed innovative BIPV design-management and planning models are developed and tested, using IDEF methodology. The Sir Michael Latham and Sir John Egan's task force recommendations were used as a framework for the development process.

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Introduction

1.1 Background

Growing concerns for the world's dwindling natural resources and environmental pollution has stimulated the production of solar cell and photovoltaic panels for generating electricity in building as well as for other applications, Gyoh (1996).

The growth of electricity demand and site problem of large scale power generation plants require dispersed generation systems such as co-generation and renewable energy technology, Imanura (1998). Photovoltaic (PV) energy generation systems have great potentials in the world energy system and are currently largely installed form the environmental point of view. The building integrated photovoltaic (BIPV) system has been identified as the most promising route for the large-scale deployment of photovoltaic in Europe. Photovoltaic technology is the only electricity generating renewable energy technology that could be deployed on a large scale in urban areas, Toggweiler (1997). PV systems can be integrated into roofs, façade or shading structures on new or existing buildings, Gyoh (1996).

However, a major factor deterring the take-up of Building Integrated Photovoltaic (BIPV) cladding is the cost. A BIPV cladding system costs approximately £900/m^2, including Balance Of System (BOS) cost, NPAC (1999).

Desperate attempts are being made to reduce the overall cost of photovoltaic systems installation. Hitherto, much effort has been channelled towards product/material research and development, Pearsall (1999). Very little has been undertaken on process development. There is substantial on-going research, which can be categorised into four main domains, Pearsell (1999):

I. **Devices for solar energy capture:** I) Thin film PV cells electodoposition; ii) Dye sensitised organceramic nanocomposition PV cells, iii) GaSb/GaAs heterojunctions for thermophotovoltaic and solar cells, iv) CdTe/CdS solar cells development.

II. Electronic technology (network integration) Examples such as: I) integrated electronic power conditioning ii) Power-electronic network interfaces iii) a/c inverter design development and optimisation.

III. Building integration: I) Improved solar cell performance in building integration, using non-imaging optical concentrators and innovative temperature control methods for maintaining low operating temperature on building integrated photovoltaics, ii) Matching demand and supply for houses with PV roofs, iii) Development of electrical connection for roof integrated PV.

IV. Stand-alone systems*:* I) Battery change management for minimum cost PV system ii) Self – optimising tracker for small PV concentrators.

Whilst improvement in conversion and mass production efficiency can be expected in the next ten to twenty years; a substantial fraction of the cost of a BIPV system can be attributed to the installation produce. Within the context of this study, installation cost includes design, specification, and planning, estimating on-site installation and all associated hardware costs. Hitherto little has been published in terms of exploring the possibility of BIPV cost reduction via design-optimisation, planning and installation procedures.

It is widely accepted amongst construction professionals that effective design-management and planning functions conducted during the early stages of a project often have a significantly greater effect on the project outcome than efforts taken during actual project implementation, (Howes, R (1997), Palmer, H (1996), Griffth, A (1996)). The quest to improve project performance is now moving from the site to the office, (Thompson (1998), Anumba et al (1996), Franks (1998)). The integration of proliferated construction design-management and planning systems are heralding a possible means of improving efficiency in the industry (Latham (1994), Egan (1998)).

Earlier attempts to integrate application software in design-management merely linked various systems, ignoring the flaws within the existing processes, (Anumba (1996), Thompson (1997)). These systems were developed to mirror the proliferation of complex and fragmented functions within processes and sub-processes inherent in existing practices. Wasteful activities, duplication of function, rework and rediscovery of information are some of the shortcomings found within these processes.

The present research is therefore focused on the development of a rational integrated framework for design-management and planning activities for projects involving BIPV work package(s) within the UK construction industry. An Innovative design-management model is developed for construction activities aimed at encouraging integration. Optimally lean functions for BIPV installation procedures are determined and then super imposed on the integrated innovative design-management and planning model. The prerequisite of this approach is the use of System Architect / Business Process Re-engineering (SA/BPR) methodology, which supports IDEF (Integrated DEfinition for Functional) modelling techniques. SA/BPR methodology is used to tackle the arbitrariness in the design-management and planning process that was militate against effective and efficient integration. There is strong evidence to suggest that the UK BIPV sector, characterised by lack of standardisation, is more fragmented than the cladding and construction industry, (Oldach, R (1999) Gyoh (1996)).

This research project starts by investigating and analysing the problems associated with existing-design-management and planning processes or systems. The need to review and re-engineer the existing processes is client driven, (Latham (1994), Egan (1998)). The quest to develop an appropriate framework and architecture capable of integrating design, specification, estimation and planning processes, devoid of the arbitrariness found in existing processes and sub-processes is client centred and geared towards raising the aspiration of all those who might be involved with the project.

1.2 Scope of the Problem

Due to the nature of building integrated photovoltaic (BIPV) cladding systems, different procedures to normal conventional cladding procurement practices are used. BIPV system involves the introduction of additional functions and consultants in the design, specification and installation procedure. As a result, careful co-ordination of the activities of the cladding contractors, fabricators, installers, electrical contractors, photovoltaic specialist, and other interface work-package contractors is paramount to the outcome of BIPV projects. Mounting evidence of fragmentation, compartmentalisation and lack of standardisation in the UK BIPV sector further exacerbates the problem.

The call to develop effective design-management and installation process in this domain is primarily client driven. Architects, clients and developers, who took part in a survey conducted as part of this research, indicated that they would be more likely to opt for BIPV cladding if they had assurance in the following areas:

- Project delivery time-scale
- Project cost certainty
- Product quality assurance
- Reliable supply chain
- Appropriate procurement strategies
- Legal framework to support procurement method and complex nature of the BIPV work package (in terms of liability, responsibility and insurance)

Some of the fundamental problems facing the BIPV cladding sector, as identified by a survey carried out as part of this research, are as follows:

- No clear strategy, so far, has been adopted in satisfying the diverse and dynamic needs of client on a BIPV project
- Very little attempt has been made to effectively interface the BIPV sector with the cladding industry or indeed the construction industry as a whole.
- Poor interface between the activities of participants in BIPV projects. Case studies reveal a high degree of fragmentation and compartmentalisation within the sector.
- Vital authoritative information for the effective design and installation of BIPV systems are not readily available to the wider construction industry.
- Duplication of function, rediscovery of information, rework and redesign characterise the BIPV work package.
- Lack of a benchmarking against other industrial sectors. A clear absence of R& D in the in terms of installation process optimisation and lean functional determination within existing procedures.

- The problems have been further exacerbated by the lack of standardisation in the photovoltaic industry – manufacturer produce to different component standards, sizes and specifications.

The Banwell Report of 1964, identified certain key issues that have dogged the construction industry for decades, as follows:

- Insufficient regard paid to the importance of time and its proper use
- Clients seldom give enough attention to defining their own requirements at the start of a project
- Failure of the construction industry to satisfy the client's needs particularly in respect of the management of exceptionally large or complex projects.
- As the complexity of construction work increases, the need to form a design team at the outset, with all those participating in the design as full members, becomes vital

Most of these key problems continue to haunt the industry today. The perpetuation of these difficulties gave rise to Sir Michael Latham's report of 1994 and Sir John Egan's report of 1998. The terms of reference of Sir Michael Latham's report 'Construction the Team' was as following:

1. Current procurement and contractual arrangements
2. Current roles, responsibility and performance of participants, including clients with regard to the following:
   - the process by which clients requirements are established
   - methods of procurement
   - Responsibility for the production, management and development of design.
   - Organisation and management of the construction process.

Latham's report contains the famous phrase: 'the time to choose has arrived; the construction process cannot wait 30 years for another Banwell or 50 years for another Simon', Latham, (1994). The report 'Constructing the Team' made 30 recommendation, which have been summarised as follows:

- A check list for design responsibilities should be prepared
- Use of co-ordinated project information should be a contract requirement
- Design responsibilities in building services engineering should be clearly defined.
- Tender should be evaluated by client on quality as well as price
- A target of 30% real cost reduction should be achieved by the year 2000
- Clients should set up a new construction client's forum to provide them with a single/strong voice.

The Sir John Egan's task force's report 'Re-thinking Construction,' published in 1998, states that: the UK construction industry at its best is excellent. The report goes on emphasise that the UK construction industry's capability to deliver the most difficult and innovative projects matches that of any other construction industry in the world. Egan praised the engineering ingenuity and design flair that are renowned both at home and overseas.

However, Egan's task force expressed deep concern that the industry as a whole is under achieving. The task force identified the reasons responsible for the industry's shortcomings as follows:

- Far too many clients are dissatisfied with the overall performance of the industry.
- The industry invests too little in R&D
- Good specification and best practice are factors that would encourage better and more efficient construction, in terms of quality and customer satisfaction; timeliness in project delivery and value for money.
- The task force encouraged increasing interest in tools and techniques for improving efficiency and quality- borrowed form other industries.

Sir John Egan's task force report to the Department of Environment Transport and Regions (DETR) identified the follow areas for improvement:

- The industry thinks more about the next employer in the contractual chain than about customers needs and makes no attempt to raise customer aspirations.

- The industry too often sees a project as a series of sequential and largely separate operations undertaken by individual designers, contractors and suppliers, who have no stake in the long-term success of the project and no real commitment.
- Too much talent is wasted, particularly through the failure to recognise the significant contribution that suppliers can make to innovation.

Egan's task force calls for a major change in the culture of the UK construction industry. A summary of the recommendations of the Egan's task force is as follows:

- Develop construction performance indicators to measure progress.
- Reduction on reliance on tendering and contracts, and a move towards partnering as a way forward.
- Increase in the involvement of subcontractors in the areas of design and project management
- Improve health and safety conditions for those who work in the industry
- Minimise waste in all areas.

The DETR construction best practice initiative is a direct consequence of the Latham and Egan recommendations. The Best Practice initiative intended to encourage construction-related organisations achieve greater efficiencies through improved knowledge and change in possible detrimental business practices. The DETR and the construction round table (CRT) client forum demonstration project initiative will form the centrepiece of the newly launched construction activity Best Practice Programme (BPP). These projects represent a £1billion of construction activity. The CRT construction client forum has a collective construction turn over of over £8.5 billion per year. The Movement for Innovation Board (MIB) a wider corporate client forum has a collective turn-over of £50 billion per year. The drive and demand from these newly formed client groups cannot be ignored. These developments are bound to change the landscape of the construction industry and set a new agenda for the 21st century.

Rethinking Construction (1998) – Egan's task force has set the following targets for the UK construction industry to be achieved by the year 2000.

- Reduction in capital cost by 10%
- Cut construction time from, client's approval to practical completion by 10%.
- Increase the number of projects completed on time and to cost by 20%
- Increase value-added productivity (per head) by 10%
- Cut back on reportable accidents by 20%

The present work is obviously undertaken within the framework of the Latham and Egan recommendations and involves the development of an optimum and systematic approach to design-management and planning processes for BIPV cladding systems within the UK construction industry.

1.3 Rationale

The Inter governmental Panel on Climate Change (IPCC), which provides scientific advice to government, has stated that a 60-80% cut in emission of greenhouse gases is needed to avert the worst effects of climate changes. The 1992 Rio de Jeneiro UN conference confirmed the urgent need for major changes in the worlds energy system – hence Agenda 21 advocating new polices and programs.

Energy consumption in buildings lie behind at least 50% of CO_2 released in the atmosphere (300 million tonnes of CO_2). By the year 2000, the UK is projected to produce 30% more CO_2 than the 1990 figures if fossil fuel continues to the used at the same rate, (Greenpeace (1996), Smith I (1999)).

In London the commercial sector uses up 25% of the city's energy, producing 30% of its CO_2 emission, yet every half-hour the earth receives enough energy from the sun energy to power humankind's activities for a whole year, Greenpeace (1996).

The current argument for photovoltaics hinges on offsetting anthropogenic emission of CO_2 and CFC gases – as opposed to providing a cheap alternative to fossil fuel power generation. Each square meter of PV installed on a building in the UK will displace one tonne of carbon dioxide in its lifetime. The UK Government is committed to 20% reduction in green-house gases over 10 years, (DTI (1998), Smith I

(1999)). Under the current regime of construction regulation and practices there does not seem much chance of getting anywhere near this target. When it becomes evident that the drive to cut greenhouse gases on this scale is failing' the construction industry is likely to receive more than its far share of the blame. Against the background, the Chartered Institute of Building (CIOB) and the British Research Establishment (BRE) has issued a compendium of reports on waste reduction, environmental management systems and on how partnering based on the Latham model promotes environmental improvement and sustainability.

Two-thirds of the UK's current electricity production could be generated using photovoltaics, despite Britain's cloudy weather, if PV is deployed wholesale to homes and offices, Greenpeace (1996). PV can replace building materials for such as facades and roofs. Commercial building peak-electricity demand is between 9am-5pm. This corresponds with PV peak power generation period. A typical PV façade could generate up to 30% of annual electricity requirement of a commercial building. A huge market opportunity exists for PV in the UK, where 2 million square meters of new commercial and industrial roofing are built each year, Greenpeace (1996).

The photovoltaic manufacturing industry is about 25 years old. Sales are growing at an impressive rate of around 15% per year. The industry is poised for a dramatic growth in production capacity and is ripe for alliances with other industries. During the past two decades module prices have steadily decreased, reliability has improved and components are being certified to international standards, thereby easing the acceptance, Johansson, T (ed)(1995).

Electrical contractor and inspector training are underway and utility customers' service staff are beginning to learn about photovoltaics. Rules and standards for grid connection are being developed. The industry is beginning to turn towards profitability. The photovoltaic power systems business appears to be evolving from a market development and education emphasis to that of sustainable profitability.

While photovoltaics are a value-based technology with a large potential market at current prices, they must still become more cost competitive. In a price-sensitive market such as the UK, PV would benefit from value-based product differentiation and the ability to meet customer demands. Furthermore, BIPV offers architects new opportunities for creating design at the cutting edge of clean and sustainable energy technology.

To achieve the necessary level of price reduction in building integrated photovoltaic (BIPV) installations, technical improvements and a substantial increase in PV module production are required. However, these are necessary but not sufficient as a substantial part of the cost is involved in the installation procedure. BIPV installation procurement systems require new business approaches and structure to further reduce cost, installation time and significantly improve the quality of the product as well as client satisfaction.

1.4 Aims

The aim of this research is to develop a practical, persuasive and conceptual framework to integrate design-management and planning activities of building integrated photovoltaic systems procurement and installation. The IDEF methodology is used to determine optimal BIPV function, which is then superimposed on an innovative integrated design-management and planning model to facilitate the co-ordination and communication of information within the processes. This is all channelled towards:

- Providing a Best Practice Guide for Design-management and planning of BIPV installation within the UK construction industry.
- Providing a checklist for the design, planning and installation of BIPV systems – aimed at clients, designers and contractors.
- Providing a framework for the development of a multiple decision support system (DSS) that would feed into a central repository.
- Providing a specification for the implementation of an interactive object based decision support system for the design-management and control of BIPV cladding projects.

Within the context of this research, the objectives are the means by which the aims are achieved. Based on the critical analysis of the scope of the problem in this research, the following objectives are drawn form the aims of this work.

1.5 Objectives

The main objectives of this research are:

- To carry out process re-engineering for integration of design-management activities which incorporate design, planning and cost estimating functions.
- To develop integrated information models to support the re-engineering process.
- To determine optimal functions and processes, thereby reducing overall installation cost and time. This would encourage lean construction/installation by eliminating non-value-added activities.
- To tailor clients' requirements to project objectives, thereby ensuring client satisfaction and confidence in BIPV projects.
- To identify problems, constraints and limitation - minimising duplication of functions and rediscovery of information.

1.6 Methodology

The work commences with a comprehensive literature review aimed at acquainting the reader with the current situation and prevailing arguments with regard to technical and non-technical issues. This is intended to highlighting the key issues in the debate. A major question that has emerged is "How can cost reduction be achieved to made PV more competitive". The International Energy Agency challenge set up the agenda in tasks as follows:

Task I – deals with the exchange and dissemination of information on photovoltaic power systems (PVPS). Task III- is concerned with the use of photovoltaic power system in stand-alone PV installations. Task V deals with grid connection of building integrated and other dispersed PVPS. Task VI focuses on the design and operation of modular photovoltaic system. Task VII, which is the domain of this research, is concerned with Photovoltaic in the Built Environment. Task VII concludes that- in order successfully to achieve market implementation, a number of consecutive actions are required:

- Further cost reductions in improvement of the economics of BIPV
- Enhancement of the technical and architectural quality of BIPV
- Assessment and removal of non-technical barriers
- Encourage demonstration and dissemination of BIPV projects

A questionnaire survey followed with personal interview techniques used for wide consultation of construction professional. Construction professionals who have had experience with BIPV projects as well as those who indicated an interest should the opportunity arise took part in the survey. The main line of enquiry was: What sort of information would participants require to perform their traditional duties in a construction project and: Who's responsibility it might be to provide such information and: at what stage would it be required. They were also asked to point out any anticipated problems or suggestions to BIPV installation procedures. The consultants foresaw safety, risk management, liability and insurance matters as potential problem under the current supply chain and procurement regime, Pitts and Gyoh (1996).

Three UK based BIPV installation case studies were carried out. The case studies were used as a platform to expose current practices in terms of function and process determination in design-management and planning. This information was captured and expressed in IDEF0 functional modes and IDEF3 process models. The IDEF0 functional model is a prerequisite for the optimisation and re-engineering of existing practices. Based on the outcome of the 'AS IS' models an innovative rational design-management and planning model was developed for BIPV projects.

The IDEF0 functional model served as a central piece in the analysis and documentation of the processes and functional activities. Key functional activities were analysed to identify:

- Key inputs and outputs
- Resources and mechanisms used to perform activitives
- Factors that regulate activity
- Build a consensus and identify activities with high potential for improvement.

The IDEF3 process models take the knowledge captured in IDEF0 and supplement it with UK based BIPV project case study of how the process works. This was used to produce a reasonably accurate and robust process scenario, which fed directly into the simulation environment SA/BPR.

The IDEF3 modelling technique was used to model how the processes work; 'capture timing' and 'decision logic'; and also to provide realistic models for simulation. IDEF0 and IDEF3 were used to manage the complex models through multiple levels of abstraction and decomposition.

In the quest to achieve the research objectives, the methodology for the major works undertaken during the research were as follows:

1 An overview of the design-management domain in relation to the entire construction project structure was undertaken to gain a full understanding of the various functions, the participants involved and the information requirement of the various functions. The effect of the functions in design-management over the overall project examined in chapter 9. The main design-management activities were analysed, and the methods used to procure project were also examined in chapter 6 with the prime notion of outlining their strength, weakness, opportunities for improvement and the threat of these methods to the achievement of full integration in this domain.

2 An overview of the design-management processes was undertaken in order to gain a thorough understanding of the functions, information flow and the problems associated with these processes (chapter 9). The various methods used to analyse and present the problem domains and the means to effect changes were also critically examined in chapter 9 and 10.

3 After the review of the design-management process, a critical analysis of the problem domain was undertaken and the methods to provide radical and innovative changes to these problems were also analysed. A new approach based on Business Process Re-engineering methodology was used to perform the requisite changes in the design-management processes (chapter 10). Analysis of

the methods to ascertain the level of improvement of the innovative process was undertaken. An approach, which focused on the Process Based Costing Engineering, was used as a means of benchmarking the performance and the advantages of the process was also analysed. In an effort to effectively handle the cost drivers in the proposed Process Based Costing Engineering approach a cost model framework capable of handling the lapse in the duration of processes was developed. This provided the means to handle this process quickly and efficiently with a better understanding (chapter 10).

An experimental project – based testing of the innovative processes in design-management using a developed Process-Based Costing framework and SA-BPR CASE tool. The results showed cost and time saving of 20% and 25% respectively, as compared with the more traditional approach (Appendix)

1.7 Main Conclusions

One of the reasons for this research stems from the fact that existing tools and techniques and current integrated systems and methods for design-management processes developed so far still have inherent limitations and do not allow effective sharing of common information in this domain. In a quest to find solution to these problems, it was necessary to identify the factors that have militated against rational integration in the design management processes. The process of finding solution to the problems brought about the following achievements, which have contributed to knowledge and are grouped into three main parts. The first part of the achievement is on the re-engineering of design-management processes, which incorporate design, project planning/scheduling and cost estimating. This approach virtually removed the arbitrariness in existing processes, which include ridge functional barriers and nose-on-tail sequences. In addition to elimination of duplication of functions commonly found in the traditional approach, the research provided the vital platform for information sharing in this domain. The second part of the achievement is the development of integrated information model to support the re-engineering processes. The third part is the optimal BIPV installation functional determination and the superimposition of the optimal functions on the rational innovative model - based on the Latham and Egan models as well as the results of the survey and BIPV case study analysis (appendix).

1.8 Outcome

Some of the main achievement of this work in terms of design-management, planning and installation of BIPV work-package within a wider construction project have been:

- Reduction of installation time
- Improved product quality by ensuring client satisfaction
- Shorting procurement time
- Optimising installation procedure
- Minimise non-value added activities
- Minimise duplication of function and rediscovery of information
- Facilitate informed decision making by all involved in the procurement process.
- Best practice guide, which also serve as a framework for the development of a decision support system that feeds into a central repository.

1.9 Thesis Structure

This section provides a guide to this thesis. This thesis consists of eleven chapters, which can be summarised as follows:

Chapter One: chapter one contains the introduction. It gives a background to the issues. It also includes a descriptive introduction to the scope of the problem, rationale, aims, objectives, methodology, main achievement, outcome and the thesis structure.

Chapter Two: the analysis of the history of energy use and a review of renewable energy technologies is dealt with in chapter two. This chapter reviews the potential of some of the major mature renewable energy technologies.

Chapter Three: chapter three contains a review of photovoltaic power sytems and system design options available to designers, client, and their advisers. This would enable BIPV project consultant adequately match system design options with individual project objective / client requirement throughout the design-management process.

Chapter Four: chapter four contains a reviews photovoltaic module typologies and possible array configuration. Like in chapter three, this information would enable designer mitigate the adverse effect of individual site constrain during the design and installation phase. The various configuration possibilities discussed in chapter four could provide the solution in a cost engineering or value engineering exercise during the design-management process.

Chapter Five: photovoltaic installation and maintenance techniques, functions and procedures is dealt with in chapter five. This chapter also highlights some of the critical issues that need to be considered at various stages and some of the limitations as currently experienced in the UK in this domain.

Chapter Six: chapter six contains a review of the UK cladding industry, it's structure, supply chain and procurement strategies. This chapter also reviews the strength, weakness, opportunities and treats of the UK cladding industry as well as the potential for innovation. It also looks at how PV cladding could exploit the strengths and opportunities and how it could mitigate the weaknesses and treats facing the UK cladding industry.

Chapter Seven: chapter seven contains a review of UK building procurement systems and project management techniques. This chapter deals with the analysis of the organisation structure the design-management domain, in relation to the entire construction project structure in both the traditional and current trends/ practices. It also deals with the problem context in the design-management domain. The chapter analysis the contractual and communication links in the major procurement system highlighting the suitability of their application.

Chapter Eight: chapter eight contains a review and an appraisal of IDEF (Integrated DEfinition for Functional) modelling techniques, which is a prerequisite of the approach use in System Architecture / Business Process Re-engineering (SA/BPR) methodology. IDEF methodology is the under pinning modelling technique used in this work.

Chapter Nine: A robust analysis of design-management processes and the factors in these processes, which affect integration, is dealt with in chapter nine. This chapter also analyses the implicit functions in design-management, using pilot survey, followed by questionnaires, case studies and formal discussions to establish current thinking, practices and other key issues relating to integration of functions in design, estimating and planning. The flaws found in these processes are also discussed in this chapter.

Chapter Ten: The approaches used in the research to handle the arbitrariness in design-management and planning processes and also the means to achieve an all-embracing process in design-management is dealt with in chapter ten. The use of business process re-engineering approach and a developed innovative framework to provide the requisite tool to support process modelling in providing innovative changes to existing processes in design-management is also discussed in this chapter. Optimal BIPV installation function are superimposed on the rational innovative model in this chapter. Finally this chapter discusses the results and analysis of the BIPV case studies and tests carried out as part of this study.

Chapter Eleven: chapter eleven contains the summary of the work carried out in the research, the contribution the research has made to knowledge and the conclusions derived from this research, including the limitations, recommendation and suggestions for future research.

Appendices

The last section of this thesis contains additional information relevant to this research. It is deemed that this research will not only serve the research and development fraternities, but also make such a factual and valuable knowledge accessible to all members of the construction profession. It will also make knowledge accessible to individual institutions which are desirous to get an in depth study into the processes and optimal function determination for BIPV installation as a formal vital platform for the development of a rational integration in BPIV construction projects. This will also serve as a paradigm for the development of a decision support system aimed at designers, clients and their advisers.

History of Energy Use

2.1 World Energy Use

The large-scale use of fossil, and to a lesser extent, nuclear fuels is a dominant feature of industrial societies. Energy is regarded as essential for the growing, distribution and preparation of foods. It is also used for construction, manufacturing, communication and the organisation of many other activities. The use of energy sources other than the human body has characterised human cultures for far longer than there have been industrial cultures, Johansson (1993).

For over a million years, mankind has used wood fire to keep warm, to provide light and to cook food. Fire was used to extract and work metals, fire clay pots and bricks. Animals have been used for traction in agriculture; wind has been used to power ships in the Mediterranean for over six thousand years ago, Goulding (1992). Natural forces have been used for centuries to move objects, transportation and production, Johansson (1993).

A number of civilisations with elaborate social systems and specialised systems of production have risen and fallen, using only the energy of human bodies and other sources of renewable energy, World Commission for Environment and Development (WCED) (1983). These energy sources are still predominant in many parts of the less industrialised world, Harland (1993).

Energy use changes can be traced to the industrial revolution. The industrial revolution introduced the increase in dependence on fossil fuels. The earliest stages of the industrial revolution were powered by water mills. The invention of the steam engine introduced burning coal and coke fuels, replacing running water as the power source. During the revolution coal and iron ores were plentiful. Crude technique and inefficient energy use were employed in industrial processes; adverse environmental effects were ignored, Laughton (1990).

Towards the end of the nineteenth and early twentieth century saw the development of electricity and internal combustion engine, oil and gas as additional fuels and the development of the chemical industry that could create new materials using oil as a feedstock, Boyle (1996). Power was provided directly from combustion of oil or gas in engines, or from electricity generated from burning coal, oil, and gas or from hydroelectric plant, Boyles (ed) (1996)

The mid-twentieth century saw the widespread distribution networks of electricity, to the point at which it was available nearly universally in industrial countries. Industrial culture became totally dependent on fossil fuel with the opening of major oil fields in the Middle East and North Africa. The development of nuclear sources of electricity after the Second World War introduced an additional power source, Bevan (1994).

After the Second World War, fuels were seen as cheap and plentiful. The uses of these fuels were predominantly crude, inefficient, whilst their environmental effects were still largely ignored.

In the later part of the twentieth century, manufacturing has continued to increase, but is no longer the largest sector of the economy. Services, particularly communications and information processing, have become dominant activities, accompanied by developments in support technologies, Evans (1990).

Since the late 1960's there has been a growing recognition of the environmental impact of industrial societies, and especially of the burning of fossil fuels, Houghton (1992). The oil crises of the 1970's - saw the growth in new techniques for making more efficient use of energy, providing energy from renewable sources. Major reductions in fuel use are now seen as technically possible, simply through care and attention to the energy aspects of the design of buildings, equipment and industrial processes, and many other methods, Gyoh (1993).

In the 1990's, this understanding of energy efficiency is only beginning to be applied, however, economic constraints have been a major bottle neck year, Word Energy Council Statistics (1993).

Interest in renewable energy has been growing steadily over the past twenty years. Currently, few observers would perceive a future without the renewables contributing to world energy demand. Recent studies indicate that renewable energy will make a substantial contribution to global energy supplies in the longer term, Alexander (1996). Interest in renewable energy has been heighten by a number of concerns over the use of fossil fuel energy technologies and their adverse effects on the earth's ecological system, Harldland (1993). Increased concerns about the environment at large, particularly the impacts of conventional energy systems on global warming - has revitalised interest in renewable energy technologies. Renewable energy has little or no net emissions of polluting gases and is widely, seen as part of the solution, Boyles (1996).

Interest in non-conventional energy sources, new and renewable energy, also arises from the recognition that the commercial forms of energy in popular use today such as liquid and gaseous hydrocarbons and solid forms of fossil fuels - represent limited and eventually exhaustible resources of energy, Boyle (ed)(1996). Peoples' aspirations for greater comfort and wealth leads to increase in per capita demand for energy. Some observers fear that conventional supplies of energy may not be able to meet the demands of future generation, Gyoh (1996).

The energy crisis of the early 1970's brought in its a much increased awareness of the possibility of utilising 'soft' or 'alternative' energy technology, Wozniak (1990). The advantages of such energy supply systems are that they are fuelled from a source whose continued existence is virtually assured and not easily subject to political or military interference. Renewable Energy is environmentally friendly and does not interfere with the earth's ecological system.

2.2 World Energy Supply

Modern societies, particularly industrial societies, are now largely dependent upon the use of large quantities of energy, mostly form of fossil fuels, for virtually all aspects of life, Houghton (1992).

In 1992, the estimated total world consumption of primary energy (in all forms) was approximately 400EJ per year, equivalent to some 9500 million tonnes of oil (mtoe) per year. Assuming, a world population of about 5300 million, this gives an annual average world-fuel-use equivalent to about 1.8 tonnes of oil Boyle (1996). This is equivalent to about 470 imperial gallons of oil per person per year.

The magnitude of the energy problem that may face future generations can be illustrated by the following calculation: the world's population stood at approximately 5 billion people, in 1990. The best United Nations (UN) estimates population trend show it continuing to increase to around 8 billion by 2025, but stabilising towards the end of the next century at somewhere between 10 and 12 billion people. Most of that increase will be in the less developed countries (LDCs). Fuels are used at an average rate in the developed countries, which is more than six times that in the LDCs. The present situation is summarised in table 2.1. It can be seen that the developed countries use nearly twice as much fuel as the LDCs, even though they have less than a third of their population, Greenpeace (1996). Given the expected population increase, there is still a rise of 50% in the overall level of global energy use, Boyle (ed)(1996).

Year	Population	Total energy use		Energy use per person	
	(Billions)	(EJ/y)	(TW)*	(GJ/y)	(KW)
1990 (dev)	1.2	284	9.0	237	7.5
1990 (Idc)	4.1	142	4.5	35	1.1
1990(world)	5.3	426	13.5	80	2.5
2025 (dev)	1.4	167	5.3	120	3.8
2025 (dev)	6.8	473	15.0	69	2.2
2025 (dev)	8.2	640	20.3	78	2.5

Table 2.1 Increase in energy use expected as a result of population increases

Dev = developed countries. Ldc= less developed countries. *= Equivalent power

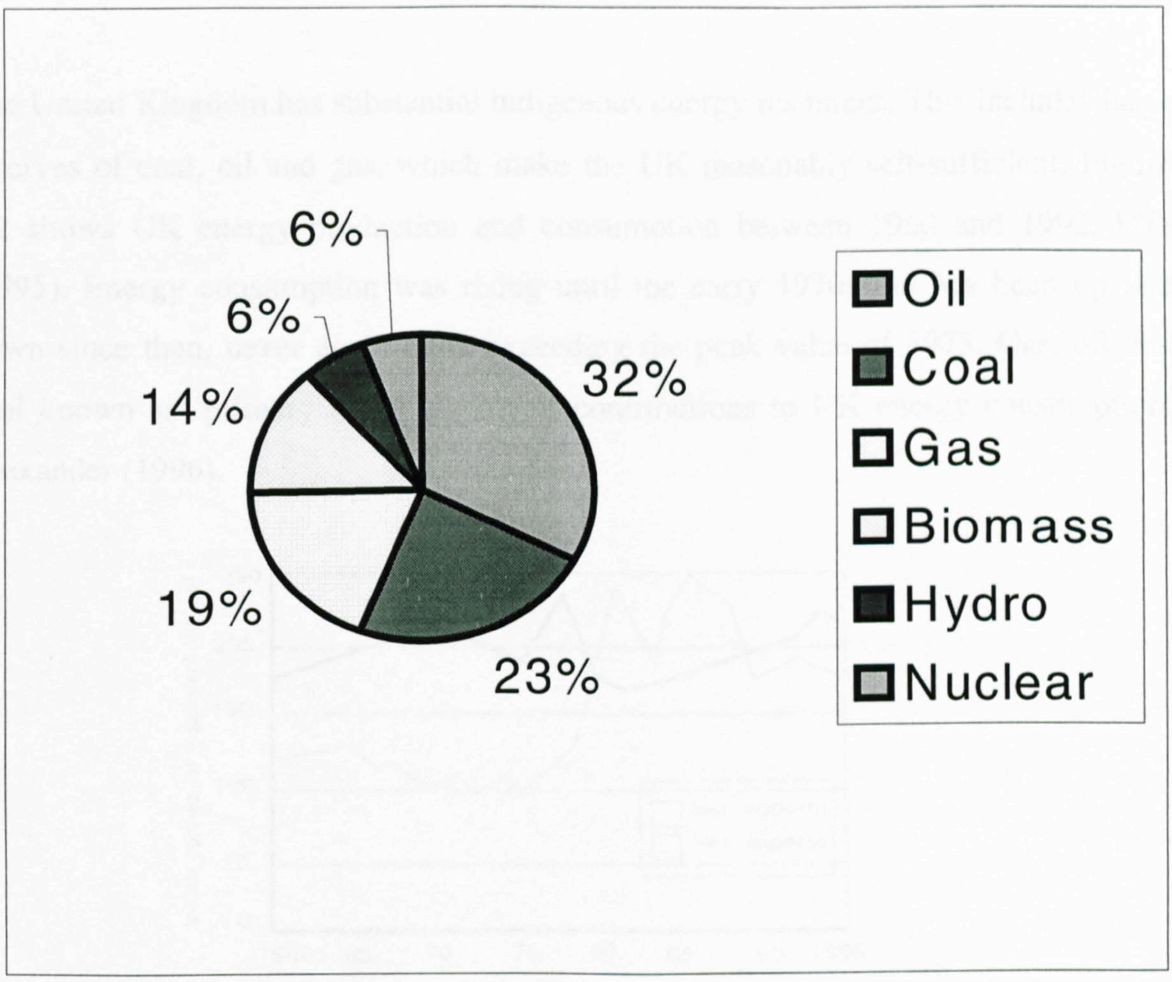

Figure 2.1: Estimated annual energy consumption 1992
(Source: Renewable Energy, Oxford Press 1996)

A breakdown of world primary energy consumption by source in 1992 is shown in figure 2.1. Oil is the dominant fuel, contributing some 32%, followed by coal at 23%. Coal was once the dominant world fuel, but is now losing ground rapidly to oil and gas, which has a 19% share, DTI (1995). Hydroelectricity and nuclear are much less used, at around 6% each, with biomass at about 14%, DTI (1995).

2.2.1 UK Energy Sector

The United Kingdom has substantial indigenous energy resources. This includes large reserves of coal, oil and gas, which make the UK reasonably self-sufficient. Figure 1.2 shows UK energy production and consumption between 1960 and 1992, DTI (1995). Energy consumption was rising until the early 1970s but has been up and down since then, never again quite exceeding the peak value of 1973. Gas, oil and coal known as 'primary fuels' are major contributions to UK energy consumption, Alexander (1996).

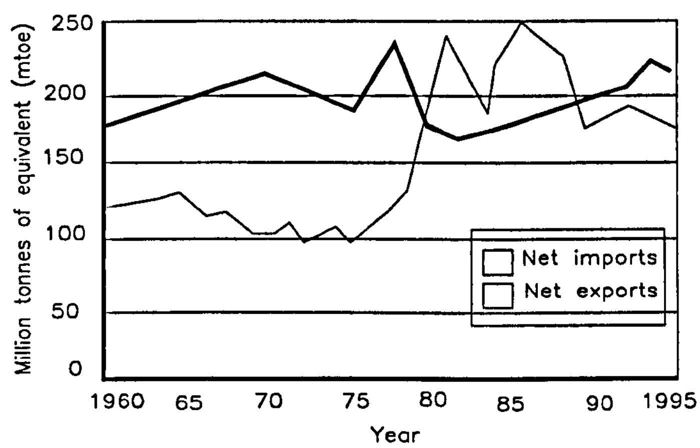

Figure 2.2: UK Energy production and consumption, 1960-1992.
(Source: DTI Statistics, 1993)

In 1992, about 60% of the UK's electricity was generated from coal, with nuclear as the next largest source. However, there has been a steady move away from coal, DTI (1994). The amount of gas used for electricity generation at present is quite small. The electricity industry is currently building substantial gas-fire capacity, Boyle (1996).

2.3 Environmental Problems

It is widely accepted that various environmental problems loom largely in the public consciousness at present, IEA (1992). Many of these are as a result of large-scale fossil fuel use. One of the most significant problems appears to be that of 'global warming': a gradual increase in the global average air temperature at the earth's surface. Most scientists now believe that global warming is probably taking place, at a rate of around 0.3^{o}C per decade, and that it is caused by increases in the concentration of so-called 'greenhouse gases' in the atmosphere. The most significant single component of these greenhouse gas emissions is carbon dioxide (CO_2), released by the burning of fossil fuels, Houghton et al (1992).

Recent studies using complex computer-based mathematical models of the climate predict a doubling of CO2 or equivalent greenhouse gas concentrations by the year 2050, if present trends continue. The Intergovernmental Panel on Climate Change (IPCC) studies predict a global average warming of between 1.5 and 4.5^{o}C.

2.3.1 Acid Rain

Another side effect of the burning fossil fuels is acid rain. Some of the gases which are given off when fuels are burned (particularly, sulphur dioxide and nitrogen oxides) combine with water in the atmosphere to form sulphuric acid and nitric acid respectively. This results in acid rain. Acid rain does cause damage to plant life. In some serious cases, acid rain affect the growth of forests, erode buildings and corrode metal objects. About 70% of the sulphur dioxide released in the UK come from power stations. SO_2 results mainly from the burning of coal (together with some oil) which contains sulphur in concentrations ranging from 0.5% to almost 5%, Houghton (ed)(1992).

2.3.2 Oil Pollution

Not all the harmful environmental effects are a result of burning fossil fuel. Underground coalmines can cause subsidence, and open cast mine cause great scars in the landscape – though later restoration work can minimise the long-term impact. Power stations and oil refineries, like many other industrial installations, can cause significant visual intrusions and can produce significant smells and other effluent locally. Although the transportation of oil is generally a safe industry, the scale of it and the size of the tankers, means that when accident do occur, they have a large net effect. Although the number of accidents is small in proportion to the number of tanker journeys, thousands of minor incidents involving oil spills from tankers and oilrigs, Boyle (ed) (1996).

2.3.3 Environmental Sustainability

According to an RIBA report on Environmental and Energy -'Towards Sustainable Design', July 1990. The United Nations International Panel on Climate Changes (IPCC) maintains it would need a 60% reduction world wide in carbon emission to be reasonably sure of arresting global warming. However, predictions regarding population growth and rapid economic development of countries like China has meant that the industrial countries should be looking at carbon reductions of the order of 80%. Realistically it is unlikely such a target could be achieved. Against this background much more constructive consideration should be given to environmental sustainability and energy efficiency within the built environment.

2.4 Renewable Energy

Renewable energy is the term used to cover that energy flow that occur repeatedly in the environment and can be harness for human benefit, HGA (1992). The ultimate sources of most of these energies are the sun, gravity and the earth's rotation. The source of renewable energy technologies that have been considered candidates for deployment in the UK as published by the ETSU report include, wind power, hydro-power, tidal power, wave energy, photovoltaic, active solar and thermal solar power, as well as passive solar design. *'An Assessment of Renewable Energy for the UK'*, ETSU (1994). Renewable energy technologies are beginning to find place in public utility resource portfolio as considerations of fuel diversity, environmental concerns, and market uncertainties are increasingly factored into electric utility resources planning.

Major research finding indicate that, if the world economy is to meet the aspirations of countries around the world, energy demand is likely to increase even if strenuous efforts are made to increase the efficiency of energy use, Laughton (1992). Given adequate support, renewable energy technologies can meet much of the growing demand at prices lower than those usually forecast for conventional energy Thomas et al (1997).

International Energy Agency (IEA) statistics forecast that by the middle of the 21st century, renewable sources of energy could account for three-fifths of the market for fuels used directly and two – fifths of the market for fuels used directly, figure 2.3. It is widely accepted within the international scientific community,

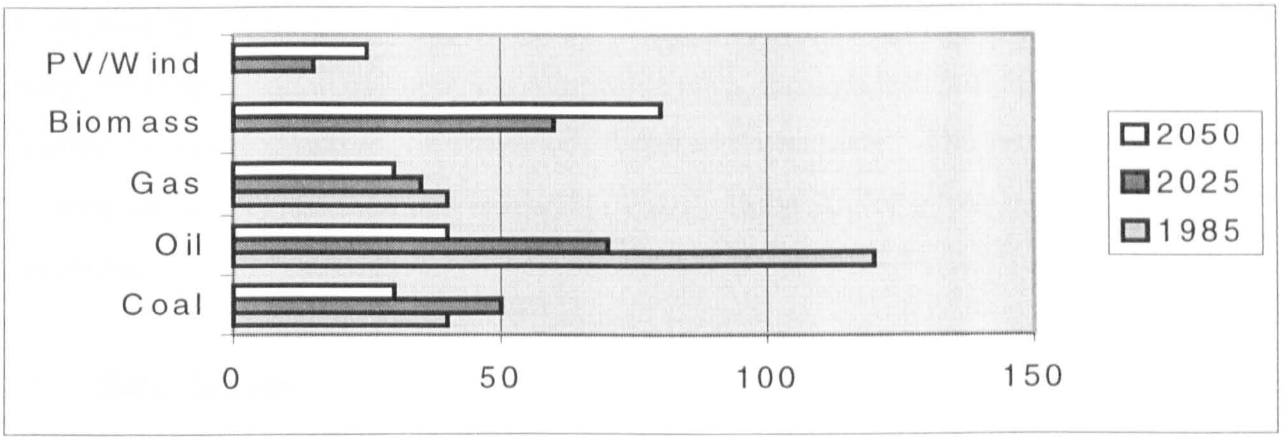

Figure 2.3: Direct fuel-use for the renewables-intensive global energy scenario.
(Source: Renewable Energy Sources of Fuels and Electricity Island Press, 1993)

making a transition to a 'renewable –intensive' energy economy would provide environmental and other benefits not measured in standard economic accounts. Recent studies indicate that by 2025 global carbon dioxide (CO_2) emissions would be reduced to 75% of their 1985 levels, provided energy efficiency and renewable are both pursued aggressively, Johansson (1997) see figure 2.4. Renewable energy is expected to be competitive with conventional energy, such benefits could be achieved at no additional cost.

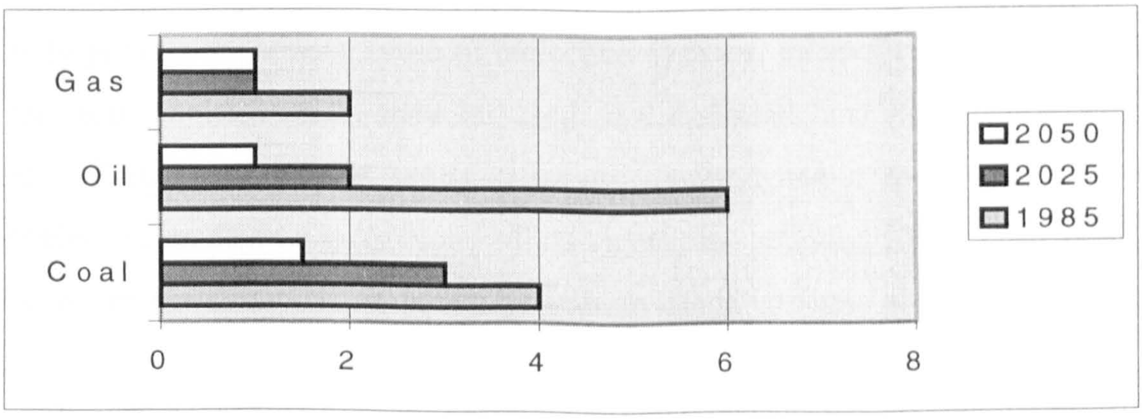

Figure 2.4: World Per capita emissions of CO_2 for renewables-intensive global energy scenario.
(Source: Renewable Energy Sources of Fuels and Electricity Island Press, 1993)

The United Nations Conference on Environment and Development (UNCED) held in Rio de Jeneiro, Brazil, in June 1992, address the challenges of achieving worldwide sustainable development. The goal of sustainable development cannot be realised without major changes in the world's energy system. Accordingly 'Agenda 21', which was adopted by UNCED, called for "new policies or programs, as appropriate, to increase the contribution of environmentally safe and sound and cost-effective energy systems, particularly new and renewable ones, through less polluting and more efficient energy production, transmission, distribution and use". The next section of this chapter will review the main renewable energy technologies in use in the UK and elsewhere.

2.5 Solar Energy

Solar Energy can be converted into other forms of energy using various technologies. Solar energy can be absorbed by solar collectors to provide space and water heating, at low-temperatures. 'Passive solar' design strategies can be employed in building design allowing energy to be distributed to the building space heating requirement. Solar radiation can be converted to useful energy indirectly via other forms of energy i.e. Thermal energy conversion and Photovoltaic electrical conversion.

2.6 Solar Thermal

Solar Thermal Systems collect the thermal energy from solar radiation, for direct use in low-to high-temperature thermal applications. High-temperature applications include the generation of electricity using conventional steam cycle technology. For electricity generation, several types of collection systems, parabolic through, central receiver, and parabolic dish, may be used to concentrate and convert the solar resource. Higher temperatures result in greater thermodynamic energy conversion efficiencies. Solar thermal technology offers significant potential for meeting utility peaking or intermediate electric power generation needs in sunny climates IT Power (1992).

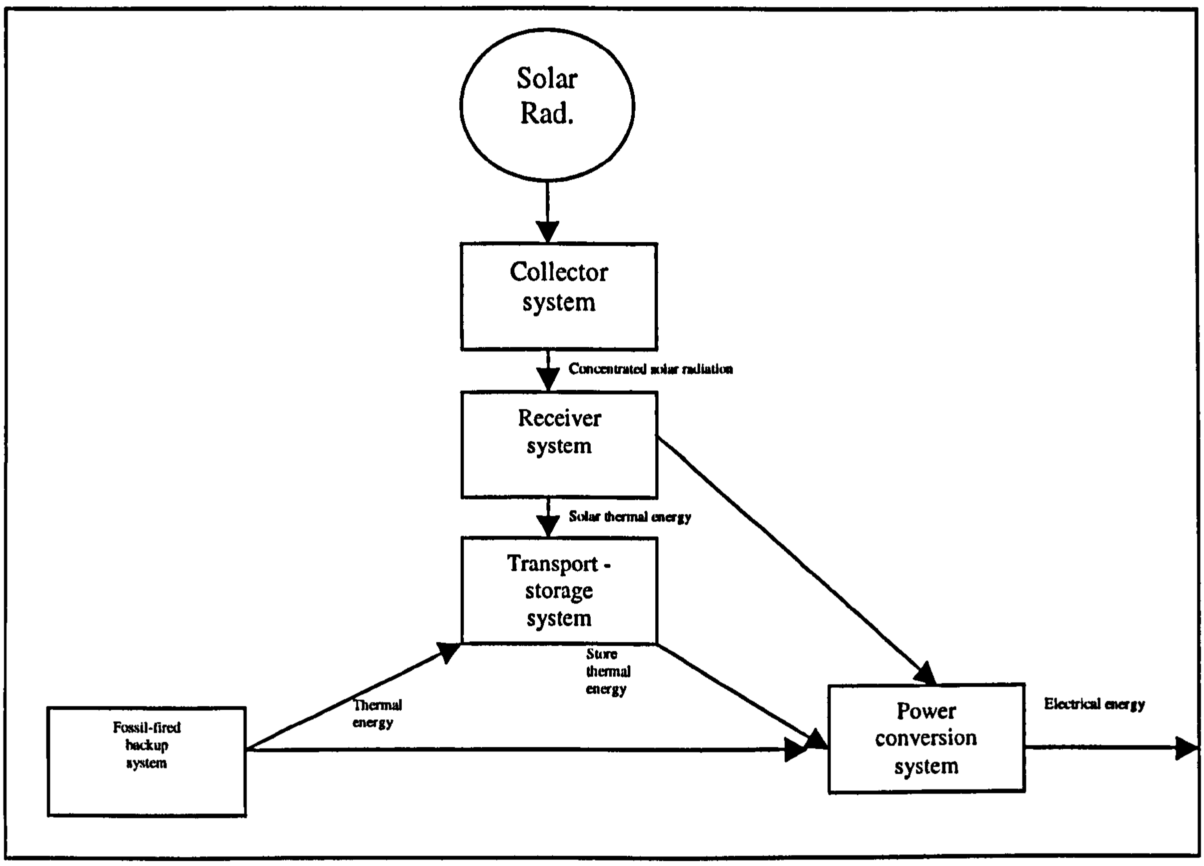

Figure 2.5: Schematic model of Solar Thermal energy conversion

All solar-thermal power technologies rely on four basic systems: collector, receiver, transport-storage, and power conversion in figure 2.5, Johansson (ed)(1995). The collector captures and concentrates solar radiation, which is then delivered to the receiver. The receiver absorbs the concentrated sunlight, transferring its heat energy to a working fluid.

The transport-storage system passes the fluid from the receiver to the power-conversion system; in some solar thermal plants a portion of the thermal energy is stored for later use. The power-conversion system consists of a heat engine and related equipment for converting thermal into electrical energy. Some designs also include a secondary, fossil fuel driven heat source that can either charge the storage system or drive the power-conversion system during periods of low sunlight.

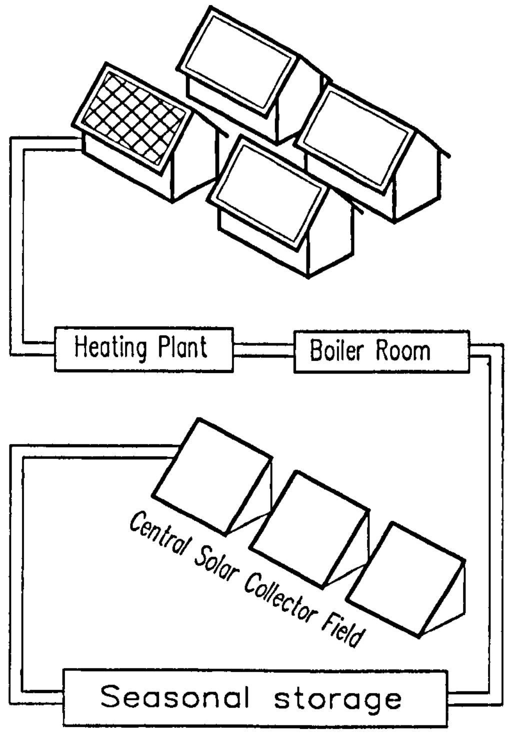

Figure 2.6: Schematic Solar Thermal System

The advanced solar-thermal systems are still at an early stage of development; hitherto, their cost and performance potential can not be easily quantified. Nonetheless, these systems have attractive features that are likely to spur their development. In addition to producing electricity, solar-thermal technologies produce hot water and steam for industrial applications. Figure 2.6 is a schematic diagram of a solar thermal system.

While much has been accomplished in the field of solar-thermal technology during the past 15 years and several large-scale commercial power plants have been built, additional development is needed to render the technology truly cost-competitive. Each of the three major solar-thermal electric technologies has unique attributes, strengths, and weakness. For each technology a path exists by which cost can be lowered and performance increased without the need for technological breakthrough, Johannson et al (Eds).

2.6 Wind Energy

Wind turbines capture the wind's energy with a rotor, usually consisting of two or three blades mounted on a shaft; the spinning blade shaft rotates a generator to produce electricity. The turbines are mounted on towers to maximise the capture of wind energy, because the wind is generally slower and more turbulent close to the ground. There are two, fundamentally types of wind turbine designs: the vertical - axis wind turbine (plan view) in figure 2.7b, which resembles an eggbeater, and the horizontal - axis wind turbine, figure 2.7a, which resembles a windmill, BWEA, (1993). Although the wind turbine can be stand - alone systems there are operating advantages to siting wind turbines in a large array to form

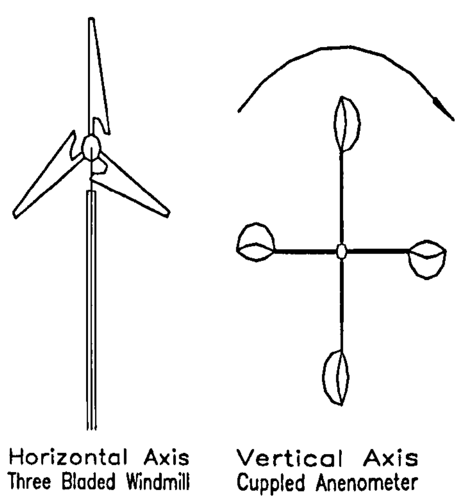

Figure 2.7a Figure 2.7b

(Source: Renewable Energy, Oxford Press 1996)

a wind plant, Taylor (1993). More than 20 000-wind turbines are in use around the world the world for generating electricity, and over a million pumping water (Mays 1993). Although experimental wind turbines up to several megawatts in size have been built, the optimum size currently appears to be around 300 - 500 kilowatts, BWEA (1995).

2.8 Hydroelectricity

Hydropower uses the energy of flowing water to turn a turbine, which rotates a generator to produce electricity. Although many hydropower facilities use large impoundment dams, diverting a portion of a stream or river can also generate hydropower. Such diversion projects may require a dam but such dam is usually much smaller and less obtrusive than impoundment dam, Fleischer (1993). Hydropower can also be used to store energy. During low-load periods, excess electrical supplies can be routed to pumped storage facility, which stores the energy by pumping water from a lower reservoir to another reservoir at a higher elevation. During peak-loads, the water is allowed to return from the upper reservoir to the lower reservoir, turning a turbine and generating electricity in the process.

Hydroelectricity is well established as one of the principal energy-producing technologies around the world, providing some 20% of the world's electricity. In the 'less industrialised nations', the proportion of energy generated form hydroelectric dams rises to around 40% Boyle et al (1996). The capacity of large hydroelectric schemes can be several times that of a conventional power station. They are highly efficient, reliable, and long lasting, figure 2.8. They are also

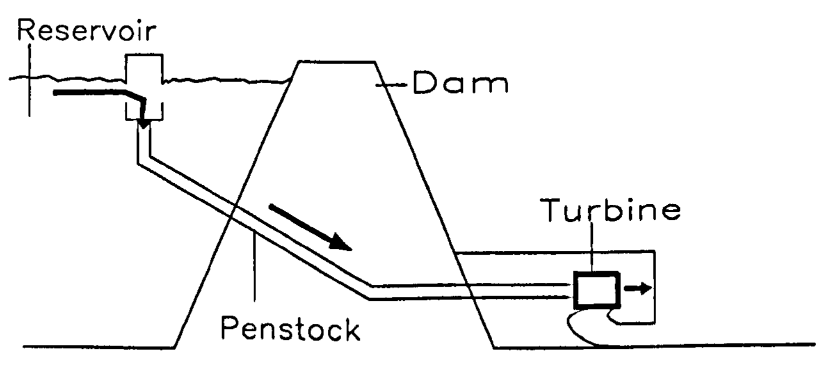

Figure 2.8: Schematic Hydroelectric Dam

controllable and add an element of storage into an electricity supply system, thereby allowing compensation for the varying intensity of other renewable sources and for variations in electricity demand.

2.9 Biomass Energy

Biomass energy is, widely believed to be, one of the oldest energy sources known to man. It uses the energy embodied in organic matter, mainly plants. Biomass – based energy systems utilise wood, agriculture and wood waste, municipal waste, and landfill gas as fuels. Biomass, in all its energy uses, currently supplies more than 3% of total US energy needs and provides almost 10 000 MW of electric generating capacity (US Department of Energy Washington DC 1995). Biomass is one of the worlds major fuel sources especially in the 'less industrial countries. In less developed countries biomass provides more than 40% of the energy requirements. Biomas is also important in some of the forest-rich parts of the industrial nations, 8% in Sweden and 14% in Canada (New Review Issue 27 December 1995, DTI). Although the exploitation of landfill gas as an energy source is in its infancy, total energy savings are now believed to be in excess of 2 Mtce (million tonnes of coal equivalent), that is 510 million therms, per annum. This figure represents a near doubling of the contribution made from landfill gas since the last survey was carried out 23 months ago (T521 R5.8 World landfill gases pp1-6). Further rapid expansion seems likely due to increasing calls for gas control from an environmental as well as an energy point of view.

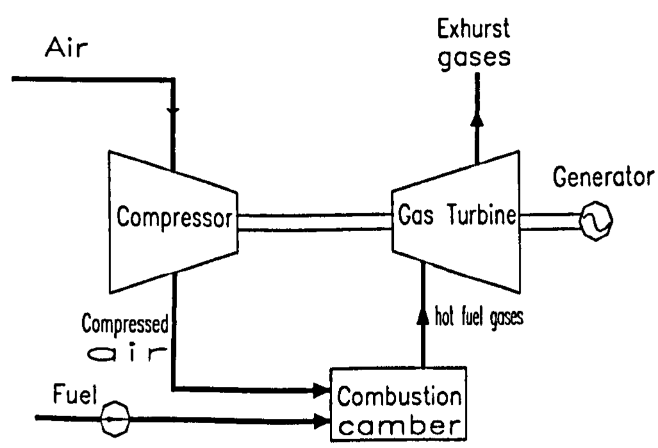

Figure 2.9: Schematic Simple gas turbine

(Source: Renewable Energy, Oxford Press 1996)

The substitutes of gas form biomass gasifiers would serve a double purpose, conserving a premium fuel and reducing the emission of green house gases.

2.10 Wave Energy

In order to capture energy from sea waves, it is necessary to intercept the waves with a structure that can respond in an appropriate manner to the forces applied to it by the waves. If the structure is fixed to the seabed or seashore then it is easy to see that some parts of the structure may be allowed to move with respect to the fixed structure and hence convert the energy into mechanical energy. This mechanical energy is converted into electricity (electrical energy).

Fixed seabed and seashore-mounted devices are the only wave energy converters to have been tested as prototypes at sea, Boyle (1996). Having a fixed frame of reference and with good access for maintenance, they have obvious advantages over the floating devices, but do operate in reduced wave power levels and may ultimately have a limited number of sites for future development, Boyle (1996).

Floating wave energy conversion devices include the Clam and Duck form the UK, and floating OWCs such as the Whale and the Backward Bent Duct Buoy from Japan, Boyle (1996).

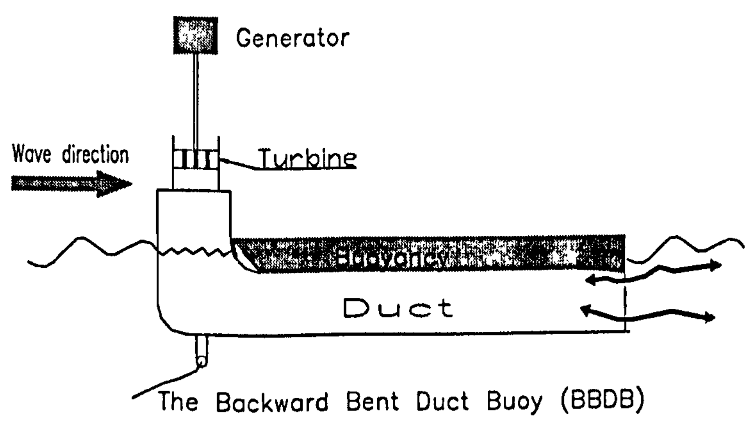

Figure 2.10: The Backward Bent Duct Buoy (BBDB) Wave Energy Generator
(Source: Renewable Energy, pp334, Oxford Press 1996)

These devices are able to harvest more energy than fixed, on-shore devices, since they wave power density is greater offshore than in shallow water and there is little restriction to the deployment of large arrays of such devices, Boyle (1996). The BBDB floating wave energy harvester is illustrated in figure 2.10.

2.11 Geothermal Energy

There are some places where the hot rock is very close to the surface and heats water in underground aquifers. Such places have provided hot water streams for centuries, Harrison (1990). Geothermal energy resources can be used for power or heating. They exist underground as either dry stream or hot water. Geothermal energy is also found in form of geopressured brines. These brines are hot pressurised water that contain dissolved methane and lie at depths of about 3 km to more than 6 km, Di Pippo (1988).

The normal technique of harnessing this energy resource is to use naturally occurring steam- tapped from deep holes. It is also possible to drill deep holes, insert explosives or other devices to fracture the rock, and pump the water through the fracture to extract the heat, Freeston (1990) – figure 2.11, illustrates a schematic geothermal energy plant.

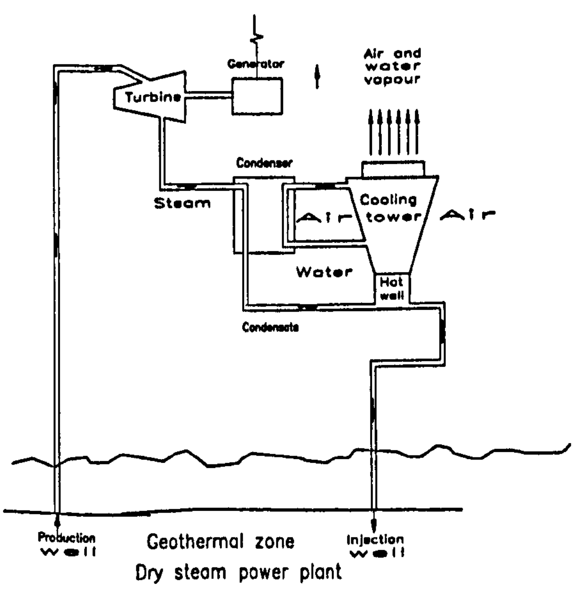

Figure 2.11: Schematic Geothermal Electrical Energy Production Plant.
(Source: Geothermal Energy, Oxford Press 1996)

2.12 Photovoltaic Energy

Photovoltaic (PV) energy technology employs a solid-state device to directly convert sunlight into electricity. PV cells, also called 'Solar Cells', represent one of the most benign forms of electricity generation available. They can be used to make stand-alone systems with no fuel or cooling requirements and no operating emissions or noise. Photovoltaic technology is one of the most attractive of the renewable energy sources in terms of a large accessible resource, potential for cost reduction, simplicity of operation, flexibility of deployment and small environmental impact. There is a major word-wide effort at the R&D and manufacturing process level to develop systems of suitable performance and cost for widespread deployment Johansson (1993).

