TOWARDS THE REFORMATION OF ABU DHABI TO BE AN ENVIRONMENTALLY SUSTAINABILE CITY

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DEDICATION

This thesis is dedicated to my mother Mrs. Mariam Ali and in the memory of my late father Mr. Hamdan Rashid

ABSTRACT

Abu Dhabi, the Capital City of United Arab Emirates, evolved through various stages since its formation. However, unlike other Golf cities, policy makers, planners, and designers sought to guide its growth and development towards a sustainable responsive city. Sustainability has become a central theme of policy and practice, and the design of the built environment is playing a major role towards this. Abu Dhabi developed the World renowned City of Masdar, as a model of sustainable development and design, and established the Estidama Rating System to enforce specific sustainable applications.

This aim of this study is to examine the cost-effectiveness of shifting the development of Abu Dhabi from a conventional approach to a sustainable one. In particular, it sought to determine whether vernacular design and architecture could help to address the quest for a sustainable city.

The methodology adopted for this research was based on quantitative and qualitative approaches. Three buildings were selected to determine the cost-effectiveness of the proposed sustainable solutions.

1. Masdar building was studied to represent what is classified as a sustainable prototype.
2. Educational Building of Abu Dhabi Police Academy, which has an open courtyard at the centre of the building, represents a vernacular design.
3. Administrative Building of Abu Dhabi Police Academy, which has a closed atrium in the centre without any skylight, represents a conventional building design.

The research involved an environmental investigation of power consumption, carbon dioxide emissions, indoor and outdoor temperature, indoor and outdoor relative humidity, and levels of indoor carbon dioxide. Monitors were installed in the three prototype buildings for a period of time, and the results of the readings were compared and analysed. In addition, a questionnaire survey was used to determine the impact of the three buildings on sustainable lifestyles and attitudes. Ninety users of the three buildings responded to the questionnaire. Their responses were also compared and analysed.

The results of the monitoring of the thermal performance, power consumption and carbon dioxide levels indoors confirmed that most indoor temperature readings were similar due to the use of air-conditioning in the three buildings. However, cooler temperatures were recorded in similar rates in the alleyways of Masdar and in the courtyard of the Police

Academy Educational building. In some cases, courtyard spaces in the Educational Building in the Police Academy recorded even lower temperatures than those of Masdar. These readings were much higher than those of the outdoor exposed temperature, whether in Masdar or in the Police Academy outdoor spaces. Considering that the cost per square meter of the Masdar prototype was almost the double of the other prototypes, these findings challenged the cost-effectiveness of the prevailing Masdar City approach. The results also highlighted the importance of the architectural heritage of Abu Dhabi to address the sustainability agenda, including its implications on planning and building regulations.

The findings of the questionnaire survey revealed that there were no significant differences between user responses of Masdar and the Police Academy buildings. These also questioned the cost effectiveness of the Masdar prototype. However, the results also confirmed that the lack of awareness of the sustainability agenda for the users of the three buildings, thus highlighting the wider implications on the sustainability agenda.

PREFACE

During my studies for the Bachelor of Architectural Engineering, I had two dreams: to do my postgraduate studies towards the PhD, and to translate my passion to Abu Dhabi by being a part of its future development.

I came to an understanding of environmental sustainability while studying the "Heritage Conservation" course. The strong link between vernacular buildings and sustainability turned my ambition toward participating in the sustainable development of Abu Dhabi.

As the Government established its initiatives toward sustainability, I decided to search best methods to shift the progress of the city into a sustainable one. Therefore I decided to submit my proposal for the PhD to investigate the cost-effectiveness of shifting the growth of Abu Dhabi from a conventional into an environmentally sustainable one.

I chose to take two prototypes; sustainable and conventional. To encounter all research elements I was allowed access to monitor power consumption, temperature levels, relative humidity and carbon dioxide levels in three buildings; Masdar Institute of Technology, the Educational Building and Administration building in the Police Academy in Abu Dhabi.

Due to some obstacles to obtaining the power consumption of Masdar during the first period of monitoring in September-October, 2010, a second period of monitoring was established in May 2011. Questionnaires were distributed, and were completed by both Masdar Institute students and AD Police Academy students.

Analysis of the monitoring results of the thermal performance, power consumption and carbon dioxide levels indoors was conducted. Links were established between the analysis results and the basic building cost of one square metre of each building over the period of 20 years. The questionnaire analysis established links between each building type and the occupant's impressions and awareness.

The results showed that it is cost-effective to shift the growth of Abu Dhabi toward a sustainable approach. They also pointed out the vital need to formulate special strategies towards making the sustainable shift.

One of the most important results of the study indicated the need to re-consider extracting techniques, expertise and building regulations from the architectural heritage of this area.

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Special thanks go to my personal assistant, Reem Jouma, for organizing and archiving the different pieces of study achieved in this thesis.

Finally, I am deeply indebted to my wife, who held extra additional burdens on my behalf with my children, when I was busy working on my research. Without the support of my wife, mother, brothers and sisters, I wouldn't have been able to do all the work needed for this research in addition to my official responsibilities. I am greatly in debt to all of them.

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Abbreviations

-	AC	Air-Conditioning
-	AED	Arab Emirate Dirham
-	ASHRAE	The American Society of Heating Refrigerating and Air-Conditioning Engineers.
-	BedZED	Beddington Zero Energy Development
-	BP	British Petroleum
-	BREEAM	Building Research Establishment For Environmental Assessment Method
-	CBD	Central Business District
-	CFCs	Chlorofluorocarbons
-	CH_4	Methane
-	CHP	Combined Heat And Power
-	CO2	Carbon Dioxide
-	FNC	Federal National Council
-	GDP	Gross Domestic Product
-	HFCs	Hydro fluorocarbons
-	HVAC	Heating, Ventilation, and Air-Conditioning
-	IAQ	Indoor Air Quality
-	ICT	Information and communication technology
-	IP	Innovative Practices
-	IRENA	International Renewable Energy Agency
-	KAU	Kerela Agricultural University
-	KWh	Kilowatt Hour
-	LEEDS	Leadership In Energy & Environmental Design
-	LRT	Light Rail Transit
-	NEF	National Energy Foundation
-	NIOSH	The National Institute for Occupational Safety and Health
-	NREL	National Renewable Energy Laboratory
-	OSHA	Occupational Safety and Health Administration
-	PA	Police Academy
-	PFCs	Per fluorinated compounds

-	PRT	private remote transport
-	RH	Relative Humidity
-	SBS	Sick Building Syndromes
-	TBL	Triple Bottom Line
-	TWh	Terawatt-Hour
-	UAE	United Arab Emirates
-	UNDP	United Nations Department Programme
-	UNESCO	United Nations Educational, Scientific and Cultural Organization
-	UNFCCC	United Nations Framework Convention on Climate Change
-	UPC	Urban Planning Council
-	UV	ultraviolet
-	VOCs	Volatile Organic Compounds
-	WHO	World Health Organization

CHAPTER ONE:

Introduction

1.1 Introduction

The Gulf region has witnessed a diversity of changes during the last few decades. The capital obtained from oil markets provided a tool to promote development in all aspects of life in addition to the building industry. What used to be known as small desert countries with limited resources turned into desert urban developments in most of the Gulf region areas.

Building has become one of the major occurrences in this area. The Emirate cities became models to others in the area. Dubai has developed through its marketing and has become known on a global level.

The United Arab Emirates (UAE) is situated at the core of an important and rapidly changing region. Over the past forty years, the UAE has experienced a period of rapid economic development and growth. During this period, it has assumed a complex regional leadership role as: 1) an economic and financial hub; 2) an innovative economy and technological frontrunner; 3) the commercial centre of the region and platform for accessing business opportunities. Over this time, the UAE has experienced very strong growth in economic activity, as measured by gross domestic product (GDP).

However, the government of Abu Dhabi is being more cautious in its steps toward development. The observer can easily figure that this caution relates to the determination to pursue excellency in urban development.

In an attempt not to make any regrettable mistakes in urban design, in addition to full state commitment to sustainability in all possible aspects and applications, the government of Abu Dhabi engaged in extensive research and studies before taking any decisions that would affect the future of the city.

Abu Dhabi, being the capital of the UAE, and the emirate behind the union of the country, has significant importance in the country.

1.2 Linked topics to the research

1.2.1 Urban identity

The importance of cultural identity stands clearly in the lives and thoughts of the people of Abu Dhabi. The need to draw an outline for the identity of the city is the main motivation behind this study. The author believes that an in-depth study of the possible cultural elements and tools on city planning and design levels in the light of sustainable applications can transform Abu Dhabi into an iconic sustainable city. Elements of city furniture can be utilized to enhance the cultural identity.

The government of Abu Dhabi dedicated huge financial allocations to initiate sustainable pioneer projects in order to establish standards for the Emirates, the region and global cities of similar environment.

1.2.2 Urban facilities

People are moving more than ever towards cities. As time passes, people shift from small villages and towns into major cities. More jobs with higher salaries are available in the cities than in the smaller towns. Due to the relatively more compact housing schemes in major cities, doing business is more cost-effective. Living in a city is more attractive to most of the people, as it is more convenient and has better global transport connections. Entertainment is easy and affordable. The list goes on about motivations behind the shift toward major cities.

The impact of cities on the globe is described as the “footprint”. This term indicates the size of land needed to provide resources to the city and to absorb its waste. A thorough study will be undertaken to examine this area of knowledge.

1.2.3 Environmental sustainability objective

Environmental sustainability problems might not currently be obvious in Abu Dhabi. However, the usual scenario of urban planning and building with hardly any response given to sustainability is alarming due to the overwhelming upcoming shortage of resources and pollution problems, unless precautions are taken as early as possible.

Decisions taken formerly, like replacing primary and secondary schools in certain areas with no previously designed routes to link to residential areas with their specific schools, are directly responsible for creating school bus trips all over the city. These trips, if eliminated, would give rise to many advantages, such as: less traffic on the roads (see Figure 1.1), less CO_2 emissions, less energy consumption, less depreciation of buses, cleaner air in the city, more healthy children as they exercise on their way walking to and from school.

Figure 1.1: Less traffic on the highway

The above case is an example of how potentially sustainable changes in urban planning and building regulations can lead not only to stopping the damage done globally, and can lead to a reversal of the damage already done.

A new phenomenon which has appeared and been exacerbated is the presence of greenhouse gases and global warming. Human civilization has, during the last few centuries, induced a huge shift in climate and general environmental conditions on the planet, which has resulted in significant negative effects on the sustainability of the global system. These defects cover the atmosphere, water, land and ecology of the planet. A thorough study will be undertaken in this research to investigate this area of knowledge.

1.2.4 Abu Dhabi government initiatives

The Masdar project, which is subsidized by the government, is designed to create a zero carbon city and be a role model for future urban developments. New (old) attitudes of designing narrow pedestrian roads and car-free people places will be tested in the urban fabric of the city. A further in depth-study will be done in this research using Masdar as a case-study.

Another example is Estidama. This is a governmental initiative established by Abu Dhabi Urban Council. Its main duty is to set a rating system of sustainable indicators similar to international rating systems such as LEEDS or BREEAM, yet it is designed for the specific hot humid or hot dry climate, in addition to specific environmental conditions such as the shortage of drinkable water.

Global environmental problems have been considered as an alarm to the nation to think, act and build in a sustainable way. Even though the country has a large oil reserve, it is obvious that this reserve will not be perpetuated and taking precautions by turning towards renewable energy resources should be done while financial resources are currently available. The study of sustainability and its application in this research is mainly derived from the previous factors.

1.2.5 The architectural heritage

The architectural heritage of this region, as in the rest of the world, provides a magnificent example of how the region's ancestors gave full consideration to building in total harmony with nature while considering thermal comfort. A thorough study will investigate the sustainable applications achieved in local vernacular buildings. The author believes that new generations of architects should apply the valuable lessons and sustainable techniques of the vernacular architecture in combination with modern emerging sustainable technology.

Sustainability might look like a fashion today. However, turning toward sustainable applications became a must after all the damage induced by human beings since the Industrial Revolution. The development of industry induced profound changes in sustainable global systems.

1.2.6 The historical roots of environmental sustainability problems

The historical roots of sustainability problems first appeared in the Industrial Revolution era. An extensive study of the cities and communities of that period will be conducted for the following two reasons:

a. To examine in depth the importance of state interference to make strategic, crucial and fundamental changes. Reforms to control housing and infrastructures of cities were introduced by governmental health bodies, not engineering bodies, as it directly affected people's health and living conditions.

b. It is very well known that global warming, environmental pollution and global energy shortages were all induced by the industrial and technological advances throughout the last couple of centuries, besides the global demographic explosion.

The revolution induced by the invention of farming and animal domestication in the Neolithic Age has been considered as the first revolution which affected the way people live in settled communities.

Mankind has gone through a series of changes of city development. However, the invention of expanded cities accompanied with urban living in suburbs originated in the Industrial Revolution period. Starting from the Renaissance (14th to 17th centuries), Europeans started to introduce sophisticated machinery especially in transportation, such as ships. Communications were made easy by the improvement of printing techniques. This fact served the Industrial Revolution as it facilitated the exchange of ideas and mechanisms. Britain was the first to make the change on a global level, however, Germany and America followed and expanded the Industrial Revolution. Industrial facilities are seriously in cities as shown in Figure 1.2.

Figure 1.2: Carbon emission
Source: Guardian, 2011

During the 18th century, the Industrial Revolution in Britain started to affect all ways of life, society, economy and the general image of Great Britain. In the next century the Industrial Revolution spread through regions of Europe and the United States. The Industrial Revolution is considered to be a revolution because it changed society both significantly and rapidly.

The social, political, and legal terms of organizing business in Britain were particularly advantageous to change. Property rights of all kinds of creativity were established in favour of investors and manufacturers. The stability of the rule of law in Britain and the clear tax systems led to generally safer earnings. Business people had better chances in Britain than the rest of Europe. This led to the settlement of the people with capital in the UK, as they were able to accumulate wealth accompanied with social prestige and power. These factors encouraged the transformation of business from Europe to Britain.

The achievements of this era were diverse and enormous. Some of these are listed below:

- Introduction of machinery led to speeding up the process of production, besides the possibility of manufacturing greater quantities.
- The mass production system represented a new stage of the production of unlimited quantities of products.
- The use of unlimited sources of power and energy.
- The production of raw iron, bar iron, and other metals changed the building industry, railways, and trains.
- Commerce became easier with improved train transportation leading to the spread of economic growth inside Britain.
- The flourishing marine industry brought Britain into concord with many parts of the world, in addition to opening new markets for industrial products worldwide.
- Iron was well suited for heavy machinery because of its strength and durability.
- Steam engines and machinery technology were also crucial inventions of this era.
- The production of glass and ceramics changed the design from limited-sized small openings into wider glass windows in buildings.
- Creative ways of organizing business through technical and scientific knowledge were applied to its practices on a large scale.
- The textile industry introduced advancements in British machinery which was sold to many parts of the world.

1.2.7 Sustainability & the 20th century

In the 20th century, improved, affordable and available public transport was an important factor in encouraging people to move from the city centres to the surrounding suburbs.

Germany and the US did gain advantages from Great Britain's experience. They went through a diversity of changes and development in order to lift their industry to compare with the level of industrialized Britain.

It was thought that if some of the vast diverse terrains of the United States of America were transformed into farms by industrial machinery, the country will be able to feed all people in America, and will start feeding the world. That is why the emphasis on manufacturing agricultural machinery was made a top priority in the United States. The steel industry and farming machinery helped revolutionize agriculture.

However, Germany followed another path by reinventing the manufacturing expertise of textiles, iron, steel production, steam engines and railways, industries which had flourished in Great Britain.

1.3 Research Aim

The aim of the research is to evaluate the cost-effectiveness of shifting the growth of Abu Dhabi from a conventional approach to city development and building design into an environmentally sustainable one.

1.4 Research Objectives

- Establish links between the current global sustainability problems and their root causes, originated during the Industrial revolution.

- Examine the local vernacular architecture and determine the most suitable, applicable and sustainable solutions that can be implemented in the building industry of this era.

- Ascertain the prevailing environmental conditions by examining human activities that have affected the global environment and led to the deterioration of the environment.

- Analyse the cost-effectiveness of the salient approaches in building design to achieve low impact buildings.

- Investigate the relationships between building design, building cost and the environmental impact.

- Revisit the prevailing sustainable solutions in the remaking of Abu Dhabi as a sustainable model coastal city.

1.5 The thesis structure

This section presents a summary of the structure of the thesis. The thesis is divided into eight chapters and each describes a concise synopsis of what it entails and sets out to contribute.

CHAPTER II

This Chapter investigates the roots of the current sustainability problems, which started since the Industrial Revolution during the Victorian Era in the United Kingdom. A diversity of phenomenon resulted from the immigration of labours from rural areas to cities, such as overcrowded residences, lack of ventilation, living in cellars, lack of public service, deteriorated health conditions and immorality. The Chapter explores policy reforms towards improving the housing and infrastructure of the Victorian cities.

CHAPTER III

This Chapter undertakes the broader impact of the current global environmental problems. The study is divided into two sections. The first section is dedicated to investigating the global demographic changes, high consumption patterns, modern food patterns, deforestation, transportation effect, bio-fuel and food scarcity and indoor air qualities. The second section covers the environmental defects induced by human activities such as; global warming, climate change, greenhouse gases, rising sea levels, species endangered with extinction, fresh water shortage, ecological degradation, ozone deletion and acid rain.

CHAPTER IV

The vernacular architecture of the region is thoroughly undertaken. The study reviews the multiple benefits of natural ventilation, natural lighting, courtyard effect on thermal performance and the occupant's physical and mental health, passive cooling and exploitation of solar energy.

CHAPTER V

This Chapter covers the history of Abu Dhabi formation. Resources were not easily available, yet, this gab was filled by interviewing specialists to have a wider perception of the many stages in which the city of Abu Dhabi evolved and sometimes changed dramatically. The study includes case-study projects initiated by the Government on sustainability bases.

CHAPTER VI

The methodology Chapter is built upon quantitative and qualitative approaches. It includes monitoring three prototypes buildings. The three buildings chosen are; Masdar Institute of Technology to represent the sustainable prototype, the Administrative Building in Abu Dhabi Police Academy to represent modern design strategy with an fully closed atrium in the middle with no skylight or natural ventilation, the third prototype is the Educational Building in the same site with open court in the middle of the building to represent a closer type of buildings to the vernacular concept. That will be achieved by measuring; Indoor and outdoor temperatures, Indoor and outdoor relative humidity, Indoor carbon dioxide and the power consumption leading to carbon dioxide emissions.

The Questionnaire is designed to investigate responses of students of the different prototypes about; the impact of a building on the sustainable awareness of the occupants, and the impact of people on the buildings they occupy.

CHAPTER VII

This chapter discusses and analyses the results. It is built upon choosing the three prototype buildings based upon their environmental impact.

Links is established between power consumption and the basic building cost (including building construction and maintenance) of one square metre of each building over the period of 20 years.

CHAPTER VIII

This Chapter undertakes a review of the initial research objectives followed by the results of the Field Study such as; indoor levels of carbon dioxide findings, thermal performance (indoor and outdoor temperature and relative humidity) findings, power monitoring findings. Questionnaires finding relative to sustainable awareness, student's impressions, student's heritage appreciation and student's awareness of their national responsibilities toward participating in the sustainable future of Abu Dhabi.

The Chapter will be concluded by the Contribution to Knowledge based on the findings of the importance of the vernacular techniques in design. The Chapter will also be concluded by proposed strategies.

CHAPTER-TWO

Defining the historical origins of sustainability

2.1 Introduction

This chapter seeks to shed light on the historical origins of sustainability. For this reason, it focuses on the study of the Victorian experience as it witnessed two major issues during the Industrial Revolution, namely public health problems and state interference to enforce changes.

1. Although the reasons behind the improper indoor environments of the past few decades are different from those which led to health problems in the Victorian Era, it is essential to understand the shared problem, and the steps taken to bring about an effective solution in both cases.
2. During the Industrial era, epidemics ravaged the working class, killing tens of thousands of people. This had a direct effect on the industrial workforce and economy. Hence, state legislations addressed the improvement of indoor and outdoor environments to promote health for occupants.

The overwhelming changes occurring in Victorian Britain resulted in the need for alterations to city planning and infrastructure, housing and living conditions. The implications of lessons learned during the Victorian experience on Abu Dhabi development are examined.

2.2 Implications of the industrial revolution on British way of life

The revolution induced by the invention of farming and animal domestication in the Neolithic Age has been considered as the first revolution to affect the way people live in settled communities (Bellwood, 2004). Mankind has lived through a series of changes in city development. However, the development of expanded cities accompanied with urban and suburban living, originated during the period of the Industrial Revolution.

During the Renaissance, which occurred between the fourteenth and seventeenth century, Europeans began to introduce sophisticated machinery, with marked improvements in transportation devices, such as ships. Communications were made easier by the improvement of printing techniques, an advancement which facilitated the exchange of ideas and mechanisms.

During the eightieth Century, the Industrial Revolution in Britain began to alter the general image of Great Britain in terms of society, economy and way of life. In the next century, these changes had spread through regions of Europe and the United States. It is considered to be a revolution because it changed society both significantly and rapidly (Hartwell, 1971).

The social, political, and legal terms whereby business in Britain was conducted were changed dramatically, and advantageously, by the Industrial Revolution. Property rights protecting creativity were established in favour of investors and manufacturers. The stability of the rule of law in Britain and the clear tax systems introduced led generally to safer earnings. Business people had better chances in Britain than in the rest of Europe. This led many people with capital to settle in Britain, where they were able to accumulate wealth accompanied with social prestige and power. These factors encouraged the transfer of business from Europe to Britain (Foster, 2004). The changes to industry, economy and society were so overwhelming that they affected all cities. Despite economic growth, the revolution was accompanied by a deterioration in living conditions, therefore, counterchanges were necessary to remedy this defect.

Nature provides the main resource for any materials for human utility. Sustainability entails meeting needs, while reducing demands on resources. Saving and minimising consumption are therefore sustainable approaches. It is essential to spread a new attitude of sensible spending, while taking into consideration the effect of any human activity on natural resources, in order to prevent their exhaustion.

Health represents a major cost on a global level; "*Total global expenditure for health is over US$ 4.1 trillion*" (World Health Organisation, 2010). Healthy people are more productive, contributing to a better economy, and at the same time they induce less public health cost. Therefore, it is essential to reduce health problems in order to maximise health savings by creating healthy built-environments.

2.2.1 The Industrial Revolution and Victorian demographic changes

The Industrial Revolution in England was getting underway by the second half of the century. The revolution brought gradual changes in economic, demographic and social structure. These changes were not sudden, but progressed at a quick and steady pace. The Industrial Revolution can be described as the great series of changes in technology, communications, financial and industrial organisation that began somewhere during the second half of the eighteenth century and continued well into the fifth and sixth decades of the nineteenth century.

"Or, to put it another way, from about the accession of George III in 1760- this marked the beginning of the canal era and the revolution in communications - to the 1850s when the great period of railway building was coming to its end and the 'coal and iron revolution' was almost complete." (Berry, 1974, p.9)

The Industrial Revolution had a number of effects on English society, one of the most serious and complicated ones being a previously inexperienced increase in the population density of major cities.

It was estimated that in the year 1750 the population of England and Wales was approximately 6-6.5 million. After that, the population density started to rise gradually. By the year 1801, population growth had reached about 50%, climbing up to 8,893,000. Table 2.1 shows that it then doubled within the next 50 years:

Year	England and Wales population	Percentage increase by decade
1801	8,892,000	-
1811	10,164,000	14.0
1821	12,000,000	18.1
1831	13,897,000	15.8
1841	15,914,000	14.3
1851	17,928,000	12.7

Table 2.1: Population increase in England and Wales 1801 –1851
Source: Burnett, 1978, p.4

There was an increasing demand for labourers in the industrial cities. It was clear that the more flourishing the industries, the more the need for workers. The steady availability of work, and tempting wages had encouraged the poor populace living around these cities to migrate inwards looking for work and better income. As people immediately around industrial cities were migrating towards the major cities, people from rural surrounding areas inhabited their original residences, and so the population shift towards industrial cities was a steady process (Burnett, J. 1978).

As a result of working in industries, labourers had more available cash than before. The increasing demand for accomodation raised both property prices and rents. The percentage of rent to wages rose steadily higher, putting more pressure on labourers to work and leading to a lower quality of living standards. Symptomatic of this trend was overcrowding. Sharing a residence, usually between two or more families, in a bid to reduce the residence costs, freed up more finance for other living costs, but at the same time reduced residence quality.

The steady increase in Victorian population density accompanied the growth of industry in major cities. *"Most of the more intransigent social problems of this period grew out of the ever increasing concentration of the population into towns.*" (Chadwick, E. 1842) Table 2.2 indicates the extremely rapid growth of the population in some cities.

Cities	Period	Population Growth (%)
Glasgow	1831-1841	37%
Manchester and Salford	1821-1831	47%
Bradford	1821-1831	78%
West Bromwich	1821-1831	60%
West Bromwich	1831-1841	70%
Dukinfield	1821-1831	Nearly trebled

Table 2.2: The rapid growth of some industrial cities during the first half of the nineteenth century
Source: Chadwick, 1842, p.4

While migration was the major cause of the rise in population density, it was not the sole cause- higher concentrations of population resulted from many interrelated factors. Increased financial stability encouraged higher birth rates. Longevity also gradually increased through the eighteenth century. In the nineteenth century, despite waves of death from epidemics like cholera, and a steady number of deaths caused by endemic diseases, the population's density continued to rise throughout this period.

The new arrivals in the city required food, shelter and other services, a pressure for which the cities were not prepared. A series of changes in the urban environment was just about to begin.

2.2.2 The onset of the problems faced by English industrial cities

The many interrelated changes that accompanied the Industrial Revolution were indeed revolutionary, as they touched every aspect of people's lives. It is not suitable, and seemingly impossible, to explore here the overwhelming adaptations and adoption of new attitudes which must have been necessary to cope with the Revolution and its many changes. Gradually, the living conditions of labourers deteriorated However, it was only many decades later, when the symptoms of the industrial cities had overflowed, that the extent of the social and health problems brought about by the Revolution became clear.

The working classes suffered from many problems in the early stages of the Industrial Revolution. Overcrowding and lack of public amenities provoked the development of other, related problems. Bullock states that *"Long before the housing reform movement there had of course been housing without drainage, water supply, ventilation or light; dwellings in which whole families were crowded into single rooms were nothing new in the 1840s and 1850s*" (Bullock, 1985, p.3).

There was a period of about half a century between the commencement of the Industrial Revolution, and the appearance of the uncontrollable health and living situations in the industrial cities. During the eighteenth century, these cities gradually found themselves loaded with the pressure of a population explosion. Public services and amenities, which needed to be improved and expanded, were either ignored or no serious efforts were made for their improvement. The standards of public amenities were deteriorating quickly, induced by the disproportional increase of the population and the size of these cities. Neither the government nor the public appeared to notice the deteriorating living conditions of what was then called the working class.

Poorly managed public amenities, such as clean water supply, drainage, street paving and rubbish removal, added to the health problems in overcrowded residences. The accumulation of these problems, side by side with steady and uninterrupted migration, further increased the complexity of the situation. Ignorance of the possible results of such an atmosphere was reflected in a general ability to ignore the health situation. It was only when the epidemics devastated the population during the first half of the nineteenth century, that the nation truly woke up to the problem.

The unplanned increase in population densities had created urgent need of more residences, and more services including health and public amenities. It was thought that it was neither possible nor affordable for the then government to fulfill any of these urgent needs. The interrelationship between these factors created, in its turn, a new range of social and health problems, thereby exacerbating the situation. It took the officials a few decades before they took practical steps to search for the reasons behind the deteriorating health and living conditions in the early nineteenth century.

Sanitary arrangements in the eighteenth century village or small town had always been simple and crude. They were not thought unsatisfactory as long as the number of inhabitants remained small (Hopkins, E. 1979). A comparison of early nineteenth century housing with eighteenth century housing for the poor does not reveal an obvious difference in details like the number and size of rooms, or the lack of amenities such as piped water and water closets. The difference lay in the sheer scale of the building operations and the cramming together of very large numbers of houses.

2.2.2.1 Quality and quantity demand in housing

Health in England had gone through periods of grim crises, including many thousands of deaths throughout the first half of the eighteenth century. When the bubonic plague was controlled in the seventeenth century, it was thought to be the end of the age of epidemics. But the Industrial Revolution brought with it new health outcomes that had direct effects on life within the community. The changes touched most of the people, across social levels. "*Over half a million were dying every year from preventable causes arising mainly from living conditions*" (Wright, 1957, p.144).

Ignorance of the effects of explosive growth during the Industrial Revolution had put the Victorian government in a difficult situation. By the first few decades of the nineteenth century, complications had accumulated and were difficult to overcome. The higher income of labourers encouraged early marriages and more children at an early age. The growing numbers of families created an urgent need for dwellings. It was thought that there was neither the ability nor the money to provide dwellings for all the new urban inhabitants of the major cities.

"But the most urgent housing problem of the first half of the nineteenth century was that, because of the phenomenally rapid growth of population, the stock of accommodation had to be utilized and expanded at a rate which constantly fell short of need, and which produced many ill-effects on the comfort and health of the inhabitants." (Burnett, 1978, p.1)

2.2.2.2 Lack of public services

Many factors led to the lack of public services in industrial cities. Table 2.3 demonstrates the state of the streets in Manchester. A special Board of Health carried out the inquiry in 1832. This table is taken as an example of the deteriorated environment of neighbourhoods and a lack of public amenities, especially in the housing of the poor populace.

Districts	Streets Inspected	Streets Unpaved	Streets in part paved	Streets ill Ventilated	Streets containing heaps of refuse, stagnant pools, ordure& c.
1	114	63	13	7	64
2	180	93	7	23	92
3	49	2	2	12	28
4	66	37	10	12	52
5	30	2	5	5	12
6	2	1	0	1	2
7	53	13	5	12	17
8	16	2	1	2	7
9	48	0	0	9	20
10	29	19	0	10	23
11	0	0	0	0	0
12	12	0	1	1	4
13	55	3	9	10	23
14	33	12	0	8	8
Total	**687**	**248**	**53**	**112**	**352**

Table 2.3: Public services in Manchester, 1832
Source: Gaskell, et al., 1833, p.135

The table shows that more than half of the streets inspected were dirty and seriously contaminated, with almost half of the sample of streets remaining unpaved or partially paved. Mortimore points out that drainage would also have presented a major problem; "*Drains or a water supply were rarely provided, since it was uneconomic to extend pipes* *along dead-end roads, nor were such streets adopted as public highways"* (Mortimore. et al.,1952, qtd. in Dennis, 1984, p.153).

Gavin, H. (1847) suggested tracking down the fever districts in London and comparing them with the map of the Commissioners of Sewers. He predicted that typhus locations would be the same of those of un-drained streets, and that, wherever drainage was applied, typhus would tend to disappear. The presence of efficient drainage raises health levels, and therefore raises the longevity of inhabitants. Table 2.4 shows the influence of drainage in St. Margaret, Leicester in 1846 on the inhabitants' longevity.

Inhabitants living in	***Average longevity***
In the drained streets (not 100% sound)	*23.5 years*
In the partially drained streets	*17.5 years*
In the streets entirely undrained	*13.5 years*
The whole inhabitants of 22,000	*18 years*

Table 2.4: Relationship between drainage and longevity in some streets, 1846
Source: Gavin, 1847, pp. 34-35

Table 2.4 demonstrates that the average longevity of the population living in the drained streets was slightly less than double that of the entirely un-drained streets.

The lack of paving and street cleaning had made the situation even worse. In addition, many poor people had animals living with them, in order to extend their income through raising food. This made areas even filthier. Diseases brought about by a complete lack of water, or by unhygienic water supplies were definite outcomes of such environments. Most of the dwellings of the poorer classes were either without water, or had a very scanty supply of unfiltered water. In London in the 1840s, of 270,000 houses, there were upwards of 70,000 houses without any supply of water (Gavin, 1847).

The lack of rubbish removal services was directly reflected by the squalor, filth and dirt of both houses and streets. Accommodation would also have lacked comfort and convenience, being cold, damp and filthy.

"Adverting to the local reports they received, the Commissioners state—"*Those reports have awakened in us the sad conviction that many localities are quite devoid of even the most simple ideas on public health; the inhabitants live surrounded by marshes, drains, stagnant pools, manure heaps, without having the slightest idea of the dangers they are* *incurring. Indeed, many of them blindly speculate in these heaps of infection, increasing the manure, which is to enrich their fields at the expense of their health, and often of their lives."* (Chadwick, 1842, p 217)

An improvement in the situation required effort to persuade both those in charge and the public of the necessity of re-evaluating the importance of public amenities. Changes had to be brought about through a holistic approach. Doctors, Poor Law Commissioners, report officers, and many others helped in alerting the nation to the overwhelming health and social dangers induced by a correlation of many factors, but mainly by crowded residences and lack of public services.

By 1893, a great deal of attention was being paid to the details of sanitation, the purity of water supply, the disposal of waste products, and so on (Fussell, G.E. 1949).

"Housing could not be improved without more water and better drains… Open space, natural light, fresh air, the rapid dispersal of 'vitiated' air, the need for abundant and continuous water supplies and for waterborne drainage systems in newly designed sewers were all canvassed as necessary measures; yet it took many years to convince the doubting public that these were pressing social problems which must be solved by the community itself." (Tarn, 1971, p.2)

It was a recognised that the extension of the infrastructure of cities, including appropriate public amenities, would be a real burden to execute. Therefore, this objective needed to be supported by the conviction of the community and the government in order to be achieved.

2.2.2.3 Overcrowding and lack of ventilation

As described previously, the phenomenal growth of the population had put pressure on housing, which tended to result in overcrowding. The choices readily available to the poor were 'lodging houses', which appeared as ordinary houses from the outside but were plagued by dirt and lack of ventilation inside. Homeless people had no choice but to accept living with others in residences. Overcrowding, regarded as a better solution than homelessness, was in fact a major factor in the deterioration of health. Those who spent most time in these overcrowded conditions were most affected. "*Women, because they live more at home, are more frequently affected by consumption than men. In 1839, out of 33 milliners who died in London, 28 died of consumption"* (Gavin, 1847, p.9).

A comparison of the general living environments of country districts and those of the towns, shows that better living conditions were associated with the lower densities available in country districts. Mortality levels also differed as shown in Table 2.5.

Inhabitants per square mile	Annual death rate	Death rate percentage
199 Inhabitants (in country districts)	1 in 52	1.92%
5,108 Inhabitants (worst town districts)	1 in 37	2.70%

Table 2.5: Inhabitant density per square mile and death rates
Source: Gavin, 1847, p.4

Figure 2.1: Rural interior, 1864
Source: Burnett, 1978, p 8.

People had no choice but to accept overcrowding. They had to live close enough to their places of work to access them on foot or by ferry. There was no other means of travel for working men until the 1860s (Best, 1971).

Dirt, filth and undesirable living conditions were the usual state of houses with single poor families. The common case, however, was that three or four families were living in one

house, or even in one bedroom. Health problems were compounde in such overcrowded residences. Such an atmosphere was ideal for the spread of epidemics as shown in Figure 2.1.

2.2.2.4 Back-to-back houses

The urgent need for urban housing, especially at the end of the eighteenth century, had led to the emergence of attached housing, or back-to-back housing, as it was then called. This new approach increased density and allowed landowners to increase profits. This kind of housing impeded access to adequate light and ventilation. There were more difficulties in getting rid of dirt and less or no access to sunshine. These residences provided a dark, humid and squalid atmosphere ideal for the rapid spread of vermin and contagious diseases. Building back-to-back houses reduced the possibilities of having sufficient openings and windows. In these houses, windows were situated on the one exterior wall of the house facing the alley. The alleys were narrow, dark and filled with stagnant pools, filth and manure- a particularly unhealthy atmosphere. See Figure 2.2.

Windows were usually small and built to a ratio of one per room. Broken glass or blocked locks were frequent occurrences, resulting from lack of maintenance. Windows, if they existed, were usually kept closed because of cold and damp weather, and the unbearable smells of the alleys. In addition, the number of people in overcrowded put pressure on the available air, creating a continuous need for high rates of air circulation. The residences of poor and working class Mid-Victorians were therefore inappropriate for human living conditions.

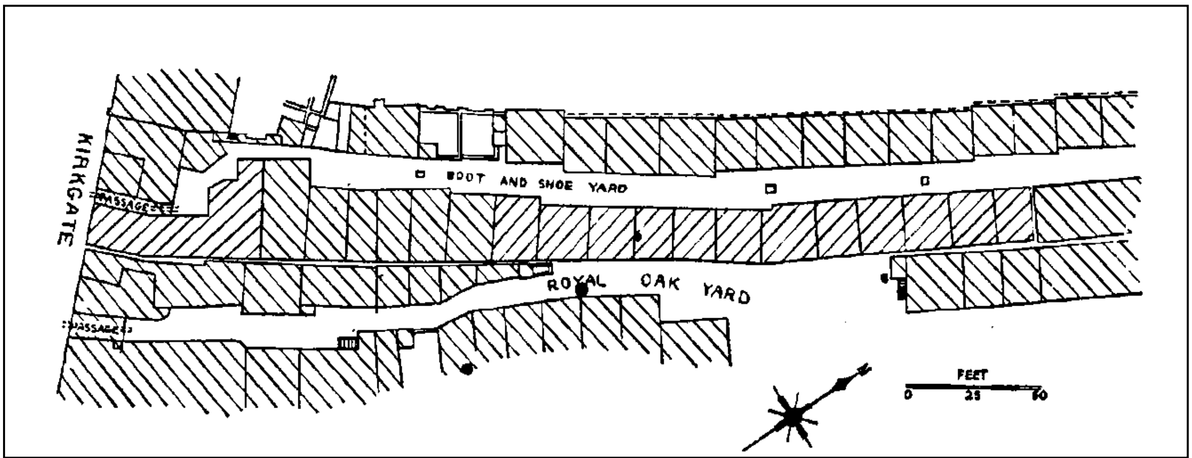

Figure 2.2: Back-to-back houses
Source: Chapman, et al., 1971, p.99

Both Hopkins and Wright outline the cramped and unhealthy conditions prevalent in back-to-back housing:

"Another and much more common way of building economically was to cram as many houses as possible on the land available-hence the long lines of terraced houses in narrow streets still standing in some Lancashire mill towns today; and sometimes 'in-filling' took place-that is, a row of houses would be squeezed in across the back gardens of existing houses. One notorious kind of house was the back-to-back, a house with only one room up and one room down, built back to back with another, usually in terraces. Leeds in particular had thousands of these houses, but they were common elsewhere as well.

Houses often faced each other across narrow spaces called courts, while there were numerous passage-ways or alleys between blocks of houses, and these were sometimes built over at first floor level so as to form tunnels. These covered alleys might be the only way into an otherwise completely closed court." (Hopkins, 1979, p 19)

"The old London rookery of St. Giles had 95 small houses containing 2,850 people, and was flooded by its own sewage… The new jerry-built working-class houses, though they had no cellars to house rats or humans, were built in double rows back-to-back, without ventilation or drainage, their windows cut to a minimum number to avoid the Window Tax. They formed squalid courts, with a pump at one end and a privy at the other to serve perhaps twenty dwellings." (Wright, 1957, pp. 144-145)

The definition of back-to-back housing includes only residences attached completely by three or sometimes two sides to other residences, sharing mostly one, or possibly two, facades each facing an alley. In effect, the overcrowded housing of the working classes was deprived of light, ventilation, privacy, and cleaning. The back-to-back house was finally banned in 1909 (Beresford, qtd. in Dennis, 1984, p.153). More suitable forms of housing became viable after the Clean Air Acts, which saw the introduction of adequate internal hygiene facilities, street cleaning, etc. Not every residence attached to others was deemed as back-to-back housing. Some houses were built attached with others back-to-back but, being situated on a wide street, they provided an ample amount of light, air and sunshine, with reasonable land area. Such houses were not included in the ban of back-to-back houses.

2.2.2.5 Living in Cellars

Cellar dwellings became common in the late eighteenth century, and the early decades of the nineteenth century. These accomodations were even more damagingl to health than the back-to-back dwellings (Report of the conditions of the Hand-loom Weavers (1841), qtd. in Chadwick, 1842, p.6).

Living in cellars was one of the symptoms of the serious lack of housing. Irish migrants were the first to live in cellars in the rapidly expanding cities.

"Almost always, cellar dwellings were described as dark, damp and airless, the abodes of the most feckless, improvident and intemperate sections of the population, and the sources

of much of the dirt and disease which sullied the industrial towns. Very often they are equated with the period of rapid Irish immigration from the 1820s to the 1840s, with the implication that cellars had not been used for habitation by the English worker until his standard of living was forced down by alien influence. Undoubtedly, housing and sanitary horrors abounded in some of the cellars, and rightly attracted the reformers' indignation." (Burnett, 1978, p.58)

The living conditions in cellars were extremely inappropriate and unhealthy, accompanied by the lack of any sort of convenience. It is obvious that the massive scale of problems experience by residences on the ground were exacerbated for those living in cellars. In Manchester in 1833, it was stated that poor Irish migrants used to keep a pig in their residences alongside the family once they could afford to buy one (Gaskell, 1833). With no drainage or pavement, occasionally flooded and invaded by vermin, a particularly unhealthy living environment was created. "*There are upwards of 8,000 inhabited cellars in Liverpool, and I estimate their occupants at from 35,000 to 40,000"* (Local Reps. qtd. in Chadwick, 1842, p.105).

Knowledge of the problem by no means meant that government or community were able to put an end to inhabited cellars at that stage. The working classes were already accumulated in overcrowded houses above ground, and priority was therefore given to first solving the problems of housing and public amenities.

2.2.2.6 Deteriorated health conditions

The harmful effects of dirt and lack of ventilation were highlighted before the beginning of the nineteenth century. Medical staff had by then connected the presence of diseases to unhealthy living conditions, especially within the working class. The reports of medical officers in major cities frequently described housing and living conditions. These observations were made as a by-product of work detailing health conditions and possible applications of medical prevention.