Although the Photovoltaic (PV) effect has been recognised since 1839, practical application began in the early 1970s, lannucci & Shugar (1991). The adaptation of PV cell by the US space Programme spawned a number of innovations. Prices fell and commercial producers were able to sell PV systems for a growing number of land–based applications.

In 1990, worldwide Photovoltaic sales reached 48 mega-watts, Gergorg & Pearsall (1996). This included small-scale markets such as pocket calculators and other consumer goods. The larger-scale markets consisted of communication systems, buoy and other transportation-related systems, pumping stations, building integrated system and other grid-connected systems, to mention a few.

Photovoltaic equipment differs significantly from fossil fuel- powered equipment currently used to provide much of the world's electricity. It is not surprising that photovoltaics offer a unique collection of benefits and difficulties. PV power is intermittent in that electricity can be generated only while the sun is shining. However, such sunny periods are often when power is most valuable. The output of PV systems typically correlates with periods of high electricity demands – during office/ business hours, 9am – 5pm in the UK, Hill, R and Pearsell N (1994).

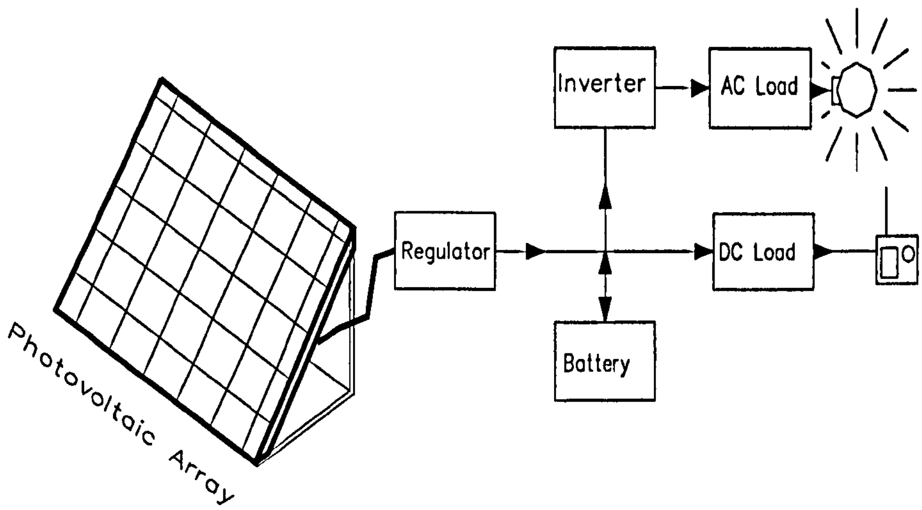

Figure 2.12: Typical Photovoltaic System

Figure 2.12, illustrates a typical arrangement of a photovoltaic system with dc storage facilities, inverter to convert dc to ac and supply power to ac loads. The system also supplies power directly to dc load. The system is fitted with a voltage regulator.

2.13 Summary

The prospect of producing clean, sustainable power in substantial quantities from renewable energy sources is now arousing interest world-wide. This is partly simulated by recent technological developments, which have improved the cost-effectiveness of many of the 'renewables', and by increasing concerns over the environmental consequences of conventional fossil and nuclear fuel uses. This chapter provides a robust overview of the principal renewable energy sources:

- Solar thermal
- Photovoltaic
- Biomass
- Hydroelectricity
- Wind
- Wave

- Geothermal

Basic energy concept and current energy system are outlined, as are the key issues of economics and resource assessment. This chapter also seeks to examine how the energy system of the 21st century may change in order to incorporate an increasing proportion of renewable power supply.

The next chapter review photovoltaic technology and photovoltaic system design options. This, is believed, will set the frame work for a better understanding photovoltaic systems installation and maintenance processes discussed in chapter 3. Chapter 3 and 4 form the building blocks for functional determination and value management for an optimum design and installation solution for a BIPV system.

This research study is aim at contributing effectively to the energy requirement of buildings in the built environment, using PV technology. This, is hoped, will be achieved by optimising buildability and sustainability in the design, planning and installation processes of BIPV systems in the UK construction industry.

Photovoltaic Power and System Design Options

3.1 Photovoltaic and Solar Radiation

All energy on earth originates within the thermonuclear fires of the sun. Solar energy comes to earth in the form of waves of radiation waves of photons possessing varying amounts of energy and travelling at a uniform speed of 186,000 miles per second. The more energy a group of photos possessing, the shorter the wavelength. A means of identifying the varying solar wavelengths have been developed, based upon the range of visible light as well as those upper and lower reaches that are imperceptible to the human eye. The entire continuum is called the solar spectrum, Houghton (1992).

At the lower end of the solar spectrum are the low frequency, invisible wavelengths called infrared, which make up nearly half of the sun light reaching earth. Next is the visible spectrum, with wavelengths growing progressively shorter from red to violet. Once the infrared and visible wavelengths are accounted for, only 5 to 7 percent of the solar spectrums remain. This is taken up by the wavelengths beyond violet, the ultraviolet radiation. Ultraviolet radiation has the shortest frequency of all, this implies that, the their photons possess a relatively high amount of energy.

Not all of the wavelengths of solar radiation are readily convertible to electricity within a photovoltaic cell. Those wavelengths that contain the highest-energy photons are most useful to the conversion process. This amounts to roughly ¾ of the solar spectrum. The remaining ¼, comprising most of the infrared zone, has no part in the process, even though some infrared light is absorbed by silicon atoms, as can be seen in figure 3.1. The radiation that occupies the ideal spectrum of wavelengths is not available in its entirety to photovoltaic cells. This is because of the filtering and reflective qualities of the earth's atmosphere and the constantly changing orientation of the sun.

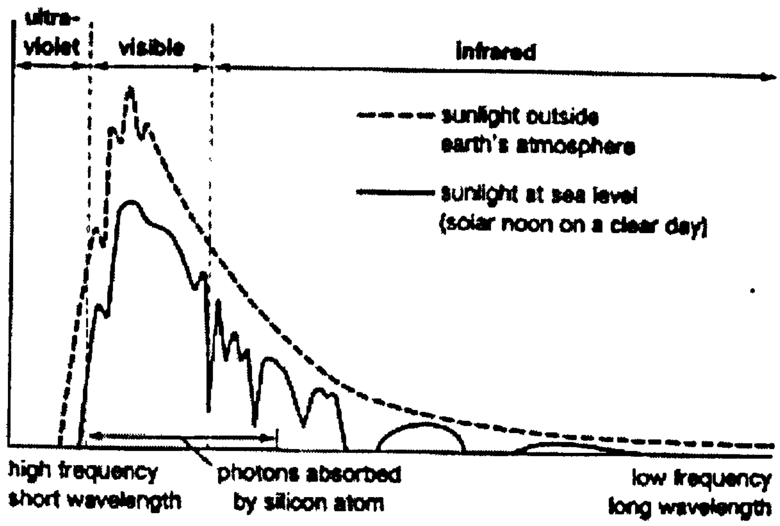

Figure 3.1: The solar spectrum. Note that only the higher-energy photons are useful to photovoltaics.

(Source: Renewable Energy, Oxford Press 1996)

Approximately 10 to 15% of solar radiation are absorbed by ozone, water vapour, or carbon dioxide in the atmosphere and thus never reach the earth's surface. Another 30 to 35% don't even make it that far; it is reflected off the atmosphere and accounts for the phenomenon called earthshine, Houghton (1992).

The output of a photovoltaic module or array is directly proportional to the amount of sunlight it receives, in terms of both intensity and duration. Seasonal and daily variations in available sunlight are functions of the earth's rotation and its angle of tilt towards the sun. During the summer months, when solar radiation is most direct, there are optimum angles at which collecting devices- photovoltaic or thermal- ought to be placed, Strong (1993). These vary according to latitude.

Insolation (short for: incident solar radiation) data is very useful in the design of photovoltaic systems. However, such data alone cannot answer the question of how cost-effective such a system may be in a particular location. Many variables must be taken into account in making that decision.

3.2 Silicon and the Photovoltaic effect

When a photon of sufficient energy strikes an atom of silicon, it pushes an electron from the valence shell into the conduction band, where it is free to become part of an electrical current. Silicon exposed to light, absorb photons, results into displacement of electrons. Photon energy not converted into electricity is given off as heat. The empty places in the valence shells, where electrons used to be are called holes. Holes appear as rapidly as the electrons can vacate them, but they are being filled just as rapidly by dislocated electrons from neighbouring atoms, figure 3.2.

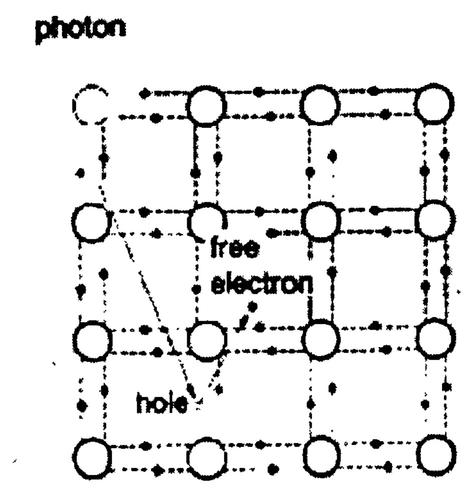

Figure 3.2: The lattice structure of single-crystal silicon
(Source: Geothermal Energy, Oxford Press 1996)

In order to get the electrons flowing out of a cell, photovoltaic engineers resort to a technique called 'doping', which involves the introduction of special "impurities" into the silicon cell. Silicon has four electrons in its valence shell. The element boron has three, and phosphorus has five. Boron and phosphorus are the 'dopants' used in manufacturing silicon solar cells. When added to pure silicon in minute quantities, they create the imbalance within the silicon atoms necessary to make photovoltaic work. Two imbalances work together during a photovoltaic reaction. When silicon doped with boron, its atomic structure is affected by the electron deficiency that the boron introduces. Instead of a regular series of pure silicon atoms with four electrons in their valence shells, the crystal structure of boron-doped silicon reveals an occasional extra 'hole'. Electrons carry a negative charge, therefore, this deficiency results in an overall positive charge for the boron doped crystal. Boron doped silicon is referred to as p-silicon. Silicon doped with phosphorus produces the opposite effect. Phosphorous creates in the silicon an abundance of electrons rather than holes. The result is called n-silicon, because it carries a negative charge.

A silicon photovotaic cell consists of separate layers of boron and phosphorous-doped silicon. The n-silicon component of the sandwich is so much thinner than its positively charged counterpart. The thickness of an entire cell is generally no more than a hundredth of an inch (0.25mm) with the phosphorus-doped silicon accounting for only a few microns at the top surface, Norton (1999) Figure 3.3.

The phosphorus-doped, electron-rich side of the cell is oriented to faces the sun. However, both sides respond to photon bombardment. Electrons are driven into the conduction band, where they naturally begin to seek the spaces in the valence shells of atoms that have been vacated by other freed electrons. On the p-silicon side there are more holes to begin with, while in the n-silicon a shortage of holes prevails. The accrual of electrical current in a photovoltaic cell is made possible by the presence of a static electrical charge that is created between the n-silicon and p-silicon layers. This charge region, which is only a few atoms thick, is called the cell barrier (the n-p Junction) because of the resistance it offers to migrating electrons. The barrier is formed by an electrical reaction that accompanies that joining of the two layers and lasts for the life of the cell. The usefulness of the cell barrier lies in the fact that it does not offer equal resistance to all the photoelectrically agitated electrons in the cell. The n-silicon side has a lot of electrons and shortage of holes. The free electrons move at a slower rate of speed – as a result has a low energy level. Over on the p-silicon side, free electrons are far less abundant and can circulate with greater energy. The more energetic electrons on the p-silicon side are thus better equipped to breach the static resistance of the cell barrier, while the n-silicon electrons are more frequently repulsed.

It does not take long for the n-silicon layer to become top heavy with electrons. The electrons from the n-silicon layer accumulation, resulting to a build up the electrical pressure (electrical voltage). When an external electrical load is connected between positive and negative side of the silicon cell an electrical current will flow, figure 3.3. The electrons thus channelled off from the n-silicon layer, so that the process is repeated continuously.

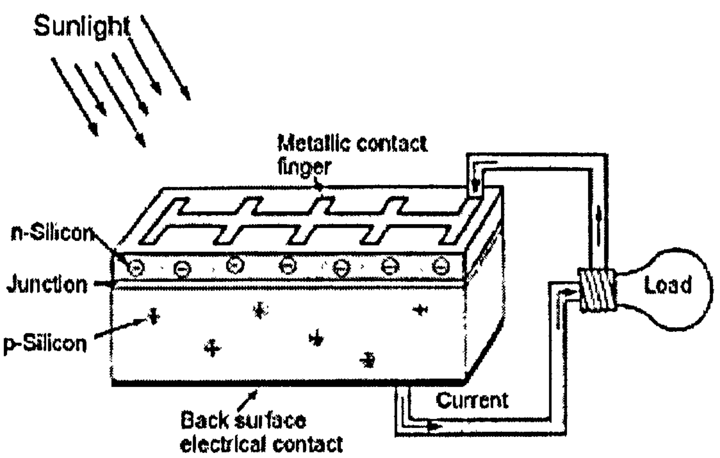

Figure 3.3: Schematic Diagram of a Cross Section of Photovoltaic cell.
(Building Home with Solar Power, Green Peace, 1996)

Free electrons produced by millions of photon/atom collisions resulting in a flow of electric current that can be harnessed through an external circuit

A limited amount of electricity that can be generated within a single solar cell. In condition of bright light, all silicon photovoltaic cells have an output of approximately 0.5 volts, Reehal (1999). Voltage is a measure of electromotive force (emf), the pressure of the electrons in a circuit and is only one of the parameters that electricity comprises. Amperage (another parameter) represents the amount of current being generated and distributed. Voltage is a function of the cell's physical composition. The amount light falling on the cell, the area of the cell as well as the intensity of light falling on it affects amperage. The third unit of electricity is wattage. Wattage is the product of the current and the voltage. The wattage indicates the amount of power developed in an electrical circuit.

Increase in the voltage and amperage output of photovoltaic cells depend upon the way in which the cells are joined to each other in a PV module. In order to achieve higher voltage, the cells are linked in series. This means that the back contact of each cell is connected to the front contact of the one that follows it. As shown in figure 3.4. Two cells so connected would have a cumulative voltage of 1 volt, six would be rated at 3 volts, and so on (given that each cell produces a voltage of 0.5V)

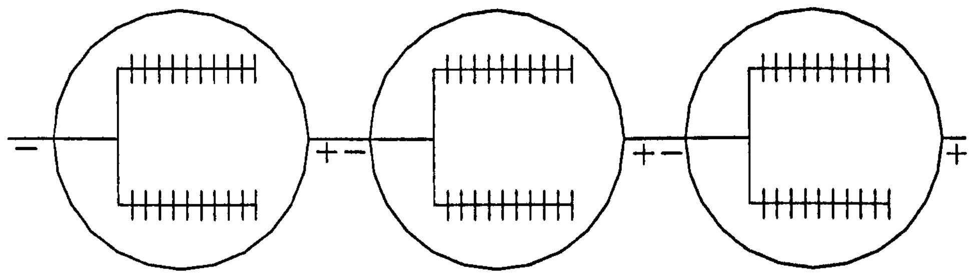

Figure 3.4: A schematic of solar cells connected in series.

The back contact of each cell is connected to the front contact of the cell that follows it (positive to negative to positive) Series Connection.

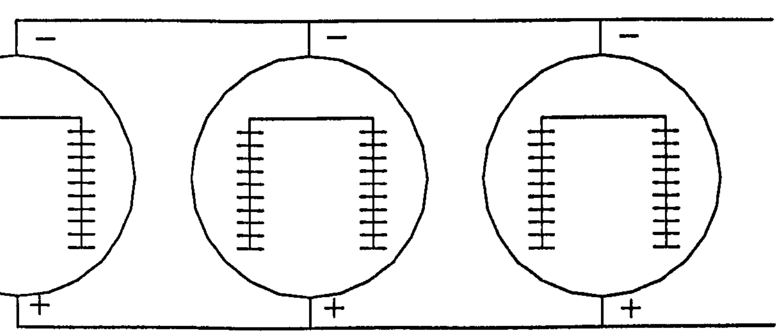

Figure 3.5: A schematic of solar cells connected in parallel.

The parallel connections of cells boost the amperage of the PV module. In this type of connection the back contact of each cell is connected to the back contact of the cell that follows it and the front contact of each cell is connected to the front contact of the one following (positive to positive and negative to negative) – hence parallel connection.

Series solar cell connection is the way in which cells are usually arranged in many commercial modules. The current (amperage) output of such a module would nevertheless be the same as that of an individual cell. In order to boost amperage, the cells must be connected in parallel – i.e., front to front and back to back as shown in figure 3.5. Photovoltaic arrays commonly have modules wired both in series and in parallel. The proper combination of series and parallel connections in a PV array provides the necessary power output required performing the work expected of it, Pearsall (1997).

3.3 Photovoltaic – Grade Silicon

Several characteristics serve to differentiate ordinary silicon from the silicon in photovoltaic cell. Photovoltaic reactions are accomplished most efficiently in a material having a crystalline or polycrystalline structure, Reehal (1999). In a crystal, all of the atoms and molecules are arranged in a definite, constant repeated pattern. A polycrystalline sample is one in which several crystal patterns occur, with the lines of demarcation between them known as 'grain boundaries'. A perfect crystal is a great deal more difficult and expensive to produce than one that exhibits grain boundaries, improved performance is widely balanced against increase expense. There is also a place in photovoltaic for amorphous silicon – that is, silicon whose atomic and molecular structure lacks regularity. Non crystalline silicon (such as amorphous silicon) responds photoelectrically to sunlight, although it efficiency is remarkably lower, therefore, larger cell area is required to produce the same amount of electricity as compared to crystalline or high grade polycrystalline cells. Very thin films of amorphous silicon are currently used in solar-powered watches, calculators and other small, low wattage consumer products. This approach holds considerable promise for amorphous silicon as a major photovoltaic technology in the future, Uniacke (1999).

Photovoltaic-grade, polycrystalline silicon requires less stringent manufacturing procedures than the single-crystalline variety, Wolf (1997). Theoretically, producing an adequate supply of polycrystalline silicon is relatively easy, Sick & Erge (1996). The computer industry and other industries that use semi-conductors grew to maturity while solar electric technologies are still in their infant stages. Existing silicon-processing facilities are geared towards single-crystal production of semiconductor-grade silicon, Norton (1999). Tremendous capital investment in new manufacturing facilities will be needed if polycrystalline silicon is to be produced in the quantity needed to create a cheap abundant supply of solar-grade silicon, Strong (1993). There is evidence to suggest that such investment in now under way, with the 1 million-roof programme in the USA as well as similar programme in Europe, Japan and Australia, Pitts and Gyoh (1998).

3.4 Manufacturing Solar-Grade Silicon

The first step in putting together a silicon photovoltaic cell is the processing of raw silicon. Two objectives dominate this phase of the operation. Firstly, the silicon must be virtually free of impurities, except for the deliberately added dopants. Secondly, it must be delivered in a crystalline or acceptable polycrystalline state, Wolfe (1997). Manufacturing of solar silicon has more latitude in terms of purity. Instead of the one part per billion impurity ceiling mandate for computer-chip silicon, impurities in the base PV materials need only be held to one part per million. This translates into a considerable reduction in processing cost, which helps make photovoltaic affordable.

3.4.1 Monocrystalline Silicon

In the early days of solar cell manufacturing, single-crystal technology was predominant. It was dependent largely upon the *Czochralski* method of growing a perfect crystal, Boyle et. al.(1996). In this process, pieces of pure refined silicon are melted in a crucible. A seed crystal is then inserted into the liquid silicon and withdrawn at a slow, precise rate temperatures above the molten surface are controlled so that solidification proceeds according to an orderly pattern. This pattern is a repeat of the crystalline structure of the seed, resulting in one boule - a solid, cylindrical, single-crystal-ingot ready for processing into solar cells. The quality and efficiency of the material is high, but it is in the next phase of processing that problem of practicality and expense is encountered.

A great disadvantage of slicing wafer from silicon cylinders is that: each slice is so thin, the cuts are so numerous, that up to one-half of the silicon ingot is wasted in the process. The search for a solution has led to ever thinner saw blades and wire-cutting devices. The mechanisation of labour-intensive hand finishing steps. All this has brought prices far below the $2000 per watt cost incurred for photovoltaics on the pioneer satellites of the 1950, Strong (1993). Some observers question whether, even with these improvements, this early crystal-pulling method will ever produce low-cost cells for the "mass market". Manufacturers who continue to cast their lot with Czochralski wafers argue that single-crystal cells yield greater electrical output early and late in the day and are more efficient than polycrystalline cells. They maintain that this is especially so in unfavourable weather conditions and extreme latitudes. Competitors of single-crystal PV technology are steadily improving in efficiency and their lower production costs are making them increasingly attractive.

Single-crystal silicon is the highest efficiency material for converting light energy to electrical energy per unit area (for commercial BIPV systems) typically between 12-17% efficiency. They can now be produced in a verity of colours with a uniform finish. Crystalline silicon is widely believed to be a stable, well-proven material, Hill and Pearsell (1994).

3.4.2 Polycrystalline Silicon

There are two widely accepted ways of getting around the problem of sawing wafers from a single-crystal ingot, Hill (1995). One involves reducing the expense of the ignot and hence the seriousness of the waste; the other completely eliminates the wafer-sawing process. With the first option, the carefully pulled, cast ingot with a polycrystalline structure replaces ultrapure ingot of single crystal silicon, NPAC (1999). The expense of the process is lower because it doesn't require as pure a grade of silicon as feedstock and it is not as tedious as Czochralski crystal growth. The slicing methods are essentially the same, but does lose a fortune every time the saw hits the ingot given that the feedstock is relatively cheap, NPAC (1999).

The cast polycrystalline ingots are square or rectangular in shape, which is a noteworthy advantage over cylindrical silicon stock. When round cells are mounted in a module, there is a fair amount of dead space between them. This is obviously not true with cells cut from blocks. Since dead space generate no kilowatts, a photovoltaic module of a given size made with square cell will be more efficient than a module of the same area that incorporates round cells of comparable efficiency. Manufacturers of single-crystal photovoltaic have recently begun to machine their round boules into a square cross section before cell slicing to take advantage of the efficiency advantage square cells offer.

Polycrystalline is slightly less efficient than monocrystalline. Polycrystalline cells have efficiency levels of about 10.5%, Wallace and Wolfe (1997). Due to the manufacturing process these cells are produced as perfect squares. Its appearance is blue with distinctive grain boundaries. They can also be produced in different colours

3.4.3 Amorphous Silicon

Amorphous silicon is a 'thin film'. It is only a tiny fraction of the thickness of a crystalline cell wafer; its material cost is much lower and can be produced much faster. These cell types capture more sunlight in much lower thickness. They do not have a crystal lattice structure as a result recombination occurs much more readily in this material. Part of the process of achieving reasonable efficiency is by reducing the speed and levels of recombination. This is done by a process that imbues hydrogen into the 'thin film' to 'heal' the dangling bonds that cause recombination. Unfortunately, many of these bonds get released when sunlight breaks the electrons bonds between the hydrogen. This let the hydrogen escape into the atmosphere, resulting into the return of recombination centres. This means that amorphous silicon degrade when exposed to high ultra violet rays over long periods of time resulting to as much as 50% loss in efficiency levels, (Wallace and Wolfe (1997), Reehel (1999)).

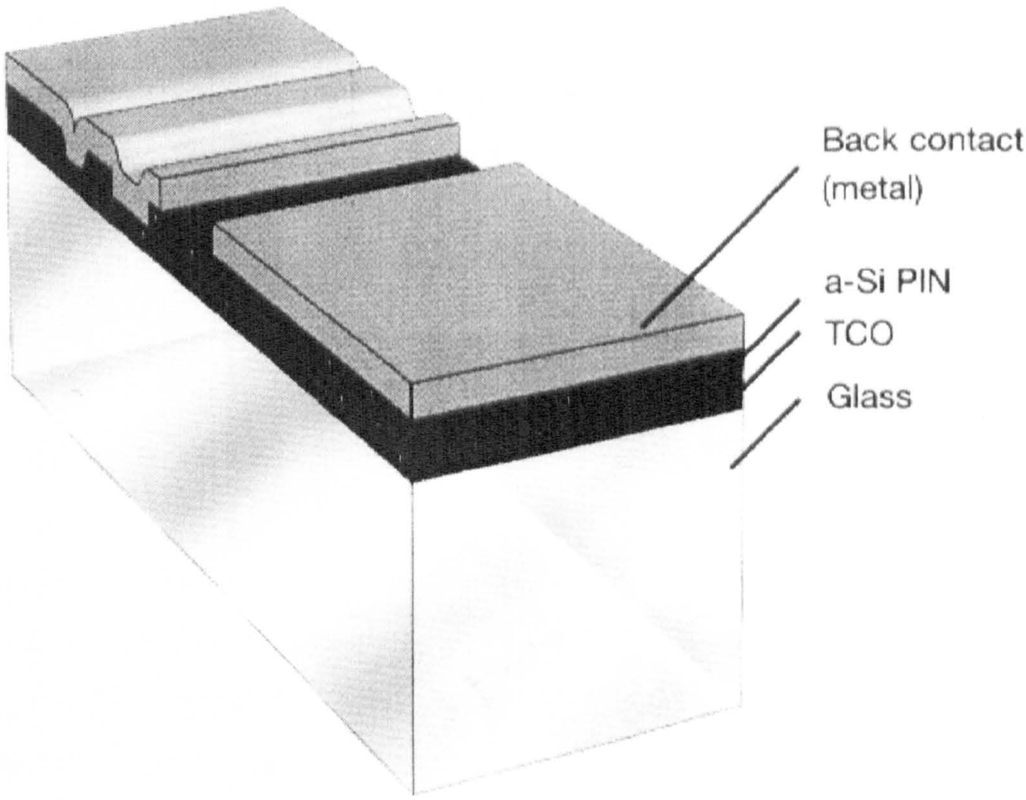

Figure 3.6: Amorphous silicon cell – deposited on glass substrate.
(Source: Intersolar Manufacturers Detail, 1999)

Amorphous silicon is the material used in solar powered calculators. It is made by depositing the material on glass substrate and as such in constructed in a very different way to crystalline cells, (1991).

Amorphous silicon cells tend to be used in applications where degradation is not a serious problem. However, with all the trade-off of lower manufacturing costs, amorphous cells are of much lower efficiency than crystalline cells, Pearsall (1997).

Amorphous silicon module sizes are available up to 1m x 0.5m in one piece. This product is very dark red in colour. Due to its construction the efficiency of these panels is between half and two thirds of crystalline products, Uniacke (1999).

3.5 Solar Cells

Procedure involved in producing solar cells from silicon wafers and assembling these cells into modules i.e. from the fabricating the wafer and its n-p junction is only the first step. Subsequent steps include 'metalisation' or installing contacts for collecting and conducting electricity; applying an antireflective coating; connecting individual cells together to achieve the module's desired output voltage and current; and encapsulation, or sealing, of the modules to assure efficient electrical insulation, protection from the environment, and structural integrity, NPAC (1999).

There are many different cell designs, but each has the same function – to draw electric current efficiently from the cell's top surface without obstructing too much of its area. Since those portions of a cell that are covered by the metallic contact 'fingers' are incapable of absorbing solar radiation, an inefficient contact design will reduce overall output of the cells and hence of the module and complete arrays. The electrical resistance of both the contacts and the interface they create with the cell must be kept low in order to keep internal power losses to a minimum, NPAC (1999).

Since electricity must flow both from-and-to each cell, contacts must be provided at both the front (negative) and back (positive) surfaces. Interference with sunlight is not a prime consideration on the back of the cell, so the contact here is often thin plating of metal over the full area of the cell. In thin film technologies, this plate can even be the substratum to which the semiconductor material is applied. At the front, or n-silicon surface of the cell, contacts appear as a fine metal tracery in parallel, herringbone, pronged, or other configurations, all of which connects with one or more heavier contact bars running near or along the edge of the cell. These contacts are applied by a painting, printing, or plating method, depending on the pace of production and the method favoured by individual manufacturers. The finished product resembling the printed circuitry found in any modern electronic device, figure 3.7.

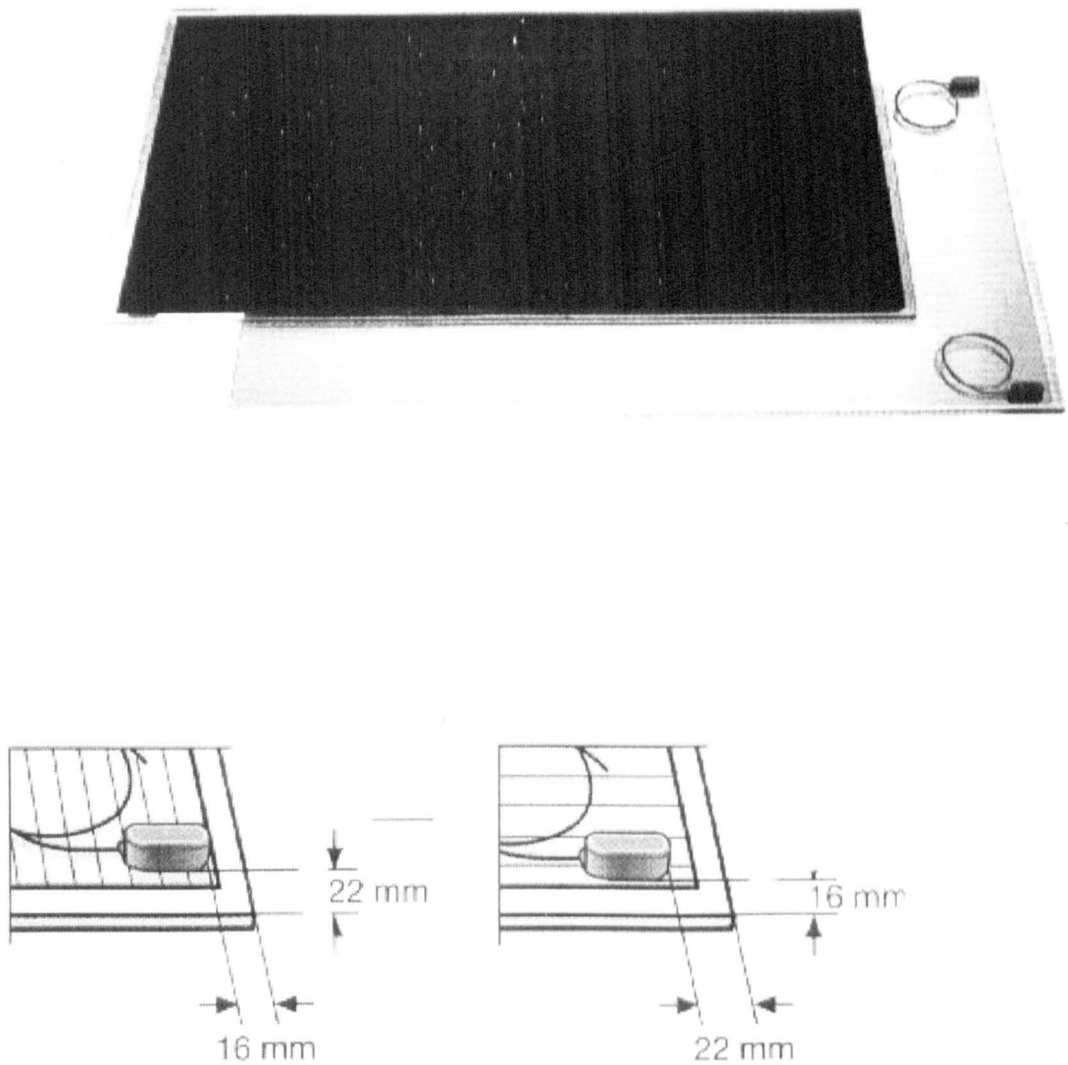

Figure 3.7: Amorphous Silicon Solar Cell Module.

(Source: Complete Power Solution, TRACE Manufactures Details, 1998)

The metallic contacts on the front and back of each cell are also the point series or parallel cell-to-cell interconnections are made. The connections require a linkage that is strong yet somewhat flexible to allow for thermal expansion and contraction. These interconnections made between cells should also be sufficiently redundant so that failure at one point does not jeopardise the entire module. The conductive elements used to join cells are called interconnects. A good deal of research has gone into their composition and design, resulting in an assortment of contemporary options that offer high conductivity, flexibility, and strength, Wallace and Wolf (1997).

Most of the basic 30-40 –watt photovoltaic modules currently available on the market incorporate cells connected in series, while complete arrays may make use of both series and parallel connection between modules. However, many manufactures are now building modules that combine series and parallel string of cells within module, increasing reliability and providing more flexibility in module current and voltage output options.

After each cell is given its metallic contacts, the front surface is provided with an antireflective coating. The reason for this is simple; silicon is highly reflective, and in its polished state throws back approximately 35% of the light that strike it Reehal (1999). To counter this, manufacturers coat their cells with an extremely thin layer of material such as silicon monoxide or titanium dioxide. This type of antireflective coating used gives the different brands of solar modules their characteristic colour. The reflection-resistant, interconnected strings of cells are assembled in a module. Since they are the building blocks of photovoltaic array that may be expected to perform reliably for 25 years or more, the modules must be weatherproof, impact resistant, and capable of withstanding the environmental stresses, such as thermal cycling, wind, and snow loading, to which they will be exposed. Clearly, there is more involved in the making of a PV module than simply wiring together strings of cell affixed to a rigid surface, Gyoh (1996).

3.6 Photovoltaic Modules

The solar cells themselves are very vulnerable to the effect of the environment. Traditionally they are encapsulated to form a solar module. The cells are electrically connected together and placed in a sandwich of toughened special glass and an impervious plastic backing material. This construction is laminated in the same way as a car windscreen to give the cells perfect weather proofing, NPAC (1999). A junction box is fitted at the back of each solar module to provide the outlet for the electricity. An aluminium frame may be fitted around this solar module to provide rigidity and a means for mounting to a support structure (SUCHCO International (1999), Kawneer Europe Architectural System (1999), BP Solar (1998)). Another method of construction is to embed the cells in a resin between two sheets of toughened glass.

The early practices of embedding cells in silicon rubber pottant has given way to more advance and reliable mutilayer lamination assembly techniques. The glass-superstrate module with a multilayer-laminated encapsulation is now the industrial standard. Some manufacturers encapsulate strings of rectangular ribbon cells in a seven-part, heat-sealed sandwich that has as its topmost surface a sheet of low-iron, highly transparent 'water white' tempered glass. Next come a sheet of ethylene vinyl acetate (EVA) for mechanical bonding and encapsulation, and then the cells. These are followed by a cushioning sheet of glass fibres, then another layer of EVA and one of mylar, which provides the dielectric isolation important in high-voltage systems. Finally, the module's backing is applied in the form of a Tedar/ aluminum foil/ polyester laminate, which seals the unit against moisture, (Intersolar (1999), BP Solar (1998), SCHUCO International (1998), Kawneer 1999).

The module is then placed in a lamination chamber, which performs the joint function of evacuating all air from the module and then heat-sealing the layers into an integral unit, with positive and negative ribbon conductors terminating at screw terminals for connection with adjacent modules in an array. The only steps remaining in production are module testing and enclosure of the laminated module in a lightweight frame of aluminium extrusion. Most major photovoltaic manufacturers now follow a similar procedure, with some variation in materials.

The standard solar module arrangement has resulted in module sizes approximately 1m x 0.5m, which are widely available, Intersolar (1999). Given the need of the building market complete panels are now beginning to be produced up to 2m x 2m in size. A much wider variety in PV module sizes is now available.

Solar modules have been available since the late 1960s. Experience suggests that the lifetime is a minimum of between 20 –30 years, BP Solar (1996). The silicon itself is very stable so this figure is expected to be conservative, NPAC (1999).

Most major companies will guarantee the output of their solar modules to up to 90% of power rating for at least 10 years, (Kawneer (1999), SCHUCO (1998), BP Solar (1998)) Figure 3.8, shows a typical profile of a photovoltaic panel.

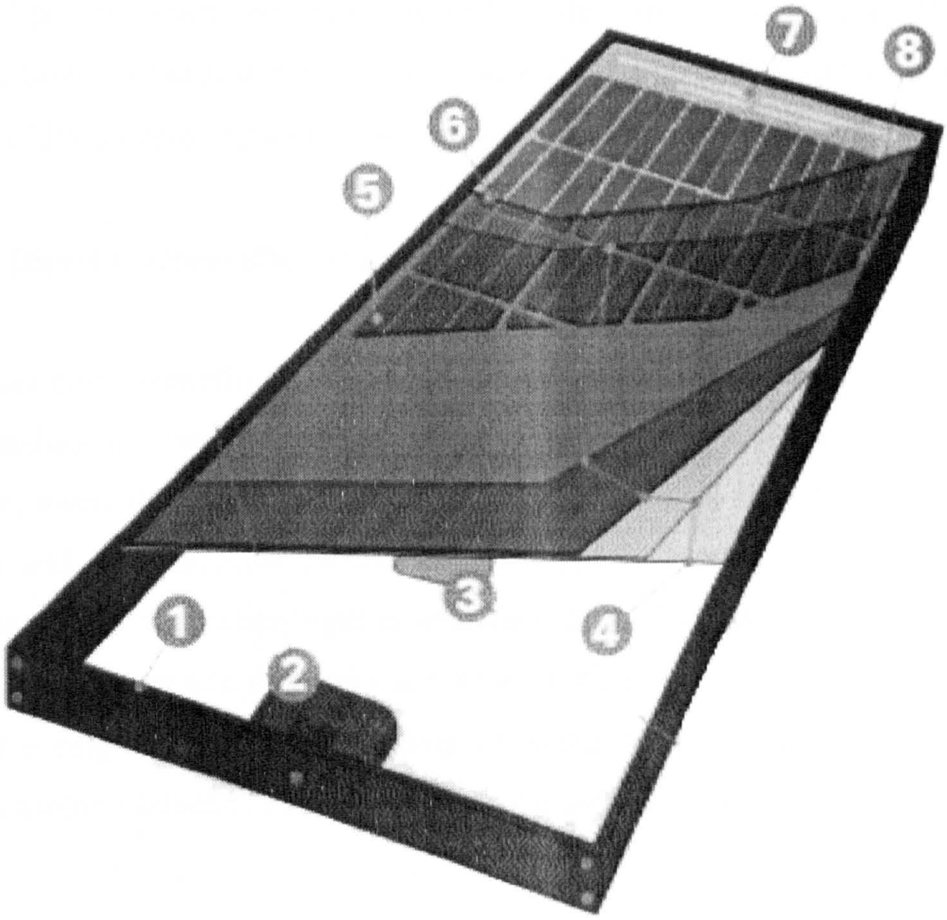

Figure 3.8: Typical profile of a photovoltaic solar panel.

(Source: Solar-Electric Products for Buildings, Solarex Manufacturers Details, 1998)

1. Heavy-duty frame
2. Weatherproof junction box
3. True power rating
4. EVA-tedlar encapsulation
5. PV cell
6. Tempered low-iron glass
7. Reliable outside bussing
8. Frame clearance

3.7 Photovoltaic Power System Design Options

Photovoltaic system takes many forms. Some systems involve storage of current not immediately needed others do not. Some are equipped with devices to regulate the flow of current; others have no such devices. Some use inverters to convert DC output into AC power; others are used only with equipment capable of operating on direct current. Some are linked to the utility grid and interact with it, others stand-alone. A review of PV systems options is carried out in this chapter.

3.8 Direct Current (DC) Stand Alone System

The most basic scenario for the application of photovoltaic electricity to a load is a DC stand-alone system. An electrical system designed and dedicated for a single purpose, where the DC output of the PV array is delivered directly to the load with no storage and no control or regulation. This type of system will power a load that requires power only when light is available. Most PV-powered consumer products such as calculators use this approach. One of the most common applications of this system configuration is the pumping of water with DC variable-speed, variable voltage motor, Oldach (1995). No storage is provided, figure 3.9.

Figure 3.9: A Schematic of the most basic DC Stand-alone System - PV array connected directly to the load with no storage provided.

The next order of complexity in photovoltaic systems involves the use of a storage medium for array output not immediately used by the load. The configuration is still quite simple: the PV array's DC output goes directly to the load, with excess stored in a battery. In the most basic version of this scheme, no voltage regulator is used.
This means that the PV module or array of modules must be carefully sized to provide a self-regulating flow of current to the batteries. If this is not done, the batteries' state of charge must be monitored on a regular basis to prevent overcharging. The system must be checked frequently to ensure that the batteries are not being discharged too deeply. If this is the case, then the load must be disconnected manually to prevent

further drain on the batteries. A typical application for this rudimentary system is depicted in figure 3.10.

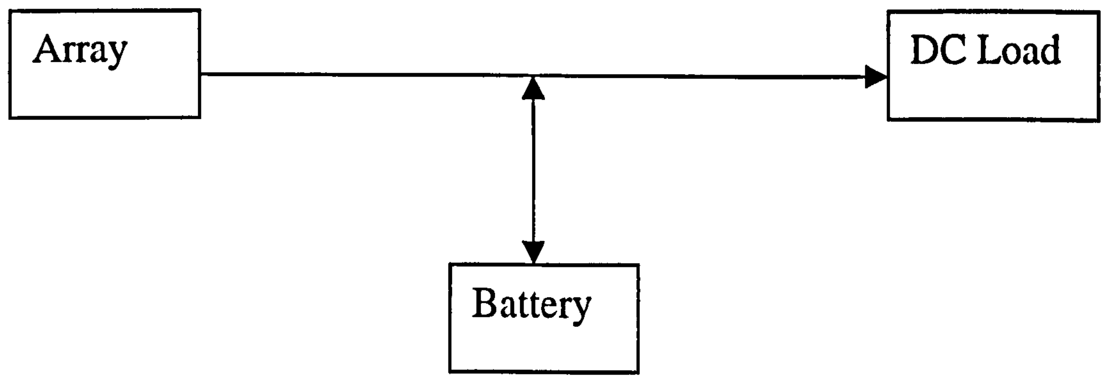

Figure 3.10: A schematic of a basic DC Stand-alone System - PV array connected to the load with storage provided.

The next step in system sophistication is to install a voltage regulator between the array and the batteries. In this way the proper state of charge can be maintained, prolonging battery life. The voltage regulator is an indispensable component in every photovoltaic system that is to be left unattended. Examples include remote communications relay stations, all but the most basic residential installations, and all other PV applications where daily monitoring of Battery State of charge is not practical. Even with a regulator, a straight-DC system of the type shown in figure 3.11 would seldom be used in residential photovoltaic systems that have an array much larger than 500 peak watts (kWp), NPAC (1999).

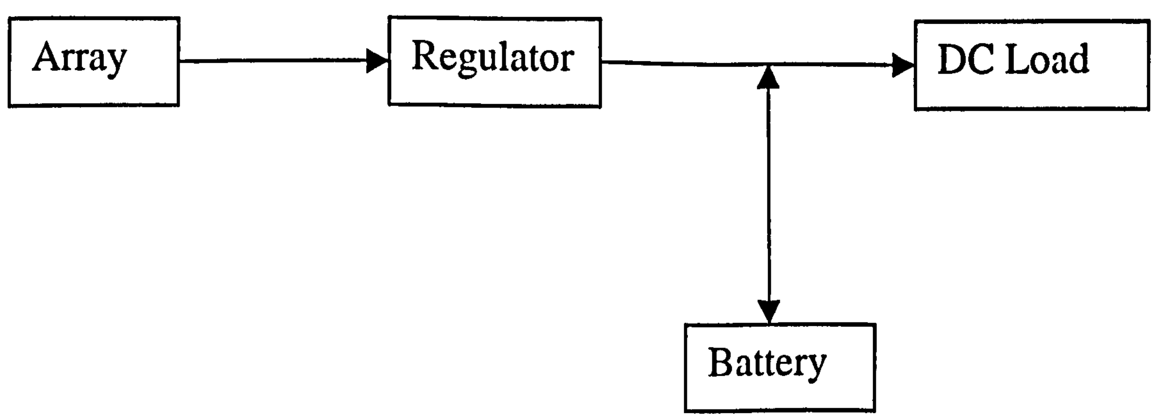

Figure 3.11: A schematic of a basic DC stand-alone system in which the PV array is connected to the load and the battery via a voltage regulator.

3.9 Basic AC/DC Systems

The next stage in complexity is a system that offers the AC option as well as supply of DC electricity. This system, like the one just described, consists of the photovoltaic array, a voltage regulator, and storage batteries. The new element here is a DC –to-AC inverter. The stand alone AC power system is entirely site generated and typically will be part of a scenario calling for between 500 and 1500 watt peak of array output, Strong (1993). As illustrated in figure 3.12, the inverter is interposed between the array, regulator, batteries and the AC load. The DC load in this application is still served by a direct supply of current from the array and batteries.

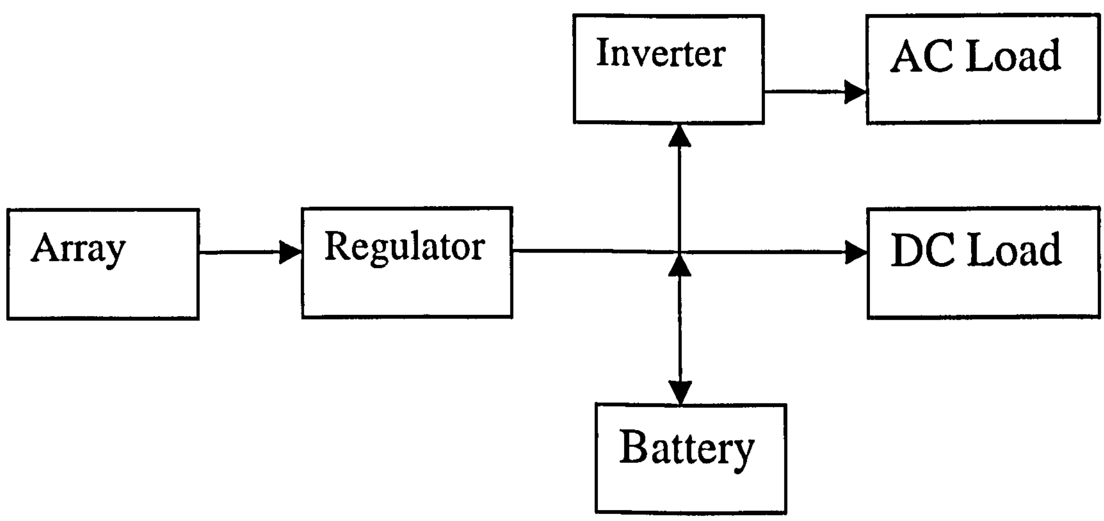

Figure 3.12: A schematic of AC/DC Stand-alone PV System equipped with a voltage regulator, battery storage, and a DC-to-AC inverter.

With its ability to supply power to a wide variety of AC appliances, the system outlined in figure 3.12 represents a substantially more versatile option than the DC-only configurations. However, it still does not address the shortfalls between photovoltaic array output and load demand that might occur after a long period of low insolation and /or the discharge of the batteries to their maximum recommended depth. To deal with this problem when it arises, many owners of stand-alone PV system opt to install an auxiliary engine-generator set. This is similar but less expensive than increasing the size of the PV array and battery storage to cover extreme weather and load conditions. A stand-alone system that includes a generator is depicted in figure 3.13. Generators of the type shown are usually powered by propane or diesel fuel. When the output of the photovoltaic array is insufficient and the batteries are approaching their maximum advisable depth of discharge, the generators is brought into service. The power output of the generator, transferred to the batteries via an AC-to-DC battery charger, brings the storage bank back up to its optimum charge level while at the same time supplying DC loads. The AC side of the system is served directly by the auxiliary generator's AC output, delivered through a transfer switch that disconnects the inverter and connects the generator output to the load distribution.

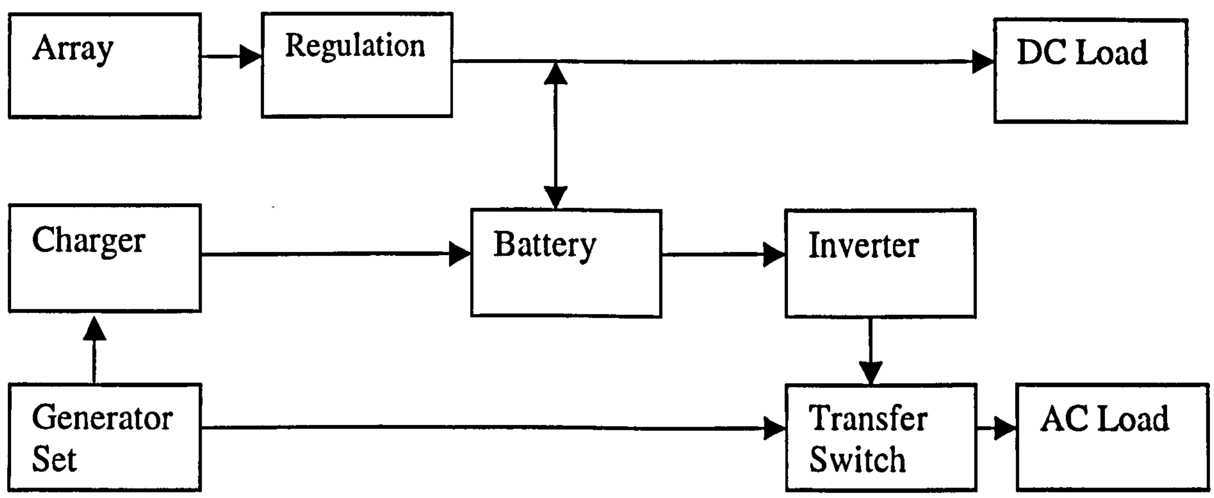

Figure 3.13: A schematic of an AC/DC Stand alone PV system with a voltage regulator, battery, an auxiliary generator, and a battery charge

For all practical purposes, this generator-assist system represents the highest level of sophistication for stand-alone photovoltaics. However, it can be modified in several ways, Strong (1993).

3.10 Grid Connected Photovoltaic Systems

The traditional utility-interactive photovoltaic system is one in which electricity is brought in from the grid to supplement the system's output when needed and sold back to the utility when the PV array's output exceeds the on-site load demand.

Figure 3.14 depicts a transitional system, one that does not completely stand-alone but does not fully interact with the utility grid, either. In this system, power from the grid is substituted for the generator set as an auxiliary source of electricity.

This hybrid system has a DC load, served by direct array output and the electricity stored in the batteries. AC loads are served through an inverter that processes the DC output from the batteries. When both the array output and the level of battery charge are low, power from the grid comes in to make up for the shortfall. The utility-supplied power flow to the DC side of the system through the battery charger. A simple transfer switch disconnects the inverter, allowing the utility power to handle the AC load directly, HGA (1993).

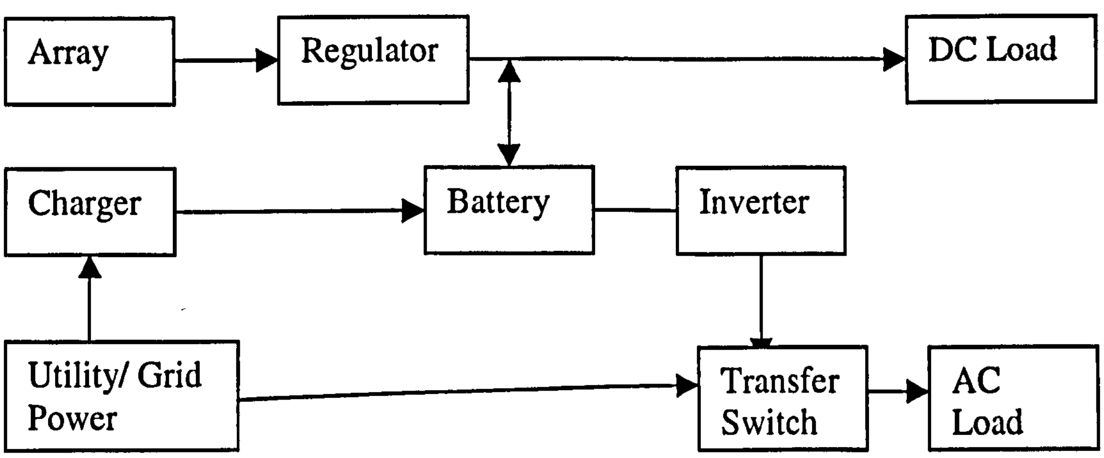

Figure 3.14: A schematic of an AC/DC PV System.

The AC/DC PV power system is equipped with a voltage regulator, battery storage, and an inverter, which uses the utility grid to supply backup power via a battery charger.

This approach has been found to be especially good for people just beginning to use photovoltaics in an area where utility power is available, because it allows for incremental change. At the outset the PV system can be kept small, with power from the grid playing a substantial role. Over time the size of the array and PV systems output can be increased gradually, reducing the amount of auxiliary power needed from the utility. A survey carried out during the course of this study suggest that such a set up is reliable and relatively inexpensive but full interaction (with regards to sell-back of power) with the utility is not possible because of a poor buy-back rate and other policy problems.

With regards to a fully grid interactive photovoltaic system, figure 3.15 and 3.16, here is no provision for battery storage of PV output, since none is needed. All loads are AC loads, and consequently the system's entire PV output is converted to alternating current by means of an inverter, or power conditioner, designed especially for use with a grid interactive system. Any shortfall between load demand and array output is automatically met by power form the utility grid. Conversely, all site-generated PV power exceeding the load demand is fed into the grid.

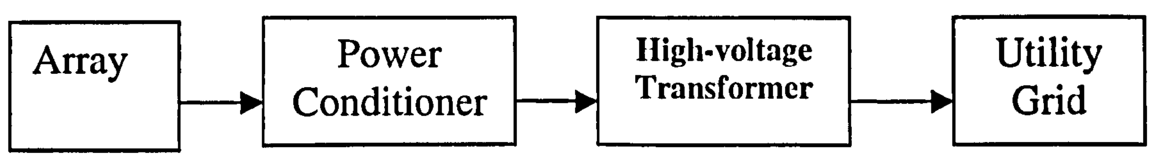

Figure 3.15: A Schematic of a Central – Station utility PV system, which employs both power conditioner and a high voltage transformer.

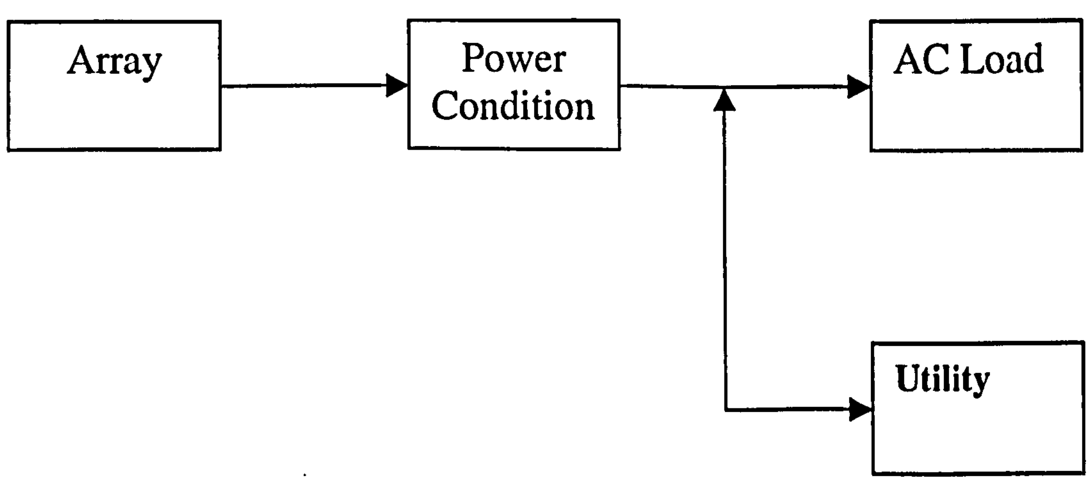

Figure 3.16: A Schematic of Utility Interactive PV System.

The utility interactive (grid connected) system employs a power conditioner designed to make the power produced by the array compatible with the available on the utility grid.

Another component that would be included in an ideal hybrid installation is a small standby battery bank. When the photovoltaic system is interacting with the utility, the batteries would be "floated" at constant full charge. Then, during a utility blackout or at any time when the home owner wishes to isolate the PV system from the grid, the dual-mode inverter would convert the DC battery power to alternating current for the house loads (figure 3.17 depicts this type of system)

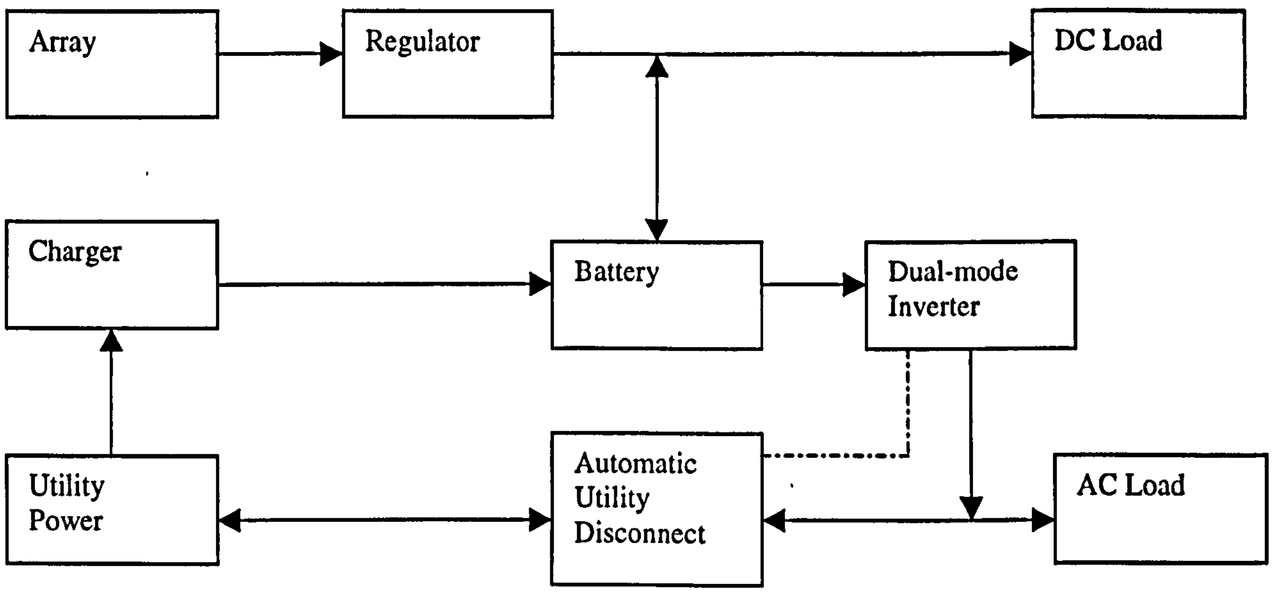

Figure 3.17: A schematic of a dual-mode system PV Power System

The dual-mode PV power system employs a voltage regulator, battery storage, and a dual-mode inverter capable of either utility-interactive or stand-alone operation and features an automatic disconnect to prevent PV system power from flowing out onto the utility line during a line failure – islanding capabilities, (HGA (1993), Weigong He (1999)).

Creating a complete photovoltaic (PV) system involves a series of design steps. One of the first steps is to determine the output of individual photovoltaic modules and to figure out how to assemble them into a functional array. The next chapter focuses on the design aspect involving: photovoltaic module and array configuration to meet the systems power out-put requirements. Whilst chapter 5 reviews the additional components needed to complete a system, system sizing, installation, operation and maintenance.

Photovoltic Modules and Arrays

4.1 Combining Cells into Modules

In each individual solar cell the voltage remains nearly constant regardless of the cell's size. The way to increase voltage is to link several cells together. A specific number of cells are connected in series i.e. positive to negative or back contact to front contract. This is given as:

$V_T = V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots + V_n$, where V_T = Total Voltage, and V_1 to V_n = Individual cell voltage, (series connection).

Current flow, on the other hand, is a function of cell area and the amount of light to which the cell is exposed. Current flow, measured in amperage, is also best increased by linking groups of cells rather than by producing impracticably large and expensive cells. In this case, individual cells are joined in parallel i.e. negative and positive, with contacts joined front to front and back to back. Similarly this is given as:

$I_T = I_1 + I_2 + I_3 \ldots\ldots\ldots\ldots\ldots\ldots + I_n$, where I_T = Total Current, and I_1 to I_n = Individual cell current, (parallel connection).

A group of photovoltaic cells that are joined in a series or parallel configuration, or both, combined into one sealed unit, which results is the PV module, the basic power-producing unit in all PV energy systems. All PV modules that deliver electrical energy to the same load are collectively referred to as the PV array. A group of modules within the array connected and mounted together to form a single structural component is sometimes referred to as a PV panel. PV modules wired together to form a series circuit within a PV array. These are often called a series string or array string, and are sometimes referred to as a source circuit. The relationship between these different parts of a PV array is shown in figure 4.1.

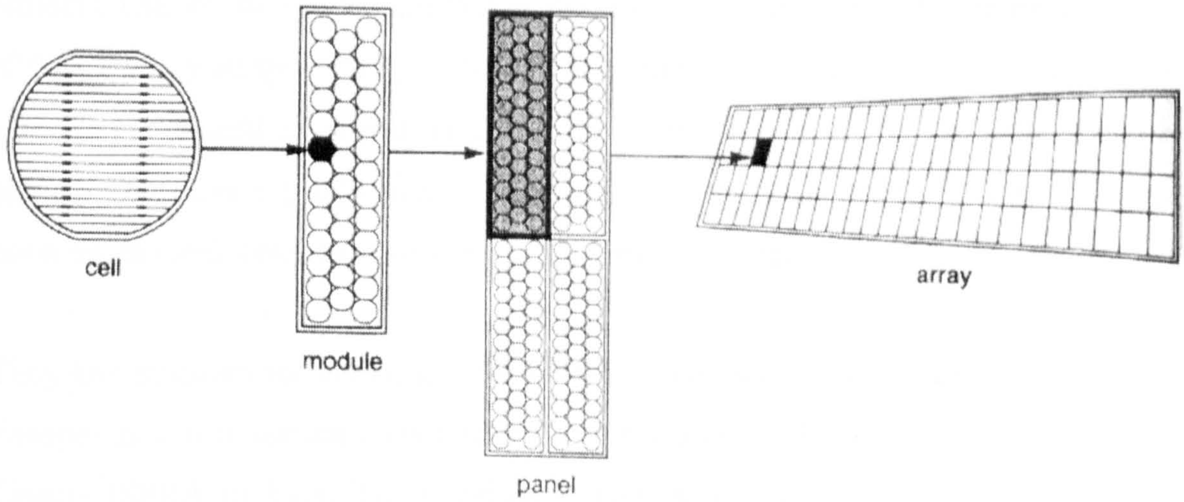

Figure 4.1: The relationship among a photovoltaic cell, module, panel and array.
(Solar Electric House, Library of Congress Publication, 1993)

4.2 Photovoltic Module Rating

The amount of power produced by a photovoltaic module or array and delivered to the load is dependent upon many factors. The two most important ones are the intensity of sunlight striking the cells and the operating temperature of the cells. Additional factors are the matching of the output of the array with the electrical load and the internal electrical matching losses between individual cells in a module and individual modules in an array.

Photovoltaic devices are most productive when they are cold; they produce less and less electricity as their operating temperature increases. Furthermore, the relative thickness and composition of the earth's atmosphere influences the output of a PV cell or module by selectively filtering out certain portions of the solar spectrum. Because of these and other variables, a common set of criteria is need for describing PV hardware

Fortunately, the U.S.A Department of Energy (DOE) with its European counter part ISPRA (in Italy) have created an industrial standard for testing and rating photovoltaic hardware based on performance specification established for (DOE) and European projects. One of the most important of these rating terms applies to the measurement of the power, wattage output, of the PV cells, modules and arrays. It is the peak watt, sometimes referred to as watt(s) peak abbreviated Wp or kWp. The watt peak of a photovoltaic device is defined as the amount of power it can be expected to produce at noon on an ideal, cold, clear day under full, bright sunlight.

They key standard for verification of solar module design (in the UK and the rest of Europe) is a test standard undertaken at the European Union (EU) Joint Research Centre, ISPRA in Italy. The standard is known as 'European Solar Test Institute' (ETSI)-ETSI 503. As part of this standard of test procedures, modules are subjected to the following type tests, Oldach (1999):

- Twist test of 1.2degrees
- Thermal cycling from –40°C to 85°C.
- Mechanical loading of 2400 Pascal on both front and back
- Hail resistance of 25mm diameter ice ball at 23m/second

If the temperature is likely to exceed 85°C such as potentially found in curtain wall installations, then the glass/glass resin infill construction method should be utilised.

For every manufacturer's watt-peak rating to mean the same thing, the industry, under the guidance and direction of ISPRA in Europe and the (DOE) in the United States of America, agree upon a set of Standard Test Condition (STC) under which the peak power rating of modules would be determined. These standards are defined in terms of operating temperature and the amount and type of solar energy available for conversion.

The specified operating cell temperature under standard test condition is 25°C. The measurement for solar insolation is expressed in watts per square metre (W/m^2) of module area with a value for air mass (AM). The idea behind the air mass figure is that since the earth's atmosphere interferes to a varying degree with the transmission of the solar spectrum, some means of expressing this interference is necessary. In space, where there is not atmosphere, the air mass is set at 0. On earth an ideal air mass value would be called 1, but the ideal situation is seldom found. It is usually mitigated by the presence of haze, dust, water vapour, pollution, or any combination of such agents. ISPRA mandated STC for photovoltaic testing includes: an air mass value of 1.5 and an irradiance of 1000 watts (1kW) of solar energy falling on each square metre of module surface. In shorthand, the formula is 1,000 W/m^2 @ AM 1.5. This peak-watt rating is very good for comparative purpose but is unfortunately of little direct value in PV system design because the parameters under which it is taken represent an unrealistically high electrical output, Gyoh (1996). Under typical field conditions, the sun seldom shines on a modules at 1,000 watts per square metre, and cell operating temperature is seldom as low as 25°C, Alison J (1993).

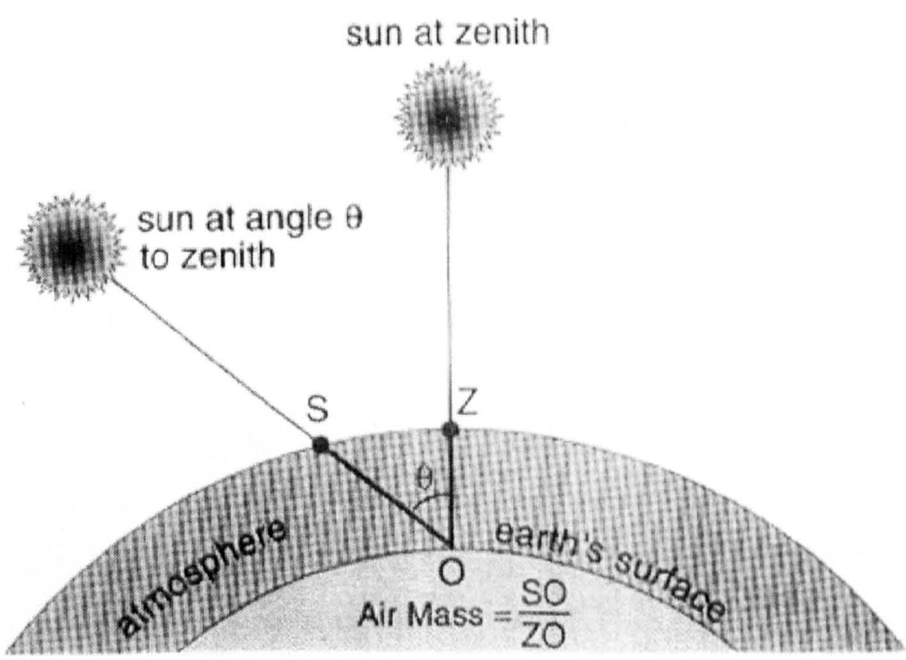

Figure 4.2, Air Mass: is the ratio of the path length of the sun's rays (SO) through the atmosphere when the sun is at a given angle (θ) to the Zenith, to the path length (ZO) when the sun is at its Zenith.

(Source: Geothermal Energy, Oxford Press 1996)

To account for the effect of temperature and create a module rating that more closely represents the electrical output under actual field conditions. ISPRA in conjunction with the American DOE, under the Jet Propulsion Laboratory (JPL) initiative established another set of criteria called - Standard Operating Conditions (SOC) and Nominal Operating Cell Temperature (NOCT), along with several other systematic measurements of insolation and environmental variables.

Nominal operating cell temperatures vary for different cells and modules and for the same module in different mounting configurations, Pearsall (1995). According to JPL and ISPRA specifications, the NOCT is defined as the temperature reached by a cell while it is functioning under standard operating conditions SOC. This also consist of the following set of ambient micro-climatological circumstances: insolation of 800 watts per square metre; air temperature of 20°C; a wind velocity of 1 metre per second; the module mounted in it's final position and oriented toward solar noon; and at open-circuit voltage – i.e. no current flowing. The SOC and NOCT set of conditions, much more, closely approximates what the photovoltaic module will experience under actual field conditions than do the standard test conditions (STC), Oldach (1999).

The impact of cell operating temperature on cell output is an important variable. All photovoltaic modules experience a drop in operating voltage as temperature rises. This results in approximately 0.4% reduction in power output for each degree Celsius of increase in cell temperature, Pearsall (1995). The NOCT of a module in the field will vary from 20 to 40 degrees Celsius above the ambient temperature, depending on the design and packaging of the module, the manner in which the module is mounted, and the amount of insolation it is receiving, Strong (1993). In virtually every installation reviewed during the course of this study - the NOCT was substantially higher than the 25°C specified for STC, Sick & Erge (1996). In an existing PV installation reviewed as part of this study, the installation produces 40 kWp under STC, NPAC (1999). The system delivers only 36.8 kWp at a more normal operating cell temperature of 45°C, under insolation of 1000 watts per square metre. When the

insolation level is reduced to the 800 watts per square metre specified in SOC (which more closely represents actual average field conditions) the module's output will drop to about 28 kWp, Gergory & Pearsall (1996).
A review of analysis of monitoring records of photovoltaic installation carried out during the course of this study clearly indicate that, in practice, the impact of temperature on photovoltaic array output is most significant on large, high-voltage systems. On smaller, battery-charging systems it may never be noticed, provided the array's nominal operating voltage (V_{no}) does not drop below that required in completing the charge cycle. The V_{no} is the maximum voltage produced when a cell, module, or array is functioning under actual field conditions.

Many photovoltaic module manufacturers now list the output of their products at both STC and SOC. If only the rating at STC is available, the system designer must de-rate the modules from the ideal output taken at STC in order to size PV systems properly for actual field conditions of higher cell operating temperature and lower insolation, NPAC (1999). Recent and ongoing studies indicate that it is well worth while to design module and array mountings to allow for maximum free-air cooling of modules and arrays, Jones (1999).

4.2.1 The I-V Curve.

Each photovoltaic cell, module and array has its own unique current (I)/ voltage (V) relationship, known as an I-V curve, which is graphically depicted in figure 4.3 Figures 4.3 right through to figure 4.5 are graphs obtained from studies carried out by the Jet Propulsion Laboratory, California, USA, Strong (1993). The graph (figure 4.4) shows the relationship between current (I) output, measured in amperes, and voltage (V) output, measured in volts. Measurements can be from 0 volts at short-circuit current to 0 amperes at open-circuit voltage - as the resistance of the load across the module is increased from short to open circuit. Short-circuit current (I_{sc}) is current flowing unimpeded from its source through an external circuit with no load or resistance factor; it is the maximum flow of current possible. Open-circuit voltage

(V_{oc}) describes an open circuit with the absence of following current. The voltage potential across a PV cell or module in full sunlight in open circuit is the maximum possible voltage the device is capable of producing, Strong (1993).

On every I-V curve, there is a point in the "keen" of the curve, approximately midway between short circuit and open circuit, at which the relationship of voltage and amperage is optimum and ideal – where the product of the two, power in watts, is the highest. This point is called the modules maximum power point (MPP). The voltage at this point on the I-V curve is represented as $V_{m,}$ the current as I_m, and the output as P_m.

The I-V curve shown in figure 4.4 taken at STC of 1000 W/m^2 and 25°C cell temperature, provides the following module performance data: I_{sc} is roughly 2.1 amps, V_{oc} of approximately 18.3 volts, I_m of slightly under 2 amps, and V_m of about 14.9 volts.

Module output current varies linearly with solar intensity as shown by the family of I-V curves found in figure 4.4. A 20% decrease in insolation results in a decrease in current output from 2.1 to 1.7 amps. Current also increases slightly as temperature rises. Voltage remains nearly constant as a function of solar intensity but is affected by variations in cell temperature, as shown in figure 4.5. As ambient temperature rises, operating cell temperature also rises, reducing output voltage.

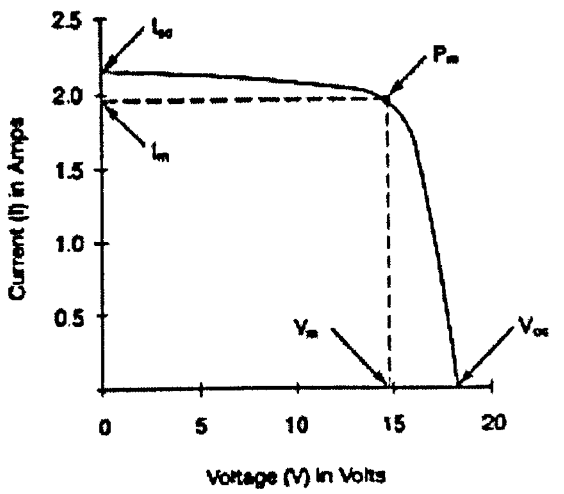

Figure 4.3: I-V curve showing the relationship between current and voltage
(Source: The Solar-Electric House, Library Cataloguing Publication, 1993)

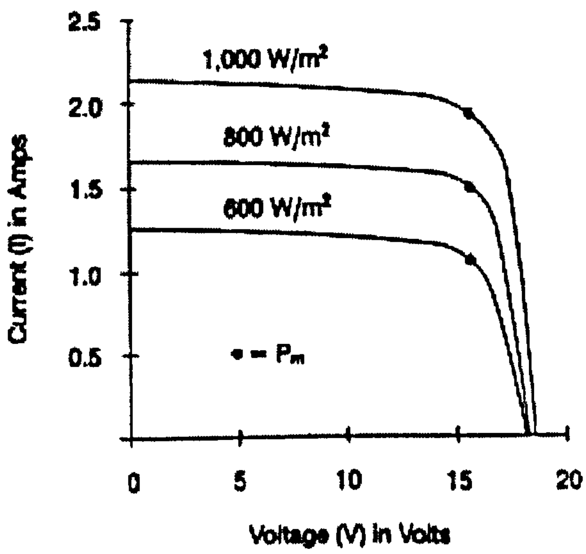

Figure 4.4: A Module I-V curves showing the effect of insolation intensity on current.
(Source: The Solar-Electric House, Library Cataloguing Publication, 1993)

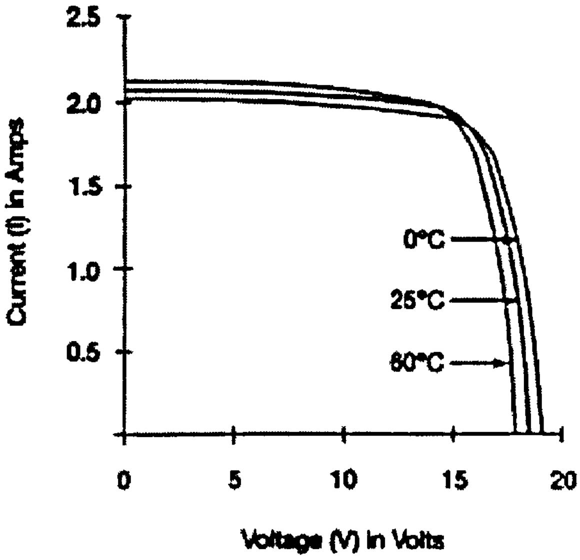

Figure 4.5: A Module I-V curves showing the effect of cell temperature on voltage.
(Source: The Solar-Electric House, Library Cataloguing Publication, 1993)

Peak power is at the knee of the I-V curve. It is the point at which the product of voltage and current is at its maximum. Figure 4.4 and 4.5 indicate that peak power is affected far more by variations in solar intensity than by variation in temperature.

I-V curve serves as useful design tool for a photovoltaic system designer and can be developed for cells, modules, panels, or arrays. They provide the necessary information to ensure that a PV system is configured to operate as close to its peak power point as possible. The I-V curve is valuable both during the design phase and during installation and operation of a photovoltaic system. Through the use of an electronic device called an I-V curve tracer, it is possible to chart the course of a curve and its maximum power point either as part of a troubleshooting procedure or as a step in matching the modules to be connected in series to form an array string. Some manufacturers provide I-V curve data with each new module to make this procedure that much simpler.

Many large and more sophisticated photovoltaic systems are designed to be used with an automatic electronic control circuit called a maximum-power point tracker that forces the array to operate at its optimum power point. This allows the system to extract all the power available under constantly varying conditions. Maximum power tracker, come as a standard feature in higher-quality DC-to-AC inverters and can also be purchased as discrete components for use in large-scale PV systems, at the time of this study.

4.3 Review of Commercial Photovoltaic Modules

Currently, there are several dozen manufacturers of commercial photovoltaic module word wide, many of whose products are well suited for use in building integrated photovoltaic installations. Table 4.1 compares a small sampling of these modules, representing a cross section of current approaches to silicon technology. It is worth while mentioning that innovation strides are made on an almost weekly basis in this dynamic new technology, so the specification cited here necessarily reflect only a momentary state of the art. The voltage output for an individual photovoltaic cell remains at a fairly constant value of about 0.5 volt, give or take fractional variations. The nominal 16.5-volt rating for the Mobil Solar Ra39-12 module represents an accumulated voltage made possible by the connection of a string of 36 cells in series. Connecting two of the 36-cell series strings in parallel to boost amperage has no effect on the voltage. Majority of the photovoltaic modules, currently, available on the market are designed to charge 12-volt batteries, Derrick (1995). This means that they have the appropriate number of cells to deliver between 15 and 17 volts DC under standard operating conditions (SOC). For design of large photovoltaic systems, the ideal PV module will usually have a nominal output voltage higher than the standard 12 volts- perhaps 24 or even 48 volts, Strong (1993). Mobil Solar Energy Corporation was the first to enter the marketplace with large-area, high-voltage modules. Their Ra-220 module, which measures 1.2 by 1.8 metres, can be ordered in 12, 24, 36 or 48 volts versions to provide optimal flexibility to the system designer. These high-voltage modules are valuable to the designers of large-scale PV systems because they require fewer module-to-module series string connection to deliver the high array voltage requirements, Sick & Erge (1996).

The cost per watt peak, is not the only factor to consider when choosing a particular module. The manufacturer's basic standards of integrity and the long-term operational performance of the product are equally important. Building integrate photovoltaic array installations should be designed to meet the criteria set by Jet Propulsion Lab in the United States and ISPAR, requirement-protection class II, in Europe. These criteria establish both electrical and mechanical design standards and measure the effect upon performance of environmental influences such as extreme temperatures, humidity, hailstones, wind, and show loads.

4.3.1 AC Modules

AC modules offer a lot of advantages compared to traditional photovoltaic systems with one central inverter, Oldach (1999). These do not only relate to safety, but also to economics, especially of smaller systems. AC modules are especially interesting to use for the integration into buildings, as the independent operation of AC modules prevents that a whole PV system will function poorly due to shading of only one PV module.

Research and development into AC module inverters started in the early nineties, Oldach (1999). The development efforts have resulted in AC modules inverters ranging from 100 to 250 watts. The available inverters are all more or less mature. Currently the Dutch are at the stage of market introduction, NPAC (1999). Large experimental projects are being carried out to gain data about inverters, on site. Safety standards are being developed in order to guarantee safe operations on the inverters, Oldach (1999).

Oldenkamp and Delong (1998) argue that: traditional photovoltaic (PV) systems require complex DC cabling giving rise to a lot of problems. In particular grid connected PV systems - with one central inverter have shown significant problems with respect to:

- High DC voltage levels
- Safety
- Cable losses
- Risk of DC arcs.
- Fire hazard and protection

Most of these problems can be overcome by expensive cabling and installation systems, but such solution increases the cost at system level. Components like inverters, switchgear, cable, have to be selected in accordance with system size. This requires an individual design of each system and is an obstacle in expanding the system.

The installation of traditional PV system is rather complex. AC modules, in which the inverter is integrated in the PV module, overcome these problems. The advantage of AC modules compared to traditional PV systems are as follows:

- Each module works independently: if one fails, the other AC modules will carry on delivering power to the grid;
- High modularity allowing easy system expansion;
- Low minimum system size of one AC module, lowering the threshold for individual to start their own PV plant;
- Use of standard AC installation material, which reduces cost of installation material and system design;
- Low conduction losses and cable costs;
- No mismatch losses at system level as each AC module operates in its own maximum power point (MPP)
- No need for string diodes;
- No need for bypass diodes;
- Low lighting induced surge voltages, because of the DC compact system layout.

The main advantage of the use of AC module is summarised in figure 4.6, simplicity of the total system. All these features make AC modules an interesting option for the integration of photovoltaic system into buildings. AC modules operate independently of each other; this avoids the poor operation of an entire installation resulting for the shading of a single PV module.

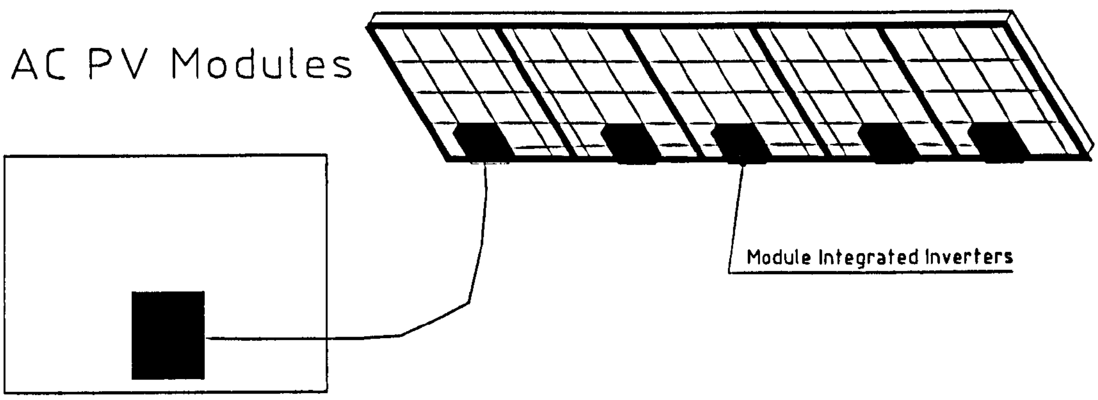

Figure 4.6: AC Module.

In the USA strong government support and utility push has led to AC module inverters based on traditional techniques. In Europe developments are rather initiated by private companies, although in some cases supported by national governments. In countries that enjoy government support more innovative concepts have been observed in the research and development of AC modules, NPAC (1999).

The various development efforts, over the past 3 – 7 years, has led to AC modules inverters ranging from 100 to 250 watts. The selection of power size is based on technical feasibility, economics and the size of available PV modules. The switching techniques used range from more conservative (low frequency, 50-100kHz) to more innovative (high frequency of up to 500kHz).

Inverters of AC modules are mounted on the rear side of the PV module. The OK4-100 model (one of the most popular models) offers the possibility of mounting the

inverter on the frame. Some of the inverters are fully potted, which has a positive effect on safety and life span.
The first prototype AC module inverter was developed in 1992. It was developed by the 'Zentrum fur Sonnenenergie und Wasserstoff' (ZSW), Germany. It consists of a 50 watts inverter, using high frequency concept.

In 1994 ZSW produced the first series of 100 watts inverters, based on the same technique. Economics and electromagnetic interference factors has resulted in ZSW use of low frequency switching concept for their small inverters.

Whether AC modules can compete with traditional PV systems does not only depend on the price of the inverter itself: the selling price of the whole AC module is decisive. Generally the PV manufacturers that sell the AC modules set the price. There is a tendency to increase the price of AC modules, due to its' high added value, compared to a PV module - with more than the price of the inverter. Prices of AC modules differ significantly- ranging from US$6 –to- US$ 9 per Watt peak. Depending on the country, AC modules are priced competitively with traditional PV systems for systems up to about 700watts, Oldenkamp (1998).

There is a distinct difference between the perception of the market in Europe and the USA. In Europe the private market is seen as the largest potential segment. Roof top implementation offers opportunities for AC modules De Jong (1998). The 'Growth project' started in 1998 in the Netherlands is serving as an example. On 9000 roof initially four AC modules will be installed. The private owners of the houses will be encouraged to expand their PV plants with additional AC module in years to come. In the USA however, observers expect most AC module plants of 1-10 kWp or even larger to be the convention. AC module manufacturers perceive the government and utilities as the main buyers of AC modules.

Currently AC modules are being implemented in several large projects. Most of these projects still focus on demonstration and obtaining data about AC modules in the field. Examples of projects are found all over Europe. In the Netherlands currently 2100 AC modules are being implemented in a large sound barrier. With growing market projects focus on other aspects of AC modules: safety, life span and economics.

In several countries safety standards for AC modules are being developed. In the Netherlands this has resulted in the KEMA-approval for AC module inverters. Currently all AC module inverters used in the Netherlands have to comply with this approval. In the USA the Underwriters Laboratories (UL) developed a standard (UL 1741) especially for AC modules. The SunSine 300 and the M1250 are both UL listed, while the OK4-100 probably will be listed in the spring of 1999.

The market of AC modules will strongly grow especially when private persons enter the market. It is expected that before the next millennium 50,000-100,000 AC modules will be installed. With these numbers the reliability of the AC module will be proven by the year 2000 and beyond, Oldenkamp (1998).

Manufacturer And module	Cell Type	Peak Power (W)	Physical Dimension (mm)
ARCO Solar M-51	Monocrystalline	40	900x300
Mobil Solar Ra39-12	Monocrystalline	39	900x300
Kyocera PSA100H-361S	Polycrystalline	40	900x300
Mobil Solar Ra220-24	Monocrystalline	220	1800x11200
Solarex SX-42	Polycrystalline	220	1791x1097
Solarex Max-120	Monocrystalline	120	1097x981
BP Solar BP275/270	Monocrystalline	75	1188x530
AC-100 AC Modules	Monocrystalline	100	1289x648
Intersolar UK A-Silicon	Amorphous	14	900x300
ASI ASI Oi	Amorphous	50	1000x600

Table 4.1 A comparison of module specifications (Source: Compilation from the various manufacturers details and specification)

4.4 Photovoltaic Modules and Arrays

A single photovoltaic cell produces approximately 0.5 volt at 2 amps, NPAC (1999). Virtually all loads in building integrated photovoltaic systems require higher levels of both voltage and current. Every photovoltaic system is depended upon an appropriate compounding of both voltage and amperage. This is accomplished at two levels within the modules themselves and through the electrical interconnection of the modules to form the array. Connecting cells or modules in series results in an accumulation of voltage, while connecting them in parallel causes current to be compounded, figure 3.5a and 3.5b.

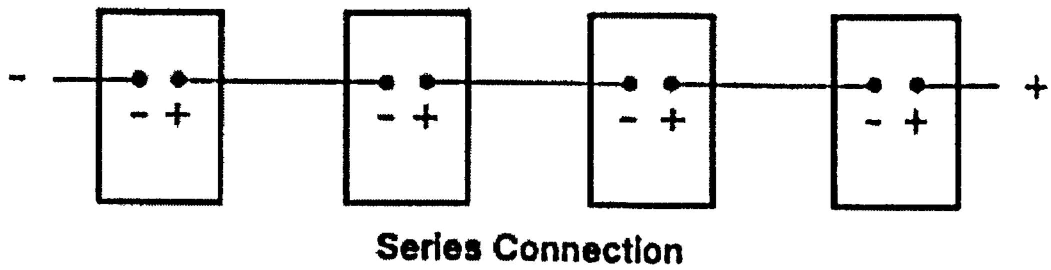

Figure 4.7: Cell connected in series to accumulate voltage (V)

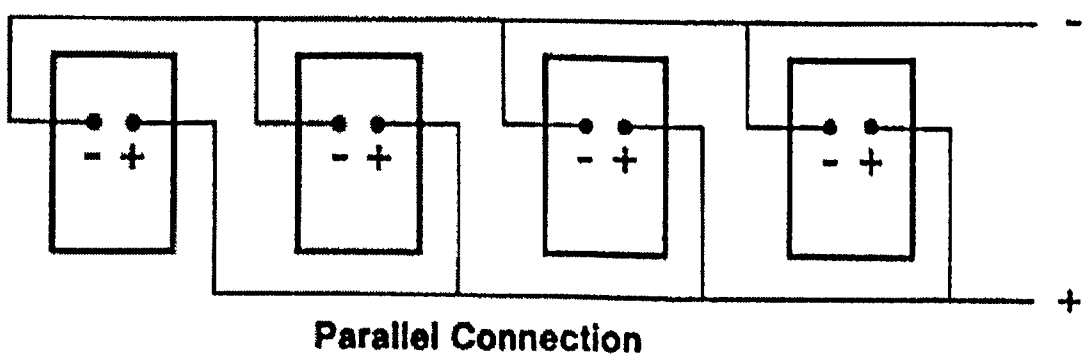

Figure 4.8: Cell connected in parallel to compound current (I)

Photovoltaic module output ratings are affected by operating conditions – most notably insolation and temperature. The understanding of these rating, and the ability to configure multiple series/ parallel combinations of modules, to deliver the desired voltage and current, are prerequisite to the design of a photovoltaic array to handle a particular load requirement , Strong (1993).

4.4.1 The Series String

The basic intermediary unit between module and array is the series string or source circuit. This is the number of individual modules connected in series that will produce the nominal amount of voltage desired for the array output. The string itself thus becomes an integral electrical sub-component of the array. The required number of series strings are then connected in parallel to bring the system amperage (and thus voltage) up to the desired level.

When assembling a series string, it is important to avoid or at least reduce module mismatch by joining together modules that are identical or near identical in performance- hence the usefulness of I-V curve. The series string is like a chain, it is only as strong as its weakest link, that is, its weakest module or even its weakest cell. Despite the uniformity of testing procedures and manufacturers' claims for rated performance, the fact remains that output will vary from module to module within a single product line. The series string output will be no better than that of the poorest-performing module in the series. If the modules are purchased from a manufacturer who provides individual ratings, the job of matching them in a string is, of course, that much easier, Gyoh (1996).

Mismatch is not nearly as much of a problem in the next phase of array assembly: the parallel connection of series stings to achieve the necessary accumulation of current. This is because a parallel sequence of connections, unlike a series, will result in an averaging of the individual strings' output rather than a reduction of output to the lowest common denominator, Pearsall (1998). The stronger modules in a parallel string can help to pick up the slack for the weaker ones. The parallel connection of the individual series strings is usually done inside a device called a string combiner box.

4.4.2 Effects of Array Orientation

Whilst it is clear that tracking makes possible a greater array output, studies show that the additional power does not justify the complexity and expense inherent in a tracking system, Pearsall (1995 (1)). An exception may be made for very small PV systems used in the Sunbelt. For small arrays of three to six modules, a rather elegant passive solar tracker has been developed by Zome work that uses freon to provide reliable unattended polar-axis tracking. Despite the availability of such devices, the majority of PV systems in operation today utilise an array at a fixed tilt angle.

For optimum output, a photovoltaic module not only must be mounted at the proper tilt, it also must face in the best direction. For all location in the UK , PV modules should be oriented towards true solar south for maximum output. The farther north the location of the installation, the more important the true south orientation is, because the path of the winter sun becomes ever more limited.

The sun's path changes through out the year. The angle that is formed between the horizontal and an imaginary line that begins at solar noon from a particular location on earth and travels through the centre of the sun is called the sun's altitude angle. This angle varies by over 46 degrees between the summer and winter solstice. When the path taken by the sun across the sky in relation to a fixed surface inclined at a particular angle is considered along with solar insolation data, the resultant relationship becomes a dynamic model. This is because the sun's angle of incident to the fixed tilt surface is constantly changing as a compound function of both altitude angle and azimuth angle (the angle of deviation from true south). Often the only insolation data recorded for many locations throughout the world is taken from a horizontal surface. This data is available on both a monthly and yearly basis. Photovoltaic modules are not mounted horizontally (except perhaps at or near the equator), but instead are usually tilted at an angle from the horizontal corresponding to the site latitude.

Thus, the amount of insolation striking this tilted surface will be somewhat greater than that which occurs at the horizontal. The formula for calculating the amount of *total tilted insolation* (TT) at a particular site using horizontal data is as follows:

$$TT = \frac{\text{Total horizontal insolation}}{\text{Cosine of (latitude x 0.85)}}$$

The altitude angle of the sun changes constantly over the course of a year.

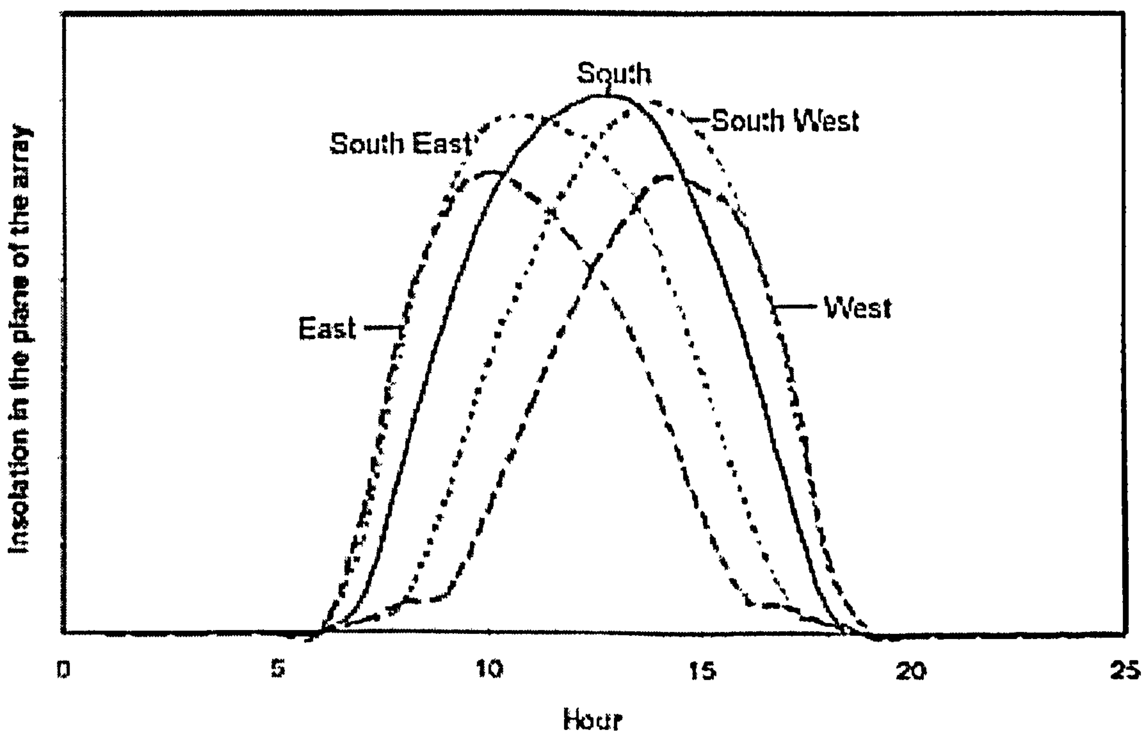

Figure 4.9: The effect of orientation on incident solar radiation reaching a PV array.
(Source: Newcastle Photovoltaic Application Centre, 1997)

Result of simulation and experiments carried out at the Newcastle Photovoltaic Application Centre, Newcastle UK, Pearsall (1995(1)).

4.4.3 Tilt Angle

Setting the tilt angle, of PV arrays, by latitude works fine midway between the solstices – that is, on March 21st and September 21st – but is not ideal during the remainder of the year. During the other times, to find the ideal angle for mounting PV modules, the *declination angle* need to be factored in. The number of degrees higher or lower than the latitude angle that the sun reaches at solar noon on a given day. The declination angle varies each day, changing from – 23.45 degrees on December 21st to 0 degrees on March 21st to +23.45 degrees on June 21st and back to 0 degrees on September 21st, Pearsall (1995(2)). The sun's altitude angle at solar noon for any given site on a given day can thus be expressed by the following simple formula, Strong (1993):

Altitude angle = 90° – Latitude angle + declination angle

The problem is that the declination angle changes every day. Changing the tilt of an array consisting of more than a few modules on a daily basis often creates more problems than it is worth, and the increased electrical output that results seldon outweighs the labour costs involved. In practice the tilt of a flat-plate photovoltaic array should be changed a minimum number of times over the course of a year, if at all. Generally speaking, it is best to determine the optimum fixed tilt for the system being designed and size the array accordingly. This produces the best overall results in terms of cost and complexity of the system, Toggweile (1998).

For a load that remains constant throughout the year, the best approach is to set the tilt angle equal to the latitude plus 15 degrees, which orients the array toward the low altitude angle of the sun in winter when the least amount of insolation is available. Even though this is about 30 degrees away from the best 'summer tilt' the extra light available from the sun during the summer makes up for this non optimum setting. This result is a fairly steady module output throughout the year.

Figure 4.10 shows the effect on the Tilt Angle (TA). Simulations and experience carried out at the Newcastle Photovoltaic Application Centre (NPAC) on the effect of tilt angle to the amount of solar radiation that incident of the PV modules.

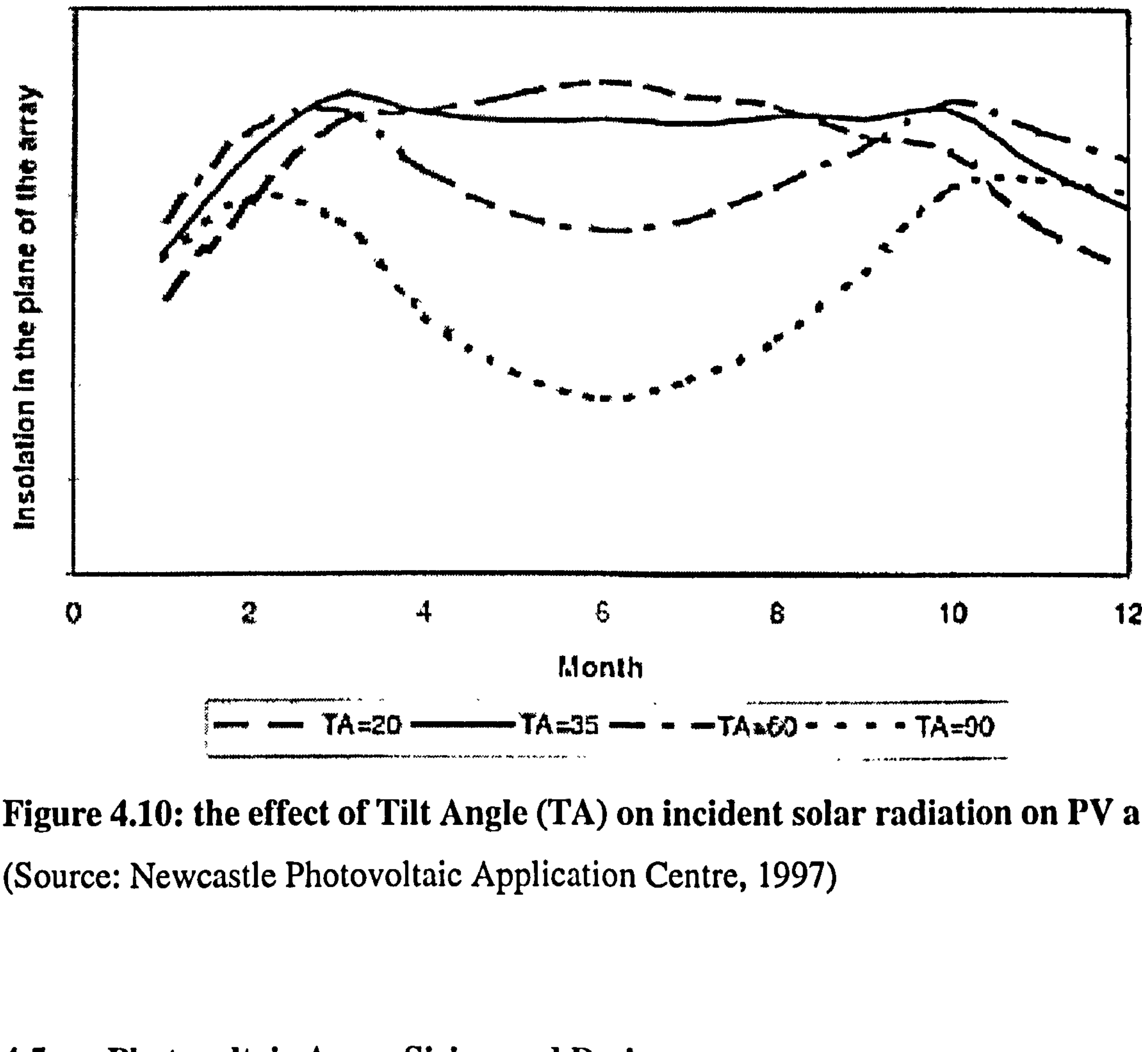

Figure 4.10: the effect of Tilt Angle (TA) on incident solar radiation on PV array
(Source: Newcastle Photovoltaic Application Centre, 1997)

4.5 Photovoltaic Array Sizing and Design

The process of sizing a photovoltaic array begins by determining the number of PV modules that are needed to ensure that the user of the system can rely on receiving the desired amount of electrical power, Pearsall (1997). To accomplish this, the PV system designer requires detailed information on two basic parameters: first, the amount of electrical power required by the load; and second, and the amount of solar energy available at the site, NPAC (1999).

Performing a detailed design analysis for a photovoltaic system requires accurate knowledge of the load in term of both the amount of electricity required and the time when it is required. They are basically two methods commonly used in the sizing of

PV arrays. The first method utilises calculations whose electrical units are expressed in term of ampere-hours, or amp-hours. This method is most often used in the sizing of stand-alone systems that are used to charge a battery storage bank. The second method of array sizing expresses electrical units in terms of watt-hours or kilowatt-hours and is usually employed when sizing utility – interactive photovoltaic arrays or stand-alone systems that work without battery storage (such as direct-coupled water pumping systems)

4.6 Balance of System

The Balance-of-system components are the parts of a photovoltaic system supplementary to the modules. These include the lighting protection device, string combiners, blocking and bypass diodes, voltage regulators, shunt regulator and inverter to mention a few

As electricity flows from the array through the system toward the load the first specialised component it should encounter is a lighting protection device. The threat that lighting activity poses to a conventional house is compounded in the case of photovoltaic-powered building by the potential damage to electronic balance of system (BOS) equipment by high-voltage surges.

The physical point at which the leads from the photovoltaic array strings or source circuits are joined in parallel to create the main array output leads is called the string combiner. It is essentially a sophisticated junction box, the place where all the positive and all the negative leads from the strings are brought together after being protected from 'high-voltage transients' by the surge arrestor.

In photovoltaic systems that interface with the utility grid and incorporate no provision for storage, voltage regulation is taken care of by the utility since the utility interactive inverter operates at the utility supplied voltage. However, when the electrical output of a PV array is stored in batteries, it is necessary to include a separate voltage regulator as an intermediate component between the array and the batteries. The basic purpose of a voltage regulator is to control the flow of current from the array to the storage batteries in a stand-alone photovoltaic power system and to maintain the state of charge of the batteries, preventing them from overcharging or undercharging. Direct current (DC) generated within the modules of the array flows through lighting protection and source-combining equipment directly to the inverter, which, along with its filters and controls, is referred to as the power conditioner in a grid connected system, figure 4.11.

At the power conditioner, the raw DC output of the array is inverted to alternating current (AC) electricity of the quality required for load consumption and grid interface. Depending upon the level of output and the fluctuating demand of the building loads the AC power from the power conditioner flows either to the building load or – during times of excess output – to both the loads and the utility grid. If there is no on-site loads, all of the PV generated electricity will flow into the grid.

However, with a Grid connected photovoltaic system, there are then two paths by which electricity can enter the building circuitry leading to the loads: the output line from the power conditioner and the line from the utility service entrance, both can function simultaneously. The utility mode can function separately without any contribution from the PV system, because utility power does not flow through the power conditioner to enter the building distribution. However, the PV side of the system cannot operate with complete independence from the utility. With present equipment, the utility requires that the PV system immediately disconnect from the grid, when the grid fails. This eliminates any possibility of PV-generated power being fed out onto a downed line and endangering service personnel, Gyoh (1996).

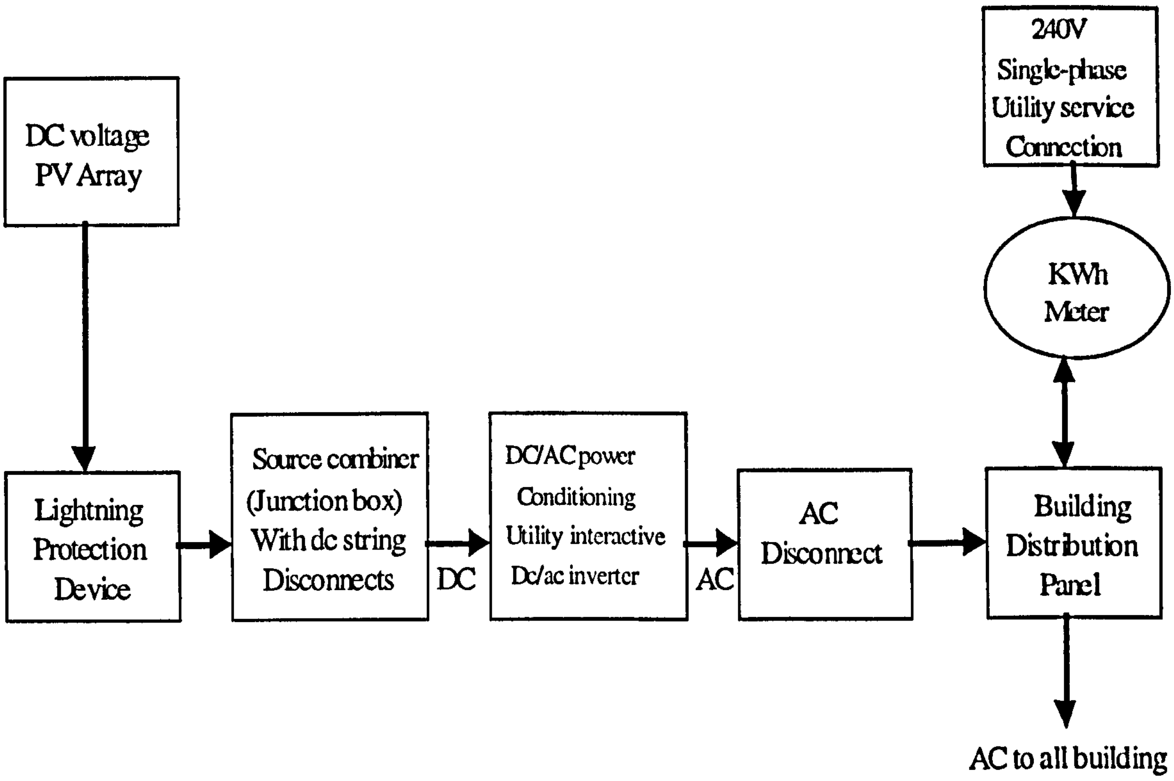

Figure 4.11: A block diagram of a utility interactive Building Integrate Photovoltaic (BIPV) system.

Chapter 4 reviewed issues concerning PV system design-management strategies and option, from cell connections to module configuration and array orientation within the framework of photovoltaic system design and installation procedures. Maintenance procedure as is currently the practice was also touched upon. Chapter 5 provides a framework for value management during the design development and planning process for BIPV installation. The system choices would also provide the basis for re-engineering of project object along the requirements of individual client/project objective. This chapter also reviews Balance of System (BOS) design option. BOS is crucial to a successful PV system design and has far reaching implications in terms of optimising installation and maintenance procedures and processes. A successful PV cladding systems installation within the context of this study is a system that satisfy the clients need and project objectives. Chapter four looks more closely at the installation and maintenance implication on a PV system design. This is believed would provide a prelude to the optimisation process of the design-management planning and installation practices of BIPV system within the UK construction industry.

Photovoltaic Systems Installation and Maintenance

5.1 Photovoltaic Systems Installation.

In large photovoltaic systems with DC voltage greater than 48 volts, the choice of a PV module determines string length. String length, in turn, influence both the electrical characteristics and the physical sizes and shape of the array. Module selection immediately establishes the number of options available to the architect and system designers when sizing and laying out the configuration of the PV array. This is especially critical for arrays that will be integrated into the structure of a building.

The importance of module voltage and string length increases with the size of the array and its operating voltage. A survey carried out during this course of this study indicated that a system that required 13 modules in a series string to achieve the necessary operating voltage can be symmetrically in only one way: rows or columns of 13 modules. A 14-module string can be arranged in two ways: 1 times 14 or 2 times 7. A 12- module string can be configured in many ways- 1 times 12, 2 times 6, 3 times 4, L-shape, and so on. The ideal situation would be to allow the array to be physically configured to fit the building and not the other way round, Strong (1993).

It is widely accepted amongst PV specialist that the more ways a string can be evenly divided, the more different array configuration is possible. Array strings using prime numbers of modules should be avoided, if configuration flexibility and diversity is to be achieved in design. Generally, the higher the module operating voltage, the fewer modules will be required to make up a given string and the more flexible the array design can be in terms of both physical configuration and power output options. When building integration of photovoltaic cladding array is added to the many, often conflicting, issues already involved in the building design process, this kind of flexibility becomes critical to the efforts by the architect or designer to create aesthetically pleasing living environment that people will enjoy and appreciate, Gyoh (1996)

A survey of consultants that have actively participated in BIPV projects in the UK and continental \Europe was carried out during the course of this study. PV specialist, engineering consultants, and architect that participated in the survey suggested that, from their experience, high-density, high-efficiency arrays using large area (at least 2 square metres), high-voltage PV modules (24 to 48V DC nominal or greater) would eventually become the industrial standard for building integrated systems. Currently some manufacturer offers such large-area modules. Other manufacturer has recently begun to combine many of their small modules as unframed laminates into large-area, higher-voltage panels, DTI (1995).

Engineering consultants that took part in this study suggest that, the design of large-area, high-efficiency modules is an important priority because the support structure for a PV array is expensive. This is especially true if the supporting structure is a building. The architects and quantity surveyors pointed out that it is very hard to justify constructing a bigger building to support a large, low-efficient PV array. Against this background, a design objective may be to select photovoltaic modules that provide flexibility in array sizing and configuration while delivering the maximum power that is economically practical from a given array area. This, is believed, keeps construction cost low and reduces the architectural impact of the array, allowing the designer more freedom and making more façade and roof area available for other / solar applications, AD (1997).

5.2 Array Mounting

Photovoltic array installation fall into two general categories: building mounted and ground mounted. In addition, a distinction may be made between arrays installed as a part of new construction and those retrofitted on an existing structure. At present, most retrofit installations have been limited to relatively low-output arrays that address modest load requirements, (Gyoh (1996), Baumann & Hill (1995)).

PV systems can be installed on surfaces of building, along roads or railways, allowing the possibility to combine energy production with other functions of the building envelope, such as roof and façade integration, sun blinds and heat production. Cost saving through these combined functions can be substantial, for instance, for expensive façade systems where cladding costs may equal the costs of the PV modules. Furthermore, the additional cost of high-value land for ground mount system is eliminated in façade integrated installations. Electricity is generate at the point of use, reducing transmission and distribution losses, it also reduces the utility company's capital and maintenance costs. Successful PV building integration goes beyond simply mounting of PV modules on roofs or façade. The integration process commences at the beginning of the planning stage right through to the installation phase for both new build and retrofit construction.

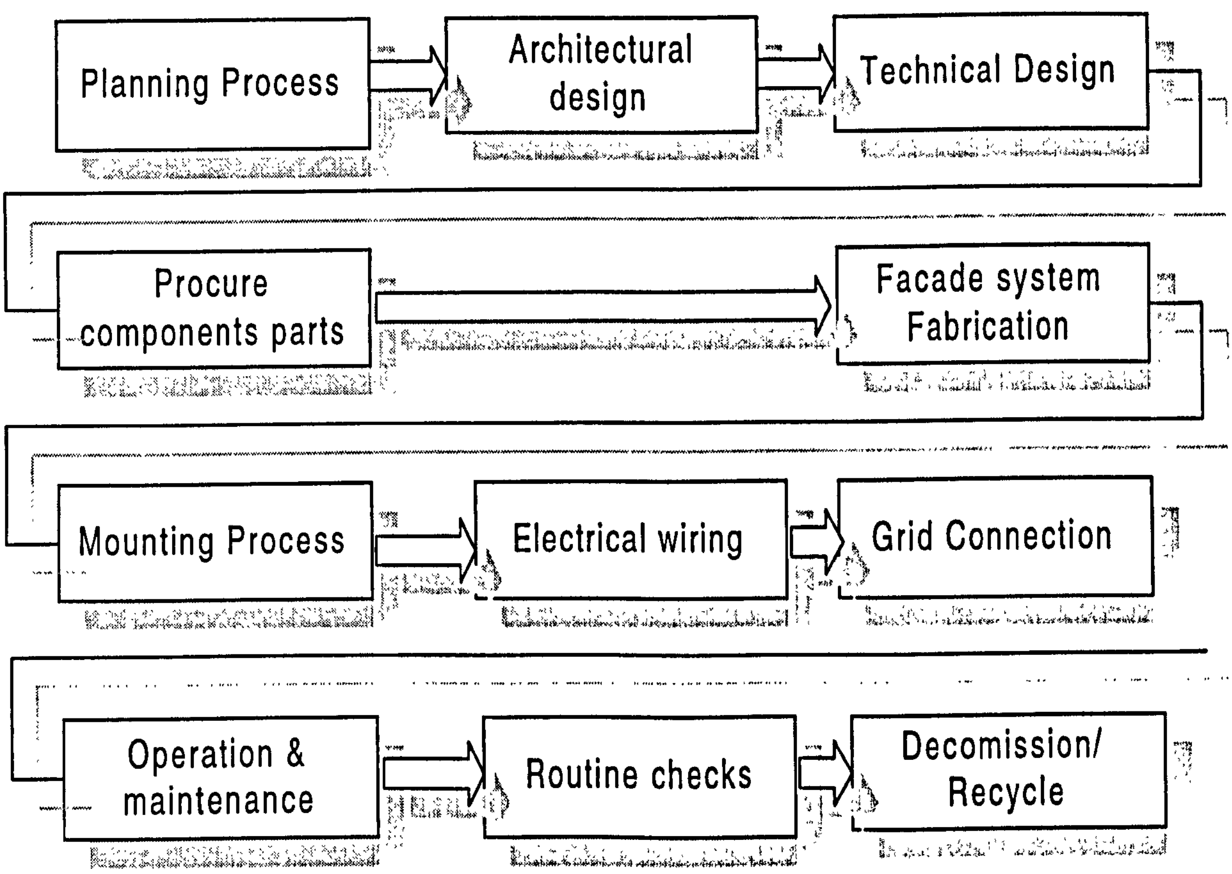

Figure 5.1 PV building integration process.

The integration of PV into the architectural design, is widely believed to, offers more than cost benefits. It also allows the designer to create environmentally benign and energy efficient building without sacrificing comfort, aesthetics or economy, Toggweiler (1998).

Four generic methods have been developed for the mounting of photovoltaic arrays:

5.2.1 Rack Mounting

Rack mounting is where the modules are mounted on a support structure on the ground or above the flat roof of a building in a plane different from that of the roof.

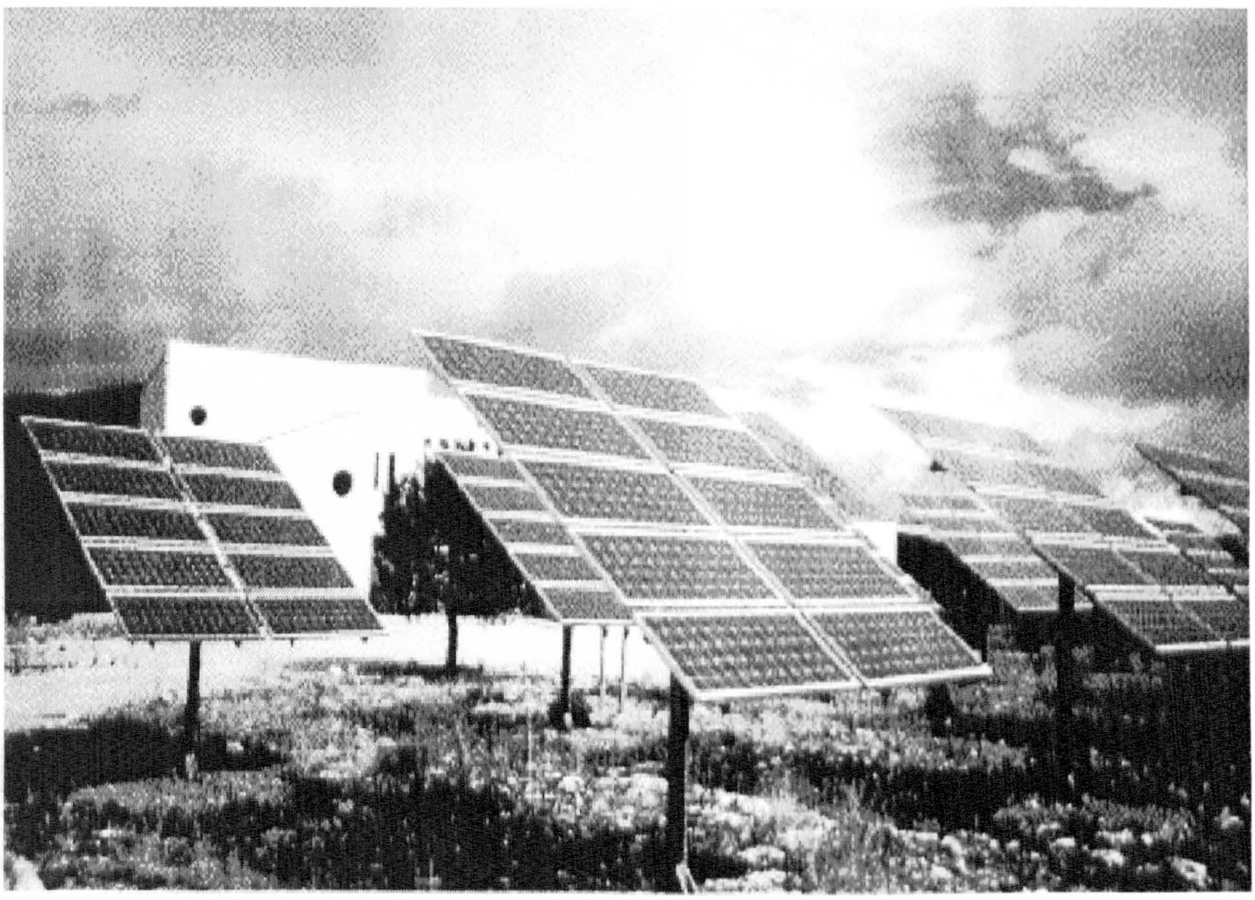

Figure 5.2.1: Rack mount installation - PV system support to rural power supply, Maria, Almeria, Span.

(Source: International Energy Agency, Photovoltaic in Europe, 1997)

5.2.2 Stand-off Mounting

Stand-off mounting, is where the modules are mounted on a frame that stands 5 to 15cm above the finished roof of a building, in the same plane as the roof, AD (1997).

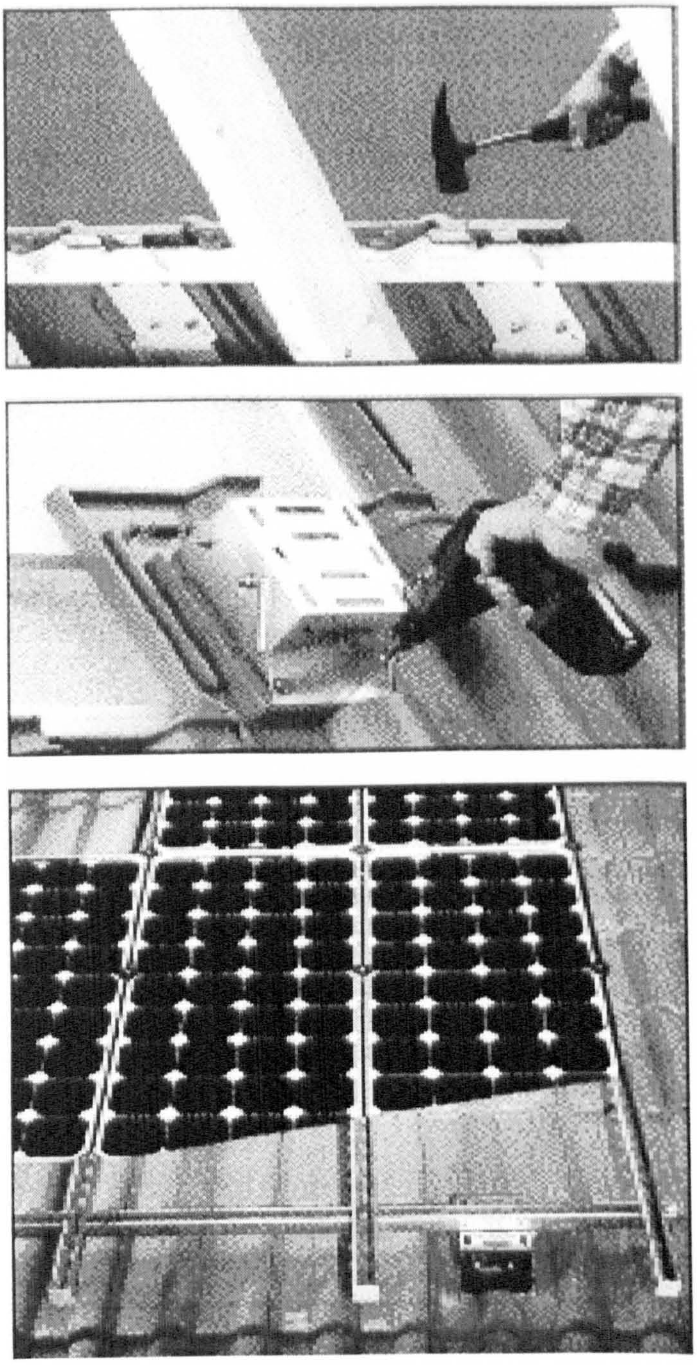

Figure 5.3: Stand-off Mount Installation. The BP Solar SES, stand-off system with high-efficiency solar cells.