Mortality rates, when they could be obtained, demonstrated the health conditions of major industrial cities. In general, a steady increase in the death rate was experienced throughout the first three quarters of the nineteenth century. Following that, an unbroken decline in death numbers was observed from the 1870s onward (Best, 1971).

Like mortality rates, the rates of occurrence of preventable diseases differed between towns and the country, Table 2.6 shows that the environment of the country was healthier than that of towns. It also shows that the worst of the diseases were scrofulous, tuberculosis (then called consumption), epidemics and contagious diseases. The mortality rate attributed to these diseases in towns amounted to 10,600 per million, while all other diseases accounted for a total of 7,650 deaths per million.

Diseases	Mortality per 1 Million in the Country	Mortality per 1 Million in Towns
Small-pox	500	1000
Measles	350	900
Scarlet fever	500	1000
Typhus	1000	1250
Epidemics and contagious diseases	3400	6000
Infants' diseases	1300	3500
Scrofulous diseases & consumption	3800	4600

Table 2.6: A comparison of mortality induced by diseases in towns and the country
Source: Gavin, 1847, p.60

2.2.2.7 Immorality

The correlation between good housing and good manners, and vice versa, has always existed. Caring, hardworking people might have better chances of gaining better housing. The convenience of a good indoor living environment also improves people's abilities and might make them better workers. "As the homes, so the people" (Lees, et al., 1866, p.1). "As better houses would make better men, so better men would make better houses" (ibid., p.112).

A loss of morality accompanied the symptoms of sickness experienced by most of poor society in the major industrial cities. The poverty of the labourers had resulted in higher levels of overcrowding, making privacy impossible in the housing of the working classes. It became quite usual for families, then, to use one room for both living and sleeping, with parents sharing a bedroom with their children in one bedroom, even if they had adult sons and daughters.

It was often not possible to provide a bed for each person. Sleeping together with no private beds made it very difficult to obtain appropriate separation between individuals.

"*Family life for the worker is almost impossible under the existing social system. All he had is a dirty and comfortless hovel which is barely adequate as sleeping quarters. It is badly furnished and unheated. Often the roof leaks and there is no comfort to be found in the stifling atmosphere of an overcrowded room. The various members of the family only see each other in the mornings and evenings, because the husband is away at his work all day long. Perhaps his wife and the older children also go out to work and they may be in different factories."* (Engels, et al. 1971, p.145)

These situations resulted in moral problems within single families or between different families living together. One health officer reported that in one house, the children did not have names, only nicknames, and did not know who their parents were.

"It is to be regretted that the coincidence of pestilence and moral disorder is not confined to one part of the island, nor to any one race of the population. The over-crowding and the removal of what may be termed the architectural barriers or protections of decency and propriety and the causes of physical deterioration in connexion(sic) with the moral deterioration, are also fearfully manifest in the districts in England, which, at the time to which the evidence refers, were in a state of prosperity." (Chadwick, 1842, pp. 199-200)

Deterioration of morality can bring with it damages to health, productivity and well-being. As good manners raise the self-esteem and confidence of the individual, these attributes can contribute to the potential and stability of both family and society.

Immorality was not exclusive to the overcrowded residences, but was also to be found in the lodging-houses. These also suffered from the unhealthy living conditions of dirt, darkness and inappropriate ventilation, but what was described as being of greater concern was the indecency, prostitution, immorality and crime. Even children were included in these experiences. Best describes these circumstances: *"Some of the lodging houses present no appearance differing from that of ordinary houses; except, perhaps, that their exterior is dirtier. ...Some… are of the worst class of low brothels, and some may even be described as brothels for children."* (Best, 1971, p.28).

2.3 Chadwick and the "sanitary idea"

Edwin Chadwick was a doctor in the mid-Victorian era. He was secretary to the "Poor Law Commission" at the time when he presented his *Report On The Sanitary Condition Of The*

Labouring Population Of Great Britain on the 9th of July, 1842 to the House of Lords. Although Chadwick was responsible for the entire compilation of the book, the whole work of the report cannot be ascribed to Chadwick for two reasons. Three other doctors, also "Poor Law Commissioners", worked on the material alongside Chadwick. Their impression of the final production of the report was that it was too radical, and they were therefore not ready to submit it. It was decided later that Chadwick should submit the report under his name only (Chadwick, 1842). The report was of lasting importance: "*It was an epoch-making document, based on a questionnaire sent to all the local Boards of Guardians, upon evidence of three eminent doctors, Kay, Arnott and Southwood Smith, and upon Chadwick's own visits to certain large towns."* (Tarn, 1971, p.2).

Other contributors to the report were groups of investigators who enriched the book with their detailed local reports about living conditions of the poor in different urban areas in major cities. Their investigations, which were being conducted long before Chadwick took charge of the report, covered housing, health, public services, morals, and other social factors. The investigations were presented in the report as quotations from those who had directly witnessed the deteriorated living conditions of the poor populace.

Chadwick, being a doctor, realised the depth of the correlation between health and housing. Most of the investigations provided descriptions of a dwelling as well as a detailed view of each of its inappropriate aspects. Most of the reports mentioned many such defects. Much work was done to explore each aspect in detail, in order to understand the depth of housing problems and their serious effects on health deterioration. These aspects are listed below:

- Overcrowding
- Attached housing
- Living in cellars
- Defective ventilation
- Defective lighting
- Dampness
- Lack of maintenance
- Unpaved floors
- Lack of cleansing
- Raising animals indoors for profit
- Vermin

- Lack of heating

These residences, being filthy and unmaintained, were invaded by all sorts of vermin. Being inhabited by the poor, there was no possibility of heating these dwellings. However, there were no complaints regarding the lack of heating, as this was a luxury expected only in the houses of the rich. Aside from the low expectations associated with poverty, lack of heating might be related partly to dependence on warmth from densely packed occupants together with the use of candles and lamps, which give heat as well as light.

2.4 Public services

The following lists the problems found with public services in Victorian times:

- Lack of clean water supply
- Defective drainage
- Lack of rubbish removal
- Lack of street cleansing
- And unpaved streets and alleys

The lack of these public services was widely known. Chadwick was not the first to mention their absence or emphasise its negative effects on health and living conditions, for the public in general, and labourers especially. The importance of Chadwick's work in this field was established by two factors.

- The first was the issue of numerous reports which stated the condition of major cities as a result of the lack of public services. They presented in detail the dangerous effects induced by a lack of amenities.
- The lack of these services and its interrelation with concurrent defective housing conditions drew a clear picture of an unacceptably squalid environment and atmosphere. The report gave evidence on how the interaction between these two factors exacerbated the situation.

The lack of a water supply made the matter of cleansing too difficult for individuals who wished to be clean. Diseases and epidemics, which invaded all major cities, were difficult to control due to the lack of cleansing and hygiene associated a water shortage. Defective drainage and unpaved streets in cities were determinant factors in making houses and streets wet, muddy, filthy and unhygienic. The presence of filthy pools was normal in the neighbourhoods of the poor and exacerbated ill health in all cities.

"There, however, as in most cases, the internal economy of the houses were primarily affected by the defective internal and surrounding drainage that produced the damp and wet, and thence the dirt against which the inmates had ceased to contend. On inquiry of the male labourers in the district, it appeared that almost every third man was subjected to rheumatism; and with them, it was evident that the prevalence of damp and marsh miasma from the want of drainage, if it did not necessitate, formed a strong temptation to, the use of ardent spirits. With them as with the females, the wretched condition of the tenement formed a strong barrier against personal cleanliness and the use of decent clothes." (Chadwick, 1842, p.196)

A lack of services such as rubbish removal and street cleaning had exacerbated all other problems, causing the accumulation of filth, manure and dead animal bodies. Chadwick spoke of the far reaching effects of street cleaning, saying "*The sanitary effects of road cleansing, to which house drainage and road drainage is auxiliary, it appears is not confined to the streets in towns and the roads in villages, but extends over the roads at a distance from habitations on which there is traffic"* (Chadwick, 1842, p.158).

The introduction of expensive public service was too great a burden for the community to execute without a deep understanding of the damaging results of the situation as it stood. Chadwick worked on convincing the public and the government that such efforts would be cost effective in that they would prevent epidemic and endemic diseases from killing people. Chadwick bravely presented the situation with no exclusions, shocking the community by revealing the bitter health and living conditions which prevailed, and provoking public consciousness and a determination to search for solutions.

2.5 Effects of education on attitudes of families with low income

It was believed that reform could be brought about through individualism, but that state action was necessary to support the individual in practicing self-help to the full (Hopkins, 1979).

Chadwick analysed the living attitudes of two different kinds of families, both of low income. In his opinion, families with similar incomes could vary greatly in their appearance and attitudes. *"I am persuaded that the filth, fever, and destitution in many families is occasioned, not by their small incomes, but by a misapplication or a prodigal waste of a part, in some cases a great part, of their otherwise sufficient wages"* (Chadwick, 1842, p.209).

The first type investigated was working families who received an income which ranged between 15-22 shillings a week. Most of the members of these families worked, with even the very young being employed. Such families were insufficiently clothed and poorly fed. Members of these families and their residences appeared filthy, disorderly and uncomfortable. They cared little for physical comfort, and were for the most part not interested in the intellectual, moral and religious education of their children. Even when they were offered free education, they preferred to send them to work at an early age to gain some, if little, income. Procuring charity seemed to be more important to them than low cost medications, and even when these were free they did not want them. It is almost be certain that several among them suffered from contagious diseases, and had defective health.

The second type investigated was other working families with the same number of persons, who received an income which ranged between 10-14 shillings a week. Although their incomes were less than the first group, they were neatly, cleanly, and sufficiently clothed. They were most anxious to give their children a good education in order to obtain better work chances in the future, and they paid for that education happily. These families cared much for medication and health, with the result of healthier children and less possibility of illnesses, although they lived in the same environment, even in the same neighbourhoods.

2.6 The necessity of health and building reforms

It was stated that all government actions in any field would produce the greatest happiness for the greatest number. "*Bentham demanded that all government action in whatever field should be submitted to the test of whether it would tend to produce 'the greatest happiness of the greatest number'. This principle was known as Utilitarianism, because every act of government was judged by its utility in increasing human happiness"* (Flinn,1961, pp.196). According to this principle, Chadwick argued the importance of the role of the government in bringing happiness to people through good health by ensuring good housing and a good living environment (Flinn, 1961, p.196-197). Public health legislation was considered a proper exercise of government authority in helping individuals to help themselves. However, Chadwick's proposals for public health reform avoided theoretical arguments by stressing repeatedly that reform was cheaper than putting up with dirt and disease (Hopkins, 1979).

Improvements in the form of state legislation, supervision and financial support by means of offering loans to the public, were a realistic bid to control a situation far beyond the abilities of individuals.

The Chadwick Report emphasised the fact that the government was in the best position to induce a revolution on the crisis affecting health, mortality, lodging, comfort, habits, taste, morals and national productivity. Legislation provided for the employment of health officers to apply standards and inspect progress, and funds were provided in the form of loans to be refunded with interest, in order to aid the management of the situation.

Officers' reports, submitted to the government from different parts of Britain, described defective districts, and in many cases presented possibilities of management and amelioration. There was a belief that the factors which had led to the deteriorated living and health conditions of the nation could be prevented. However, the improvement of such a situation could not be achieved by public action alone, but required the interference of the government.

"*The Victorian public health movement was constructed round the powerful motivating concept that came to be known as "the sanitary idea"-… The application of this idea led to the appointment of City Medical Officers of Health and Sanitary Inspectors, to departments of public health in local government, and to laws, regulations, and standards for housing, sanitation, water, and food among other things."* (WHO, 1993, p.28)

One of the issues that needed to be addressed by the government was the establishment of a network of public amenities in each city and rural area. Clean water supplies, indoor drains, appropriate sewerage, street pavements and rubbish removal, were urgently needed (Chadwick, 1842). It was thought that the government should employ professionals to advise on loans and interest rates for the construction of these amenities. The landowners or tenants were to refund these costs.

"Incontrovertible evidence was drawn together in one massive indictment of social ineptitude, and the report demanded reform, with a strong bias towards the need for an effective administrative structure and the necessary officers, with the requisite independence, to see that the law was observed." (Tarn, 1971, p.2)

The report suggested that it was the responsibility of the government to educate people on the importance of cleanliness and healthy habits, the importance of separation between sexes, the health risks of raising animals indoors, and the necessity of ventilation and light for health. The necessary efforts could be achieved by communities if supported by the government.

In his study, Chadwick demanded that families with poor management of their lives and resources should receive training and education for better management. He also mentioned the negative effect of consumption of liquor on habits and income in some families. He suggested that agents be employed to protect children from being made to work at an early, in order to ensure their education and to protect their bodies and health from work far beyond their strength and abilities.

Chadwick suggested that reforms for certain work environments should be considered. "*Public opinion has of late required legislative interference for the regulation of some points of the internal economy of certain places of work…"* (Chadwick, 1842, p.339).

In the field of public health, Chadwick recommended the engagement of properly qualified professionals.

2.7 Transportation and suburban housing

People accumulated in city centres and around industries in order to live within walking distance of their daily work. "*Over half the tenants living in the dwellings of the Metropolitan Association in the early 1880s lived under a mile from their work"* (Hole, qtd. in Whol, 1977, p.175).

The railway revolutionised social life in cities. It created suburbs and conveyed the working demographic from the overcrowded towns to these suburbs, making towns healthier and more pleasant (Flinn, M.W. 1961). Some people felt that the railway journey to and from work had an adverse influence upon the nervous system. In addition, living at a distance from work entailed spending time travelling.

"To live at a distance from their work means an earlier start in the morning, no return home for the midday meal, and a late arrival when the day's work is over. The shortening of the hours of labour would therefore probably have an important bearing on this matter. Moreover, the wages earned leave but little margin for the extra cost of travelling which, however low, would still amount to a considerable weekly sum."(Bowmaker, 1895, p.59)

However, many labourers did choose to live at a distance from their work. The tramway companies made it easier for labourers to live in the outlying districts. Railways would be utilised by labourers when they satisfied two counts. First, the amount spent on travelling should not exceed the difference between the rents of labourers' residences in the central crowded districts and the lower rents of the suburbs. Secondly, reduced fares had to be arranged so as to convey people to and from work at convenient hours (Bowmaker, 1895).

Transport also had an effect on where development occurred; the expansion of London to the east took place because one railway company there offered cheap fares. This was intended as compensation for the land taken away from the poor when the large railway stations were built in Victorian London.

In the twentieth century, improved, affordable and accessible public transport was an important factor in encouraging people to move from the city centres to the surrounding suburbs. Table 2.7 demonstrates the move of some households from London towards new suburbs.

Year	Number	Notes
1921-1937	1,400,000	Number of people moved to outer London
1921-1937	400,000	Number of people moved out of London central area
1926	25,200	Annual dwellings built during the suburban explosion
1928		Bus routes reached to every sizable London suburb, linking them to the new stations along the extensions of the Underground and Metropolitan lines
1934	72,700	Annual dwellings built during the suburban explosion

Table 2.7: Shifting towards suburbs 1920s – 1930s
Source: composed of information extracted from (Burnett, 1978, p.252)

Housing quality in suburbs was raised by building better houses with ample space and ventilation. Also it facilitated slum clearance in the cities by providing more choices for low-income households. New projects were advertised to encourage people to shift toward suburban housing new projects, as shown in Figure 2.3.

The trend towards building high towers attempted to solve the problem of land use and overcrowding by vertical expansion. Such housing might be healthy, but it induced some levels of stress and mental health problems (Burridge, et al., 1993, pp. 43-44).

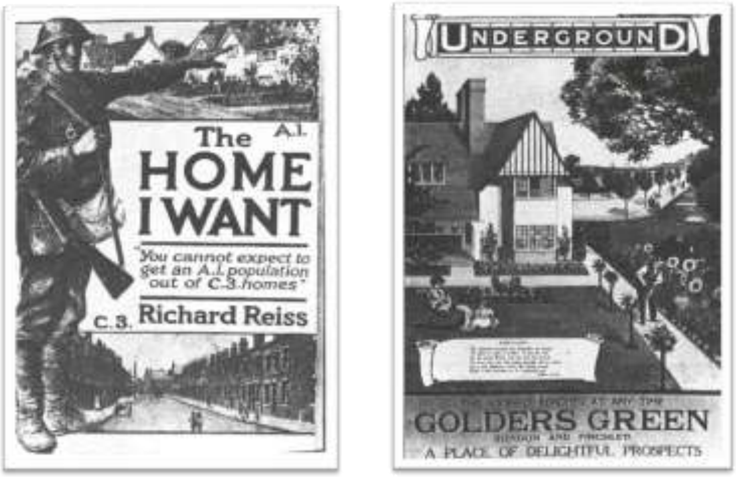

Figure 2.3: Healthy houses in garden cities
Source: Burnett, 1978, p.185

The posters in Figure 2.3 concern the sale of houses in English suburbs. They show how important it was for the labourers to live in detached or semi-detached houses with plenty of space, light, and ventilation. Open spaces and big private sections of land enabled the building of detached houses in order to ensure fresh air.

2.8 Health, building reform and legislation throughout the 19th century

During the second half of the nineteenth century, the need for new building regulations in Britain was established. Two important reasons for this were the rapid growth of the industrial city and severe epidemics. Many of the industrial towns had non-existent or feeble municipal organisations. By the establishment of the Municipal Corporations Act of 1835, it became possible to obtain the power to intervene in housing and health conditions (Berry, 1974). Major reform in housing during the nineteenth century was not the result of legislation. Philanthropists and speculative builders were, in effect, those who decided how to build housing, and in most of the towns, public health regulations were ignored.

(Gauldie, 1974). However, some small improvement in housing came as the inevitable result of public health regulations and artisans' prosperity (ibid).

The government appointed a select committee in 1840 to inquire into the circumstances affecting the health of inhabitants in large towns, and to put forward any ideas for improvement. The committee recommended a new general building act and a sewerage act. It also suggested the establishment of permanent boards of health, which ought to employ inspectors to enforce sanitary regulations (Tarn, 1971).

"In the late nineteenth century, under the auspices of the Ministry of Health, housing issues were at the core of the public health movements and health concerns were a centre-piece of the earliest housing policies." (Knill-Jones, et al., 1991, p.1)

In Section 13, The Nuisance Removal Act of 1855 contained the phrase 'unfit for human habitation'. This meant that legislators, for the first time, decided that houses below a certain standard of fitness could not be deemed habitable. The time had come for parliament to set housing standards (Gauldie, 1974, p.253). Through the 1855 Nuisance Removal Act, landlords were requested to improve their properties, or face closure. In many cases owners did not respond to the Act and had their properties closed, with the result that its inhabitants had to move to another already inhabited and overcrowded building. The Act was therefore often ignored for the sake of the poor (Dennis, R. 1984).

The earliest national legislation on slum clearance, the Torrens and Cross Acts of 1868 and 1875, were also difficult to put into practice because of the high costs of compensation to landlords when re-housing inhabitants (Dennis, R. 1984). Slum clearance could not solve the problem of housing the poor. On the contrary, it increased the need for housing, as the new houses erected charged higher rent than those demolished, and were no longer affordable to labourers. "*An analysis of relocation following the Sun St/ Worship St scheme in London suggests that of the 95 households for whom rental information is available, 81 per cent were relocated outside the area of the scheme at higher rents"* (Report on Select Committee on Artisans' and Labourers' Dwellings, 1882, p.208, qtd. in McKie, 1971, p.17).

With time, many eminent people such as doctors, professionals, politicians and philanthropists began to insist on reform.. The following quote is an example of their belief that the government was definitely capable of solving the housing and health problems:

"*Far more vivid must be our colours, deeper and darker far the shades, if we are to present a truthful picture of "Outcast London;" and so far as we have been able to go we are prepared with evidence, not only to prove every statement, but to show that these statements represent the general condition of thousands upon thousands in this metropolis…we shall be pointed to the fact that without State interference nothing effectual can be accomplished upon any large scale."* (Hill, et al. 1883, p.18)

In fact, housing was such an important issue that the public, municipalities, and professional unions all worked towards effective legislation to improve its conditions. In 1890, even the Royal Institute of British Architects RIBA asked in a memorandum for more openings for light and ventilation at the back of houses (Ashworth, p.91, qtd. in Muthesius, 1982, p.34).

2.8.1 Some Reforms towards the Establishment Of Public Health Boards and the State Control and Supervision of Victorian Cities

2.8.1.1 1795-96, The establishment of Local Boards of Health in Manchester

Under this very early legislation, local boards were established in Manchester in response to the severe typhus epidemic (Hennick, Econ. 2nd ser. X 1957, pp.113-20; and see W.H. Chaloner, *Library,* XLII 1959, p.56 qtd. in Chadwick, E. 1842, p.16).

2.8.1.2 **1831-32, Local Boards of Health established in other major industrial cities**

The establishment was a reaction to the outbreak of the cholera epidemic (ibid.).

2.8.1.3 1835, The Municipal Corporations Act

This Act allowed direct interference in order to check the conditions of public housing. Freedom to evacuate and fumigate the houses of people with contagious diseases was given to local boards. This was a response to the cholera epidemic of the early 1830s (Berry, 1974, p.14).

2.8.1.4 1846, The Local Building Act: This Act authorized the appointment of the first local medical officer of health in Liverpool (Frazer, 1947 pp.35-36 qtd. in Chadwick, E. 1842, p.16).

2.8.1.5 1848, The Public Health Act

Under this Act, towns where the average mortality rate over a seven year period exceeded 23 per 1,000 were obliged to establish a local board of health. These boards were authorised to undertake responsibility for cleanliness, street paving, sewerage and water supply (Dennis, 1984).

2.8.1.6 1871, The Local Government Act

This Act divided the country into sanitary districts. Appointments of a medical officer and an inspector of nuisances in each district were obligatory (Checkland, et al. 1964).

2.8.2 Policy Reforms towards Improving the Housing and Infrastructure of Victorian Cities

The Building Acts of London 1774, and Liverpool 1825, 1839, and 1842 are only a few examples from a long series of Building Acts which endowed local authorities with limited powers of regulation over the quality, design, and location of buildings *(Report of the Select Committee on Building Regulations and Improvement of Boroughs*,1842,qtd. in Chadwick, 1842, p.16).

2.8.2.1 1850s, The housing legislation

The early Housing Legislation of Shaftesbury represented the beginnings of control over the housing conditions of the poor (Berry, 1974).

2.8.2.2 1855, Nuisances Removal Act

"*The Nuisances Removal Act, 1855, is important because it contained, for the first time, the phrase 'unfit for human habitation' (in Section 13). Sitting in the midst of a city where thousands of people were living in conditions much worse than farm animals, whose quarters at least were regularly 'mucked out', Britain's legislators at last took it upon themselves to say 'lower than this you shall not go"* (Gauldie, 1974, p.253).

2.8.2.3 1868, The Torrens and Cross Act

This Act represented the earliest national legislation on slum clearance (Dennis, 1984).

2.8.2.4 1868, The Artisans' and Labourers' Dwellings Act

This act recommended improvement or demolition of the dwellings of the working classes.

2.8.2.5 1875, The Torrens and Cross Acts

The national legislation on slum clearance, which proved difficult enforce due to the high cost of compensating landlords when relocating their tenants (Dennis, 1984).

2.8.2.6 1875, Public Health Act

The Act detailed the specifications of the water closet. According to this Act, the space should be adjacent to at least one outside wall to help include a window for ensuring adequate ventilation. Separate cisterns, water supply, drainage, and a separate soil pipe were later introductions (Muthesius, 1982).

Section 157 of the Public Health Act (1875) enabled local authorities to make by-laws to intervene in both housing and infrastructure. Authorities could specify the proper level and width for the construction of new streets, and for provision for sewerage.

Regarding housing and other buildings in general, this Act enabled local authorities to specify the structure of walls, foundations, roofs and chimneys of new buildings, in order to secure stability and prevent fires, and for the purposes of health. It also specified the sufficiency of space around buildings to secure a free circulation of air with respect to the ventilation of buildings. Other issues covered by the Act were the drainage of buildings, water-closets, earth-closets, privies, ashpits, and cesspools in connection with buildings.

One of the most important reforms was the closing of buildings or parts of buildings if they were unfit for human habitation, in addition to the prohibition of using unfit buildings for habitation (Tarn, 1973).

2.8.2.7 1879 and 1882, amendment to the previous act

These acts again recommended gradual improvement or demolition of the dwellings of the working classes. In addition, they included recommendations for the building and maintenance of improved dwellings (Bowmaker, 1895).

2.9 Chapter summary

History shows that the mass production which began in the Industrial Era was the first step toward the modern deterioration of the global environment, a trend which has become increasingly damaging over time.

The Victorian experience of housing, infrastructure and urban reforms showed that state interference could directly affect the urban living conditions. It was found that charity and philanthropic projects were unable to prevent the health problems, high death tolls and low productivity rates among the working class which were induced by the built environment.

Charity funds played a remarkable role in housing the poor. However, these alone were not able to solve public housing problems. Government intervention and an appropriate policy of finance were a must in improving housing for the public.

In a bid to raise living conditions, the Victorians dealt with two issues in major cities; housing and infrastructure. These both had similar effects on the health level of the inhabitants. However, they differed with regard to the time and effort required for amendments. Improvements in the infrastructure of cities are less expensive, easier and faster to achieve when compared with housing improvements.

This research has shown that, without the state interference, it was impossible to redirect urban planning into the proper direction. Governmental support enabled city planners to turn what had seemed impossible mandates, into applicable laws and reforms toward the best possible practise in city planning.

The lesson to be considered here is that governmental acts and regulations are critical in order to allow Abu Dhabi to shift toward a more sustainable city with an iconic identity.

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CHAPTER-THREE

Research on environmental sustainability

3.1 Introduction

This chapter discusses the theoretical background of sustainability. The first section explains the concept of sustainability and its different elements (see Figure 3.1). Subsequent sections address the main human activities leading to the environmental destruction and their effects. Case studies provide discussion on innovative and pragmatic approach towards sustainable development within the building industry. The chapter concludes with a proposal of the 'six principles' of green architecture in the built environment.

3.2 Defining environmental sustainability

The researcher considers environmental sustainability to be a means of maintaining the beauty, purity and health of nature. Mankind operated with an attitude of inadvertent sustainability until the time of the Industrial Revolution. This attitude was not deliberate, but was the result of a limited population using simple techniques for farming, industry and general human activity. Nature was therefore able to cope with all pollution caused by humans.

A conscious attitude toward environmental sustainability is a fairly new concept, which came about only after people became aware of the intensive and diverse environmental damage that has occurred during the last two and a half centuries.

The UN Conference of 1987 defined sustainable developments as those that "meet present needs without compromising the ability of future generations to meet their needs" (World Bank 2011)

Robert Gillman, editor of *In Context* magazine, defined sustainability as "*do unto future generations as you would have them do unto you".*

Dunphy, et al. (2000) suggest a broader definition of sustainable development that emphasises the three elements of ecological, social and economic principles. A cohesive effort on the part of these elements results in overall development of environment and social equity. Thus it is generally agreed that the relationship between the environment, society and the economy—often referred to as the Triple Bottom Line (TBL)—is the underlying principle of sustainability (Savitz and Weber, 2006).

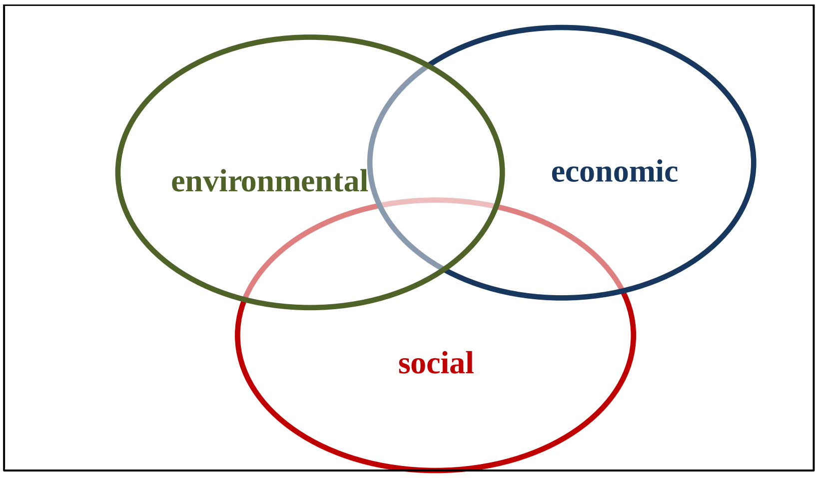

Figure 3.1: The Elements of Sustainability
Source: Institute for Sustainable Futures, 2005

Camagni defines sustainable development as follows;

Sustainable urban development may be defined as a process of synergetic integration and co-evolution among the great subsystems making up a city (economic, social, physical and environmental), which guarantees the local population a non-decreasing level of wellbeing in the long term, without compromising the possibilities of development of surrounding areas and contributing by this towards reducing the harmful effects of development on the biosphere. (Camagni, 1998)

Thus, there is no sharp distinction between the environmental and other domains (e.g. social and economic). In fact, the content of each domain overlaps other domains massively (Sutton, 2004). These definitions describe the ideal situation required for the achievement of sustainability. However, Rosenbaum's definition clarifies specific human and environmental parameters for modelling and measuring sustainable developments, and describes the tools necessary to achieve sustainability: "*Sustainable means using methods, systems and materials that won't deplete resources or harm natural cycles*" (Rosenbaum, 1993).

Sustainability is a combination of two words.

Sustain: the verb means the following:

1. Strengthen or support physically or mentally
2. Undergo or suffer (something unpleasant, especially an injury)
3. Cause to continue for an extended period or without interruption
4. Uphold, affirm, or confirm the justice or validity

Oxford Dictionary (2011),

Ability: those intellectual and behavioural abilities necessary to create sustainable processes and practices, locally and globally. Generally, this requires an ecological knowledge of the design of processes, products and policies that enhance and sustain human-environmental systems. (Webster 1966)

3.3 Human activities leading to environmental defects.

The term environmental sustainability stands for the conservation of the qualities of physical environment, such as clean water, air, suitable climate. Different types of renewable and non renewable energies necessary for the existence of human life must also be sustained. (Sutten,2004). However the conditions leading to the ecological imbalances and threats to the ecosystem can be classified in to different phenomena as follows.

3.3.1 Demographic Changes

The growth of the population of the whole planet has, as a general trend, increased throughout history. The pace of the growth formerly matched the availability of resources on Earth. However, the explosion of population in the last couple of centuries has created an imbalance between the size of humanity and the availability of resources. The growth rate differs according to the social, economic and environmental progress of each country or continent. The reasons behind the explosive population growth are shown in Figure 3.2.

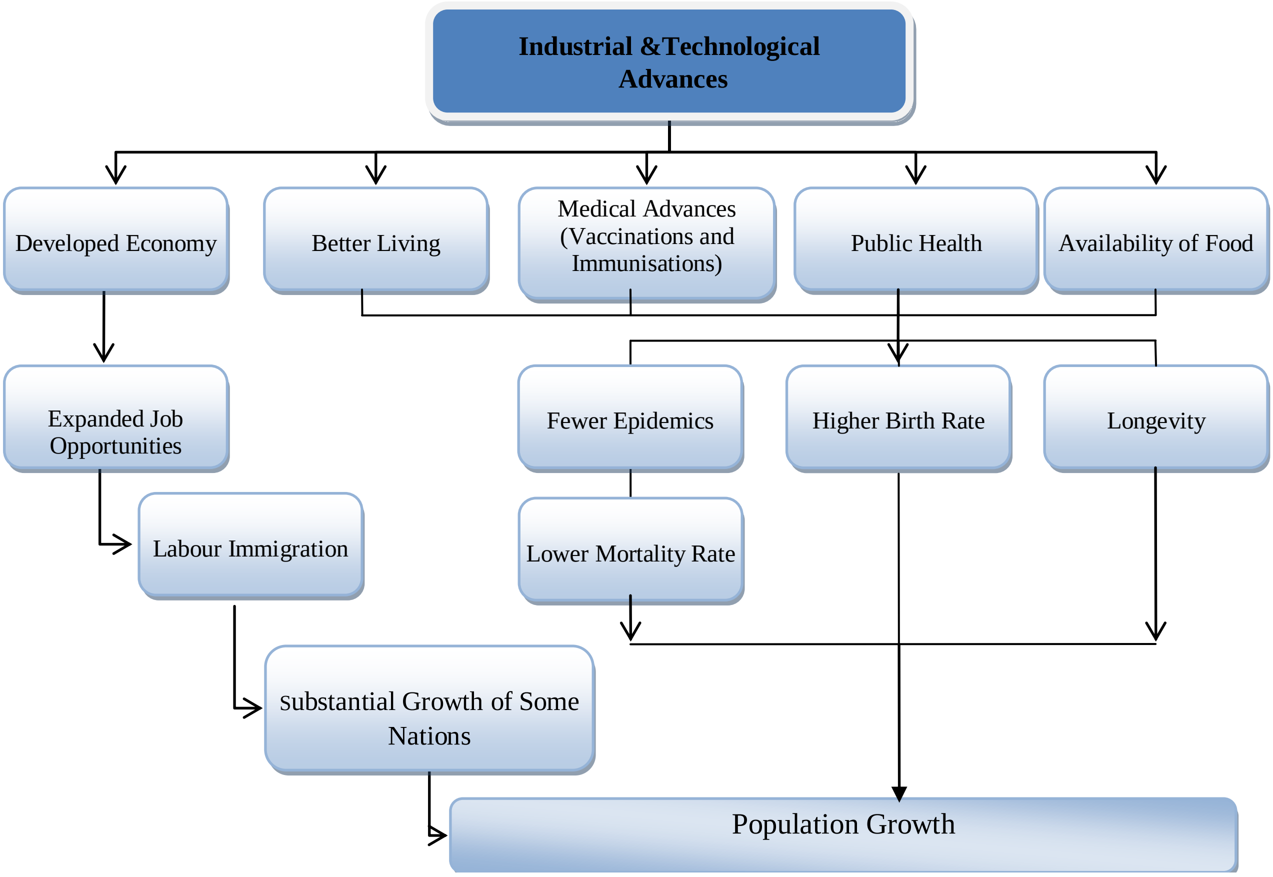

Figure 3.2: The Industrial Revolution and the phenomenon of population growth

Table 3.1 indicates the total population growth of the planet over history. It provides an indication of the period required for each increase of one billion to take place.

World Population:	
Population/ Year	**No. of years for an increase of 1 billion to occur:**
1 billion in 1804	
2 billion in 1927	123
3 billion in 1960	33
4 billion in 1974	14
5 billion in 1987	13
6 billion in 1999	12
7 billion in 2013	14
8 billion in 2028	15
9 billion in 2054	26
10 billion in 2183	129

Table 3.1: World Population Milestones
Source: United Nations Population Division (2011)

Urban life puts more pressure on global resources than rural life by consuming more resources. As people shift from rural to urban areas, more resources will be needed to accommodate them, thus expanding the ecological footprint areas of cities. The United Nations Population Division commented on the trend in 2004, stating that "The world has become increasingly urban. Currently, around 46 per cent of the world population lives in urban areas; the majority of the world's population will be urban by 2006" (UN report data, 2004). The UN's Department of Economic and Social Affairs commented that "The number of persons who have moved to another country has risen to over 125 million migrants today from 75 million in 1965". As shown on Figure 3.3, the report went on to predict that "The world's population is expected to exceed 8 billion by the year 2020" (UN Agenda 21, 2009).

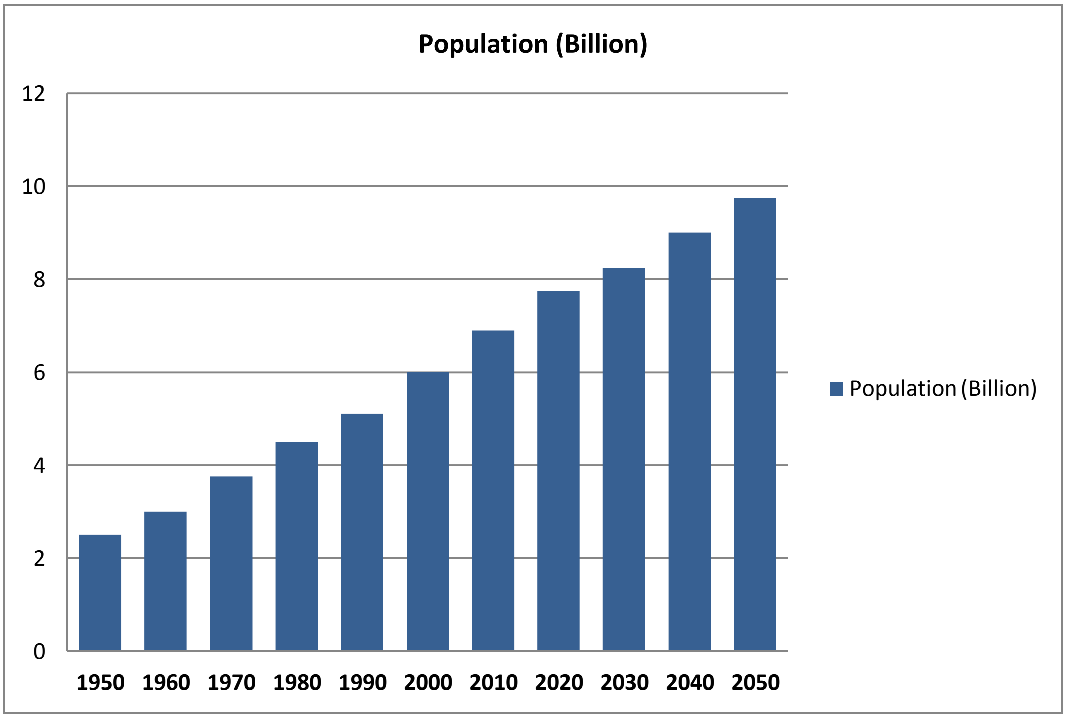

Figure 3.3: World population during 1950-2050
Source: U.S Census Bureau, International Data Base, 2008

3.3.2 Exaggerated consumption patterns

Advances in industrial techniques, including the introduction of mass production processes, reduced the cost of production, and therefore products. Machine-made materials are easier to use in production, more readily available and cheaper to procure than manmade materials. Hence, more and more people could afford to increase their consumption patterns.

Technological advances also led to cheaper and easier methods of extracting natural resources for manufacturing, leading to an increased use of resources and resource depletion. Cost-effective transport systems facilitated the transfer of resources from their countries of origin to countries of manufacture. Transport also enabled manufacturers to trade their products all over the world.

The previously mentioned, population growth and immigration provided unlimited resources of human labour, allowing for cheaper labour and cheaper products. The cheaper the products the greater their consumption.

Unprecedented advances in marketing sciences and practices helped industries and economies to flourish by tempting the public to continue to buy cyclically. The traditional system of purchase based upon NEED is no longer the major motivation behind buying. The drive behind consumption today is largely fashion, whereby people buy not only as needed, but in order to remain up to date with changing trends. This applies to many products for consumption within the mobile phone industry, garment industry, technology, furniture, appliances, and even building finishing materials.

More consumption also means more waste and more pollution. Waste disposal had not been considered a concern until pollution became a global problem.

Figure 3.4 indicates the interrelationship between a diversity of factors leading to acceleration of human consumption:

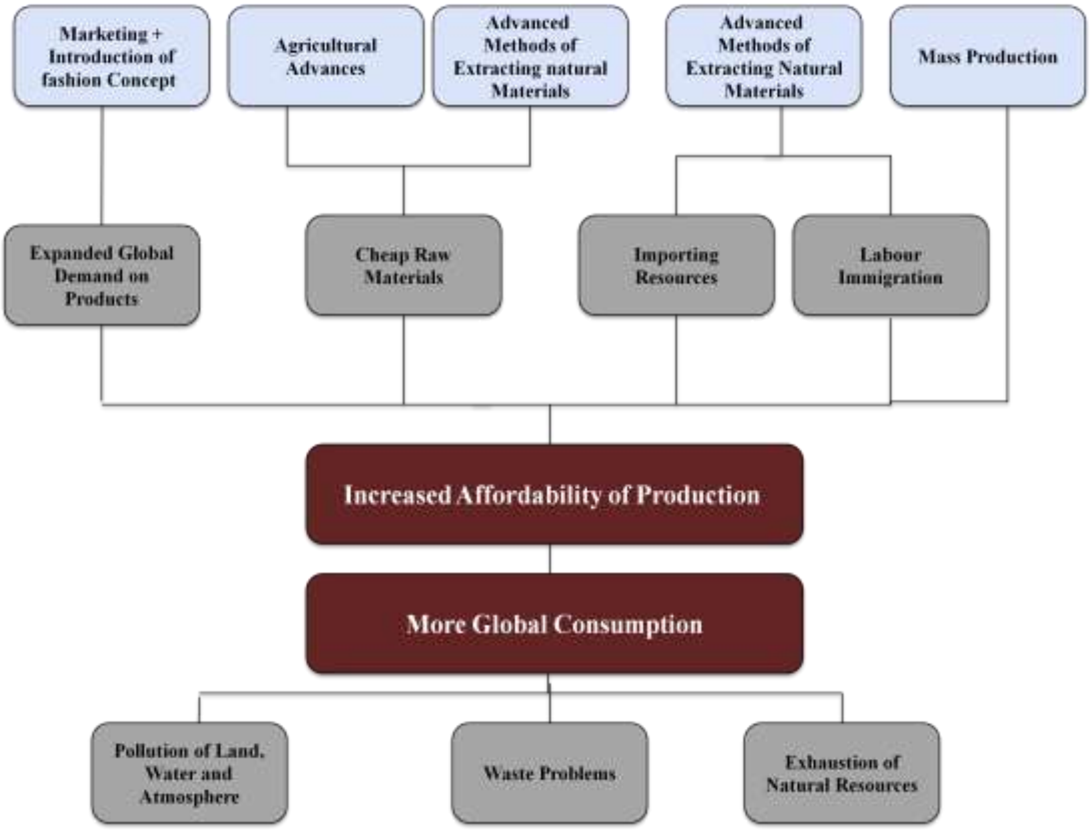

Figure 3.4: Cause and effect of exaggerated consumption

The high consumption pattern of modern life contributes directly to a diversity of problems affecting the planet, one of which is exaggerated levels of greenhouse emissions. “Industry generates 25% of greenhouse gas emissions” (Arthus- Bertrand, 2008, p.143).

In an attempt to cope with internationally escalating consumption patterns, The United Nations developed ‘The Johannesburg Plan of Implementation’ at the World Summit on Sustainable Development. The goals were:

- To assist countries in their efforts to green their economies
- To help corporations develop greener business models
- To encourage consumers to adopt more sustainable lifestyles

To reach these goals, the Plan applied the following;

- Analyse current trends, policy options and practical measures that foster the transition to more sustainable patterns of production and consumption by governments, businesses and consumers
- Organise multi-stakeholder international meetings to share the best practices and promote partnerships
- Support capacity building efforts for the application of policy toolkits on sustainable consumption and production

(UN Department of Economic and Social Affairs, 2009)

The BP World Review of Statistics shows that oil reserves are expected to have a life of about forty years at current rates of consumption, yet world demand for oil is still rising. Our global society is based on the increased consumption of a resource that is known to be finite. In the early 1970s a book called "Limits to Growth" was published by the Club of Rome, a scientific research group. This book used computer modelling to show that if current practices were continued, civilisation would collapse by 2050 from a combination of overpopulation, pollution and depletion of food and resources. Recent research by CSIRO (The commonwealth scientific and industrial research organisation) has shown that the Limits to Growth model is currently correct and that we are continuing on a trajectory towards the collapse of civilisation by 2050 (Turner, 2009).

3.3.3 Modern Food Patterns

The luxury of production of food with no concern for the environmental cost has been escalating in an unprecedented way. The new habits of global nutrition in all developed countries and in some developing countries are as follows:

1. Most food types, whether they are seasonal or not, are made available all through the year by using greenhouses for plantation. The process consumes energy and produces CO_2 emissions.
2. Locality is a main factor in sustainability as it reduces the need to transport foodstuffs. However, people have become used to having types of food from all over the world available to them. Food exporting food is a huge trade and is not an easy industry to combat. Imposing taxes on imported food might discourage its consumption and trade.

"A fruit imported by aeroplane requires 10 to 20 times more fuel than the same fruit produced locally in season: 1 kilo of strawberries in the winter requires the equivalent of 3.7 litres of diesel fuel to arrive on your plate" (Arthus- Bertrand, 2008, p.142).

3. Consumption of high quantities of meat is affecting the environment in the following ways:
    a. Consumption of high quantities of fresh water. "Nearly 15,000 litres of water are needed to produce one kilo of beef" (Arthus- Bertrand, 2008, p.131).
    b. Grains are planted to feed cattle and sheep instead the starving nations; "40% of commercial grains in the world are used to feed animals. Meanwhile, 850 million people on the planet are starving" (Arthus- Bertrand, 2008, p.132).
    c. The methane CH_4 gasses emitted from cattle's waste contributes directly to the effect of greenhouse gases. During the last 150 years, "the level of atmospheric methane has risen by 151%, mostly from agricultural activities such as raising cattle…". (West, 2009).
    d. The energy consumed to produce meat directly affects the availability of food and energy on a global level. "Production of 1 kilo of beef expends the same amount of energy as a 70-kilometre car ride" (Arthus- Bertrand, 2008, p.132).
    e. There is a diversity of health problems related to high meat consumption. Healthy life style combined with eating more vegetables and fruits will induce savings on a national level.

There is a profound need to change eating habits. Public awareness of the deficiencies caused by these excessive habits must be addressed on governmental, community and individual levels.

3.3.4 Deforestation

Deforestation is generally caused by logging or burning trees in forests. Deforestation is as dangerous as climate change; the two are causally linked.

D*eforestation is responsible for 22% of greenhouse gas emissions in the world. When forests are slashed and burned, all the carbon stored in trees for decades, even centuries, is released. This carbon immediately increases the quantity of greenhouse gases in the atmosphere. This is why, after China and the USA, Indonesia emits the third-highest level of greenhouse gases in the world. Its population is smaller and poorer, but the country* *burns the equivalent of nearly 300 footballs fields per hour.* (Arthus- Bertrand, 2008, p.141)

In another estimation, between 20 and 25% of carbon emissions come from deforestation and land use change (The Nature Conservancy, 2009). Brazil and Indonesia have the greatest forests in the world followed by Sudan, Myanmar and Congo, as shown in Figure 3.5.

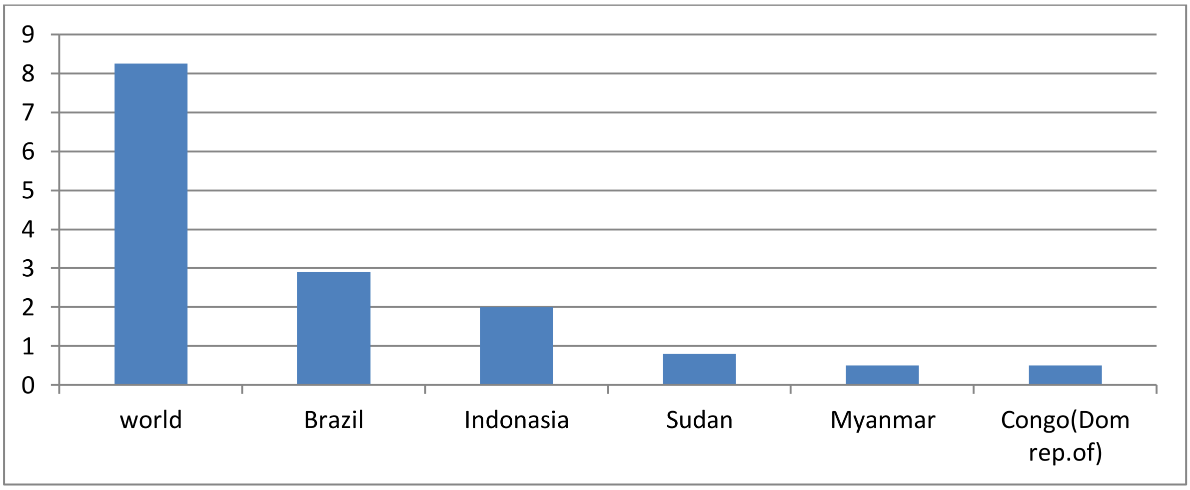

Figure 3.5: Forest area during 1995-2005 (Million hector per year)
Source: Food and Agriculture Organization FAO, 2007

Trees and other plants absorb carbon dioxide from the atmosphere during the process of photosynthesis and release some of it back to the atmosphere through normal respiration. Carbon reservoirs are created inside trees, other species, food, fruits and in soil. Decay or burning returns much of the stored carbon back into the atmosphere. Deforestation is thus directly linked to global warming as one of the major sources of greenhouse gases (mainly carbon dioxide) in the atmosphere.

Forests and woodland are being converted into agricultural land to feed the ever growing global population. Growth of crops and the creation of cattle ranches are the main reasons behind deforestation in those tropical countries, considered the lungs of the planet, which have the biggest forests.

Forests worldwide have been and are being threatened by uncontrolled degradation and conversion to other types of land uses, influenced by increasing human needs; agricultural expansion; and environmentally harmful mismanagement, including, for example, lack of *adequate forest-fire control and anti-poaching measures, unsustainable commercial logging, overgrazing and unregulated browsing, harmful effects of airborne pollutants, economic incentives and other measures taken by other sectors of the economy. The impacts of loss and degradation of forests are in the form of soil erosion; loss of biological diversity, damage to wildlife habitats and degradation of watershed areas, deterioration of the quality of life and reduction of the options for development.*(UN Department of Economic and Social Affairs, Agenda 21, 2009)

3.3.5 Transportation

Transportation had always been sustainable until the invention of the combustion engine. Human and/or animal tasks were the main source of transport, which ensured the health and fitness of all. Traditional mediums of transport used to be either 100% organic or partially non-organic; however in both cases, these transport devices were biologically degradable and hence caused no harm to the environment.

Methods of transport before the Industrial Revolution were:

1. Manpower was used in transport.
2. Animals were used for personal and commodities transport.
3. The invention of the wheel facilitated transport, especially in combination with the use of animals. Single and group carriages were invented later.
4. Boats and ships were used on rivers and at sea.

At the beginning of the twentieth century, the automobile industry was made possible by the availability of materials needed to build cars. However, not everyone could afford to buy an automobile. As time passed, cars became more affordable and available. Two types of technologies were introduced to produce cars, with development of the electrical and gasoline car occurring simultaneously. Both models involve high energy consumption, however their emissions differ. Gasoline cars are more harmful to the environment as they emit CO2 gas, which contributes to global warming. Electrical cars are considered to be more environmentally if they are manufactured and run by means of renewable energy.

Electric vehicles enjoyed success into the 1920s, with production peaking in 1912. The biggest problem of the gasoline car was its initiation, which compared unfavourably with the easy and quick engine start of the electrical car (Bellis, 2008).

The decline of the electric vehicle was brought about by several major developments:

- Better systems of roads connected cities. This established the need for longer-range vehicles, a possibility for which gasoline cars were better suited.
- The discovery of crude oil reduced the price of gasoline so that it was affordable to the average consumer.
- The invention of the electric starter in 1912 eliminated the need for the hand crank in gasoline cars.

The initiation of mass production of internal combustion engine vehicles made these vehicles widely affordable and available within the $500 to $1000 price range. By contrast, the price of the less efficiently produced electric vehicles continued to rise. In 1912, an electric roadster sold for $1750, while a gasoline car sold for $650. This gap in prices created a decline in the demand for electric cars. Electric vehicles disappeared by 1935 (Bellis, 2008).

This led to a profound advancement of the technology used in cars consuming fossil fuels. The highly advanced technology available in fuel run cars has been developed due to the annual mass production of millions of cars throughout the twentieth century. Had the electrical car been granted the same intensive research, it would also have been very cost-effective today.

A similar example is the abandonment of the helium turbine aircraft industry in favour of airplanes consuming fossil fuels. At the beginning of the twentieth century, helium turbine aircraft, which emitted no CO_2, were abandoned in favour of the manufacture of fossil fuel reliant airplanes. It is likely that, had helium turbine aircraft had the same intensive technological research invested in them as conventional airplanes, they could have developed at a similar pace.

Rail and shipping are the two most energy efficient modes of freight transportation. Coastal and inland waterways provide an energy efficient method of transporting passengers and cargoes. Table 3.2 shows that the United States Marine Transportation System National Advisory Council has measured the following:

Type of Cargo	Litres of fuel	Possible distance of travel
A tow boat	3.785	857 km
Rail	3.786	337 km
Highway	3.785	98 km

Table 3.2: The fuel consumption pattern of different modes of transportation
Source: Maritime Administration National Advisory Council MTSNAC, 2001

The Abu Dhabi Urban Planning Council set standards for an integrated system of transport for the future in its Abu Dhabi Transport Plan 2030. "The plan features an integrated public transport system involving rail, metro, trams, buses and ferries, as well as an improved road network and operations".

Transport plans in other parts of the world have also been amended with an eye to sustainability. Transport Canada's vision of a sustainable transportation system is guided by the following principles:

- Highest practicable safety and security of life and property
- Efficient movement of people and goods to support economic prosperity and a sustainable quality of life
- Respect for the environmental legacy of future generations of Canadians
- User pricing that better reflects the full costs of transportation activity and transportation infrastructure decisions that meet user needs
- Reasonable access to the national transportation system by Canada's remote regions
- Accessibility in the national network without undue obstacles for persons with disabilities
- Coordinated and harmonised actions across all modes of transport
- Partnerships and collaboration among governments and with the private sector for an integrated, coherent transportation policy framework.

(Centre for Sustainable Transportation, Abu Dhabi Dept. Of Transport. 2009)

3.3.5.1 Private and Public Transport

Transportation induced by passenger trips accounts for 60-70% of the energy globally consumed by transport activities. Private cars have become a fashion, and car ownership continues to increase. Despite the shift toward more energy efficient cars which occurred after the Arab Embargo and the rise of oil prices during the 1970s, cars remain largely energy inefficient, with only 12% of fuel actually used to provide energy.

Higher income, leads to more car ownership, and to longer trips. In 1999, the car ownership rate went up to 48.8% in the United States (Rodrigue and Comtois, 2009).

More than 800 million vehicles are in circulation throughout the world. They are mostly concentrated in industrialised countries (Arthus- Bertrand, 2008, p.149).

Worldwide, automobiles operate, on average, with about 1.6 to 1.8 occupants. In the U.S., approximately 87% of all automobile trips occur with two or fewer occupants. The average for work related trips is 1.1 occupants per vehicle. One- and two-occupant trips account for approximately 83% of all vehicle miles travelled in the U.S. (U.S Highway Information Management, 1991, page 51). The automobile is responsible for nearly 90% of the energy consumed for travel in the U.S., about 80% in Western Europe, and nearly 60% in Japan (Lee, et al., 1993 page104).

The more the city relies on private vehicles, the less suitable it is, in terms of space and encouragement, for walking or biking. "*…walking and cycling are vulnerable to the impacts of traffic. Many rapidly motorising Asian cities are quickly losing their walking spaces. In Bangkok, only 14% of all trips are on foot or bicycle compared to a whopping 45% in the enormous Tokyo metropolitan area*" (SUSTRAN, 1996).

Disincentives could help to prevent these effects. "It is no wonder that too many people drive if they are not paying the full costs of their actions. This can be corrected by road charges and taxes which are reinvested in measures to help public transport, walking and cycling" (SUSTRAN, 1996).

Transport systems require energy not only for vehicle operations (66%), but also for the provision of vehicles and infrastructures (34%) (Tolley and Turton,1995).

3.3.6 Bio-Fuel and Food Scarcity

Figure 3.6 examines a comparison between the cost and carbon dioxide emissions of the ethanol fuel extracted from sugar, maize and vegetable oil".

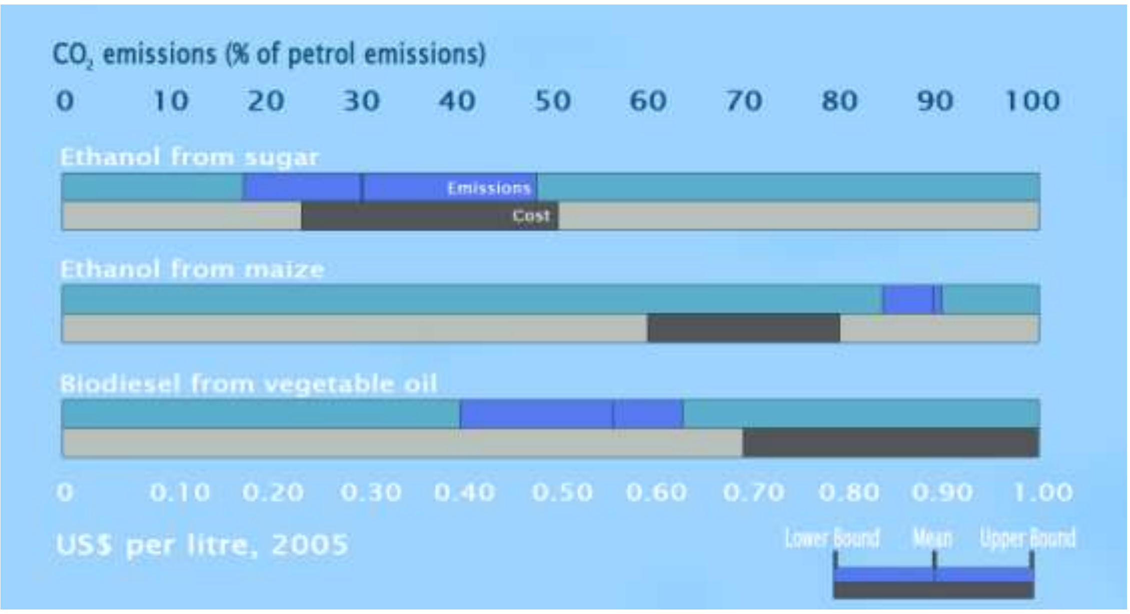

Figure 3.6: Some Bio-fuels cost less and cut CO_2 emissions
Source: IEA, 2006 and IPCC, 2007

One of the disadvantages of biodiesel is that it is currently more expensive than other fuels.

Biodiesel produced from agricultural crops is problematic, as it involves additional land use, with land area being taken up and contributing to the inevitable environmental effects of various agricultural inputs. Switching to biodiesel on a large scale would require considerable use of our arable area. Even modest usages of biodiesel would consume almost all of the cropland in some countries in Europe. If the same thing were to happen all over the world, the impact on global food supply would be a major concern, and could tranform some countries from their current status as net exporters of food products, to net importers. The result could potentially be the deployment of most arable land on the planet to produce food for cars, and not people.

Biodiesel gives out more nitrogen oxide emissions, although these emissions could possibly be reduced by blending with kerosene or Fischer-Tropsch diesel.

BDpedia (2011) “Problems with and disadvantages of Biodiesel”

Transportation & storage of biodiesel require special management. Some properties of biodiesel make it undesirable for use in high concentrations. For example, pure biodiesel doesn't flow well at low temperatures, which could cause problems for customers with outdoor storage tanks in colder climates. Biodiesel is less suitable than petro diesel for use in low temperatures. The ‘cloud point’ is the temperature at which a sample of the fuel starts to appear cloudy, indicating that wax crystals have begun to form. At even lower temperatures, the fuel becomes a gel that cannot be pumped. The ‘pour point’ is the temperature below which the fuel will not flow. As the cloud and pour points for biodiesel are higher than those for petroleum diesel, the performance of biodiesel in cold conditions is markedly worse than that of petroleum diesel. At low temperatures, diesel fuel forms wax crystals, which can clog fuel lines and filters in a vehicle’s fuel system. Vehicles running on biodiesel blends may therefore exhibit more drivability problems at less severe winter temperatures than do vehicles running on petroleum diesel. A related disadvantage is that biodiesel, because of its nature, cannot be transported in pipelines. It has to be transported by truck or rail, thus increasing its cost.

Another disadvantage of biodiesel is that it tends to reduce fuel economy. Energy efficiency is the percentage of the fuel’s thermal energy that is delivered as engine output, and biodiesel has shown no significant effect on the energy efficiency of any test engine. The energy content per gallon of biodiesel is approximately 11 percent lower than that of petroleum diesel. Vehicles running on biodiesel are therefore expected to achieve about 10% fewer miles per gallon of fuel than those running on petro diesel.

There have been a few concerns regarding biodiesel’s impact on engine durability Biodiesel has excellent solvent properties. Hence, any deposits left in the filters and delivery systems by petroleum diesel may be dissolved by biodiesel, causing them to migrate and clog fuel lines and filters. The solvent property of biodiesel could also cause other fuel-system problems. Biodiesel may be incompatible with the seals used in the fuel systems of older vehicles and machinery, necessitating the replacement of those parts if biodiesel blends are used.

3.3.7 The Building Industry and the Indoor environment

In the past, builders and architects used to design and construct buildings which caused minimum harm to nature. The running of these buildings was designed to depend mainly on the limited simple resources of energy available. As their life cycle ended, these buildings would decline and be reclaimed by nature in a benign way, creating a closed-cycle loop which ensured the continuous conservation of natural resources.

It could be said that all buildings erected prior to the industrial era were built according to the following sustainable and natural principles:

1. Using local building materials due to the difficulty of transporting building materials.
2. Importing building materials was very limited.
3. Heating and cooling buildings depended on either passive techniques or use of available limited energy resources, like burning wood or coal. Harm to nature was prevented due to the limited quantities of these materials used.
4. Limited levels of heating and cooling indoors reduced the difference between indoor and outdoor temperatures, which limited health problems.
5. Infiltration of the building increased ventilation rates, even when windows (if present) were closed.
6. Building materials generally maintained the physical character of their raw material, without interfering in their chemical consistency. Therefore, materials degraded easily back to nature at the end of the building's life-cycle.
7. In the Middle East, vernacular architecture was a result of knowledge accumulated through generations of work, error, and correction. This was achieved through post-occupancy feedback given to the builders by the occupants. This feedback was enabled by the fact that they usually lived together in a close society and knew each other. The feedback dealt with many important issues, most of which represented sustainable concerns in architecture as shown below.

The rooting of work and community over generations and centuries can result in deep concern for and understanding of a location. Reviewing the vernacular architectural heritage of a diversity of cultures would show that their different experiences, in a variety of contrasted environments, are united by a common element. They all tried, as far as possible, to create a better and healthier living environment while causing minimum damage to their surrounding environment and consuming minimum energy rates.

The care shown by the inhabitants for surroundings might be one of the most valuable lessons in the vernacular heritage. Comfort has been a concern in most of these situations, both in hot and cold climates. However, concessions to comfort level were not made at the cost of excessive use of energy, as is the case today.

Hot arid climates, such as the Middle East, resulted in conceptually creative vernacular architecture, which was a reflection of both climatic and social concerns. The extreme high temperatures and low levels of relative humidity led to compact neighbourhoods. Houses were completely attached and shaded each other in order to escape the unbearably hot days in summer, when temperatures might exceed 50°C as shown in Figure 3.8. Houses were almost completely closed to the outside, but had huge openings towards the inside courtyards (Warren, et al., 1982, p. 201). Living spaces were usually oriented towards the south, while services were usually oriented towards the north. Ground floors were inhabited in summer as they were more shaded and cooled. Basements were used for storing goods. First floors were inhabited in winter, as they were warmer. Courtyards were ideal solutions for achieving private outdoor space and an appropriate indoor living environment with sufficient light and ventilation. A courtyard usually had a pool as an aesthetic focal point, and was the favourite outdoor space for family leisure time, in winter days and summer evenings.

The narrow alleyways shaded the walkways and created a comfortable micro-climate that encouraged people to walk through. The shaded walls had also cooled the interior spaces of the surrounding houses, see Figure 3.7

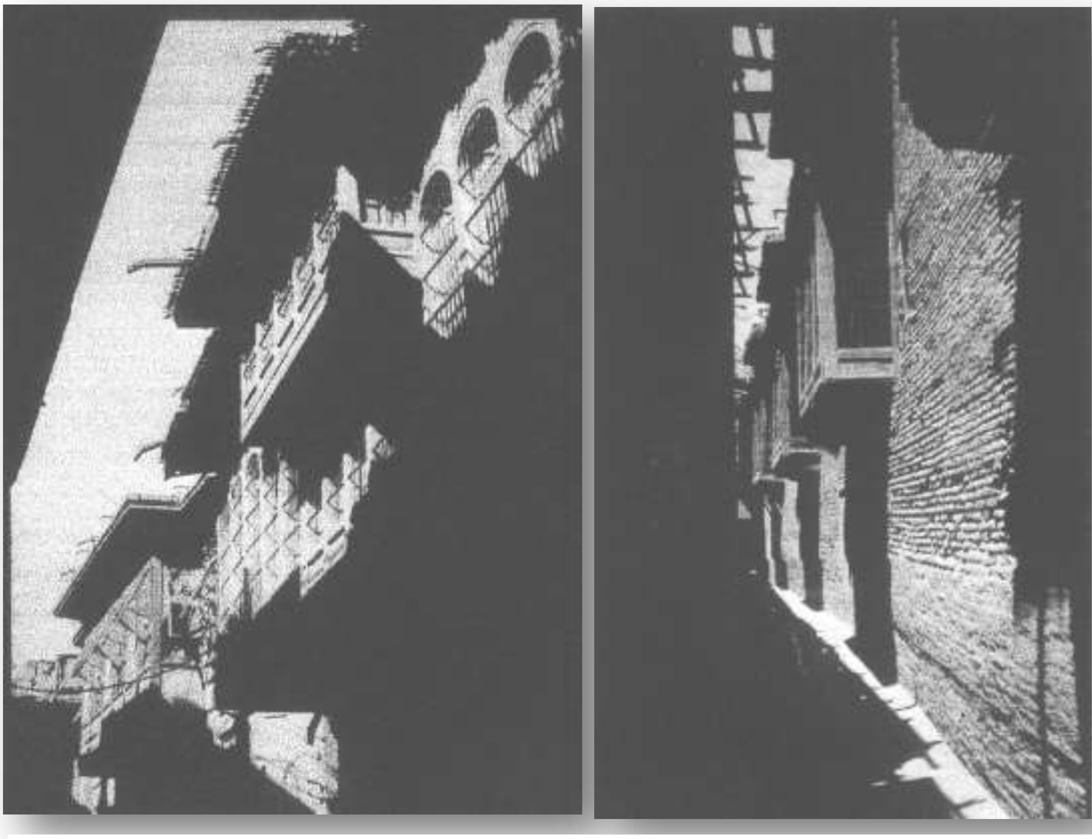

Figure 3.7: Alleyways in neighbourhoods in a hot arid climate
Source: Warren, L. et al. 1982, pp.62-64

The courtyard was responsible for two complementary effects. The presence of a pool reduced air temperature levels by evaporation and raised relative humidity (Heschong. 1979, p.23). The courtyard was also the centre of a natural ventilation system. Airshafts through walls in different rooms helped to ensure a continuous circulation of air to each room, including the basement.

The techniques employed in Middle Eastern vernacular architecture created healthy, comfortable and convenient spaces while minimising energy use.

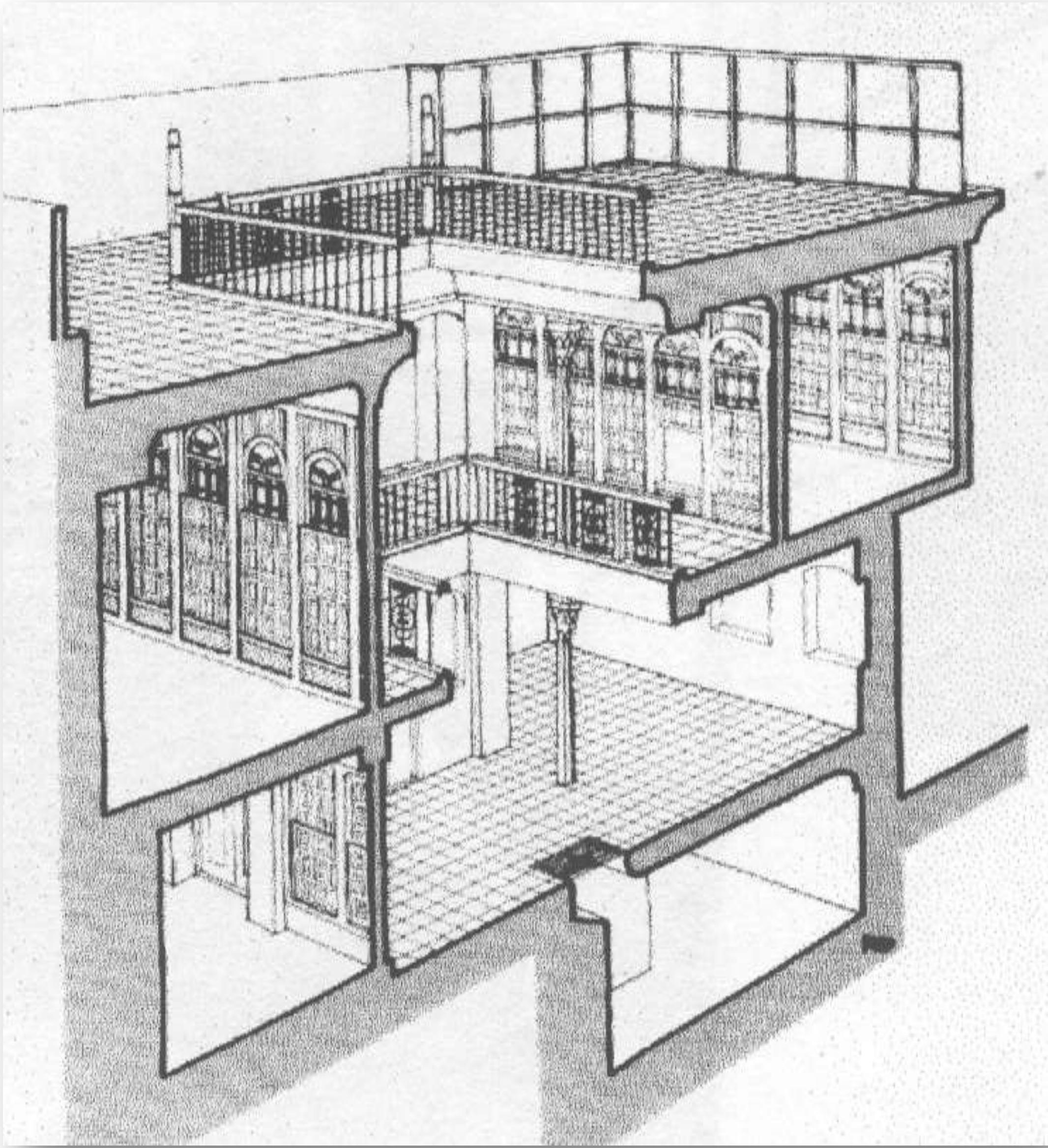

Figure 3.8: Section through a perspective drawing of a traditional house in a hot arid climate
Source: Warren, et al. 1982, p.44

Figure 3.9: Site view of traditional houses in Northern Europe with snow covered roofs
Source: Futagawa, et al. 1978, p.68

A vernacular experience in a totally different environment can be seen in the cottages of Northern Europe. In an extremely cold climate, vernacular architecture there prevented high heat losses through the roof as shown if Figure 3.9 and 3.10. The shallow roofs, built with a layer of earth on the top helped in collecting a thick layer of snow which acted as an additional insulation layer (Oliver, P. 1969, p.33).

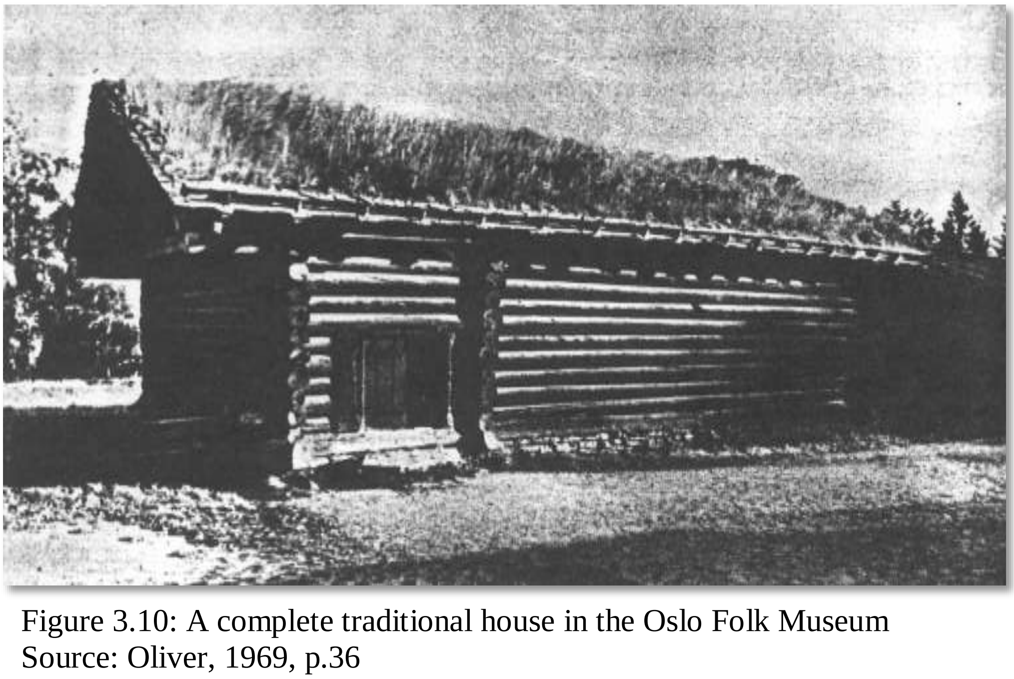

Figure 3.10: A complete traditional house in the Oslo Folk Museum
Source: Oliver, 1969, p.36

Figure 3.11: Air cooled roof in a hot humid climate, 1951
Source: Rogers, 1964, p.18

As shown in Figure 3.11, in a totally different approach in design, vernacular architecture in hot humid climates utilises light materials with minimum thermal mass to prevent the absorption of heat. There are maximum openings for higher levels of ventilation and a double roof to minimise heat gains.

Energy consumption has increased substantially all over the world. This trend occurred first in developed countries, but today it is also taking place in developing countries. The trend is a dangerous one: "…if all countries consumed as much energy per person as Britain does, the world would need seven extra planets" (Low, N. et al., 2007).

After the industrial era, building styles changed dramatically, with new theories of architecture emerging due to a diversity of reasons. The following factors led to the creation of new fashions or approaches in design:

1. Mass production of building materials like cement and steel
2. The affordability of glass
3. Advanced technologies in heating, cooling and ventilating
4. High production of piping and sanitary equipment
5. Advanced systems of lighting in buildings and sites
6. The possibility of building high-rise buildings (more than 4 floors)
7. The invention of lifts

8. Wide span concrete slabs and lintels led to the ability to create big cantilevers and windows respectively
9. Initiation of a wide range of building and finishing materials
10. Cheaply available resources of energy, especially oil
11. Effective systems of transport

The new style of architecture, which had international reach, was led by architects like Le Corbusier. The new assumption was that the same design of building could be built anywhere on the planet, south or north, east or west with no respect or consideration to the local environment. The main motivation behind this attitude was the availability of cheap energy resources which made it easy to light, air-condition and ventilate buildings wherever they were located. This style led to a whole stock of twentieth century buildings that consume energy in an unsustainable way and lack harmony with their local environment. (Hitchcock, et al., 1997, page 40-50).

In the 1970s, after the ‘oil crisis’, a global trend toward reducing dependency on fossil fuels emerged. There was an urgent need to decrease the exacerbated demand on fossil fuels and find substitute resources. Solar energy was seen as one of the most important and available resources that could replace fossil fuels. However, the world’s technology was, and still is, built around the consumption of fossil fuels. Therefore, there was a need to develop new knowledge for the running of technology by solar energy. This represented a financial burden, and once the oil crisis had passed, enthusiasm for solar energy faded.

However, during the 1980s, the link between global warming and high consumption of fossil fuels emerged, leading to a new review of the quantities used. The diversity of problems associated with global warming, such as pollution, the greenhouse effect and rising sea levels once more made it urgent to search for less harmful substitute resources that could replace fossil fuels. Therefore, a new interest in the importance of solar energy emerged.

It became clear that the energy consumed by buildings for construction and running needed to be considered. Architects were faced by the damage which modern architecture had caused to the earth and its atmosphere.

It became important to reduce the amount of energy consumed by buildings, as "Energy production is responsible for 27% of world emissions. The majority of power stations run on coal, combustible fossil fuels that emits a high amount of carbon dioxide" (Arthus-Bertrand, 2008, p.143). Attempts to reduce energy consumption in buildings brought about a revival of interest in vernacular architecture. Vernacular architecture presents a body of experience in dealing with the local environment, and making use of local building materials to provide thermal comfort, thus leading to better health and limiting damage to the environment. Passive thermal control was reconsidered, and architects began to implement these tools in their designs:

- Greenhouse use in cold climates
- Thermal mass in floors, walls and roofs
- Super insulation
- Minimised thermal bridging
- Using the time lag principle
- Deciduous trees and evergreen plants
- Double roofs in hot areas
- Orientation to the sun
- Orientation to prevailing wind
- Shadings and cantilevers
- Building inside the earth
- Natural ventilation
- Ventilation shafts, mulqaf, badgir, water-cooling
- Mechanical ventilation
- Shade cloth

Studies on the achievement of zero or low energy housing are being conducted by means of theoretical studies and practical experiments, in a bid to produce buildings that consume less energy, and depend predominantly on solar energy as a source of power (Vale, 1976).

Air infiltration from cracks and around windows and doors, was identified as an important factor in the loss of heated or cooled air, and therefore the consumption of more energy to replace it with newly heated or cooled air.

But if there are draughts from doors, windows, under floor voids or downdraughts from falling streams of cold air near large, cold surfaces such as windows, then the increased heat loss will have to be compensated for by air temperature or radiation adjustments. (Burridge, et al., 1993, p.158)

One of the most important advancements in the last few decades has been the reduction of infiltration in new buildings. New building materials were invented to seal building joints. Aluminium was introduced for framing of windows and doors. These innovations, in addition to other factors, such as the prefabrication of walls and roofs, contributed to highly sealed buildings. This was regarded as a positive advancement as it minimised heat loss by uncontrolled ventilation from building joints and cracks. However, the result was fairly poor ventilation indoors unless ventilation was deliberately controlled as part of the design.

A wide diversity of new construction and finishing materials, mostly manmade, are used in modern buildings. These materials can pollute the indoor environment. High rates of pollution indoors, accompanied with low and poor ventilation, induced a new danger to health (British Medical Association, 1998, p.108). Here again architects have a responsibility to avoid damages caused to the indoor environment and health.

3.3.8 Indoor Air Quality (IAQ)

Sustainability entails meeting demands while reducing the cost to resources. Therefore, excessive spending can be described as unsustainable. Health problems can greatly reduce people’s productivity, in addition to the inducing health care costs.

The followings are some examples of inappropriate indoor conditions leading to sick building syndromes (SBS) that can affect the health of the occupants.

- Lack of indoor ventilation due to sealing materials, prefabricated panels and aluminum window frames
- Use manmade materials containing hazardous chemical components
- High levels of RH (relative humidity) indoors
- Fungus and other species
- Dust mites housed in carpets, fabrics, heavy curtains and net curtains
- Bacteria presence in HVAC duct systems

- Open fires in cold climates
- Radon gas in some locations
- Interaction between toxic emissions and some volatile species in the air might create volatile organic compounds (VOCs), leading to various sicknesses

There is a diversity of illnesses induced by inappropriate indoor living environments. These illnesses include:

- Asthma and other respiratory illnesses
- Allergies
- Tuberculosis
- Cancers

Indoor air quality (IAQ) can generally be considered to have been healthier prior to the twentieth century, for the following reasons:

- Unsealed indoors due to cracks and window frames
- Use of natural material in building; brick, wood, lime, mud, etc.
- High levels of ventilation due to infiltration
- Less humidity generated indoors
- Less variation between indoor and outdoor temperatures
- No air-conditioning

People are spending more time than ever indoors. Modern lifestyle and habits can have the following undesirable effects:

- Spending more time indoors
- Depending on artificial rather than natural means of controlling indoor atmosphere
- Lower ventilation rates
- Less movement and more time spent in passive activities such as watching television
- Children spend more hours playing games rather than playing outdoors, leading to social isolation
- Increased consumption of junk and fast food, combined with reduced movement, leads to higher rates of obesity and heart problems
- More house plants bring fungus indoors

- Concentrated use of fabrics (heavy curtains, carpets, wallpaper, etc.) accommodates more unseen species indoors

3.3.9 Healthy levels of carbon dioxide indoors

Carbon dioxide (CO_2) is one of the indoor pollutants emitted by humans. It is directly linked to human metabolic activity. High levels of carbon dioxide may cause occupants to grow drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor levels are an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity.

Total indoor carbon dioxide levels should be maintained at less than 600 ppm above outdoor levels. The National Institute for Occupational Safety and Health (NIOSH) considers that indoor air concentrations of carbon dioxide that exceed 1,000 ppm are a marker suggesting inadequate ventilation. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommend that carbon dioxide levels not exceed 700 ppm above outdoor ambient levels. The UK standards for schools say that carbon dioxide in all teaching and learning spaces, when measured at seated head height and averaged over the whole day should not exceed 1,500 ppm.

(Centers for Disease Control and Prevention (2008) "Indoor Environmental Quality: Building Ventilation. National Institute for Occupational Safety and Health"

The 'whole day' here refers to normal school hours (i.e. 9.00am to 3.30pm) and includes unoccupied periods such as lunch breaks. European standards limit carbon dioxide to 3500 ppm.

As the statistics above indicate, different sources suggest different limits. For instance, the U.S. Occupational Safety and Health Administration (OSHA) says that average exposure for healthy adults during an eight-hour work day should not exceed 5,000 ppm (0.5%). For infants, children, the elderly and individuals with cardio-pulmonary health issues, the maximum exposure level is significantly lower. For short-term (under ten minutes) exposure, NIOSH and American Conference of Government Industrial Hygienists (ACGIH) set the limit at 30,000 ppm (3%). NIOSH also states that carbon dioxide concentrations exceeding 4% are immediately dangerous to life and health (Occupational Safety and Health Administration. 2001; Glatte, Motsay and Welch, 1967).

3.4 Environmental defect induced by human activities

The main focus of this research is a study of the defects induced by those human activities which are related to the building industry. This covers the global depletion of resources induced by building, whether through the construction process, fabrication of building materials, running and maintenance of buildings or degradation of materials at the end of a building's lifecycle.

The building industry has not only depleted global resources, it has also created a new phenomenon of pollution affecting land, seas, oceans and the atmosphere. The pollution has been so overwhelming that current environmental policies and attempts to reduce the continuality of pollution must confront the near impossibility of reversing the cycle and remedying its resultant defects.

3.4.1 Global warming

The main resource of heat and energy on our planet is solar rays. Most of the energy held in these rays is absorbed by the Earth. However, a partial reflection of this energy goes back to space as shown in Figure 3.12.