(Source: Solar-Electric, BP Solar Manufacturers Details, 1998)

5.2.3 Direct Mounting

Direct mounting is where the modules are mounted directly on the plywood roof sheathing

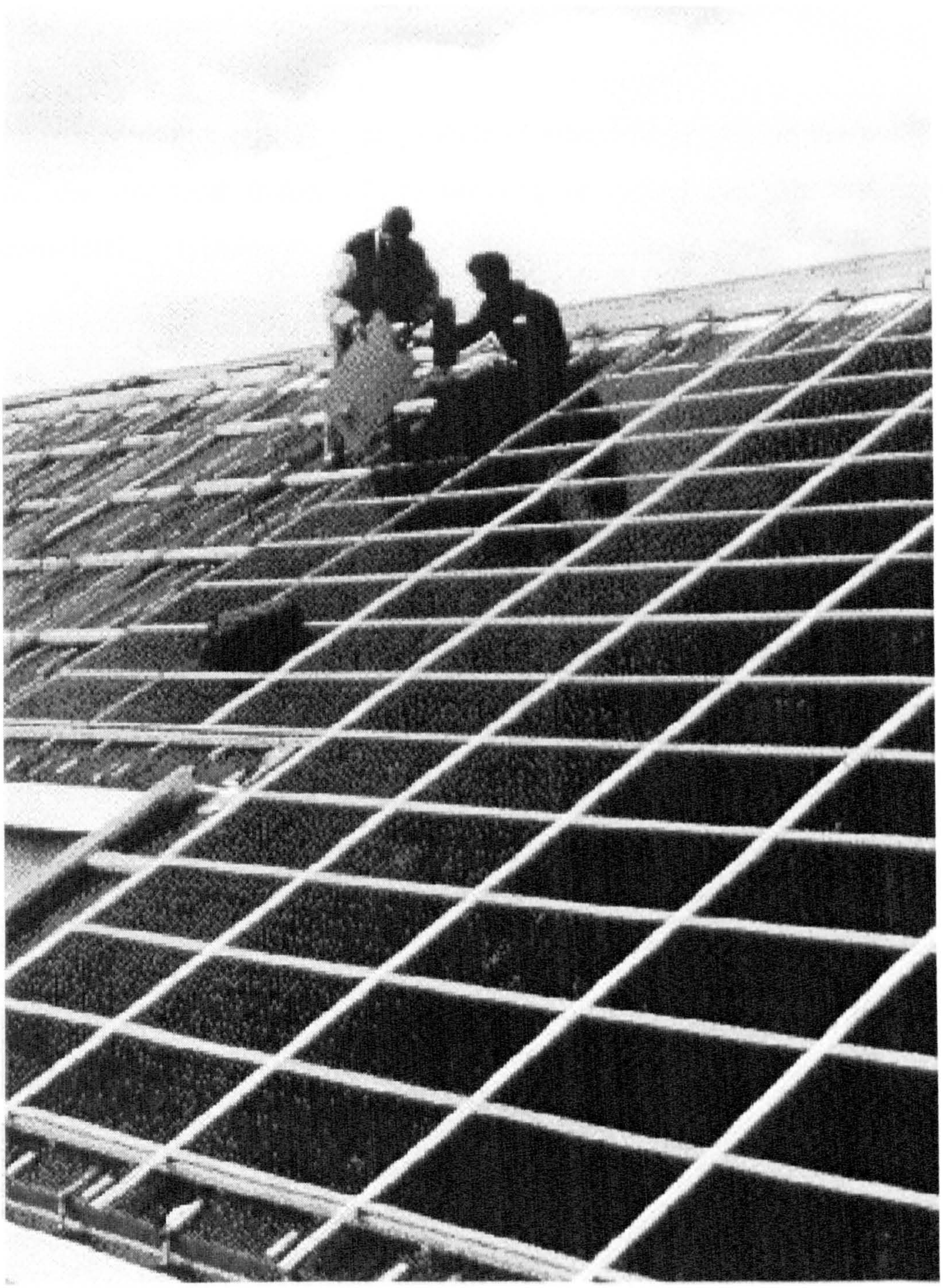

Figure 5.4: Direct Mount Installation- the 100 PV houses in New Sloten, Amsterdam, Netherlands.

(Source: Solar-Electric, Green Peace, 1996)

5.2.4 Integrated mounting

Integrated mount is where the module is mounted directly on the building structure i.e. the structural frames of the building or indeed the structural roof members, completely displacing the conventional cladding system.

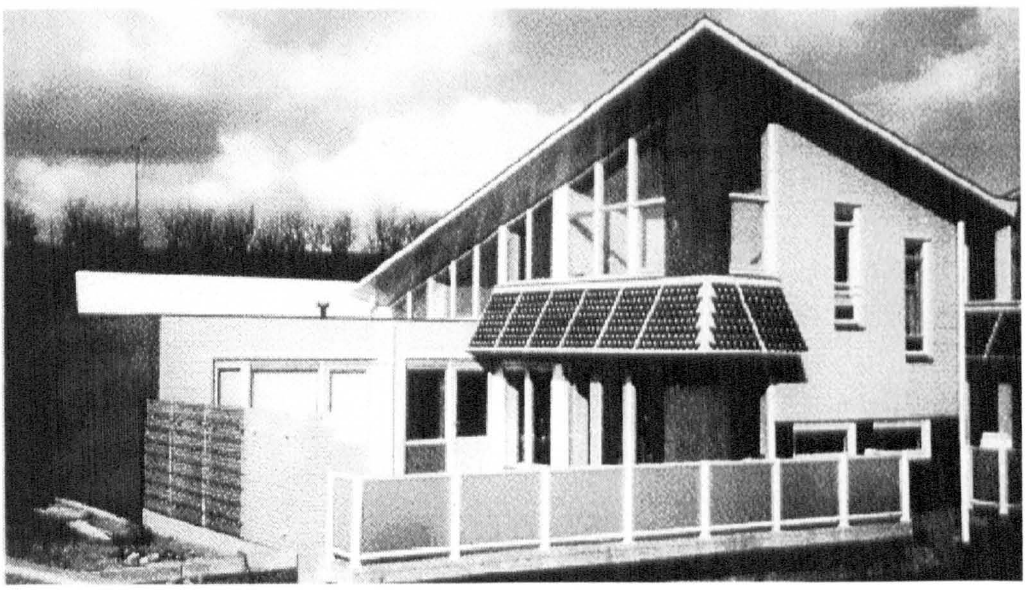

Figure 5.5: Integral mount- architectural integration of PV modules in shading devices of solar dwelling, Dordrecht, Netherlands.

(Source: International Energy Agency, Photovoltaic in Europe, 1997)

5.3 Ground Mounting Review

Unless a building lacks sufficient south-facing façade area, the architect will most likely want to consider a roof-mounted array for a building integrated photovoltaic system. When compared to a well-designed roof-mounted or façade integrated installation, a ground-mounted array is less elegant, requires long wire runs, is more likely to be shaded, and occupies land that could be used in other ways. Fencing is desirable to keep out animals, children, and trespassers. Wiring must be protected form damage by rodents. Weeds and drifted snow may also need to be cleared from time to time, though falling snow will usually slide off if adequate ground clearance is provided.

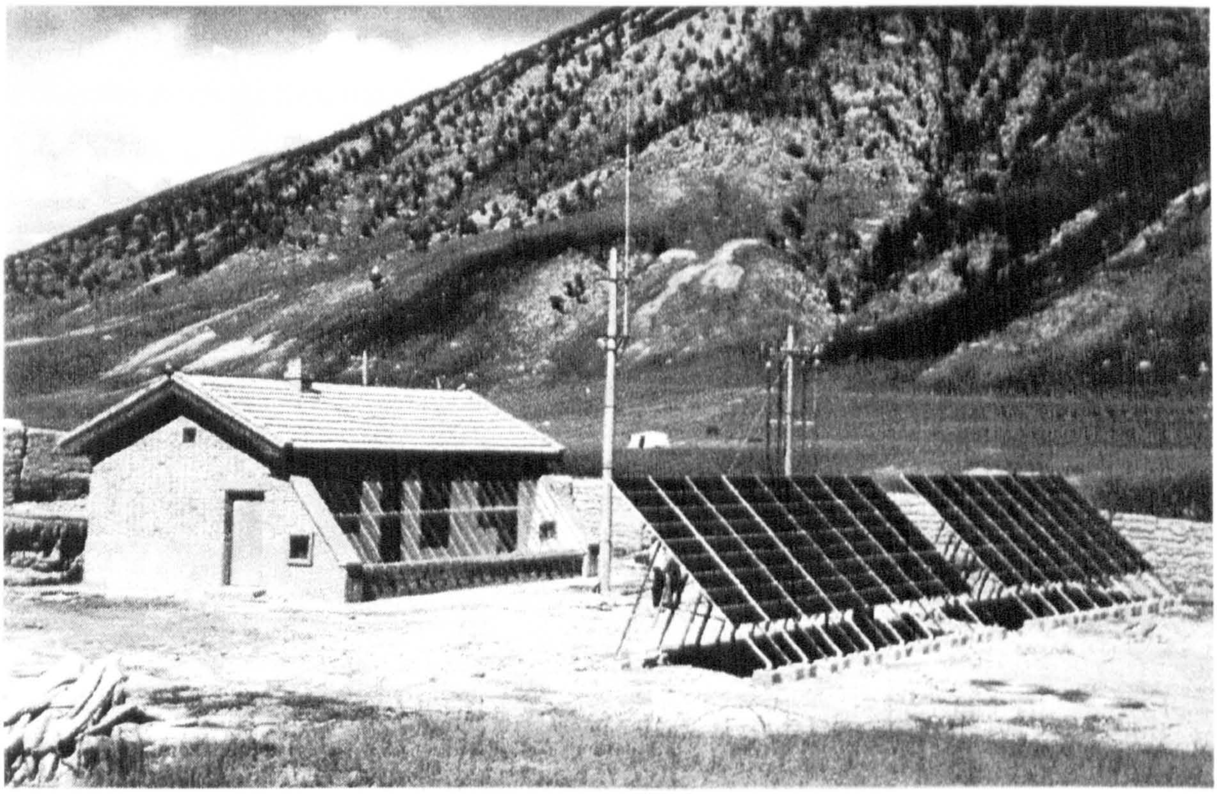

Figure 5.6: Ground Mount installation – PV solar power system in Shenge village China.

(Source: International Energy Agency, Photovoltaic in Europe, 1997)

However, there are some advantages to ground mounting, particularly if adjacent open land is available at little or no cost. A ground-level photovoltaic array is easily accessible during installation, as well as for cleaning and occasional maintenance after system start-up, and may easily be expanded to incorporate additional modules.

Ground-mounted systems are usually built with structural frame members of: steel, aluminium pipe or angle, or in some cases wood - similar to those used in the rack mount system. Whilst the roof-mounted rack is secured to the building, the ground-mounted support structure is usually, and best, secured to a foundation of concrete piers or pad.

5.4 Rack Mount Review

As reviewed in chapter three, to obtain the highest annual array output, the angle at which the modules face the sun should roughly equal the latitude of the site. Sheffield for example is about 54^0 North latitude; thus a photovoltaic array in the Sheffield area

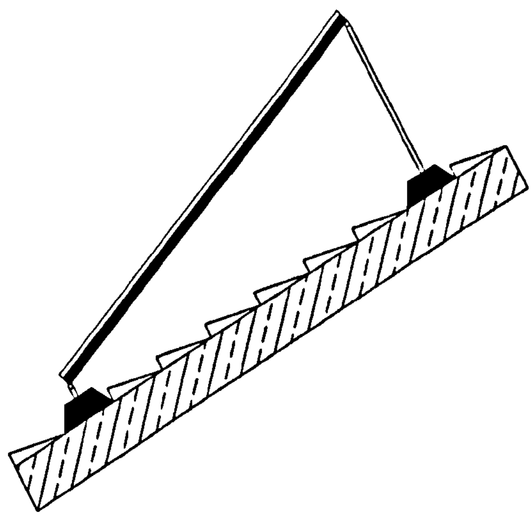

Figure 5.7: Rack Mount – schematic section of rack mount installation

would be ideally angled at approximately 54^0 degrees from the horizontal. A survey of PV system installation in the Europe suggests that, buildings expressly designed for photovoltaic is given an optimum roof or façade pitch before leaving the drawing board, Toggweiler (1996).

Rooftops that are flat or inadequately pitched for photovoltaics will require rack mounts with a structure very similar to that used for ground mounts. In a rack mount, the modules are supported at the desired altitude angle by a triangulated under structure commonly built of aluminium, steel angle, or steel pipe. Sometimes an easily assembled and adjusted system of manufactured pipefitting is used, such as the Speed Rail and Kee Klamp system favoured by many installers of solar thermal collectors. Occasionally, wooden framing is used. The rack-mounted array stands free above the roof, replacing none of the traditional roofing materials. The frame members are usually lag-bolted to the rafters beneath the roof sheathing or through-

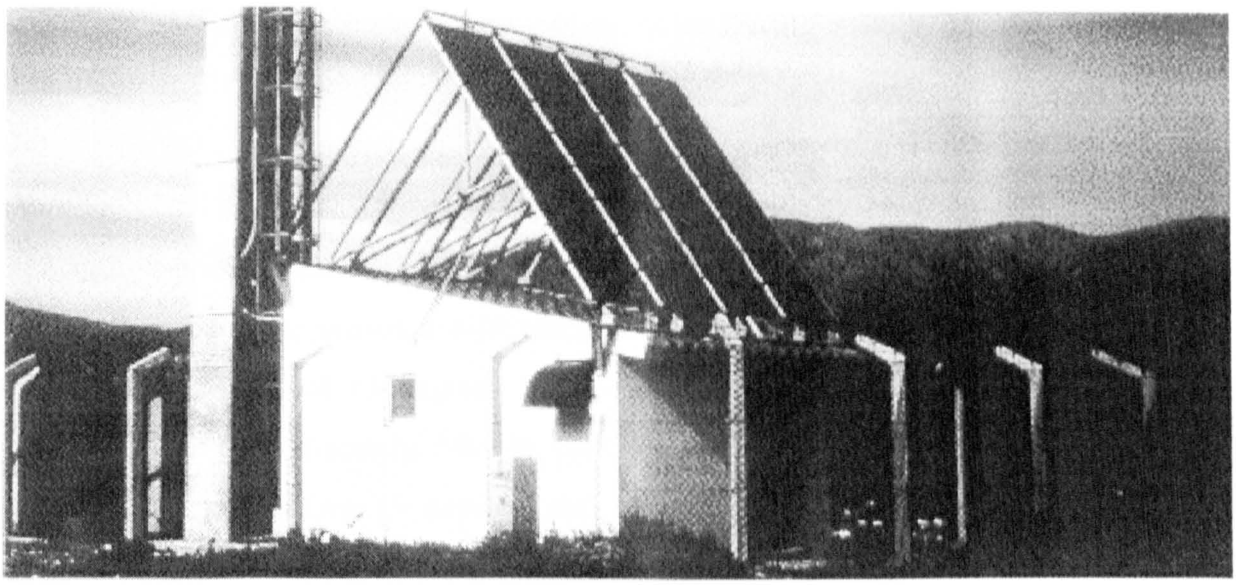

Figure 5.8: Rack Mount – PV power system for TV repeaters in remote mountains of Portugal.

(Source: International Energy Agency, Photovoltaic in Europe, 1997)

bolts into solid blocking placed between the rafters. Waterproofing these penetrations in the roof membrane is an important consideration.

When rack mounting is necessary, it will involve some additional expense as well as increase the weight and design loads of the entire installation. The additional weight is unlikely in itself to pose any danger to a sound roof, if the support structure is properly attached. However, the elevation of modules above the roof will require that maximum anticipated wind velocities be carefully taken into consideration during the array design. A simple wind or snow load (downloading) is one phenomenon to be considered. Often more important is the negative load or uploading created by the lift effect that can result when the wind blows from the rear against a sloped rack-mounted array.

There are some advantages to the rack mount. Since photovoltaic cells undergo some loss of efficiency when operated at high temperatures, the free-air ventilation on both front and rear modules surfaces, afforded by the rack mount helps to keep the modules cooler. Furthermore, the exposed rear surface in a rack mount offer ease of access to electrical connection between modules during installation and for testing and maintenance.

Another benefit of rack-mount, which perhaps only the more dedicated technically demanding photovoltaic users might wish to pursue, is the ability to adjust the array angle to account for seasonal differences in the direction of solar radiation. In the winter, an increase of 15 degrees in the altitude angle will improve the seasonal efficiency by approximately 5%. In the summer, the same improvement may be achieved by subtracting 15 degrees and bringing the array closer to a horizontal position. However, most PV users are content with the knowledge that, during the summer, the marginal efficiency drop associated with imprecise angling is compensated for by the greater abundance of sunlight, Scheller (1993).

Many photovoltaic manufacturers and distributors have pre-engineered rack-mounting systems available for their modules. These kits are most often made of aluminium extrusions and are shipped with the pieces pre-cut and predrilled, ready to assemble. There are several advantages to buying a pre-engineered rack. Besides being prefabricated and ready to install, it is designed expressly for the mounting of PV modules and built to withstand the forces of wind and snow loading imposed on rack-mounted array. A number of manufacturers both offer pre-engineered racks for their modules whilst others design prefabricated rack-mount systems that can accommodate PV modules from several manufacturers.

Most of the pre engineered rack-mounting systems available allow the altitude angle of the array to be varied, providing flexibility during the initial installation and allowing those who wish to adjust their array seasonally the ability to do so as and when necessary. Another pre-engineered option for rack mounting is the family of support hardware produced by some manufacturers. Originally designed for solar thermal collectors, the system replaces the frame, the support, and the mounting feet of a traditional rack mount with telescoping supports that are adjustable to allow field setting of the altitude angle. The top of the support fastens to the module's frame rail and the bottom is lag-bolted into the roof. Some manufacturers have recently added a theft-resistant hardware option that should deter thieves in remote locations. The advantages of the system are best obtained in small to medium-sized building power systems installed in areas that do not receive much snow, Strong (1993).

Since PV are far less tolerant of shading than solar thermal collectors, the angle of sunlight at each season of the year must be taken into consideration when a ground or rooftop rack-mounted array is designed. Shadowing can result not only from the interference of trees, buildings, or other obstructions but also from positioning one rack of modules too close to another. In the winter, the sun's rays fall more obliquely, and shadows are much longer. Partial shadowing of a module in which cells are connected in series will fully incapacitate the module for the duration of the shadow. For series-connected modules the effect will be the same, with the entire string of modules incapacitated as long as some of the modules in the string are shaded. This loss may have to be tolerated if space is at an absolute premium. However, this should be avoided if at all possible, since only so much trade-off may be allowed if the installation is to prove worthwhile, Pearsell (1997).

5.5 Stand -Off Mount Review

The stand-off mount might be described as a rack mount without the rack. The modules in the array stand upon a framework separate from and above the finished conventional roof or facade, but that framework is only a few centimetres high and lies parallel to the roof's own pitch. This is the preferred method for retrofit installation on buildings having the proper roof angle and orientation where the photovoltaic modules are not expected to take the place of conventional roofing or cladding material, Toggweiler (1998).

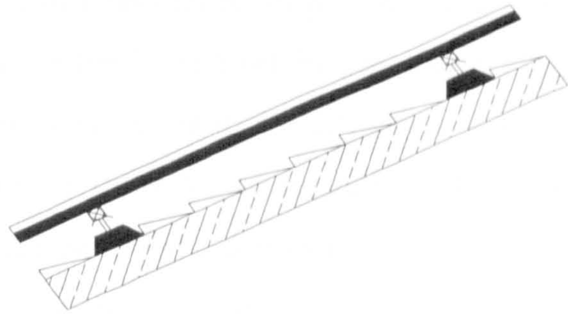

Figure 5.9: Stand-off Mount –Schematic section of stand-off mount installation.

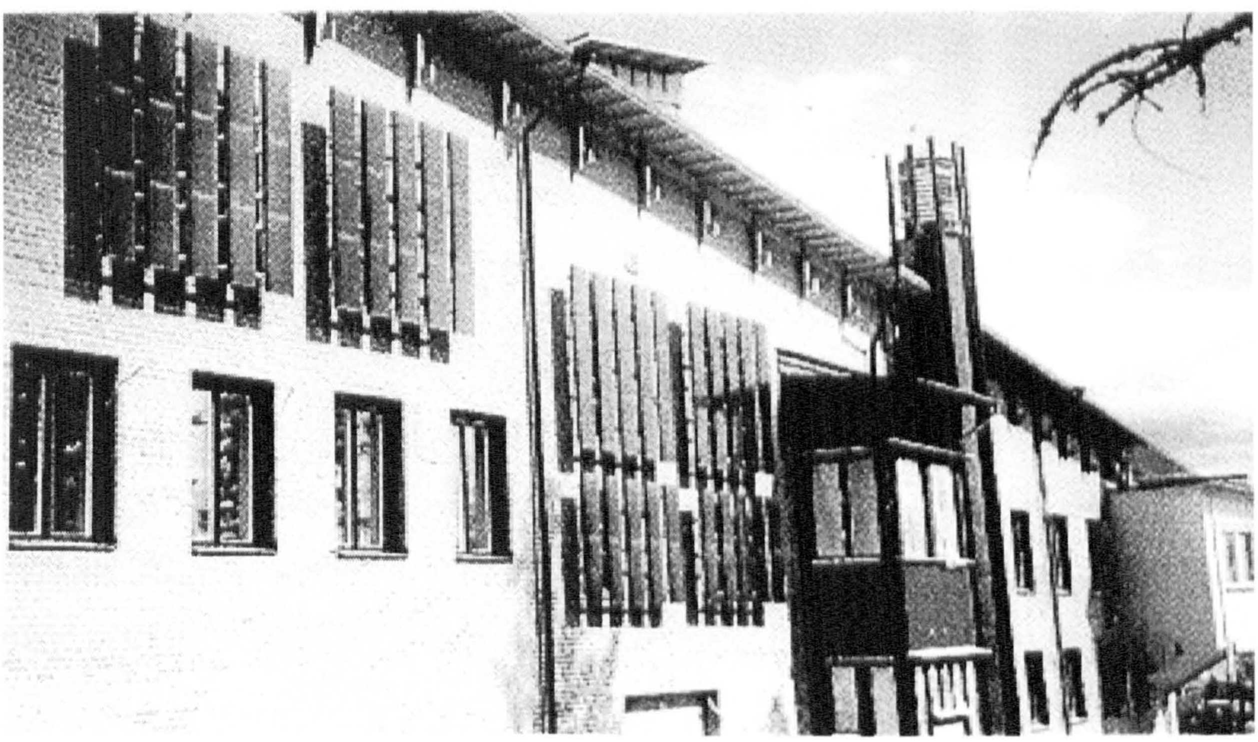

Figure 5.10: Stand-off PV Cladding Installation – Harnosand building, Sweden.
(Source: International Energy Agency, Photovoltaic in Europe, 1997)

Stand-off mounting, support rails, usually aluminium or steel; sometimes wood, are fastened to stand-off supports or lag-bolted directly to the roof. The modules are in turn fastened to the rails. As with the rack mount, weather-sealing of the roof need take place only at the points where the bolts penetrate. Recent innovation work has resulted in the design of stand-off mounting system that use the photovoltaic module's own frame as the support structure and relies on prefabricated roof jacks to support the modules and provide the desired stand-off height above the roof. Stand –off mounts retain most of the rack mount's ventilation advantage if it is designed to allow adequate free air flow behind the photovoltaic modules, between the array and the roof. Since the hardware requirements are less than they are for the rack mount, costs are somewhat lower. However, non of the conventional cladding materials are displaced, and consequently no savings in that area may be balanced against the PV installation costs. In addition, when the conventional cladding or roofing requires maintenance, the array may have to be dismantled to provide access for repair or replacement.

5.6 Direct Mount Review

The direct mount concept presents savings in the cost of conventional cladding materials. Economy and simplicity are also possible with the direct mount through the elimination of support frame work and mounting rails. The installation is exactly as the term implies- direct. The photovoltaic modules are not mounted atop a superfluous layer of shingling but are secured directly to the roof sheathing. PV modules in a direct mount must be installed to serve as weathering skin of the roof or façade. Adequate caulking or sealant that can withstand wind forces repeated thermal cycling, and prolonged direct solar exposure is essential to this task.

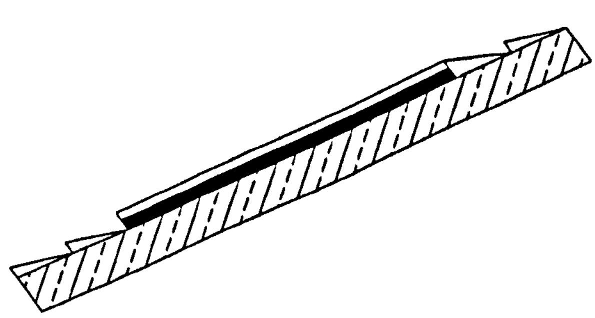

Figure 5.11: Direct Mount – schematic section of direct mount system.

The concept of direct mount of building with photovoltaic arrays had the attention of PV researchers in the late 1980s, early 1990s and some current ongoing research at The University of South Wales, Cardiff, UK. However, there are some notable disadvantages to the direct mount method that have been responsible for its, apparent, general lack of acceptance by architects and other design consultants. Since the modules are applied directly to the structural cladding or roof sheathing, there is no open space between the module and the cladding in which cooling air can circulate. This absence of ventilation can result in direct sunlight operating temperatures as much as 20 degrees Celsius hotter than those common to other mounting methods, causing a significant decrease in electrical conversion efficiency, Strong (1993). In addition, module-

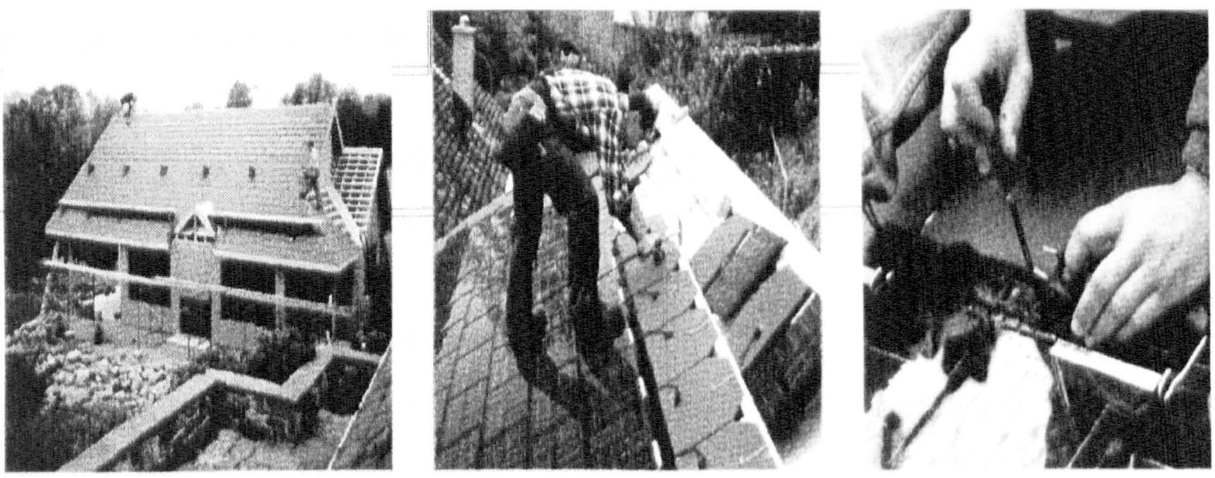

Figure 5.12: Direct Mount Installation – PV Sunslates™ installation Stroudsburg, USA. (Source: PV Sunslate Installation Strougdsburg USA 1999)

to-module interconnections require special flat cables and connectors. Ever more important access to the electrical connections of the individual modules after installation in a direct-mount array is very difficult, making routine diagnostic and maintenance operations a major task. Some manufacturers have in the past produced prototype photovoltaic modules designed especially for direct mounting. These designs proved unworkable for the reasons just stated. Currently, at the time of this study, no PV manufacturer produces modules that are designed specially for direct mounting.

The University of South West Wale Cardiff in conjunction with British Steel Research Centre Cardiff is currently in the process of developing direct mount

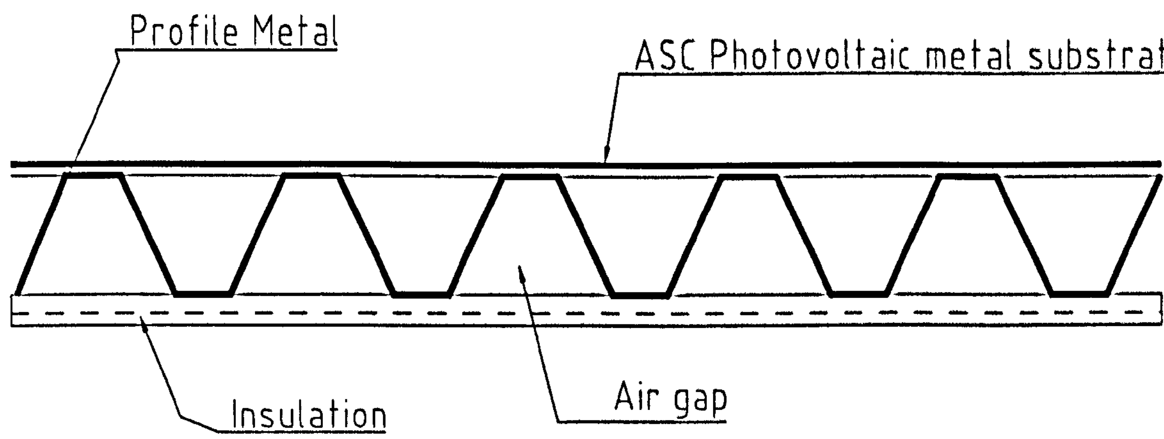

Figure 5.13, is a typical section of conventional British Steel profile metal cladding. (Source: ASC, BIPV, Cardiff University, 1999)

system being developed into direct mount ASC BPIV cladding systems at Cardiff.

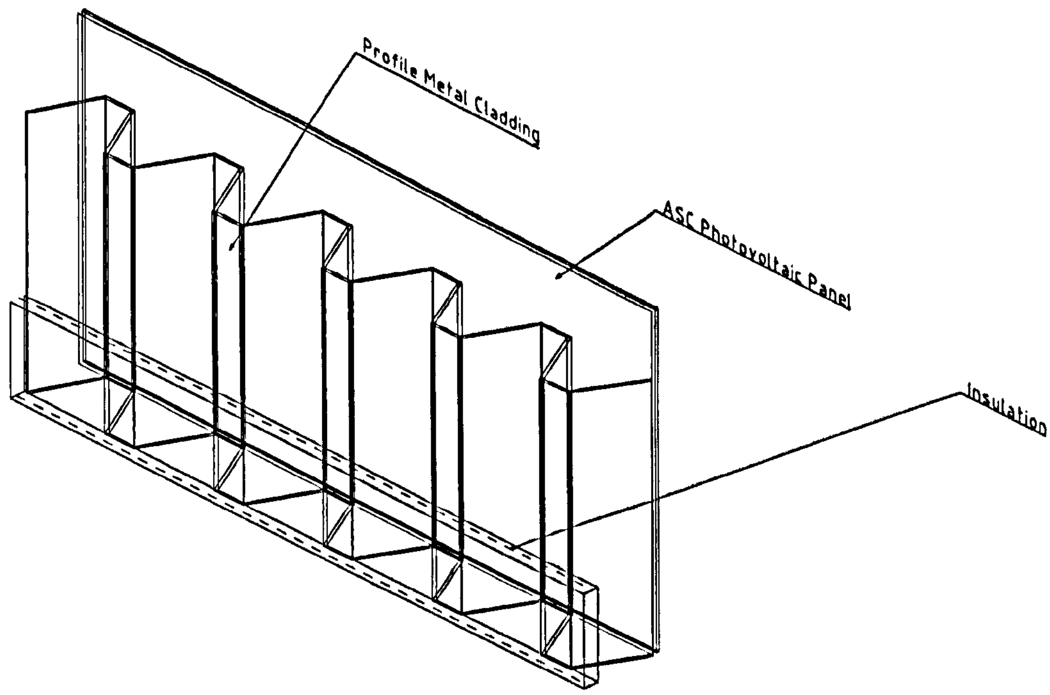

Figure 5.14. A three-dimensional schematic representation of the ASC BPIV being developed at Cardiff.

(Source: ASC, BIPV, Cardiff University 1999)

5.7 Integral Mount Review

The integral mount is favoured to emerge as the preferred installation method for new buildings and light industrial construction where the roof is designed at the proper orientation. It represents a logical progression from the direct mount, eliminating all of its bad features while improving on the module-cooling characteristics of the rack mount. This approach not only eliminates the exterior cladding material, it also get rid of the wooden sheathing and roofing felt by attaching the photovoltaic modules directly to the building rafters, making them both the visual and structural surface of the roof as well as its barrier against the weather.

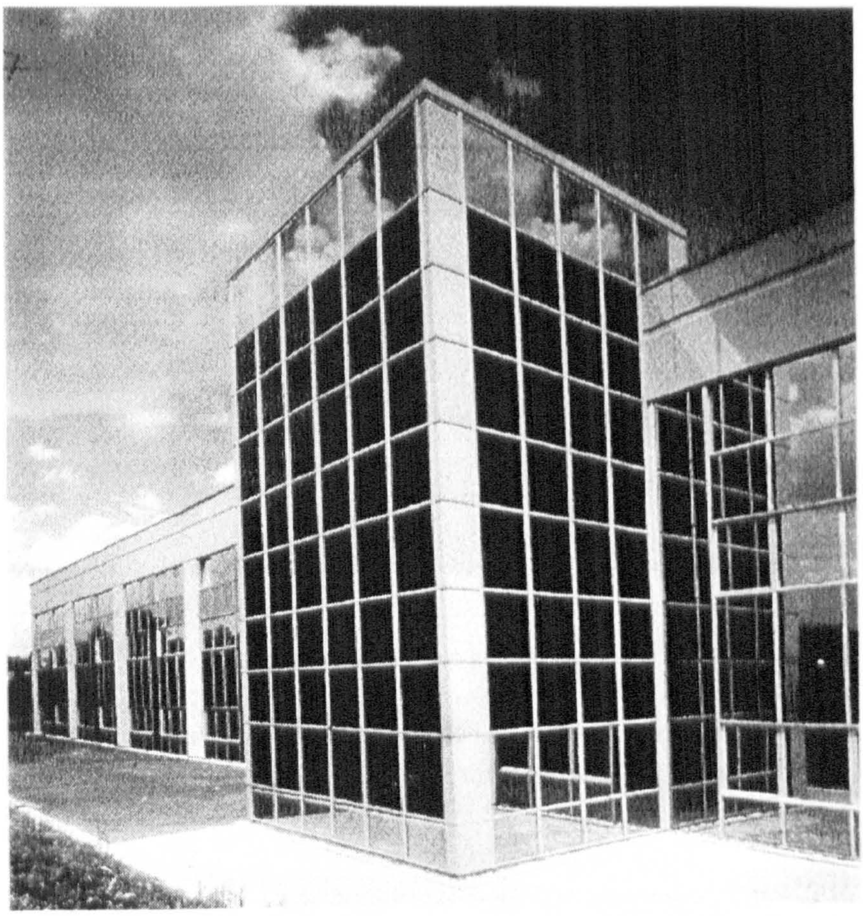

Figure 5.15: Integral mount - integrated PV curtain wall with rear ventilation at the Flachglas factory, Germany.

(Source: International Energy Agency, Photovoltaic in Europe, 1998)

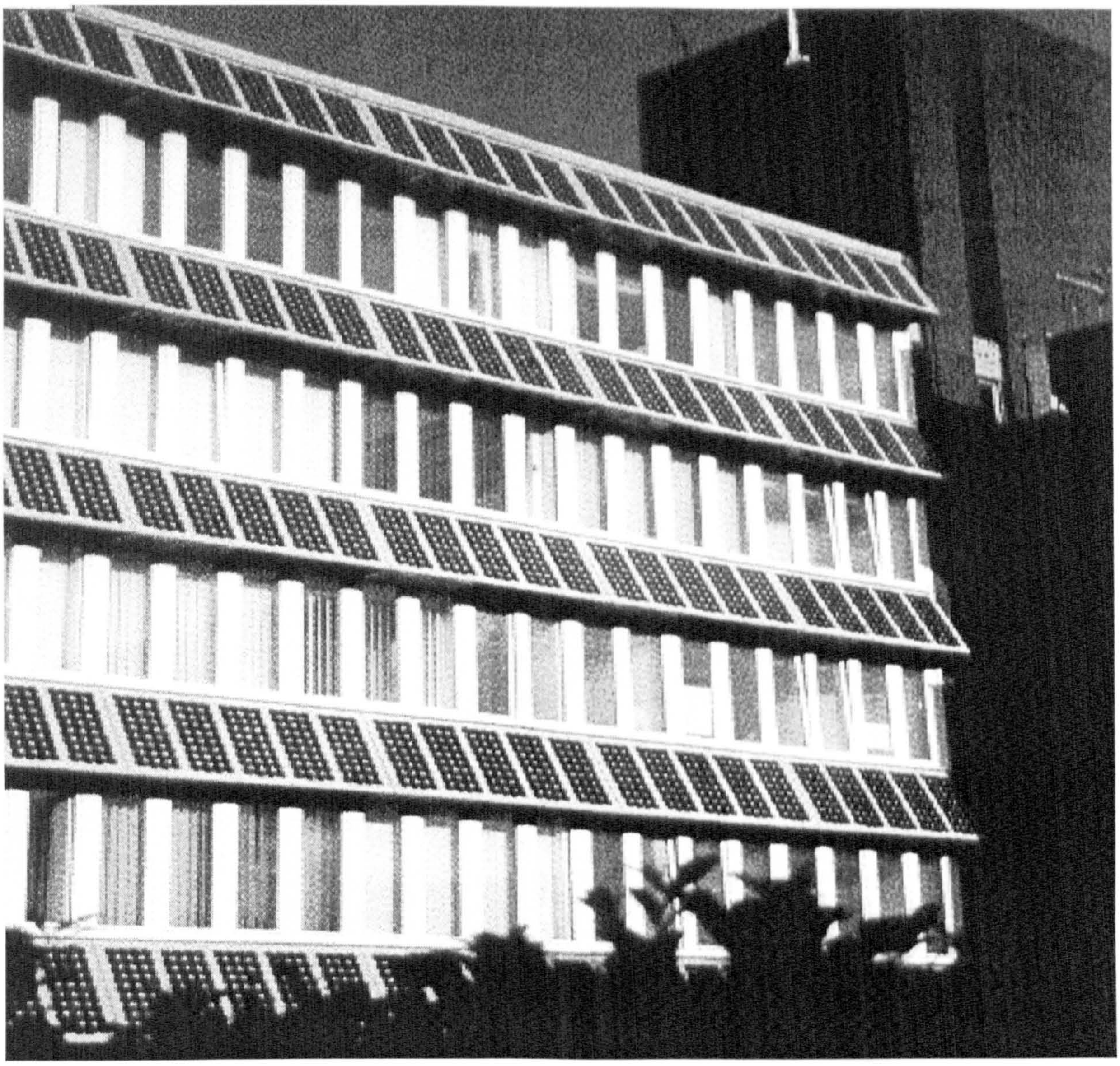

Figure 5.16: Integrated Mount, PV Overcladding Northumbria Building, Northumberland University, Newcastle UK.
(Source: Solar-Electricity, BP Solar, 1997)

The tempered glass, generally in a 1.875mm thickness, is used as the structural element and top 'cover plate' for (nearly all) photovoltaic modules. It is strong enough to serve as a building's cladding or roofing material if they array mounting is properly designed, Toggweiler (1998).

Mechanical load standards dictated by building codes apply to all structures, be it glazed sun space, photovoltaic cladding or conventional construction. However, many manufacturers of PV modules have already seen to it that their product meet and exceed these standards, Thornycroft (1999). For example, some manufacturers of large-area 1.2m by 1.8m PV modules has passed the rigorous mechanical load testing routine performed by the European Testing Laboratories ETSI in ISPRA (or a comparable test). The current valid testing procedure is generally known as "ISPRA 503". At the end of 1993, an international standard, IEC 1215, with very similar specifications was issued. Almost all current standard modules are subjected to this qualification test. Standard PV modules tested under these regime is expected to withstand equivalent of 125 miles per hour positive and negative wind loading in an integral mounting configuration without damage or leakage.

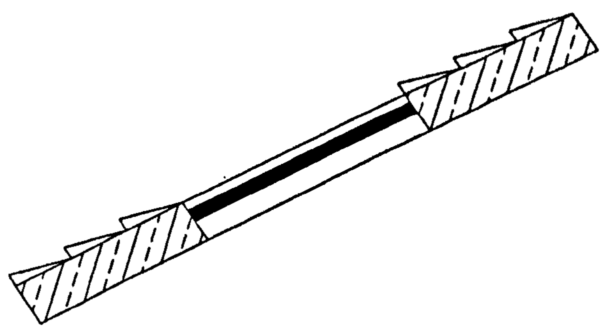

Figure 5.17: Integral Mount – schematic section of integrated mount.

One immediate benefit of the integral mounting is improved ventilation, which moderates temperature and assures more efficient operation of the modules. In roof installations, an extra added advantage of this approach is the cooling of the attic space, which results in a more comfortable living environment with less burden on climate-conditioning equipment and less load on the photovoltaic system as well. The integral mount shares with the rack mount the advantage of allowing, working from a flat surface during array installation and provides easy access to the electrical connections at the underside of the array out of the weather for initial connection and for future testing and maintenance. Replacement of individual modules within an array is extremely uncommon, but should it ever become necessary, this 'back door' will be appreciated.

Corporate clients, architects and other construction professionals, that took part in a survey, were of the opinion that integral mounting of building PV arrays holds an appeal beyond that represented by the cost savings in cladding materials or the ease of installation and service. This appeal is partly aesthetic and perhaps partly philosophical and relates to the fundamental departure from traditional concepts of energy supply and building design of which the solar electric building is a part. While the mounting techniques are unquestionably serviceable and even desirable in the case of retrofits to existing buildings, they nevertheless, suggest a certain redundancy: If the modules can serve as a finished cladding material, why shouldn't they? The promise of photovoltaic is in many ways is the promise of a new architecture whilst the physical lightness, simplicity and translucence of an integral array can only reinforce this spirit. BIPV systems creates an energy-producing structure where the building's own skin produces some or all the energy it requires with perhaps a surplus for export to less energy-conscious neighbours, Gyoh (1996).

5.8 Photovoltaic Systems Wiring Review

PV generating systems have many wiring interconnections between components of the system and this should be catered for in the design process. They inherently produce DC electricity and when linked together in some modes, can be potentially dangerous. Attention should therefore be paid to this area and wiring should not be accessible to building users. For ease quite often, solar modules are connected together electrically via junction boxes to reduce the number of cables passing around the building. As this electricity is DC it will not be possible to use the existing building AC wiring system.

With regards to PV System Wiring Design, the general consensus in a survey carried out during the course of this study suggest that: cable should be selected such that it is capable of handing the generated current and voltage; losses are minimised whilst being suitable for the operating environment. The interconnecting system usually incorporates the following safety features:

- Bypass diodes allowing individual groups of modules to be by passed if there is localised shading,
- Blocking diodes to prevent energy leaking back into the PV panels.

- Fuses to protect against ground fault or short circuits.

In addition the solar modules should be integrated into the building's lightning protection earth network.

To convert the power to AC standard main voltage, an inverter is required. This is directly connected to the solar panels and also performs the function of regulations the output of the solar panels for optimum performance. This device has to meet specific requirements for disconnection from the grid system if there is a fault (Islanding requirements) and also ensure output voltage and frequency is in line with main electricity requirements (harmonics), Rolf Oldach (1999).

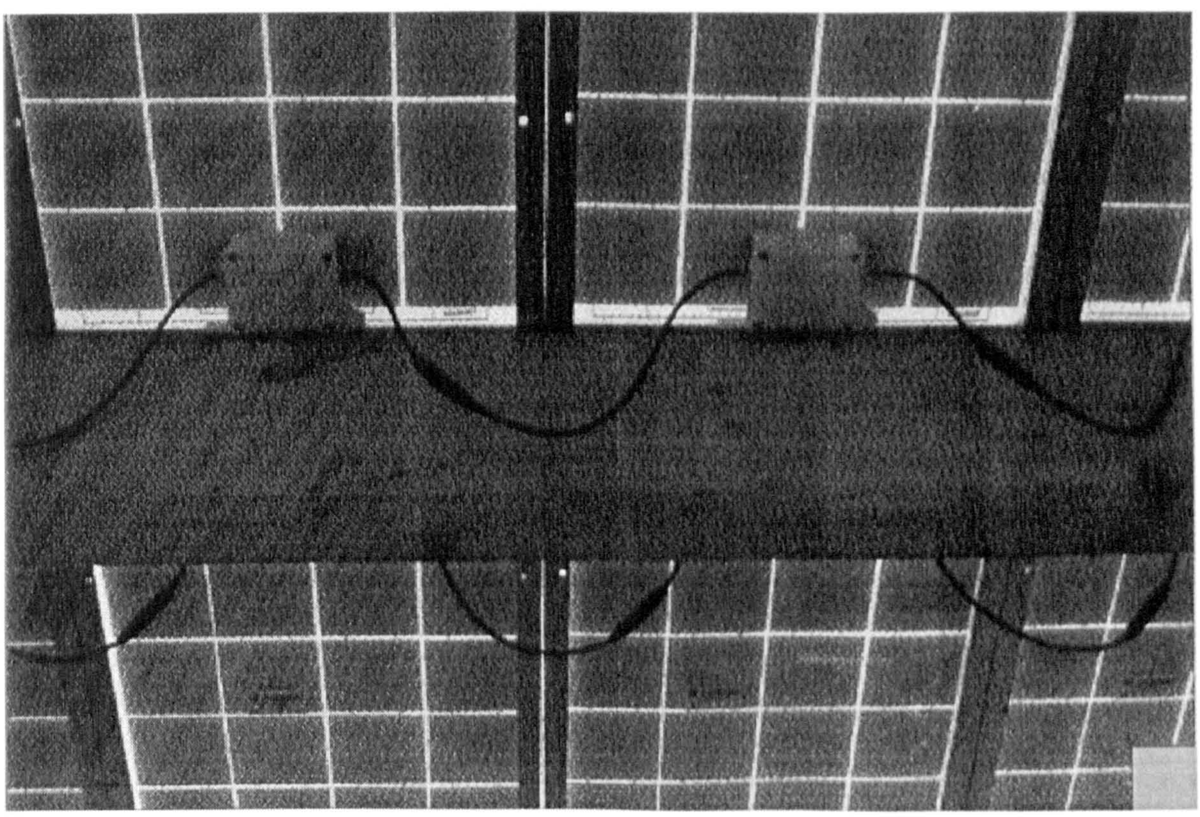

Figure 5.18: Rear view of PV modules showing plug-in electrical connectors

Source: Solar-Electricity Products for Building Solarex 1998)

5.9 Mounting Balance-Of-System (BOS) Components Review

It is of fundamental importance, equal attention to planning details and logical integration be given to balance of system (BOS) components mounting, as is with PV array installation. BOS component functions varies with specific conditions. An inverter should be accessible for possible servicing yet out of the way of building occupants traffic. An auxiliary generator should be located where the noise of its periodic operation is not annoying and near a safe storage place for fuel. The batteries should be well ventilated yet kept warm with access provided for maintenance. A system well planned ahead of time and put together properly from inception is most likely to be a trouble free, Weidong He (1999).

5.9.1: Diodes, String Combiners, Lightning Protection

Following the circuitry of a typical photovoltaic installations: electricity flows from the array to loads, the first system component encountered are the bypass diodes, lighting protection devices, blocking diodes and the string combiners that make parallel connection of the array's module series string.

Lightning protection; is commonly accomplished by the inclusion of surge arrestors between the positive DC output conductors from the array strings and earth ground. Lightning protection devices will very likely be an integral part of component circuitry of string combiners/ junction boxes. On smaller photovoltaic systems that do not employ a sting combiner, the surge arrestors are often furnished as part of the internal working voltage regulator.

Bypass diodes present very little difficulty for building integrated PV system at the current stage of photovoltaic module development. Most module manufacturers now build bypass diodes protection into their products either at intervals between series strings of cells or in the module's junction box. Bypass diodes are recommended for arrays to be wired with strings of more than two modules, Cross (1998). Bypass diode should be installed across the output terminal of the junction boxes of each module, they are usually installed in parallel with each module should modules to be installed not come with bypass diode protection.

Blocking diodes are used to prevent a reverse flow of current into the array strings. They are located in series with the positive DC power lead from each array string, with a diode's anode connected to the positive array terminal and its cathode to the load. On many photovoltaic systems, the blocking diodes will require a heat-sink mounting. Since blocking diodes are now frequently found as integrated components in factory-made string combiners, they will not usually require separate installation. Small, low-voltage Stand Alone PV systems with modules wired in parallel will usually not require blocking diode. However, in large arrays with multiple strings, blocking diodes should be included in each string.

The string combiner (source combiner) is the focal point for input from the series connected strings of photovoltaic modules. In the combiner, the series strings are combined in parallel to produce the desired array input current. A well-designed string combiner should feature heavy-duty terminal blocks for DC array string input, the DC output and grounds. It should include DC-rated discount switches to isolate each individual string. Blocking diode and lightning surge arrestor of the appropriate rating are often included in the string combiner. However, on large arrays the lighting-protection devices will likely be housed in a separate enclosure located between the string combiner and the array. Capacity of expansion to include additional module strings should also be provided for the string combiner to make future system upgrade easier. The string combiner is now increasingly available as an off-the-shelf component designed to comply with code requirements and it is commonly assembled with ease of installation in mind. Photovoltaic component suppliers and Balance of System Specialist are able to provide string combiners to suit system requirement. It is recommended that, string combiners should be installed indoors, near the power conditioner and utility distribution panel in a Grid Connected system or near the voltage regulator and battery bank in a Stand Alone system application Cross (1997). As with other electrical components, the location chosen should remain dry and be out of reach of children and the casually curious person.

5.9.2 Grid-Connected BOS Installation

In a Grid Connected system, after the photovoltaic array source circuits have been paralleled within the string combiner, the dc output circuit is usually run directly from the array to the power conditioner. Some utility interactive inverters will require DC output filters that physically separate from the inverters and occasionally separate isolation transformers on the output AC side as well. However most units now on the market have been refined to the point where all the necessary circuitry is contained within the power conditioning unit (PCU). When mounting the utility interactive inverter, designers should follow the same principle for mounting of Stand Alone units, He (1999). Special care should be taken in design to exclude water, moisture. Attention should also be paid to temperature and cooling air requirements of inverters location spaces.

Electromagnetic interference (EMI), radio-frequency interference (RFI), and audible noise often case problems with utility interactive inverters, although fortunately less on than with Stand Alone units. However, the same preparation and precautions are recommended for locating Stand Alone inverters. After the power-conditioning unit the PV system output now (AC) is run directly to the standard building distribution panel.

5.9.3 Stand-Alone BOS Installations

After the string combiners, the system installation procedures for Stand Alone systems differ from those of utility interactive systems. In stand alone systems, the photovoltaic array DC output circuit is run to the voltage regulator. The regulator should be installed near the battery bank. This is important for several reasons: firstly, the regulator should operate at a temperature as close to that of the battery bank as possible. Regulators with remote temperature compensation will need to be mounted within the reach of their remote temperature probes. Secondly, the DC wiring should always be kept as short as is practical to avoid transmission losses. Thirdly, in small systems where the regulator serves as the system's master controller, managing the battery bank output in addition to the array charge. The distance of the regulator from the battery bank is even more important, since the power demand from the load often requires heavier current flow than that from the array. In small systems design consideration should be given to the distance between the regulator and battery bank given that power demands from loads require heavier current flow than compared to the PV array.

When deciding the mounting positions of the regulator close to the battery bank, designer should be certain that no risk of explosion of hydrogen gas is created. The battery bank should be installed and located such that adequate provision for venting any gas produced during charging. The regulator should never be installed with the battery bank in a sealed enclosure such as the outdoor battery box sometimes used in small remote PV systems. The operating temperature range of regulators should be taken into consideration, when choosing a mounting location for regulators. Adequate provision should be made for easy access for initial installation, check up and maintenance.

In a small system the regulator may just be fastened to the wall in a convenient location. In large systems, with more sophisticated controls, special panels will likely be made and the system's charge controller, load-management devices, disconnects, over current protection and even load distribution will all be pre wired in the shop and delivered to the site in a completed assembly. I any case, the principles is the same regardless of the degree of sophistication of the system.

5.9.4 Battery Installation

The DC array output goes from the regulator to the battery bank. In a new build construction with Stand Alone systems in mind, the location of the battery bank should be determined as part of the initial design process. If the building is to be provided with a basement, one corner can be given over to the batteries, with or without partitioning. In a buildings without out basements a utility room can be designed to provide unobstructed storage for the batteries.

For retrofit Stand Alone installation in existing building, the question of battery location may be a little more difficult and a shed-like addition will be ideal, should it prove necessary. With small system battery location should bot prove much of a problem. A few batteries placed on the floor or in a warm, dry crawl space will probably be all right. However, for large systems with many batteries, careful preparations must be made to house the batteries. Large battery banks are very large and quite heavy. If a large battery bank is to be installed, a concrete floor should be planned, and if the batteries are to be stacked, a heavy-duty structural steel rack should be used. Regardless of the exact location of the batteries it is impossible to over stress the need for the preventing them from getting too cold or too hot. With regard to the temperature and performance, batteries are the opposite of photovoltaic cells. The colder a battery gets the lower its capacity for electrical storage.

As temperature rise above 27°C, battery capacity actually increases above 100% of the manufacturer's rated level. But above 30 °C , at 105% of rated capacity, there is a danger of shortended battery life unless a lower concentration of electrolyte is used. Temperatures above 52°C should be avoided it is also worth mentioning that electrolyse freeze at -50 °C. In any event effort should be made to operate batteries as close to the desired 16°C to 27°C optimum range.

5.9.5 Battery Charger Installation

The location and installation of AC-to-DC battery charge follows the same general principles as the location and installation of an inverter. Battery chargers have the same requirements with regard to temperature, water and cooling air. Like some inverters most battery chargers feature an internal cooling fan that must be free to provide unimpeded flow of cooling air through the unit. Battery chargers are heavy; as a result floor mounting would seem an attractive option for a typical installation. Floor mounting should be avoided if there is a chance of the floor getting wet. The battery charger should be mounted as close as possible to the battery bank to minimise the length of battery runs and minimise the length of wire runs. In so doing designers should leave enough room for disconnection switches for both the AC and DC side of the unit. Photovoltaic installation should be viewed not as a collection of discrete units but as an integrated system. As such each stage of installation of the installation – from selection and mounting of modules to selection and positioning of the BOS component – should be carefully considered in relationship to the entire system, Pearsall (1998).

5:10 Inverter Installation

Stand alone building photovoltaic installations will probably include a DC-to-AC inverter, except for very small systems. The Stand Alone inverter should be located close to the battery bank to minimise wire losses and simplify installation and maintenance. Like voltage regulator and other electronic devices, inverters are adversely affected by water or moisture and operate best if kept at or near room temperature. However, even at room temperature, most inverters will need good air circulation to cool their power semiconductors and internal transforms. Some inverters even have built-in cooling fans to ensure good internal airflow. In PV system design and installation practices, care should be taken to ensure all inverter intakes and outlet air passages have good access to cooling air - to avoid damage to the inverter due to poor ventilation.

Some inverter inverters are very heavy due to the type and quantity of metal found in their power transformers. Large models can weigh as much as two hundred pounds. The size of the inverter should be taking into consideration during the design and planning stages, if for any reason there is a chance of flooding the floor mounting will not be recommended. Ideally, it is best to plan the inverter installation so the unit will be wall mounted about 1.5m above the floor, Cross (1997). Brus Cross agues that holding the unit up off the floor keeps it dry and improve the flow of cooling air. Having an eye level also simplifies wiring and provides easy access for future maintenance. Fortunately, as inverters are improved, their weight will be reduced through the use of high frequency switching that requires smaller, lighter transformers.

The amount noise from an inverter varies widely from unit to unit and should be carefully considered before the inverter location is decided. Inverters can also generate troublesome EMI (Electro Magnetic Interference) and RFI (Radio Frequency Interference). This can be more of a problem than audio interference as it is difficult to quantify and plan for in advance.

5.10 Generic Inverter Configuration

The choice of inverter is crucial to the balance of system design in a photovoltaic installation exercise.

According to Nicola Pearsall, power conditioning determines the fundamental success of photovoltaic installations. Basically there are generic three types of inverter design currently in use for building integrated photovoltaic systems. The inverter types are:

5.10.1 The Single Inverter

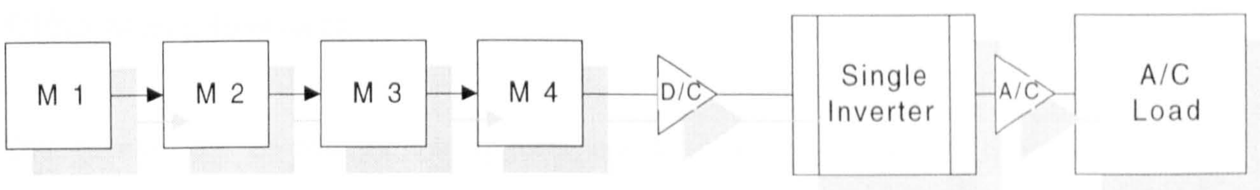

Figure 5.19: Single Inverter, (M1.....M4) = PV modules in array.

With the single inverter, PV arrays d/c output is converted to a/c by a single inverter, figure 5.19, which in turn supplies the building load with a/c and possibly export to the grid, if grid connected. This type of connection and use of inverter is not suitable where uniformity of module output is an issue.

5.10.2 Mater Slave Inverter

The array d/c output goes into a master inverter. This is distributed to subordinate or slave inverters, which in turn convert d/c to a/c to be supplied to the load and possibly the national grid, if system is grid connected in a BIPV system.

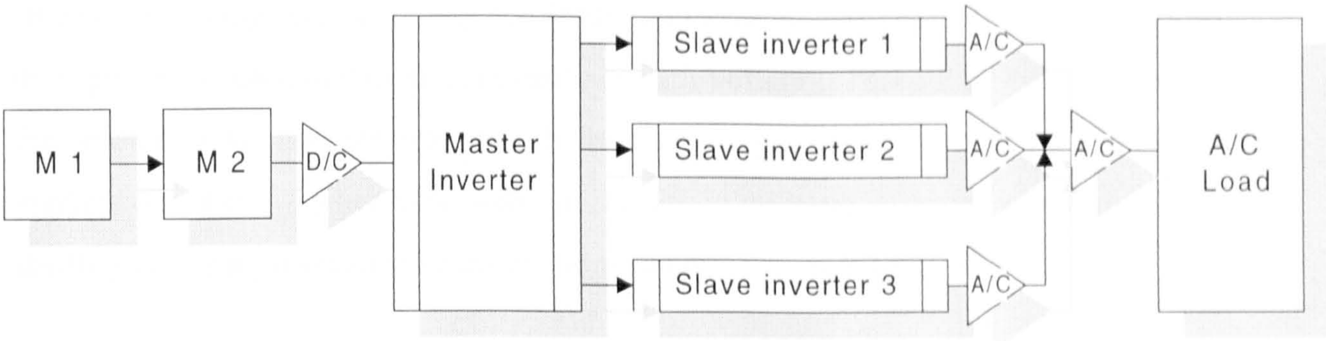

Figure 5.20: Master-Slave Inverter, (M1…M2) = PV modules in array.

This type of design allows for smaller inverter to be used and also decentralises power conditioning. Figure 5.20, if inverter S1 breaks down, inverters S2 and S2 may not be affected and will still be operational.

5.10.3 String Inverters

String inverters as the name suggests are a series of inverters, designed to be, connected to individual strings within an array installation, figure 5.21

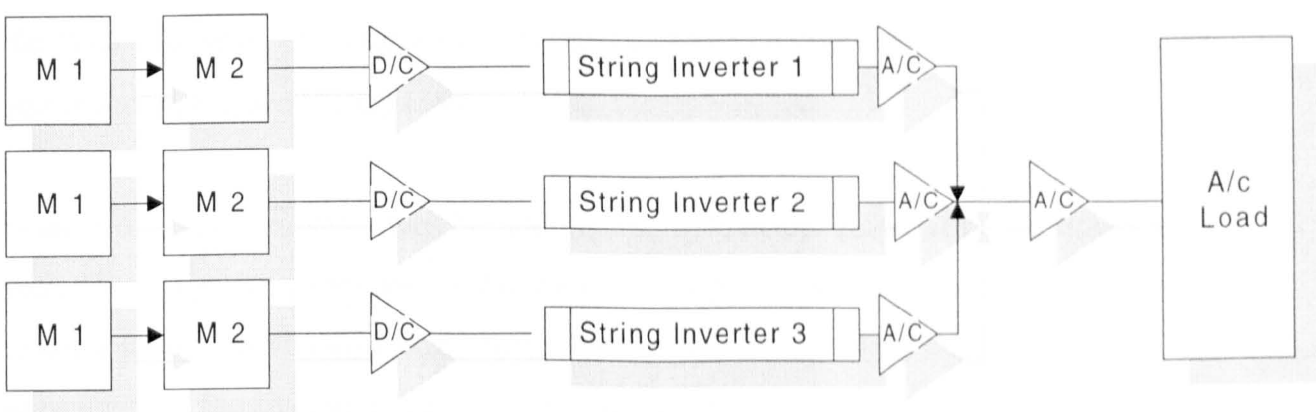

Figure 5.21: String Inverters, (M1…M2) = PV modules in array.

Each string is connected to its own inverter such that the d/c to a/c conversion of individual string is carried out independently of the others. The advantage of string inverters is that – a less than optimum performance of a string does not affect the conversion efficiency of the other strings within the installation.

When specifying and designing for BPIV application, designers need to recognise that: power is converted more efficiently at high voltages, Pearsall (1998), as a result the master slave inverter option will be more appropriate for low power output applications. On the other hand were uniformity is an issue, especially with regard to shading the string inverter may prove more suitable for such applications.

5.11 Generator Installation Review

The auxiliary generator is the heaviest of the individual BOS component in a Stand Alone photovoltaic installation. It has also got the most moveable parts. Generators are the noisiest and the only one to draw on a conventional supply of fuel. All of these factors have to be taken into consideration when locating and installing a generating machine.

Three factors are paramount in siting the auxiliary generator. These are weight, noise, and the need for air intake and exhaust connections. The weight of a generator requires that it be mounted on a solid floor surface, preferably a concrete slab at ground level. In order to best distribute the weight and keep the generator set up off the floor in case of flooding, an additional 100mm high concrete equipment-mounting pad is recommended Strong (1993).

Generator noise problem may be addressed by distance. Installation designers may start by siting the generator as far away as is practical from living areas and by making proper provisions for muffling and exhaust outfall. Since the generator set in a photovoltaic installation is an auxiliary machine, noise will not be as much of a nuisance as in system entirely dependent upon generator set operation. Timers are often included in large Stand Alone systems to automatically start and run the generator and to limit its operation to the part of the day when it is least obtrusive to the building occupants.