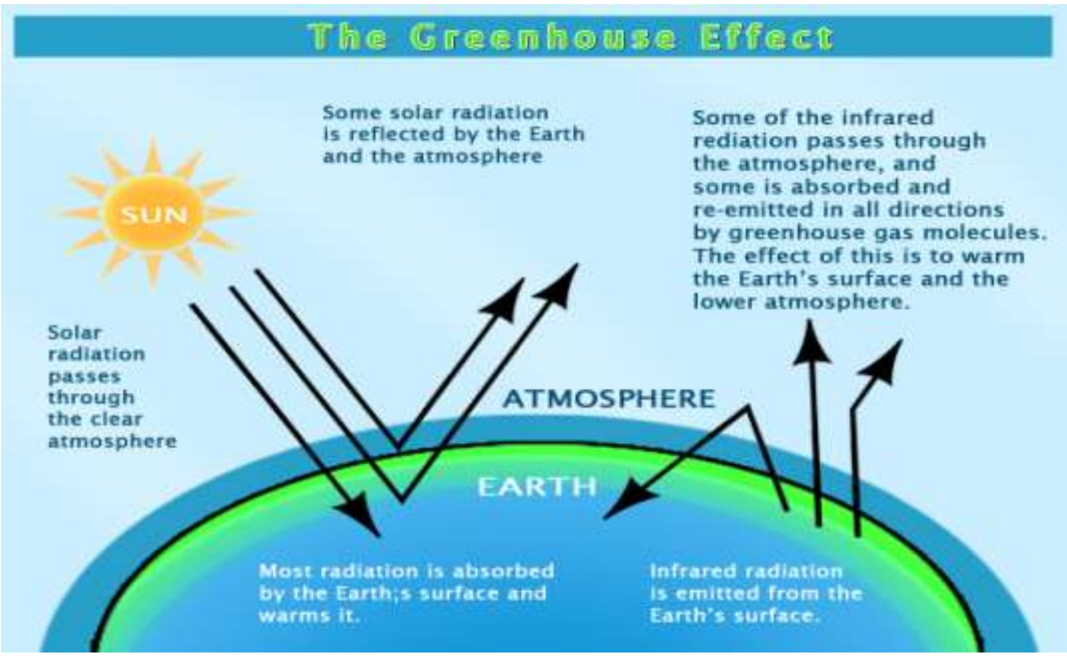

Figure 3.12: The Greenhouse Effect
Source: US Department of State, 1992

Without a layer of gases (the atmosphere) surrounding and warming the planet, Earth would freeze. However, the clarity of the atmosphere facilitates the reflection of heat gains from the sun back to outer space. Pollution compromises the clarity of the atmosphere, and increases heat retention around the planet. Some of the gases in the atmosphere are called greenhouse gases, as they tend to retain heat in the atmosphere. The retention of heat in the atmosphere is called the greenhouse effect (US Environmental Protection Agency, 2010).

(Scientific evidence shows that the temperature of the globe has been increasing over the last couple of centuries. This increase, called global warming, has a massive effect on the atmosphere, oceans and landmasses of the planet.

Until the late nineteenth century, the average temperature of Earth was approximately 15°C (59°F). Scientists estimate that during the twentieth century, the average temperature has risen by about 0.7°C (1.3°F), (The Nature Conservancy, 2009).

As the temperature rises, so the ice in the Antarctic and the Arctic melts. The melting process requires heat, and absorbs the heat of the atmosphere, thus minimising the perceived effect of the rising temperatures. In the future, when all the planet's ice has melted and joined the oceans, the pace of temperature increase will speed up, dramatically affecting atmosphere, climate, biodiversity and the well-being of the planet. Without the polar ice to disguise the real effects of global warming, people will sense and feel the rise in temperature as never before.

The materials which have led to global warming and climate change have always existed in nature. However, throughout history nature maintained its materials in specific locations, and reservoirs. Whether inside the Earth, oceans or the biosphere, these materials existed within a closed cycle which kept the temperature of the atmosphere in a constant condition. Modern civilisation has created an unbalance in the positioning of natural materials (for example, extracting fossil fuels and burning them) leading to a break in the original cycle.

The Earth sustains what is called the 'carbon cycle', in which carbon in the form of gas is transferred between places where carbon is stored

Such places are the atmosphere (which contains carbon dioxide gas), the land biosphere (the Earth's cover of vegetation on land, which contains solid carbon in plant and animal matter), and the oceans (which contain both plant and animal matter and dissolved carbon dioxide). These are the main storages of carbon; 'carbon pools' or 'carbon sinks'. An exchange of carbon is continually occurring among these carbon sinks. (Low, et al., 2007)

3.4.2 Climate change

Global warming and climate change are interrelated, and have both brought about a number of abnormal phenomena on the planet. Some of these changes are:

- Higher temperatures
- Higher evaporation in response to higher temperatures
- Droughts and changes in landscape
- Rising sea levels
- Storms and hurricanes
- Unpredictable rain fall- change in rainfall intensity and location
- Changes to biodiversity, putting wildlife at risk
- Extinction of some species
- Illnesses and diseases related to increased heat
- Economic losses
- Dramatic warming in the Arctic, where temperatures have risen almost twice as much as the global average (The Nature Conservancy, 2009).

As shown in Table 3.3, some of the catastrophic effects predicted to result from global warming and climate change are:

Millions of people exposed	Anticipated problems
334	Tropical cyclones
521	Floods
130	Droughts
2.3	Landslides

Table 3.3: The impact of global warming
Source: Human Development Report, 2009

"Global temperatures could increase from 3.5 ºF to 11.5 ºF this century" (Arthus-Bertrand, Y. 2008, p.135).

In Rio de Janeiro, 1992, the global community undertook the first international conference about global warming and greenhouse gases, which later became known as the Earth Summit. 150 countries signed the United Nations Framework Convention on Climate Change (UNFCCC), thus agreeing to work toward the reduction of greenhouse gases. The aim was to stabilise the concentrations of greenhouse gases in the atmosphere at a level that would minimise the deterioration of the natural environment.

The Kyoto Protocol in Japan, 1997, set new standards. Developed countries were asked to commit to cutting greenhouse emissions to 5% below 1990 levels, by the year 2012. Developing countries were not expected to commit to this agreement. The reasons behind requiring greenhouse gas limitation from developed countries were:

1. Due to industrialisation, developed countries were responsible for most of the greenhouse emissions.
2. Developed countries have the financial capability to initiate the reduction efforts.

(United Nations Department Programme UNDP, 2009)

3.4.3 Greenhouse gases

Short wave radiation from solar rays provides light and heat. This heat is either absorbed by Earth or reflected back into the atmosphere surrounding Earth as long wave infrared radiation. A high percentage of long wave radiation returns to outer space. However, due to reflections induced by the presence of gas particles such as water vapour, carbon dioxide or methane, some portion of the rays are trapped in the atmosphere. The process of reflecting and trapping heat radiation by atmospheric gases is similar to some extent to the role of glass in greenhouses. Therefore, this process has become known as the greenhouse effect.

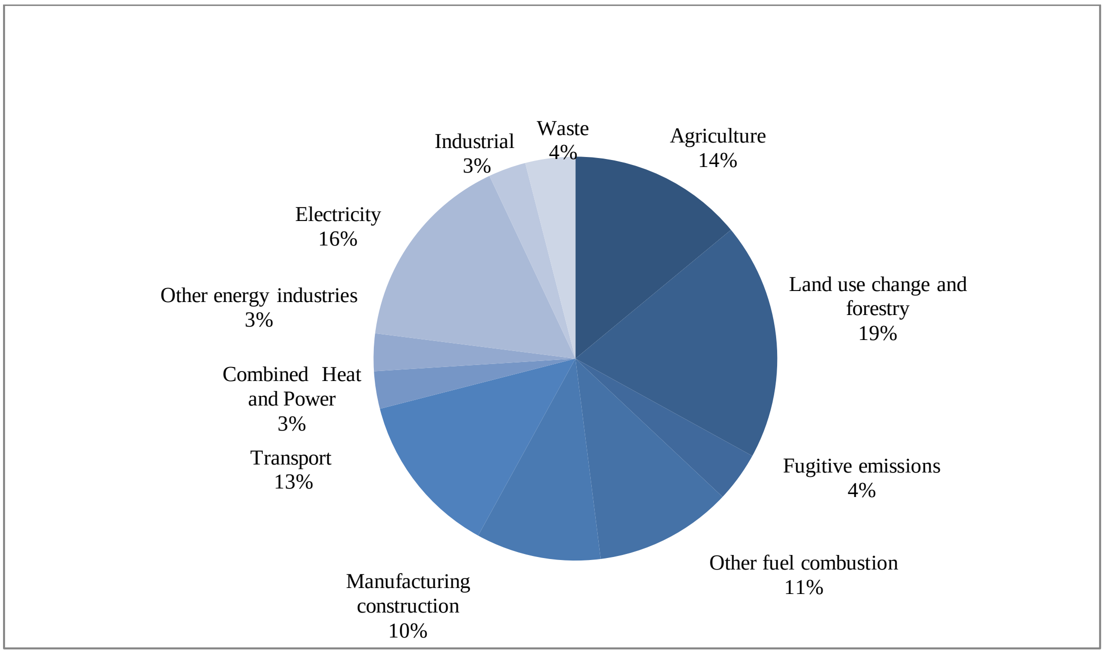

Figure 3.13: Global Greenhouse Gas Emissions by Sector in 2000
Source: Pew Centre on Global (2000) Climate Change, Climate data: A Sectoral Perspective

Water vapour is a common greenhouse gas produced by water evaporation from oceans, lakes and rivers. As shown in Figure 3.13, unlike other greenhouse gases listed below, it is a natural gas which is unaffected by human activities. Human processes and the gases directly related to them are as follows:

- Carbon dioxide (CO2)
- Methane (CH4)
- Foam production
- Refrigeration
- Dry cleaning
- Chemical manufacturing
- Hydro fluorocarbons (HFCs)
- Per fluorinated compounds (PFCs) produced by the smelting of aluminium
- Automobile emissions of nitrogen oxides, volatile organic compounds (VOCs)
- Industrial processes form ground-level ozone (considered as urban smog)

(US Environmental Protection Agency, 2010)

Over the past few centuries, the progress of civilisation has led to the deterioration of the atmosphere; "*…scientists know that greenhouse gases have now risen to levels higher than at any time in the last 650,000 years"* (Encarta, Global warning, 2009).

Although Methane is being emitted in relatively lower quantities than carbon dioxide, it induces greater harm to nature. Weart tells us that "*Methane is a greenhouse gas that can trap about 20 times more heat than carbon dioxide. Enormous quantities of the gas exist in solid form as methane hydrates, or 'clathrates'. These are ice-like substances found in sea-beds around the world"* (Weart, 2003, p.129).

As listed in Table 3.4, attempts have been made to alert people to the damage being done to the planet. Public awareness might need to be addressed on a global level in order to minimise the new pattern of excessive consumption of the planet's resources. "*To prevent the increase in the greenhouse effect, every inhabitant of the planet should emit no more than 460 kilos of carbon*" (Arthus- Bertrand, 2008, p.141).

460 kilos of carbon are equivalent to	**1.7 tons of carbon dioxide CO_2** **81 kilos of Methane CH_4**
American person emits	10 to 12 times 460 kilos of carbon
European person emits	3 to 6 times 460 kilos of carbon
Chinese person emits	2 times 460 kilos of carbon

Table 3.4: The magnitude of pollution
Source: Arthus- Bertrand, 2008, p.141

As shown in Table 3.5, different countries emit different levels of CO_2 emissions. The below table indicates that only two countries, China and the United States of America, are responsible for almost 42% of global CO_2 emissions. The USA, representing only 5% of the global population, emits 20% of the global CO_2 emissions.

Country	Annual carbon dioxide emissions for 2006 in Tons	Percentage of global total
China	6,103,000,000 Ton	21.5%
United States	5,752,000,000 Ton	20.2%
Russia	1,564,000,000 Ton	5.5%
India	1,510,000,000 Ton	5.3%
Japan	1293,000,000 Ton	4.6%
Germany	805,000,000 Ton	2.8%
United Kingdom	568,000,000 Ton	2.0%
Canada	544,000,000 Ton	1.9%
South Korea	475,000,000 Ton	1.7%
Italy	474,000,000 Ton	1.7%

Table 3.5: Ten countries with the highest CO_2 emissions
Source: World Bank (2011)

Table 3.6 examines statistics that show some Arabian Gulf countries, including United Arab Emirates, have among the highest CO_2 emissions/ per capita in the world. However, as these rates are counted per capita, and the Gulf countries have small populations, the real effect of the emissions is minor when compared to those of countries with larger populations.

Countries with highest per capita CO_2 emissions/ year (metric tons per capita) **(2007)**					
1	Qatar	55.4	6	Aruba	22.3
2	Kuwait	32.3	7	Luxembourg	22.6
3	Bahrain	29.6	8	Brunei	19.7
4	United Arab Emirates	28.7	9	United States	19.3
5	Trinidad and Tobago	27.9	10	Australia	17.7

Table 3. 6: Countries with highest per capita CO_2 emissions/ year, (Tons per person) (2006)
Source: World Bank, 2011

The current building revolution in the Gulf region has had a definite impact on general levels of CO_2 emission. However, no specific figures are available to distinguish what percentage of emissions is attributable to the building industry as opposed to public consumption.

3.4.4 Rising levels of oceans, seas and coasts

Direct results of global warming include the rising temperatures of the Antarctic, and the consequential melting of ice and raising of sea levels. This represents a great danger to flood relatively low coastal land all over the globe. This is great cause for concern, considering that "*Sixty per cent of the world's population already lives in coastal areas, while 65 per cent of cities with populations above 2.5 million are located along the world coasts; several of them are already at or below the present sea level*" (UN Department of Economic and Social Affairs, Agenda 21, 2009).

People in affected areas will become environmental refugees, and have to be relocated accordingly.

Bangladesh is massively populated, achingly poor, and something like a sixth of the country is going to go away. The Maldives Islands in the Indian Ocean have the same problem. They are a nation of 1190 islands with an average height of about 1.5 meters above sea level. If the sea level rises, more than 200,000 people will have to abandon their homes.

(The Online Environmental Community (2011),

If global warming continues as it is today, it is estimated that within a few decades millions of people will be affected by rising sea levels. "*By 2050, as many as 135 million people may be forced to leave their land because of climate change*" (Arthus- Bertrand, 2008, p.137).

3.4.5 Endangered health of species

Civilisation has, to an extent, interfered with and corrupted the constant interaction and interchange loop between species and their natural systems. This interchange loop between living and non-living materials is called the ecological system or ecosystem. The ecosystem can also be described as the relationships between organisms and their physical environment.

Natural ecosystems purify air, water and land from harmful waste, most of which is induced by people. The species and organisms present in ecosystems provide essential materials such as food and elements used in pharmaceuticals. The more diverse is the ecosystem, the more useful it is to mankind.

Global environmental changes affect not only the people who provoked them, but cause massive disruption and damage to the entire ecosystem of the planet. The causes of this widespread damage can be listed as, but not limited to, the following:

1. Melting polar ice and glaciers, combined with warming oceans, will lead to expanding ocean volume and rising sea levels. These changes will affect the coastal living environments of all species. The ecological habitats of these areas will have to be relocated or wiped out.
2. Changes in temperature and precipitation patterns may damage food crops and disrupt food production in some parts of the world. Plant and animal species will shift their ranges toward the poles or to higher elevations, seeking cooler temperatures. Species that cannot do so may become extinct.
3. The rising levels of carbon dioxide in the air lead to increased ocean acidity, which severely damages ocean ecosystems.
4. Clearing wetlands and forests to establish human cities or for agricultural purposes directly endangers the ecosystem.
5. Changing the course of rivers and streams in order to harness their energy for electricity and their water for irrigation directly diminishes river habitats.

Climate change and global warming have an effect on human health, which can be described as follows:

- Droughts and floods affect food security, leading to malnutrition, which is already responsible for an estimated 3.5 million deaths each year.
- More potential deaths and injuries are anticipated to be induced by storms and floods. Floods are often followed by outbreaks of diseases, such as cholera.
- The expected scarcity of water, which is essential for hygiene, will increase the risk of related diseases like diarrhoea. Diarrhoea is already the second leading infectious cause of childhood mortality, and accounts for approximately 1.8 million deaths each year.

- Heat waves impact the morbidity and mortality of vulnerable people, like the elderly, children and people with special health concerns such as respiratory or cardiovascular illnesses.
- Changing temperatures and patterns of rainfall area are expected to alter the geographical distribution of insect vectors that spread the infectious diseases. Illnesses such as malaria and dengue fever could potentially affect more people (The Nature Conservancy, 2009).

3.4.6 Natural water cycle

Plants and trees absorb water from the soil, and through the evaporation process, release it from their leaves into the atmosphere. Removing trees and plants creates a drier atmosphere. Forests increase the capacity of landscapes to intercept, retain and transpire precipitation. The more rain and humidity exists in the atmosphere, the more water is collected and reserved. Forests retain water in their trees, plants and soil. Wiping out forests flushes this water out into seas and oceans with the inevitable result of desertification.

The organic waste of trees and plants slow down the surface runoff of soil. Extensions of plant’s roots in the soil increase the infiltration of water and reduce soil moisture. The presence of trees increases the quantity of water on the surface, in the soil and in groundwater, thus reducing erosion.

3.4.7 Ecological degradation

The rich biodiversity of forests is endangered by clearing trees, and the lives of micro- and macro-organisms are threatened with extinction.

“Our planet's essential goods and services depend on the variety and variability of genes, species, populations and ecosystems. Biological resources feed and clothe us and provide housing, medicines and spiritual nourishment. The natural ecosystems of forests, savannahs, pastures and rangelands, deserts, tundras, rivers, lakes and seas contain most of the Earth's biodiversity. Farmers' fields and gardens are also of great importance as repositories, while gene banks, botanical gardens, zoos and other germplasm repositories make a small but significant contribution. The current decline in biodiversity is largely the

result of human activity and represents a serious threat to human development."(UN Department of Economic and Social Affairs, 2009)

3.4.8 Ozone depletion

Ozone is composed of oxygen; each particle has three atoms (O3). Two types of ozone are known. The first type is related to the environmental pollution and is found in the lower level of the atmosphere close to the Earth's surface. It is created through a chemical interaction, stimulated by sunlight, between volatile organic compounds (VOCs) and nitrogen oxides originating from organic or industrial emissions, car exhaust, gasoline vapours, and chemical solvents. This type of ozone is the main constituent of urban smog, and causes a diversity of respiratory illnesses.

Unlike this lower layer of ozone, the presence of the upper layer of ozone in the stratosphere (3-6 miles from Earth surface) protects human health by blocking harmful ultraviolet (UV) rays. However, the use of man-made chemicals like chlorofluorocarbons (CFCs) has depleted the upper ozone layer and allowed more UV radiation to reach the ground in some parts of the world. The result has been more cases of skin cancer, cataracts, and other health and environmental problems (US Environmental Protection Agency, 2009).

3.4.9 Acid rain

Burning fossil fuels such as coal, natural gas and oil produces sulphur dioxide and nitrogen oxides. Automobiles and other industries can be considered as the main sources of these two substances. As sulphur dioxide and nitrogen oxides spread in the atmosphere they react with water vapour and other chemicals in the air to produce sulphuric acid, nitric acid and other pollutants. The wind transfers these acids all over the globe, and they fall to Earth with rain, snow or fog.

In most cases, acid rain washes away the necessary nutrients in the soil. In other cases, toxic substances like aluminium or mercury are naturally present in the soil. The acid rain dissolves these toxic substances and allows plants and trees to absorb them and become polluted or poisoned. This slows the growth of plants and trees. The thicker the soil, the less is the damage it sustains from acid rain. Thinner soils, such as mountain soils, are more at risk.

As acid rain falls on lakes and rivers, the water becomes uninhabitable for some species. "*In Sweden, as many as 10,000 lakes have been polluted by mercury released from soils damaged by acid rain, and residents have been warned to avoid eating fish caught in these lakes"* (Encarta, Acid Rain, 2009).

Urban smog causes respiratory illnesses for city inhabitants. Acid pollutants in cities corrode almost all structures and finishing materials. Buildings of historical value are endangered by the citric pollutant.

There is a belief that sulphate substances in the upper layer of the atmosphere reflect some of the solar rays heading toward the planet, thus reducing heat gains on Earth. Some scientists believe that this fact has helped slightly in retarding the global warming phenomenon.

3.5 Renewable energy

The availability of oil that could be cheaply extracted led to the establishment of a global dependence on excessive energy consumption. Although energy from oil is a relatively cheap resource, its unseen environmental cost has been mounting steadily, until the deterioration of the environment and depletion of resources have reached an appalling stage. Figure 3.14 indicates the decline of the cost of wind power during the years 1997 - 2005. It is anticipated that future research will profoundly induced lower cost.

The search for clean, renewable energy alternatives continues. A diversity of natural renewable energy resources have been discovered:

- Hydroelectricity
- Geothermal energy
- Wind power
- Solar power
- Biomass
- Bio-fuel

The main obstacle is the primitive technologies available to extract these resources of renewable energy. There is an urgent appeal for initiating research in this field in order to gradually abandon the use of oil as an energy resource. Depleted resources of oil should not be burnt, but rather be used in industries serving humanity.

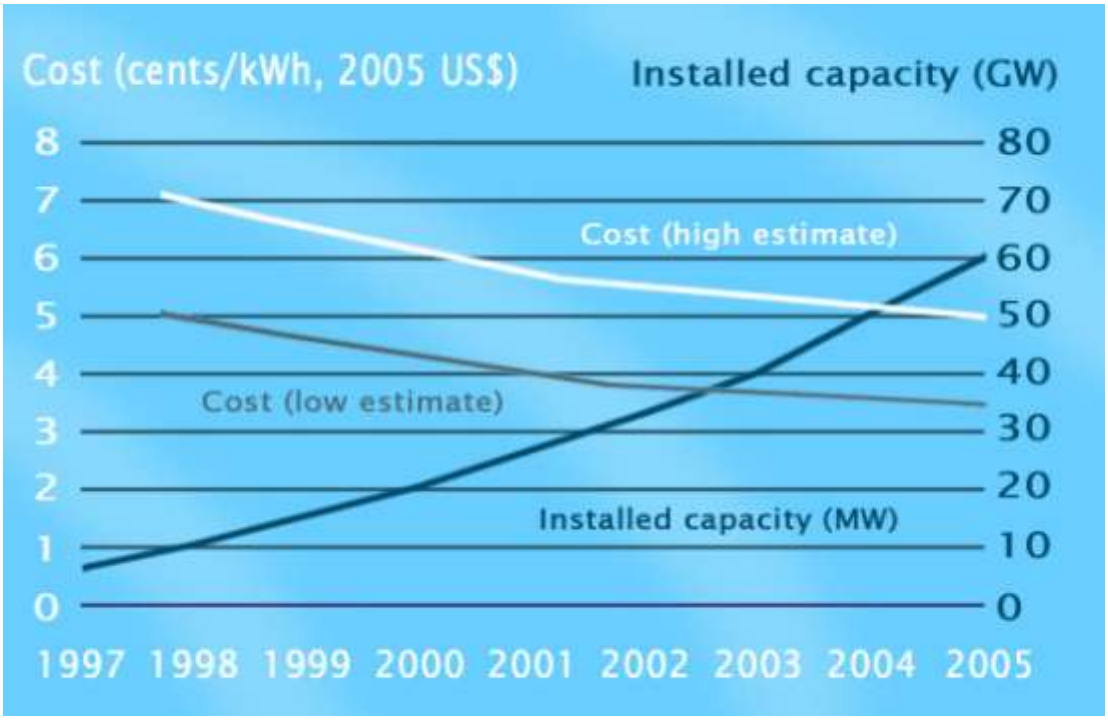

Figure 3.14: Wind Power in the US
Source: (National Renewable Energy Laboratory (NREL), Energy Analysis Office, 2005a; World Wind Energy Association, 2007

Green initiatives enforce the use of renewable energy instead of oil or other fossil fuel resources in order to reduce the environmental impact of the building industry on the planet. According to (Leadership in Energy & Environmental Design LEED), the intention of the renewable energy indicator is to "*encourage and recognise increasing levels of on-site renewable energy self-supply in order to reduce environmental impacts associated with fossil fuel energy use*" (LEED, 2002, p.26).

3.6 Case studies

3.6.1 Bedzed project, United Kingdom

The BedZED project shown in Figures 3.15, 3.16 and 3.17 provides solutions to a large number of sustainability concerns in the modern building and construction industry, aiming for the enabling of a carbon neutral lifestyle. In 1999, the UK's Peabody Trust, one of the largest and most innovative housing associations in London, nominated Arup to formulate an innovative design for the Beddington Zero (fossil) Energy Development (BedZED).

Figure 3.15: General views
Source: Twinn, C. (2010). The Arup Journal, pp.10

With team set out with the objectives of creating a unique design which would reduce the consumption of natural resources, curb pollution and waste, increase the longevity of the building and recycle high quality secondary materials, thereby reducing the demand for raw materials. The features of the design are as follows:

Figure 3.16: Green roofs and ecological impressions
Source: ZED Factory, (2010)

Figure 3.17: Indoor- outdoor interaction
Source: Twinn, 2003

1. BedZED’s new-build development consists of 83 mixed tenure homes (social, key worker, and for sale), plus some 3000 m^2 of space for living, work, retail, and leisure uses. It occupies an urban brown field site in South London (Twinn, 2003).

2. BedZED’s design emphasises the provision of facilities like public transport and passive solar and daylight access. Green roof areas and gardens add ecological and aesthetic value (Twinn, 2003).
3. BedZED adopts the energy grading technique. It estimates the sources of renewable energy and the actual energy demands. It helps to provide the lowest possible grade of source with respect to the energy demand of the building. It also evaluates the efficiency of conventional energy providing systems. It stresses the significant cost benefits of passive solar heating and passive cooling for room comfort and the cost-effectiveness of designing buildings for reduced energy demand (Twinn, 2003).

Figure 3.18 : Passive solar heating and lighting and natural ventilation
Source: ZED Factory, (2010)

4. The physical design of the building allows mechanical and electrical systems to achieve the optimum efficiency in energy use (Twinn, 2003).
5. Building massing and orientation favour environmental friendly, efficient energy saving modes (Twinn, 2003).
6. For the purposes of energy autonomy, BedZED has adopted bio-fuelled combined heat and Power (CHP), generating energy from its own site. It uses the wastes from the site and produces the required energy in a sustainable way.
7. BedZed’s wind cowl system provides preheated fresh air to each home and extracts the vitiated air from each room. See Figure 3.18.

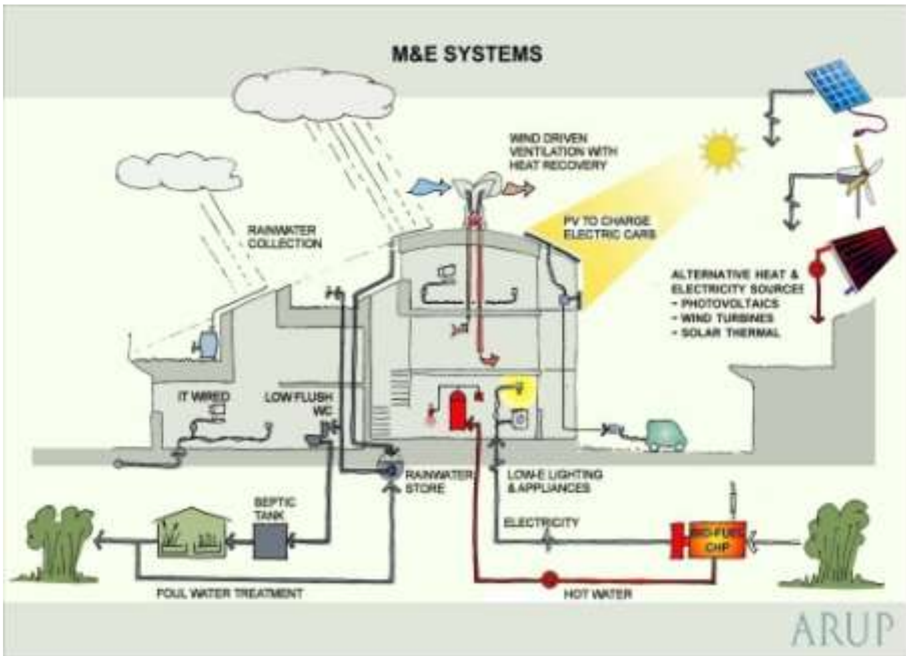

Figure 3.19: Sustainability Systems
Source: ZED Factory, (2010)

8. BedZED has been following a number of water conservation strategies, such as the prevention of excessive water flows in pumps and showers; the water meter is visible to the consumer. Very low/dual flush toilets are in use, and rain water is harvested and stored underground to ensure efficient use of water on the site. See Figure 3.19.
9. Reduced environmental impact materials were used for construction. Reused structural steel was used in the workspace framing structure, and reclaimed timber for internal partition studwork. Building wastes are separated and sent for recycling.
10. Information and communication technology (ICT) allows the community access to modern advantages like a computer-based system enabling remote reading and billing of electricity, heat, and water meters (Twinn, 2003).

The BedZED triple bottom line that concludes the social amenities, financial effectiveness and reduced environmental impact, have been listed in Figure 3.20.

BedZED Sustainability 'Triple Bottom Line'.

(1) <u>Social Amenity</u>

- *Mixed tenure for home owners and occupiers*
- *Living and working spaces*
- *Community activities*
- *Urban density community*
- *Proximity to wider community facilities*
- *Private open spaces in homes*
- *Access to sunlight Air quality and comfort*
- *Reduced need for car, and availability of local car pool*
- *Community-led management*
- *Communal internet*
- *Individual choice for carbon-free lifestyle*

<u>(2) Financial effectiveness</u>

- *Housing association build costs*
- *Affordable key worker accommodation*
- *High demand for private sales*
- *Commands margin over market value*
- *Planning adds development value*
- *Live / work spaces assist business start-ups*
- *Links improve public transport viability*
- *Addresses fuel poverty*
- *Low energy running bills*
- *Internet access links community to local businesses and services*

<u>(3) Reduced Environmental Impact</u>

- *Zero fossil fuel*
- *100% renewable energy use*
- *Zero heating in homes due to passive solar heating*
- *PV power for 40 electric vehicles*
- *50% reduction in use of potable water*
- *On-site ecological water treatment*
- *Wind-powered ventilation systems*
- *Low embodied energy materials*
- *Recycled timber and reused structural steel*
- *Urban tree waste bio-fuelled CHP*
- *Improved ecological value of site*
- *Bicycle facilities*
- *Recycling facilities*

Figure 3.20: BedZED Sustainability "Triple Bottom Line"
Source: Twinn, 2003

Figure 3.22: A new urban typology using local traditional material
Source: Twinn, 2003

Figure 3.21: Bow Zed's PV laminate glazed sunspaces
Source: ZED Factory, (2010)

Figure 3.23: Zed Housing Development
Source: ZED Factory, (2010)

3.6.2 Masdar city project

Masdar City is a new project in Abu Dhabi. It is a future city designed to implement sustainable strategies and applications such as city planning, sustainable community and building design. It is also a carbon neutral and zero-waste city.

Figure 3.24: Aerial View showing Masdar City

Source: Masdar, 2010

Masdar City will be located outside the main island, 17 km from the Abu Dhabi city centre, strategically close to the Airport. The location is between Abu Dhabi's four lane motorway, with motorways linking the main island with the surrounding smaller ones. The city is designed to host 50,000 residents and 40,000 commuters. A high residential density of 135 people per hectare has been planned in order to create a compact residential complex with a sustainable transport system to link business and residential sectors.

The compact city is a revolutionary divergence from the vast villas of Abu Dhabi with their high walled private gardens. One of the main objectives of Masdar is to establish a change of behaviour and attitude and foster environmental awareness in citizens and residents. A sense of belonging and responsibility towards the wider environment is promoted through plans for communal engagement which aims to establish a strong link between people and their environment.

The city is to occupy 6 million square metres and cost 14 billion UK Pounds to build. Masdar's ambition is to be a living laboratory of low-carbon design. Yet it faces serious challenges. Although sunshine is available almost all year round, the inhospitable climate makes it difficult to implement and maintain solar plants due to exposure to the desert sands that reduce the absorption of solar energy. The government's intention is to engage the most up to date technologies. There are currently 110,000m^2 of photovoltaic test arrays on the Masdar site.

3.6.2.1 Masdar transport system

Private cars of all residents, commuters and visitors must park in one of the eight gateway car parks. People should leave cars and take the PRT (private remote transport), electrically powered driverless vehicles that accommodate four passengers. The vehicles have a maximum speed of forty km/hour. These vehicles are designed to run for up to ninety minutes. The route is 1.2 km with two stops in Phase 1.

The PRT is connected to a central Light Rail Transit (LRT) system through six special LRT stations. The transportation network ensures that this is a sustainable city that promotes a healthy lifestyle by encouraging walking habits and exercise while also providing a transportation system which consumes only renewable energy. 2getthere, a

Dutch company, supplied the first ten vehicles to be used in Phase 1. However, Masdar's target is to provide 90 stations and 3000 vehicles.

3.6.2.2 Renewable Energy in Masdar

All buildings in Masdar, including the Masdar Institute, have been designed to be energy efficient, with their energy supply derived from solar energy. Masdar is currently investing in photovoltaic panels in addition to other solar technologies.

3.7 Chapter summary

People spend abound 90% of their time indoors. Approximately 50% of the pollution in the global atmosphere is a product of buildings and the building industry, whether from the removal of vegetation to clear sites, manufacturing of building materials, transport used to import building materials, building and construction process or energy used to run buildings. Considering the importance of buildings in modern lifestyles, and in terms of sustainability, the role of the architect has become increasingly important.

Green architecture is a term which applies not to landscaping or colour choice, but which describes economical, energy saving, environmentally friendly, and sustainable architectural developments. The following six principles outline the intentions of sustainable green architecture:

1. ***Principle 1: Conserving energy***

   A building should be constructed so as to minimise the need for fossil fuels to run it.

2. ***Principle 2: Working with climate***

   Buildings should be designed to work with climate and natural energy sources.

3. ***Principle 3: Minimizing new resources***

   A building should be designed so as to minimise the use of new resources and, at the end of its useful life, to form the resources for other architecture.

4. ***Principle 4: Respect of users***

Green architecture recognises the importance of all the people involved with it.

5. ***Principle 5: Respect of site.***

   A building will "touch-this-earth-slightly".

6. ***Principle 6: Holism.***

   All the green principles need to be embodied in a holistic approach to the built environment.

(Vale, and Vale, 1991)

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CHAPTER FOUR:
Environmental sustainability and local vernacular architecture of the Gulf Area

4.1 Introduction

The first look at any traditional buildings in the Gulf area might bring a lot of questions and wondering about some details and the specific building methods. Why does the entrance have many angles before leading to the court? How does the barageel (airshaft) work? And why is it in all the houses the majlis (guest's room) is close to the entrance? Why use many high openings with lots of decoration patterns in living rooms or bedrooms? etc.

What is certain is that these buildings were designed and built for specific people of a specific culture, living in that specific environment and in specific living conditions. The multi-specific details of that society had been reflected in the methods of building and construction.

The following are the main factors that led to the certain building method in this area.

4.2 Religious factors

Religion has had great effects on the tradition of building in the Gulf area, like other parts of the Islamic world. Some of these effects were:

a. Respect for neighbours' privacy at the same level as considering private privacy was an apparent phenomenon.

b. Based on the tendency not to worship living creatures for religious reasons, it was found that there was normally no decoration with human or animal shapes. This led to most decoration using shapes of plants, Arabic letters or geometric shapes see figure 4.1.

Figure 4.1: The decorations

Source: Alkaabi, et al. (2009)

Gender separation between brothers and sisters in bedrooms was also based on religious reasons.

c. Also a separation between visitors and the family was deliberately made for religious reasons.

d. Beds in bedrooms were usually located in a different direction to that used for praying.

e. In extended families, many houses were designed in the shape of multi-unit houses.

f. The effect of Islam is shown clearly in the traditional buildings by means of the equity between people. Equity had been reflected in building materials and construction methods between all the houses in one community. Houses of people in power were mostly similar to others. The major difference might be the size of their houses and some decorations. This fact can be seen clearly if comparing big palaces of the rich and slums of the poor in the tradition of other nations. (Steel, J. 1997)

g. It might not be possible to find an Islamic community without a mosque in the heart of that community. A high degree of connection with Islam had exemplified itself by the availability of mosques everywhere, even alone in the case of having scattered residential units. (Hakim, 1986)

4.3 Social factors

It might be difficult to separate the social factors from the religious factors. The influence of Islam covers every aspect of people's lives. Therefore, the social and traditional culture of the community is mainly based on the Islamic ideology and instructions in addition to the environmental influence.

a. Special and sincere relations with neighbours reflect on the respect of privacy. Also these relations have become deeper as it was usual for people to build adjacent to each other.

b. Residential communities had included a mixture of rich and poor people living together in the same place. Recently, this has become unusual due to the tendency for people of the same socio-economic level to gather and live in a special community resulting in rich communities and poor communities in different locations.

c. The allowance for the family extension was part of the design of the residential units. This tendency was based on the principle of the extended family, which was encouraged by Islam in order to help the parents as they get older and let the grandchildren be more connected to their ancestors.

d. Storage facilities and tools were part of the culture of the community due to the difficulties of providing food. Therefore, stores were considered while designing a house to provide room for food as it became available.

e. The court was a multi-influential factor in the house. One of these is providing a space for the family to gather in a private landscape. Close neighbours can also be invited and enjoy using the court on summer nights and winter days.

f. It was usual to have more than one entrance, one for visitors and another for the family. The entrance is mainly designed to obstruct direct view from the road into the court or other parts of the house. (Oliver, 1969)

g.

h. The beautiful design of the wooden windows "mashrabiya" was made to allow a view of the road while maintaining privacy, see Figure 4.2.

Figure 4.2: Wooden windows (Mashrabiya)
Source: Alkaabi, et al. (2009)

The main visitor room "al majlis" was an important element of the house. This was made to welcome visitors, and offer the highest level of hospitality to them as part of the generous manners of Islamic people. The majlis was separated completely from the house and had its opening towards the road only and not toward the court. (Michelle, 1978)

4.4 Environmental factors

This factor includes the consideration given throughout the design strategy and the building process to the following:

4.4.1 Thermal Environment

Most of the cities in the Emirates are coastal cities. These have mostly moderate winters and hot humid summers. However, other cities had the same winters with hot dry summers. The consideration given to this specific climate created a comfortable thermal performance in the heritage buildings. It might be true to say that these considerations have no limitations, as it was part of the design strategy and the building construction. Therefore, the following are the apparent considerations given to ensure high thermal performance indoors.

1. The airshaft “barageel” was planned as a square divided by its two diagonals to provide four triangles facing all four orientations. This helped to catch breezes coming from any side, whether prevailing, seasonal or contemporary. The thermal mass of the barageel walls allowed the absorption of heat from the incoming airflow to provide the indoor space with relatively cool air compared with the air outside.

2. In cities with dry summers, water was provided at the bottom of the barageel to allow evaporation and more cooling for the airflow coming through the barageel.

3. Air pullers were built as longitudinal openings with horizontal bases within one wall, usually about 80-100cm above the floor. Such openings provide complete privacy accompanied with ventilation, see Figure 4.3.

4. Another way of providing ventilation indoors is the use of big openings, mostly square or rectangular and sometimes circular, at the higher part of the wall in the living room. These openings usually confront each other by being built in two walls facing each other. Therefore, they provide an ample airflow and at the same time provide an escape for the hot air going up from the lower level of the room. Being located on the higher part of the wall, they provide privacy. However, the big openings were secured by filling them with special decorative patterns, which does not disturb ventilation and at the same time provides security and decoration both inside the room and to the wall facing the court. (Heschong, 1979)

Figure 4.3: The Airshaft (Barageel)
Source: Alkaabi, et al. (2009)

5. The time lag principle was used while building walls and roofs. This was achieved by providing thick walls and roofs, which delayed the heat flow within the thermal mass in order to reduce its effect on the indoor environment. The direction of heat flow inside the wall was going toward the indoor surface of the wall to keep them cool during the day. This was reversed during the night, with the direction of heat flow inside the wall going toward the outside surface of the wall, leading also to keep the indoor surface of the walls cool. Cool surfaces of the indoor walls absorbed the heat from the air and from the occupants' bodies, giving the impression of coolness indoors.
6. In some cases, small openings, with no room for decoration, were used in circular, rectangular or squared shapes to provide a limited level of ventilation. They also represented some decorative patterns in the exterior walls facing outside, and in the interior walls facing the court.
7. The natural building materials, whether organic or not, usually cooled the building as they were used thickly for both constructional and environmental purposes.

8. Another way of providing ample amounts of ventilation was implemented in the “leewan”. This was achieved by providing big openings covered with wood screens toward the road that allow ventilation and privacy at the same time. On the other side the leewan was opened completely to the court and separated only by decorative columns. The leewan was usually located on the South-North orientation to prevent sun penetration and avoid excessive heat gains. The leewan was usually used as a living room for the family, as shown in Figure 4.4.

Figure 4.3: The Leewan
Source: Alkaabi, et al. (2009)

9. Different seasonal uses of different floor levels was in fact for thermal reasons. The two or three levels of the house (basement, ground floor and first floor) might not all be used in the same season. Partial use of the house can depend on the proper temperature in that part, as shown in the following.
10. In compact cities, where houses are completely adjacent to each other, people used to use the ground floor level or the basement for living in summer to escape from the heat of the sun, whereas the opposite happened in winter as the people used the first level to enjoy the warmth of the sun. (Warren, et al. 1982)
11. This is reversed in the houses built separated from each other in some villages in the Emirates. In the houses built with light construction of the date-palms products only, people lived in the ground floor in winter to enjoy the warmth of the sands and

escape from that heat in summer by living in the first floor level. The same type of seasonal use of houses or places (like the House of Sheikh Saeed Al-Maktoom) was used.

12. Dwellings in mountain areas in the Emirates had original environmental treatments. Each family had one house with two separate parts.

    - Winter residences were built with rock walls and mortar. These walls prevented ventilation and gained warmth indoors by the heat gains absorbed by the thermal mass of the wall which were radiated indoors. Limited airflow to minimise ventilation and hence minimise energy losses helped maintain warmth indoors in winter.
    - Summer residences were built with rock walls with NO mortar. These walls allowed ventilation no matter what direction the wind came from. Having open spaces with a continuous airflow day and night allowed the thick rock walls to absorb the heat from the air and produce a relatively cool environment indoors. (Al-Shayeb, 1985)

4.4.2 Light Control

The elements of the traditional heritage are so correlated that it might not be easy to separate them in order to analyse each factor. Every element of the building is usually designed to provide many effects, whether the effect was religious, social, environmental, visual or aesthetic. An attempt has been made here to figure some of the elements that could produce the special visual effects in these buildings.

1. Visual disconnect from the outside does not mean social disconnect from the outside. However, having small and limited openings toward the outside might suggest that these buildings are mostly dark. This is not the case in the Islamic buildings due to the use of the court.
2. Openings toward the outdoors were not confined to mashrabiya only. Big vents were usually used at the top of the walls of living rooms to obtain fresh air. However, this was not limited to the air only. Light was allowed to enter in a decorative pattern, repeating the same decorative pattern of these openings. The light entered the room in limited amounts and the occupants enjoyed its reflection from the wall facing that

opening. The relaxing impression was a result of controlling the amount of the bright light coming indoors.

3. Due to the absence of glass, the heritage buildings used wooden screens to control the light coming from the outside. The small openings designed through the mashrabiya were deliberately made to allow a view from the inside and obstruct it from the outside toward the house. The bright sunrays were allowed to enter through limited spaces in order to reduce its uncomfortable effect on the occupants, damage to furniture and raising the heat gains indoors.
4. Using the court, as shown below in Figure 4.5, solved the problem of providing light indoors. The special design of the proportional size of the court compared to the size of the building in addition to its position at the heart of the building made it possible to provide the light to all the indoor and outdoor spaces in the building.

Figure 4.4: The courtyard of the conventional residential building
Source: Alkaabi, et al. (2009)

5. The same previous principle was applied to another kind of opening, although these openings were small and did not usually include decorative patterns due to their small areas. This was solved by using the small openings repeatedly, which resulted in having a limited amount of light reflected from the wall facing these openings and creating a relaxing feeling indoors.
6. Shading the ground floor by walkways surrounding the court in the first floor created a comfortable microclimate in the area surrounding the court.

4.5 Aesthetic factors

1. It might be possible to say that most of the elements of the heritage buildings were built while considering the aesthetic effect. This included most if not all the

constructional factors, starting from ventilation openings, walls, ceilings, columns, staircases and their handrails, etc. Colours also played an important role in the visual and aesthetic effect of buildings. Consideration was given to providing harmony between the building elements and masses, and at the same time to the harmony between different buildings in one community. The following are some of the apparent aesthetic considerations in the heritage buildings. (Fitch, 1982)

2. There was usually harmony between all the buildings in one community. It was noticed that big houses, small houses, mosques, and public buildings were harmonised in the use of the same building materials. Decorative patterns in the wooden screens (mashrabiya) were also harmonised with each other. Natural mud colours with natural brown wood colours were also putting more emphasis on the harmony between different buildings in one location. (Fitch, 1982)
3. Another way of matching between buildings in one community was the matching in height (mostly one or two floor levels) in addition to the harmony between the blocks and masses of the different residential units and other buildings.
4. In addition to the importance of the b barageel as breathing towers, they also represented focal points in the city skyline. The proportionate height of the minarets and the barageel reflected the same proportionate of their importance. (Fawcett, J. 1982)
5. In addition to the effects of the court on the thermal and visual microclimate of the buildings, the court was a very influential aesthetic factor as it represented the focal point of the whole house.
6. Decorative wooden patterns of the mashrabiya added beauty to the indoor (inside rooms) environment and to the outdoor (toward the court or the road) environment of the building.
7. Decorative patterns were used in the big openings for ventilation at the top of the living room walls. These decorations added beauty to the indoor environment, especially by decorating the light coming indoors by the same patterns of the openings. The other effect was the influence of the decorative shape of these openings on the court, giving special treatment to the walls facing the court.
8. Also repeating the small openings, which were located at the higher level of walls of living rooms, formed some decorative patterns in the walls from both sides (indoor and outdoor).

9. Using some decorative patterns in parapets facing the court also added beauty to the environment of the court. These were mostly used in squared panels with geometric or floral patterns. It is not known to the author whether they were prefabricated or engraved in spot. It would be an important phenomenon if these were prefabricated, as this would indicate a high level of perfection and knowledge in building process at that time. (Dubai Municipality, 1996)
10. Decorations in columns (mostly imported) also added beauty to the court, leewan, and shaded walkways.
11. The exposure of the bare constructional details of ceilings by showing the wooden structure, the use of vaults, arches, domes, etc. had always added beauty to the indoor environment.
12. The use of decorative patterns at the top of walls in some buildings was demonstrating the importance of these buildings and adding beauty at the same time.
13. Decorations were even used in the fences of forts by designing special openings for fighting the attacking strangers.
14. Another aesthetic factor was the usual use of creative designs of stairs and their handrails in the heritage buildings, see Figure 4.6. (Vine, et al. 1992)

Figure 4.5: The handrails of the heritage building
Source: Alkaabi, et al. (2009)

15. Sometimes decorations were used in creating recess in walls indoors for storing or for showing family treasures or weapons, Figure 4.7.

Figure 4.6: Recess in walls indoor
Source: Alkaabi, et al. (2009)

4.6 Securityfactors

The security concerns were translated into design treatments. This was a reflection of the functional attitude in design as great emphasis was placed on the needs of the inhabitants. The following are some design solutions based on the need to protect each community.

1. To protect each community from attackers, a fort might be a common building in civil communities. The fort included a group of buildings or, sometimes, a smaller site with either the castle or “Mrabaa” or both of them. High fences and big gates separate the fort from the outside space.
2. The big gates were opened only in peace times or for special celebrations. However, these gates were closed while there was an attack. A small door was usually designed as part of the big gate. During the ordinary days, because there was no need to open the whole big gate, only the small door was opened.
3. High fences were designed specifically to provide the chance to hunt the attackers and protect the local fighters;

    a. In many cases high walkways were built continuously behind fences to enable the defendants to move around the whole fort behind the fence.

b. "Al-anf", or the nose, was an enclosed projection of the outside walls. It had the shape of a nose and was usually located on top of the main gate of "Mrabaa" or the castle. It had a narrow horizontal rectangular opening, which allowed the throwing of boiled or hot water on attackers.
c. Small cylindrical or triangular openings located horizontally through the upper part of the fence enabled the fighters to hunt the attackers from long distances.
d. Another type of opening, which was more sophisticated in design, was designed to allow the hunting of attackers from short distances. The special design provided the possibility of hunting with high security from being attacked by the attackers.

4. The fort usually included a castle, which provided a space on a high level to watch and control the situation. It also included a room for weapons to be used at the spot in the case of fighting. It might be possible to say that both the castle and Mrabaa were defending buildings with two or three levels; the only difference between them was that the castle had a circular plan and the Mrabaa had a square or rectangular plan. They both included weapon stores and were used as jails sometimes.

4.7 Energy efficiency elements in vernacular architecture of the Gulf Area

It might be possible to say that all the thermal design solutions discussed in 4.4 Environmental factors / 4.4.1- Thermal environment**,** are in fact energy-efficient solutions. These were deliberately made to achieve a good thermal performance in the indoor environment and the outdoor microclimates through the design of courts in the traditional buildings.

The ancestors in the Middle-East area built (smart) high standard buildings. Their main concerns were the thermal, social and functional performance of their designs. It might be possible to say that, generally, these were given more attention and importance than decorations and ornamentations. (Al-Rostomani, 1997)

The reasons behind the special attitude of designing energy-efficient buildings are as shown below.

1. The designer and builder had an ethical responsibility to produce healthy, comfortable and functional buildings.

2. No cheap and ready-to-consume energy was available. Therefore, the ethical responsibility was interpreted by designing energy-efficient buildings that did not depend on energy to produce habitable and comfortable indoor environments.
3. The interrelated communities with deep relations between their members, helped to sustain recognition of the building by its designer and builder after the project delivery. The designer was in touch with the people living in buildings which he built. This allowed the recognition of positive and negative factors in the design. Therefore, it might be possible to say that the high level buildings in the heritage in this area was related to the rule of error and correction based on the experience of previous designs. This is not the case today. Architects build and leave their buildings with no study of how these buildings work while occupied, in order to repeat positive attitudes and avoid mistakes. (Fathy, 1986)

4.8 Environmentally sustainable elements in the vernacular architecture of the Gulf Area

Energy efficient buildings are sustainable buildings, therefore, as shown previously the architectural heritage in this area can be described as being sustainable as it is of a high thermal performance, which provides thermal comfort while conserving energy.

However, there is more to providing sustainable buildings than just making them energy-efficient, and hence it is possible to say that the heritage buildings in this area are sustainable for the following reasons.

1. Sustainable architecture respects the needs and culture of its occupants, therefore, the heritage buildings are sustainable as they are based on the concept of considering these issues.
2. As shown previously, the heritage buildings are completely integrated with the site, whether in the case of building in mountains, coastal areas or in the desert. Therefore, the heritage in this area is sustainable as it respects the characters of the site.
3. Heritage buildings in this area are mainly built with local building materials. However, there was an exception, which was the use of imported wood in limited quantities in some buildings. This is because marine trading was and still is very common and because there is no plantation that can provide wood except date palms. The locals were fascinated with the decorative columns and doors in other countries, specifically in the East. These were brought for the rich and were used to decorate

their houses or the public buildings. However, heritage buildings were sustainable as they were mainly built with local buildings materials.

4. Using local desert plantations needs less maintenance and water than other plants in a desert climate. Planting date palms provided the shade for creating microclimates underneath these palms. It also provided food. Wooden trunks were used as a constructional building material. The leaves were netted and used as rugs for flooring over the sand, or laid over the date palm trunks to provide shelter in roofing.
5. Creating thermal comfort in buildings leads to healthier indoors. Therefore, the use of natural building materials accompanied with considering the thermal comfort indoors enhanced the creation of healthy and sustainable buildings. (Vale, et al. 1991)

4.9 Chapter summary and lessons learned

Energy-efficient buildings are sustainable buildings, therefore as shown previously the architectural heritage in this area can be described as being sustainable, as it is of a high thermal performance, which provides thermal comfort while conserving energy.

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underneath these palms. It also provides food. Wooden trunks were used as a constructional building material. The leaves were netted and used as rugs for flooring over the sand, or laid over the date palms trunks to provide shelter in roofing.

4. Creating thermal comfort in buildings leads to healthier indoors. Therefore, the use of natural building materials accompanied with considering the thermal comfort indoors enhances the creation of healthy and sustainable buildings.

Buildings were designed and built for specific people with specific cultures, living in that specific environment and in specific living conditions. The multi-specific details of that society has been reflected in the methods of building and construction.

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CHAPTER FIVE:

Urban History of Abu Dhabi City

Since its establishment in 1763 by the Bani Yas tribe, Abu Dhabi has undergone various developments. While it began as a primitive society, each stage of its development process has been informed by necessity and the qualities of logic, common-sense and conventional wisdom. In the decades following the discovery of oil, however, drastic changes in urban planning and development activities took place within a condensed period of time. The governing authorities have always been eager to provide the best amenities to citizens, and have paid special attention to the element of sustainability in each stage of development. Currently, an ambitious plan for 2030 is in motion, which aims to establish a completely environment friendly framework, geared towards future generations and towards achieving the status of global capital city.

5.1 Introduction

This chapter explores the urban development of Abu Dhabi city. Urban development occurs in stages. There have been various studies detailing these stages, influencing factors, internal arrangements with respect to external forces, adjustments and maladjustments. In understanding the development process (urbanism), it is useful to approach this dynamism in chronological sequence (Abu-Loghad, 1999). For this purpose, the study has been classified in to two phases, the first phase being Abu Dhabi pre-oil era (1761-1961) and the second phase being Abu Dhabi post-oil era (1961 to present).

Urbanism depends on the presence of a number of factors; skilled labour, sufficient population or a high density of population, houses built with durable materials and permanent settlement rather than transient habitation (Bairoch, 1988). According to Faisal (2003), an urban system is the framework of organisation and inter-connection within an urban settlement according to size and functions. The study of urban development and transformation is usually accompanied by certain constraints, being conducted through analysis of difficult to obtain historical urban data (Ataman and Wingert, 2000).

Like most pre-industrial cities, prior to the discovery of oil, Abu Dhabi was a sustainable city. The availability of cheap resources of energy like oil and coal changed the global attitude to sustainability. This new disregard for sustainability extended to every dimension of human life, and was, also present in architectural and urban planning design.

From the end of the eighteenth century and the dawn of the nineteenth century, buildings started to be designed according to aesthetic and functional rather than sustainable concerns such as controlled resource consumption, public transport and minimal city footprint.

However, the government of Abu Dhabi has showed a profound interest in and support of sustainability. Capital funds have been dedicated to the establishment of a group of sustainable initiatives- government interest has directed attention toward changing the philosophy of urban planning and the search for renewable energy. Projects such as the establishment of an Urban Planning Council, Masdar and Estidama aim to ensure that Abu Dhabi grows into a sustainable modern city characterised by sustainability and respect to local environment.

5.2 Methodology

The investigation of the historical urban development of Abu Dhabi incorporates both qualitative and quantitative data, and is supported by secondary data sources such as maps and master plans which track the physical growth and urban development of Abu Dhabi. Statistical data obtained from government departments like Abu Dhabi Municipality and Abu Dhabi Urban Planning Council provided further support.

An extensive literature review on urban development, in addition to a study of the city's establishment and original planning, allowed for a thorough understanding of the subject matter, and of the city's historical stages, in terms of setting and shape

Locating reference sources on Abu Dhabi's historical evolution was a hard task as they are rare and difficult to find. An interview with a former planner, Abdul Rahman Makhloof, helped in providing books, maps and even personal memories about the experience of working as a planner in Abu Dhabi Municipality during the second half of the last century.

This study adopted the following methodologies:

a. Literature review to gain in-depth knowledge on subject matter.

b. Primary survey with an expert to obtain a practical view.
c. Secondary data from government institutions which provide an overview of the current government achievements and trends affecting the urban design of the city.
d. Intensive observation of each aspect undertaken in the study.

5.3 Urban developments in the pre-oil era (1761-1961): a theoretical review

There are two major forms of urban development, namely organic and planned. Organic development is irregular and unplanned; institutions are not systematically organised, and as a system it is uncomplex. Planned urban development takes a more sophisticated form, as it allows for planning with respect to the environment of a particular urban atmosphere, developing and executing plans according to local needs (Alsheriani, 2009).

A city is a social institution with social components and urban structure (UNESCO, 2004). Its evolution was historically based on the fulfillment of different needs. These needs can be classified into; social needs (establish groups, tribes, societies), economic needs (trade and industry) and protection needs (against intruders and attackers). In the primitive system, cities were established to accomplish the aforementioned needs, in addition to providing habitable space for people and shelter for culture, religion, governance, trade, industry, agriculture, defense, etc. The location of the city is dependent on the availability of drinking water, connectivity through land or sea, economic resources and safe and easily defended sites (Hanzel, 1983). Abu Dhabi city's urban development and its historical evolution has been analysed in the sections which follow.

5.3.1 Establishment of Abu Dhabi city

Following a war with the Al Ghwafer tribe, the Bani Yas tribe returned to their established residences in Al Dhafra, and decided to establish a new city in a location closer to the sea. Envoys were sent to search for that location. The main concerns were the accessibility of water and the possibility of safety, security and easy defense.

In 1761 (1175 in the Hijri calender), Sheikh Diab Bin Eyssa Bin Neheyan, the ruler of Al Dhafra Emirates, sent patrols of his tribe, Bani Yas, to establish a capital coastal city that would be designed to include marine and military bases. The capital at the time was called Al Maria.

Figure 5.1: Qasr Al Husn, 1966
Source: Courtesy of the Documentation & Research Center and the residential Court, Abu Dhabi

The patrols concurred that Abu Dhabi island was a suitable site for the new capital. The water barrier to the south of the island was seen to be so shallow that it could easily be crossed by a camel at low tide, making it easy to control access to the island, and isolate it as needed in war times. Hence, groups of Bani Yas settlers started immigration to the new island city. It is said that within only one year, the number of houses had increased from twenty to four hundred. These groups gradually established residential areas, as their main activities were related to the sea. These activities included diving, pearl trading, fishing, and ship building.

The island's name was initially Umm Dhabi, meaning 'mother of gazelle' in Arabic, but was later it was changed to Abu Dhabi, meaning 'father of gazelle'. The name was derived from the gazelles which ranged all over the island, especially in the area now called Khalidiya. Figure 5.1 and 5.2 show the first building established, which is Qasr Al Huson.

Figure 5.2 :Qasr al Husn, date unknown.
Source :Courtesy of the Documentation & Research Center and the Presidential Court, Abu Dhabi

In the year 1793 (1210 in the Hijri calender), Sheikh Shakhboot Bin Zayed, ruler of Al Dhafra, and his people moved from Maria Oasis to the new seat of governance in Abu Dhabi, making Abu Dhabi the official capital of the emirate. He built a palace called Al Hosn Palace. Since that time, the entire emirate was named after Abu Dhabi island (Hanzel, Faleh. 1983, pp. 208,209,219).

To conclude, the establishment of Abu Dhabi City was based upon the urgent need of the Bani Yas tribe to gather in a place that could be easily defended. The proximity to the sea provided this advantage, and also allowed for the building of a marine base in a strategic coastal location that offered the fundamentals of:

1. Being connected to the marine trading routes in the Arabian Gulf.
2. Effective connections with other Emirates through land routes.
3. Being close to marine pearls and fishing resources.
4. Being surrounded by plenty of creeks and small islands made the land easily defensible, and difficult for enemies to attack.
5. The availability of drinking water.

Figure 5.3: Qasr al Husn, 1995.
Source: An exterior shot of the east wing showing the north eastern tower.
Photograph by The Culture Foundation's photographer Abdulrahman Tikat.

The evolution of the city has continued over the past two and a half centuries, and has led to the political, commercial and cultural city of Abu Dhabi as it is today.

As shown in Figure 5.4, between the time of the establishment of Abu Dhabi in 1761 and the 1960s, the two main communal centres were as follows;

1. The biggest centre was in the Dhaher area, which is located at the far end of the road from Maqtaa to Farda. This centre is 16 km from the island's entrance.

2. The second centre was in the Al Batten area, which is located on the interior of the island, 4 km from the main central axis road. This area was chosen due to its suitability for fishing, pearl catching and ship building. This area was also very much isolated from the overwhelming sea waves and resultant floods.

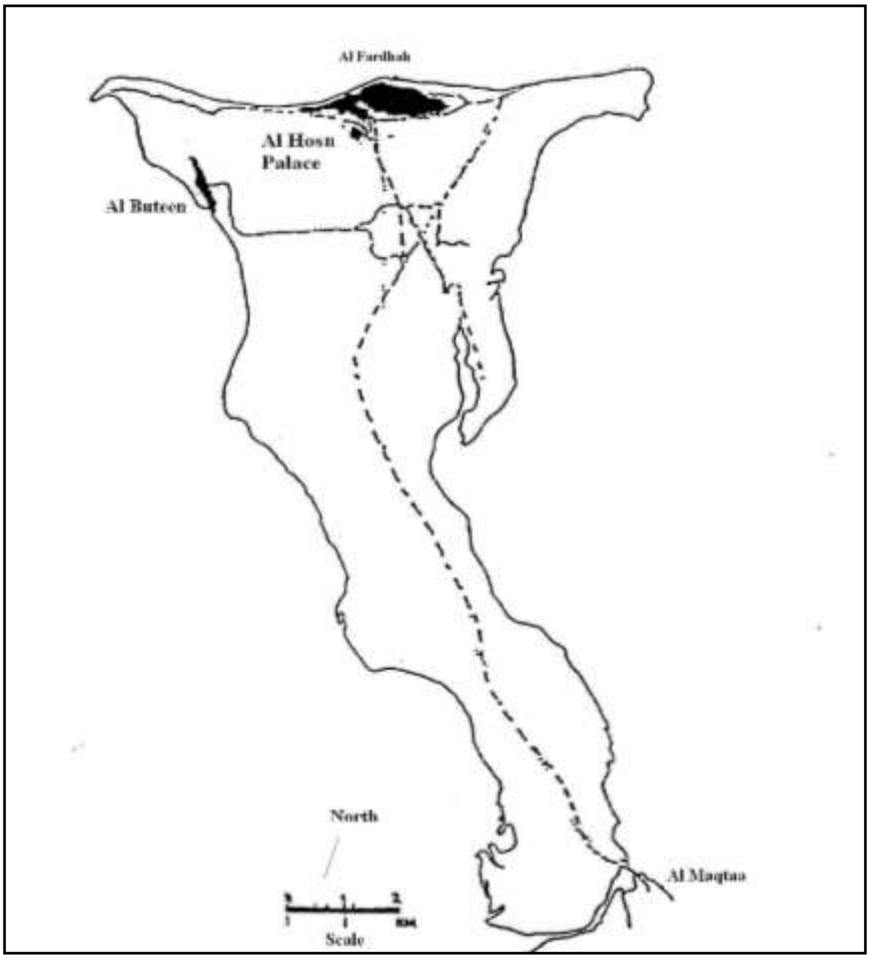

Figure 5.4: Abu Dhabi's layout in the early sixties.
Source: Makhloof, 2006

In Figure 4, it is possible to see, at the far south end of the island, the Makhada Khor which separates Abu Dhabi Island from the mainland. It was so shallow that during low tide, camels could cross over from one side to another.

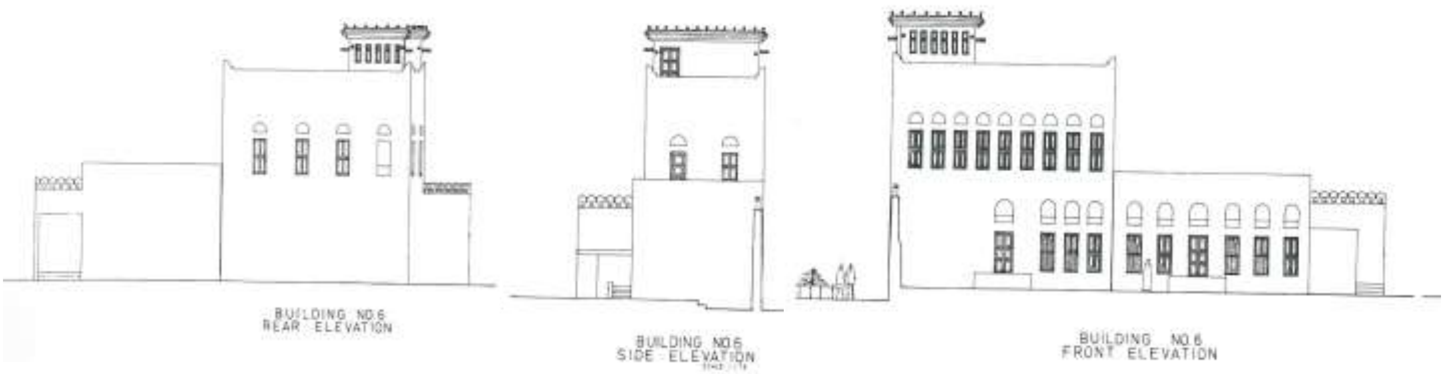

Figure 5.5: Qasr al Husn
Source: Buildings elevations, 1983.

Figure 5.6: Qasr al Husn. The mosque, north east façade.
Source : Photograph by The Culture Foundation's photographer Abdulrahman Tikat, 1995.

5.3.2 Economic development

As was the case with other cities in the region, the economy of Abu Dhabi was slow in growth until the advent of the oil era. The local economy was based upon:

1. Pearl trading
2. Camel trading
3. Fishing
4. Agriculture – using the limited available resources

Export was confined to the pearl trade only, as agricultural and fishing activities provided hardly enough for local use.

The search for oil began in 1948. The first place examined for suitability for oil production was in the Ras Al Sadar area. It was later discovered that due to the stones and hard substances which formed the land, it would not be cost-effective to extract oil from this location. In 1954, the search shifted to the Tarif area. The third attempt was a successful one, as it provided high yield and cost-effective production. It was considered to be the first well in the Abu Dhabi area to produce oil in a commercial manner. By the end of 1960, a fourth well was found, cementing the state's status as a commercial oil producer. The discovery of further oil wells continued.

To conclude, the oil industry in Abu Dhabi began in 1948, with the first commercial production starting in 1954. However, the year 1960 is considered to be the beginning of the competitive oil era in the city.

5.3.3 Planning of the City

Urban expansion in Abu Dhabi in the pre-oil era has mistakenly been thought to be an arbitrary expansion. Despite the lack of maps and photographs which would visually record the evolution of Abu Dhabi through that period, it is possible to draw a likeness of the city based on historical facts and urban planning fundamentals.

Many characteristics of Abu Dhabi in the pre-oil era lent it the image of a calm coastal city blessed with a relaxed social life and guided by its inhabitants' commitment toward their society and religion. Abu Dhabi was an example of a small desert city with a simple orthogonal form. It was built in total harmony with human and social needs, with an interrelated social life induced by the fact that the inhabitants knew each other.

Figure 5.7: Qasr al Husn,1992. Photograph by the culture Foundation's photographer Abdulrahman Tikat

The urban layout of the city was designed for convenience, to ensure that the maximum walking distance did not to exceed 1000 metres. The maximum height of buildings was two floors.

Buildings and urban planning were designed in response to people's need. Building techniques focussed on practical solutions which effectively utilised the natural resources of the local environment, see Figure 5.5 and Figure 5.6. Roads were laid out in an east-west direction, so that buildings would be oriented on north-south lines. This assisted in avoiding sun rays and harnessing shade on buildings. Over its history, the city has developed intelligent ways of providing a livable habitat, despite limited resources. Urban planning in the two decades prior to the 1960s can be described as follows:

5.3.4 Iconic urban features

A number of iconic buildings and sites affected the image, urban planning and shape of the city, see Figure 5.8, as wells as its main connective routes. The selection of sites and locations for those iconic buildings was based upon social, geographical and strategic factors. The following serve as examples of such iconic sites:

a. **Al Hosn Palace**: built for the ruler in a strategic northerly location to provide full control of the city, see Figure 5.1 and Figure 5.2

b. **Al Fardha**: built at the southern end of the island. Both Al Fardha and Al Hosn lie on the south-north axis of the city.

c. **Central Area**: contains the central elements of the city; mosque, police buildings, central souk, etc.

Figure 5.8: Aerial view of Abu Dhabi in the 1950s.
Source: Makhloof, 2006.

d. **Al Mishab**: spaces between the palace and other buildings of the city were used for sport and racing arenas. This added an urban feel to the landscape of the city, which was mainly desert sand.

e. **Residential areas**: orientated north, and built facing the sea in order to avoid the harsh sun, see Figure 5.9.

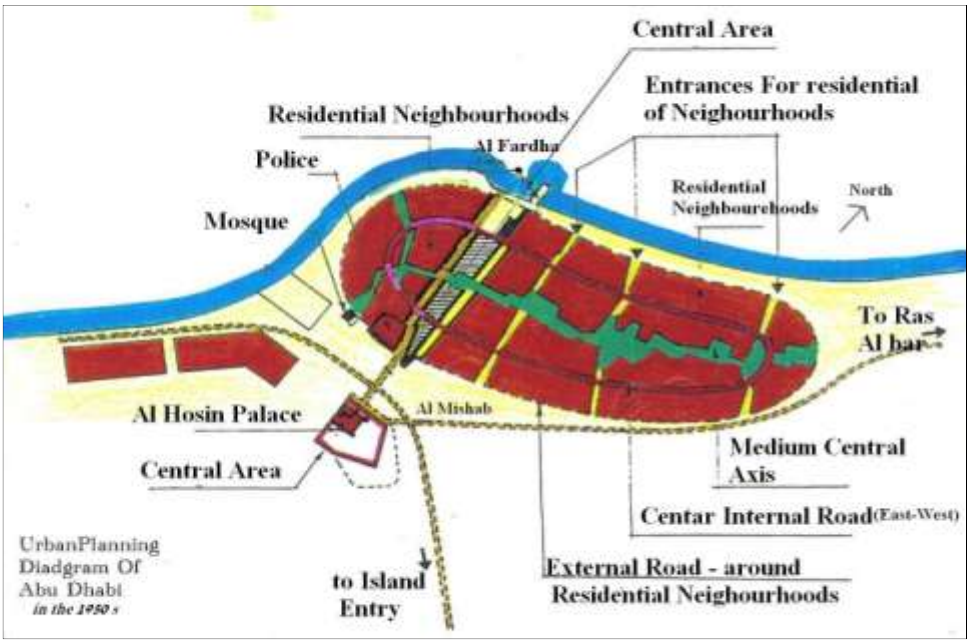

Figure 5.9:City zoning and main routes.
Source: Makhloof, 2006.

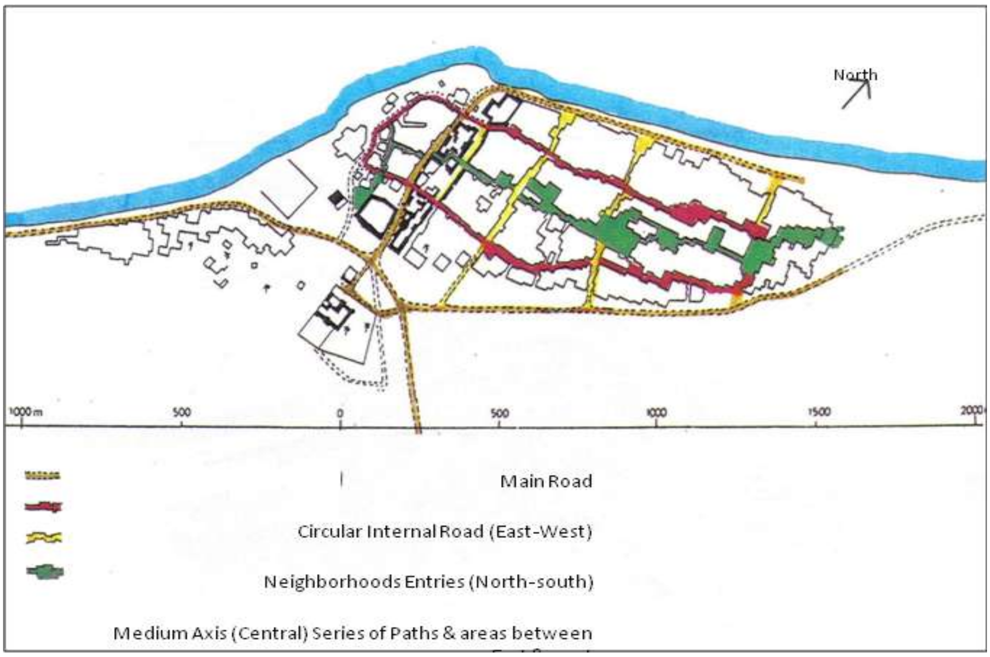

Figure 5.10: City main roads and paths.
Source: Makhloof, 2006.

5.3.5 Main routes

Routes through the city linked all the iconic buildings and facilitated interaction between all the inhabitants. Methods of transport consisted of walking or riding animals, see Figure 5.10.

The two types of routes in the city were as follows:

1. Main roads:

i. From Al maqtaa (island entry) to the palace.

ii. From the palace towards the east, running parallel to the southern residential area.

iii. From the palace towards the west, running parallel to the beach and to the north of the western residential area.

iv. From the palace to Al fardha, the axis of the central area.

2. Routes in and around the central area, of which there were four types:

i. Surrounding routes around the central area

ii. Internal parallel roads

iii. Medium axes

iv. Sub-entrances to the residential areas

5.3.6 Main urban sectors

Six sectors were created surrounding the central area, with three sectors to the right, and other three to the left of the central area. All six sectors ran parallel to each other. The biggest sector had an area of 600 by 450 metres. This was a deliberate piece of planning aimed to keep the walking distance suitable and convenient. In fact, the city was designed to ensure that the maximum walking distance did not to exceed 1150 metres from the central area to the extreme end of the east side of the city. The same logic applied in limiting the distance from the centre to the extreme west end of the city to 1000 metres. Similarly, the distance between the northern edge of the city (Al Hosn Palace) and the southern edge (Al Fardha) was also designed not to exceed 1000 metres, see Figure 5.11.

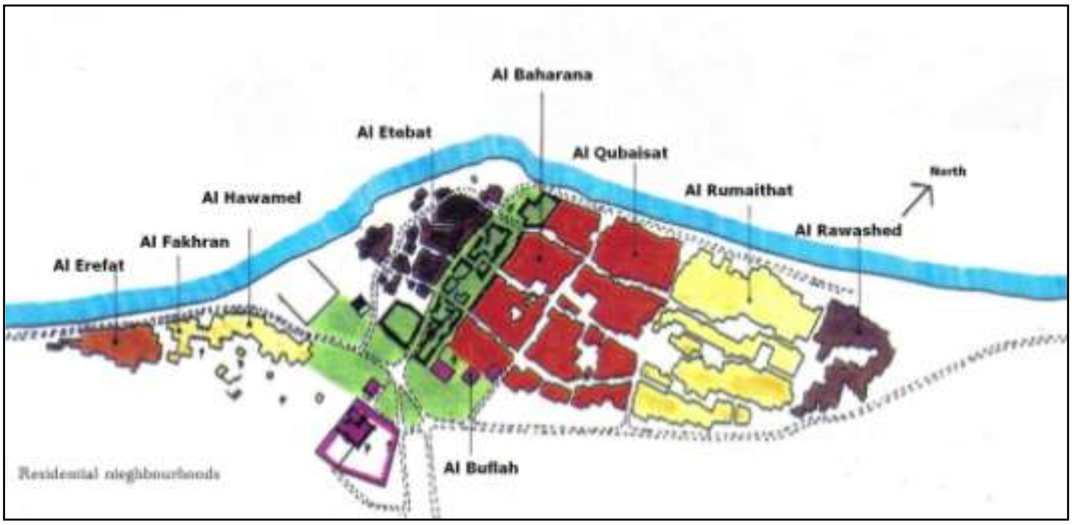

Figure 5.11: Urban sectors of the city of Abu Dhabi
Source: Makhloof, 2006

5.3.7 Residential areas

Figure 5.12 shows clearly that the residential sectors were deliberately oriented northward, facing the sea. In an age before power or air-conditioning technology, the planners and builders showed a real understanding of their environment. It is also clear from the city planning that the central east-west axis connected all residential sectors, creating a series of channels and intersections which allowed social interaction between all city sectors.

Figure 5.12: Ariel View Showing Residential Neighborhoods in the 1950s in Al Bahya Town.
Source : Abu Dhabi Municipality & Town Planning Department (2003).

5.4 Abu Dhabi in the Post-Oil Era (1961 to Present)

Abu Dhabi city was founded at the dawn of the Industrial Revolution. The real recognition, growth and expansion of the city was initiated with the commencement of oil production in 1961. Increased funds led to an increase in immigration, growth of urban population and the expansion of the city. This cycle of growth has continued.

Year	Population of Abu Dhabi	Mode of Calculation	Rate of Change	Area of Abu Dhabi Island in Hectares	Area of Urbanisation of Abu Dhabi Island	Percentage of Urbanisation of Abu Dhabi Island
1958	10000	Estimated	0	6000	54	0.9%
1968	22023	Estimated	10.023%	6000	272	4.53%
1973	81000	Census	53.56%	6500	389	5.98%
1975	127763	Census	28.87%	7000	3900	55.87%
1980	243257	Census	18.08%	7300	6696	9.73%
1985	283361	Estimated	3.3%	7700	7400	96.15%
1990	374000	Census	6.4%	8900	8400	94.38%
1995	405245	Census	1.67%	9400	8600	91.49%
2001	1,170,254	Census	6.84%	9600	9000	93.78%

Table 5.1: Abu Dhabi Population and Urban Growth, 1958-2001
Source: Abu Dhabi Municipality & Town Planning Department, 2003

Table 5.1 demonstrates that Abu Dhabi's population increased from 10,000 to 1,170,254, thus increasing pressure on land, and leading to extended land use (6000h to 9600h).
The modernisation process has impacted drastically on all aspects of life in The Emirates, especially on demographics, and social, political and economic developments. Today, plans for progress are being laid with the benefit of an unprecedented budget.

5.4.1 Political Achievements

The liberation of the country, followed by the establishment of the government and its organisations, was a significant political achievement. It happened in accordance with the expiry of the British-Trucial Sheikhdoms treaty on December 1, 1971. UAE became fully independent on December 2, 1971, with the unification of seven emirates. Ras al-Khaimah joined the union in 1972 (Bureau of Near Eastern Affairs, 2011). The modern state faced challenges of governance on multiple levels. Under the constitution, each emirates is to be governed by a prime minister, while the country is to be ruled by the president and vice president, who hold office for a tenure of five years, governing with the assistance of a supreme council of rulers and the 40 member Federal National Council (FNC). Abu Dhabi was chosen to be the capital city of the country.

5.4.2 Demographic and Social Development

Advances in living conditions led to an increase in population. The government put emphasis on the importance of elevating the living standards of local families. Immigration was also widely encouraged. As a result, an environment of multiculturalism and an atmosphere of healthy interaction were introduced, see Figure 5.13.

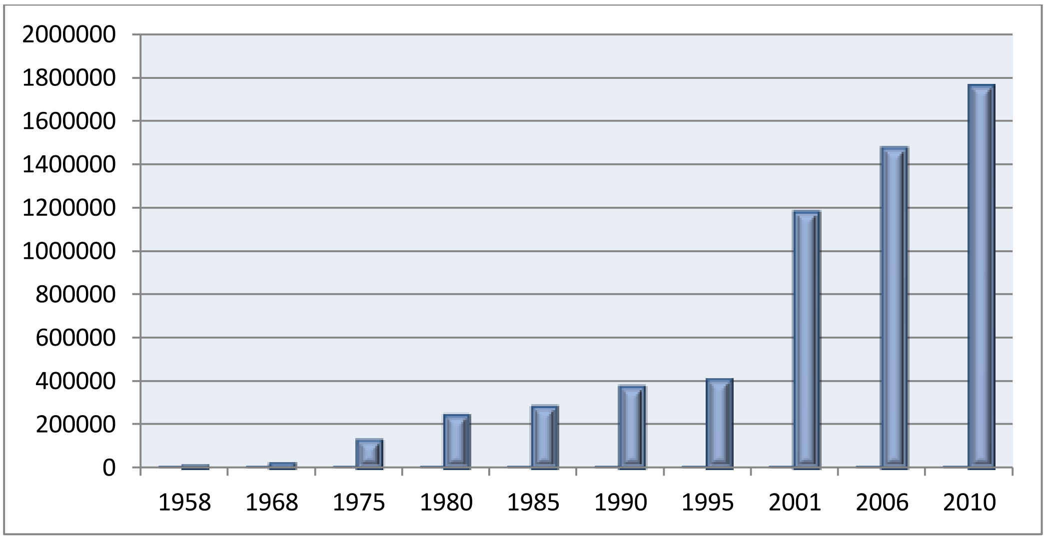

Figure 5.13: Abu Dhabi population between 1958 and 2010
Source: Abu Dhabi Municipality & Town Planning Department, 2003.

5.4.3 Economic development

The discovery of oil and the initiation of its production for commercial purposes in Abu Dhabi led to an income unprecedented in its history. Specialised organisations were established and developed to deal with the increased national capital generated by oil production. This capital was used to provide foundations and infrastructure for the newly flourishing economy of the country.

Indicators of economic growth can be deduced from the size of oil production in relation to the rise in its prices. Another indication of economic growth is the amount of annual spending on urban development programmes. Increased financial capability played a crucial role in forming and influencing strategic urban policies and urban decisions in Abu Dhabi.

Figure 5.14 indicates that, in terms of per capita GDP, Abu Dhabi is among the richest financial systems in the world. The figure demonstrates that the per capita GDP in Abu Dhabi is higher than Ireland and the United States and close to that of Luxembourg.

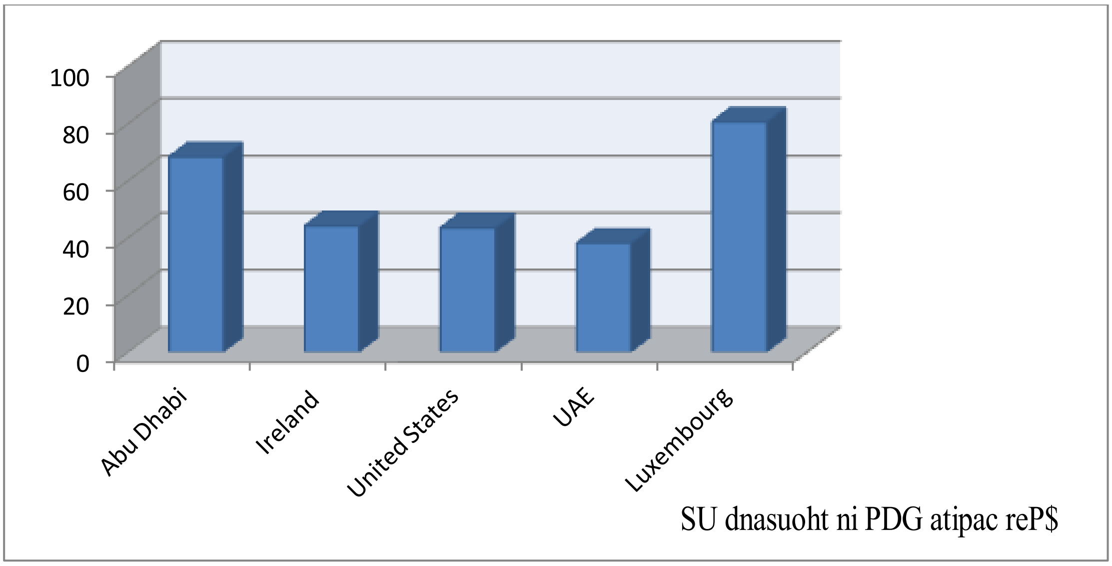

Figure 5.14 :Per capita GDP of Abu Dhabi in 2006
Sources: Abu Dhabi Chamber of Commerce and Industry, Madar Research and International Monetary Fund

5.4.4 Stages of Urban Development

The series of changes during this period of time were interrelated and affected all aspects of life. Unfortunately, there is a dearth of quality documentation and statistics recording these developments. However, in his book, *From Rags to Riches, a story of Abu Dhabi,* Al Fahim records the changes which he witnessed, and offers his view on the story of Abu Dhabi's evolution:

"*We had electricity by 1967, mobile phones in 1972, at roughly the same time, if not before, they were introduced in England, America or anywhere else. The electricity was supplied by diesel generating sets which had been purchased from Hawker Siddeley, one of two British firms who had competed for the contract. The generators were later completely*

dismantled and replaced by a much larger gas turbine generator which provided thousands of kilowatts of power to Abu Dhabi and AI Ain. Work was undertaken on more projects even before town plans were completely finished. Wherever we turned something was under construction - government buildings, homes, roads, telephone lines. Cables and sewer pipes were laid in deep trenches below ground, while above, street lights were put up on high posts. The Corniche was being built to protect the city against the ravages of the wind and sea. Water desalination plants were constructed; gas pipelines were laid to feed them as well as the electrical generators. The port was being dredged while the airport was under construction and both were completed in 1969.
On the educational side schools went up, teachers were hired, and text books were prepared. Some very fortunate young locals were sent abroad to begin their education immediately so they would be able to make a meaningful contribution to the development of the country in the long term.", (Al Fahim, 1995)

These stages in urban achievements were facilitated by extraordinary financial expenditure.