Air intake for both combustion and engine cooling and exhaust outfall is crucial to the operation of any internal-combustion engine. The generator will have to be sited so that intake air ducts and exhaust piping runs are not impracticably long or complicate. Running more wiring to a generator site is far cheaper than extending ductwork or piping. Other factors to be considered in generator set siting include dryness and complete assurance against flooding; ease of access for maintenance; and room, within a reasonable distance, for safe storage of fuel.

Careful advance planning is necessary to ensure that every decision made regarding equipment and its interconnection will minimise difficulties that can arise in the installation and operation of a PV system.
Safety and convenience should both be kept constantly in mind in the decision making process, Gyoh (1996).

5.12 A Review of Photovoltaic Systems Maintenance

The photovoltaic energy system and the components that make it up represent a triumph of solid-state electronics. The absence of moving parts and of mechanically replenished fuel supply or combustion render PV installations virtually maintenance free-or at least relegate most maintenance to the category of preventive care. However, when storage batteries and auxiliary generators are involved, maintenance becomes more demanding, though still far less complicated compared to more conventional power generating systems.

This section reviews the maintenance procedures starting with PV arrays. PV arrays is widely accepted to be the simplest part of the system installation to take care of once it has been properly installed. The most important external factor in the efficient operation of photovoltaic modules is the unimpeded transmission of sunlight. Whilst much cannot be down about atmospheric interference from occasional haze or suspended particulate matter, it is possible to get rid of dirt and dust that settle on the module surface and cut down on the amount of light reaching the cells. Usually, normal rainfall will be sufficient to wash settled dust from any array with more than a 15 degrees tilt from the horizontal. However, if rain is infrequent or the array is located in an area of heavy particulate pollution or dust build-up, such as near a heavily used dirt road, it might become necessary to clean the modules a couple of times a year. Ordinary dust can be got rid of with the stream from a garden hose. Heavier accumulation of grime will require washing with soap and water. For rooftop arrays, use of a wooden or fibreglass ladder to reach the eaves and work with a soft mop or sponge on an extended handle. Then hose down the array from blow. The use of abrasive brushes or cleaning pads or any abrasive cleanser should be avoided; mild soap will do just fine. If the glass on the surface of the module is scratched, a problem far worse than dirt might be created. The light-transmitting quality of scratched glass is permanently reduced and the cells beneath will never be able to function at top efficiency. Most important is to make certain that the array disconnect switch is in the "off" position, disconnecting both the positive and negative power leads, before any attempt is made to clean the PV array.

For rack-mounted or integrally mounted array, it is important to occasionally check the security of the electrical connections behind the modules. And regardless of the mounting procedure used, it's a good idea to make a semi-annual inspection of the space beneath to make such the mounting hardware is tight and there are no leaks at the point where the mounting hardware enters the roof or façade. With integrally mounted system, it is good maintenance practice to check for leaks between the module. Silicon-based caulking may be used, on a dry day, to correct minor problems.

Maintenance of power-conditioning equipment- inverters and controls- is not for the layman. The solid-state construction that makes modern inverters relatively trouble free also make it difficult for anyone other than a trained professional to diagnose problems when they do occur and to make whatever repair may be necessary. Terrence Paul, in "How to Design and Independent Power System" (Best Energy System for Tomorrow 1991), looks toward the day when all inverters have modular components that can be easily replaced. But that begs the question of diagnosis, which is in any event necessary before the consumer can know what modular part to order and plug in.

Preventive maintenance is by far the best policy with inverters and controls, beginning with first the stages of load estimation and sizing of power-conditioning equipment. Beyond elementary precaution power-conditioning equipment is to be safely left alone. It is good practice to install it in a clean, low-traffic part of the building, preferably in its own closed area or utility room. Inverter cabinet doors should be kept closed and air circulation paths free from obstructions. Finally, it should be made clear to children and curious visitors that power-conditioning equipment is not to be tampered with.

5.12.1 Battery Maintenance

Battery storage banks are the only photovoltaic system components requiring a regular schedule of inspection and maintenance. It all comes down to two specific areas:

- Electrolyte replenishment
- Cleaning

As batteries are discharged, the water component of the electrolyte solution in their cell is diminished. A typical lead-calcium battery will require the of water anywhere from one to two time each year, depending on the electrical capacity of the battery, the volume of electrolyte it holds and the use patterns it sees. It is good practice to check batteries more often, adding water to cells and remember to always use distilled water.

The schedule for cleaning batteries is not determined by any predictable formula but by simple visual inspection. Acidic film that may form around the tops of batteries should be cleaned away immediately; it's conductive and can sap current, as can other forms of grime and dirt. If a build-up of corrosive white power is observed around the battery terminals, disconnect the batteries. Clean the terminal with a solution of baking soda and water. When the terminals are clean and dry, reconnect the batteries to each other, making sure all terminal contacts are tight and coat the terminal with grease or petroleum jelly to protect against further corrosion, Strong (1993).

5.13 Summary

Solar electricity is the direct conversion of sunlight into electricity by solar photovoltaic cells. It is a truly elegant means of producing electricity on site allowing clients to take control of their energy destiny and create their own pollution, no by-products, no depletion of resources, these solid-state devices simply make electricity out of sunlight.

Solar electricity is the ideal source of electricity for an environmentally responsive building. With the right design, the sunlight that falls on building sites will power the building. Solar electric system can also be easily configured to provide on-site recharging of solar / electric vehicles allowing client / users to meet their transportation needs with renewable energy.

This chapter provides a technical overview of BPIV system design and component choice selection. It also reviews issues concerning installation and maintenance of building integrated photovoltaic power systems. The first part of the chapter looked at various mounting configuration and their application whilst the second part of chapter five reviews PV power system design and component configuration. The chapter reviews the major procurement system in the construction industry as well as the project management techniques and methodology aim at developing the more appropriate method of procurement and management technique for BIPV projects.

Review of Cladding Systems and the UK Cladding Sector

6.1 Introduction to Cladding

Cladding is an all-encompassing term for the external envelope of a building which keeps out the weather, generally supports only its own weight and transfers wind loading to the structural building frame. Curtain walling is so called because it 'generally' hangs from a building like a series of drapes.

This chapter identifies the types of cladding most commonly used in the UK construction industry. The method of fixing the various cladding systems to the building is reviewed and also on going proposals for the integration of PV modules in building have been appraised. A range of costs of the various cladding systems is included to enable comparison with adding cost associated with PV cladding. This chapter also looks at the complex mapping structure and supply chain of the UK construction industry, aimed at understanding the business environment, culture, and attitudes shaping the industry and influencing its ability and desire to innovate. This chapter analyses the organisation of the UK cladding industry, in terms of its strengths, weaknesses, and opportunities for innovation. Process maps showing interaction between organisations involved in the cladding industry are used to: evaluate the need and scope for cultural and organisational change to increase innovation within the cladding sector; evaluate research options; and understand the potential for improving the competitiveness of UK cladding sector and consequently BIPV systems.

Masonry and concrete cladding systems have not been considered in detail during the course of this study. However, there are large areas of these cladding types available, were integration of photovoltaic modules would tend to be carried out on site as a retrofitting exercise and therefore they do not fit strictly within the main thrust of this study. More attention has been paid to light-weight architectural cladding systems.

The successful procurement of architectural cladding on a building contract is totally dependent on the identification of suitable tenders from companies who have the necessary skill, knowledge, experience, capital and resource to undertake the cladding contract.

6.2 Type of Architectural Cladding

Curtain wall is generic terms describing cladding attached to the primary structural frame or floor edges of a building at discrete fixing points. It includes all non-load-bearing walls except for brick and block infill panels, in-situ brick and block outer leaves and industrial metal cladding. Curtain walling is understood to be a complete wall and include everything from outer weather shield through to the inner decorative finishes. Curtain wall can take any form below:

- Stick curtain walling
- Unitised curtain walling
- Panellised curtain walling
- Structural silicon glazing
- Structural glazing

6.2.1 Stick Curtain Walling

The stick system, also known as mullion/ transom system is a fairly common form of curtain walling construction, figure 5.1. This system is delivered to site with its components in loose form. Such components include mullion (vertical members), transoms (horizontal members), double glazed units (for vision areas), opaque double glazed units, insulated pressed metal panel or other material

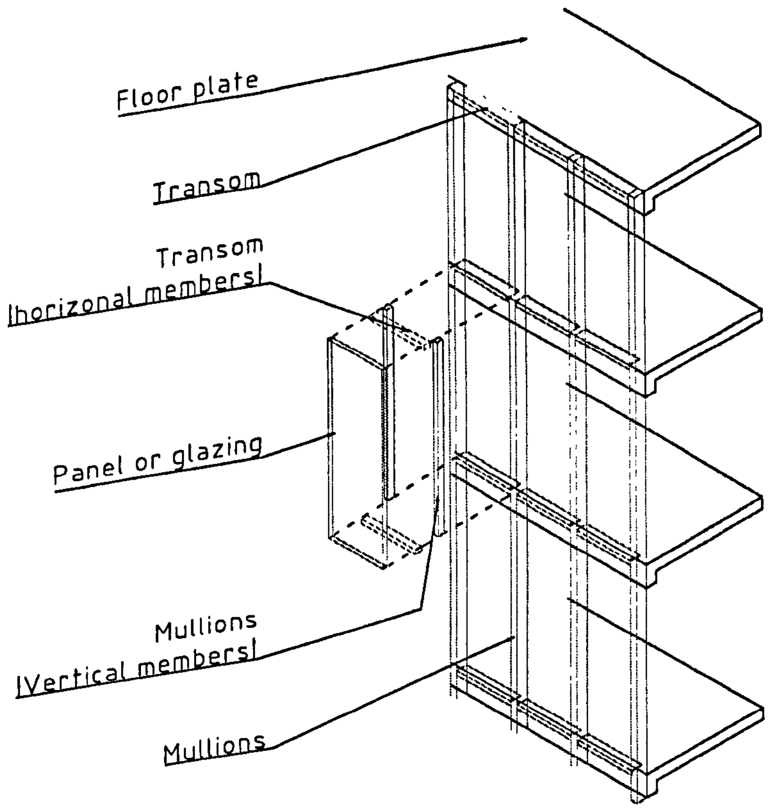

Figure 6.1: Stick system curtain wall. (Source: CWCT, Bath, 1997)

(for non-vision areas). Pre-formed gaskets and all associated bracketry for both fixing of components together and securing the cladding system to the building structure, figure 6.1.

This form of construction is widely used for buildings where a middle-to-high quality cladding system is required. Typical applications might be out of town business parks, and general speculative office block and retail developments.

This system relies heavily on a skilled site workforce since it is assembled on site rather than in a factory. As a result, quality control procedures need to focus sharply on site operations if the cladding is to perform satisfactorily. Factory based quality controls would concentrate on materials and finishes while site base controls would deal with issues such as installation procedure, tolerance, movement joints and sealing of the system. Manufacturing lead in times is relatively short, but this is offset by extended on-site operations.

An initial canvass for views from the UK construction professionals community regarding conventional cladding system indicate that: generally curtain walling system can be procured form a single cladding contractor, the procurement as well as the design co-ordination is a relatively simple process.
By 1998/99 figures, the typical cost of the mullion/transom stick system is in the range of £200 - £400/m^2 for good quality systems, and can be up to £600/m^2 for high quality systems.

6.2.2 Principles of Construction of Stick Systems

With stick system construction, the mullions transfer the horizontal wind forces and vertical gravity loads of the façade to the floors and framework of the building. The mullions are usually storey-high, but they can sometimes be continuous over two storeys.

Transoms are fitted between the mullions to form frames defining the vision and spandrel areas. These are fitted with fixed double glazed units or opening windows in the vision area and glass, metal, stone or other opaque material in the spandrel areas. The weather seal between the in-fill panel and the frame is usually made with pre-formed gaskets tapes and sealant. The in-fill panels are held in place with continuous pressure plates fixed to framework. Movement joints are provided in the framework to accommodate movement in the frame itself relative to the building structure.

The in-fill panels may be retained by a glazing rebate that holds the glass or opaque in-fill. Alternatively, panels may be fixed in front of the grid as the case of structural glazing systems or natural stone panels

The Stick System can also be made semi-bespoke by use of non-standard components such as pressure caps and other architectural features. If done (currently) it retains the proven performance of the system while giving the appearance of a bespoke design.
Bespoke sticks are used when the geometry is highly complex or the appearance cannot be obtained with a standard system. However, the standard stick system offers

economies of profile design & development. This may be a relatively large cost on a small contract but on large and more complex projects the cost is less significant.

Façade engineers and consultant that took part in a pilot study conducted during the course of this research argue that: the stick system has been developed to provide, in the most advanced systems, a more elegant form of weathertightness. This is based on the principle of a rainscreen with pressure equalisation and contains the outer rainscreen to deflect the bulk of the rain, a drained and ventilated cavity to remove any water penetration through the rainscreen, and an inner airtight vapour barrier to the inside. A typical example is shown in figure 6.2.

6.3 Rain Screen Cladding Review

Rain screen is a generic term used for multi-layer wall in which the outer layer acts only as the principle weather barrier and the inner layer of the wall satisfy the requirement for air tightness thermal insulation and so on. Rain screen may be constructed of curtain walling, where it is supported from a structural grid that also

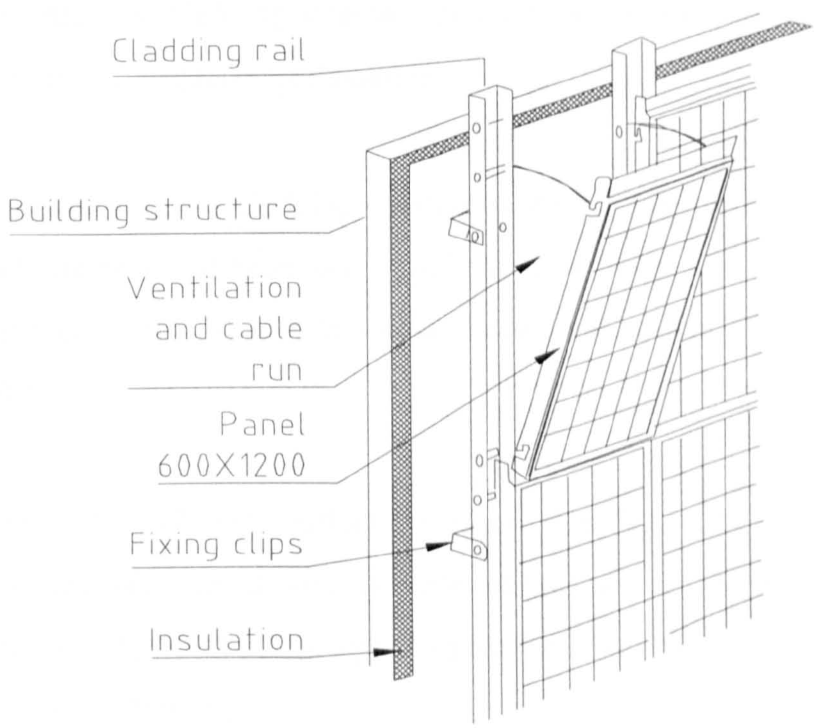

Figure 6.2: Schematic diagram of typical curtain wall construction
(Source: Photovoltaic in Buildings, A Design Guide, DTI, 1999)

supports the inner layer of the wall from which it is supported. In the later form of rain screen it is often used as refurbishment over cladding - although it is used as a form of cladding for new builds is increasing.

A resent study carried out by Centre for Window and Cladding Technology (CWCT) Bath UK (1997) reveal that: by present day standards the external envelope of many existing building is inadequate in terms of appearance, weathertightness, comfort and energy conservation. Even buildings, which were carefully detailed and constructed, have deteriorated over the years. Sometimes this ageing process has been accelerated by lack of adequate care and maintenance. The UK building stock has considerable number of such buildings, especially the high rise housing or office blocks of the 1960's and 1970's.

In order to extend the useful life of these buildings, overcladding systems have been developed. For most re-cladding projects in the UK, where rainscreen cladding is used, the re-cladding mostly takes the form of over-cladding - over the existing façade. The concept of the external protective rainscreen is not new and over the years a number of cladding contractors have developed various systems using different materials, and design philosophies.

In addition to overcladding existing buildings, these systems are also appropriate for cladding new buildings. It is widely applied in Canada, Scandinavia, Switzerland, and Germany and in recent years has been used in the UK on capital projects, CWCT (1997)

A feature of all overcladding systems is their lightness of weight, which has followed from the need to impose as little additional load as possible on existing building structure. The cost of the typical rainscreen overcladding system would be in the range of £150 - £250/m^2.

6.3.1 Principles of construction

Rainscreen overcladding adopts a two-stage approach to weather resistance whereby the rain and wind barriers are separated by an airspace. The outer leaf acts as a rainscreen and provides the major barrier to rain penetration. The inner leaf of the wall, which forms the air barrier, is kept relatively dry. There are two variations of the system – the first known as the drained and back-ventilated rainscreen and the second the pressure equalised rainscreen. Both are normally constructed using a lightweight metal rainscreen panel, usually coated aluminium, fixed to the building using bolts, studs, locks or purposed designed cladding rails, figure 6.2. The difference between the two systems is the amount of water that is permitted into the cavity. In the drained and back ventilated rainscreen, no deliberate attempt is made to prevent water ingress through the joints, and relatively large quantities of rain penetrate the joints and run down the reverse side of the cladding panel. This water is allowed to drain and evaporate from the cavity.

In the pressure equalised system, water penetration is controlled by the use of baffles, compartmentation, drips, upstands and opening sizes in the assembly, and in order to equalise the pressure in the cavity with the external pressure. This results in only minor leakage into the cavity. Positive drainage and ventilation are still provided however to remove this water

6.3.2 Drained and Back-Ventilated Rain Screen

Consist of impervious cladding materials with joint designed to provide protection against wind-driven droplets of rainwater. However, the joint does not prevent leakage due to the gravity and induced air pressure difference. This results to relatively large quantities of rainwater penetration, which runs down the reverse of the cladding system.

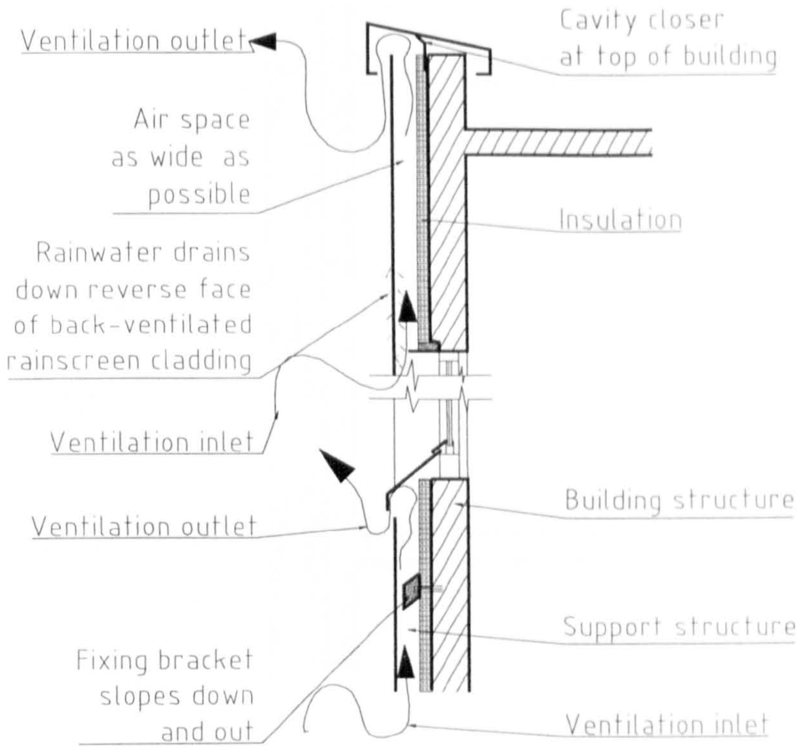

Figure 6.3: Back-ventilated Rain Screen cladding

(Source: Rain Screen Cladding, CIRIA, Butterworths, 1983)

Successful design depends upon preventing this water from reaching the inner leaf in sufficient quantities to cause heavy wetting. In the back-ventilated approach the claddings are allowed to leak and no deliberate attempt is made to minimise the effect of wind by means of pressure equalisation. Instead, the cavity is drained and positive back-ventilation is used to promote the rapid evaporation of any rainwater deposited in the inner leaf.

6.3.3 Pressure-Equalised Rain Screen

In the pressure-equalised technique the effect of kinetic energy KE, surface tension, gravity and pressure-assisted capillary action are control by incorporating baffles, labyriths, drips and up-stands in the joints in the assembly.

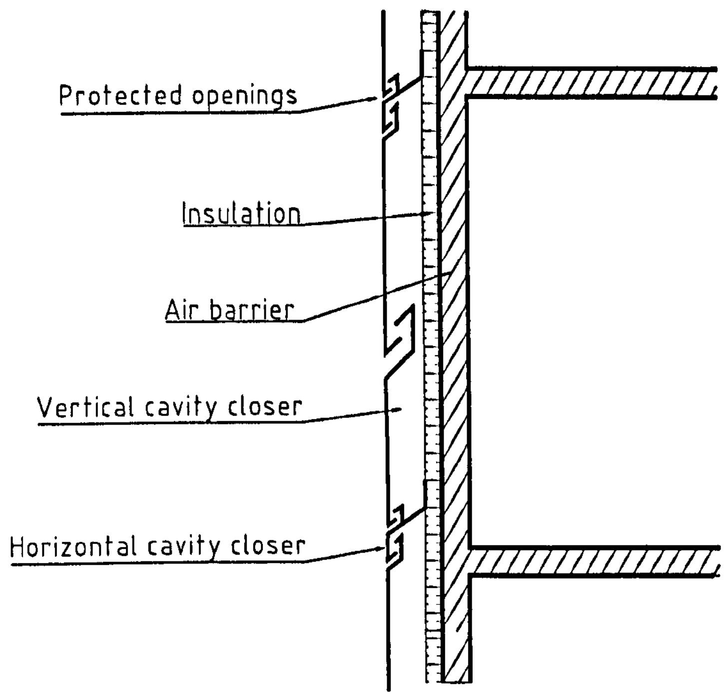

Figure 6.4: Pressure-equalised rain screen cladding.
(Source: Rain Screen Cladding, CIRIA, Butterworths, 1983)

The successful application of the technique require joints within the cladding assembly which have been designed to give a high degree of resistance to rain penetration caused by kinetic energy, surface tension and pressure-assisted capillary action. It is designed to ensure that:

- effective and continuous barrier against air infiltration on the internal side of the cavity, airspace sub-divided into a series of compartment so that the air pressure can be equalised
- it protects opening within the cladding assembly to minimise the wind induced air pressure differentials, which act across the rain screen.

Rain screen is sometimes fabricated and erected as part of a curtain wall by a curtain wall contractor. However, there are sub-contractors who specialise in rain screen over cladding. These companies may be the most appropriate for the installation of over cladding but do not necessarily have the ability to make and erect a curtain wall.

6.4 Unitised Curtain Walling

Unitised curtain walling is pre-fabricated typically delivered to site in glazing bay widths but greater sizes are sometime used. Units are either suspended from the floor, edges or from a secondary structure provided for the purpose. It may also be used as means of pre-fabricating a stick wall

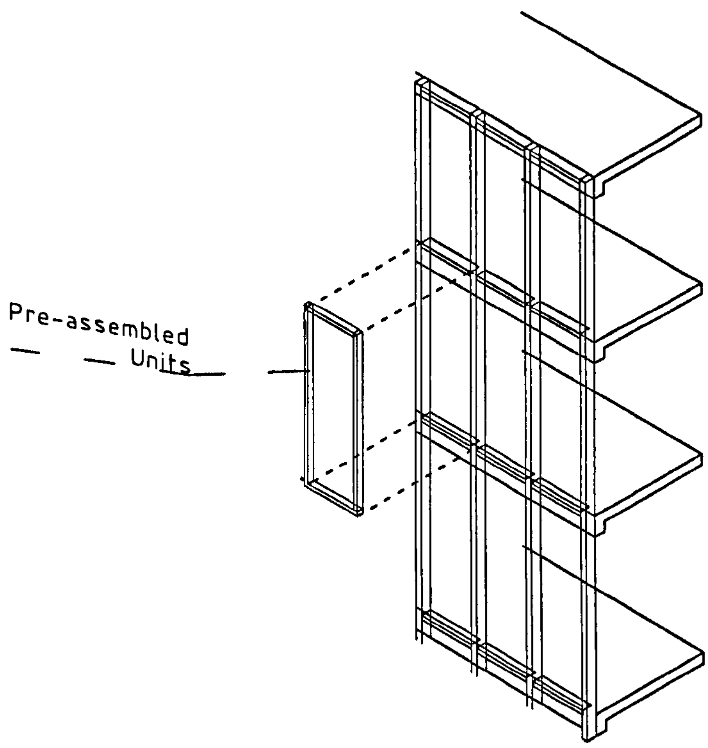

Figure 6.5: Unitised curtain walling (Source: CWCT, Bath, 1997)

The benefit of unitised construction is better quality from factory assembly, a reduction in site work and a quicker construction programme. However, it requires a tighter control on tolerances than the stick construction.

Unitised curtain wall is not commonly used in the UK. Pre-cast concrete walls are normally constructed as panellised walls. However, unitised cladding is widely used in North America, where the scale of individual projects is larger and the walls are of a more uniform and repetitive design. Under these condition the additional cost of unitised construction are reduced and the benefit of higher qualify control are more value.

6.5 Panellised Curtain Walling

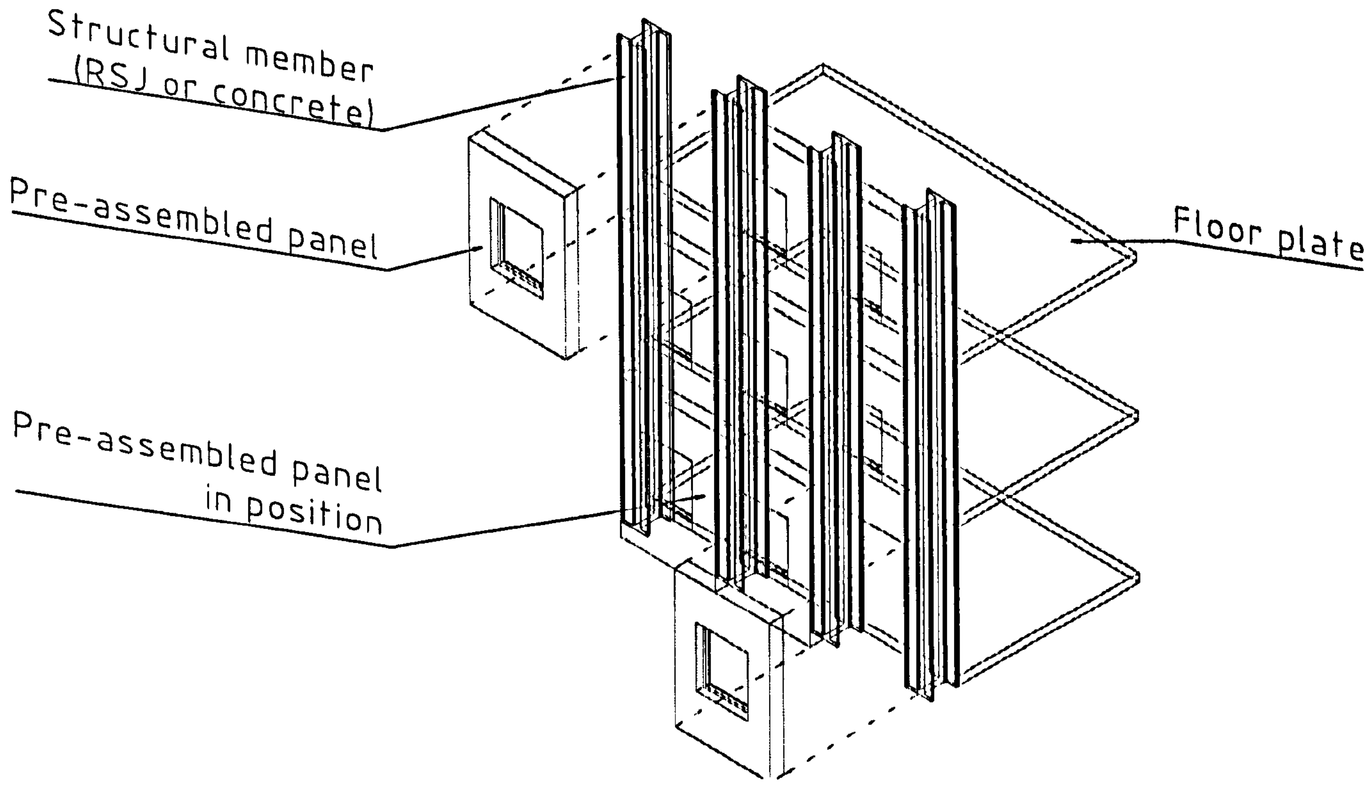

Figure 6.6: Panel cladding system (Source: CWCT, Bath, 1997)

The panel system is, widely believed to have been, developed to overcome problems associated with the installation of the stick system and to reduce the on-site installation time, Harris & Ledbetter (1997). It consist of large panels, usually as big as can be transported from factory to site. In their most developed form these panels are typically of storey height and up to 8m long. These panels which are fully manufactured in the factory contain all the necessary elements that the external building fabric would require-external weathering elements, insulation, vapour barrier, structural framing, fir protection, window and internal finish. The external weathering element is frequently made of natural stone or metal in the non-vision areas and of double glazed units in the vision areas. This type of panel can be considered as a basic building block or unit of construction and is sometimes referred to as a unitised panel, figure 5.6.

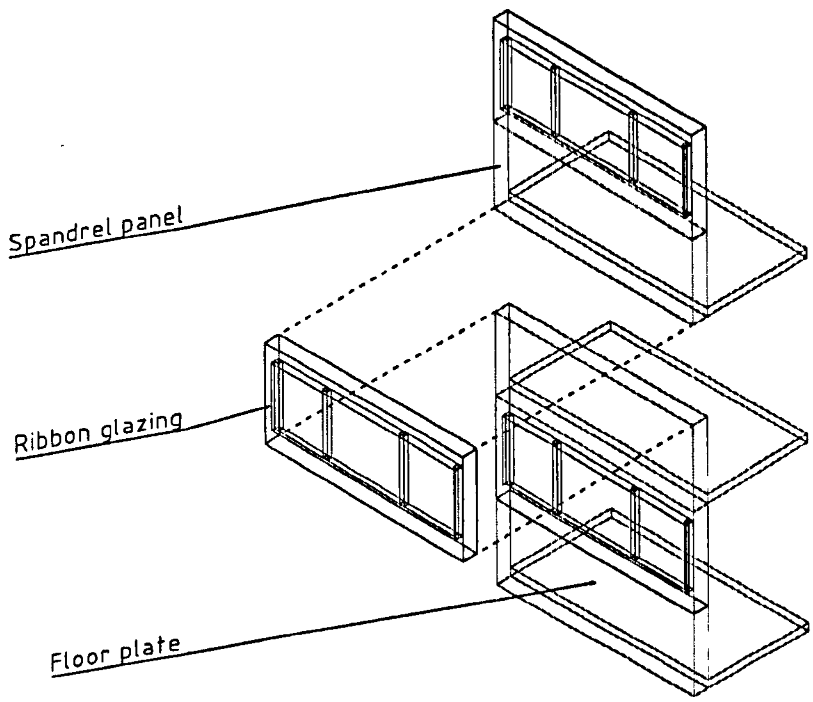

Figure 6.7: Strip Window System (Source: Curtain Walling CWCT Bath 1998)

A simpler version is the strip window system, figure 6.7. In this system, panels are installed in the spandrel area to form horizontal bands on the building with windows fitted between them. The panels are large, up to 10m long, self-supporting and are assembled in a factory before delivery to site. They include all the same elements as the unitised panel. The infill panels between the spandrels are commonly designed as continuous double glazed window units or alternating window and opaque panel, figure6.7.

Installation of both the unitised and the spandrel panel systems on the building is relatively simple. Most of the work is factory based; complete operation can be organised, carried out and supervised much more, effectively and efficiently, than the work required for a site-based systems, like the stick system.

Panel systems are particularly suited to highly articulate facades finished in heavy materials, such as natural stone. They, therefore, tend to be used on the more prestigious city centre commercial development where the cladding would be of the 'bespoke' nature. Panel wall systems fall within the middle-to-high cost range. Costs for a panel system would vary significantly since these systems are generally of bespoke design. A typical range might be £500 to £1000/m^2, ESTU (1995)

6.6 Panel System Principle of Construction

The structural frame of the panel is designed to carry the full weight of the panel plus all superimposed loads, primarily wind load. The material used for the external facing is a major factor in deciding the material to be used in the frame. Natural stone facing, which would normally be 40 mm thick, would require a mild steel frame due to its weight, whereas a light weight metal facing may only require an aluminium frame. Fire resistance requirement will also dictate frame material type. The facing is fixed to the frame using studs, bolts or rails, with allowance for a cavity of approximately 40mm plus rigid insulation and vapour barriers. Fire lining boards and internal finishes are applied to the internal face of the frame.

The construction is based on the drained and ventilated rainscreen principles. The external face forms the principles weather barrier. In the case of stone facing this would be formed with either open joints or sealed joints with provision for drainage and ventilation between panels. In the case of metal facing it would be detailed in such a way as to reduce water penetration into the cavity. The cavity however, should be considered as a 'wet' area, with positive drainage and ventilation. The vapour barrier in the panel forms the inner airtight seal and the 'site applied' panel to panel joints, using either sealant or a pre-formed gasket.

The window in the vision areas, formed with double glazed units, can be either fixed or opening casements. These components are very similar to those used in the glazed panels of the stick system. The panels are fixed to the building structure by means of gravity brackets and wind restraints.

Panellised curtain walling is used for pre-cast concrete walls; the other forms of panel construction make use of steel secondary frames to form strong backs on to which the individual cladding panel of stone and metal along with windows sills and so forth are mounted.

Panellised curtain walls are erected as story height panels of width equal to the column spacing of the primary structural frame, weighing several tonnes; each of these panels is attached to the primary structural frame at or near the column/beam joint of the primary frame.

Panellised construction offers the same benefits as unitised construction and also avoids the need to attach the curtain wall to relatively flexible floor edges or to stiffen the floor edges. Panellised construction is generally associated with high quality walls but may be used for more economic walls. However, the benefits are only realised when a high number of panels are to be produced with only a few differences. For this reason it is widely not used in the UK except for pre-cast concrete walls.

6.6.1 Profiled Metal Cladding

This form of construction has traditionally been used for industrial buildings, factories and warehouses. The design, manufacture and erection of these systems usually employ relatively low technology concepts. Whilst many are quite acceptable, they are not normally used in high quality visual applications. However, the eighties boom in areas such as leisure facilities and out of town retail developments has meant that profile metal cladding systems are now more widely specified and used than in the past, ETSU S/P2/00131/REP. These types of building tend to have very large roof and walls.

Manufacturers supply a vast range of systems and materials, most of which are designed to be fixed to thin gauge galvanised steel support members of primary rails. For the purpose of this study four of the most used systems in the UK have been identified and considered for PV module application in a study carried out by the Energy Technological Support Unit, 'ETSU S/P2/00131/REP'. The profiled metal cladding system identified were as follows:

- Single Sheet System
- Formed Panel System

- Metal Sheet Over-Rail System
- Metal Sheet Sandwich Rail System

6.6.2 Single Sheet System

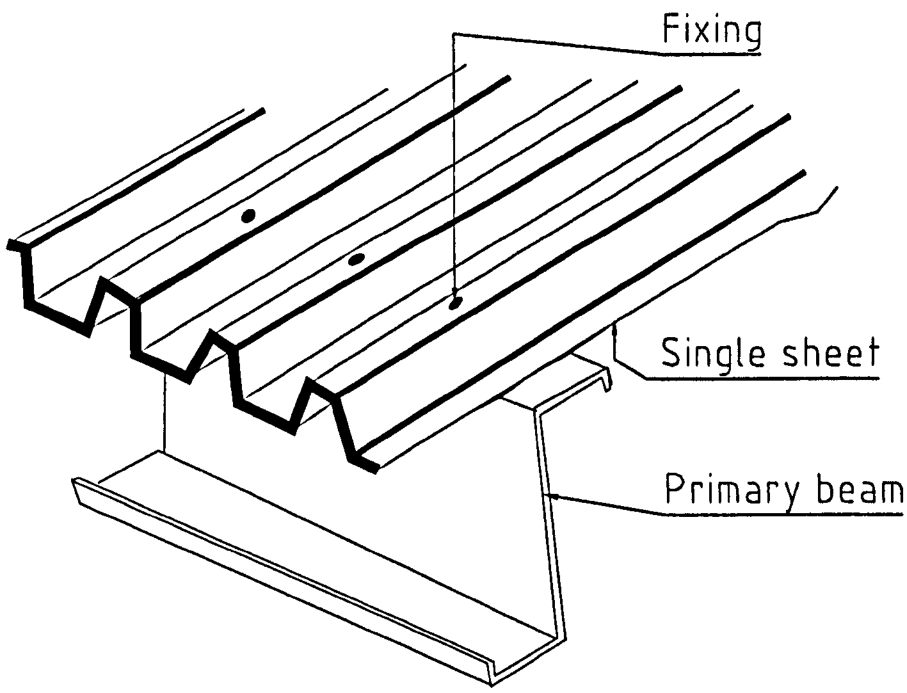

Figure 6.8: Single sheet system. **(Source: Development of PV Cladding System ETSU 1996)**

The fundamental principles governing PV installation in vertical façade can be liked with that of horizontal or inclined facades. The following inclined as well as Profile Metal roof façade will be examined in this section:

- Single sheet system
- Foamed panel system
- Over rail system
- Sandwich rail system

Thereafter, other vertical facades will be reviewed. The inclined Profile Metal façades reviewed in this section have the similar constructional detail as their vertical counter part.

The single sheet system is widely believed to be the simplest of all profile metal systems, figure 6.8. It consists of a single sheet of pressure-coated steel or aluminium fixed to the primary rails. Such a system has limited usage and might be found in agricultural buildings, storage sheds and other applications where building cost need to be kept low and thermal insulation/ heat gain are not critical. Sport stadia roofing might also be a suitable application.

6.6.3 Foamed Panel Systems

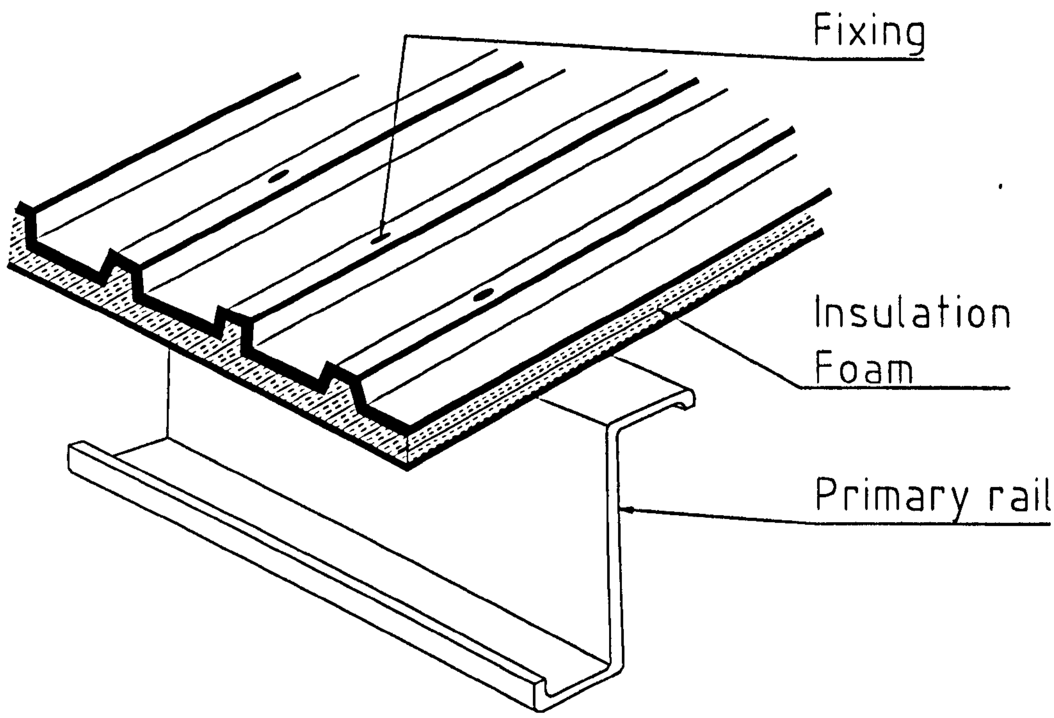

Figure 6.9: Foamed panel system (Source: Development of PV Cladding System ETSU 1996)

These panels are quite sophisticated in terms of manufacturing techniques and materials, and therefore quality control procedures concentrate on factory operations, figure 6.9. The panels are manufactured as one piece and site erection is fairly straightforward, the panels are erected and fixed and the joints sealed. Such systems are generally specified for buildings at the top end of the metal sheeting market. These tend to be leisure centre and retail shopping developments especially where ancillary office accommodation is required.

6.6.4 Metal Sheeting Over-Rail System

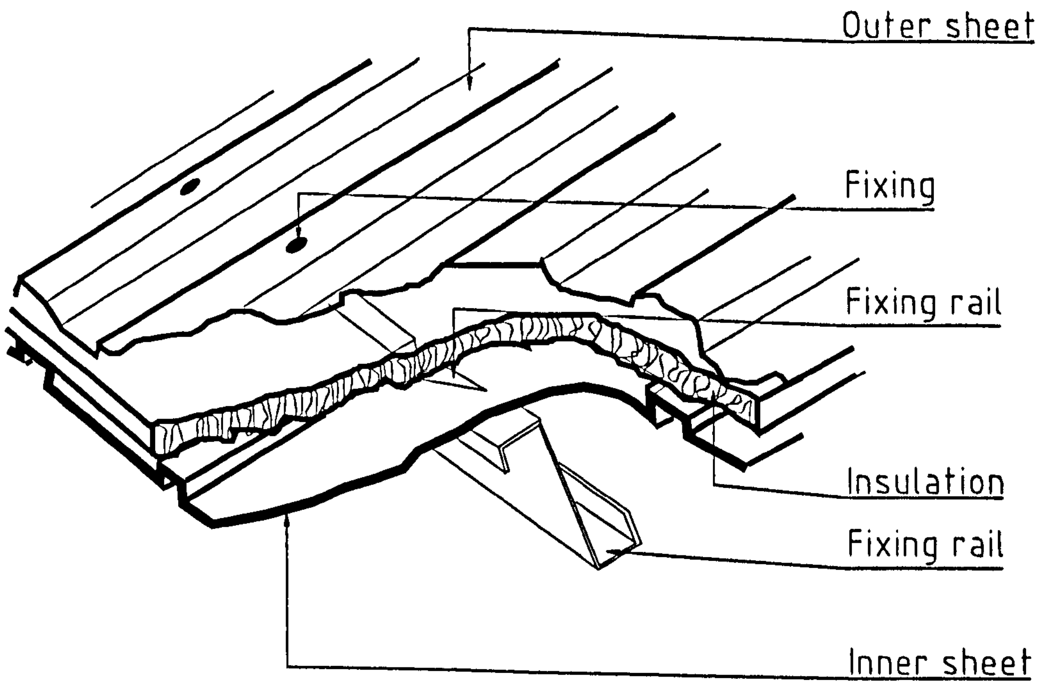

Figure 6.10: Over rail system (Source: Development of PV Cladding System ETSU 1996)

This is perhaps the most common of all the metal sheeting cladding systems, figure 6.10. It provides the ideal balance between good quality construction, in aesthetics and functional terms, and costs ETSU (1993). The thermal insulation can be designed to a good standard and is therefore suitable for most applications. The panels themselves are in two parts, the inner lining plus insulation, and the outer sheeting. Components are delivered separately to site, erected, fixed and the joints sealed. The panels are attached to the outside of the primary structure.

6.6.5 Metal Sheet Sandwich Rail System

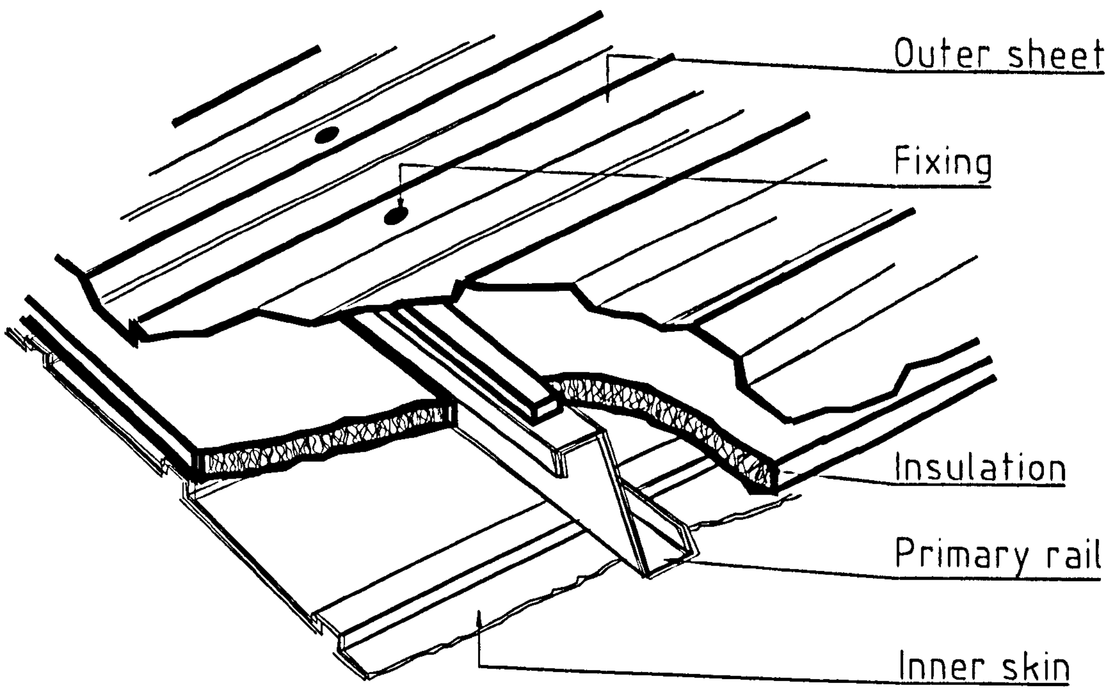

Figure 6.11: Sandwich rail system (Source: Development of PV Cladding System ETSU 1996)

This sandwich rail system places the inner lining plus insulation below the primary structure but is otherwise similar to the over-rail system in terms of quality and usage, figure 6.11. Because of the detail, it may be more suitable where internal appearance needs to be of a higher quality. The cost of panel metal cladding range between £20/m^2 and £45/m^2, Brookes (1996).

6.5 Structural Glazing

Structural glazing describes facades that support glass panels by direct mechanical attachment without the use of a glazing frame to support the edges of the glass. In some walls the glass is supported by mechanical attachment to ever glazing unit to a stick grid figure 5.12a and 5.12b. Alternatively the glass may be joined one panel to another and suspended from a top support. The use of structural glazing calls for particular design skills. The fabrication and installation of these walls also require specialist skills and not all wall contractors are able to undertake this work unless they sub-contract it as a package.

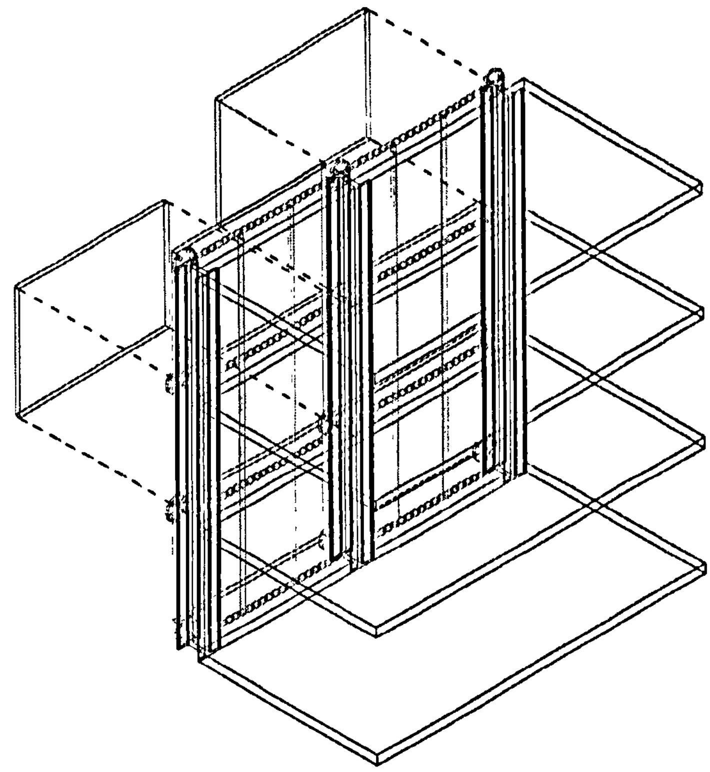

Figure 6.12: Structural glazing bolted glass assembly (Source: CWCT, Bath,1997)

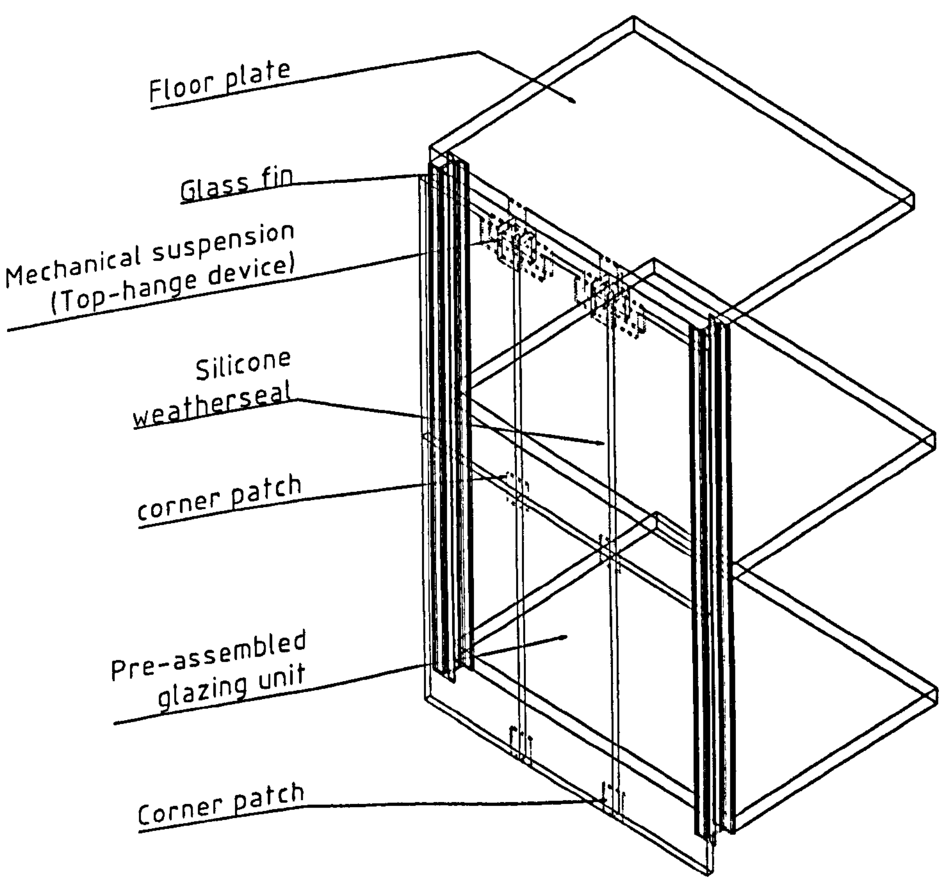

Figure 6.13: Structural glazing patch plate system (Source: CWCT, Bath,1997)

6.5.1 Structural Silicon Glazing

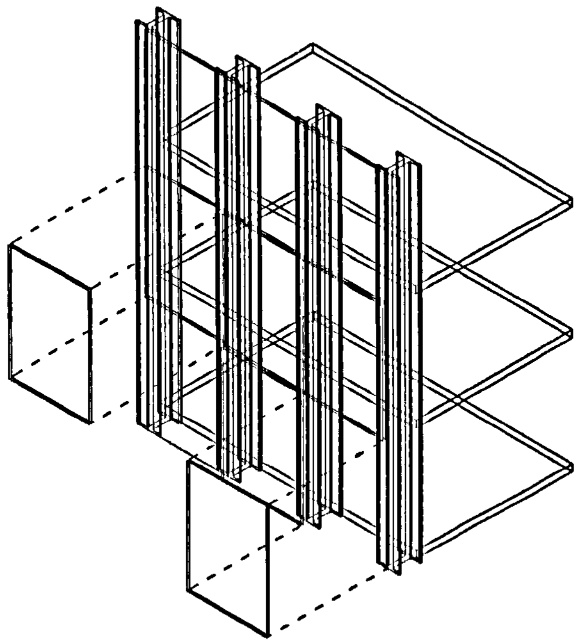

Figure 6.14: structural silicon glazing (Source: CWCT, Bath, 1997)

Structural-silicon-glazing uses silicon-adhesive to attach the glazing units to the structural support frame, which is usually aluminium stick grid. In practice the silicon adhesive joints have to be made under factory conditions. Normally the glazing units is stuck to a glazing sub-frame as a factory operation and resulting assembly is often bolted to the stick grid on site. However, structural silicon joints may also be used to install glazing units unitised and panellised walls. The fabrication and installation require skill over and above those commonly available amongst stick system fabricators and will normally involve the use of highly specialised manufacture.

6.6 Cladding Sector Mapping and Supply Chain.

A study carried out by Stephen Ledbetter of the Centre for Window and Cladding Technology Bath University, suggest that the cladding industry is called on by its' clients to supply complex solution to satisfy current fashion in architecture and to create semi-bespoke wall on most buildings.

According to the study, this can only be achieved through a large number of specialist contractors all of whom have access to the whole range of components from different suppliers. The ability to mix and match is a necessary requirement and strength of the industry. However this has been found to be a weakness in situations where it breeds a 'this can do' attitude with companies tempted through necessity or ignorance to accept contracts well beyond their normal scope of work and ability. The study also highlights the need to vet companies prior to forming a tender list. The report says this can take considerable time and resources from a main contractor or client and may be disproportionate to the value of the contract on smaller contracts.

Respondents who took part in the survey indicated that a list or register of specialist fabricator contractors able to undertake particular type or size of job would facilitate the selection of appropriate tenders, in the UK construction industry. An evaluation of specialist contractors appropriate to specific contracts could be used to produce a list of certified or registered companies similar to the register of qualified steel work contractors run by the British Constructional Steel Work Association.

6.7 Types of Company

Companies involved in the manufacture and construction of cladding systems may be categorised in one of two way firstly by Process or processes:

- System design
- Fabrication
- Installation
- Component supply

Secondly they may be categorised by ability:

- Specialist Contractor
- Supplier to a specialist contractor

It is the specialist contractor that enters into a contract with the client or their contractor and acts as the bridge between the construction and manufacturing process

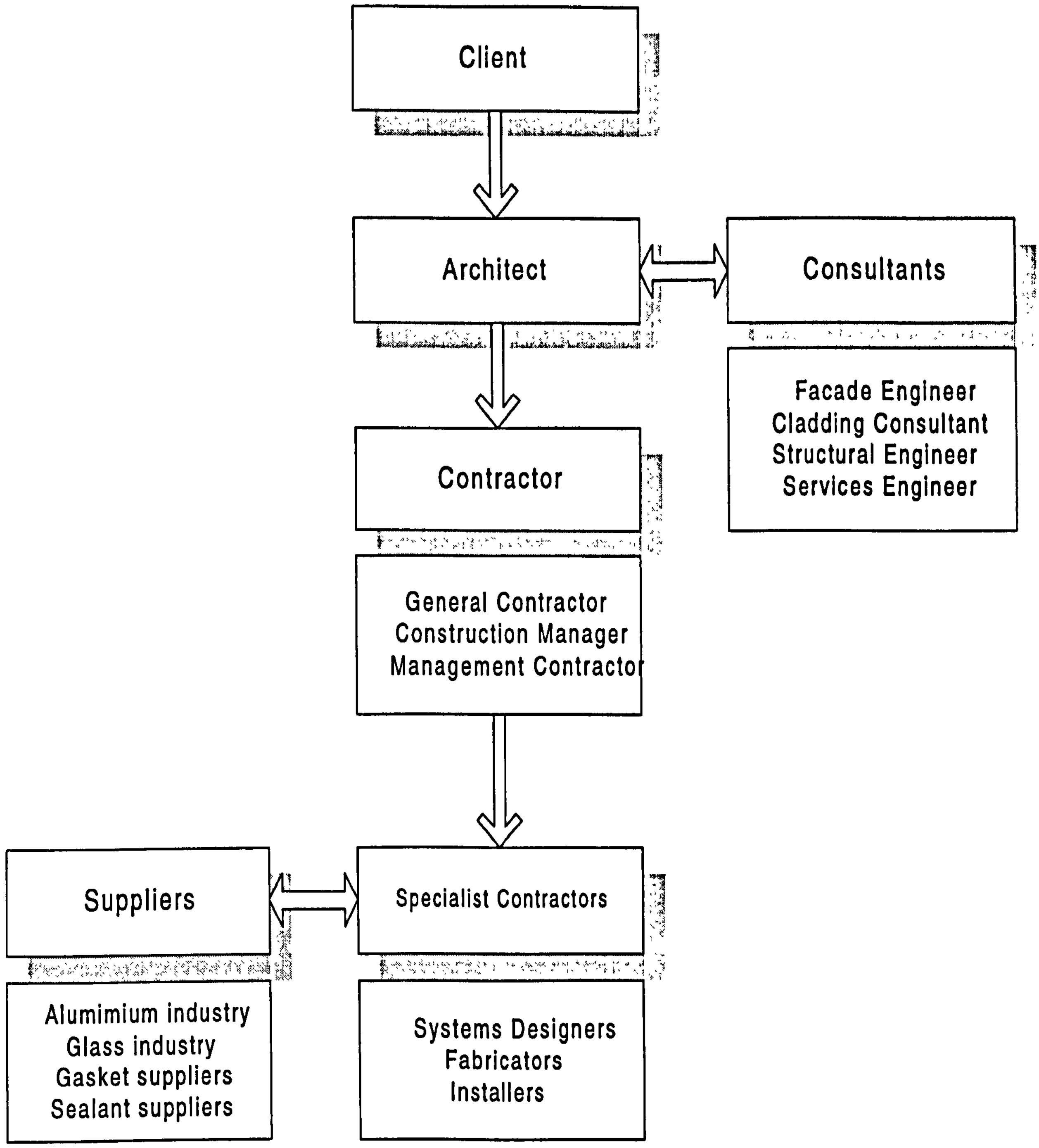

Figure 6.15: Typical communication link within the UK cladding sector.
(Source: CWCT, Bath University, 1998)

The Centre for Window and Cladding Technology is developing a mapping system link with a database for the selection / identification of appropriate specialist contractors for generic cladding projects, Ledbetter (1998).

Currently specialist contractors are selected/identified by the following routes

- direct contact from the main contractor
- recommendation of system supplier where particular system is specified

- system supplier having a recognised dealership

The most appropriate of specialist contractors will depend on the type of cladding to be constructed. The most appropriate specialist contractors have been identified against the following parameters

- Design
- Fabrication
- Installation

Recognising that some companies are vertically integrated, complex bespoke wall cladding will often require an integrated company that can design profiles and fabricate to meet the requirement of the contract.

6.7.1 Management Sub-contracting

Management sub-contracting, is an alternative method of procurement. Under this arrangement the contractor will manage the letting of individual sub-contract for design, manufacture and installation of cladding.