5.4.4.1 Preliminary Stage 1961– 1966

This period is considered the first era in the evolution of Abu Dhabi city. State funding was exceptional when compared to the economy of the emirate of Abu Dhabi and the regional economy. It is estimated that urban planning during this period cost approximately 336,000,000.00 Bahraini Diners, as at this time there was no Arab Emirate Dirham (AED). The population was estimated to be 4000 in the year 1962. The period of 1961- 1968 can be divided into two stages.

Abu Dhabi Municipality was founded in the year 1961. The goal was the initiation, organisation and development of all city facilities. This period also saw a new government approach. It was decided that the city would be developed according to a holistic strategic urban plan. Three consultant bodies were assigned to work on the vision of the government. These were:

- William Halcrow & Partners
- Scott Wilson
- Kirk Patrick & Partners

They submitted a diversity of suggestions in 1962. Figure 5.15 shows a layout was designed to outline the new shape of Abu Dhabi.

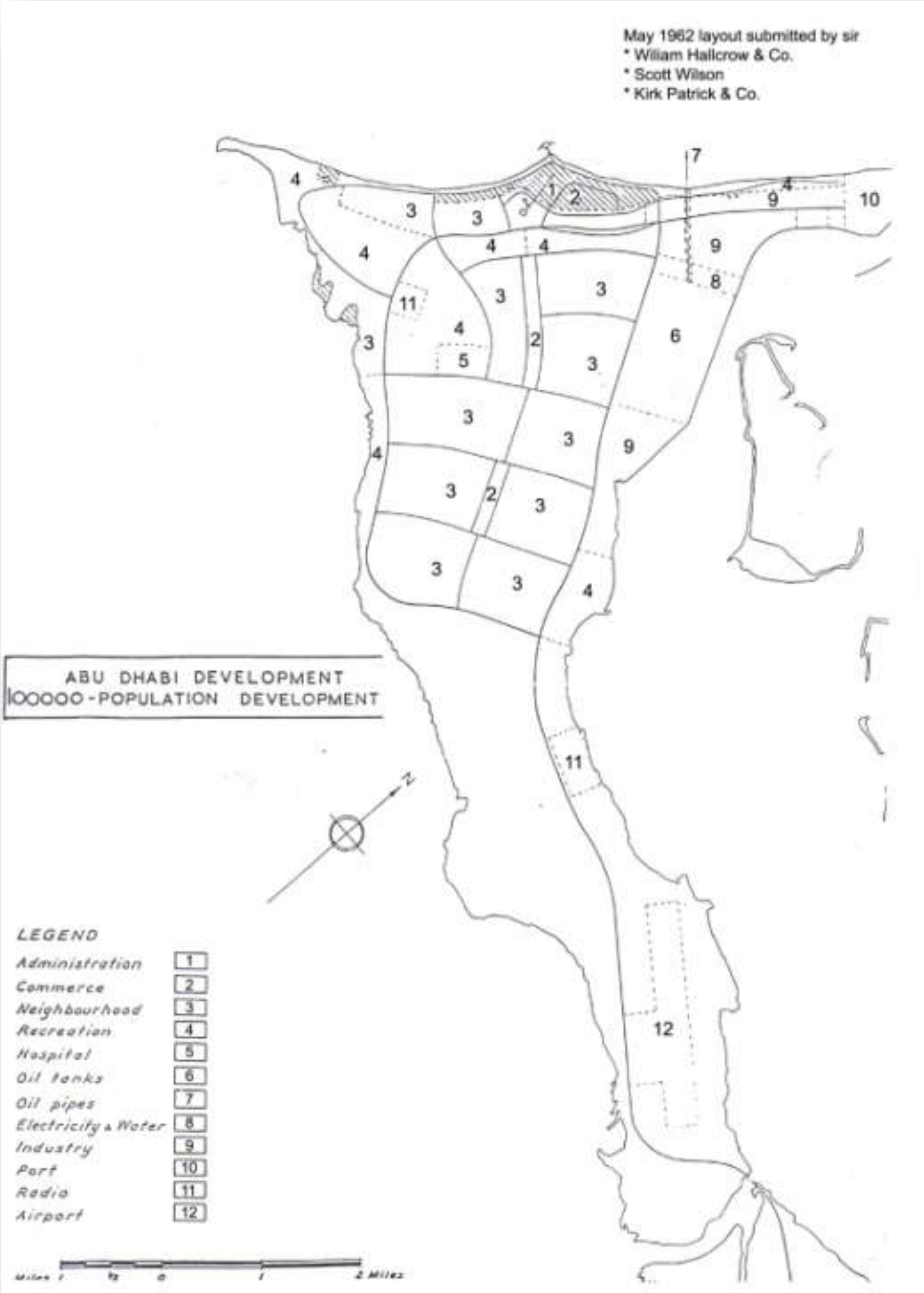

Figure 5.15: Zoning as proposed by William Halcrow & Partners, Scott Wilson and Kirk Patrick & Partners.
Source: Makhloof, 2006.

The urban planning report was based upon the following issues:

- Main activity of the city

The report confined the importance of Abu Dhabi to being a station to extract and export oil to non-coastal cities. The report referenced Das Island, which exports oil to coastal cities. The estimation of urban growth was not accurate, and proposed limitations on immigration.

- Anticipation of population

The population was estimated to be around 32,000 at that time. Studies anticipated a maximum population growth of 100,000 in the future of Abu Dhabi city.

- Technical proposals

  - Adopt northward orientation for buildings in Abu Dhabi
  - A road network based on a grid with curved roads
  - Ensure a raised ground level for buildings using reclamation dredging from the sea.
  - Water and sewerage systems.
  - A new layout was proposed to replace the old city.

- Administrative suggestions

Some administrative suggestions included the foundation of a Department of Works and an Engineering Department in the Municipality. No suggestions about the establishment of an Urban Planning body were mentioned.

The report missed the following indispensable elements:

- Political significance of Abu Dhabi

The report ignored the fact that Abu Dhabi was the Capital of Abu Dhabi Emirate.

- Administrative growth

The report did not anticipate the substantial governmental, organisational and administrative growth which would occur in the capital, given the exceptional funding available. In fact,the report predicted that there would be limited urban growth.

- Limited population growth

The maximum population growth anticipated was 100000. However, according to the Abu Dhabi Municipality & Town Planning Department (2003) the population was 10000, 22023, 81000 and 127763 in 1958, 1968, 1973, and 1975 respectively, see Figure 5.16.

The limitations proposed in the report ignored the dynamics of city evolution and imposed static urban conditions, as in the case of the sewerage treatment plant, Abu Dhabi Airport and the industrial area. Changing the locations of these strategic facilities became imperative. The airport was relocated from Al Butain on the island to a new location off the island. The location of the industrial area was later moved off the island to Al Musaafah on the mainland.

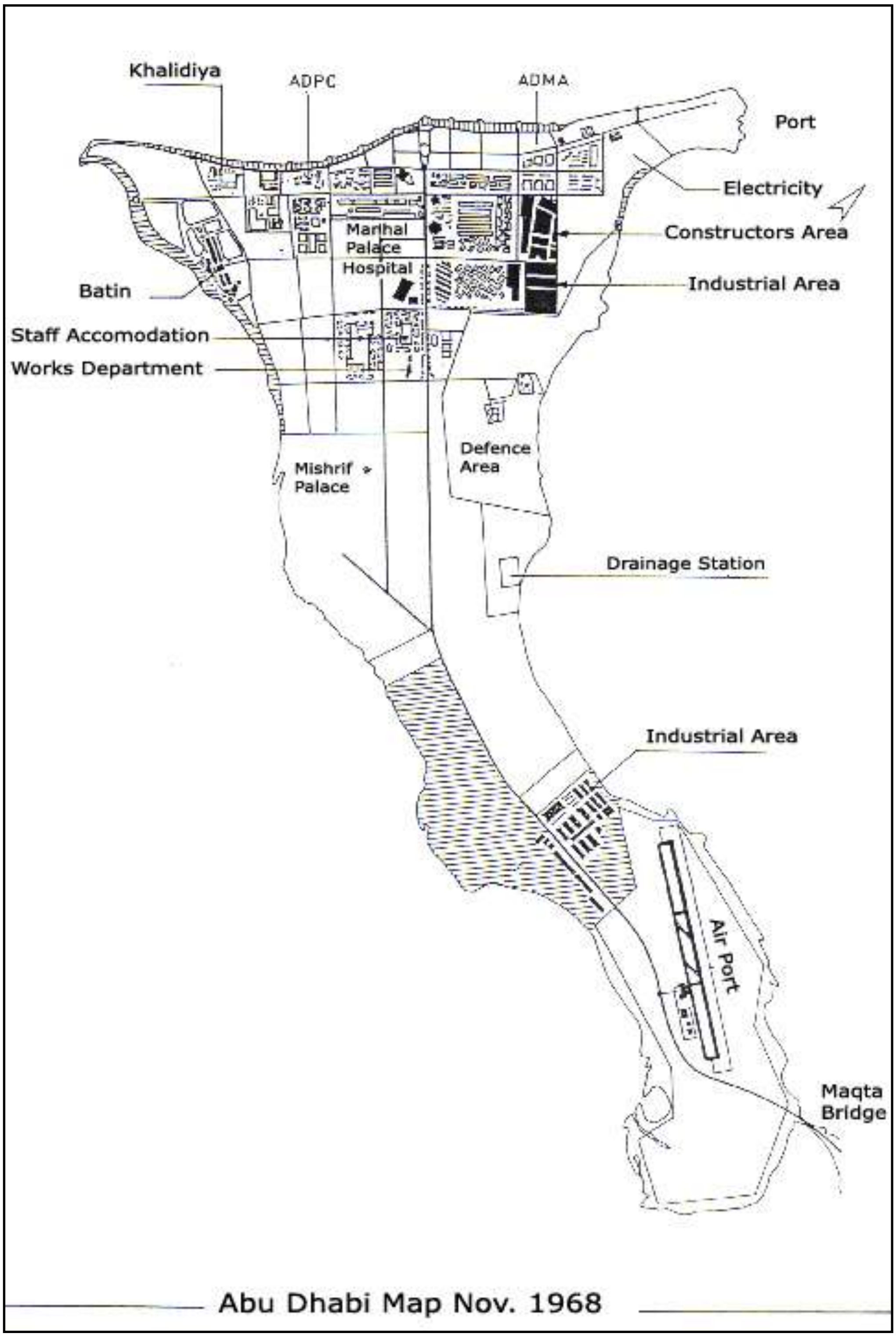

Figure 5.16: Abu Dhabi 1958 grid system, zoning, and infra-structure
Source: Makhloof, 2006.

5.4.4.2 The Period between 1966 and 1968

In the year 1966, governmental development in Abu Dhabi Emirate was extended. This led to the establishment of specific governmental bodies covering mandates such as building and urban planning . Other areas of support were provided by the initiation of educational, health facilities and services, see Figure 5.17.

Arabicon Consultants was assigned to update the original Halcrow urban plan of 1962. An evaluation was conducted in view the changes which would occur between 1962 and 1966. Arabicon prepared detailed plans for the newly proposed (then) residential neighbourhoods.

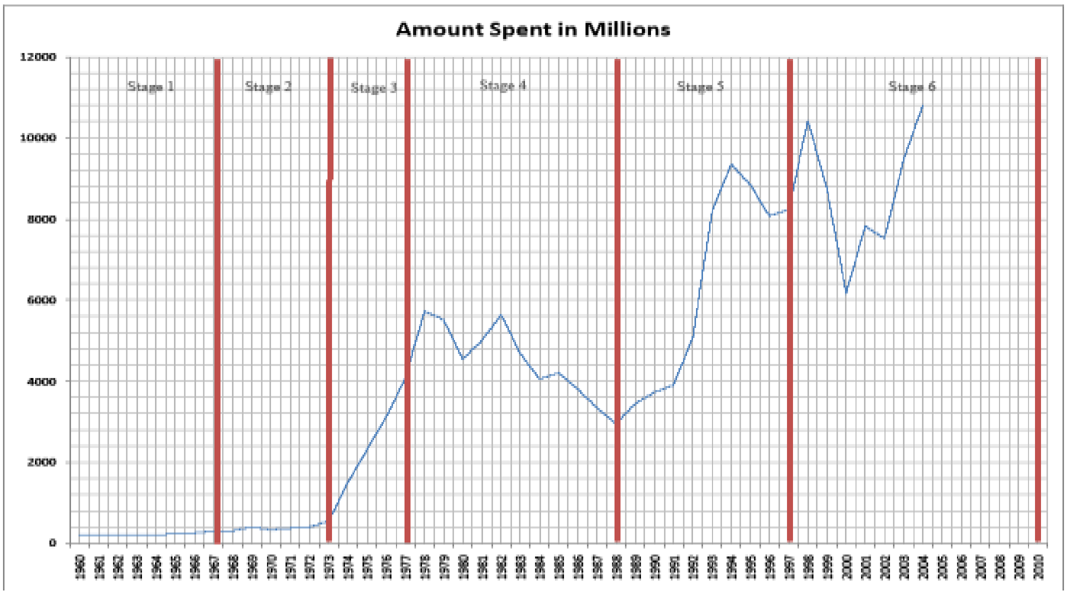

Figure 5.17: Governmental spending. The chart indicates the budgets allocated for urban development from 1961 to 2004.
Source: Makhloof, 2006.

In 1967, Abu Dhabi Municipality appointed a Japanese urban planner called Takahatshi as a chief town planner. He proposed a system for archiving documents and detailed urban drawings. He developed a general layout for the city. Working drawings, with in-depth attention paid to details, enhanced the quality of the urban design of the city, see Figure 5.19.

Figure 5.18: Aerial view of Bu Tinab area 1968.
Source: Abu Dhabi Municipality & Town Planning Department ,2003.

Figure 5.19: Plan designed by urban planner Takahatshi
Source: Makhloof, 2006.

Figure 5.20: Aerial view of Abu Dhabi, 1968.Source: Abu Dhabi Municipality & Town Planning Department, 2003.

It was at this stage that the Administration of Works signed contracts with a number of consultants, who were to design and submit full drawings for the following important projects:

- Al Manhal Palace
- The Grand Mosque
- Al Mina Area
- The airport
- Sewerage treatment plant
- Power plants
- Al Maqtaa bridge
- Al Cornish
- Water and power networks

The introduction of roundabouts in the main intersections of Abu Dhabi was considered to be an advancement for city traffic for the following two reasons:

1. They ensured secure roads with fewer accidents, as there were not enough policemen to monitor traffic. As power was not constantly available, no traffic lights were used at that time.

2. The gardens or monuments set into roundabouts at the centres of intersections formed aesthetic focal points in the desert environment.

One of the main changes in the amended urban layout plan in this period was the design of straight and perpendicular main roads in a grid system. This system was applied in the north part of the island.

5.4.4.3 Comprehensive Urban Establishment during 1968 to 1977

The period between 1968 and 1977 witnessed an unprecedented increase in oil revenues. It also witnessed independence, and the establishment of the United Arab Emirates. Abu Dhabi, being the capital of UAE, received a great deal of attention, as it represented the modernization and development of the country, see Figure 5.21.

Different information has been recorded regarding the population of Abu Dhabi during the year 1968. According to Maana Al Atiaba (1973), the population was 46375. However, according to the Abu Dhabi Municipality & Town Planning Department (2003) the population at that time was only 22000.

The development plans enhanced the urban, social and economic infrastructure of the whole emirate of Abu Dhabi, see Figure 5.22 and Figure 5.23. The effects included the following:

- **Economic plans;**

a. Annual governmental development
b. Proposals to increase income possibilities for all citizens
c. Diverse approaches to the enhancement of national income.

- **Social plans;**

Governmental administrations were modernised in order to elevate general performance and services, leading to better and higher living standards.

- **Urban plans;**

This period witnessed the establishment of the Administration of City Planning. A revised holistic urban plan was submitted for the whole island of Abu Dhabi. This plan included:

- Land use allocations
- Residential densities
- Main highway network
- Detailed plans for the central and sub-central areas
- General facilities (mosques, markets, schools, etc.)

The budget allocated to undertake the whole programme of planning and building was around 13,381,000,000 AED. The achievements of this period included the following:

- The horizontal expansion of buildings
- A new highway system
- A substantial range of new buildings appeared in the central area in the north of the island
- Greening the city
- New residential complexes, equipped with the necessary facilities
- Building high-quality brand hotels
- Building distinguished buildings to accommodate ministries
- Development of ports
- Development of Abu Dhabi airport

- Developments occurred off the island as well:

- An industrial city was established in Al Musaafah
- The planning and execution of cities outside of the island took place in cases such as Al Mafraq, Al Wathba, and Al Khaz.

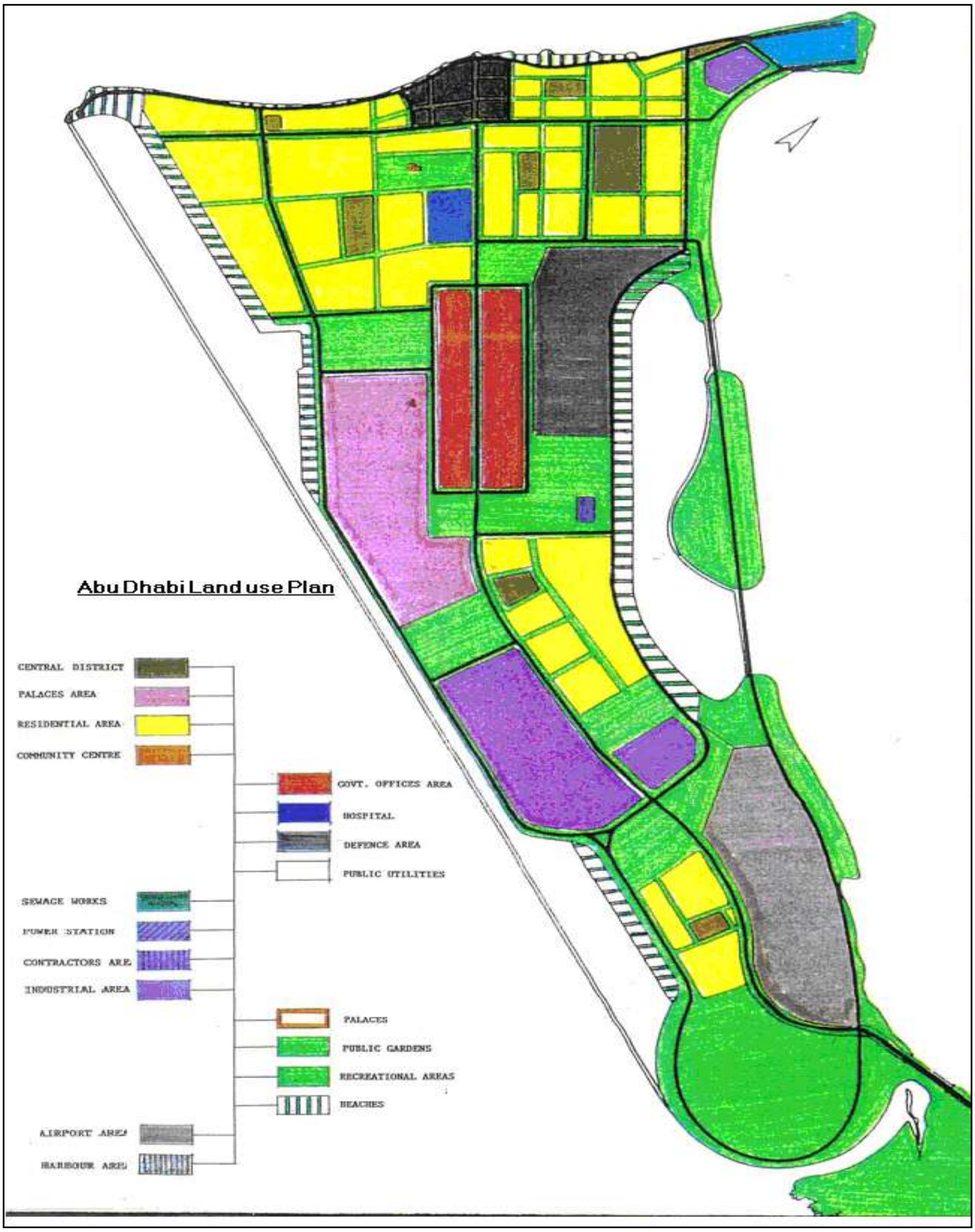

Figure 5.21: Urban plan as designed by the Administration of Works in the year 1968.
Source: Makhloof, 2006.

Figure 5.22: Aerial view showing city planning around Airport Road in the 1970s.
Source: Abu Dhabi Municipality & Town Planning Department, 2003.

Figure 5.23: of the prevailing building style in Abu Dhabi during the sixties
Source: Makhloof, 2006..

Figure 5.24: A view showing Hamdan Street in the 1970s
Source: Makhloof, 2006

5.4.4.4 Vertical and Horizontal Expansion 1978 – 1988

This era was characterised by both the horizontal expansion occurring in most areas of the island and the vertical expansion occurring in the central area, tourism club area and along the main highways.

W. Casher Consultants was appointed to design the traffic engineering of the city, see Figure 5.26 and Figure 5.27. Security standards were considered in designing new roads and bridges. A road network for the city was established, and traffic lights were introduced at main intersections, see Figure 5.25.

Figure 5.25:Aerial view of Abu Dhabi 1978.
Source: Abu Dhabi Municipality & Town Planning Department, 2003.

Figure 5.26: W. Casher Plan. 1978.
Source: Makhloof, 2006.

Figure 5.27: The city in the 1970s.
Source: Makhloof, 2006.

The development programmes covered the following areas:

1. State subsidies for investment and commercial buildings.
2. Development of main highways, intersections, traffic lights, internal roads, etc.
3. General services and facilities.
4. Upgrading Zayed port and the establishment of the free zone area.
5. Upgrading of Abu Dhabi airport (off island).
6. Building new residential sectors outside the island (Al Shahama, Bani Yas, etc.)

The total budget allocated to achieve the above projects was 46,493,000,000. The total population, according to the 1978 census, was 143280.

5.4.4.5 Internal Changes and External Expansion 1989 – 1999

During this period, work continued on the projects established in the previous years. However, this period did see a change in land use on the island. For instance, areas occupied by degraded houses with only one or two floors were demolished totally or partially in order to accommodate new commercial and residential properties with average heights of 3 – 6 floors. The same process took place in the central area of the island; old buildings were demolished and replaced with new towers with a height range of 15 – 30 floors, see Figure 5.29 and Figure 5.30.

Usually the Central Business District (CBD) of a city is dedicated to business use and is therefore largely abandoned at night. The CBD of Abu Dhabi, which is located in Abu Dhabi’s central area, includes official, commercial and residential properties. The presence of the residential buildings led to an atmosphere of activity and security in the central area, both day and night.

However, the urban planner neglected the essential need for provision of parking facilities for all buildings. As both residential and business buildings require parking spaces the problem is exacerbated over time.

Off of the island, building continued at a great pace. New residential and commercial communities started to appear, mostly of one or two floors, as in Musaafah and Khalifa City. New systems of highways connected Abu Dhabi island with the airport, and new residential compounds started to be constructed.

During this period, Abu Dhabi Municipality assigned W.S. Atkins Consultants to prepare the Abu Dhabi new general layout, extending up until 2010, see Figure 5.28

Figure 5.28: Holistic Abu Dhabi urban layout designed by Atkins, 1991
Source: Makhloof, 2006.

Figure 5. 29: Abu Dhabi Corniche in 1992.
Source: Makhloof, 2006.

Figure 5.30: Multi-storey buildings
Source: Makhloof, 2006.

5.4.4.6 Recent development stage 1999 – 2004

Development during this period took place both on and off the island. Huge projects, like the construction of Abu Dhabi Corniche, were initiated.

The main motivation behind the Corniche project was the lack of public space, thought to

Figure 5.31: Abu Dhabi Corniche after development phase 1 (2002)
Source: Abu Dhabi Municipality & Town Planning Department, 2003

be the result of having buildings in the central area close to the sea, see Figure 5.31. The project was initiated in order to create more outdoor public spaces for families, tourists and people in the city. The design encouraged biking, running, exercise, social gatherings, swimming and spending time in the natural environment outdoors. This was an advantage, especially for residents living mostly in apartment buildings.

The Government of Abu Dhabi undertook achieving landmark projects, as in the case of the Grand Mosque, which is located close to Maqtaa Bridge, see Figure 5.32. Other residential projects like Al Bahya, Al Shahama, Al Wathba, Al Falah established the suburban areas of Abu Dhabi, see Figure 5.33 and Figure 5.34.

Figure 5.32: The Grand Mosque of Sheikh Zayed during construction

Figure 5.33: Residential Complex Al Bahya Town
Source: Abu Dhabi Municipality & Town Planning Department, 2003.

Figure 5. 34: View of Abu Dhabi showing relative buildings and greenery in 2002
Source : Abu Dhabi Municipality & Town Planning Department, 2003

The total budget for governmental projects built between 1999 and 2004 was 50,013,027,000 AED, see Figure 5.35.

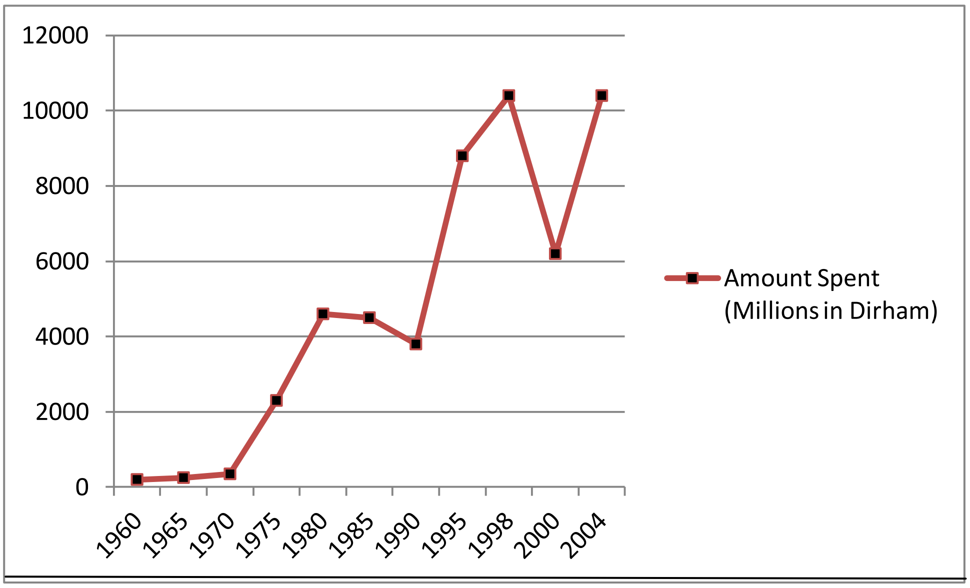

Figure 5.35: Governmental budget allocated for urban development from 1961to 2004.
Source: Makhloof, 2006.

5.4.4.7 Establishment of UPC & new investment reforms (2005 – onward)

Under Emiri Decree number 23 of the year 2007, the Abu Dhabi Urban Planning Council was established with the objective of being an expert agency responsible for all future urban developmental activities in Abu Dhabi.

(Abu Dhabi Urban Planning Council UPC, 2010)

For the first time in the history of Abu Dhabi, new reforms were initiated, allowing foreign investment in Abu Dhabi city. Prior to these reforms, only local nationals were allowed full free hold of properties. New investment companies were established by local and foreign bodies leading to the commencement of extraordinary design and budget wise projects.

Government authorities are committed to landmark projects with significant national and global impact. Projects such as Masdar, Al Sorbonne University, the Louvre Museum, Yas Island, Reem Island, Al Raha Beach, Emirate Palace, etc., represent innovative and momentous schemes in architectural and engineering history, see Figure 5.36 and 5.38.

Figure 5.36: Al Dana, Al Raha Beach Development
Source: Al Dar Properties

Figure 5.37: Bandar, Al Raha Beach development
Source: Al Dar Properties

Figure 5.38: Ferrari building, Yas Island
Source :Al Dar Properties

In 2007, The Abu Dhabi Urban Planning Council was founded. It is considered responsible for the future of Abu Dhabi's urban environment.

(Abu Dhabi Urban Planning Council UPC, 2010)

'Abu Dhabi 2030' is an urban structural framework plan. It is designed to help Abu Dhabi filter and respond to current and future development needs, establish a planning culture and introduce strong guiding principles for new development. According to the plan, the city's population is expected to exceed three million.

It is anticipated that the rapid population growth will be accompanied by some negative impacts, such as the erosion of the traditional Emirati lifestyle and unplanned development in natural areas, traffic congestion and shortages of affordable housing, see Figure 5.39.

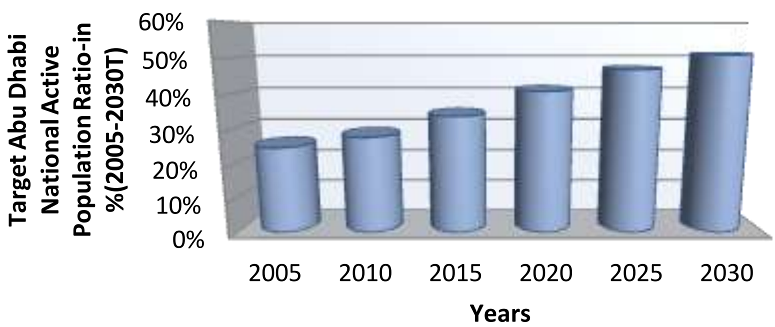

Figure 5.39: Target Abu Dhabi National Active Population Ratio, 2005- 2030,shown in percentage
Source: Abu Dhabi Statistical Year Book, 2005; Abu Dhabi Census, Abu Dhabi Economic Vision 2030 Team Analysis

The plan aims at creating a stronger sense of community and identity across the city. As a result, it will deliver new, higher levels of social cohesion and wellbeing.

The Abu Dhabi 2030 Urban Structure Framework Plan has been designed to optimise the city’s development. The aim is to lay foundations for a socially cohesive and economically sustainable community that preserves the emirate’s unique cultural heritage. Abu Dhabi Urban Planning Council UPC ,
(UPC, 2010)

5.4.4.8 The Philosophy of Estidama

Estidama is first and foremost, an aspiration – the desire to achieve a sustainable way of living. It is not a program, or a rating system, but an overarching way of viewing all aspects of our life based on its 4 pillars, environmental, economic, social, and cultural, to ensure that its sustainable goals and aspirations are well rounded.

(Abu Dhabi Urban Planning Council UPC, Estidama, 2010)

Estidama was launched in May 2008, with an objective of overall sustainable development in all facets of society. However, there is currently a profound emphasis on implementing and monitoring the pearl system in all of Abu Dhabi’s current and future projects. The system is applicable at the development, design and construction stages of a project. Tools such as the Pearls Rating System, pilot projects and stakeholder engagements are used, in addition to regulatory and code alignments and integrated design processes in education and training.

5.4.4.9 The Regulatory and Code Alignment

The current stage of development in Abu Dhabi is considered to be a unique opportunity. This is due to the fact that rapid development is occurring at a pace never witnessed before in the emirate’s history, while at the same time, governmental initiatives are working to draft development regulations, building codes and sustainability standards concurrently. This is an unusual practice, as typically, the adoption of progressive standards toward sustainable development involves adding sustainability policies and initiatives on top of long entrenched codes and regulations. This typical practice often leads to confusing standards, inefficient reviews and limited effectiveness.

For Abu Dhabi, this period offers a unique opportunity to draft all of its codes and regulations in a manner that will synchronise and align sustainable development practices with all other major codes. This practice will include framework development regulations and the building codes of the Municipality of Abu Dhabi.

(Abu Dhabi Urban Planning Council UPC, Estidama, 2010)

In order to have the CBD active day and night, the 2030 Plan proposed having a mixed use of facilities including, residential, commercial and office buildings. "*The intensity of residential development is strongest at the heart of the CBD but generally tapers off towards the peripheral edges, providing the opportunity for lower density housing communities in a city setting"* (Plan Abu Dhabi 2030/ Urban Structure Framework Plan, 2007, p.13).

A well-conceived transit network will help guide and phase development as Abu Dhabi's population increases.

"The first component is a high speed rail line…The next layer is a fine-grained network of surface light rail, street-cars and buses to ensure that no one ever has to walk more than five minutes to use public transit….Finally, since walking is inescapable with even the most advanced transit planning in the world, improving the streetscapes to maximize pedestrian safety and comfort is an absolute priority… This will involve increasing the width of sidewalks, adding shade trees and shading devices, and comprehensively designing the entire public realm."(Plan Abu Dhabi 2030/ Urban Structure Framework Plan, 2007, p. 64)

5.4.4.10 IRENA HQ in Abu Dhabi

Abu Dhabi was selected to host the headquarters of the International Renewable Energy Agency (IRENA). The agency advises governments on technical and financial issues linked to renewable energy and promotes the use of such technology in developing countries. Strong objections have been raised by some nations concerning the perceived contradiction of Abu Dhabi being one of the largest oil exporters in the world and at the same time seeking to house the IRENA agency.

The UAE is committed to environmental issues, and has proposed to locate IRENA's headquarters in Masdar. Hosting IRENA in Abu Dhabi demonstrates the commitment of its government, which is a fossil fuel exporter, to the enhancement of renewable energy. The government's vision is to be a lead exporter, now and in the future, of all types of energy, including renewable energy resources. The government plans to make renewable energy sources up seven percent of its total energy production by 2020.

5.5 Chapter summary

Abu Dhabi was established as a capital city by the Bani Yas tribe in 1793. Its location was strategic, due to its ability to provide suitable drinking water, easy transport by land or sea, available economic resources and a safe and easily defensible location. The pace of development in the region was limited until the discovery of oil in the Tarrif area in 1954, at which time the city began to expand beyond its original status as a small coastal desert city.

The sixties and seventies of the twentieth century witnessed an unprecedented increase in oil revenues and the establishment of the United Arab Emirates. The eighties were characterised by both horizontal and vertical expansion in the island's business and residential areas. During the nineties, degraded houses were demolished and replaced by relatively higher buildings with 3 to 6 floors.

At the dawn of the third millennium, landmark projects in architecture and urban planning were instigated. One of these projects is the Abu Dhabi Corniche. From the year 2005 onwards, new investment reforms were initiated in Abu Dhabi Emirate. International investment was permitted for the first time in history of the real estate industry.

In 2007, The Abu Dhabi Urban Planning Council (UPC) was founded. It is considered responsible for the future urban environment of Abu Dhabi. UPC designed Abu Dhabi's 2030 urban structural framework plan, which is designed to help Abu Dhabi respond to current and future development needs.

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CHAPTER SIX:
Research methodology

6.1 Introduction

The chapter provides a detailed description of the research methods adopted for this study. It highlights the salient research issues examined and provides a rationale for answering the research aims and objectives. In addition, it outlines the procedures adopted for conducting the research. Finally, it examines the research sampling methods selected for this study.

6.2 Salient research issues

The key concern of the study is to evaluate the cost-effectiveness of shifting the growth of Abu Dhabi from a conventional approach to city development and building design into an environmentally sustainable one. It also sought to address the issue of sustainable lifestyles and attitudes.

The research objectives are as follows:

- Establish links between the current global sustainability problems and their root causes, originated during the Industrial revolution.
- Examine the local vernacular architecture and determine the most suitable, applicable and sustainable solutions that can be implemented in the building industry of this era.
- Ascertain the prevailing environmental conditions by examining human activities that have affected the global environment and led to the deterioration of the environment.
- Analyse the cost-effectiveness of the salient approaches in building design to achieve low impact buildings.
- Investigate the relationships between building design, building cost and the environmental impact.
- Revisit the prevailing sustainable solutions in the remaking of Abu Dhabi as a sustainable model coastal city.

6.3 Research methods

The methodology adopted for this research was based on quantitative and qualitative approaches. The quantitative approach involved a case study research approach involving a detailed examination of three buildings contrasting in sustainable design approaches. Case study research can help to provide a better understanding of a complex issue such as sustainability. Case studies focus on detailed analysis of a small number of events and seek to clarify their relationships. Case study research method was defined as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used (Yin, 1984). Three buildings were selected to determine the cost-effectiveness of the proposed sustainable solutions.

In order to examine the issue of sustainable lifestyles and attitudes, a questionnaire survey was adopted. Questionnaires provide useful tools for a researcher when the requirement is to ask a number of people the same questions. The advantage of questionnaires is that the questions are self-administered and the researcher does not supervise the person who is filling in the questionnaire. Users of the three buildings were asked to complete the same questionnaires to determine their attitudes towards sustainable lifestyles and sustainability agenda.

6.4 Procedure

The research involved an environmental investigation of power consumption, carbon dioxide emissions, indoor and outdoor temperature, indoor and outdoor relative humidity, and levels of indoor carbon dioxide. Monitors were installed in the three prototype buildings for a period of time, and the results of the readings were compared and analysed. The monitoring included the thermal performance, power consumption and carbon dioxide indoor levels.

The study also covered the sustainable applications used within the vernacular architecture of the Gulf region. It also covered the urban history of Abu Dhabi and the current governmental initiatives toward shifting the growth in an environmental sustainable direction.

The field study includes monitoring two prototypes to investigate the financial and environmental cost of each prototype.

a. Masdar Institute of technology, and
b. Abu Dhabi Police Academy

The two prototypes must be close in the physical shape, load of occupancy and the facilities they offer. Areas of similarity must include the following;

a. Number of building storeys
b. Similar structural design
c. Similar type of usage and facilities
d. If possible, similar load of occupancy

The methodology also includes a questionnaire to be undertaken by the occupants of both buildings in order to uncover environmental awareness, passion toward sustainability and the limitations that need to be addressed in order to enhance environmental awareness.

6.5 Sampling Methods

It was important to choose three prototype buildings that can represent a diversity of design approaches, concepts and strategies. Three prototypes were selected to represent a sustainable design model; a vernacular design; and a conventional design. The following buildings were selected as case studies:

a. Masdar Institute of Technology, to represent the high-cost Government subsidised sustainable prototype building.

b. The Educational building in Abu Dhabi Police Academy to represent a building partially close in design strategy to the heritage building due to its use of the courtyard at the centre of the building. The relative proportion of the depth, width and height of the courtyard with the surrounding class rooms allowed best shading and ventilation rates.

c. The Administrative building in Abu Dhabi Police Academy to represent the conventional type of buildings. This building uses a huge closed atrium in the centre of the building which is fully air-conditioned and has no skylight or natural ventilation openings.

A successful questionnaire survey one of the critical requirements is the size of the sample and its representativeness. In quantitative studies, when the size of the population under the investigation is small (less than 50) a possible approach is to distribute questionnaires to the whole population. However, when a larger population is targeted, selections of representative samples are necessary. Sampling plans include probabilistic and non-probabilistic methods. Probability sampling is used where the researcher has access to a sampling frame. Non-probability sampling is used where the researcher can only have little control over the selection of participants or controlled selection of participants is not an issue. A simple random sampling method was used in this study. The target population was defined as all residents of the selected buildings. Ninety users of the three buildings responded to the questionnaire. Their responses were compared and analysed.

6.6 Research Tools

The experimental research tools were based on a diversity of monitoring procedures. The tools needed to conduct the research were the following:

6.6.1 **Thermal performance digital electronic monitors**; to investigate the temperature and the relative humidity of specific spaces in and outside the Institute. HOBO monitors were ordered from the United Kingdom. It was originally expected to have the indoor temperatures as being similar due to the use of air-conditioning (AC). Yet, it was found that the best way was to check if the AC was running all the time or only sometimes. The outdoor monitors were used in the courtyard of the Educational Building, the courtyard of Masdar complex, the exposed outdoor open area in Masdar and the outdoor exposed area of the Educational Police Academy.

6.6.2 **Monitors of power consumption in kilowatts**; meters to measure the power consumed during the research period. The Police Academy complex is a big site and holds many buildings. In order to take accurate readings of the two buildings chosen, two monitors were installed; one in the Administrative building, and a second monitor used for monitoring the Educational building. In Masdar a different scenario was going on, based on the fact that they have full monitoring systems for each and every facility. However, in October, power consumption readings were taken in the Police Academy, but those of Masdar were not activated. In May, 2011, power monitors in Masdar were activated. Readings were taken every 15 minutes; therefore, Masdar power readings were only available in May 2011, for two weeks only.