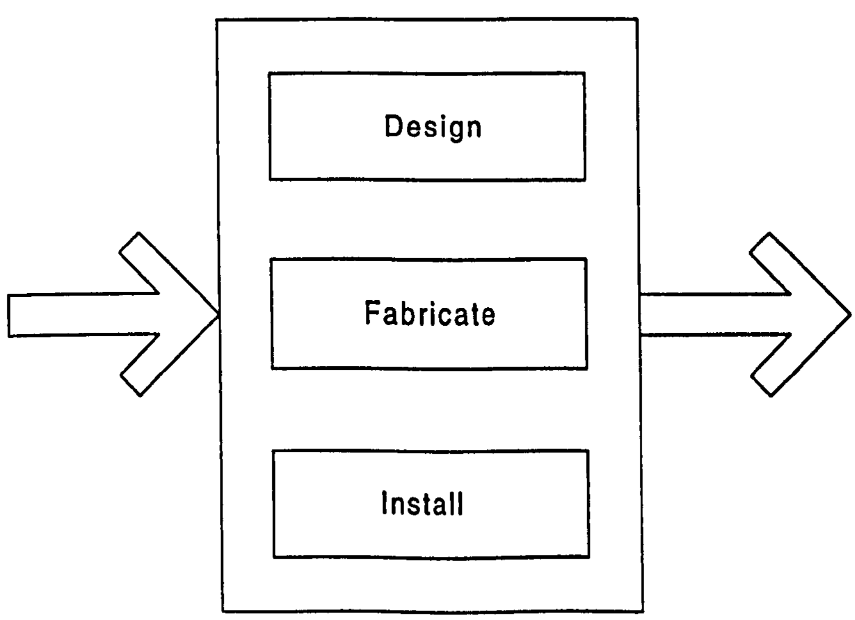

Figure 6.16: Fully integrated contractor

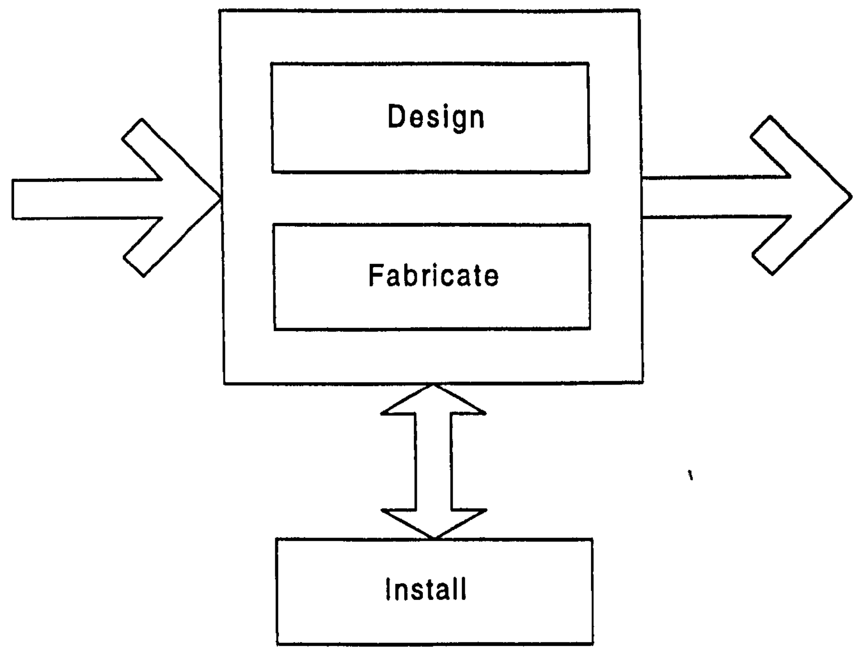

Figure 6.17 Integrated design/make cladding contractor with sub-contractor installation

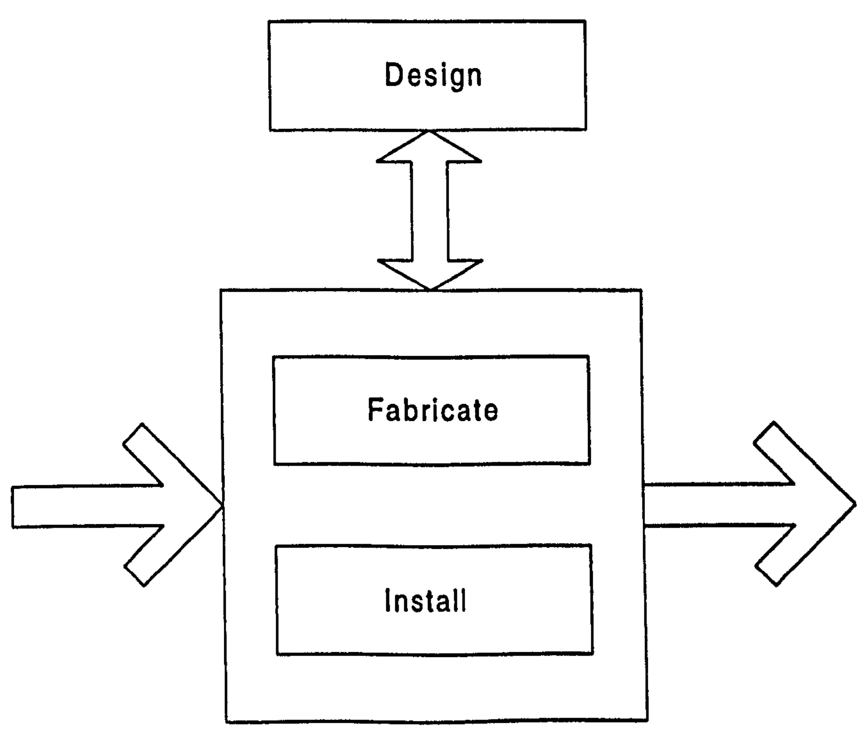

Figure 6.18 Integrated, Make / Install by fabricator cladding contractor.

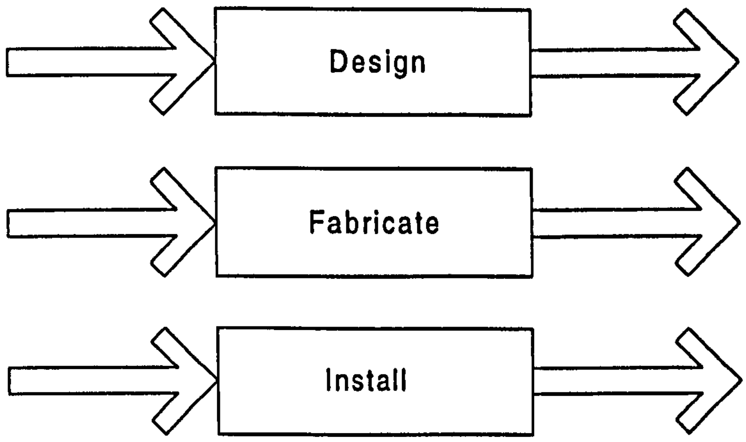

Figure 6.19 Separate and independent, Design/ Make/ Install cladding contractors.

6.8 UK Cladding Industry Profile

The profile of UK cladding industry consists of the follow types of cladding companies

- integrated cladding company
- cladding system suppliers
- cladding system fabricators
- cladding system installers
- cladding system testing and certifying organisation.

6.8.1 Integrated company

Integrated companies can within a single company undertake all the activities of tender-design-manufacture-install. These companies were more common in the past. This is still the structure of companies supplying pre-cast concrete. For other forms of walls this type of company is facing increasing competition from other types of companies and forms of supply chain.

Traditionally integrated companies have employed permanent staff for all aspect of design - fabrication - installation. To do this they have to secure enough work to enable them to maintain sufficient workload at all times. Integrated companies accept various types of work including complex architectural cladding. Complex architectural cladding appears to be a cyclical business – as revealed by a recent study carried out by CWCT (CWCT, Curtain Walling, Bath University, 1998). These businesses tend to follow the general economic cycle of the UK.

However, large integrated companies can no longer compete on smaller and simpler contracts. This market is dominated by economics that are inherent in the system company/fabricator supply chain. Nowadays, integrated companies have either to win other work to fill in during lean times and turn away work in good times or have a flexible workforce, which generally means bringing in temporary staff or sub-contracting packages such as design or some part of fabrication and installation. Very few integrated companies remain compared to 20 years ago, Ladbetter (1998). These companies occupy the top end of the market i.e. contracts of £1m and above, CWCT (1996). With the exception of small companies working in particular skilled niches such as entrance canopies, complex door ways and small atria, there is a shortage, Europe wide, of companies capable of undertaking jobs in excess of £1m. Companies working in this market are able to properly charge their design and management overheads. Many are able to choose which jobs to accept and work only for good clients.

6.8.2 Cladding System Suppliers

System designers are responsible for designing the aluminium sections used for cladding and the methods to be used in their manufacture and assembly. Their business depends on establishing close links both with fabricators and with those responsible for design and specification. They allow scheme design to be turned into workable building.

System suppliers design and supply components that enable others to fabricate and install walls. These companies came about with the introduction of standard steel profiles for the fabrication of windows and glazing screens.

The introduction of aluminium and later plastic (PVC-U) as framing materials lead to a proliferation of different profile supported by competition between the primary material suppliers, CWCT (1997).

System supplier is also able to dominate this market by developing and holding specialist skills. They spread the cost of development over a large number of construction contracts as the system is reconfigured to suit many / any job by the fabricators / installers.

System suppliers are also provides technical support –as and when required. Therefore, fabricators / installers do not need to support this service as a standard resource within every individual company. Some fabricators develop additional profiles of their own. In addition to technical support and development, system suppliers promote their systems nationally to clients and help their fabricators to win work. This shared resource reduces the overheads of the specialist contractor.

With few exceptions, system supply companies will not accept legal obligation for anything other than the supply of materials. System suppliers are large companies that are risk averse and they do not accept the unnecessary risk of sub-contracting to the construction industry. However, large system companies will provide project specific advice to their fabricators and will develop bespoke profiles for use on a contract.

Some system supply companies have a net-work of fabricators, many of which are small. Most suppliers recognise that fabrication companies have different skill, abilities and financial standing. They supply the more advanced system only to more competent fabricators. System supply companies supply framing profiles, gaskets, hardware and all components necessary to construct a wall.

6.8.3 Cladding System Fabricators

Fabricators are responsible for the fabrication and (sometime) installation of specified cladding system.

System fabricators vary in ability from those that make and install windows into regular holes to those capable of making and erecting whole walls valued at millions of pounds sterling.

A fabricator will work from architectural drawings to produce general arrangement drawings for the walls, work up a detailed design using components from a system supplier and when necessary identify other suppliers and components.

A system fabricator would usually have design office and factory facilities for basic manufacturing processes for: cutting, drilling and punching. However, many fabricators sub-contracts some element of manufacture. System suppliers are increasingly acting to co-ordinate/ project manage joint working ventures of their fabricators to even out workload and to win large contracts.

The less well-resourced fabricators need the support of their system suppliers and do not necessarily have the skills to access and incorporate other components into a wall, Ledbetter (1997). At the top of the spectrum system fabricators are major companies in their own right with the ability to design components when appropriate but otherwise content to use a system that is know and accepted by the client.

6.8.4 Cladding Systems Installers

Installer-only companies sometimes act as specialist contractors to supply and install, but only carry out installation themselves. The risk with these companies is that they do not possess manufacturing skills or facilities and may not understand the construction and design of the wall components, Kawneer Manufacturers Details and Specification Guide (1999).

Installation only companies are commonly employed by fabrication companies who sub-contract/let the installation of a wall to them under direct supervision. This approach is favoured by system fabricators and integrated companies as it enables them to use local labour for work remote from their manufacturing base to meet demand for labour at peak times. Very often, long standing arrangements (partnering) between installers and fabricators has the advantage of installer becoming familiar with wall systems and to know the personnel involved in the design of the wall as well as management of the contract. That way, an effective feedback and feed forward system is put in place, enhancing innovative development in cladding design planning and installation procedure.

Installer only companies have a core of permanent staff but rely heavily on installers hired on a contract basis. For this reason it is important to know that installers are properly trained and knowledgeable about the wall they are installing. To this end the system suppliers and integrated companies are now providing training for installers and the Centre for Window and Cladding Technology Bath maintain a register of trained installers

6.8.5 The Architect/Cladding Consultant

The role of the architect is to translate the client's requirements into design that is both acceptable to the client and practicable for the systems designer. Systems designer that took part in a survey conducted as part of this study are of the general opinion that architect tend to have an idealised view of the cladding industry that does not conform with reality.

Architects that took part in the survey indicated that: because of their concern for the building image and performance, architects tend to be wary of standardised cladding systems, expecting systems designers to be imaginative and innovative in meeting their requirements. This approach suggests that they are not always fully conversant with the industry's existing structure. Detailed analysis of the above mentioned survey may be found in chapter 9 whilst further analysis and documentation may be found in the appendix.

Architects are to some extent responsible for innovation, particularly at the upper end of the cladding market where style is of real commercial significance. Their interest is strongly project-specific and mainly at the system performance level. They view the cladding system as part of a larger building 'system' and as part of the solution to a unique design problem. The systems designers, however, set the ultimate boundaries, figure 6.20. System designers determine what is on offer and what makes sense commercially both for them and for their fabricators. Elsewhere in the market, the system designers are even more 'in control', providing standard solutions while recognising that architects must retain a sense of responsibility as well as a liability for the finished design.

6.8.6 The Main Contractor

The main contractor is an important link between the design/specification process and fabrication/installation, Figure 6.20. Although their role varies with the type of contract and the kind of service provided, main contractors frequently occupy a position of some power. They can often influence the final specification, and their selection of fabricators is limited to those they perceive to be financially healthy.

Most main contractors that took part in this study indicate that they remain wary of new technologies with their perceived potential for failure. When faced with an unusual specification, most will try to make the scheme. Others will respond by seeking to ensure that any liability falls elsewhere, should problems arise.

6.9 Conventional View of Innovation in the UK Cladding Sector

Innovation within the cladding industry is widely believed to originate in the activities of architects and specifies, table 5.1. They advise the client as to the options available. They also set the requirements and targets in terms of appearance and performance that the industry must meet. In the conventional view, the introduction of innovative ideas and techniques depends on their beliefs and practices and on the preferences and priorities of their clients.

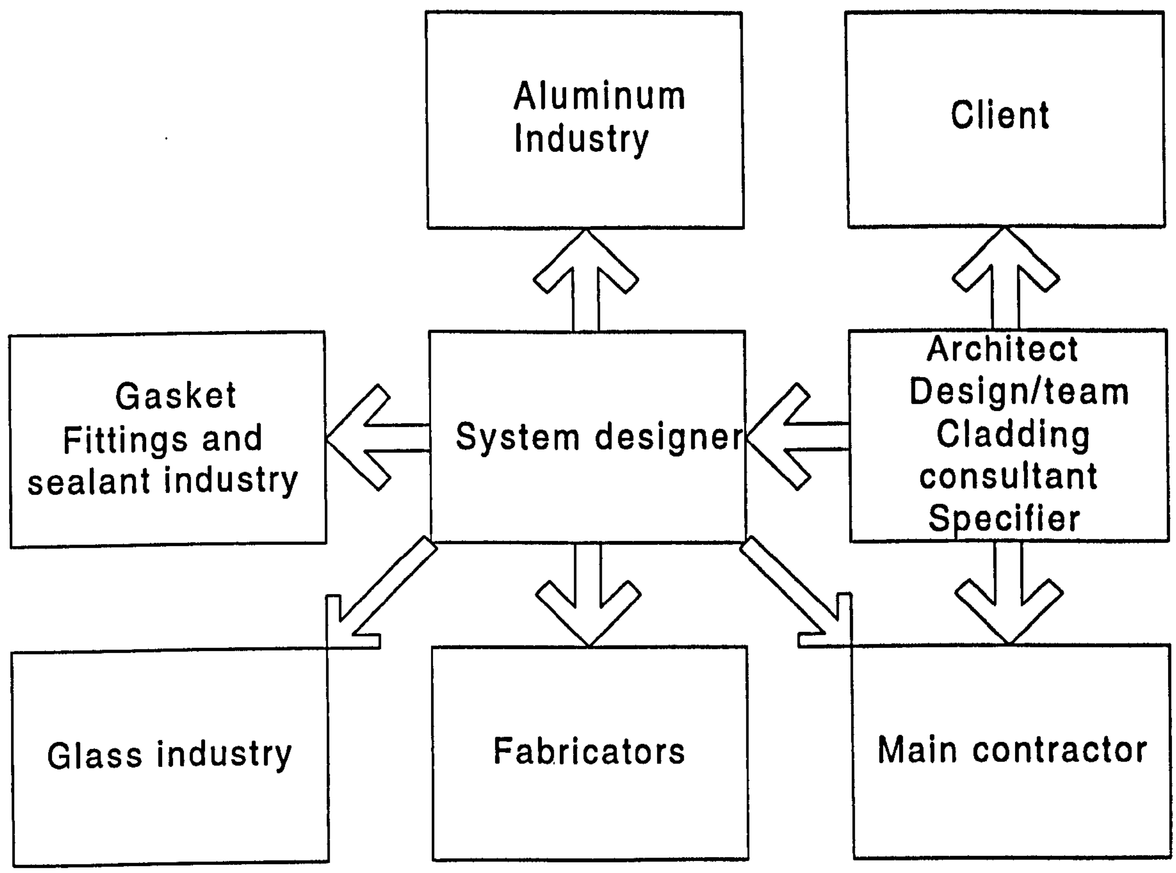

Figure 6.20: Conventional view of UK cladding sector, Communication Link.

(Centre for window and Cladding Technology Bath University 1998)

Organisation	Activities
The Client	Commissions the building and sets the standards in terms of cost, Building performance and value for money
The Architect / Specifier	Interprets the client's needs, design and specifies the performance of the cladding system and, where appropriate Introduces new techniques
The System Designer	Designs and develops the system in response to the architect's specifications.
The Fabricator	Manufacturers and installs the system
Other participants Main contractor Glazing manufacturers Gasket makers Sealant makers	Have an important role to play in terms of decision-making with regards to innovation

Table 6.1: Decision-making and innovation: the conventional view

(Source: CWCT, Bath, Innovation in the UK Cladding Industry 1997)

Subsequent diffusion of the new techniques has frequently been assumed to follow a linear pattern. Innovations, which are normally both more costly and more risky than tried and tested solutions, are applied first to high-status building, Brookes (1996). New technologies are expected to 'trickle down' until adopted by those working on less prestigious projects. Relative costs and the perception of risk are believed to be the critical determinants affection the speed of this diffusion. The hierarchical innovation and diffusion patterns described above is widely believed to exist within the cladding industry. However, a study carried out by CWCT showed few signs of any linear sequence of influence and little evidence of the trickling down of new ideas or any progressive reduction in cost and risk. Various industry players can initiate innovation: system designer, fabricators and architects and other cladding consultants.

The Centre for Window and Cladding Technology Bath University places innovation within the cladding industry at three levels:

- at the material or component level, to enhance performance and reduce relative cost;
- at the material/ component interface, to enhance performance
- At the cladding system level, to enhance performance and possibly, though not necessarily, to reduce costs.

The study concluded that important opportunities for innovation can also arise upstream of the construction process, with each component manufacturer seeking to improve manufacturing performance and / or reduce cost. The result of the CWCT study has been summaries in table 6.2.

Level of Innovation	Purpose of Innovation To Enhance Performance	Purpose of Innovation To Reduce Relative Cost
Material/ component	Project type: Prestige Key participant: System designer	Project type: Standard Key participant: Fabricator
Material/ component Interface	Project type: Mid-range Key participant: system designer	
Whole system	Project type: Prestige Key participant: Architect/ Designer and System designer	Project type: Standard Key participant: Fabricator and System designer

Table 6.2: Level of innovation in the cladding sector.

6.10 Cladding Systems Test and Certification Bodies

Testing and certification is a complex issue in the UK although the problem is by no means unique to the UK. There is no single accreditation body for the approval of window and cladding components or assembles. Not all test houses test to the same written standards and certainly some approval bodies are regarded as being tougher than others.

With the adaptation of European standards (CEN), otherwise known as the European Committee for Standardisation, there will be a greater uniformity across Europe for products to which standards apply. Despite the harmonisation of standards there will be no requirements under the European Construction Directives, Product Directive, for privately funded contracts to work to CEN standards. In addition there are going to be cladding systems for which standards do not exist for instance rain screen cladding system Ledbetter S (1998). There is confusion about the application of standards to walls assembled on site; the big question is -should the factory-produced kits be subject to CEN standards or the constructed work on site.

The standard has generally been established for weathering and mechanical performance. There is still no British Standard for doors. The UK has not had a standard endurance test that subjects a window or door to several thousand cycles of loading as is common in many other countries. Durability and weathering of materials under the effect of UV and problems of corrosion are not subject to agreed test regimes

Test methods are established for new materials such as adhesive bonded panels and new constructions such as rain-screen façade. However, no standards or methods of testing have been agreed in any these areas where standard test regimes have not been established. Each laboratory or approved body will set their own requirements to test to client's specification for testing. This leads to a wide diversity of test and large cost to industry as many products are tested specifically for one project and retested to different regime for the next project. Currently standard fall into three categories those provided by

- National standard bodies i.e. British Standard Institute (BSI) and (CEN)
- British Board of Agreement (BBA)
- Union Europeenne Pour l' Agrement Technique dans la Construction (UEAtc), which is the European equivalent of (BBA)

6.10.1 Testing Organisations

British Standard Institute (BSI) has a testing arm that tests products with its own laboratories for compliance with British Standards (BS) so that BSI may certify them under the kite-marking scheme. There is also a Product Approval Scheme (PAS) that is used for aspects of product performance not covered by British Standards. To date only one PAS relates to windows and cladding, PAS 011 for window security.

The testing facilities at BSI relate mainly to the performance of windows, doors, associated hardware and glazing. Mainly companies supplying windows in domestic markets, where it is recognised by some homeowners, use the kite mark scheme.

6.10.2 British Research Establishment (BRE)

The BRE are able to test cladding systems for air and watertightness. However, they are currently unable to accommodate such large cladding specimens as Taylorwood Rhode Engineering Limited (TEL). BRE do not operate an Aero Engine and Dynamic watertightness testing. Testing is undertaken using smaller fans over a localised area. BRE do not run an approval or certification schemes but provides test reports. BRE tests far less cladding systems than TEL and normally only undertake testing requested by manufacturers.

6.11 Review of PV Module Integration in Conventional Cladding Systems

This section reviews recent and on-going studies on proposals for the integration of PV modules into conventional cladding systems. Various R&D groups have put forward proposal for the integration of PV modules into conventional cladding system. Conventional systems that required little or no modification were favoured in a study carried out by ETSU on behalf of the Department of Trade and Industry (DTI), ETSU S/P2/00131/PER (1993). The views and judgements expressed on the feasibility and viability of the proposal where those of contractors, cladding consultant and other professional members of the construction industry. On going research at Cardiff (sponsored by British Steel and EPRSC) have developed a profiled metal PV integrated cladding system. These systems consist of amorphous silicon PV modules incorporated into (British Steel products) standard profile metal cladding products. The results are to be published at the end of 1999 or, at the latest, the first quarter into the next millennium. However, it is worth mentioning that the modules are up and running and interim test results look promising, Uniack (1999)

6.12 PV Modules Integrated into Double Glazed Units - Stick System

Double glazed units (DGU) are factory-assembled units, consisting of two panes of glass with a sealed cavity between. A common make up of DGU might be 6mm outer pane, 12mm cavity and 6mm inner pane giving 24mm overall thickness.

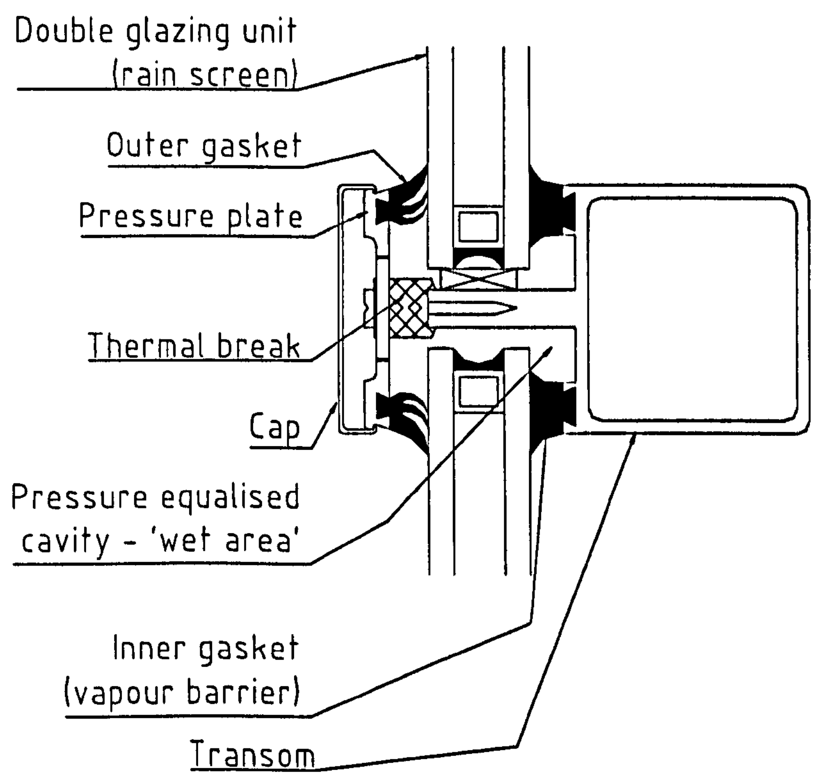

Figure 6.21: DGU Mullion/transom Stick System - pressure equalised- transom system.

Currently, PV modules are manufactured as a sandwich consisting of 3mm thick low iron toughened glass, an array of silicon wafers (the PV component) encapsulated in an EVA (ethylene vinyl acetate) matrix with a poly vinyl flouride backing sheet. Sheet sizes are approximately 1.0m x 0.5m. The 3mm glass would be considered too thin for virtually all 'cladding' applications. In the medium - long term, PV modules would need to develop using thicker glass in the existing configuration (glass/PV/backing sheet) or a glass/resin/glass laminate. The thickness of glass for conventional systems would depend on specification of a variety of factors including wind load, panels size to mention a few – but should be a minimum of 6mm thick.

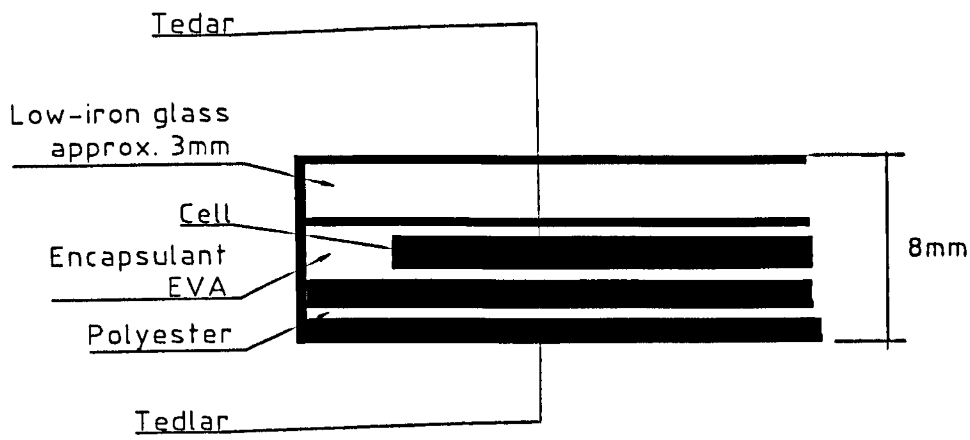

Figure 6.22: Glass/EVA/Tedlar ™/Polyester/Tedlar ™ typical module construction. (Source: Photovoltaic in Building, A Design Guide, DTI, 1999)

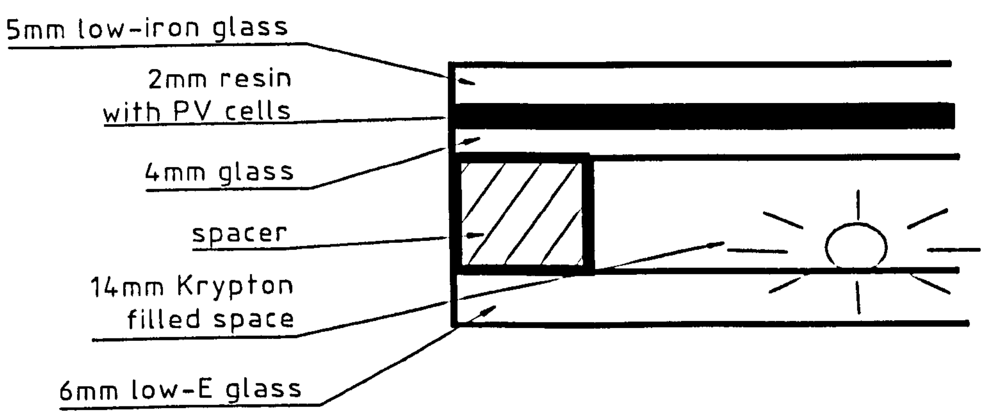

Figure 6.23: Glass/Rein/Glass typical module construction
(Source: Photovoltaic in Building, A Design Guide, DTI, 1999)

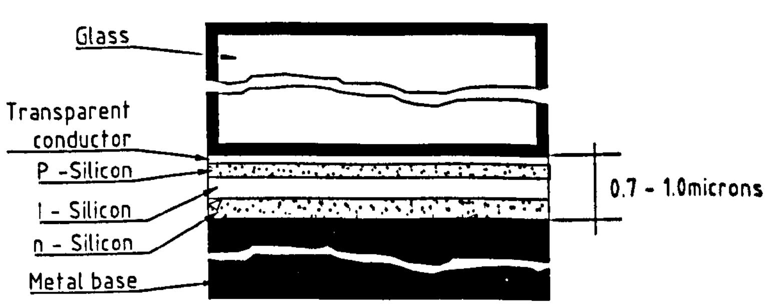

Figure6.24: Thin Film Silicon (TFS) Amorphous silicon typical module construction (Source: Photovoltaic in Building, A Design Guide, DTI, 1999)

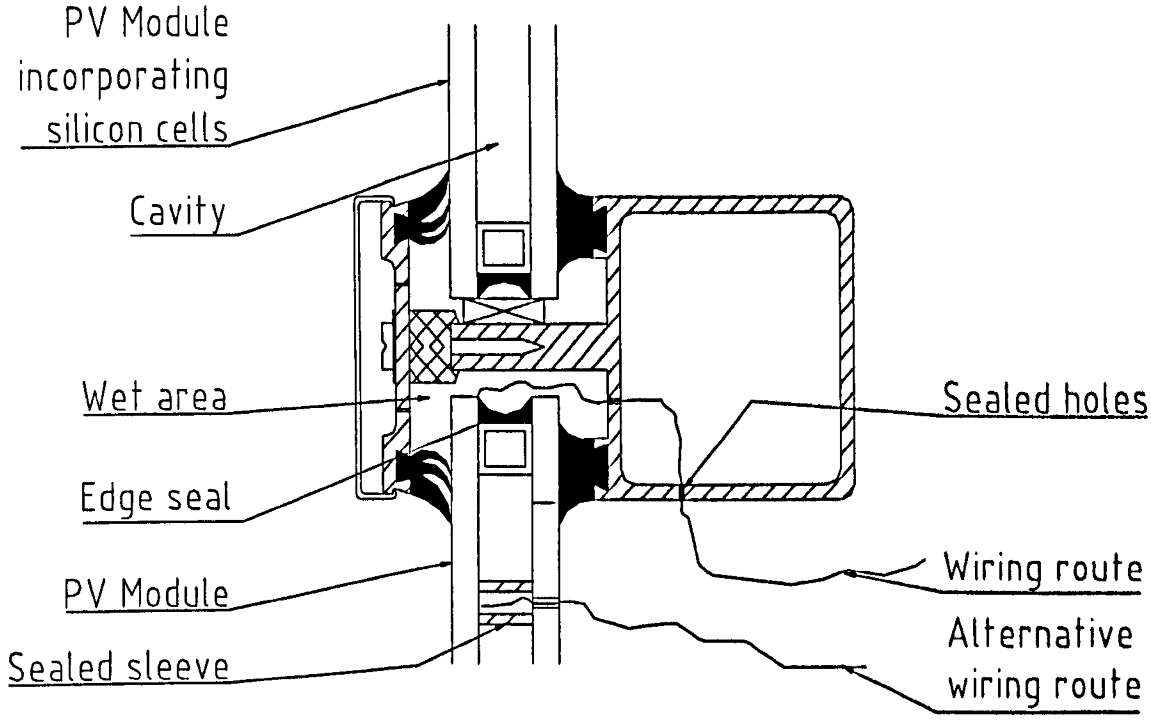

Figure 6.25: PV Module integrated in double glazed unit of mullion and transom system. (Source: PV Modules A Commercial Building Material, ETSU, 1993)

Replacing the outer pane of glass with a PV module has modified the double-glazed unit, in figure 6.25. In this situation a PV module with 6mm thick glass or two-laminated sheet of 3mm glass could be manufactured and integrated into a double glazed unit. This component could then be glazed into the mullion/transom stick system in the normal way.

The suitability of existing technology to this proposal is that:
Double glazed units are currently manufactured in the factory under well-established quality control procedures. Therefore the integration of PV modules should not present major problems in producing line/ manufacturing terms.

Most existing mullion and transom extrusion would not need extensive modification. Minor variations in thickness between a standard double glazed unit and a modified one incorporate PV modules could be catered for in the design of the gasket and /or pressure plate. A modified double glazed unit could be applied to most cladding systems as a non-vision spandrel panel.

Consequently, waterproofing, thermal and acoustic performance would be similar to a standard double glazed unit.

An initial canvass for views from the photovoltaic specialist and 'conventional' cladding consultant community highlighted the following areas, which require further research and development:

1. Junction boxes of existing dimensions would need to be mounted remote from the PV module. These could be located either on or inside a mullion or transom, or inside the ceiling or floor void. Connections between the modules and the junction box need to be developed. Edge sealing of the modified DGU during manufacture could be difficult with loose wiring projecting out of the unit.
2. PV modules generate heat in operation, and would raise the temperature of the DGU. This would reduce the output of the modules and require further research to minimise the loss.
3. The heat generated would also affect the EVA bond, and reduce the life of the edge seal to the modified DGU. New methods of bonding and sealing need to be researched.
4. Double glazed units may require modification to incorporate wiring.

These wiring would pass through the cavity surrounding the modified DGU, which is considered to be a 'wet' area. Millions and / or transoms may need perforations for wiring to pass through. These would require careful detailing to prevent airs and water leakage.

Some of the disadvantages of incorporating PV modules into DGU, identified during the course of this study is are follows:

1. Access to repair a cell or cell connections would be difficult since this would require the seal DGU to be dismantled. Replacement of the cell would require replacement of the whole DGU.

2. The current limit on thickness (3mm glass) would restrict its use in larger panes due to the requirement to resist wind loads. Thicker panes or laminated panes need to be developed.
3. The thermal performance of the modified DGU would need to be checked against the standard DGU. Any significant shortfall would need to be allowed for in the overall design of the façade.

An opinion sample of cladding consultants and PV specialists, suggest that: the concept of a modified DGU incorporating a PV module is a feasible one. However, significant research and development work would be required to address the above issues before it would become a viable product.

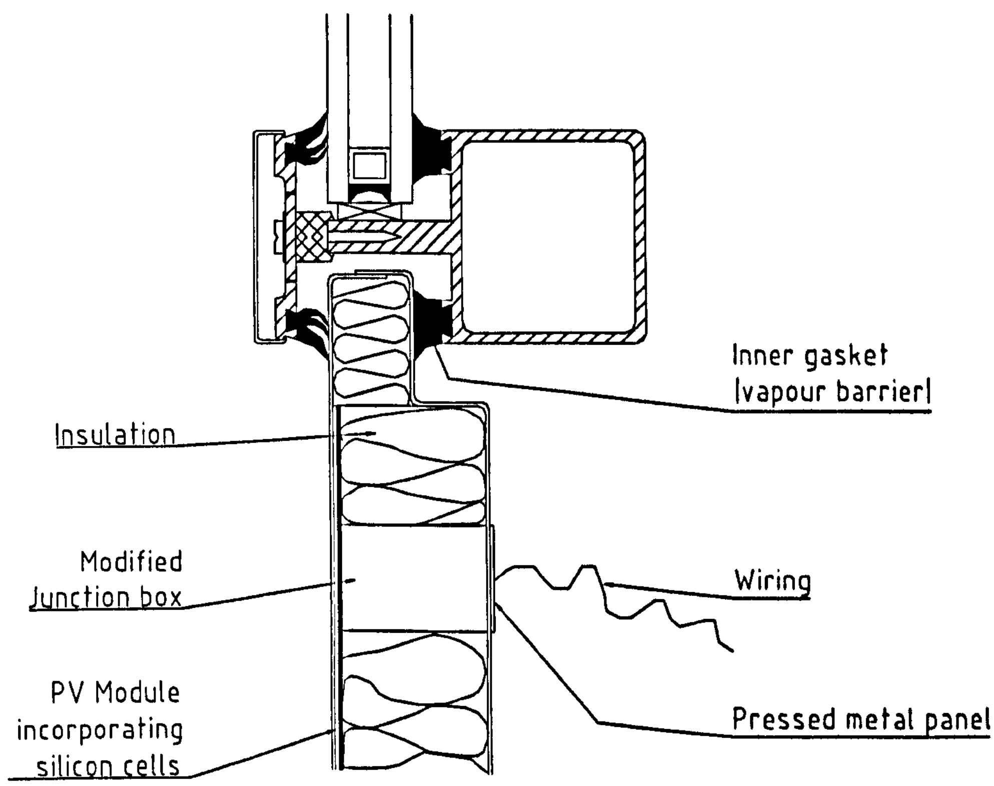

Figure 6.26: PV Module integrated in sandwich panel
(Source: PV Modules A Commercial Building Material, ETSU, 1993)

Sandwich panels are typically constructed with 2 pressed aluminium or steel sheets suitably spaced apart to house a layer of insulating material. The metal sheets have an applied finish of the required colour, both internally and externally. The outer sheet could also be made of glass. The units are usually designed to a high thermal standard so as to compensate for the shortfall in performance of the vision area. The edges are factory sealed and usually detailed to a thickness similar to double glazing units so that the panels can be built into mullion and transom without modification. They are used in spandrel panel areas of curtain walling systems, often as a contrasting feature of glazed vision panels by careful colour selection, or, on entire elevations where the are no windows, lifts and services cores. PV modules could be used to replace the external metal or glass component of such a panel, thereby forming an integrated PV module/ sandwich panel figure 6.26.

The suitability of existing-sandwich panel technology is that - like the modified double glazing option, the manufacture of the modified sandwich panel would be carried out under well-established and carefully controlled procedures
Mullions and transoms would not need modification; therefore the modified sandwich panel could be incorporated into most systems. Waterproofing, thermal and acoustic performance would be similar to standard sandwich panels. Because of the extra thickness when compared to a DGU, the junction box could be built in the unit and be accessible from the inside of the building using existing technology.

In this type of installation areas identified for further research and development include:

1. If an integrated junction box were not feasible, then the problem associated with remote location as for the modified DGU may apply i.e.: wiring in wet areas, perforations/ sealing through cladding components, edge sealing of the panel and loose projection of wiring, to mention a few.
2. Working temperature within insulated panels would be very high, and in some cases they would exceed 100°C. This would reduce the output of the PV module and affect the EVA bond.
3. As with double glazed unit, thicker panes or laminated panels need to be developed.

The concept of a modified sandwich panel incorporating PV module is an attractive one. However, significant research and development work would be required to address the above issues before it would become a viable product.

6.13 PV Modules Attached to Sandwich Panels - Stick System

This method of installation PV modules to a cladding system varies from those previously described since this would be an addition to an existing system rather than an integral part of it. The PV modules could be spaced off the sandwich panel by purpose-designed bolts, studs, hook on fixings, or rails and the whole unit could be factory made, see figure 6.27. Most insulating panels used in spandrel areas could be modified to support PV modules in this manner.

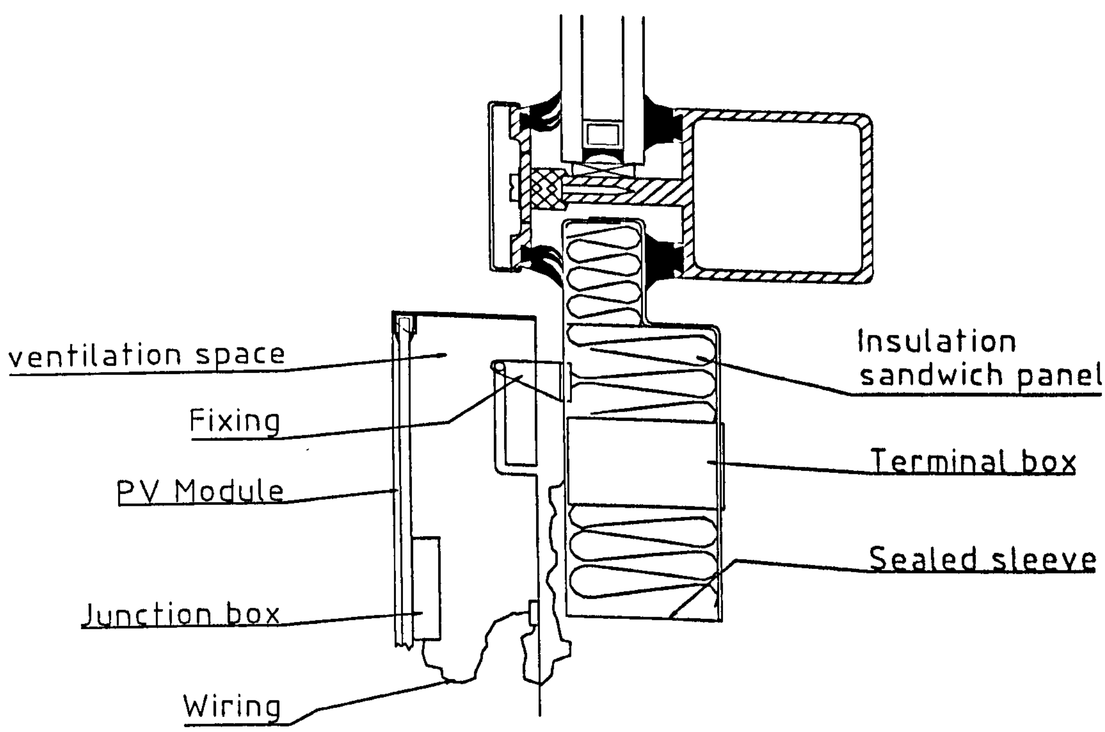

Figure 6.27: PV module attached to sandwich panel.
(Source: PV Modules A Commercial Building Material, ETSU, 1993)

The suitability of the current sandwich panel technology to PV module integration is as follows:

1. As the insulating panels are made in factory controlled conditions, manufacturing the modified units would utilise existing technology and should not present major problems.
2. Mullion/ transom systems would not need any modification.

The sandwich panel and the PV module could be made in separate specialist factories and brought to site and erected at different times to suit the construction Programme. This would avoid exposing the PV modules to soiling and damage during the construction process.

1. Waterproofing, thermal and acoustic performance would be that of a standard insulated panel.

2. Existing junction box technology would be adequate for this system

3. The PV module, being spaced off the curtain walling, would have free air circulation behind it, which would keep its working temperature relatively low. Service conditions would be similar to those encountered by PV modules as used in current application.

4. Replacement / repair could be carried out from the outside with little or no internal disruption.

5. Two or more PV modules of existing dimensions (approx. 1x 0.5m) could be fitted to a larger cladding panel, thereby allowing the use of existing PV modules glass thickness (3mm).

6. PV modules and coloured aluminium panels could be incorporated into the wall for architectural effect or commercial gain. Alterations could readily be made during the life of the building.

Items requiring further research and development include:
The insulation panel would have to support the additional weight of the PV modules, but this will have little effect in practice.
Manufacturing of the panel would have to allow for wiring penetration to the inside of the building whilst maintaining weather tightness. The major disadvantages of this system are:

- the PV module is an addition to the cladding system, hence and additional cost

- Junction boxes would be set on the outside making access awkward, this would be offset by the ability to remove the entire PV module to a workshop for easy maintenance.

A cladding component consist of PV modules attached to the outer face of a sandwich panel utilises existing technology and manufacturing process for both parts. It is therefore recommended that, in the short/ medium term, this proposal represent the greater opportunity for product development.

The mullion/ transom stick system is the most widely used form of curtain walling in the UK. It is offered by virtually all-cladding manufactures in different forms, colours and framing configurations, which allow the building designers endless scope of expression.

Usually, the vision areas are fitted with double glazed units, either fixed or built into opening casements. The non-vision spandrel area are filled with either opaque double glazed units or insulated pressed metal panels. This type of system offers a good framework in which to mount modules as part of the building cladding.

6.14 PV Module Integrated into Panel System

One of the obvious ways of integrating PV modules into prefabricated panel cladding systems is to replace the facing material (natural stone or metal sheet) with PV modules. The PV modules would be fixed to the prefabricated cladding panel either in the factory or on site using purpose designed brackets. The junction box could either be immediately behind the PV modules (using existing technology) or located further inside, possibly within the void in the structural framing zone. The replacement with PV modules could be total or partial, figure 6.28, depending on architectural considerations.

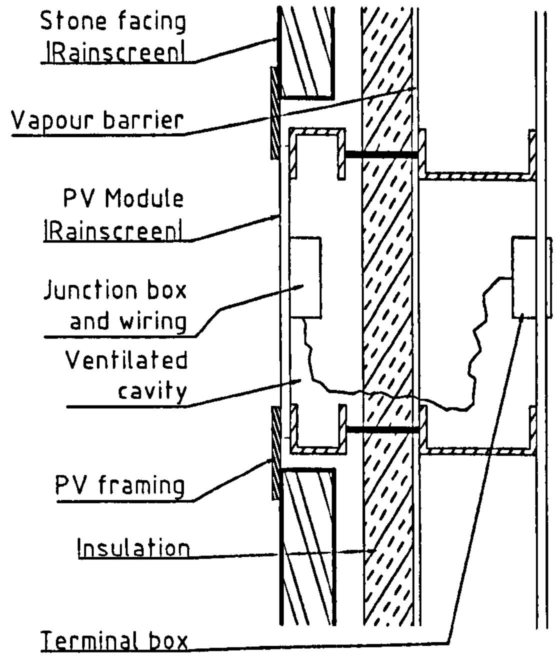

Figure 6.28: PV module integrated into panel system

(Source: PV Modules A Commercial Building Material, ETSU, 1993)

The suitability of existing technology is that the whole unit would be assembled in the factory, thereby reducing site operation; waterproofing, thermal and acoustic performance would be similar to a standard panel; existing PV module technology could be used.

6.14.1 PV Modules Integrated into Overcladding Panels

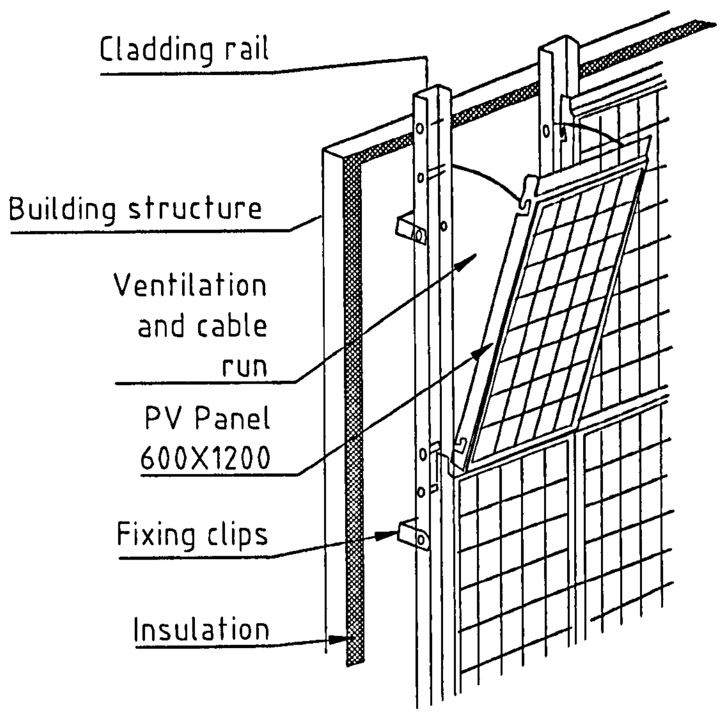

Figure 6.29: Rainscreen Overcladding - PV module integration.
(Source: PV Modules A Commercial Building Material, ETSU, 1993)

The pressed metal panel could be modified to receive PV modules, figure 6.29. The panel could be modified to form a frame into which the modules could be fixed. The suitability of existing overcladding panel -technology is that: The existing cladding technology would not need major modification; existing PV module technology would be adequate. The ventilation cavity would help keep operating temperature down. Panels could be hooked on/off fairly easily, for maintenance or replacement. Small arrays of PV modules could be used thereby allowing the use of existing glass-thickness (3mm) subject to limitations with respect to wind loading and suitable edge framing.

6.15 PV Modules Attached to Overcladding Panels

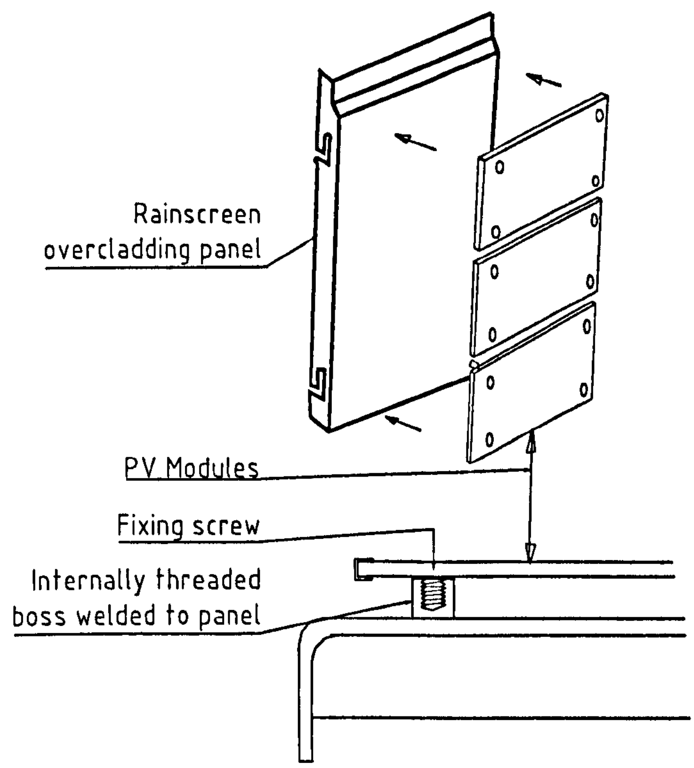

Figure 6.30: Rainscreen module attached to panel-Rainscreen Over-cladding.
(Source: PV Modules A Commercial Building Material, ETSU, 1993)

The PV modules could also be fixed to and spaced off the face of a conventional overcladding panel using specially designed rails or bolts, figure 6.30. The suitability of existing technology is that:

- existing cladding panels could be easily modified;
- existing PV module sizes could be used, that is two or more modules could be fitted onto one cladding panel;
- the ventilated cavity would keep operating temperature down;
- Panels and PV modules could be easily fairly easily for maintenance purposes.

Some items requiring further research and development with regard to PV module integration into overcladding panel include:

Overcladding of existing building would need to be designed to suit existing dimensional modules (floor heights, panel sizes, grid, to mention a few). This would mean that PV modules would need to be produced in a range of sizes.
Depending on the type of rainscreen, the reverse surface of the module will be exposed to varying amount of water. Wiring will therefore be carried out in a 'wet' area.

6.16 PV Modules Integrated into Shading Devices

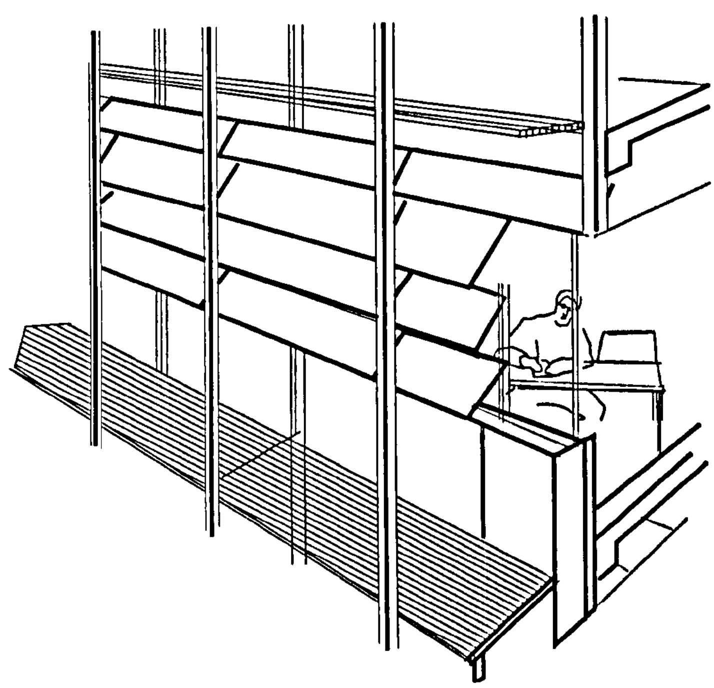

Figure 6.31: PV integrated into sun shading devices.

External louvers, both horizontal and vertical, have been used on many buildings. These are usually mounted close to the window and some are made retractable for cleaning. PV modules could be readily substituted for the metal, timber or plastic materials now used, but would probably be too fragile to retract.

A more promising option would be to mount them some distance from the window and incorporate them in to a walkway system, which would provide access for cleaning and maintenance, figure 6.31. These louvers could be adjustable and turned automatically to provide maximum shade, matching the angle of the sun. The power for this operation, which would only be necessary when the sun was shining, could be derived from the PV modules themselves. Large sunshades offer another opportunity to use PV modules in a positive manner.

6.17 PV Modules Bonded to Metal Sheeting

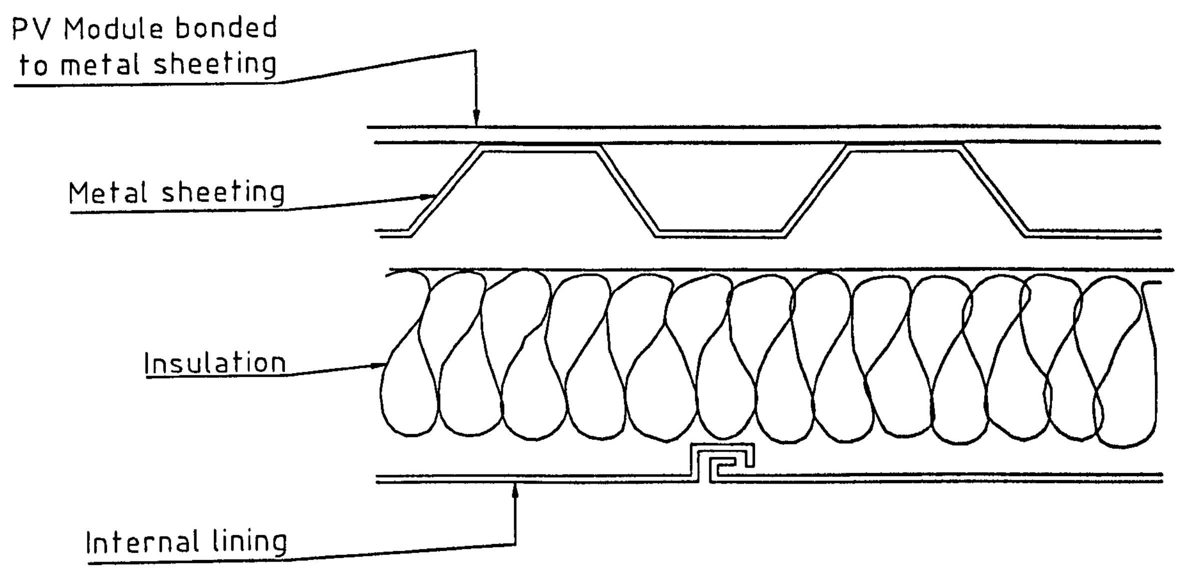

Figure 6.32: PV Module bonded to metal sheeting
(Source: PV Modules A Commercial Building Material, ETSU, 1993)

The module is bonded to the outside face of the profile metal sheeting figure 6.32. This approach applies to single sheet, over rail and sandwich rail systems. Bonding to foam panel systems is not appropriate.

The suitability of this system to PV integration is that: existing PV technology would not need major modification. The air cavity would be ventilated, thereby reducing operating temperatures.
PV modules could be bonded at various intervals and be of any size. They would give large scope for architectural detailing, especially on walls.

6.18 PV Modules Integrated into Profile Metal Cladding Panel

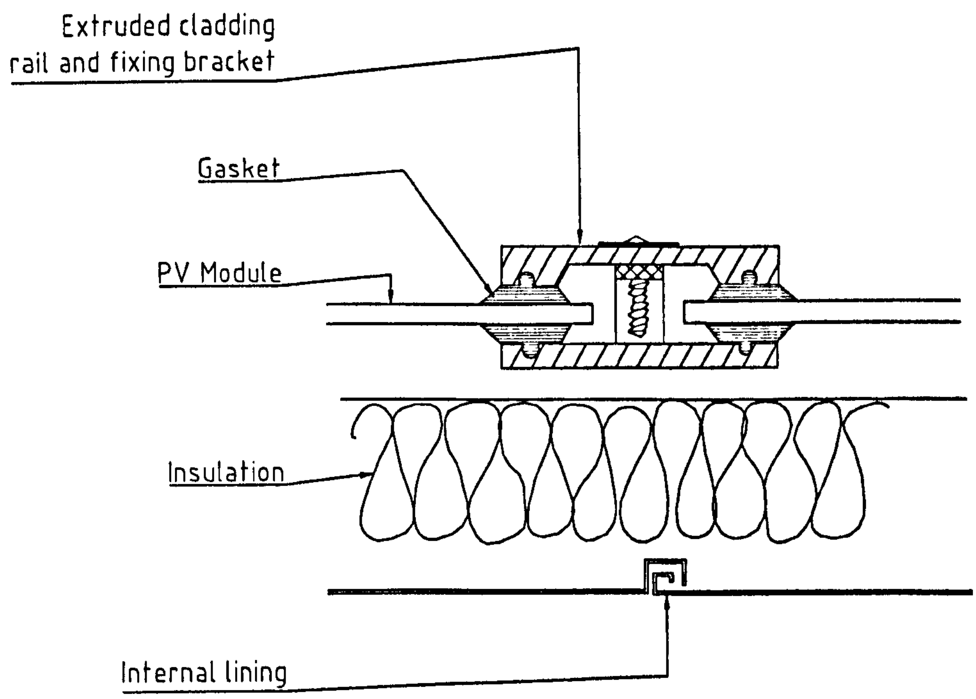

Figure 6.33: Metal sheeting replaced by PV module

(Source: PV Modules A Commercial Building Material, ETSU, 1993)

Profile metal cladding systems are generally an assembly of loose components put together on site, the simplest way of integrating PV modules into such a system is to remove the outer component, the metal sheeting, and replace it with the PV module, figure 6.33. Purpose made extrusions could be manufactured to receive the PV modules, similar to sheets of glass in patent glazing system. This solution would apply to both walls and roofs of metal clad buildings. It is equally suitable for single sheeting systems, over rail systems and sandwich rail systems.

The suitability of existing technology is that: existing PV module technology would not need major modification; as this is effectively a front sealed system, there should be no wet cavities; a network of wiring could be contained within the insulation zone.

6.19 PV Modules Integrated into Foamed Panels

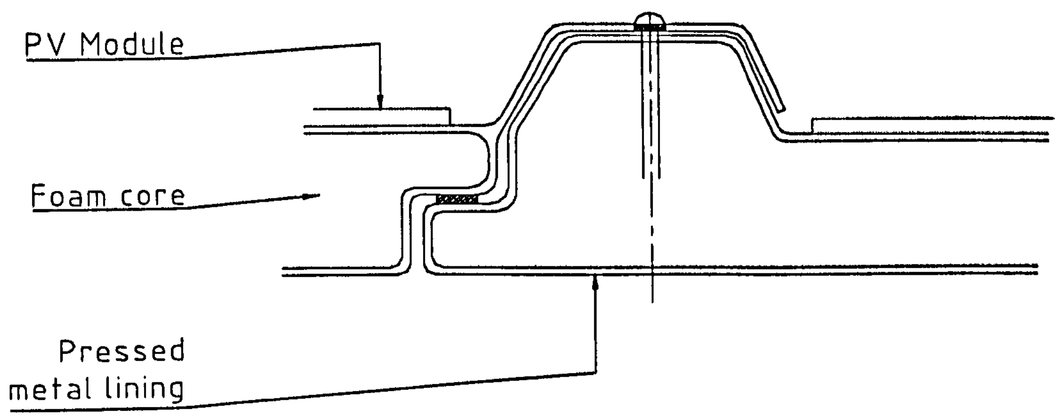

Figure 6.34: PV module incorporated in foamed panel of metal sheet cladding.
(Source: PV Modules A Commercial Building Material, ETSU, 1993)

The fully insulated sandwich unit could be modified by removing the outer metal sheeting component and replacing it with a PV module. Figure 6.34, where the edges of the panel are folded over and lapped with a PV module. This proposal would require research and development work to be carried out, similar to that detailed for the modified sandwich panel described in figure 6.34.

6.20 Conclusion

Problems associated with conventional cladding systems are reviews this chapter: aimed at understanding the supply chain, design and procurement processes. This understanding will create the basis on which an optimum procurement and installation strategy will be developed for BIPV systems towards the preparation of best practice guidance to encourage the take-up of PV cladding.

Testing organisations that took part in a survey carried out during the course to indicated that many weather-tightness problems occur either because of difficulties encountered when adapting standard cladding systems to complex building shapes or, more frequently, because of the complexities associated with one-off bespoke designs.

Common failures involve the ingress of water or air though joints. Most appear to occur within 12 months of installation due to poor design and / or workmanship.

The three common cladding scenarios have been identified: firstly, standard systems used in standard applications. A standard system is self-regulating. The systems designer, minimising the likelihood of faults in future systems rectifies problems with new systems. Secondly, standard systems adapted to non-standard applications. Failure may occur if the systems selected were inappropriate for the non-standard building. Improving the system selection process reduces defects. Thirdly, one-off bespoke arrangements: failures usually associated with poor design or workmanship. Paying more attention to fabrication and installation at the design stage can usually alleviate poor workmanship. The problems that arise in the second and third of these scenarios are clearly the result of inadequate interaction between those operating in the cladding industry's three main design environments: *building design, cladding system design and fabrication detail.* The solution lies in integrating the design, manufacture and construction processes as well as developing new technological solution through the research proposed the 1998 CWCT review.

In the short/medium term, the attachment of PV modules to the outer surface of a sandwich panel represents the greatest opportunity for product development, since it utilises existing-technology and manufacturing processes for both the module and the sandwich panel. In the long term, the development of integrated PV module cladding panel (either into double glazed units or as part of a sandwich panel) would require considerable research and development.

The panel system caters for the specialised end of the cladding market, is quite versatile in design terms and material selection and offers a good quality product. The greatest use of the panel system would be in prestigious city centre buildings. The proximity of adjoining building and shadows might therefore be a problem. City centre buildings typically have highly articulated facades and consequently lack the large areas that would be needed to make PV modules installation viable. Whilst the application of PV modules to spandrel panel cladding systems would be technically feasible, the widespread use of the modified system may be limited for these reasons.

It is therefore recommended that the integration of PV modules into panel system should not be identified as a major opportunity, Lord et al (1993). However, should the opportunity arise, it would be possible to manufacture such a panel utilising the development work carried out on the stick system.

The only disadvantaged about this system, as indicated by cladding consultant that took part in a survey, is that: PV module is an addition to the cladding system hence an additional cost. However, Rainscreen Overcladding Systems offer a very good opportunity for the integration for PV modules. There are many building projects, both refurbishment and new-build, which are suitable for this form of cladding. This system would readily allow existing PV modules technology to be used in most applications. It is suggested that pressure equalised rainscreen-overcladding represents the best opportunity for product development.

The suitability of existing technology with regards to large sunshade louvers is that: External shades could be designed to incorporate PV modules, and the PV modules in their present form could be readily adapted.

- The operating condition of the PV modules is very similar to those for which shading devices have been developed.
- The PV modules could be maintained and cleaned for the access walkways.
- The installation would be a clear expression of the building owner attitude to energy conservation.
- The operation and power for the installation could be self-contained.