6.6.3 **Carbon dioxide monitors**; to investigate the levels of this gas indoors in order to examine to what extent the indoor air quality provided a healthy environment for the occupants. HOBO CO_2 monitors were utilised and readings conducted during two periods. In the first two weeks of October, 2010 the monitor was activated in one of the Educational Police Academy lecture halls. For the second two weeks of October, 2010 the same monitor was used in the lecture hall in Masdar Institute of Technology.

6.6.4 **Questionnaires**; to be designed to investigate occupants' satisfaction, thermal comfort and production levels induced by living in a sustainable building compared to its counterpart of a conventional building indoors. The questionnaire shall also investigate the effect of living in a sustainable environment on the environmental awareness of the occupants.

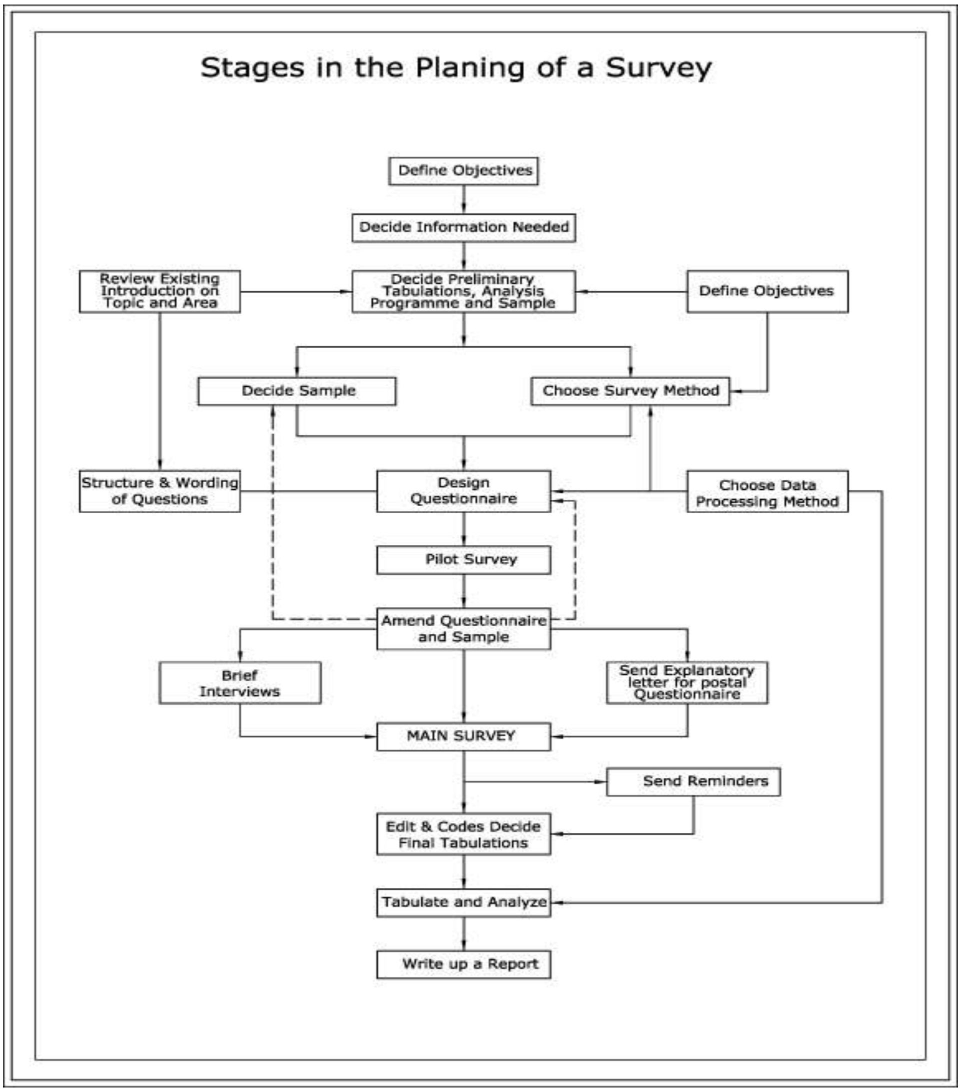

Figure 6.1: Stages in the planning of a survey
Source: Cohen, 2007

According to Cohen, L. (2007), in his book "*Research Methods in Education (6th Edition)",* the stages of planning a survey are as follows, see Figure 6.1. With the above in mind, the questionnaire design is discussed in the following sections.

6.7 Questionnaire Design

In an attempt to surround the whole scenario of environmental sustainability, in addition to social and cultural sustainability awareness, a questionnaire was seen as appropriate to support this research. A diversity of issues has been listed in order to reveal the impact of occupying a building designed to some extent with some environmental considerations in mind.

The questionnaire was delivered to the students of Masdar and Police Academy. 43 students from the Police Academy filled in the questionnaire, whereas only 35 students from Masdar completed the questionnaire. The process was deliberately done in the second semester of the year, in order to give new students the chance to build impressions about the building they are studying in.

6.7.1 Ethical consideration and obtaining informed consent

Voluntary informed consent was considered the norm for the conduct of this research. In conducting this research, as required by University of Wolverhampton, ethical approval was sought from the ethics committee. Permission was obtained from all participants in the research. Participants were informed about the various activities of the research and were given the opportunity to withdraw, including any information and/or materials they supplied if they did

6.7.2 Sustainable Awareness

In order to investigate sustainability awareness, the following questions were delivered:

1. Have you ever heard about sustainability?
2. Have you ever come through an educational or media programme about sustainability?
3. Would you be interested in studying about sustainability?
4. If a change of attitude from high to moderate consumption would save Earth's resources for future generations, would you be interested to be part of this change?

6.7.3 Thermal comfort and occupant's satisfaction

Sustainable design respects, and responds to, occupants' needs, whether they are physical needs or needs for convenience. The following questions investigate the thermal comfort and the occupant's satisfaction.

1. Do you consider the indoor environment of this building to be comfortable?
2. Would you build your future house on a sustainability basis?
3. Do you think that this building is healthy?
4. Does it induce fewer flues, less allergies or asthma, and better breathing?
5. Do you enjoy using a sustainable research building? (for Masdar students only)

6. Would you recommend this building type to others? (for Masdar students only)
7. Does living in such a building change the way you dress? (for Masdar students only)

6.7.4 Effects on Performance or Production Levels

The questionnaire also aims to investigate the effect of the design of the building on students' performance and production levels.

1. Do you feel that the indoor living environment of your building affected your productivity level at work or study?
2. Would you prefer natural lighting rather than artificial lighting?
3. Do you think that natural lighting makes you feel happier?
4. If you have homework would you study in the Academy or study at home?

6.7.5 Environmental Awareness of the Occupants

It is expected that a specific design has special effects on the occupants. Therefore, the following questions seek answers regarding the occupants' environmental awareness.

1. Do you have a good understanding about global warming and the greenhouse effect?
2. Will you be willing to avoid, as far as possible, imported goods, in order to reduce transport trips and CO_2 emissions respectively?
3. Do you think recycling paper is:
    a. Reasonable?
    b. Possible?
4. If you were told that to be more sustainable you should not eat foods out of season, would you follow that advice?
5. If you want to go up only one or two flights of stairs, would you take the stairs or an elevator?
6. During spring or autumn, when the temperature is moderate outside, would you open windows or switch the air-conditioning on?
7. Does studying or living in this building lead to your learning more about
    a. Power consumption?
    b. Healthy indoor environment?
8. Does living in an environmentally friendly building raise your environmental awareness?

9. If yes, please list in points below any sustainability lessons learned.

6.7.6 Impressions

The questionnaire also demonstrates the opinions of the students and how they see the effects of these buildings on them.

1. Do you think that it is important to design environmentally friendly buildings?
2. In your opinion, would we gain any of the following benefits:

a. Financial savings?
b. Environmental savings?
c. Education for future generations?
d. Health savings on a personal and national level?
e. Savings of planet resources?
f. Minimising CO_2 emissions?
g. Participating in giving UAE a green image?

3. Would you be ready to be part of a Governmental approach towards making Abu Dhabi a sustainable city?

6.7.7 Future Approach toward Private Buildings (Residential, Investment)

Students were asked if they are able to make an investment, would they consider asking consultants to design that investment using a sustainable approach.

6.7.8 Heritage Appreciation

According to the Pearl Rating system (Estidama) designed by the Urban Planning Council, sustainability is based upon four pillars, one of which is culture. Therefore this section of the questionnaire investigates heritage appreciation of the students:

a. Do you feel that the building heritage of this culture deserves to be re-sighted?
b. To your knowledge, do you feel that there is any link between the building you are using now and our ancestors' way of building?
c. Have you learned anything using this building that makes you feel closer to the heritage of our region?

d. If you were asked, would you be interested to learn more about the living environment of our ancestors, given that they lived in sustainable environmental systems which had harmony with nature and no negative impact on the planet?
e. What would you choose:
f. Raise up your children in a built environment that is convenient to a certain level, yet it has strong links with our specific heritage and culture; or
g. Raise them up in an absolutely convenient environment with no link to our building heritage?
h. Do you think that there is proper public awareness through education or the media about the values, techniques and importance of our heritage buildings?

6.7.9 National Responsibilities

This section investigates the general awareness of students toward their country and its natural resources.

a. Is acting in an environmentally sensible manner relevant to being patriotic?
b. The Abu Dhabi Government is making profound efforts toward sustainability; do you feel that the local public is making serious attempts in the same direction?
c. Should we become more careful with using natural resources?

6.8 Anticipated Research Outcomes

The in-depth study of the environmental and financial cost of all the buildings investigated will indicate the possible space of improvement on a building scale and an urban scale.

1. A full investigation of the power consumed in both prototypes will be undertaken.
2. The readings will be translated into financial cost of each prototype in order to extract the financial savings if available.
3. The financial cost will cover both running and initial costs of each prototype. Inflation shall be considered for both costs.
4. Power consumption can also be translated into a measure of the carbon dioxide footprint emitted into the atmosphere by each building.
5. Thermal monitoring (temperature and relative humidity) will demonstrate the difference in building indoor and outdoor environments. However, it is anticipated that the indoor environment of the conventional type might be cooler and more convenient

in summer due to the use of air-conditioning. Yet it is also anticipated that this will not be the case in the surrounding spaces, in courtyards or the outdoor landscape.

6. Questionnaires are anticipated to demonstrate the occupants' impressions and interaction with the local environment. A comparison between the environmental awareness induced by living in an environmentally friendly building or a conventional building shall be investigated.
7. The CO_2 levels in the indoor spaces will indicate the health levels of indoor spaces.

6.9 Chapter Summary

This chapter reviewed a general listing of the context of the study, which was thoroughly examined in the literature review. This was followed by stating the hypothesis of the study. The methodology employed and the research tools have been listed, categorised and analysed. They included monitoring the thermal performance, monitoring power consumption, calculating the resulting carbon dioxide emissions, and the questionnaire design.

The questionnaire investigated a diversity of elements: sustainability awareness, thermal comfort and its effect on production level, environmental awareness and students' impressions, the effect of the prototypes used on future investment of students, heritage appreciation and national responsibility toward creating a sustainable built environment.

Chapter Seven will undertake a full investigation through the field study. Three prototype buildings with three different design strategies located in two sites will be undertaken: Masdar Institute of Technology and Police Academy of AD Police. All the tools of the methodology mentioned above will be tested. Chapter Seven should also provide a summary of each part of the field study.

Chapter Eight shall wrap up the study by giving the conclusions of each and every chapter of this research. It is anticipated that the findings of Chapter Seven will cover indoor levels of carbon dioxide findings, thermal performance findings, power consumption findings, and questionnaire findings.

Chapter Eight will conclude by looking at contributions to knowledge and proposed strategies emerging from the field study investigation, if any.

6.10 References

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CHAPTER SEVEN:

Field study and Results Analysis

7.1 Introduction

To examine the cost-effectiveness of shifting the urban strategies of Abu Dhabi into sustainable strategies in order to alter its growth from the scenario-as-usual, modern non-environmentally-friendly city into a healthy sustainable one, two prototypes were developed and investigated. The choice of the two included the selection of Masdar Institute of Technology, with its residences, and the Abu Dhabi Police Academy Administrative and Educational Buildings.

The research examined a diversity of matters through monitoring specific spaces and at the same time exploring the occupants' awareness and impressions of the thermal, health and comfort levels of the places investigated.

The two sites investigated offered three deferential patterns in construction. The diversity of the spaces not only covers the structural and constructional details of the buildings, rather it expands to the huge differences in the interior and surrounding landscape. A brief overview of the different types investigated are listed below, before going any further in fully examining the prototypes subject to the field study.

1. A state-of-the-art new research project with high budget allocation and full attention to details of sustainable design; is the case of Masdar building.

2. A low-cost two floor building of classrooms surrounding a confined courtyard built with concrete block walls and a reinforced concrete slab on the ground floor and steel trusses roof in the first floor; is the case of Police Academy classrooms.

3. A two-storey administrative building built with hardly any insulation, and the same system of the Educational building in the Police Academy. However, the main difference is in the expanded double volume in the centre of the building. The central double volume area could have been used as an atrium with sky light and natural ventilation, but this has not been considered in design.

The underpinning elements of this research are based upon a diversity of factors such as; power consumption in Kw/h, temperatures in $^{\circ}$C, percentage of relative humidity and occupant responses and sustainable awareness. The study diagram (Figure 2.6 Study Diagram) indicates the research tools and the sequence of using them.

However, two methods have been used to encounter all the elements affecting the environmental impact of the case studies, and the incurred environmental awareness of the occupants. The two elements are;

1. An experimental study that includes monitoring different measures in three research buildings, and
2. A questionnaire designed to investigate the effect of the building on the general sustainable awareness of its occupants.

The aim is to link the general performance of a building to the impact of that performance on the occupants. It is anticipated that the overall attitude of the occupants would have to be affected to a certain level by the general environment of the occupied building. These two aspects can then be aligned to the initial and operational costs of the building.

7.2 Masdar Project

Masdar Project has been described in Chapter III 'Research on Environmental sustainability' as a case study. The project represents a research city which obtains a multi-functional high density urban fabric including residences, work, retail, and an educational centre. Masdar Institute of Technology is intended to be 'one of a kind' in its region, engaging its faculty and students in the adventure of searching for energy conservation, renewable energy resources and best practices in sustainable living. The first batch of 90 students started in September 2010. The importance of investigating Masdar is double, in addition to investigating best practices of environmentally sensible design, that of the research investigating the effect of living in a sustainable building on the general awareness of the natural environment, between a group of young people who have grown up in a non-responsible and non-sensible pattern of consumption.

7.2.1 Masdar Residential Buildings

The design approach took into consideration the importance of the technical sustainable application beside the spiritual value of traditional looks that brings back memories of the traditional sustainable architecture of the region. Balcony screens are decorated with innovative Islamic patterns designed to imitate the shape of the traditional mashrabiya screen. They are made of light thermal mass material, which is glass-reinforced concrete material GRC. The low thermal mass limits the time of heat radiation after sunset. The screens protect building exterior walls from the sun in order to reduce heat gains, while their decorated screens help ventilate balconies. "*The balconies create a self-shading façade, screening the building envelope. An inner layer of 90 per cent recycled aluminum reflects light within the balcony, and its high thermal conductivity allows it to cool down quickly.*" (The Architects' Journal, (11.02.2010), Low Carbon Design. Page 30.)

The exterior walls environmental details of Masdar buildings have been intentionally made highly insulated to ensure best thermal performance see Table 7.1.

Exterior walls environmental data		
Materials	***U-value (W/m²K)***	***Material Embodied energy (kg CO_2/m²)***
Glass	***1.20***	*65.20 (16mm thick)*
Timber	***1.20***	*0.591 kg CO_2*
Aluminum (recycled)	***0.25***	*14.2 (3mm thickness)*
Glass reinforced concrete	**-**	*12.2*

Table 7.1: Exterior walls environmental data
Source: The Architects' Journal, (11.02.2010), Low Carbon Design. Page 30

Windows in the apartments allow natural ventilation, See Figure 7.1. On many evenings in the UAE natural ventilation is favourable; however, it is comfortable at day and night-time during winter. The more exposed upper floors are about 25 per cent glazed, while the glazing ratio on shaded lower floors increases by up to 45 per cent. A high-level reflective clerestory, and vertical slot windows maximize daylight in the apartments.

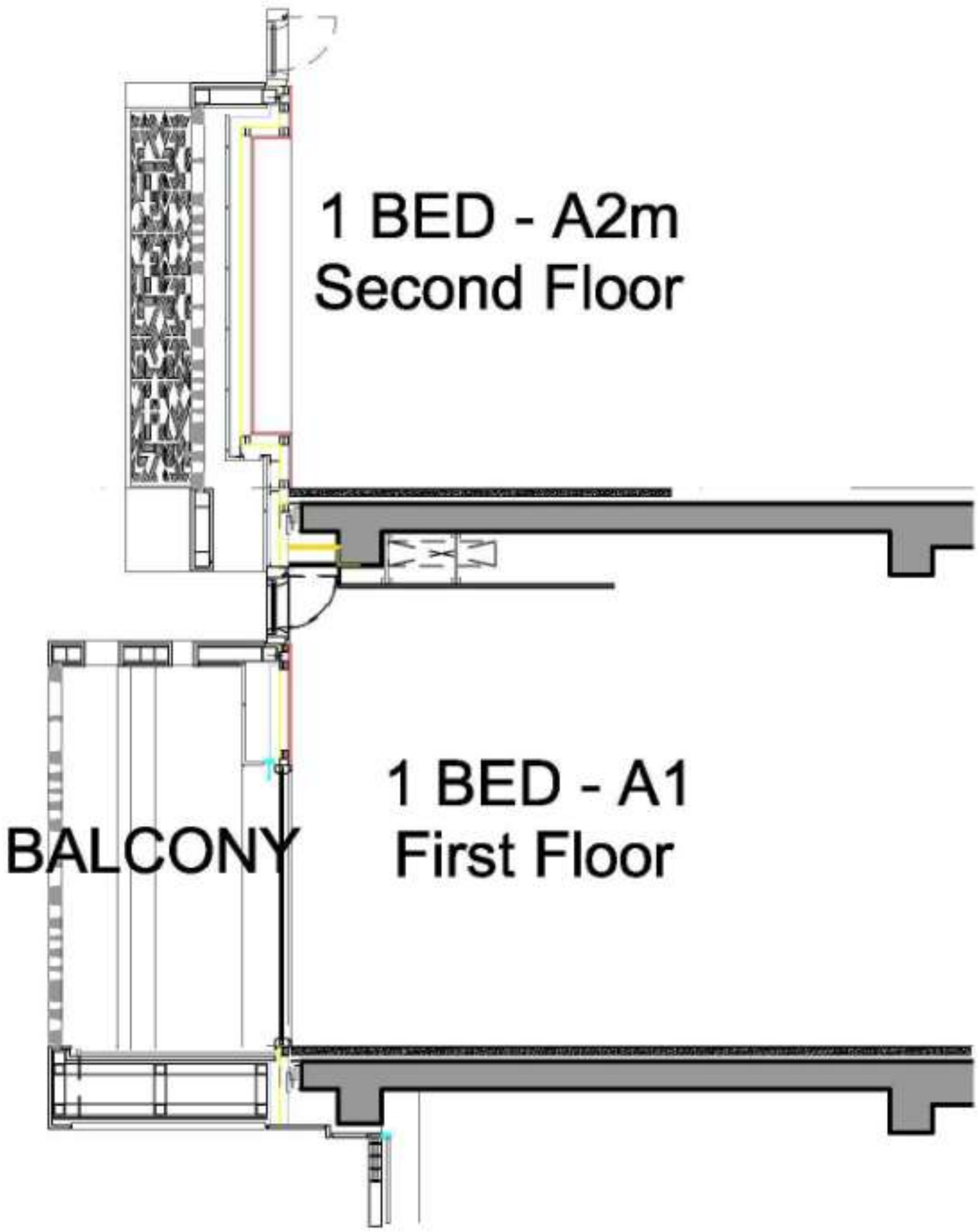


Figure 7.1: Partial section of Masdar Residential Apartment
Source: PDF extracted from Masdar drawings

The four-floor residential buildings that surrounded Masdar Institute of Technology have the traditional elevations and patterns with either narrow alleyway or semi-closed courtyard, see Figure 7.2.

Figure7.2: Four-floor residential buildings surrounding Masdar Institute of Technology.

7.2.2 Masdar Laboratories

One of the main concepts of the Masdar Institute is shared spaces between interdisciplinary research facilities and various academic programs. Every design decision was influenced by the need for flexibility and adaptability, and the labs will have easily moveable casework systems and quick disconnects for all bench services. The laboratories must contain a stable internal temperature due to the sensitivity of the laboratory-calibrated, as they should be open around the clock.

Laboratories are eleven metres column-free depth. It is arranged in a C-shape around a court providing light. The façade is highly insulated and air-tight with a glazing ratio of 22%.

As it is the case in the partial section of the residential building, a high level continuous clerestory illuminates the deep spaces of laboratories as the light is reflected by aluminum light shelves.

The level of windows has been deliberately made either at the same desk levels or at eye-level in some specific locations. Windows have been shaded with a combination of fins. Horizontal fins are used to cut the high-angle sun, whereas, vertical fins are used cut out the low angle-sun.

The Ecotect computer modelling building analysing programme was used to examine the maximum use of shades to avoid and minimise heat gains as much as possible.

7.2.3 Masdar outdoors

The wind tower in the main courtyard in Masdar is designed to suck the warm air from the courtyard and all the narrow alleyways surrounding it in order to cool the micro-climate of the outdoors inside Masdar Complex, see Figure 7.3. Two types of outdoors will be investigated. The first type is the intimate walkways surrounding the Institute Building and separating it from the surrounding residences. The second outdoor spaces to be investigated are exterior spaces at the outskirts of Phase I, which represents the educational complex. Sensors will be located in shaded spaces in order to avoid the direct radiation of floors and record the air temperature and its relative humidity. Co2 levels will also be tested. It is anticipated that later links between comfort levels, public awareness and the data recoded will be used to extract findings.

Figure7.3: Wind tower in the main courtyard of Masdar, designed to suck hot air upwards

7.3 Abu Dhabi Police Academy

When a tertiary academy in Abu Dhabi was approached, the administrative building were a bit hesitant and later reluctant due to their feeling that the ineffective thermal and energy performance of their buildings might affect the image, reputation and marketing of the Institute.

Figure 7.4: Police Academy Administrative building

Therefore, the Police Academy Campus was chosen, see Figure 7.5. Two types of buildings with two different design strategies were investigated; the Administrative building with its 'square plan' shape and Educational Buildings with their rectangular plan shape, see Figure 7.4, and an open courtyard in the middle, see Figure 7.7. Monitors were installed in both buildings and daily readings were taken throughout a period of over a month.

This Academy was developed gradually in stages. The Educational building chosen, was built around 1996 by a consultancy firm called 'Architectural Consultant Group'. The structural type is generally similar to the current type of low height buildings, except that the roof is a steel truss with steel cladding.

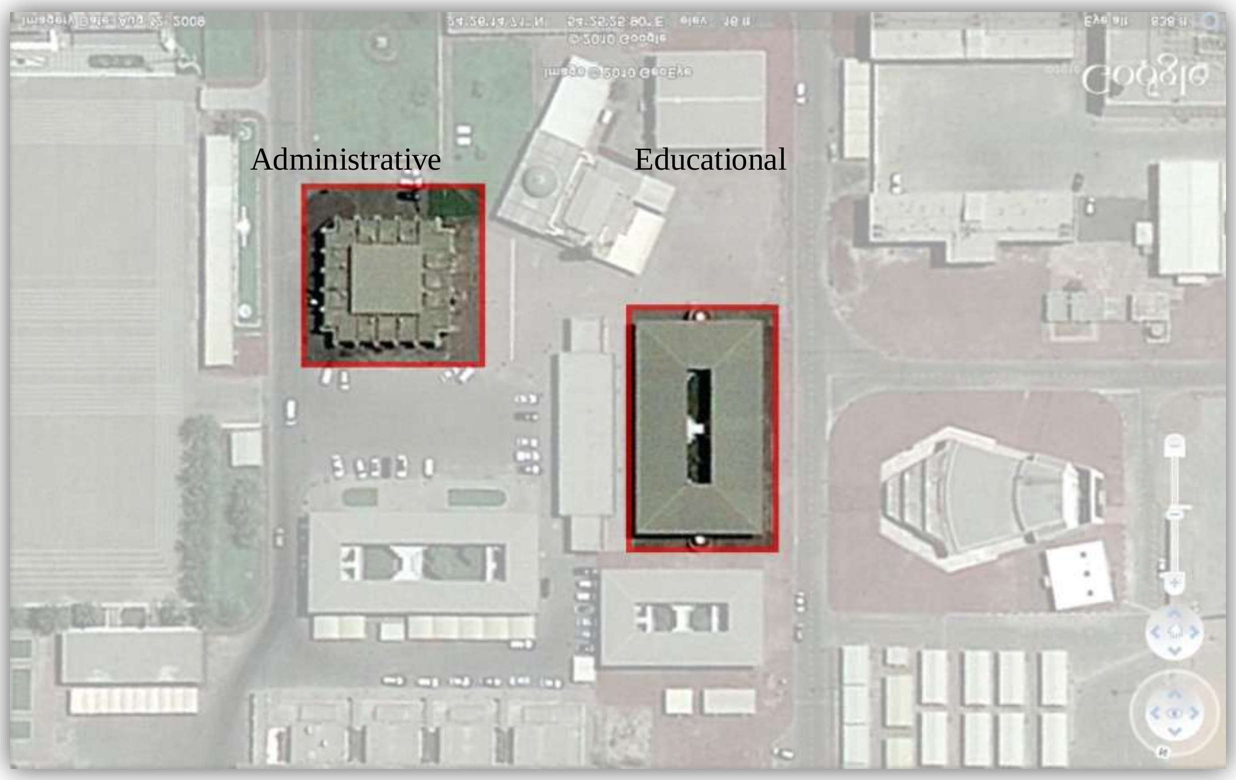
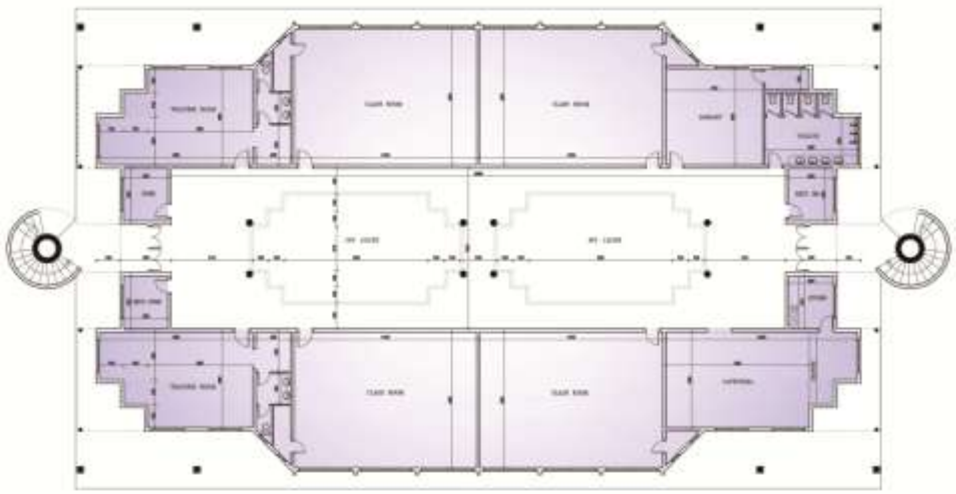


Figure7. 5: Aerial view of the Police Academy campus showing the two blocks chosen to be investigated.
Source: Google Earth, 2010

7.3.1 Educational Building

Two lecture halls have been chosen; one on the Ground and another on the first floor of the English Language building.

The concept of the building was based on using a central courtyard. This courtyard is closed on the ground floor level as it is surrounded by lecture rooms and services. However, two small openings across the two ends of the courtyard are located on the first floor level. Please see the ground and first floor plans of the building in Figure 7.6.



GROUND FLOOR PLAN

Figure7.6 Ground Floor Plan of the Lecture Halls Building
Source: Archive drawings of the building

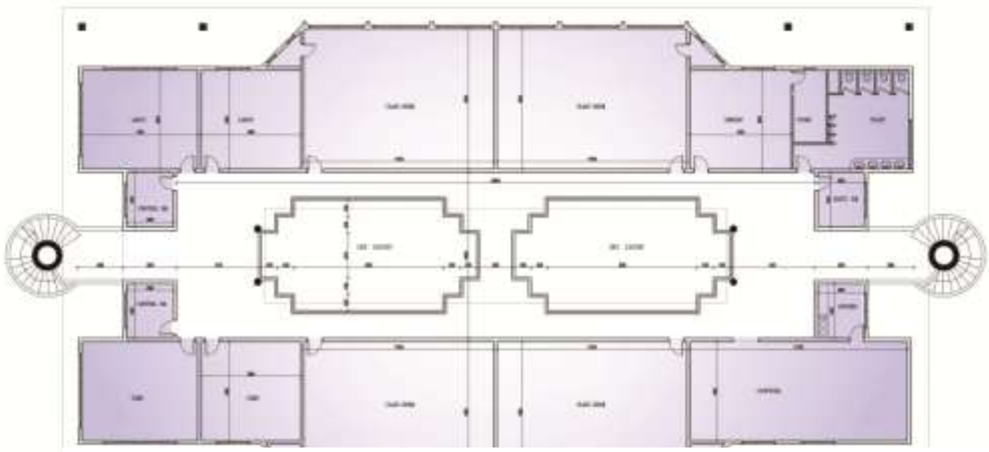


Figure7.7: First Floor Plan of the Lecture Halls Building
Source: Archive drawings of the building

FIRST FLOOR PLAN

As shown in Figure 7.7, the proportions of the courtyard dimensions have deliberately been designed to create a microclimate that is protected from the harsh weather while creating a focal, green point of the building in addition to providing a social gathering space for students. The group of cooled classrooms represented a thermal insulation zone that isolated the courtyard from the natural ambience of the UAE, as shown in the zoning diagram.

Figure7.8: Police Academy Educational building

The building's construction is made up of concrete blocks with cement rendering from outside, and gypsum plastering from inside, see Figure 7.8 and Figure 7.9. The slabs of the ground floor and first floors are reinforced concrete; however, the roof of the building is built with steel trusses covered with steel cladding sheets. Roof insulation is made up of 50mm of polyurethane solid panels, as described here by the maintenance engineer due to the lack of structural detail drawings.

Figure7.9: Section in the Lecture Hall Building
Source: Archive drawings of the building

Moveable windows are provided alongside both the exterior walls and those facing the courtyard. As the temperatures are very pleasant in winter seasons and during the academic semesters, it is normal to keep the class door open to allow for natural cross-ventilation, as shown in Figure 7.8.

The two floors surround a small, relatively convenient courtyard that combines the two sides of the class halls and the staircase in the middle. The length and width of the courtyard are around 40 and ten metres long, respectively. The total height of the building is around eight meters. The proportions of the length, width and height of the courtyard created a relatively cooler microclimate that, in addition to being convenient, is appropriate to human scale. Breezes as described by building users are very pleasant in winter and less harsh than those outdoors in summer.

The air conditioning system is made up of window type and split units located on the exterior walls of the building. This issue has not been further investigated due to the fact that cooling system used in both prototypes of the Police Academy is the same.

7.3.2 Administrative Building

This building consists of two storeys. It was built in 2003. The building construction is a concrete column and beam with cement cladding on the outside and cement plastering on the inside. Both the Educational and the Administration buildings were chosen to represent the conventional and most common type of construction.

The building is designed to have a big atrium that represents a double volume space in the central part of the building. The design sacrifices a relatively significant office area on the ground floor to provide five covered car parking lots and entrances to the building, as shown in Figure 7.10.

The upper floor mainly consists of offices surrounding the relatively huge atrium.

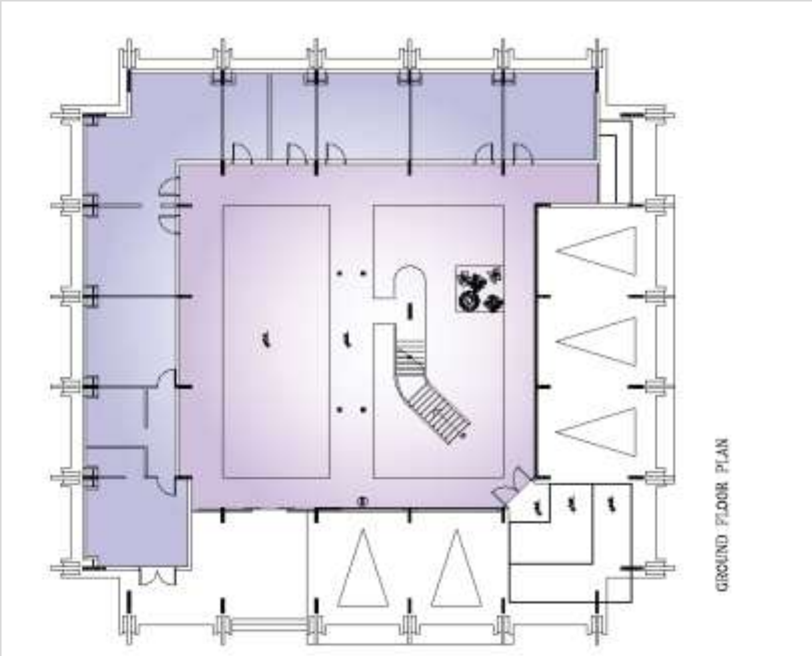


Figure 7.10: Ground Floor Plan of the Administration Building
Source: Archive drawings of the building

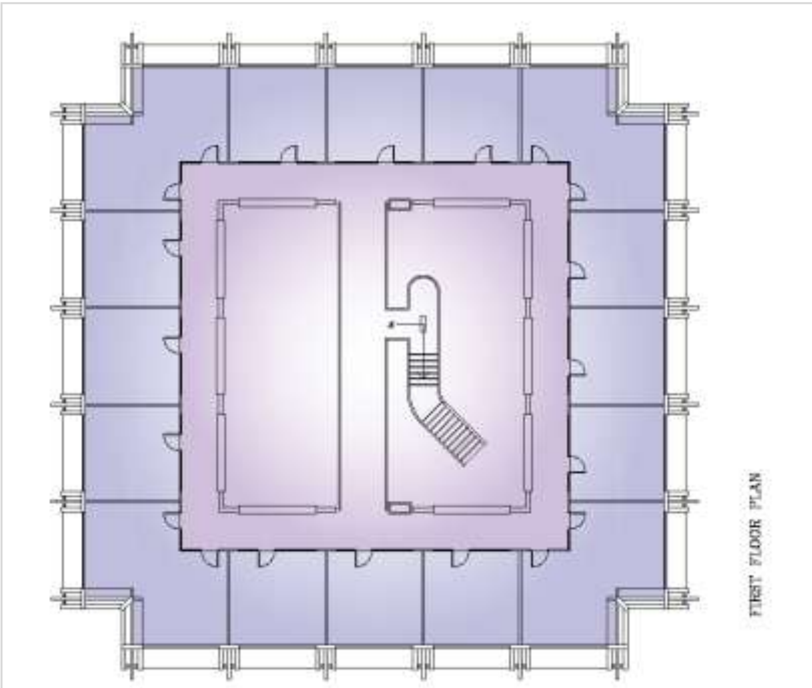


Figure 7.11: First Floor Plan of the Administration Building
Source: Archive drawings of the building

7.3.3 Outdoor spaces in the Police Academy building

The Administrative and Educational buildings would have been more habitable if a close and systematic rhythm had been repeated to create courts and shaded walkways between them. However, the current situation is that this unit stands alone, and heat gains imposed on the building are the maximum due to the expanded span that separates this building from other buildings on the site, with no shaded walkways.

The two monitors of the outdoor spaces have therefore been located in two specific locations. The first location is in the courtyard of the Educational building. The second monitor was located in the exterior space of the building.

7.4 Monitoring

The original design of the study aimed to achieve a field study in mid-summer in both prototypes, in order to investigate the thermal performance, the maximum power consumption of the two prototypes and the impressions of the occupiers.

However, it was not possible to complete the investigation on time due to the fact that the sustainable prototype (Masdar) was still under construction and the building would first be occupied by the middle of September 2010. Meanwhile at the Police Academy, all lecture halls were closed and the Administration building was only operating in part, as it was the holiday season.

It is for the above reasons that:

- The thermal investigation was postponed until September instead of July in order to have the spaces fully occupied.
- The questionnaire was postponed until December in an attempt to let all the students of Masdar who were using the campus for the first time, and all new students in the Police Academy, to build some impressions during their use of these buildings for a few months.

7.5 Questionnaire Findings

In an attempting to examine the whole issue of environmental sustainability, in addition to social and cultural sustainable awareness, a questionnaire was seen as a must for this research. A range of issues have been listed in order to examine the impact of occupying a building designed with some environmental consideration to a certain extent, as in the case of Masdar students, or the impact of living in a conventional building, as in the case of the Police Academy (PA) students.

7.5.1 Sustainable Awareness

The results below demonstrate that no one of the two parties has consistently showed a full understanding of the links between environmental awareness and the diverse issues listed below, showing the percentages of the answers to each question.

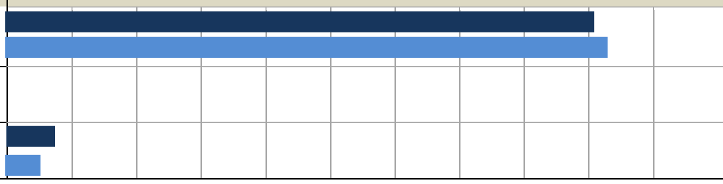
Generally high rates of similar, with some slight differences in the responses of Masdar and PA students, have been recorded, which are relevant to a general awareness of the links between the natural environment and planet resources, global warming, energy conservation, ecosystems, the impact of people's engagement on the environment, and the governmental obligation to raise public awareness. In Question 11, students showed a similar interest in studying sustainability at a rate of 89%. **Positive responses meant that a basis for a sustainable change in attitude existed, and suggest that the government and communities should invest in taking things in that direction.**

However, when investigating links between the natural environment and deforestation and desertification, building industry and greenhouse gases, Masdar students were seen to have slightly higher awareness than PA students.

A big gap has been witnessed between the high responses of Masdar students and the low responses of PA students when both groups were asked about being exposed to sustainability principles through the media, or becoming involved in any specific sustainable educational programme. **Therefore, a proposal of establishing a sustainable educational course within the curriculum of the Police Academy in Abu Dhabi Police was introduced.**

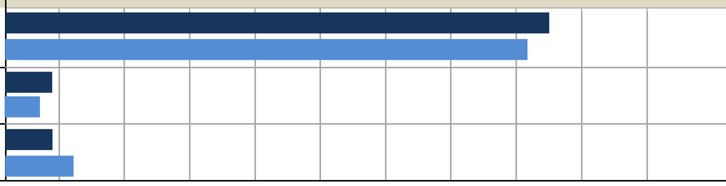
Almost a majority of the PA students expressed an interest in making efforts which could lead to preserving planet resources for future generations. This rate was higher than the 75% of Masdar students who agreed to this suggestion, and 25% who stated that they had no idea. **These results highlighted that the original concept of assuming that Masdar students have higher sustainable awareness than** PA **students was a not quite accurate perception .**

1. Do you think that environmental sustainability is relevant to Planet resources?

Options		Masdar%	P.A%
Yes		**93.75**	**92.68**
No		**0**	**0**
No Idea		**6.25**	**7.32**

Responses of students showed that there are similar rates of understanding about environmental sustainability and its link to the planet's resources: 94% and 93% of PA and Masdar students respectively.

2. Do you think that environmental sustainability is relevant to Global warming?

Options		Masdar%	P.A.%
Yes		**81.25**	**85.37**
No		**6.25**	**7.32**
No Idea		**12.50**	**7.32**

It was found that PA students have a slightly higher understanding of the link between environmental sustainability and global warming than those of Masdar students, with rates of 85% and 81% respectively.

3. Do you think that environmental sustainability is relevant to energy conservation?

Options	Masdar%	P.A%
Yes	87.50	95.12
No	6.25	0.0
No Idea	6.25	4.88

A slight difference was also recorded here, showing that PA students are a bit more aware about links between environmental sustainability and energy conservation, with rates of 95% and 88%.

4. Do you think that environmental sustainability is relevant to ecosystems?

Options	Masdar%	P.A%
Yes	100	92.68
No	0	2.44
No Idea	0	4.88

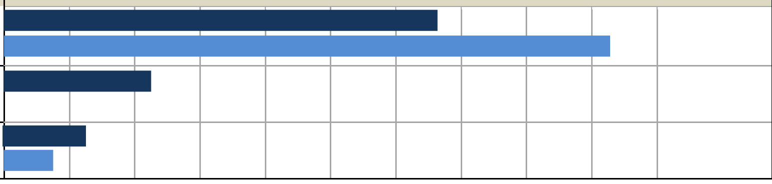
Masdar students showed a full understanding of the link between environmental sustainability and the ecosystem, which is slightly higher than that of PA students, with rates of 100% and 93% respectively.

5. Do you think that environmental sustainability is relevant to deforestation and desertification?

Options	Masdar%	P.A%
Yes	81.25	65.85
No	0	19.51
No Idea	18.75	14.63

Masdar students showed a higher understanding (81%) of o the link between environmental sustainability and deforestation compared to PA students with recorded rates of 66%. However, 19% and 15% of Masdar and PA students respectively stated that they didn't know.

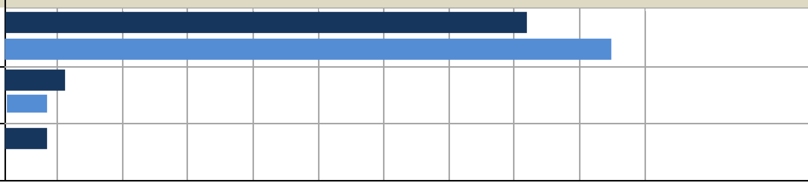
6. Do you think that environmental sustainability is relevant to building industry?