The disadvantage of this system is that: external shading provides a powerful visual statement. In architectural and planning terms there are prejudices that have to be overcome and this may limit the number of applications in the short term. However, this would be offset by the high profile each application would receive. The design, size and quality of external louvers vary enormously, therefore it is difficult to give accurate figures on cost.

Bonding of building integrated cladding modules would need to be carried out in the factory. The adhesive would require research to ensure long term performance.

Junction boxes in this type of system would need to be sited remotely form the PV module; the wiring would be carried out in wet area, and would penetrate the weather line; the module performance may be affected where the module is bonded to the profile metal sheeting. All these need careful detailing and research. The disadvantage of this system is that - it would need to be spaced to allow through fixing of sheeting to the primary structure. Construction equipment would be used in the vicinity of the modules during erection. Metal sheeting is by definition 'low tech construction'. Erection labour would need to be made aware of the fragility of PV modules. The replacement of the module will also mean replacing the metal sheeting. The PV module is an addition to the cladding system hence an additional cost.

Items requiring further research and development: an aluminium framing system to support the PV module needs to be developed; existing construction details result in the cavity between the PV module and the insulation being unventilated. This will increase operating temperatures, and reduced the PV module performance and EVA (Ethylene Vinyl Acetate) bond. The disadvantage of this system is that: metal sheeting is by definition 'low tech' construction. Erection labour would need to be made aware of the fragility of such a component; removal/ replacement of a module would mean exposing the building fabric to the elements necessitating temporary protection/ weathering.

Profile metal cladding is used on a large variety of building, including industrial sheds, and factories, leisure centres and out of town shopping complexes. It is worth noting that such construction may also be equally suitable for over-cladding projects to existing warehouse and factories, thereby increasing its market share. It is essentially a 'low tech' form of cladding when compared with sophisticated curtain walling system, but nevertheless it offers an acceptable system at competitive cost.

In the short/ medium term the bonding of PV modules to the outside of metal sheeting systems represent the greatest opportunity for extensive use. Research work will be required to confirm the long-term performance of any adhesive. In the longer term, the development of integrated PV module cladding panel would require extensive research and development.

Review of Building Procurement Processes in the UK

7.1 Introduction to Building Procurement

The primary purpose of this chapter is to provide a review of the building industry various contractual and communication arrangements, which evolved during the 1970s and 1980s for the procurement of buildings. Much of the first section of this chapter is concerned with the so-called *fast-track* alternative to traditional client – architect – contractor selected by competitive contractual arrangement. The essence of the fast-track arrangement is over-lapping the design and construction stages as a means of reducing project time. The operation and characteristics of the alternative systems are also discussed. The second half of this chapter reviews contemporary project management techniques and methodologies. This is aimed at providing a framework based on past and current research studies and practices in the industry in terms of integrated design and construction procurement strategies within the UK construction industry.

7.2 Background to Change

Until the 1960s a client with a need for building works usually commissioned an architect to prepare drawings identifying his/her requirements. These drawings would provide the basis for competitive tender by builders for the execution of the works. It is a system which was established early in the 19th century and which has continued for more than a century and a half. It is customarily referred to as the 'traditional system' or just 'traditional'

In seeking an answer to why alternatives to the traditional system have evolved one might start with Sir Harold Emmerson who was asked by the minister in 1962 to make a quick review of the problems facing the construction industry, Emmerson (1962). His report included the now famous phrase that:

'In no other important industry is the responsibility for design so far removed from the responsibility for production'. He concluded that the client suffered as a result of this divorce.

Emmerson's report led to the formation of the Banwell committee, Banwell (1964) which recommended a number of changes in contract procedures. These changes were, in themselves, significant but the most important effect of the Banwell Report was the change it engendered in the attitudes of central and local government. At the time, central and local government commissioned 60% of the construction industry's work. They were the industry's major clients and were in a strong position to dictate the contractual arrangements to be adopted, Forster (1986).

Furthermore, the existence of a government commissioned report, encouraged government departments and local authorities to consider alternative approaches to building procurement. This made them less liable to charges of misconduct, failure to obtain the lowest tender etc. The relevant departments were able to take a wider view of public accountability; a view which was concerned not just with which tender submitted in competition was the lowest but which contractual arrangement facilitated the optimum overall result.

Most of the new arrangements claimed to facilitate shorter project periods, making earlier occupation possible and allowing the client to obtain an earlier return on his/her investment. The wind of change had started to blow through the construction industry.

The key issues identified by Banwell were:

1. Those who spend money on construction work seldom give enough attention at the start to defining their own requirements and preparing a programme of events for meeting them. Insufficient regard is paid to the importance of time and its proper use;
2. As the complexity of construction work increases, the need to form a design team at the outset, with all those participating in the design as full members, becomes vital;

3. Some measure of selective tendering is preferable to 'open' tendering: impediments should be removed and rules for the conduct of selective tendering drawn up for the guidance of local authorities;
4. Serial tenders offer great possibilities for continuity of employment; the development of experienced production teams and the banding together of those who have suitable work in prospect is to be encouraged.
5. Negotiated contracts need not be rigidly excluded in the public field; methods of contracting should be examined for the value of the solutions they offer to problems rather than for their orthodoxy

Notwithstanding the stimulus that the Banwell report gave to change there were two other over-riding factors:

1. The failure of the construction industry to satisfy the client's needs, particularly in respect of its management of exceptionally large and complex projects;

2. High inflation coupled with high borrowing rates, which led to shorter project periods becoming of great importance to clients, particularly those who required an early return on their investment in property, if the project was to be viable.

During the period 1973-74 many of the oil-producing states combined to bring about massive increase in the price of crude oil. The outcome was immediate, with massive increase in the borrowing rate and inflation. The economy of the Western World was in disarray, which continued for more than a decade. The increase in the public's and the construction industry's interest in alternative ways of procuring buildings more quickly was most marked following the oil crisis, as the industry's clients and their advisers realised that for many projects time was now the essence.

There is little doubt that there was positive relationship between the increase in borrowing rates subsequent to the oil crisis and the construction industry's interest in alternative system of building procurement, Franks (1998).

The cost effect of undertaking the design stage in parallel with the construction stage is reviewed in a later part of this chapter. Recent studies strongly suggest that parallel working can produce significant reduction in the total cost of a project. These reductions are particularly pronounced when interest rates are high and when obtaining a return on investment made in the project is an important feature.

According to Frank (1993) and Turner (1997), the growth of alternative systems for the procurement of buildings has had a significant effect on the role of the builder i.e. contractor. His horizon is now wider. Previously, the builder's activities were confined to carrying out the works. Now the builder is engaged as a management contractor, construction manager, as a member of the design-and-build team, or as a project manager. The builder is able to work with members of the design team and advise the client on aspects of buildability, which may have time and cost implications and improve the overall viability of the project to the, client's advantage.

7.3 Procurement Systems

The alternative systems, types and terms are reviewed in this section of this chapter. Various terms have emerged to identify the systems in current use, some of which are shown in figure 7.1. The four principle types of system are:

1. Designer-led competitive tender;
2. Designer-led construction work managed for fee;
3. Package deal;
4. Project manager/client's representative-led.

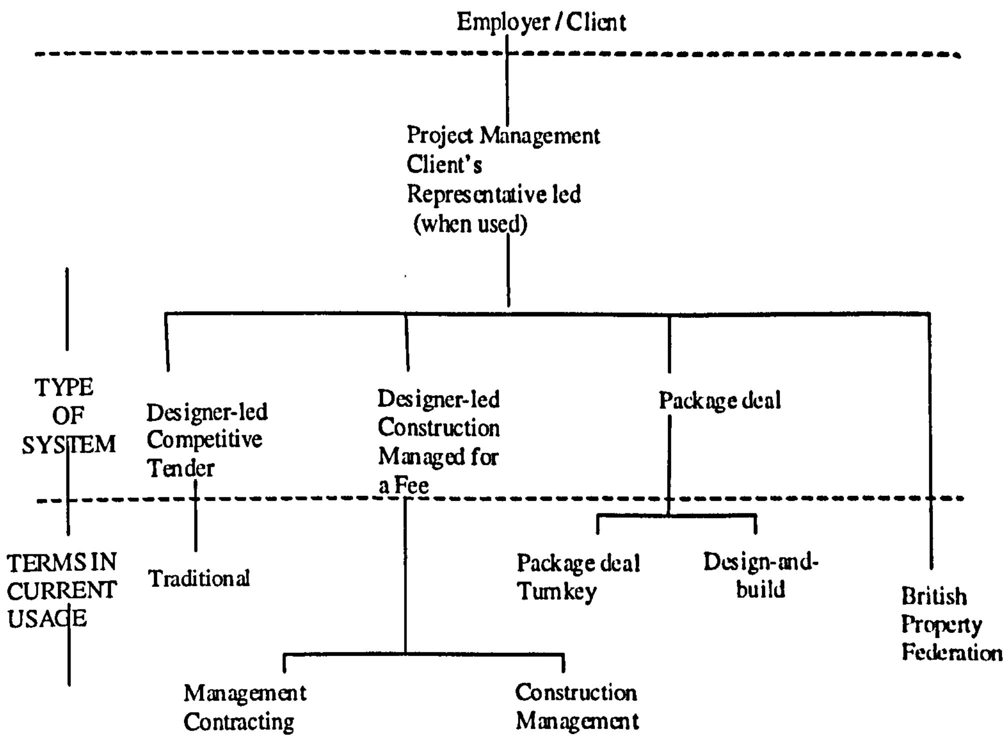

Figure 7.1: System of building procurement

7.4 Design-Led Competitive Tender

Historically, most clients for construction work seek, at first, someone who can express their needs in the form of a design - as a result the designer is, traditionally, the leader of the construction process. This 'traditional' approach provides a useful datum for consideration of the other systems available.

7.4.1 Traditional

The traditional system has evolved and developed over the centuries. The role of the architect was established in more or less its present form by the end of the 18th century by which time he was recognised as the independent designer of buildings and manager of the construction process.

Early in the 19th century bills of quantities began to be used as the means of providing a number of different contractors with a common basis for tendering, Smith (1995). By the middle of the century the quantity surveyor was established as an independent compiler of bills of quantities and an expert in building accounts and cost matters.

There is considerable evidence, extending back over several centuries, of building craftsmen acting as contractors for complete building projects embracing the work of all crafts. However, the general contractor in his present form is frequently regarded as coming into his own at the beginning of the 19^{th} century.

The present traditional system, which involves the parties mentioned above, is enshrined in the Standard Form of Building Contract (with quantities). There are no reliable figures of the extent of use of the system but indications are that, perhaps, 60% to 70% of building projects, by value of the works, adopt the traditional system, Franks (1998).

7.4.2 Traditional System Operations.

The components of the traditional approach may be seen in a simplified form in figure 7.2. The process starts, as for all such processes, with a client having a need for a building

The client briefs the architect on his needs, as he sees them and also decides the project budget ceiling. Against this background, the quantity survey provided preliminary cost advice.

The architect prepares alternative drawings/ proposals so that the client may select that which he prefers; the quantity surveyor estimates the cost of the alternatives.

The client then accepts the proposal.

The architect develops the design of the accepted proposal. This will probably entail consultations with specialist engineers and negotiations with specialist contractors.

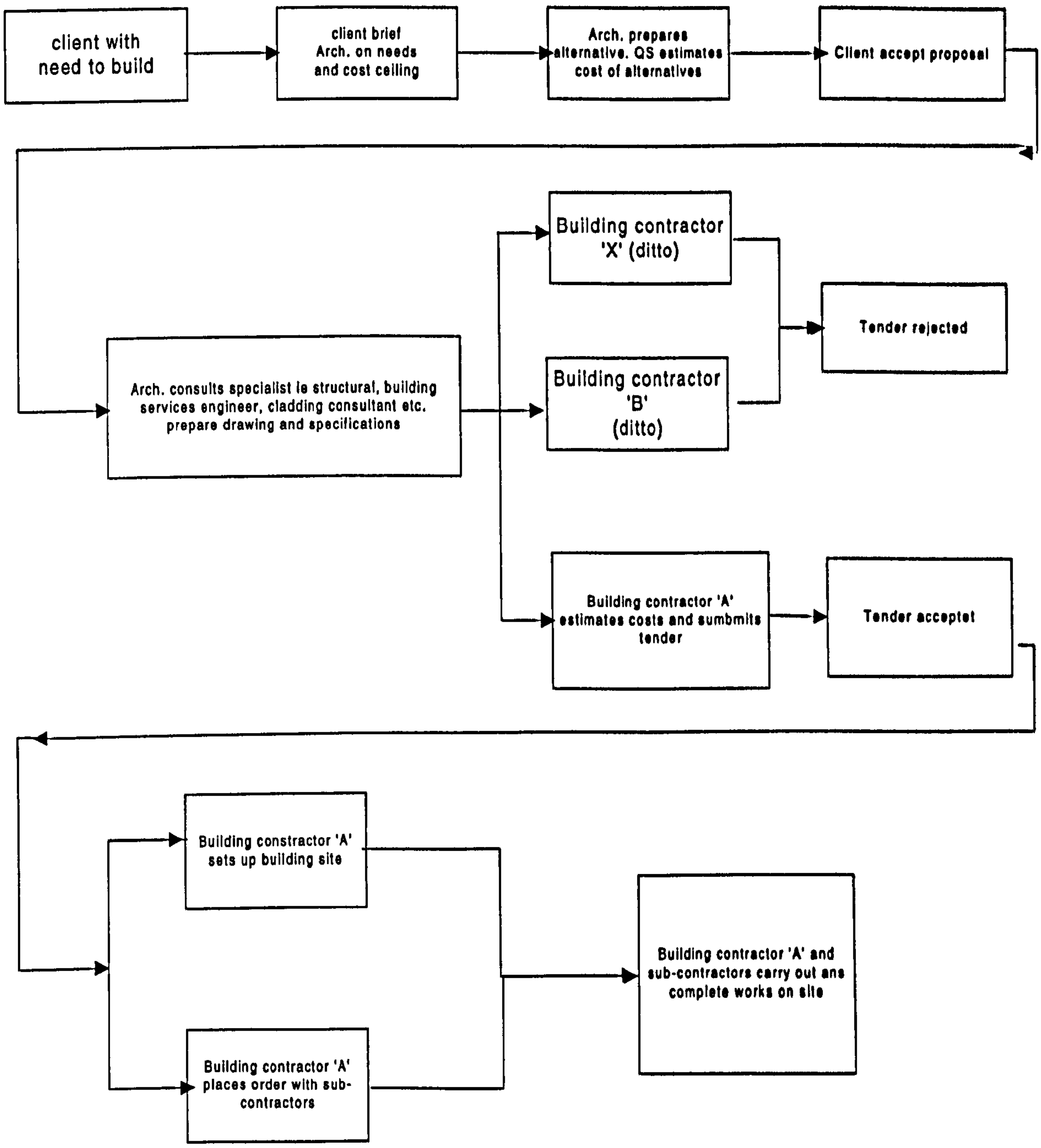

Figure 7.2: Traditional Procurement System Flow Diagram

Drawings and specifications are prepared and the quantity surveyor provides regular monitoring of the alternative design to ensure that the cost implications of the design decisions are known to all concerned. The quantity surveyor prepares bills of quantities.

Tender drawings, bills of quantities and forms of tender are sent to selected builders (contractors) in order that they may submit tenders for the work.

The builder estimates the cost of the operation involved in the project. The duration of the project is assessed from pre-tender plan prepared by the builders' project planner and managers. Management decisions determine the margin to be added to the tender for profit.

In figure 7.2, the client accepts Builder 'A' tender price. The client and the builder 'A' enter into a contract. The other tenders are rejected.

Builder 'A', sets up his site management system, plans and organises the works, schedules materials, deliveries, to mention a few. Concurrently, Builder places orders with his own sub-contractors and those nominated by the architect (nominated sub-contractors)
Builder A and the sub-contractors carry out and complete the works.

7.4.3 Characteristics of the traditional system

- The system has operated in Britain, the commonwealth and other parts of the world reasonably satisfactorily. It has stood the test of time.

- It is understood by most clients and they know their financial commitment when they accept the builder's tender, if the design has been fully developed at time of going to tender.

- The architect has considerable freedom to conceive and develop the design without excessive time or economic pressure, provided the cost ceiling is not exceeded and the client's requirements are generally satisfied.

- The project cost can be estimated, planned and monitored by the quantity surveyor from inception stage through to completion of the project.

- The architect is able to consult specialist contractors and suppliers, who he believes to be appropriate for the project. Manufacturer and /or installers of components for sub-systems, which would be compatible with the system as a whole at design stage, with a view to nominating them subsequently as sub-contractors or suppliers for the project.

- Sub-contractors may be invited to submit competitive tenders to the architect for the sub-system, in which they specialise, thus ensuring that the most economic price is obtained.

- Drawings and bill of quantities provide a common basis for competitive tenders from selected main contractors.

- In the event of the client requiring the project to be varied during the course of construction, the bills of quantities contain prices for items of work, which may be used to adjust the contract sum to take into account the variation(s).

- The design should be fully developed before bills of quantities and subsequently, tenders are prepared. If not, excessive variations and disruptions of the works are likely to occur.

- The need for the design to be fully developed before tenders are prepared leads to an 'end-on' design/build arrangement. Frequently, such an arrangement requires a longer overall project period than is necessary if both design and construction are able to proceed concurrently, Smith (1995).

- As the length of the project period increases so does the project cost, because the client usually incurs financing charges on the sum, which he has invested in land purchase, interim payments to contractor and other members of the building team.

- The separation of the design and construction processes tends to foster a 'them and us' attitude between the designers and contractors. This reduces the team spirit, which is widely believed to be vital for the satisfactory conclusion of a building project, Franks (1990).

- Lines of communication between the parties tend to be tenuous and the interests of all may suffer as a consequence.

- The traditional system has been proved to be unsatisfactory for some large and complex projects which require advanced management systems, structure and skills, Turner (1997)

- Joint Contract Tribunal (JCT) 80 and Intermediate Form of Contract (IFC) 84 may be used with quantities and are appropriate for the traditional system, JCT (1998)

- Standard Forms of sub-contractors are used for nominated sub-contractors under JCT 80 and for named sub-contractors under IFC 84, (JCT 1998)

7.5 Designer-Led, Construction Works Managed for a Fee

Under this heading are included the various management fee and construction management systems. There are almost as many variations of this system as there are firms offering management services. The vast majority of the variations have one feature in common. The management contractor or construction manager offers to undertake the management of the works for a fee. He is, in effect, in much the same relationship with the client as is the architect or any other consultant. The actual construction work is undertaken by specialist contractors, each of whom contracts to carry out and complete one or more of the work packages which make up the whole of the works.

Firms who adopt the title management contractors are normally those, which are divisions of major construction contractor companies. A few management contractors are now concerned solely with management contracting, having abandoned their original, traditional, contractor activities. The management contractor almost invariably employs the specialist contractors who undertake the work packages as his sub-contractors. It is the employment of the specialist contractors, which typically distinguishes the management contractor for the construction manager. When a construction manager firm is employed the specialist contractors are generally in direct contract with the client, rather than being sub-contractors to the construction manager.

It is not possible to make categorical statement regarding who employs the specialist contractors (client or management firm), because there are no codes of practice governing the operation of these contractual arrangements, but the broad generalisations made may be taken as a reliable guide.

The fee the construction manager, receives for undertaking management is not usually directly related to the value of the work being managed. In this way it cannot be said that the contractor has anything to gain if the value of work increases. The fee would, however, be renegotiated if the extent of the works changes significantly.

7.6 Management contracting/ construction management

A significant percentage of major building projects particularly those in South East of England, adopt a 'fee' system of procurement. Nationally, however, probably 10%, by value of the work, adopt a fee system. The use of this procurement approach appears to be declining but for major projects the management for a fee system has a considerable following of 'repeat' clients, regardless of statistical trends, Turner (1997).

The best known case of management/ fee contracting in Britain is the Bovis system. Bovis have operated fee systems, notably with Marks and Spencer as a client, for more than 65 years with proven success. Very few other contractors operated such a system before the 1960s. Management contracting is an established procurement path.

Evidence from recent studies indicate that despite the overall decline in use, fee contracts are being adopted in some cities in the Midlands and the North where they had seldom if ever been used in the past, Franks (1998).

7.6.1 Operation of Management Procurement System

The process of a typical management contracting system is shown in figure 7.3. The construction manager's role is similar to that of the management contractor but he is less likely to be appointed by competitive tender. When a construction manager is appointed the works package contractors will most usually be in direct contact with the client.

It must be emphasised that the following 'operation' description should be regarded as merely indicative of such systems. Referring to figure 7.3, the management system is similar to that of the traditional system in the first five steps. However in the fifth and sixth steps, the architect and quantity surveyor concentrate on preparing drawing and a 'preliminaries' bill of quantities in sufficient detail to enable the prospective fee contractors to determine the method to be used for construction and to prepare a firm fee tender. At the same time the architect and other members of the design team develop the design generally and prepare drawings and specification.

Beyond the point at which the client briefs the architect on the project requirement step, the contractor (or contractors if the client seeks competitive tenders) prepares the first stage tender for the management fee. It is unusual for more than two or three contractors to be invited to tender.

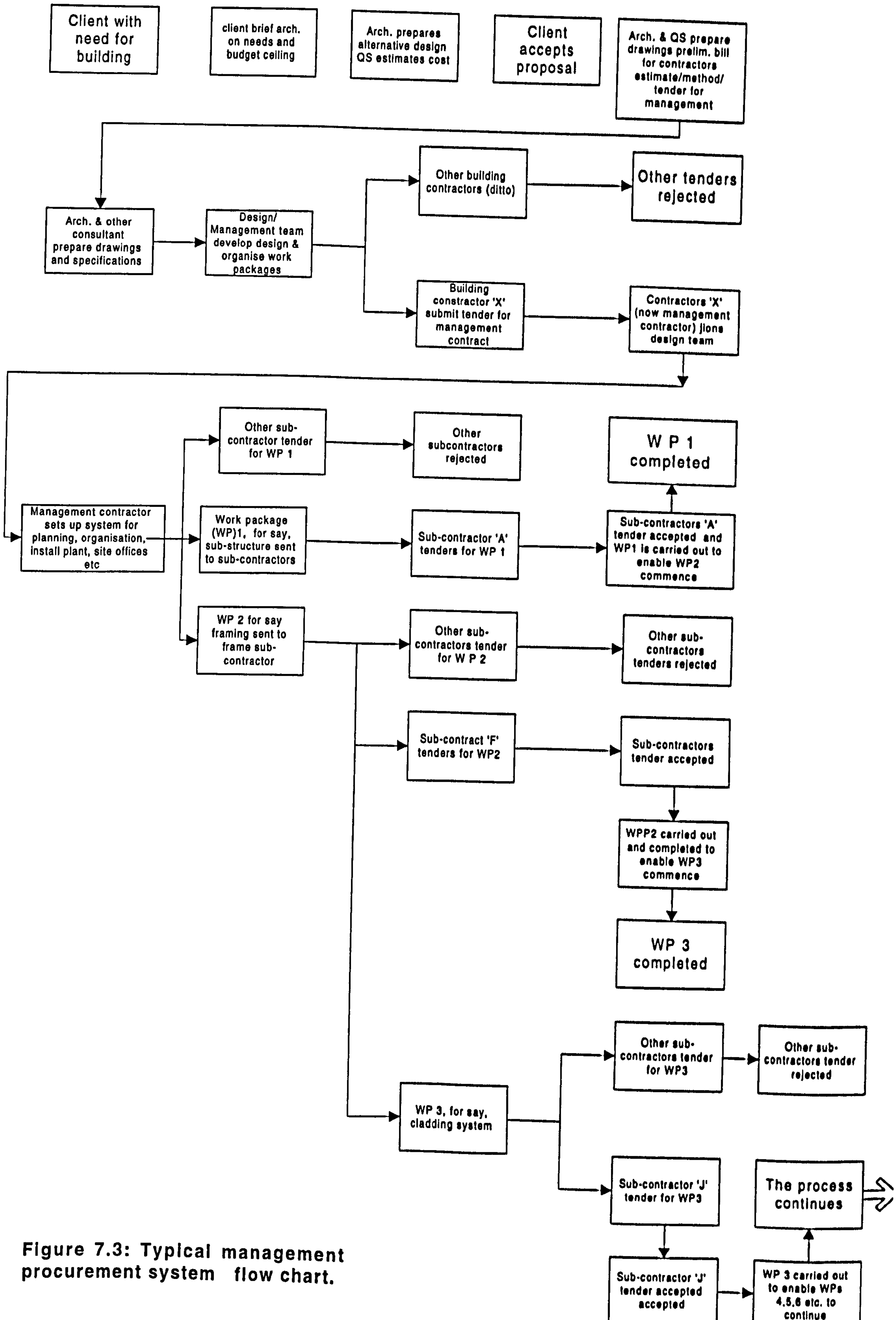

Figure 7.3: Typical management procurement system flow chart.

The most competitive tender is often regarded as of less importance than a credible construction programme and a sound track record, Gyoh (1993).

Contractor 'X' enters into a fee contract with the client and the other tenders are rejected. Contractor 'X', the management contractor has now joins the design team. Concurrently, he establishes a management system for planning, organising and controlling the project. He installs the plant, site offices etc.

The design/management team continues to develop the design and organises a series of work packages for all aspects of the work. The work packages provide the basis for a number of contracts, which are placed as soon as the necessary information is available.

The work packages are put to tender and contracts entered into. Drawings and bills of quantities or specifications may be used as the documentation for the sub-contract tender. Between thirty and forty work packages is by no means unusual. For major projects the number of work packages may be as many as one hundred and fifty, Franks (1998). The works contained in the work packages are frequently commenced almost as soon as the contracts have been placed. The project completion is achieved with completion of all the work packages.

7.6.2 Characteristics of the Management System

- Management contracting has been used successfully to limited extent since the 1920s and with increasing frequency during the 1970s, 1980s and through to the 1990s.

- Clients and contractors often adopt the system on a regular basis once they have gained experience, which suggest that it has merits. It is generally recognised that its adoption requires mutual trust.

- Work can commence as soon as the client has accepted proposals and local authorities approve design.
- The management contractor (or construction manager) is appointed much earlier than would be possible with the traditional system. He is able to become a member of the design team and contribute his construction knowledge and management expertise.
- Management contractors (or construction managers) frequently compete at first stage tender ensuring that an economical fee is charged for management.
- 'Them and us' attitude is reduced and line of communication improved.
- The management contractor finds it easier to identify with the client's needs and interests and 'integration of the team' becomes possible and practical.
- Decision regarding appointment of sub-contractors are made jointly (by designers and construction manager or management contractor), thus making use of wider experience.

- Specialist (or sub) contractors compete at second stage tender ensuring economic tenders
- Contracts are entered into near the time of commencement of works making firm-price tenders possible
- Tenders submitted near the time of commencement of work are frequently more competitive than those submitted several months or even years ahead
- When a construction manager is employed the client enters into contracts with numerous specialist contractors instead of with a general contractor, as would be the case if the traditional system were adopted. He usually has a closer involvement in the project throughout it whole life.
- Line of communication between clients and specialist contractors are shorter than with the traditional system. According to Franks (1998), advantages which stem form this factor are:

  1. The client is enabled to make prompt decisions which can be implemented without delay; it makes possible a prompt response by the client to unforeseen site problems and by the contractor to changes required by the client;

2. The cost implications of design changes can be promptly assessed and cost control for the client is thereby facilitated.

- Specialist contractors frequently prefer to be in contract with the client rather than with a management contractor because interim payments are usually made more promptly when paid direct.
- When contracts are made direct between client and specialist contractor, conditions of contract can be adopted which are appropriate to the needs of the works to be undertaken.
- Total project completion time is reduced due to 'parallel working', hence fast-tracking.
- A reduced project completion period produces a corresponding reduction in financing charges on the sum invested in land purchases, interim payments to contractors and other members of the building team. Inflation has less effect.

The client takes delivery of the building earlier because the project completion period is reduced. He thus obtains a return on his investment more quickly, more so with developers.

- The architect may have less time to develop the design because he is under greater pressure from client, contractor and sub-contractors. The design may suffer as a result.
- The JCT Standard Form of Management Contract, 87 edition (MC87), may be used for contracts between the employer (client) and management contractor, JCT (1998).
- Work Contracts, WC/1 and WC/2 are used for contracts between the management contractor and the various works (sub-) contractors, Chappell (1997).

7.7 Package Deal/ Design and Build

This includes terms such as "Turnkey", "Package Deal", "Contractor's Design", and "Design-and-Build" systems. It is widely accepted within the UK construction community that the term turnkey and package deal have, broadly, the same meaning.

The range of services offered by package deal contractors varies greatly. Some will find sites, arrange mortgages, sale-and-leaseback and similar facilities, addition to designing and building to meet the client's requirements. Others contract to design and build a unique building on the client's own site. The feature that the systems have in common is that the 'contractor' is responsible for the whole of the design and construction of the building. Responsibilities are not split between designer and builders so that the client does not find himself looking to separate 'parties' in the event of a building failure. The system offers 'single-point responsibility', a feature that commends itself to client frustrated by the traditional system. Package deal contracts involve direct negotiation between client and contractor (or several contractors if the client seeks competitive tenders). The client states his requirements and the contractor (or contractors) prepare design and cost proposals to meet the requirements. Initially, the contractor produces only sufficient information by way of design proposals to demonstrate his 'package' to the client. The design is fully developed when both parties have reached an agreement regarding specification and price.

Previous studies indicate that clients are frequently able to procure buildings more quickly when these contractual arrangements are adopted. Time savings tend to go hand-in-hand with cost savings.

Design-and-build is a more refined form of package deal, which obtained recognition form the Joint Contract Tribunal in 1981 with the publication of the JCT Standard Form of Building Contract with Contractor's Design (CD81). This recognition followed changes in British architects' codes of practice, which allowed architects to become directors of construction firms. Hitherto, they were able to be salaried employees but director status had been denied.

Recent studies by the CIOB suggest that package-deal design standards have improved as architects have taken up senior appointments in design-and –build firms.

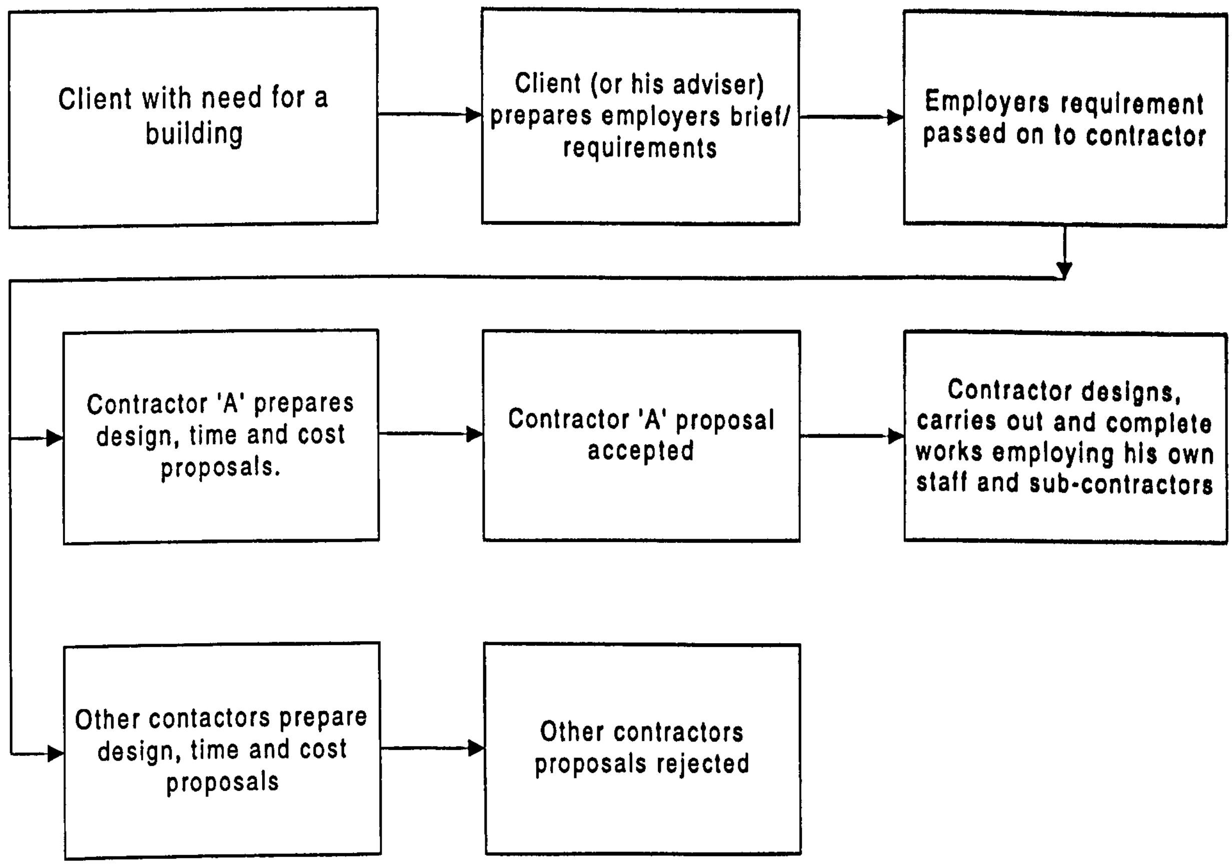

Figure 7.4 Design and Build System Flow Diagram.

Studies have also shown that most building types have been constructed using the package deal approach. However, industrial and office buildings in new development areas are typical examples of building types, which are frequently built using a package deal system. Many package deals involve a proprietary building system of one sort or another. Package dealers frequently advertise their services and / or products in the pages of newspapers and journals read by the people who are likely to make decisions regarding their firm's future building needs. Package deals provide buildings rather than design. Dealers may offer to find a site in the part of the country where, for example, government grants are available to the client, in order that he has an incentive to expand his business in that area- high unemployment areas for instance.

The package dealer will usually undertake to obtain planning permission and building regulation approval. Studies have estimated that between 15% and 20% of building projects (by value of work) are carried out by some form of package deal. The use of this procurement approach appears to be increasing, Smith (1997)

The components of the design-and-build system are highlighted in figure 7.4. It starts when the client identifies his/her need for a building and states his requirements. A survey conducted as part of this study suggest that in practice the client may ask an agent to prepare his Employers Requirements (as termed in CD 81). The client might employ an architect, quantity surveyor, building surveyor or similar competent person to state his requirements but such a person's task would be complete when he/she had prepared the statement.

The client's requirements are passed to the design-and-build contractors; each contractor will have to prepare a design and ascertains the time it will take to carry out the works. At the same time he prepares an estimate of the cost of his 'proposal' and submits a tender. No more detail is given than is necessary for tender purposes.

The client's requirements need to be submitted only in sufficient detail to enable the contractors to ascertain needs and submit their proposals. The chosen Contractor 'A' prepares a detailed design and carries out and complete the works employing his own staff or subcontractor.

The contractor's proposal normally include a 'Contract Sum Analysis', which takes the place of bills of quantities. It is generally accepted that the contract sum analysis should contain sufficient pricing data to enable the cost of changes in the client's requirement to be calculated, should changes occur.

There is provision in CD 81 for the client to nominate an 'employer's agent' whose role is to receive or issue applications, consents, instructions, notices, requests or statements or to otherwise act for the employer. The agent will probably, but not necessary, be the man who prepares statement of clients requirements. He has a much more restricted role than that enjoyed by the architect or supervising officer when the traditional system is used.

7.7.1 Characteristics of Design and Build

- It is used increasingly as a means of managing the building process in the UK and abroad.
- It provides single point responsibility so that in the event of a building failure the contractor is solely responsible. There should be no question of 'passing the buck' between architect and builder, as has so often been the case in the past. The client's interests are safeguarded in this respect.
- The client knows his total financial commitment early in the project's life, provided he does not introduce changes during the course of the works.
- The client has direct contact with the contractor. This improves lines of communication and enables the contractor to respond and to adapt more promptly to the client's needs.
- The contractor is responsible for design, construction planning, organisation and control. These activities can proceed concurrently to a greater extent than is generally possible using the traditional system.
- The package dealer may provide a comprehensive package comprising site seeking and purchases, obtaining planning permission and building regulation approval, financing facilities, leasing, to mention a few.
- The package dealer may use a proprietary building system or modular building from which reduces design time and the time required for approval of the building components.
- The client is frequently able to see examples of the package dealer's product when his proposals are being made. Most client can visualise their needs more readily in three dimensions (by moving within and sampling an actual building) than by the study of drawings and specifications. Quality, a feature, which it is difficult to specify, may be more easily indicated by comparison of samples.
- Many systems used by package dealers have been tested over a period of years and are less prone to teething troubles.
- The package dealer's components are often readily available so that manufacturing time is minimal and construction time may be correspondingly reduced because manufacture of components and work on site can proceed concurrently.

- Work on the building can commence as soon as local authority approval has been obtained and sufficient information regarding the earlier site operations is available. The design does not need to be finalised before some of the work may be commenced.
- The package dealer is familiar with the construction methods to be used for his product and work proceeds more quickly.
- Some proprietary package deal products lack aesthetic appeal.
- The range of design, which is available from some proprietary package dealers, is sometime limited.
- Competition between the contractor's proposals should ensure economic tender and alternative design concepts.
- The relaxation of the architects' code of practice makes it possible for architects to become full partners in design-and-build firms
- This relaxation should lead to the construction of buildings, which reflect the senior status of the designer in the team and lead to more aesthetically pleasing buildings than may have been built in some instances in the past.
- The nature of the system should promote the creation of an integrated design and construction team.
- The closer involvement of architects in the building process should lead to designs which have a greater appreciation of construction methods; 'buildability'.
- The integrated nature of the team improves communication between designer and builder, which encourages prompt decisions.
- A prompt response is achieved in the event of materials or manpower shortages.
- Design costs are built into the package but because the design input and 'detailing' required are less than when using the traditional system the costs involved is frequently less.
- There are no independent architects or similar professionals available to the client to advise on the technical quality of the design at time of tender, although he is not precluded from seeking such advice if he so wishes.
- The employer's agent may supervise the works and ensure that the contractor's proposals are complied with and that the work is not skimped.
- The nature of the contract tends to reduce changes (variations) from the original design and disruption of the works is less likely to occur.

- The reduction of changes and disruption produces time and cost savings, which benefit the client.
- The total project completion period is reduced.
- Time savings reduces the employers financial charges, inflation has less effect and the building is operational sooner, which in commercial context produces an earlier return on the capital invested.
- (Contractors design) CD 81 is intended for use on projects where the client provides the site, which is the subject of the contract. Many design-and-build projects use conditions of contract drafted for specific purpose. The diverse nature of these projects leads to corresponding diverse conditions of contract.
- (Domestic) DOM forms of sub-contract may be used between contractor and the various sub-contractors.

7.8 Project Management/ Client Representative

During the 1960s and 1970s construction projects tended to become larger and more complex. It became apparent that the time-honoured the traditional-client-architect-builder relationship was sometimes inadequate as a system for constructing buildings within cost-budgets and tight time-schedules, Forester (1986). There was a need for someone to manage the project as a separate, distinct member of the construction team- a project manager or client's representative, Franks (1991).

There is nothing new in the concept of a project manager. Before the end of the 17th century when architecture, as a profession, was established in Britain, virtually all major building projects for the Church and the Crown (the principal client of the building industry) were designed by Crafts Men and managed by Clerks of Works/Master of Works. The Master of Works was a client's representative. They were basically responsible for the overall management of the project. The emergence of project managers for major projects in the 1960s marked the return to a system, which existed for some six hundred years in Britain, Franks (1998).

The essence of the appointment of a "Project Manager" or "Client's Representative" is that a single person acts as surrogate client. The title project manager is that which is most generally employed but client's representative is becoming increasingly used. Whichever title is used that role is to ensure that all the needs of the client are satisfied and to act as the contract point between client and the building procurement team. It is the direct relationship between client (whose interest the project manager represents), and the project manager which distinguishes his role form other 'managers' in the construction process who frequently have the word 'project' affixed to their 'manager' title.

The Wood Report suggests that the project manager's prime task is one of co-ordinating client requirements such that clear instructions from a single source can be provided to the other parties involved. The importance of the clients identifying a single person to represent his interest (before he has a firm commitment to actually build), and to assist him with drafting the brief for the project is recognised in *Thinking about building*, which provides a guide to the selection of the most appropriate procurement path to meet a potential client's specific needs.

A vital feature of the project manager's/ client's representative's role is that he is concerned solely with managing the project. Because he is not involved in designing or construction the building works he is able to take an objective overview of the activities of all concerned.

In the 1988 the National Economic Development Office (NEDO) report "Faster Building for Commerce" identified the need for the client, (referred to in the report as the customer) to appoint an experienced customers representative when working with the construction industry, if his in-house project executive was insufficiently experienced. The report suggested that such a person could be found among architects, engineers, surveyors, and project managers or in contracting companies with management and or design skills as well as those of construction.

Such a representative must have sufficient status and authority to act on the client's behalf in the dialogue between the client's organisation and the team appointed to produce the building. There is no reason to believe that the requirements of clients for commercial building differ greatly from those of clients for other types of buildings,

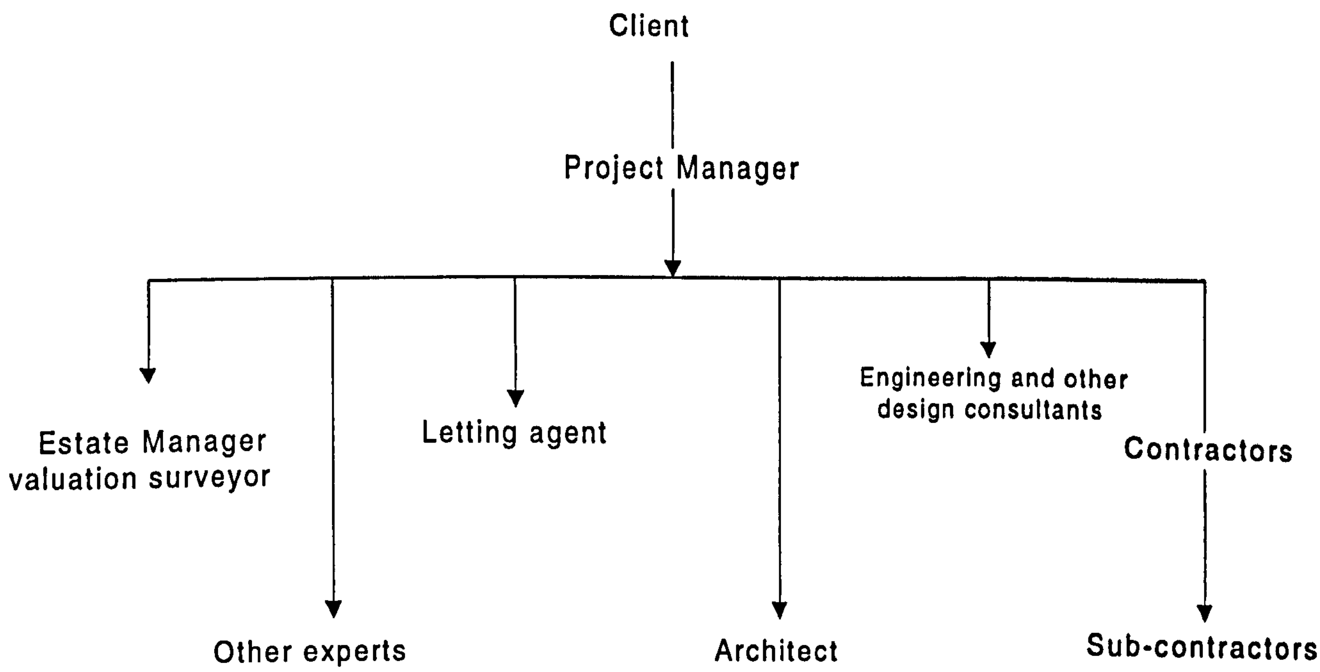

Figure 7.5: The relationship between the parties to the contract when a project manager or client's/ representative is employed

Project managers have been engaged with increasing frequency and success during the 1970s, 1980s and 1990s but there is no record of the extent of use. The components of the system may be seen in figure 7.6. As with the systems described previously there is a client with the need for a building. A project manager is engaged.

The first task of the project manager is to appraise alternative ways of meeting the client's needs. If the aim of the project is to maximise the client's return on his investment, the project manager might well consult letting agents or undertake extensive market research. The magnitude of many projects requiring the engagement of a project manager is such that his/her task at this stage would be as ' co-ordinator of expertise'. He would then present the experts' collective recommendation to the client for his decision regarding the project, which best suited his needs. In practice the client would more usually be a board of directors of a corporation or the council of a public authority.

The client making a decision to build marks the point at which a decision has to be made, regarding selection of the contracting system to be employed. If some form of management fee system is to be employed the contractor may be appointed at this stage. In the event the project manager will join the design team and the review made about this system will apply.

The project manager assembles the design team which will best suit the project's specific features, whilst at the same time endeavouring to appoint people who will work well together.

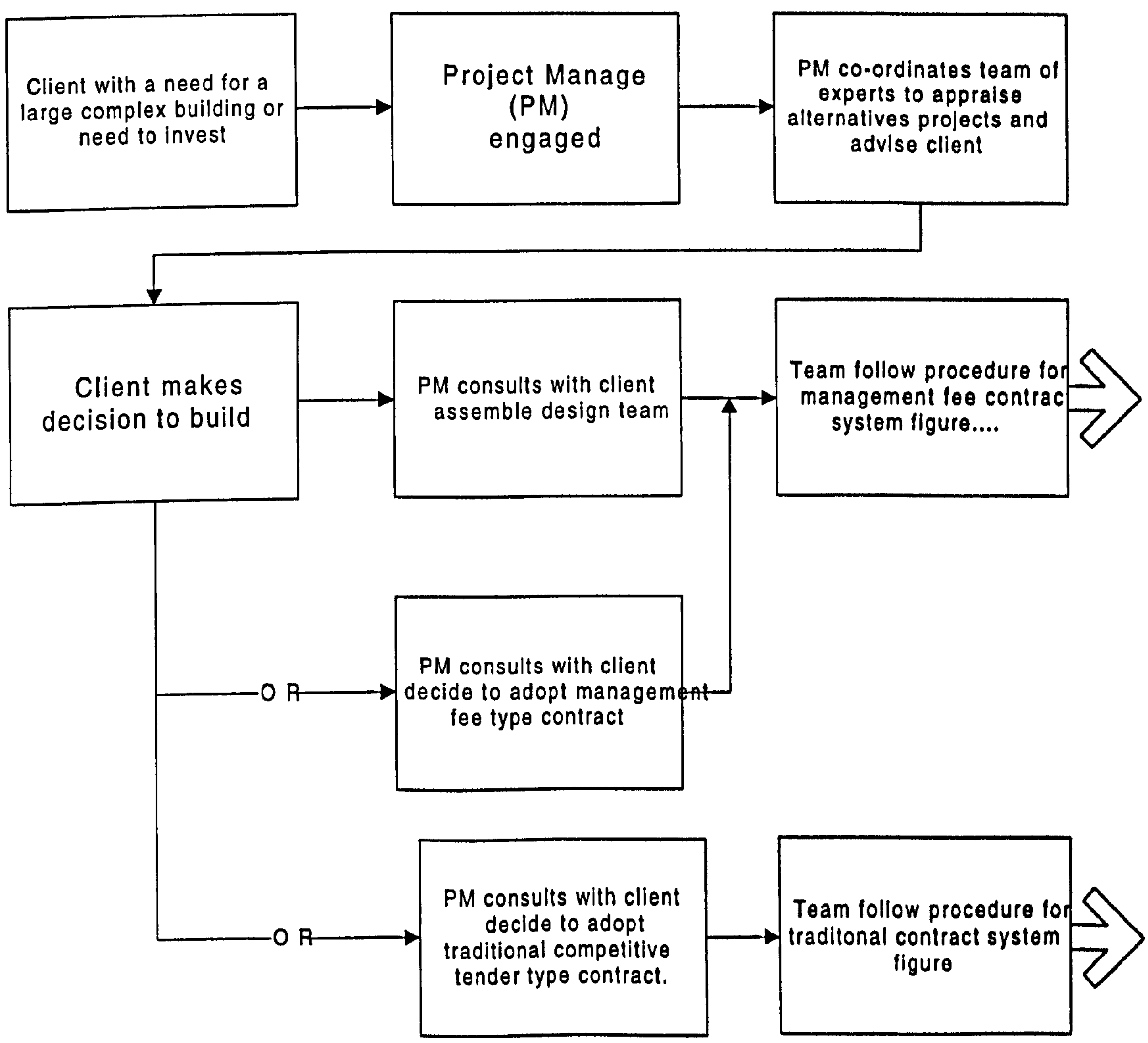

Figure 7.6: The Project Management Procurement Method Flow Diagram

An appreciation of the human aspects of management is an important part of the project manager's skills. The project is designed, costed and constructed, after the project manager assembles the design team. It is important that the cost implication of design variables are ascertained as promptly as possible so that their effect on project viability can be considered by the project team and appropriate action taken.

The contractor is selected after the contract type has been decided between the client and his project manager. The Project manager in consultation with the client may decide to adopt a management fee type contract or a traditional competitive tender type contract. Alternatively, a package deal contractor may be appointed. In which event the project manager's role would be mainly concerned with acting on the client behalf in the dialogue between his organisation and the contractor.

7.8.1 Characteristics of the Project Management System

- It has been used with increasing frequency and success during the 1970s and 1980s for complex and large projects
- It is popular because of the dissatisfaction of some clients with the traditional system and it's potential associated delays and excessive costs.
- The project manager is a professional 'surrogate-client' with the experience of identifying and stating the client's needs and requirements.
- A project manager will often have a professional background appropriate to the type of building to be constructed.
- The project manager is able to act as a leader who can take into account all aspects of the project; finance, feasibility, design and time and hold a balanced between them.
- The engagement of a project manager releases the client from the need to delegate a member of his staff (often a member without previous experience) to act as the intermediary between client and project team.
- The management function is separated so that the manager is able to act in an independent capacity.

- The client incurs an additional cost from the project manager's fee but this cost is offset to some extent by savings in his own 'management' involvement.
- The design and construction functions are separated so that those involved can act as partners on equal terms.
- 'Them and us' confrontation may be avoided as a result of this separation
- Overall planning and control which results from the engagement of the project manager ensure that both design and production are planned and co-ordinated to give as short an overall design and construction duration as possible.
- The architect and other consultants are released from the tasks and problems associated with managing a project, enabling them to concentrate on design matters.
- The quantity surveyor carries out cost estimating and planning and control throughout the overall project period.
- The system provides for alternative means of selecting the contractor.
- Reduction of the overall project period provides consequential cost reductions, as the client is able to utilise the building, or obtain a return on his investment, more promptly.
- There are no JCT standard forms of contract for the employment of a project manager. JCT 80, IFC 84, CD 81 or MC 87 may be used between client and contractor. The appropriate sub-contract forms may be used between contractor and sub-contractors, Chappell (1997)

7.9 The British Property Federation System

The British Property Federation (BPF) is a powerful client body, which has recognised the importance of the client appointing a single person to represent his interests. The BPF has done much to promote the term 'client's representative', Franks (1998).

In November 1983, the British Property Federation published a manual of the BPF system for building design and construction. The manual comprised ninety-nine pages of which thirty-six are appendices providing schedules of responsibilities, checklist and performance. The manual excited considerable interest and criticism because it proposed radical changes to established procedures. Some members of the building team saw their traditional roles threatened, Forster (1986).

The BPF system put the client's interest first. It attempts to devise a more efficient and co-operative method of organising the whole building process – to the genuine advantage of everyone concerned in the total construction effort. The reason for this enterprise is that – to build in the UK appears to cost too much, takes too long and does not always produce credible results, Latham (1994), Egan (1998).

The BPF represents substantial commercial property interests and thus it was able to exercise considerable influence on the building industry and its allied professions, particularly at a time when the industry was working at much less than its optimum capacity. The BPF is the only document of its kind, which sets out the operation of a system in such detail, in figure 7.7, Turner (1997). Clearly, the manual provides the definitive document and the 'operation' described below should be regarded simply as an introduction to the system. This disclaimer is significant because the manual is at pains to offer a system, which can be used with various methods of contracting. Although the system consisting of a series of precisely described steps, it can be used flexibly' in many respects. The BPF system is an amalgam of the various procurement pathways discussed, earlier, in this chapter.

The use of the BPF procurement approach is increasing but measured by value of work, the system's contribution to the building industry's output is not great, Franks (1998). Nevertheless, the system has made a significant contribution to developing the industry's attitudes and approaches to building procurement. The components of the system may be seen in simplified form in figure 7.7. The process commences, when a client plans to build. BPF members are largely 'commercial' but the Federation's system should be capable of adoption by a wider range of clients, Franks (1998).

The manual suggests that the client should explore the many course open to him 'at minimal cost' and appoint a 'client's representative', who is defined as 'the person or firm responsible for managing the project on behalf of and in the interest of the client'. The client's representative may be an employee of the client or an architect, chartered surveyor, engineers or project manager.

The client appoints the client's representative whose first task is to help the client develop the concept and manage the project on his behalf. Obviously, the extent to which it will be necessary for the client's representative to become involved in ascertaining the economic viability and technical feasibility of the project will depend on the client's in-house skills and expertise.

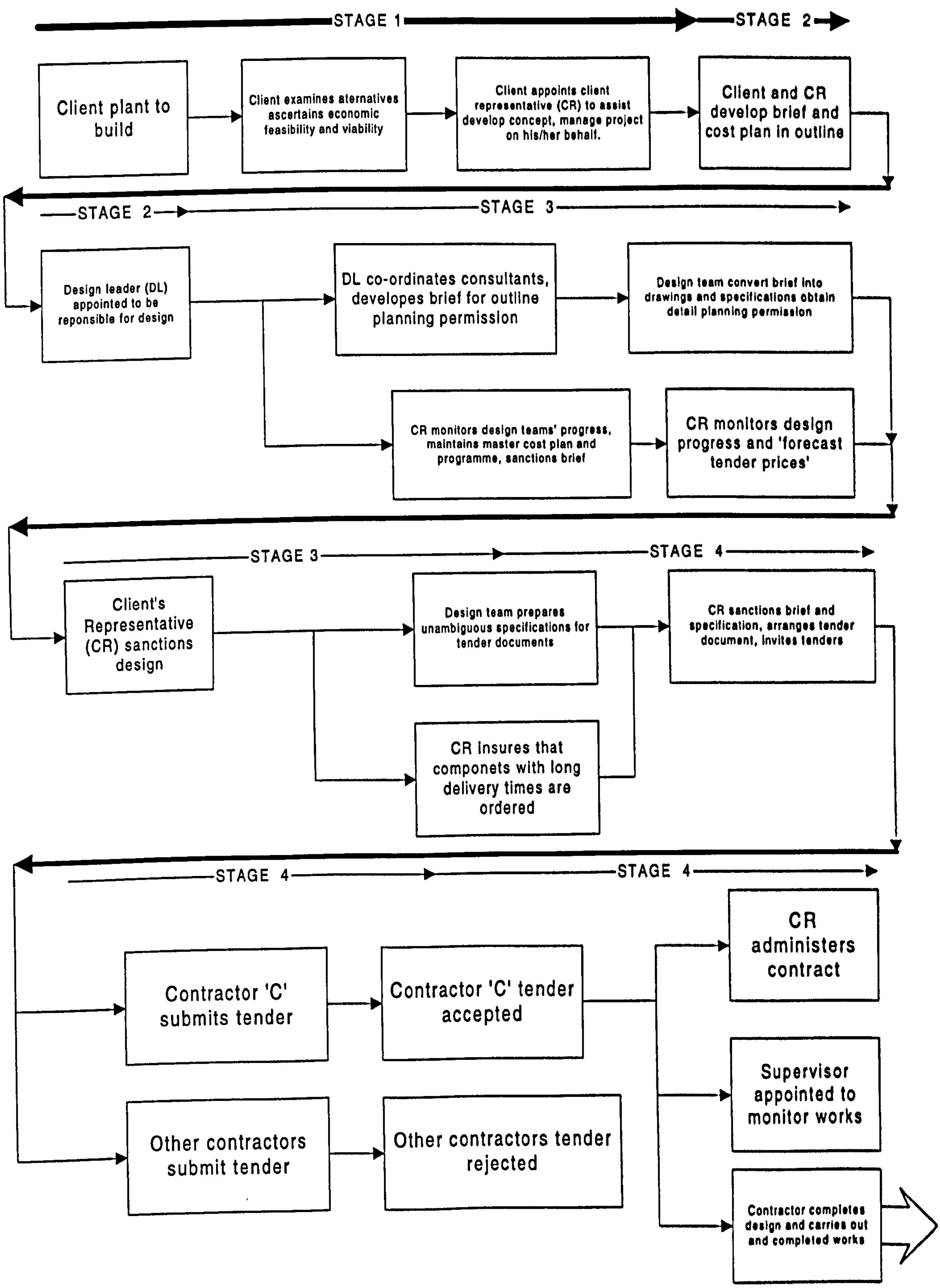

Figure 7.7: BPF System for Building Design and Construction.

The client and client's representative develop the outline brief and the outline cost plan to the point where the client is satisfied and to the extent that the full brief may be specified. These activities comprise 'Stage 1 – Concept' in the BPF manual.

The client and client's representative development of the project brief and cost plan in outline, sees the commencement of 'Stage 2 – Preparation of the brief. It is possible that the 'design leader' may have been appointed in Stage 1 but if not, he will be appointed in Stage 2.

The design leader is defined as ' the person or firm with overall responsibility for the pre-tender design and for sanctioning the contractor's design'. The design leader might be an individual, a multi-disciplinary firm, or he might be a consultant with specialist consultants contracted to him. The client's representative monitors the design team's progress, prepares and maintains the master cost plan and the master programme. The cost plan is a schedule, prepared by the client's representative, of the expenditure required to implement the project. Whilst, the master plan is a schedule prepared by the client's representative of the main activities to complete the project.

Usually, the client's representative will 'sanction' the design leader's brief and subject to obtaining outline planning permission, the design should progress to the point where an application for detailed planning permission may be obtained. The glossary of terms refers to 'sanction' as the process by which the client's representative successively agrees the work of the design team to ensure that it meets the requirements of the brief. The contractor's design is similarly sanctioned by the design leader- to ensure that it complies with the contract documents.

The client's representative continues to monitor design progress and agrees to the 'forecast tender price', which is a 'forecast made by the design leader of the likely cost of construction'. The forecast tender price forms part of the master cost plan. The design leader and client's representative work together towards the provision of tender documentation. The design team prepares, what are referred to in the manual as 'complete drawings' but this term may be misleading if the reader is accustomed to the traditional system in which design is entirely the province of the design team. Complete drawings in the context of the BPF system means that the drawings, together with clear unambiguous specifications are sufficient as a basis on which contractors might tender without being justified in claiming for omissions or inadequate descriptions. The manual points out that the quality of the information will control the standard of the buildings. The client's representative sanctions the drawings and specifications, arranges tender documents and invites tenders.

Stage 4 – Tender documents and tendering – commences with the design team preparation of complete drawings and unambiguous specifications for tender documents. This stage is completed, when a tender is accepted and a contract is entered into between client and contractor.

Usually, there will probably be a need for clarification of sundry items by all concerned with the project and that prospective contractor may be required to provide further information, cost, calculations, etc before contracts are finally exchanged. Tender documents consists of:

- Invitation to tender with its appendices
- Specifications;
- Drawings;
- Conditions of contract;
- Bills of quantities, should the client decide to use them

The contractors' tenders are submitted to the client's representative. The tender should include:

- Outline priced schedule of activities;
- Organisation chart;
- Details of personnel;
- Method statement;
- List of declared sub-contractors
- Schedule of time charges.

The tender may also contain alternative proposals for the design and construction of the building.

Stage 5 – Construction: A particular feature of the BPF system is that the contractor 'completes the design, providing co-ordinated working drawing. He obtains approval of his design from statutory authorities should this be necessary and co-ordinate the work of statutory undertakers'. The building agreement between the client and the contractor states that the contractor's design is to be sanctioned by the design leader to ensure that it complies with the tender specification.

The client's representative administers the building contract, approves payments to the contractor, decide on the need for variations and issues instructions. It is he who decides if the services of the design leader should be retained during the construction stage. It will be appreciated that the design team task should have been completed by 'tender acceptance' stage or perhaps before the 'contractors submit tender' in stage 5, as depicted in figure 7.7.

A supervisor is appointed to monitor the works; his/her duties are detailed in the appendices. They are similar to those of a clerk of works but more comprehensive in their scope.

7.9.1 Characteristic of the BPF System

- The BPF system was devised, almost unilaterally, by one party to the building contract – the client – so it lacks some of the compromises inherent in agreements devised by bodies such as the Joint Contract Tribunal. It is concerned primarily with the client's interests.
- It is designed to produce good buildings more quickly and at lower costs than the traditional system.
- The BPF system is designed to change attitudes and alter the way in which construction professional and contractors deal with one another. This is aimed at creating a fully motivated and co-operative building team and to remove as much as possible the effort overlap between the designers, quantity surveyors and contractors, prevalent under the traditional system.

- It was designed to redefine risks and re-establish awareness of real costs by all members of the design and construction team and to eliminate practices which absorb unnecessary effort and time and obstruct progress towards completion, Franks (1991).
- It provides for an independent 'client's representative' who manages the project as a whole and who is not involved in as a designer or contractor. He provides single-point responsibility for the client and by virtue of his non-involvement in detail he is able to concentrate on management.
- It creates a design leader with overall responsibility for the pre-tender design and for sanctioning the contractor's design.
- The contractor's knowledge and experience of the cost implications and buildability of design variables may be utilised to good effect because he/she contributes to the design.
- It provides a financial inventive which encourages contractors to undertake design detailing which is economical to construct, Turner (1997)
- The arrangement by which the contractor undertakes detailed design should reduce 'pre-tender' time and so enable the client to have earlier occupation of the building and an earlier return on his investment. He/she should incur lower financing cost because of a reduction in the overall project period.
- The system makes provision for the design team to name sub-contractors and suppliers who they would require (or prefer) to be invited by the contractor to tender for part of the works. There is no provision for nominated sub-contractors as with the traditional system.
- An adjudicator is appointed to decide impartially upon disputes, which may arise in the implementation of the project arrangements. His task is to carry out a prompt investigation and give a decision, which is implemented forthwith. There is provision for reference to arbitration 'after the taking over of the works' if the adjudicator, Turner (1997), cannot resolve the dispute.
- With regard to forms of contract - the Association of Consultant Architects (ACA), BPF edition is available for use with the BPF system.

7.10 Project Time-Cost Relationships

A National Economic Development Office (NEDO) report, "Faster Building for Industry" (1988), states that the traditional methods of design and tendering, the various design-and-build options and project management can give good construction times. However, on the average, the use of non-traditional routes tends to produce overall times shorter than those produced by the traditional routes. Figure 7.8 provides a 'pre-construction timetable' which demonstrates the relative times of the options.

In figure 7.8, it may be seen that the use of a negotiated contract enables construction work to commence some seven months earlier than is possible with the 'end-to-end' traditional system. It is reasonable to assume that whichever approach is used for the design, the construction periods will not differ significantly so that the total project period will be reduced if one of the non-traditional or 'fast-track' approaches is used

The term 'fast-track' has been more subject to varying definition than others but overlapping of design and construction as a means of reducing project time is a generally recognised characteristic of the term, Gyoh (1993). This overlapping, often referred to as 'parallel working', can be achieved by using a modified version of the traditional system or by adopting a form of construction management or management contracting.

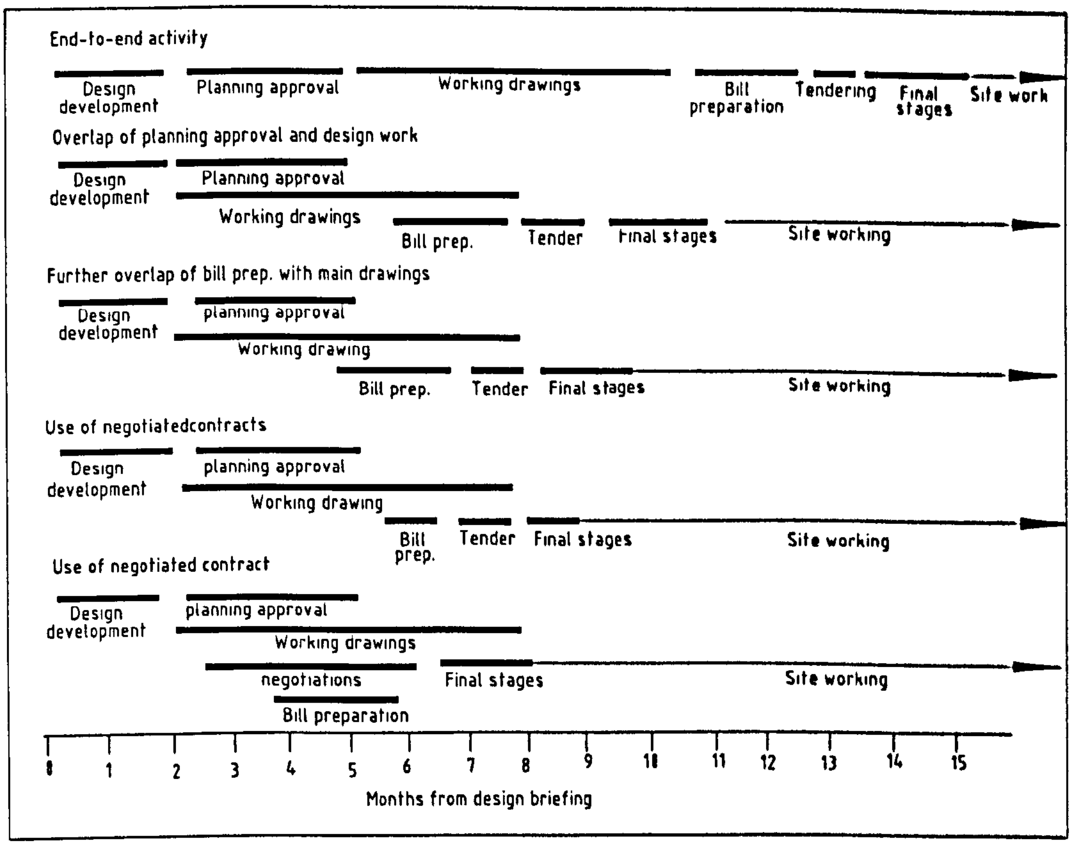

Figure 7.8: The pre-construction timetable – Faster Building for Industry, NEDO, HMSO, 1988.

A brief review of a study carried out by James Franks in 1993 on the comparison of procurement systems is summarised in figure 7.1. Franks agues that selecting the most appropriate procurement path is largely a matter of determining which 'performance requirement' heads the client's list of priorities. These might include:

- Technical complexity;
- Aesthetics/prestige
- Economy;
- Time;
- Energy Efficiency
- Sustainability
- Eco-sensitivity
- Exceptional size or complexity involving input from numerous sources and /or to satisfy several users' requirements;
- Price certainly at an early stage in the project's design development;

- Facility for the client to change/vary the works during the project's construction stage.

In Table 7.1, each of the requirements listed above is rated in so for as it is able to satisfy the requirement. Ratings have been given on a 1-to-5 scale with '1' the minimum and '5' the maximum capacity to meet the requirement. The rating are Frank's assessments of 'satisfaction' base on a study on procurement system analysis in the UK construction industry.

The study assumes that the competence of the personnel involved is similar in all instances- only the systems are being compared. The following comparison does not take into account all the characteristics of the systems, which have been discussed.

In Frank's study, the traditional system rates '4' for projects with high technical complexity and /or with high aesthetic standards because the design team is not submitted to pressure, provided the design is essentially complete before competitive tenders are sought. In this event the team is able to develop the design rationally. Competitive tenders ensure that the client obtains the benefit of the lowest building cost.

The sequential nature of the system and the experience gained by a significant number of clients of poor performance on exceptionally large or complex projects have prompted the low ratings for performance requirements (d) and (e). Priced bills of quantities facilitate the measurement and valuation of variations during the progress of the works, hence the high rating for requirement (f) and (g).

Management system Client's performance Requirement/expectations	Traditional	Management Contracting/ Construction management	Design-and-Build Package Deal	Project manager/ client's representative
A. Technical complexity; the project has a high level of structural mechanical services or other complexity.	4	5	4	5
B. High aesthetic or prestige requirements	5	3	3	4
C. Economy; a commercial or industrial project or project where minimum cost is required	3	4	4	4
D. Time is an essence; early completion of the project is required.	2	4	5	4
E. Exceptional size and /or administrative complexity; involving varying client's/ user requirement, political sensitivity e.t.c.	2	4	4	5
F. Price certainty; is required at an early stage in the project's design development.	4	2	4	4
G. Facility for change/ variation control by client, user or other during the progress of the works.	5	5	1	4

Figure Table 7.1: Building procurement systems rating.

The study gave 'management for a fee' a rating of '5' to requirement (a) because involvement of the construction team at an early stage in the development of the design should facilitate design of complex structure, mechanical services and other elements. Rating of '4' have been given for performance requirement (c) and (d) because competition between management contractors, initially, and work-package contractors subsequently, produce competition for building works. Because design and construction proceed in parallel the project period is kept to a minimum.

With regard to 'package deal/ design and build' performance requirement (a) and (c) have been given ratings of 4. The involvement of designers and constructors on a team basis from the inception of the project should produce the expertise to cope with any technical complexity, which the project may present. Design and construction progress concurrently not consecutively, which minimises total project time. Rating of 4 may be less than generous for these performance requirements, as may 3 for requirement (b). A rating of 5 has been given to requirement (d). The package deal system is used for large and complex projects. According to Franks, the package deal has been found suitable for projects of exceptional size or complexity, provided the contractor ensures that a member of the firm who has the managerial expertise is appointed to 'stand outside' the day-to-day activities and hold a balance between design and construction interest.

A rating of 4 has been given to requirement (f), price certainty, because the price is normally agreed on the basis of the client's requirements. Provided the requirements are not changed after the contractor has submitted his proposals the price should hold. From this it follows, however, that there is little facility for cost control of changes during the progress of the works. The rating of 1 for requirement (g) reflects this.

Project management / client's representative systems were developed in response to demand for better management on exceptionally large and complex projects. However, there is increasing evidence that the system is gaining popularity among architects for more run-of-the –mill projects, Franks (1998). This departure may appear surprising because when use of the system increased in the 1960s architects were its principal opponents. They saw their authority being undermined. One can only assume that this change of mind has been made because the experiences of some architects on projects, which have involved project managers, have shown them some advantages of the system.

The British Property Federation in 1983 adopted the term 'client's' representative, when devising the BPF system in preference to 'project manager'. The system, as such, has not been widely used by clients of the building industry but it is essentially a project manger/client's representative led system and should be regarded as such when making a comparison of procurement systems, Gyoh (1993)

However, the greatest advantage should be a clear definition of the client's requirements through a brief to which the project manager is a principal contributor. For these reasons the system has been rated highly. At the same time, a project manager cannot compensate for 'weaknesses' which are inherent in a system, such as the inability of the package deal system to facilitate cost control of changes during the progress of works, Turner (1997).

7.10 Value Management

Value Management is one of the contemporary techniques employed in attempt to satisfy the client's requirement in terms of project objectives at the on set of the design stage. Value management/value engineering is basically part of the design process as oppose to a cost cutting exercise/ technique, Mc George (1997). One of the contemporary techniques in use in functional determination exercises on construction projects is the value management/ value engineering technique.

Value Management (VM) was derived from the principles of Value Engineering (VE). VE was a term first used term by 'Miles' (in North America) to describe a technique that he developed at the General Electricity Company (GEC) during the World War II.

The technique began as a search for alternative product components to cope with shortages which had developed as a result of the war. The central feature of Miles work was the definition of all functions that the customer/ client required of the product.

Up until the 1970's VE was only being used in the manufacturing sector. The use of VE techniques in construction can be traced back to the 1970's in the USA construction industry; its use was mainly by government agencies. The construction industry for various reasons adapted the manufacturing VE systems and tailored them for their own use, Kelly & Palmer (1992).

The VE 40-hour workshop became a feature of value engineering when it began to be used in the construction industry. In addition, value engineering was carried out at the 35% design stage using a team external to the project. It was largely this system of value engineering that was imported from the United States to the UK construction industry.

The problem with this American system, with regard to the UK scenario, is that it deviates from the original work of Miles. It does not, other than in name, include function analysis. Value engineering in the US construction industry is basically a design audit. It consists of a 40-hour workshop structured loosely around a job plan. It is carried out at 35% of the design stage by an external team. It involves the selection of high cost areas and the generation of alternatives. The selection of high cost area is a fairly loose procedure. It is based on the comparison of elemental cost with the cost of cheaper alternatives, along with a more general cost project cost centres. This nebulous approach results in a fairly broad VE output encompassing design changes and cost cuts from all disciplines. This output however, cannot be attributed to function analysis. The actual workshop itself as an autonomous unit is a critical contributory factor in the success of value engineering studies. Within the workshop, the degree of success of the study relates largely to the personalities involved, particularly that of the team leader, the timing of the study, the interaction of the VE team, the input of the design team and the role of the client, Mc George (1997). The technique of function analysis bears little or no relationship to the output of the study, Kelly and Palmer (1992).

When the British companies tried to use the US system of value engineering, they found that they could not make it work. The reasons for this failure relate to the original objective of the value engineering studies, Mc George (1997). The US system of value engineering was born out of a need for greater accountability of government projects. The situation in the UK is very different. The quantity surveying system provided all the accountability that is needed. In the UK value engineering was required to provide a platform for the examination of value as opposed to cost. Against this background it was hardly surprising that the US system of value engineering broke down in the UK.

Once this broke down had occurred the UK construction industry was faced with two options. It could either abandon value engineering altogether or go back to the original work of Miles and build its own system that satisfied its own objectives. It appears that the latter route has been chosen. In the UK scenario, new systems of VE are developing under the title value management (VM).

7.10.1 Functional Analysis

According to Mc George function definition, function evaluation, and creative alternatives are collectively called functional analysis – a common feature of value management. Functional analysis forms the basic core of value management. Without this technique any exercises that is carried out on a project, useful though it may be, cannot be described as value management, Mc George (1997).

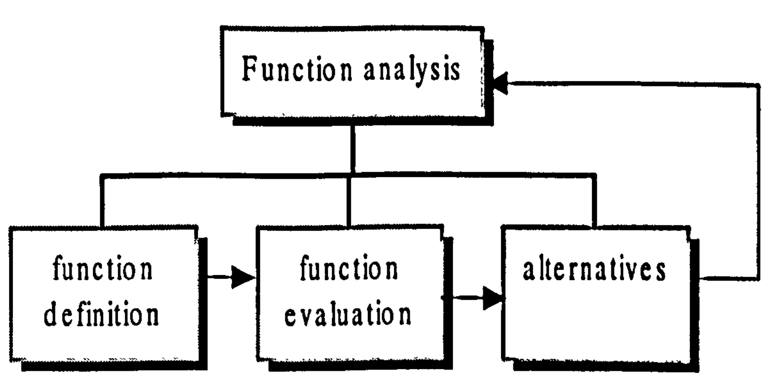

Figure 7.9: Stages of Functional Analysis.

7.10.2 Functional Definition

The problem that arises with functional definition in construction is one of levels. Functional definition in a construction project can be carried out at four levels, i.e. I) definition of functions of the project as a whole, ii) definition of the spaces within the project, iii) definition of the function of the elements within the spaces, .vi) definition of the function of components.

Once it has been decided that a particular project is required, the functions of the spaces within it can be defined. In addition to project and space function, the function of project elements can also be defined. The definition of elemental functions provides a clearer insight into design and design alternatives. It is possible to divide element into components and once again this can provide insight into design and design alternatives. In breaking a window into components of sills, heads, and jambs these parts can be examined to see how well they meet the required functions/ performance specification.

It is widely accepted that high-level function definition is much more beneficial to the project. It therefore follows that the ideal time to do function definition is before any design has taken place, thereby maximising the potential for change and for improving value. However, it is more often the case that some design exists, when the functional definition exercise is being carried out. The problem with this is that the value management team will tend to use this design to define functions. What this in effect means is that they are accepting the functions as designed before they have established that those functions are required. Too many design decisions are based on an acceptance of what was done in the past, Gyoh (1993). However, it is better to start with a fresh approach based on clients' requirement and ultimate project objectives. In that respect only necessary or desired functions will be included. Function evaluation is a catalyst to creative alternatives. The techniques of function evaluation and the generation of alternative methodology are outside the scope of this study.

7.10.3 Conclusion on Value Management

Although function analysis is the central pivot of value management, other components are required for function analysis to operate effectively. These other components have alternatives. It is the choices of alternatives that constitute the value management system. The value management system is dependent on many factors such as the project type, the time scale, the design team and the business culture of the industry. Flexibility therefore is the key to good value management.

Understanding the component parts of value management and the best time to use them is vital for successful value management. However, value management is a fairly new technique. Its appropriate application with regards to timing strategies is still unclear. More practice of value management is required, along with more research, for these questions to be satisfactory addressed.

A common mistake that is made with value management is to confuse it with cost reduction exercises. It is hoped this section of this study will has illustrated that value management has in fact very little to do with cost- it is a design process. The fact that cost reductions often come-about as a result of value management is more a consequence of it than an objective.

Some of the most contentious issues limiting the effectiveness of value management/engineering as techniques within the UK construction industry are as follows:

- It is not clear as to what is the must appropriate time for the application of VE. Guidelines do not exist for timing of VM.
- Currently, function evaluation/ analysis tend to be carried out when some design exist – this is however not being productive as it limit innovation and suggest the acceptance of existing function.

7.11 Constructability

Buildability/ constructability as defined in this study is the extent by which design facilitates the ease of construction and also the life cycle maintenance and running cost of a building.
The term 'constructability' and 'buildability' are not found in any standard dictionary. The terms, which are specific to the construction industry, have meaning only to those, operating with the confines of the industry. Within the context of this study, the terms are taken to be synonymous and can be used interchangeably.

The industry-specific nature of constructability makes it unique in comparison to all other project /process management concepts covered in this thesis. Some writers make the unusual claim that it is the only concept in the past 30 years to have been designed and developed by the construction industry for the construction industry, Mc George (1997).
By comparison with other industries, the separation of the processes of design and construction is unique to the construction industry. The compartmentalisation of these functions has been highlighted over the years in reports such as the Simon report, the Emmerson's review (1962), and the Banwell report (1964) and recently the Latham report (1994) and the Egan report (1998). In response to these deficiencies, the Construction Industry Research and Information Association (CIRIA) in 1993 focused attention on the concept of 'buildability'. According to a study carried out by CIRIA buildability problems existed in the UK construction industry, CIRIA (1993). The study goes on to suggest that this probably as a result of the comparative isolation of many designers from the practical construction process.

The shortcoming as seen by the contractors were not shortcomings of any particular people, but rather that of the separation of the design and construction functions which has characterised the UK building industry over the last century.

CIRIA defined buildability as 'the extent to which the design of the building facilitates ease of construction, subject to the overall requirement for the complete building' (Construction Industry Research and Information Association, *Buildability:*

An Assessment, Special Report 26 1983). The CIRIA definition focused only on the link between design and construction and implied that factors which are *solely* within the influence or control of the design team are those which have a significant impact on the ease of construction of a project.

The American Construction Industry Institute (CII) was founded with the specific aim of improving the cost effectiveness, total quality management and international competitiveness of the construction industry in the USA. Constructability was and is still a significant component of the CII's research and development work. The CII defines constructability as: 'A system for achieving optimum integration of construction knowledge and experience in planning, engineering, procurement and field operations in the building process and balancing the various project and environmental constraints to achieve overall project objectives (Construction Industry Institute (CII), 1986 Constructability: A Prime. CII University of Texas, Austin, Publication 3-1).

7.11.1 Review of Goals of Constructability

According to Griffith (1995), the goals of constructability are determined by the scope which constructability is intended to cover. The 1983 CIRIA definition limited the scope of the concept to the relationship between design and construction, figure 7.12.

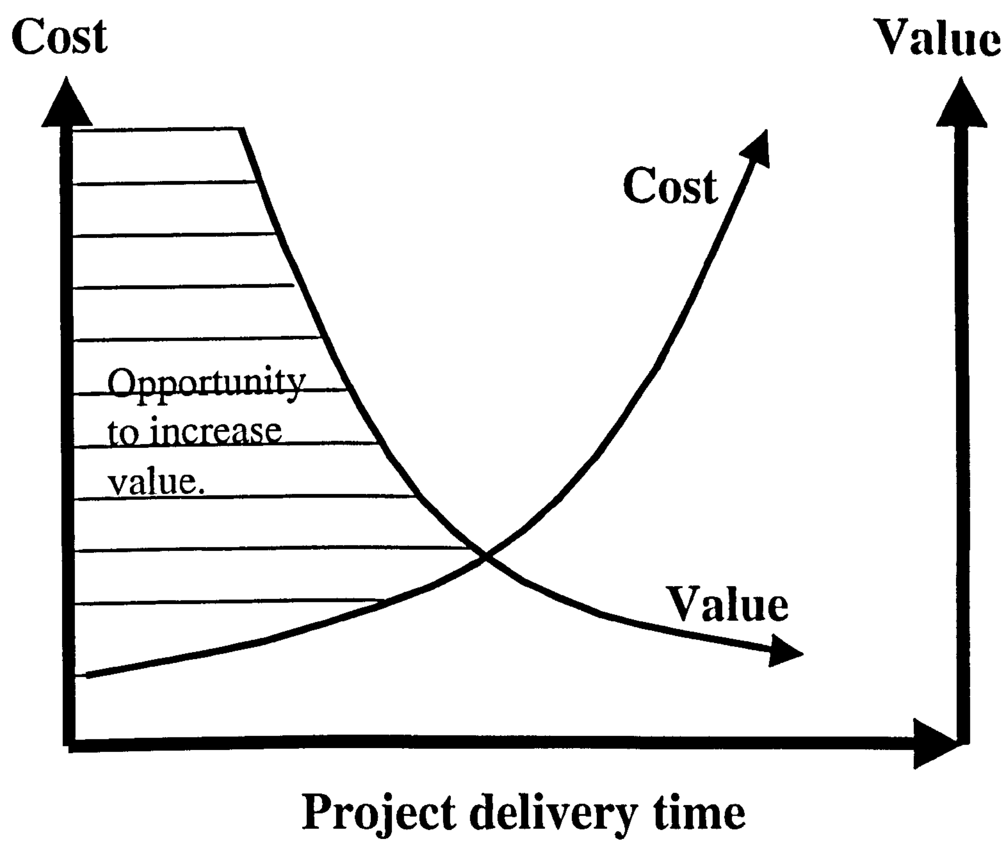

Figure 7.10: Cost-Time graph and it's impact on Value and Decision timing

Many observers believe that the scope of the definition of buildability by the CIRIA model is quite narrow, in terms of, viewing constructability purely as a design-oriented activity. According to Griffith, this approach is highly restrictive and results in the loss of some momentum in the pursuit of constructability, in the UK construction industry.

Buildability does not equate simply to the ease of construction but is also concerned with the appropriateness of the finished product. This can be seen in one definition of buildability, which defined buildability. The extent to which decision made through the whole building procurement process, in response to factors influencing the project and other project goals, ultimately facilitate the ease of construction and the quality of the completed project' Chen (1996). Figure 7.10, illustrated the relationship between cost and value in terms of decision timing during the life cycle of a project.

Decisions, which are made upstream, at the design stage, can impose constraints on the design decision process. At the same time, decisions that may not have been made by designer concerning intermediate functions between design and construction such as documentation, contractor selection, choice of contract from and procedure c.t.c, may have a significant impact on the construction process. Similarly, the maintenance manager who is conventionally regarded as being downstream of the design and construction decision-making process will be significantly affected by upstream buildability decision. If the complex nature of the procurement process is not acknowledged it may lead to an exercise, which will be of very little practical use.

The various participants in the project process will have different roles and responsibilities. They will have different responsibilities at different stages of the project lifecycle. The decision taken by the participants need to be co-ordinated in order to optimise the constructability performance of the project. Otherwise, individual participants may take different strategies towards achieving goals within their sphere of influences, thus compromising the overall constructability performance of the project.

7.11.2 Constructability and the Building product

It is surprising that so little attention has been given to the relationship between constructability and the building in-use. Decision which have a significant impact on the ease of access to components for maintenance and replacement, ease of assembly and disassembly, are made in the early stages of the project lifecycle. Research work has explored the relationship between decision taken at the inception stage of the procurement process and the downstream effect on the building in-use. The correlation between has been found to be strong, Griffith (1995).

Buildings are durable assets, which are often threatened with technical and functional obsolescence long before the end of their structural life expectancies. The maintenance and replacement of building components is a common everyday occurrence in the life-cycle of a building as a response to physical deterioration, technological obsolescence, changes in performance and functional criteria. Building performance should therefore be judged by at a specific stage in a building's lifecycle but should be considered over the lifecycle of the building as a whole, Powell & Brandon (1991). The potential for a building to extend its useful life is an important factor in its lifecycle performance. The operational efficiency of a building through its complete lifecycle is determined largely by the characteristics of its original design, operation, the construction and assembly processes and the demands generated by operational requirements, maintenance, alterations and ultimately disassembly or demolition, Bromilow (1992). The level of a building's performance is largely reflected in the quality of decision taken in the early stages of the project.

Efficient building maintenance and renewal is characterised by the need for easy access to, and disassembly and repair or replacement of existing building component. Planning for better performance with respect to these demands should be viewed as being within the domain of constructability. Constructability is often regarded as purely a design issue relating to the ease of initial building assembly. This approach limits and indeed diverts early project decision-making away from the consideration of the performance of the building throughout its full lifecycle.

The key to improving building performance is in effective information management, particularly at the early project stages where decision have the greatest potential to influence project outcomes. The identification of critical issues and the availability of timely and relevant information promote the quality of decision-making.

A constructability-oriented action plan will identify issues that have major impact on buildability and alert relevant decision-makers to the issues that they need to deal with. The timing of these actions is governed by the development of the integrated project description through each stage of the project lifecycle. This project description is the representation of the project in terms of all the decision, which have been made. At the feasibility stage, the project description could be a statement of all perceived project objectives, which eventually develops into a design brief. At various stages of the project lifecycle, aspects of the project description may be manifested in forms such as sketch design drawings, working drawings, specifications, bills of quantities, and shop drawings.

In practice, the compartmentalisation of the different functions in the project process tends to fragment of the project description put together by different participants. This contributes to communication and co-ordination problems. The use of computerised tools for integrated applications and networking would allow the development of an integrated project description is continually updated, keeping all participants informed on the status of the project and also triggering the progress of the action plan to the following decision situation.

Consideration of maintenance implications at the design stage is not a new idea. However success in this area has been moderate, Chen (1996). Maintenance and renewal consideration in the early project stages has been impeded for a variety of factors, the most critical being time-pressure, unaware decision-makers and ill-informed designers. Time is critical in the early stages of design and numerous conflicting issues are competing for the attention of the designers. The decision-maker invariably has little time to spend on investigating simple yet important operational or servicing issues, let alone more far reaching concept regarding ease of replacement and renewal consideration. The client or the project manager should address maintenance management and renewal considerations at a policy level. Maintenance-oriented design then becomes one of the objectives of the project and maintenance management and renewal becomes an integral part of project management.

Historically the attention to maintenance and renewal performance has been limited because designers responsible for new facilities have been unaware of the post-construction problems and inefficiencies experienced by those who have to maintain and operate them and which their decision impact upon, Griffith (1995). Recent studies indicate that designers have limited access to the buildings they design in the post-construction period and therefore tend to be divorced from the maintenance problems that flow from poor design, Mc George (1997).

7.11.3 Conclusion on Constructability/ Buildability

Decision-makers need to be given the required decision support in terms of access to relevant information, expertise and tools. A systematic approach might ensure that the requirements generated by the different stages of a project lifecycle and the inputs of the many compartmentalised project decision processes can be integrated buildability decision support knowledge base/database. An overall constructability-orientated management strategy would provides a logical continuity for a single integrated

framework and also serve as a common Decision Support System to all the project participants. The proposed framework might allow for the application of information technology to address the communication co-ordination and information management problems that confront most project decision-making processes of which BIPV systems designer and installation decision-makers are not an exception. The proposed information management framework, in this research, provides a singular decision support mechanism for all projects across it complete lifecycle. Harnessing of information technology enable the complex co-ordination and communication demands to be met and to overcome problem compartmentalisation, Tah and Thompson (1997).
Some observers argue that the principles of constructability are indistinguishable from the principles of good muti-disciplinary team working. This is a reasonable assumption, which is difficult to dispute. Against this background it is hardly difficult to see why constructability is not yet a commonplace management tool within the UK construction industry.

Constructability is about managing the deployment of resources to their optimum effect. This involves establishing good communication networks between members of the construction team, breaking down traditional barriers and altering professional mindsets. All members of the project team must be prepared to play a proactive role and address the complete building cycle from inception through to occupation.

7.12 Review of Reengineering

Despite being a relatively new discipline there is already some ambiguity with respect to what is meant by 'reengineering'. Much is currently being claimed about the power of reengineering. The flyleaf of Hammer and Champy's text 'Reengineering the Corporation' (1993) make the claim that 'Reengineering the Corporation' does for modern business what Adam Smith did for the industrial revolution in the 'Wealth of Nations' two centuries ago. Some writers claim that it reinvents the nature of work to create the single best hope for the competitive turnaround of business.

The emergence of reengineering is usually attributed to the publication of Hammer's Harvard Business Review article, in 1990. However, in 'Reengineering work: Don't automate, obliterate', - the origins of the reengineering concept can be traced back to the 1940s to the work of the Tavistock Institute in the UK where the 'social technical system approach' was applied to the British coal industry, Rigby (1993).

It is important to differentiate between process improvement, process redesign and process reengineering. Process improvement involves a minor degree of change with a corresponding low degree of risk together with a low expectation of improved results, McDonald (1995). Process redesign is the middle ground with a moderate degree of risk and consequently higher expectations of improvement. Process re-engineering is at the end of the spectrum with a high risk, high gain set of expectations.

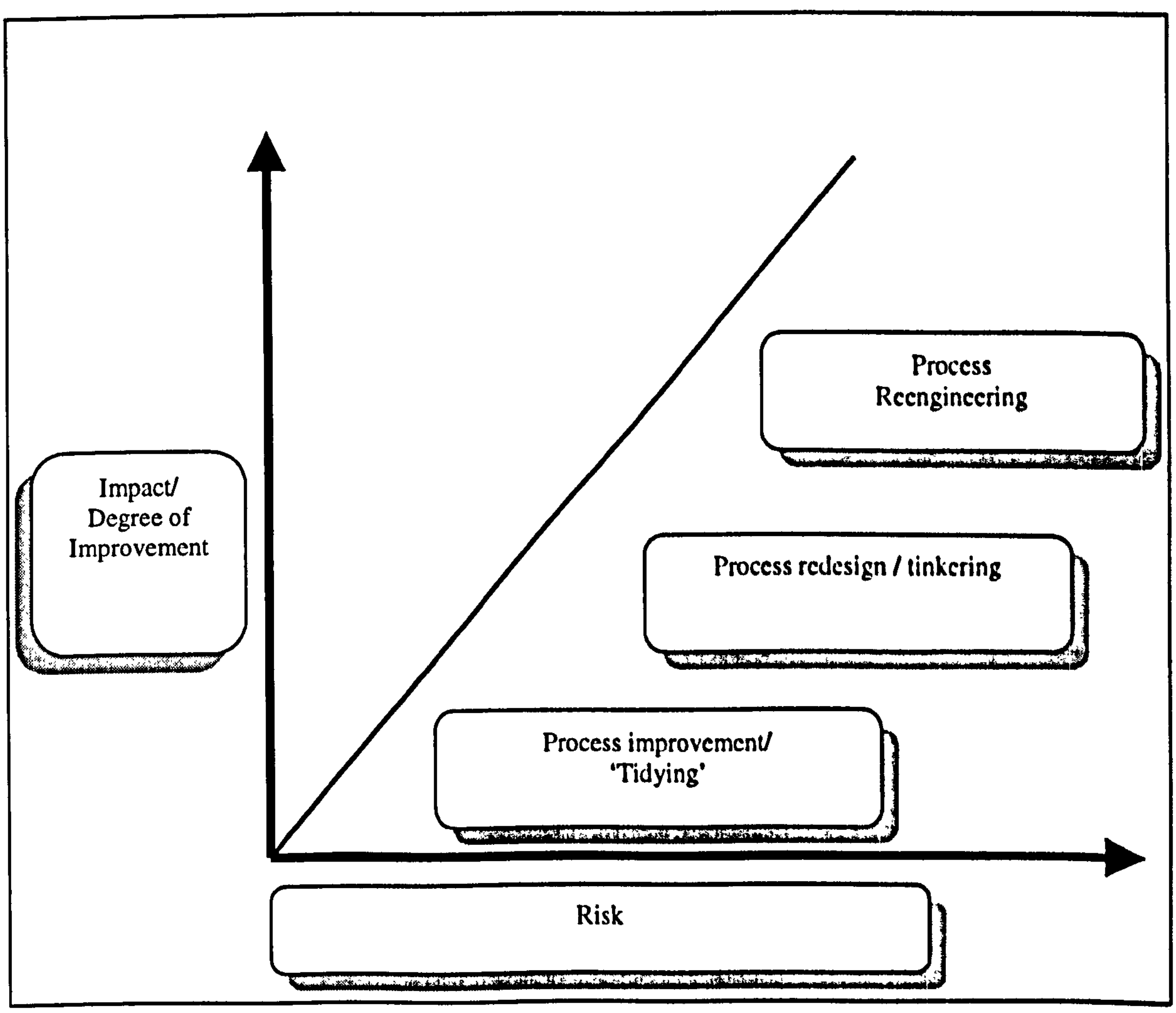

Figure 7.11: Differentiating between process improvement, process redesign, and process reengineering.

These three levels have alternatively been described as process tidying, process tinkering and process reengineering Mc George (1997). Process tidying is described as a method by which existing flows of people, information and materials are mapped and streamlined by identifying duplication. Process tinkering is described as a method by which organisation find short cuts in their processes or identifies more user-friendly ways of doing work. In general, process tinkering does not seek to change the overall process nor does it seek to move constraints, whereas process reengineering is the method by which physical or mental recipe-induced constraints are eliminated from the organisation and re-established in a way, which meets the goals of the organisation.

Reengineering involves a radical approach to change. Within the context of the construction industry – a radical approach in the construction would be to ask the questions such as 'how can processes be redesigned to eliminate waste?' rather than 'how can waste be minimised on site?

The human/ communication factor is reflected in the key success factors – as identified by Mohammed and Yates (1995) as prerequisites in implementing reengineering within the framework of the construction industry.

- Strong commitment by designers, consultants, and contractors to make a major shift in the way the existing workflow structure of design and construction work.
- An effective communication cycle must be established and maintained between major project participants as information exchange helps eliminate rework and consequently reduces time.
- Positive involvement of external as well as internal customers must be sought at the early project stages so that their requirement can be captured and implemented as input in the planning stage.
- Quality assurance technique must be developed and implemented across the various work elements of the construction process.
- Innovation should be encouraged in areas of planning, contracting, design and construction.
- New approaches should be investigated to improve construction output.

With the context of the construction industry, Hazlehurst (1995) identify potential time and cost savings, which would result from the application of reengineering. He summarised cost and timing saving benefit of reengineering are as follows:

- Reducing the extent of variation and design modification as a result of the systematic consideration of client requirement in a clearly and accurately developed design brief.
- Producing timely and more effective solutions while meeting client requirements by involving other engineering disciplines in the design phase.
- Achieving an agreed competitive overall construction time by negotiating better ways of construction with a contractor, who is selected on the basis of recognised past performance and financial stability
- Improving the quality of design by incorporating the contractor's input in the design phase. This is conducive to smoother site operations and fewer construction delays.
- Compressing overall construction time by considering constraints imposed by downstream operations such as building approvals, material availability and site conditions during the design phase.
- Improved project performance by enhancing the working relationship between project participants through the adoption of team building, partnering and strategic alliance concepts. These concepts minimise the possibility of construction delays caused by conflict of interests.
- Increasing the efficiency of construction performance by reducing or eliminating inherent time wastage in project material and information flows.

7.12.1 Conclusion on Re-engineering

The majority of the above listed areas of potential time saving can lead, directly or indirectly, to cost savings. In addition to the cost benefits attained due to the of the overall reduction in construction time, other main potential benefits have been summarised as follows, Fitzgerald and Murphy (1994).

- Development a design brief that accurately represents client requirements safeguards against additional costs caused by design modifications, omissions and associated delays.
- Selecting a design option through the application of the value management concept implies avoiding more costly options for the same functional needs (client get best value for money).
- Applying the concept of concurrent engineering and considering the downstream phase of the constructed facility helps the client select a design option with lower operating, maintenance and replacement cost (lifecycle costs).
- Appointing a contractor based upon both past performance and financial stability reinforces to a large degree the process of controlling financial and operational risks.
- Implementing the concept of team building between key project participants and partnering between the contractor and subcontractors enhance working relationships and reduces the number of costly conflicts and claims.
- Adopting proper quality measures into the design and construction processes ensure minimising the amount of rework for which the client ultimately pays.
- Employing an efficient material management system, such as the (just-in-time) approach, saves operating cost associated with material handling, storage, theft, and damage.

7.13 Quality Management

The cost of maintaining quality failure in buildings, coupled with client's demand for quality products, has prompted many construction organisations to implement quality management systems, Okereghe (1996). In the United Kingdom, quality assurance BS 5750, International Standard Organisation (ISO 9000 series), and Total Quality Management (TQM) are the main quality management systems in use.

The UK construction industry is characterised by increased waste, construction reworks, high litigation costs and growing arbitration costs. This has resulted in every increasing dissatisfaction by its clients and growing criticism from public. These concerns were echoed by the Emmerson review and the Banwell report of the mid 1960's and recently by the Latham report and the Egan report of the late 1990's.

Against this background 'quality' experts have proposed the implementation of total quality management (TQM) in the UK construction industry, giving that TQM has been successfully implemented in the United States and Japanese construction industries.

TQM is widely believed to be more robust than either BS5750 or ISO 9000, as it includes in its management system a continuous improvement process. TQM process encourages organisational cultural change in response to technological advancement. Unlike other quality management systems, TQM seeks to eliminate waste and provide, "just in time" services.

Accomplishment of acceptable levels of quality in the UK construction industry has been a problem from time. A great deal of time to time, money and other resource are wasted every year as a result of inefficient or non-existent quality management procedures in some areas, Okereghe (1996). The Building Research Establishment (BRE) 1975, Digest 176 reports on building failure patterns and implications, which summarise the results of the investigations by its Building Research Advisory Service. The digest showed that 11% of the buildings investigated had defects that could endanger lives; the functional performance of 66% was impaired; the remaining 23% had defects of a superficial nature, largely aesthetics. The research established that the main cause of defects found in the buildings were due to faulty design and these emanated from the wrong choice of building material or component for a given situation.

'Quality in New- Build Housing', February 1993, and 'Digest of Data for the Construction Industry' published by government statistical office in January 1994 showed that many of the faults found in the earlier studies are still occurring on a significant scale, despite all the attempts to eliminate them. As a result a number of approaches have been adopted by clients aimed at getting better value for their money for example, asking for evidence of a quality management procedure conforming to

BS 5750 as a pre-qualification requirement. One of the reasons for this demand is to reduce the inadequacies in construction projects as confirmed by BRE research.

Due to the increase in demand for quality construction, by clients, and international competition, most UK construction companies have decided to adopt the principles and practices of quality management systems e.g. International standardisation Organisation (ISO) 9000 series and quality assurance (QA). However, these quality management systems have their limitations with regard to application and general effectiveness, which is outside the immediate scope of this study.

7.13.1 Building Site and Quality Achievement

An attempt by the construction industry to achieve building of high quality so as to satisfy client's expectation has led to the introduction of various quality schemes. Some of these schemes are British Standard (BS 5750), National House Building Council (NHBC), Build-mark etc. Such schemes aim to control, more consistently, the levels of workmanship on site, the quality of materials and workmanship, components used, and the performance of the completed building by:

- Setting a minimum standard
- Assessing design (approval) and
- Monitoring construction processes

Despite all these attempts to achieve quality in construction, it seems that the construction industry is still falling short of customer's expectations. Building Research Establishment (BRE) Advisory Group Reported (Bentley M.J.C and Snook) that the quality achieved in theory cannot be achieved in practical, which included both commercial and residential. The report was based on a survey of several building sites, which included commercial and residential projects. The survey report blames the faults or short falls in project quality on the management practice of those involved in the project. Some of the deep concerns expressed by the report included the flowing:

1. Information flow

Poor briefing and communication of quality requirement by the client in most cases affects the level of quality obtained in the project. Most clients' architects are said to produce incomplete, inconsistent or wrongly detailed drawings and specifications lacking originality (i.e. not specific for the project at hand). The lateness of drawings diverts site agent's attention from pursuing quality to chasing the missing information. The lack of good communication between contractor's site agents and the specialist subcontractors is said to have an impact on the level of quality achieved in both mechanical and electrical services. A good project management structure with all the interface defined will solve this problem in proposal put forward by this study for the reengineering BIPV cladding system within a concurrent engineering frame work.

2. Co-ordination

Co-ordination of various participants was found to be very difficult, as design information is often incomplete before tender. Some designs were difficult to build either because of lack of the required skill or incompatibility of materials. This co-ordination problem makes it even more difficult to form site management structure. It was found in some sites that the inexperienced site agents do not know the interfaces in the project and as such do not know how to deal with them. The contractor was blame for the lack of co-ordination between subcontractors. Some site that were found to produce poor quality work have no team leader and faults were either reported too late or not reported at all. This problem is common in building sites. Some contractors think that because of the time constraint there is no need wasting time in forming a team or teams and appointing a team leader. This approach will adversely affect the co-ordination of the project activities.

3. Quality monitoring and control.

Some building sites have clerk of works representing the clients, whose responsibility it is to make sure that quality of work required is achieved. Clerk of works are often not given enough power to make the necessary corrections to avoid costly mistakes as they have to report to the architect for approval. The most successful sites are those that the clerk of works is given enough authority to make corrections when needed. Some site agents either lack experience or are too busy chasing missing information or organising project resources and therefore leave quality control to the site's clerk of work.

4. Management Style

The BRE report on the Management Style that achieved high quality in construction was consultative. This approach allowed for participation of all the parties involved in the construction process. The aim of the exercise was to encourage co-operation and good communication amongst participants. Among other things, this is widely believed to contributed to a high level of quality achievements in terms of effective project planning and control system, work in progress, feedback and feed-forward loops, health and safety, training, inspection and testing to mention a few.

5. Construction Profession and Quality Assurance

The purpose of quality management scheme i.e. quality assurance BS5750 is to reduce the number of customer complaints on the quality of building products. BS478 defined assurance as "all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality". The purpose of this definition is to assure customers and the society, of a consistent production of projects of high quality to satisfy their needs and requirements. The elements of quality management systems are identified as follows: Okereghe (1996)

1. **Quality Manual** - this contains a policy statement of commitment to quality with a full description of supporting text.
2. **Quality Procedure-** it gives a full description of how some activities that affect the level of product quality are to be executed and it also makes clear whose responsibility it is to ensure that the work is done perfectly.
3. **Quality Programme-** is a written description of quality system tailored for a specific contract making clear the organisation and responsibilities.
4. **Quality Plan-** this summaries quality requirements for the project and identifies the important contract documents, procedures and any specifications and inspections.
5. **Work Instruction-** is either a written or verbal instruction of how particular work is to be carried out.

7.13.2 ISO 9000 Series Quality Systems

The aim of ISO 9000 series (International Standards Organisation) is to enable users to have improved consistency, procession clarity and understanding, when applying the quality standards, ISO 9001, 9002 and 9003. Contractually, these series of ISO 9000 standards provides guidance for the following users:

- Suppliers and purchasers involved in contracts. The supplier here means the producer of a construction product, usually the contractor, while the purchaser is the client.
- Sub-contractors who provide raw materials to the suppliers, middle processing equivalent, services etc
- Auditors who assess and communicate the implementation of quality requirement

The ISO 9000 series provides guidelines for contract review. The standard provides guidelines for the control of contracts from the design stage to completion. A review of contract before starting work on site ensure that the contract meets the original requirements and are complete and without mistake. It is essential that contract reviews be carried out with the customer organisation.

The ISO 9000 series also promotes design control. This involves the valuation of the design work by an externally appointed officer who carries out value engineering to determine whether the design complies with building regulation, client requirement and quality standard. It also helps to reduce unnecessary cost and time delays. Design and development planning ensures that resources are well allocated to a project and that they will be available when required. ISO 9001 identifies the need to compare the actual of quality achievement to the desired quality requirement. The interfaces between the design team should be clearly identified and responsibility established. All design input to a project must be well documented and reviewed as and when required.

ISO 9002 provides guidelines on the control of a sub-contractor. It establishes that contractors should be given adequate authority to assess and control a sub-contractor's quality performance. Contractors should be given the responsibility to select sub-contractors. The evaluation of a sub-contractor should be documented.

The series also established the significance of all procedures of storage, verification maintenance, test, inspection, correction procedure and training. ISO 9003 includes in its procedure the need for auditing. It established that both internal and external auditors should be given the responsibility of assessing the level of quality achievement of the organisation.

7.13.3 Total Quality Management

Of all of the project management techniques reviewed in this chapter Total Quality Management (TQM) is the broadest and most wide-ranging. Rampsey and Roberts define TQM as 'A people focused' management system that aims at a continual increase in customer satisfaction at continually lower real cost. TQM is a total system approach (not a separate area or program), and an integral part of high level strategy. It works horizontally across function and departments, involving all employees, top to bottom, and extends backwards and forward to include the supply chain and customer chain'

It is widely believed that TQM is basically the integration of all functions and processes within construction organisations in order to achieve continuous improvement of the quality of buildings and associated services. The goal is client satisfaction', Vincent (1995), Asher (1992).

7.13.4 Conclusion on Quality Management

With the increasing demand by client for high quality construction product and the increased international competition, construction firms see the need for quality assurance. The incorporation of quality assurance into management system is to prove to the customer that a particular firm is capable of producing a product of high quality. A survey carried out as part of this study indicate most corporate clients now ask for a quality assurance certification as one of the conditions for a contract tender qualification. These demands have prompted all that may be involved in a construction project such as: the construction management consultants, contractors,

developers, subcontractors, etc, in acquiring a third-party certification of quality assurance.
In order for the UK construction industry to compete internationally, the UK department of trade and industry took the initiative by registering certification bodies who provide third-party certification to those firms involved in a construction project.

A study conducted by the in CIRIA (1996) has found that only 0.4% of some 10,000 professional firms involved in construction have registered with the DTI as quality assured firms. Hence the question, how successful is quality assurance on building sites?

7.14 Concurrent Engineering

Concurrent Engineering (CE) is a concept, which embodies several other methodologies such as multi-disciplinary teams, parallel scheduling of activities and cross-functional problem solving. It is a logical and structural framework, which facilitates up-front integration of the myriad of aspects of the product development process. These include: members of the product development team, technologies, tools knowledge, resources, experience, concepts, techniques, information and data Kamara et al (1997). A consideration of one or some of the different methodologies embodied in concurrent engineering, results in the various approaches in the many ways in which CE is defined, Harding and Popplewell (1996). However the general goals and the fundamental principles which describe the various aspects of the CE process, provide broad guidelines for its implementation.

7.14.1 Use of Concurrent Engineering

The use of concurrent engineering is becoming widespread in the manufacturing industry. This is in direct response to the need for faster development of high quality products at lower cost and the associated need for companies to remain competitive by becoming dynamic and lean. Syan (1994) suggested that the use of CE would soon become imperative for most companies in the near future. The popularity in the use of CE is, no doubt, a result of the associated benefits in adopting its principles. These include a reduction in product development time and 'time to market', overall cost saving, product that precisely match customers' needs, assured quality, low service cost throughout the life of the product and earlier break-even point, Madan (1993), Frank (1994). However, as a result of its growing use in industry, many definitions and interpretations of concurrent engineering have emerged and expectations vary as to its benefits. Prasad (1996) comments that, "expectations range from modest productivity improvement to complete push-button type automation, depending on the views expressed". Research and development activities in CE therefore tend to focus on the methodologies, technologies and tools for achieving 'concurrency'. This focus however, may disguise the fact that CE is basically a client oriented product development process, which seeks to fully satisfy the requirement of client. In this study, the importance of 'client requirements processing' and of building integrated photovoltaic systems, within a concurrent engineering framework, is emphasised. It could be argued that a rigorous up-front processing of these requirements provides a sound basis for fully satisfying the client and enhances concurrent life-cycle design and construction. Requirement processing facilitates early consideration, and subsequent management, of all life-cycle issues affecting a product by enabling compliance checking at every stage of the design and construction process. It also enables tractability of design decisions to explicit and implicit client requirements. Within the context of this study, 'client requirements processing' refers to the identification, structuring, analysis, rationalisation and translation of explicit and implicit client requirements into solution-neutral specification for design purposes.

7.14.2 Conclusion of Concurrent Engineering

According to Harding and Popplewell (1996), Prasad (1996), Evbuomvan (1995) the aims of concurrent engineering is to achieve the follow objectives:

- The reduction of product development time by providing organisational support for the implementation of business process changes that will facilitate concurrent working practices and Concurrent parallel processing wherever possible.
- Getting rid of waste by early or up-front consideration of all life-cycle issues affecting the product, which determines life cycle costing, provides for effective utilisation of resources, facilitates early problem discovery and early decision making.

- Reducing cost by continuous focus on the requirement of the customer that also satisfies the requirements of productivity, functionality and marketability.
- Increasing quality and value by continuous process improvement by incorporating lesson learned at every stage.
- Design-it-right-first-time by Information management to facilitate the flow of timely, relevant and accurate information within and between teams and across the stages of the product development process
- Simultaneously satisfying the requirement for functionality, produceability and marketability by continuous focus on the requirement of the customer and by continuous process improvement incorporating lesson learned.
- Fully satisfying the customer by the use of multi-disciplinary teams involving all the parties in the product development process and by integration of all the technologies and tools that are used to enable concurrent product development product and process design.

These principles describe the various aspects of the CE process and might also serve as guidelines for its implementation. They also provide a basis for defining the requirements for a concurrent engineering system.

The support for a concurrent engineering system is also required at the organisational, team and individual levels. At the organisational level, support involves the provision for interactions and information exchanges between different design teams, or between individual team members and other members of their particular discipline group. It also includes provision of information to support senior management in strategic decision making. At the team level the requirement are imposed by team-working methods. This includes promotion and maintenance of a common view of the team's objective and the encouragement of exchange of knowledge between team members. At the individual level, there must be sufficient flexibility to provide assistance for all members of the design team, irrespective of their role within the team. The diverse disciplines of all the individual members of the team should therefore be supported, Harding and Popplewell (1996). The satisfaction of these requirements at the three levels described in a support requirement matrix – as illustrated in Table 7.2.

Dimensions	Levels		
	Organisational	**Team**	**Individual**
Distribution	Move information between multiple sites.	Reduce remoteness and promote exchange of information between team members at different physical locations	Make information available to individuals
Heterogeneity	Support organisations to achieve different missions.	Support project teams to achieve different goals	Support individuals to perform different jobs
Autonomy	Discourage multiple individual stores of information.	Support team members to work as individuals, or as a group, and transitions between these two types of working	Support individual's preferred manner of working

Table 7.2: Support Requirement Matrix for Concurrent Engineering
Source: Harding and Popplewell (1996)

A supporting infrastructure is required to facilitate a concurrent engineering approach to product development. Such an infrastructure should therefore

- Identify, co-ordinate and communicate between the different perspectives involved in concurrent engineering
- Provide information on knowledge sources that are able to represent evolving expertise and product designs, that can be readily modified and that are easily accessible.
- Monitor the history of the decision process so as to enable future design procedure to capture best practice and to maintain accountability

- Control and configure the various system elements in a way that is transparent to the user and ensure system integration
- Provide an interactive, multimedia interface for the system users
- Provide integrating strategies for integration of the project team, the design evolution process, life-cycle activities and integration of textual and graphical project design data, Evbuomwan and Anumba (1996).

7.15 Project Planning and Control Systems

With the context of this study, a project is defined as a group of activities that have to be performed in a logical sequence to meet pre-set objectives as determined by the client requirements. While project management is defined as a way of making this happen, Gyoh (1993).

One of the main responsibilities of the project manager is to plan, track and control the project to meet pre-set objectives. To do this effectively the project manager requires accurate and timely information. This information should be supplied by the project's planning and control system, which outlines the scope of work and measures performance against the original plan.

The performance of a current BIPV project will form the estimating database for future projects. If this information is not collected by the planning and control system it may be lost forever. The Critical Path Method (CPM) of project management forces the managers to think about planning in a structured manner. The critical activities give a guide to the level of detail. The CPM representation offers a tool for discussion with other managers and project co-ordinators.

Resent studies in construction project management suggests that too much data but insufficient information may be generated on a regular basis if project reports are not structured and summaries. The Critical Path Method and the Management By Exception (MBE- a technique that focuses management attention on activities that go off course and need to be controlled to ensure activities meet their objectives) can be used to provide focused information. Timely response on project performance is also considered to be essential for effective project control. The planning and control system can adjust the feedback to address the needs of the project, Burke (1998).

According to Rory Burke, project planning and control system's database can be structured around the Work Breakdown Structure (WBS) for project reporting and around the Organisation Breakdown Structure (OBS) for corporate reporting. Without an integrated system the two reporting requirements would have to be processed separately. He agues that projects are best controlled by monitoring the progress trends of time, cost and performance. This information may not be available to the project manager if the trend parameters are derived from a number of function sources. Burke goes on to suggest that project progress reporting should be based on information supplied by the functional departments, the project manager cannot control the accuracy of information. The problem here is that it may only become obvious that the reporting is inaccurate towards the end of the project, when it becomes too late to bring the project back on course to meet its objectives. If the project manager is to he held as the single point of responsibility his authority should be commensurate with the position. Therefore when the project manager accepts this responsibility, he needs authority over the supply of project information.

To implement a fully integrated project management system will certainly increase the project's office budget. However, without an effective planning and control system the cost of mistakes due to lack of adequate control, may be even higher. The project manager is the project's single point of responsibility and the company's representative to the client. When holding meetings with the client the planning and control system will provide information about every aspect of the project.

7.15.1 Work Breakdown Structure (WBS)

It is widely accepted that the success of the whole planning and control function of a construction project depends on the project planner being able to define the projects full scope of work quickly and accurately. The Work Breakdown Structure (WBS) provides a tool to address this need, Gyoh (1993).

The WBS may be described as a hierarchical structure, which is designed to logically sub-divide all the work-elements of the project into a graphical presentation, this is similar in structure to an organisation chart, also called Organisation Breakdown Structure (OBS). This full scope of work for the project is placed at the top of the diagram, then sub-divided uniformly into smaller elements of work at each lower level of the breakdown. At the lower level of the WBS the elements of work is called a 'work package'.

The WBS can effectively increase the number of breakdown levels, with each project manager focusing only on his area of responsibility.

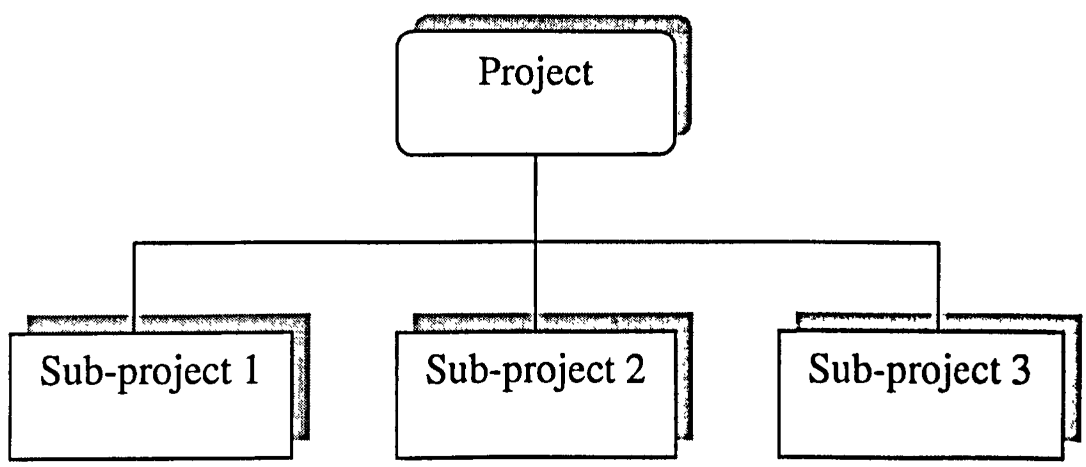

Figure 7.12: WBS / Subdivision by Sub-project.

Burke (1998) in his extensive study of project management planning and control (in the construction industry) argues that the construction project management CPM networks diagram and scheduled bar chart provided a highly structured and methodical approach to project planning. Burke, provides the following steps as a guideline, or check list to develop the baseline plan (within these steps are a number of iterative loops, which should be performed until an optimum solution is derived):

- Define the scope of work. Outline the method statement or build method, sequence of work and quality control plan.
- Define the project objectives with respect to quality, time, cost and resources.
- Generate a responsibility matrix linked to the Work Breakdown Structure (WBS) work package or activity. Develop the Organisation Breakdown Structure (OBS)

to identify the project's lines of communication through which instructions and information will flow.

- Develop the Work Breakdown Structure (WBS) to structure the scope of work and produce a complete list of activities.
- Estimate activity: time duration, cost expenditure, resource requirements and procurement lead times.
- Determine the relationships between activities and draw the network diagram
- Develop the project calendar or work pattern
- Perform the CPM time analysis (forward pass, backward pass) to establish an activity table consisting of Early Start, Early Finish, Late Start, Late Finish, Activity float and the Critical path.
- Draw the scheduled bar chart
- Analyse resources with respect to resources requirements, resource availability, resource lading and resource smoothing. If necessary re-analyse project time to produce a resource levelled scheduled bar chart. Integrate resources and time to produce a manpower histogram and 'S' curve to plan and control productivity.
- Generate project account and financial reports: budget per activity or WBS work package.

These functions together form the project 'baseline plan' as illustrated figure 7.13 During the tender phase these steps need to be performed quickly to produce a reasonably accurate outline of the project's requirements. The tender period, which is usually imposed by the client, may be considered as a small project in itself.

After the contract has been awarded, or authorised, a detailed baseline plan should be developed. It is often a contractual requirement that the detailed planning be prepared for approval within 3 to 6 weeks after the contract has been awarded.

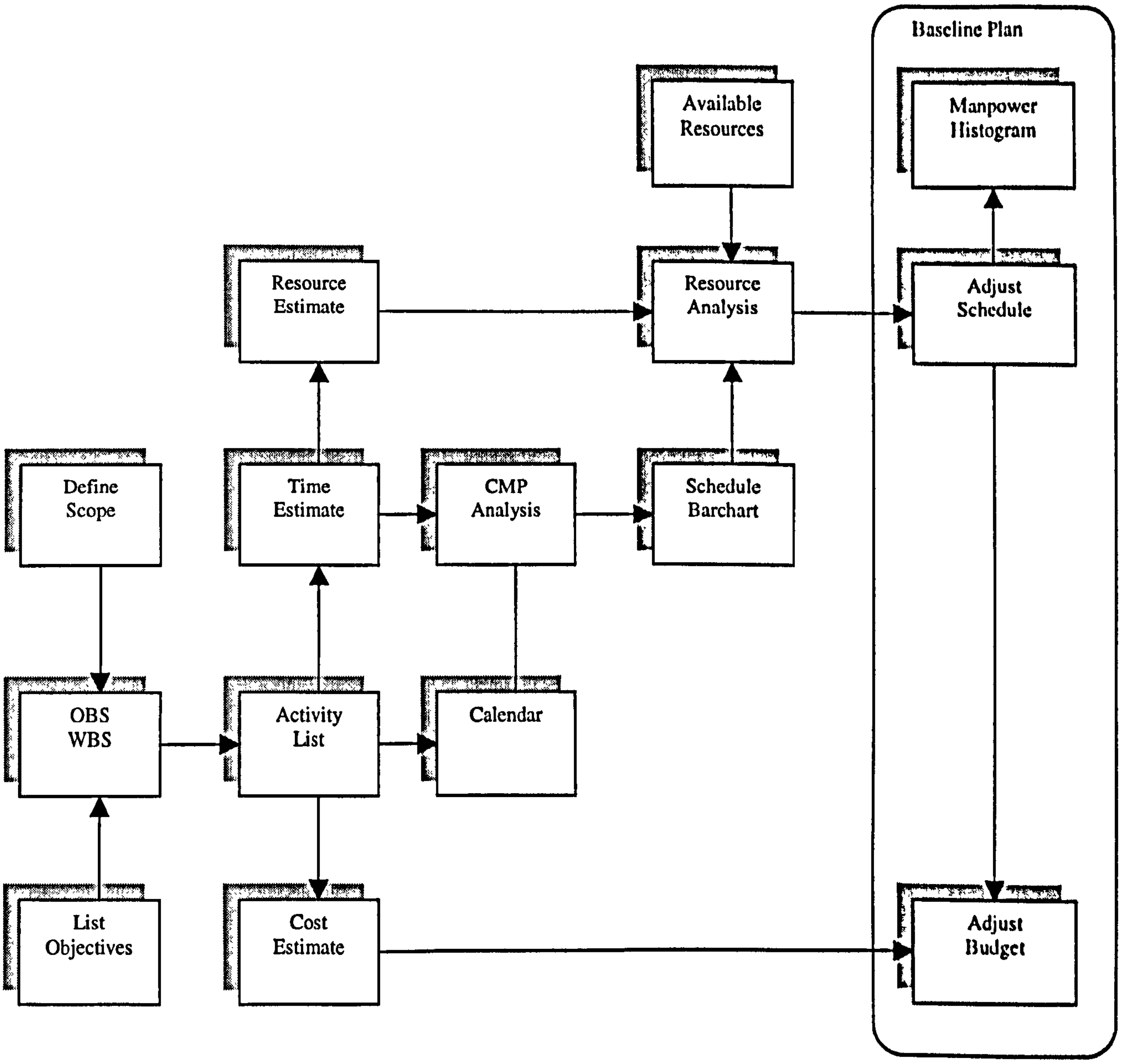

Figure 7.13: Schematic of project management, planning, monitoring and control.

According to Burke, it is advisable to complete substantially the planning before the execution of the project. He argues that this will allow the opportunity to plan and control the project before the project controls the planner(s). He suggests the execution phase be controlled through control of the scope of work through the following documents:

- Site communications
- Impact statements
- Non Conformance Report (NCR)
- Change request and Concessions
- Drawing revisions

- Modification and Variation Orders (VO)
- Extra to contract
- Specification and Configuration revisions.
- Issue instruction
- Decide on corrective action where necessary to keep the project on track

7.16 Conclusion on Project Planning and Control

As projects grow in size the complexity and the ability to plan and control them become an essential Project Management function. The second part of chapter 7 provides the underling principles and techniques of project planning and control as used in the industry and commercial environment in the UK. This chapter provides an overview of project management and control techniques. There is evidence to suggest that major construction projects within the UK construction industry are planned and controlled within the overall project structure, Gyoh (1993).

Base on the WBS and OBS, construction projects are broken down into activities, tasks and responsibility necessary to optimise installation of building element and construction of building edifies within a pre-defined time frame, cost and quality.
The WBS creates a framework for the definition of functions to be used to develop a 'functional definition model" (IDEF0). Whilst the OBS act as a key source of information used to establish function input, output, constraints and mechanisms. The OBS is also used to clearly identify and define the project line of communication through which instructions and information might flow throughout the project life cycle.
The first part of this chapter gives an overview of traditional and non-traditional methods of building procurement in the UK construction industry. This chapter also examines the strength, weaknesses, opportunities and treats of the major systems reviewed. This, is hoped, would form the basis on which recommendations will be made on the appropriateness of a particular procurement root for a particular BIPV installation. The second part of this chapter reviews project management systems being developed in terms of optimisation of cost, quality and project time delivery. These techniques, is hoped, would provide a bench mark for the optimisation of

design-management and planning of BIPV power systems with the UK construction industry. The next chapter reviews IDEF (Integrated Definition for Functional Modelling) methodology. This methodology forms the centrepiece for the functional determination, re-engineering process and the proposed innovative design-management and planning model for BPIV projects within the UK construction industry.