Options		Masdar%	P.A%
Yes		**93.75**	**65.85**
No		**0**	**21.95**
No Idea		**6.25**	**12.2**

Most of the Masdar students showed an understanding of the links between building industry and environmental sustainability, whereas PA students showed less understanding of that link, with rates of 94% and 66% respectively. 22% of PA students stated that there was no such link. The reason might be that the curriculum of the PA students does not cover anything related to the building environment.

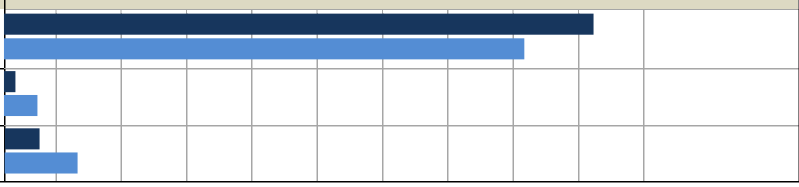
7. Do you think that environmental sustainability is relevant to Greenhouse gases?



Options		Masdar%	P.A%
Yes		**93.75**	**80.50**
No		**6.25**	**12.2**
No Idea		**0**	**7.32**

Higher awareness has been recorded by Masdar students when compared with PA students, regarding environmental sustainability in regard to Greenhouse gases, with results of 94% and 81% respectively.

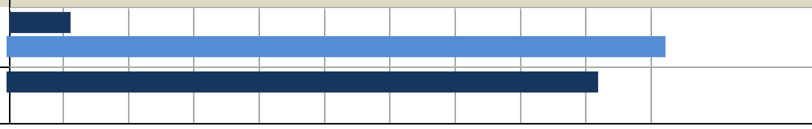
8. Do you think it is necessary to engage people in order to make an impact on the planet's sustainability?



Options		Masdar%	P.A%
Yes		**81.25**	**90.24**
No		**6.25**	**2.44**
No Idea		**12.50**	**7.32**

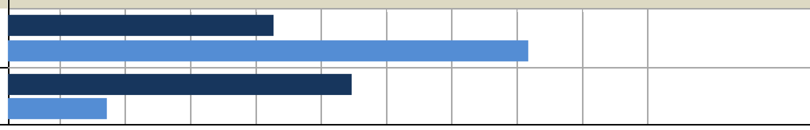
Students from PA showed a slightly better understanding of the role of people involvement in ensuring a more improved sustainable impact on the planet, with rates of 90% and 81% respectively. However, both groups emphasised the importance of people's role in making a difference.

9. Have you ever been involved in any specific sustainable educational programme or class?

Options		Masdar%	P.A%
Yes		**100**	**9.76**
No		**0**	**90.24**

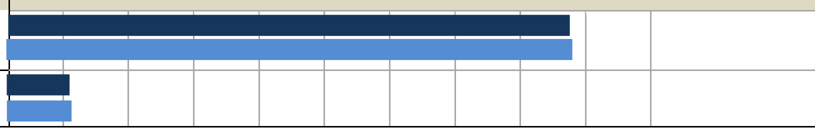
Around 90% of the PA students had not been involved in sustainable education, as opposed to Masdar students who had undertaken/were undertaking sustainable and environmental education, at a the rate of 100%.

10. Have you ever been exposed to sustainability principles via the media?

Options		Masdar%	P.A%
Yes		**81.25**	**43.9**
No		**18.75**	**56.1**

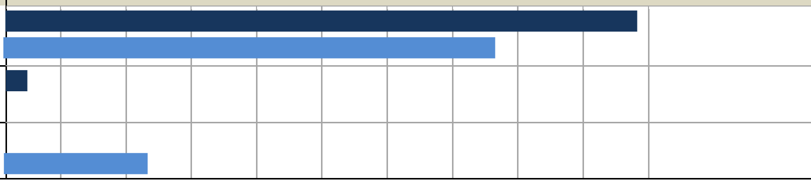
Masdar students stated that they had been exposed to sustainability through the media at almost double the rate of those of the PA students. Rates were 81% and 44% respectively. This shows that PA students were less exposed to sustainability through the media.

11. Would you be interested in studying sustainability?

Options		Masdar%	P.A%
Yes		**87.50**	**87.8**
No		**12.50**	**12.2**

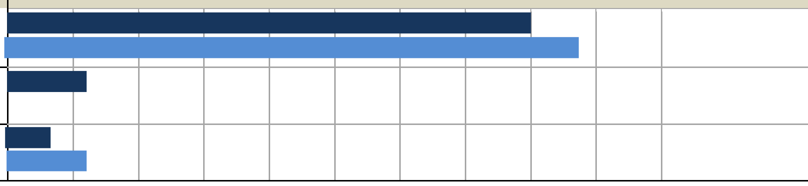
Both groups showed a similar rate or around 88% with regard to an interest in learning about sustainability. Similar rates of around 12% regarding ‘no desire to study sustainability’, were also recorded.

12. Would you be interested in making efforts that lead to saving the planet's resources for future generations?

Options		**Masdar%**	**P.A%**
Yes		**75.00**	**97.56**
No		**0**	**2.44**
No Idea		**25.00**	**0**

97% of the students of the PA showed an interest in saving the planet's resources, while only 75% of Masdar students showed the same interest. It was anticipated that there would be opposite results due to the specific emphasis placed on sustainability in the Masdar Institute curriculum. The reason was thought to be the short period of time since Masdar students had joined the newly inaugurated Institute. 25% of Masdar students stated that they had no idea about saving planet resources.

13. Do you feel that the government has an obligation to raise awareness of sustainability among the public?

Options		**Masdar%**	**P.A%**
Yes		**87.50**	**80.49**
No		**0**	**12.2**
No Idea		**12.50**	**7.32**

A small difference between the two groups has been found regarding the importance of the government's role, however most of them agreed that it was essential that the government take the lead in raising awareness of sustainability, with rates of 88% and 81% of Masdar and PA students respectively.

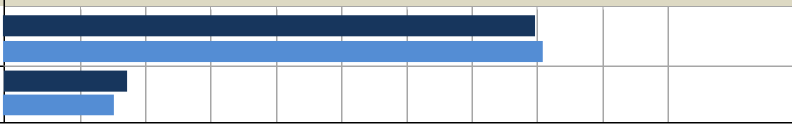
7.5.2 Environmental awareness among students

Positive or similar rates with a small gap have been observed between the responses of both groups. However, relatively negative responses came when both groups were asked to switch off air conditioning in the spring when temperature outdoors is moderate. **This indicates the need to convince the people that air conditioning has a damaging potential for their health and the planet.**

In questions about how Masdar building affected student perception of power consumption, healthy indoor environments and sustainable awareness, **major responses indicated that Masdar building did not add knowledge about sustainability for its students.**

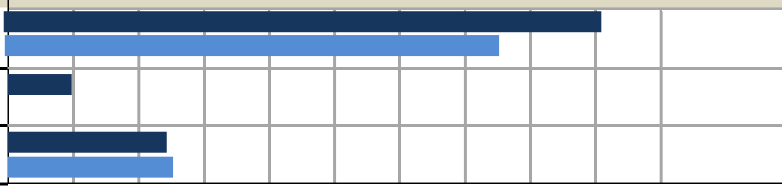
Another gap between the two parties was regarding the use of staircases; 75% of Masdar students preferred to use them, as opposed to 60% of PA students who preferred taking elevators. **This emphasised the need to raise public awareness.**

1. **Will you be willing to avoid, as much as possible, imported goods, in order to reduce transport trips and Co_2 emissions respectively?**

Options		Masdar%	P.A%
Yes		**81.25**	**80.49**
No		**18.75**	**19.51**

Both groups indicated similar rates of 80-81% willingness to avoid buying imported products to reduce the environmental impact. However, there is still a need to change people's attitudes regarding the modern high consumption pattern.

2. **Do you think recycling paper is reasonable?**

Options	Percentage	Masdar%	P.A%
Yes		**75.00**	**90.24**
No			**9.76**
No idea		**25.00**	

90% of the PA students thought that recycling paper was reasonable compared to a rate of 75% of Masdar students. The opposite results were anticipated. 25% of Masdar students stated that they had no idea, which may be hard to justify.

3. Do you think recycling paper is possible?

Options		Masdar%	P.A%
Yes		**100.00**	**95.12**
No		**0**	**4.88**

Both parties believed that recycling paper was possible. 100% of Masdar students thought that compared with 95% of the PA students.

4. Do you think recycling paper has a good impact on the environment?

Options		Masdar%	P.A%
Yes		**81.25**	**85.37**
No		**0**	**14.63**
No Idea		**18.75**	**0**

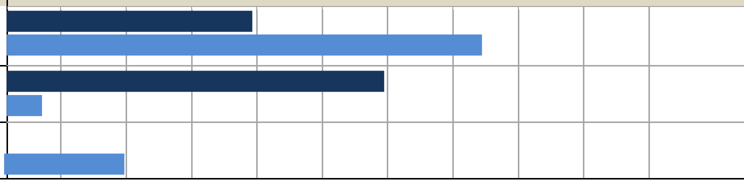
81% and 85% of Masdar and PA students respectively agreed that recycling paper has a good impact on the environment. However, 15% of PA students didn't think so. Also, 19% of Masdar students stated that they had no idea.

5. Growing food out of season requires more energy, which can be considered to be wasting energy. On this basis, would you prefer to consume food grown in season rather than out of season?

Options		Masdar%	P.A%
Yes		**75.00**	**75.61**
No		**25.00**	**24.39**

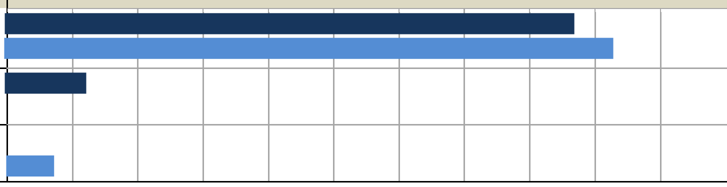
There were similar rates of 75% regarding attitude towards consuming food grown in season rather than out of season. This means that similar environmental impressions have been recorded. 25% stated that they had no idea.

6. Where possible, would you prefer to take the stairs rather than use the elevator?

Options		Masdar%	P.A%
Yes		**75.00**	**39.02**
No		**6.25**	**60**
No Idea		**18.75**	

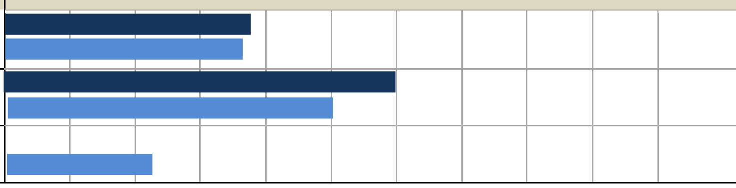
Masdar students showed a higher interest in using staircases, at the rate of 75%, compared to 39% of PA students. 60% of PA students stated that they weren't interested in taking the stairs. Around 19% of Masdar students stated that they didn't know.

7. During spring or autumn, when the temperature outside is moderate, would you open windows?

Options		Masdar%	P.A%
Yes		**93.75**	**87.8**
No		**0**	**12.2**
No Idea		**6.25**	

When asked about opening windows, responses were at rates of 94% and 88% respectively for Masdar and PA students. The Estidama rating system gives credit to openable windows. Educating architects about the importance of natural ventilation might be the only obstacle.

8. During spring or autumn, when the temperature outside is moderate, would you switch on the air conditioning

Options		Masdar %	P.A %
Yes		**37.50**	**39.02**
No		**50.00**	**60.98**
No Idea		**12.50**	

Similar responses from both groups showed that not all of the students were in favour of using air conditioning. However, the need to change attitudes is essential as 50% and 61% of Masdar students and PA students respectively showed that they would switch on the air conditioning even if the temperature outside was moderate.

9. Has studying or living in this building caused you to understand more about power consumption? (only Masdar students were asked this question)

Options		Masdar
Yes		**43.75**
No		**37.50**
No Idea		**18.75**

When Masdar students were asked about the effect of living in sustainable buildings on power consumption, only 44% of the students said that they felt that living in the Masdar building made them more concerned about conserving energy. However, 38% felt the opposite and 19% stated that they had no idea.

10. Has studying or living in this building led you to understand more about a healthy indoor environment? (only Masdar students were asked this question)

Options		Masdar
Yes		**18.75**
No		**56.25**
No idea		**25.00**

Only 19% of Masdar students indicated that living in the Masdar building raised their awareness of a healthy indoor environment. However, 56% stated that it didn't. 25% stated that they had no idea.

11. Does living in an environmentally friendly building raise your environmental awareness? (only Masdar students were asked this question)

Options		Masdar
Yes		**43.75**
No		**56.25**
No idea		**0**

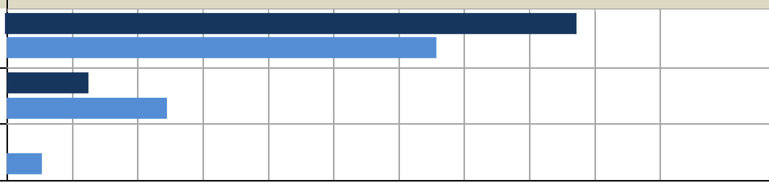
Only 44% of Masdar students found that living in a sustainable building raised their environmental awareness. However, 56% stated that they thought the opposite.

When they were asked about their willingness to avoid imported goods and food grown out of season, recycling paper, and exchanging air conditioning with natural ventilation, they described it (?) as possible.

7.5.3 Effects on performance or production levels

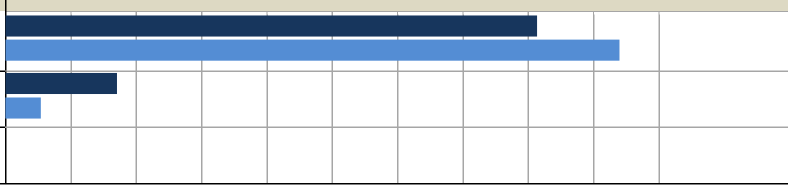
Slightly higher responses from PA students were received when they were asked if they have higher productivity as a result of studying in their specific Educational Building, and whether they prefer doing homework at school rather than home. However, higher responses came from Masdar students when asked if they prefer studying with natural light and whether or not it affected their mood. It is quite significant that Estidama is enforcing specific rates of window's area.

1. **Do you feel that the indoor living environment of this building has affected your productivity level, relating to work or study?**

Options		**Masdar%**	**P.A%**
work		**68.75**	**87.8**
study		**25.00**	**12.2**
no idea		**6.25**	

Around 69% of Masdar students, compared to around 88% of PA students thought that the indoor environment had affected their productivity level.

2. **Would you prefer natural lighting indoors rather than artificial lighting?**

Options		**Masdar%**	**P.A%**
Yes		**93.75**	**82.93**
No		**6.25**	**17.07**
No idea		**0**	

Most of the students preferred natural lighting indoors, with rates of around 94% and 83% respectively for Masdar and PA students.

3. Do you think that natural light affects your mood?

Options		Masdar%	P.A%
Yes		**81.25**	**65.85**
No		**6.25**	**34.15**
No idea		**12.50**	

Around 81% of Masdar students compared to 66% of PA students thought that natural light affected their mood. 34% of PA students thought that natural light didn't affect their mood.

4. If you have homework, would you prefer to study in the Academy or at home?

Options		Masdar%	P.A%
Academy		**50.00**	**63.41**
home		**43.75**	**36.59**
No Idea		**6.25**	

50% of Masdar students preferred to study at the Masdar Institute. 63% of PA students preferred to study in the Academy. However, 44% of Masdar students preferred to study at home, compared to 37% of PA students.

7.5.4 Impressions

All 11 questions in this section have showed that PA students have better impressions of sustainability values and their essential nature than Masdar students. Gaps in responses range from slight to big differences. **Questions covered issues including the design of environmentally friendly buildings, potential financial savings, environmental savings, sustainable design effects on environmental education, national health savings, planet resources savings, less** CO_2 **emissions, a better green image for the UAE, and being part of future co-operation and investment within the UAE ,in sustainability. Most of the responses of PA students showed a high commitment to being a part of the national momentum toward sustainability, especially regarding more awareness.**

1. Do you think that it is important to design environmentally friendly buildings?

Options	Masdar%	P.A%
Yes	**62.50**	**92.68**
No	**6.25**	**0**
No Idea	**31.25**	**7.32**

Surprisingly, around 93% of PA students agreed that designing environmentally friendly buildings was important, compared to 63% of Masdar students. 31% of Masdar students stated that they had no idea.

2. In your opinion, does sustainable design lead to financial savings?

Options	Masdar%	P.A%
Yes	**50.00**	**60.98**
No	**12.50**	**24.39**
No Idea	**37.50**	**14.63**

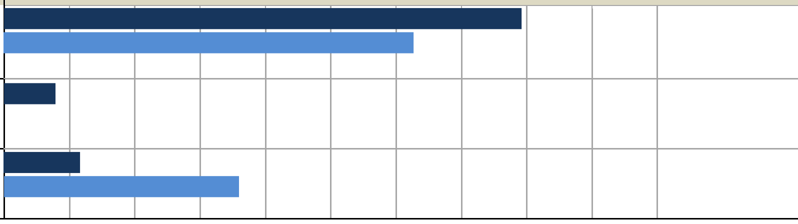
Surprising responses also came when 50% of Masdar students felt that no financial savings should be expected through sustainable design, as opposed to 61% of PA students. 38% and 15% of Masdar and PA students respectively stated that they had no idea regarding any link between sustainable design and financial savings.

3. In your opinion, does sustainable design lead to environmental savings

Options	Masdar%	P.A%
Yes	**62.50**	**82.93**
No	**6.25**	**4.88**
No Idea	**31.25**	**12.2**

It seemed that more PA students (83%) than Masdar students (63%) felt that sustainable design could lead to environmental savings. 31% of Masdar students stated that they had no idea.

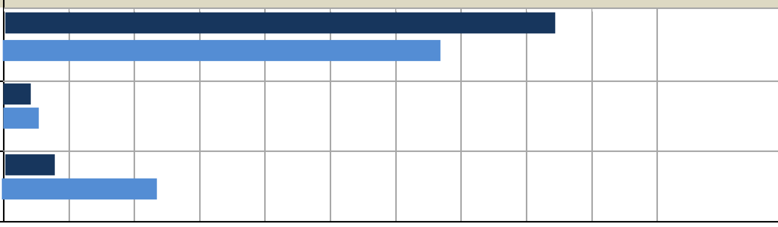
4. In your opinion, does sustainable design raise awareness of environmental education for future generations



Options	Masdar%	P.A%
Yes	**62.50**	**80.50**
No	**0.00**	**7.32**
No Idea	**37.50**	**12.2**

As seen above, PA students showed a higher understanding of the link between sustainable design and environmental education (81% compared with 63% of Masdar students). 38% of Masdar students stated that they had no idea.

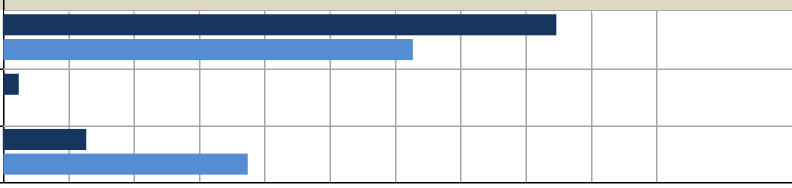
5. In your opinion, does sustainable design lead to health savings on a personal and national level?



Options	Masdar%	P.A%
Yes	**68.75**	**85.37**
No	**6.25**	**4.88**
No Idea	**25.00**	**9.76**

PA students showed a higher understanding of the effect of sustainable design on individual and national health savings (85% compared to 69% of Masdar students). 25% of Masdar students stated that they had no idea.

6. In your opinion, does sustainable design lead to planet resources savings?



Options	Masdar%	P.A%
Yes	**62.50**	**85.37**
No	**0**	**2.44**
No Idea	**37.50**	**12.2**

63% of Masdar students linked sustainable design with saving the planet's resources, compared with 85% of PA students. However, 38% of Masdar students stated that they had no idea about any link between sustainable design and saving the planet's resources, compared with 12% of PA students.

7. **In your opinion, does sustainable design lead tithe minimisation of** CO_2 **emissions?**

Options		Masdar %	P.A%
Yes		68.75	75.61
No		0	9.76
No Idea		31.25	14.63

Close rates were recorded regarding the understanding of a link between sustainable design and CO_2 emissions. However, 31% of Masdar students stated that they had no idea regarding this link, compared to 15% of PA students.

8. **In your opinion, does sustainable design lead to giving the UAE a green image?**

Options		Masdar%	P.A%
Yes		75.00	92.68
No		6.25	2.44
No Idea		18.75	4.88

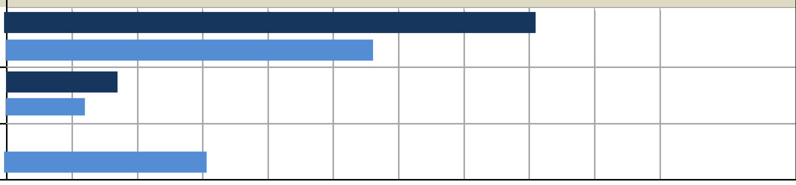
Higher awareness was recorded, as 93% of PA students felt that sustainable design could lead to the UAE having more of a green image, compared to 75% of Masdar students. However, 5% and 19% of PA and Masdar students respectively stated that they had no idea about the issue.

9. **Would you be ready to be part of a government approach toward making Abu Dhabi a sustainable city?**

Options		Masdar%	P.A%
Yes		62.50	92.68
No		0	2.44
No Idea		37.50	4.88

93% of PA students showed interest in contributing to a governmental approach toward making Abu Dhabi a sustainable city, compared to 63% of Masdar students. However, 38% of Masdar students stated that they had no idea about the issue.

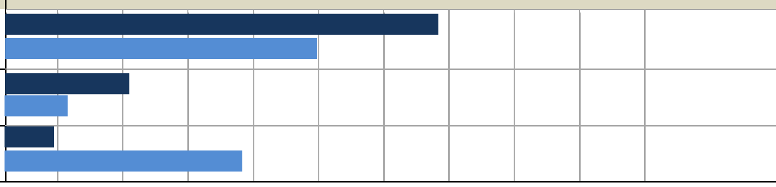
10. If you are able to make an investment, would you consider asking your consultants to design a sustainable project?



Options	Masdar%	P.A%
Yes	56.25	82.93
No	12.50	17.07
No Idea	31.25	0

PA students showed more interest in investing in sustainable projects with rates of 83% compared to 56% of Masdar students. 31% of Masdar students stated that they had no idea.

11. In making the investment, you are told that an additional initial cost of 20% will be required to make the project sustainable, and that the payback period will be five years. The environmental benefits aside, would you be interested in adding 20% to the initial cost?



Options	Masdar%	P.A%
Yes	50.00	68.29
No	12.50	21.95
No Idea	37.50	9.76

50% of Masdar students showed an interest in paying an additional 20% for the initial cost of the project in order to build a sustainable building, compared to 68% of PA students. 37% and 10% of Masdar and PA students respectively stated that they had no idea.

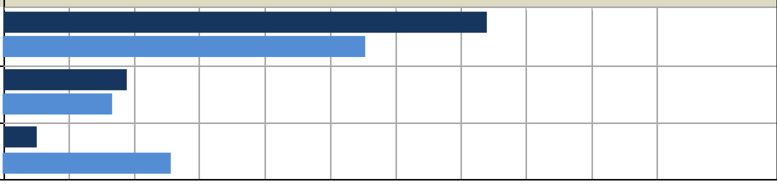
7.5.5 Heritage appreciation

Three out of seven questions in this section have shown that PA students have better impressions of heritage appreciation than Masdar students. Gaps in responses range from slight to big differences. Areas investigated were whether local heritage deserves to be seen (?), whether students would be interested in learning more about their ancestors' living environments, and whether they would prefer indoor environments, which are closer to the heritage buildings.

However, most of the two groups thought that there were no links between the buildings they used now and local heritage. Also, current buildings did not make students feel closer to local heritage.

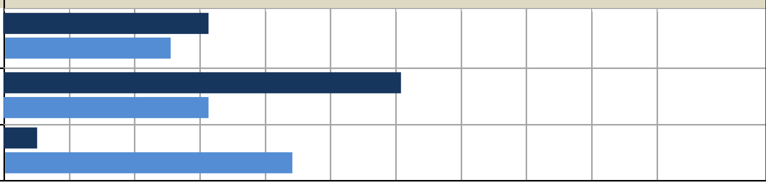
Opposite responses came from both parties when they were asked to choose between using closed air conditioning systems, convenience, health and local heritage. This also raises the need for public environmental awareness.

1. Do you feel that the building's cultural heritage deserves to be seen (?)?

Options		Masdar%	P.A%
Yes		56.25	75.61
No		18.75	19.51
No Idea		25.00	4.88

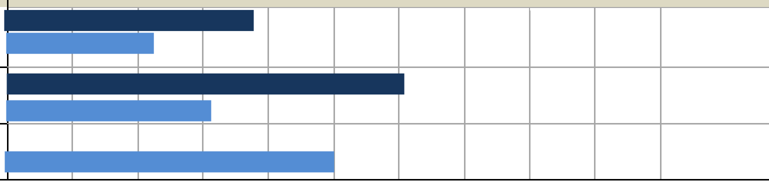
Only 56% of Masdar students felt that heritage buildings deserved to be seen, compared with 76% of PA students. Rates of 'no idea' were 25% and 5% respectively.

2. To your knowledge, do you feel that there are any links between the building you are using now and our ancestors' way of building?

Options		Masdar%	P.A%
Yes		25.00	31.71
No		31.25	60.98
No Idea		43.75	7.32

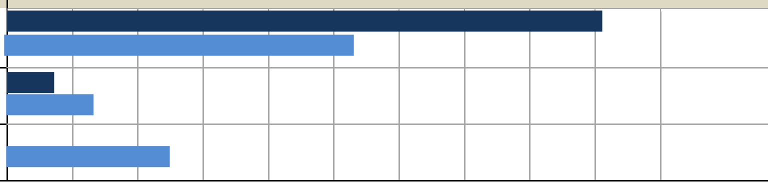
It was anticipated that there would be higher rates of understanding of the links between the Masdar building's design and the Educational building's design, with the heritage buildings. However, only 25% and 32% of Masdar and PA students respectively stated that they understood this link. Yet 31% and 61% of Masdar and PA students respectively thought there was no link between heritage buildings and the current design of the Masdar Institute, or the Educational building in the Police Academy. 44% of Masdar students stated that they had no idea, compared to 7% of PA students.

3. Have you learned anything through your use of this building that makes you feel closer to the heritage of our region?

Options		**Masdar%**	**P.A%**
Yes		**12.50**	**39.02**
No		**31.25**	**60.98**
No Idea		**50.00**	**0**

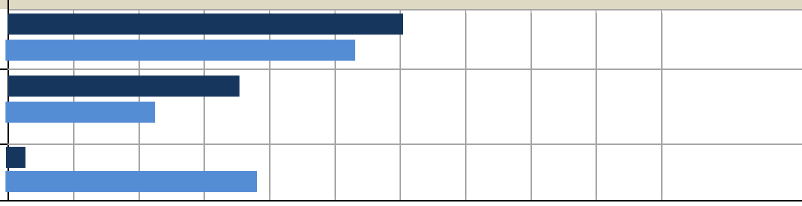
In their answers to the question regarding whether they had learned anything through their use of these buildings which made them feel closer to the heritage of the region, 13% of Masdar student and 39% of PA students agreed. 61% of PA students stated that they felt the opposite. And 50% of Masdar students stated that they had no idea.

4. Would you be interested in learning more about the living environment of our ancestors, given that they lived in sustainable environmental systems?

Options		**Masdar%**	**P.A%**
Yes		**62.50**	**92.68**
No		**12.50**	**7.32**
No Idea		**25.00**	**0**

93% of PA students showed interest in learning about the living environment of the buildings the ancestors built in the area, compared to 63% of Masdar students. However, 25% of Masdar students stated that they had no idea.

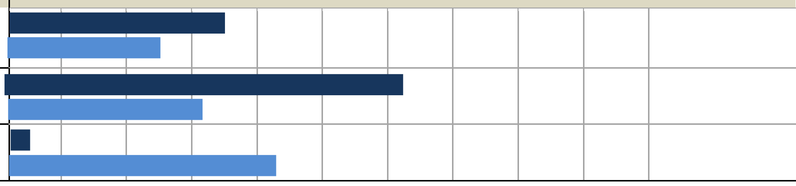
5. Would you choose to raise your children in a building environment which is not that convenient to a certain extent, yet has strong links with our specific heritage and culture?

Options		**Masdar%**	**P.A%**
Yes		**50.00**	**60.98**
No		**12.50**	**36.59**
No Idea		**37.50**	**2.44**

When students were asked if they preferred to raise children in a less convenient indoor environment which was closer to heritage, 50% of Masdar students compared with 61%

of PA students, answered positively. However, 13% and 37% of Masdar and PA students respectively rejected the idea. 38% of Masdar students stated that they had no idea.

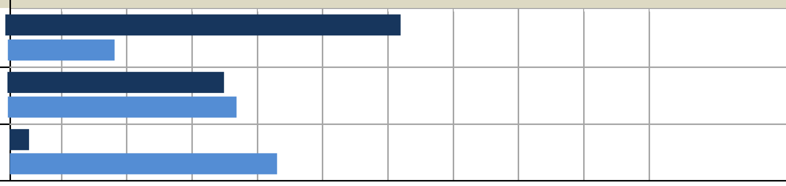
6. Or would you choose to raise them in an air-conditioned, convenient environment with no link to our building heritage and no consideration for energy conservation?



Options	Masdar%	P.A%
Yes	**25.00**	**34.15**
No	**31.25**	**63.41**
No Idea	**43.75**	**2.44**

25% of Masdar students compared to 34% of PA students showed interest in having fully air-conditioned indoors environments with no regard for energy conservation or heritage issues. 63% of PA students rejected the idea. 44% of Masdar students stated that they had no idea.

7. Do you think that there is proper public awareness through education or the media about the values, techniques and importance of our heritage buildings?



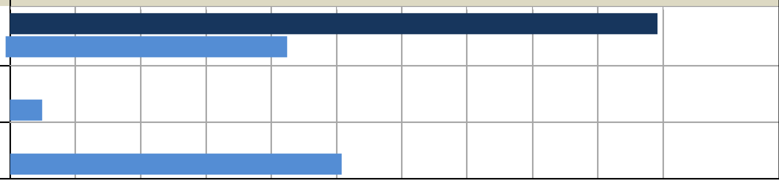
Options	Masdar%	P.A%
Yes	**18.75**	**60.98**
No	**37.50**	**36.59**
No Idea	**43.75**	**2.44**

61% of PA students thought that there was proper public awareness of the values and techniques of the heritage buildings in the region, compared with 19% of Masdar students. 38% and 37% of Masdar and PA students respectively, thought the opposite. 44% of Masdar students stated that they had no idea.

7.5.6 National responsibilities

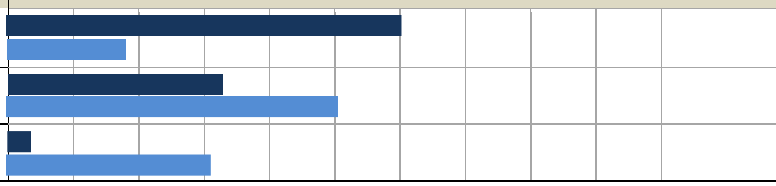
Big gaps were noted between the responses of PA and Masdar students. PA students showed more of a sense of patriotism. This was noticed when asking about whether it would be patriotic to be environmentally sensible, public engagement, and being more careful with natural resources for the sake of the UAE. **These responses showed that the nation is ready to enter a new sustainable era.**

1. Do you believe that acting in an environmentally sensible way is patriotic?

Options		Masdar%	P.A%
Yes		**43.75**	**100**
No		**6.25**	**0**
No Idea		**50.00**	**0**

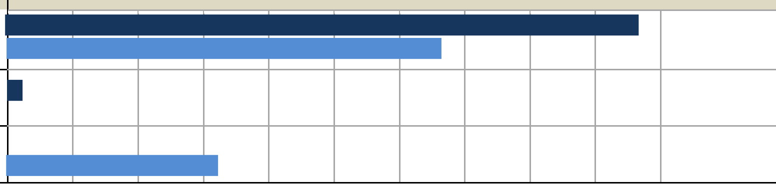
100% of PA students stated that they thought it was patriotic to act in an environmentally sensible way compared to 44% of Masdar students. 50% of Masdar students stated that they had no idea.

2. The Abu Dhabi government is making a profound effort regarding sustainability. Do you feel that the local public is making serious attempts in the same direction?

Options		Masdar%	P.A%
Yes		**18.75**	**60.98**
No		**50.00**	**34.15**
No Idea		**31.25**	**4.88**

61% of PA students felt that people were making serious attempts in the same direction of the government regarding sustainability, compared with 19% of Masdar students who felt the same. However, 50% and 34% of Masdar and PA students respectively thought that the public were not convinced regarding sustainability. 31% and 5% of Masdar and PA students respectively stated that they didn't know.

3. Should we become more careful with using natural resources for the sake of the UAE?

Options		Masdar%	P.A%
Yes		**68.75**	**97.56**
No		**0**	**2.44**
No Idea		**31.25**	**0**

69% of Masdar students felt that people should become more careful with using natural resources for the sake of the UAE, compared to 98% of PA students. However, 31% of Masdar students thought there was no need to be cautious about natural resources for the sake of the UAE.

7.5.7 Thermal comfort and occupant satisfaction or dissatisfaction

The non-consistent responses to this section showed that there was no firm belief in the way a building could be healthy and comfortable.

Most of PA students wanted to build their houses on a sustainability basis, while 37% of Masdar students stated that they had no idea.

1. **Do you consider the indoor environment of this building to be comfortable?**

Options		Masdar%	P.A%
Yes		**31.25**	**58.54**
No		**25.00**	**41.46**
No idea		**43.75**	**0**

44% of Masdar students stated that they had no idea if the indoor environment was comfortable. 59% and 31% of PA and Masdar students respectively thought that the indoor environment of their building was comfortable.

2. **Would you build your future house on a sustainability basis?**

Options		Masdar%	P.A%
Yes		**56.25**	**90.24**
No		**6.25**	**9.76**
No idea		**37.50**	**0**

90% of PA students showed interest in building future homes on a sustainability basis compared with 56% of Masdar students. 38% of Masdar students stated that they had no idea.

3. Do you enjoy using a sustainable research building? (Only Masdar.)

Options		Masdar%
Yes		**43.75**
No		**18.75**
No idea		**37.50**

Less than half of Masdar students stated that they enjoyed using a sustainable research building, as opposed to 19% who stated that they were not in favour of using such a building. However, 38% of them stated that they had no idea.

4. Do you believe that working in this building has ever impacted your health? (Only PA)

Options		P.A%
Yes		**78.05**
No		**21.95**
No idea		

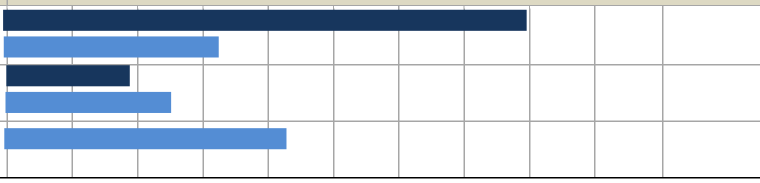
78% compared to 44% of PA and Masdar students respectively thought that there was a link between the building they were using and their health. But 38% of Masdar students thought that there was no such a link.

5. Would you recommend this type of building to others?

Options		Masdar%	P.A%
Yes		**37.50**	**63.41**
No		**12.50**	**36.59**
No idea		**50.00**	

50% of Masdar students stated that they had no idea about recommending such a type of building to others. However 63% and 38% of PA and Masdar students respectively agreed to recommend such a building.

6. Does living in such a building change the way you dress?

Options		Masdar	P.A
Yes		**31.25**	**80.49**
No		**25.00**	**19.51**
No idea		**43.75**	

Masdar answers showed that 44% stated that they had no idea compared to 0% of the PA students. 81% of PA students stated that the indoor environment of the building affected their way of dressing, as opposed to 31% of Masdar students.

7.5.8 Practical Sampling

A total of 78 postgraduate students filled the questionnaires, 43 students from the Police Academy and 35 students from Masdar. The process was deliberately delayed to the second semester of the Academic Year 2010-2011, in order to give new students the chance to build impressions about the building they are studying in. The questionnaire was filled by 100% of the students who received it.

7.6 Monitoring carbon dioxide levels indoors

Healthy levels of CO_2 indoors must not exceed a specific level (i.e. higher than the CO^2 outdoors.) Total indoor carbon dioxide should be reduced by a difference of less than 600ppm (parts per million) above outdoor levels. "The National Institute for Occupational Safety and Health (NIOSH) considers that indoor air concentrations of carbon dioxide that exceed 1,000 ppm are a marker suggesting inadequate ventilation. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends that carbon dioxide levels not exceed 700 ppm above outdoor ambient levels".(Source: *Glatte, 1967)*

Readings of the CO_2 levels through this research study have been taken by the same CO_2 logger. Due to the high cost of the instrument, it was decided to use the project for the first two weeks in the Educational Building starting from 16 September. However, the logger was moved to the Administrative building in order to examine the CO_2 over the following two weeks.

7.6.1 Findings of CO_2 levels indoors

It was found that both readings of the CO_2 levels indoors gave similar readings, with extremely low levels of CO_2 that ranged between (440ppm to 540 ppm). These rates have been considered as very healthy similar results.

7.7 Monitoring in Fall 2010

Although the United Arab Emirates is considered to be the fourth highest country in the world in terms of its carbon dioxide emissions, the government aims to shift the urban growth planned for 2030 toward making Abu Dhabi the sustainable city of the future. No specific statistics were available to estimate the ratio or the portion of the energy consumed by the building industry in the country, yet the evolutionary size of this industry in the Emirates consumes a tremendous portion of energy resources.

Although the percentages of CO_2 emissions per capita in the Gulf countries reveal that they are the highest on the planet, the real effect is minor when being compared to those of other countries with high populations, due to the fact that these rates are counted per capita and that all the Gulf countries have a significantly small population rate. (See Table 3.6, Page No. 74

The research was conducted in two periods. The first period was in fall 2010. Monitoring covered the temperature and relative humidity of the indoor and outdoor spaces in both Masdar and the Police Academy in its two investigated buildings. However, there was no possibility of monitoring Masdar power consumption at that period (as stated by Masdar staff at a later stage). Therefore, the investigation of fall 2010 only included the power consumption of the two research buildings in the Police Academy.

Two buildings with two different design strategies were chosen, both built as a part of a bigger complex of the Police Academy in Abu Dhabi: the educational building which has a central courtyard see Figure 7.12, and the Administrative building which has a central closed air conditioned atrium, see Figure 7.10 and Figure 7.11. The comparative study aimed at investigating the thermal environment, power consumption, running costs and the induced CO_2 emissions.

Figure7.12: Balconies, corridors and courtyard of the Educational Building

Monitors were installed in both buildings in order to take daily readings of the power consumption and calculate the carbon dioxide emissions respectively. Other monitors of temperature and relative humidity were also installed in the indoor spaces. The readings showed that the continuous use of air-conditioning during the day and at night, led to a similar temperature of around 21-23 C°.

Two power reading monitors were installed in both prototypes. A technician has installed both monitors in order to ensure accurate readings of the whole power consumption of each building. The readings began on Wednesday 29 September and continued until Saturday 30 October 2010.

lists all the readings of the two monitors in the two prototypes. All power readings in kilowatt/hour have been multiplied by 0.5416 in order to extract the induced kilogrammes of CO_2 emissions to the atmosphere. This figure has been quoted in the below table, issued by the National Energy Foundation (NEF) in the United Kingdom.

“These are estimated each year by DECC. The latest data (2008) can be summarised as:

Fuel Type	*Total use (TWh)*	***kgCO2/kWh***	***Gt CO_2***
Solid Fuel	*8,762*	*0.34010*	*2,980*
Gas	*359,554*	*0.18523*	*66,600*
Electricity	*125,811*	***0.54160***	*68,139*
Oil	*35,278*	*0.24683*	*8,708*
Total CO_2 emissions			*146,427*
Total UK Households (000s)			*26,336*
Average CO_2 emissions per household (tonnes)			*5.560*

Table 7.2: Conversion rate of kWh into carbon dioxide emissions
Source: The National Energy Foundation, 2011

Table 7.3 demonstrates monitor readings of both monitors installed in the Administrative and Educational Buildings in the Police Academy to record the exact power consumption between 30 September 2010 and 30 October 2010. Power consumption was converted into kilogrammes of carbon dioxide after multiplying its figure by 0.54 ratio as shown in Table 7.2.

N	Date	Educational Building		Administrative Building	
		Consumption in kWh between 30.09.2010 and 30.10.2010	Induced Kilograms of CO_2 Emissions	Consumption in kWh between 30.09.2010 and 30.10.2010	Induced Kilograms of CO_2 Emissions
1	29/09/2010	0	0	0	0
2	30/09/2010	226	122.4016	789	427.3224
3	01/10/2010	202	109.4032	680	368.288
4	02/10/2010	163	88.2808	596	322.7936
5	03/10/2010	183	99.1128	719	389.4104
6	04/10/2010	211	114.2776	813	440.3208
7	05/10/2010	229	124.0264	801	433.8216
8	06/10/2010	215	116.444	786	425.6976
9	07/10/2010	210	113.736	840	455.336
10	08/10/2010	194	105.0704	845	458.0904
11	09/10/2010	193	104.5288	666	360.7056
12	10/10/2010	186	100.7376	680	368.288
13	11/10/2010	230	124.568	788	426.7808
14	12/10/2010	209	113.1944	740	400.784
15	13/10/2010	221	119.6936	722	391.0352
16	14/10/2010	214	115.9024	682	369.3712
17	15/10/2010	198	107.2368	578	313.0448
18	16/10/2010	191	103.4456	511	276.7576
19	17/10/2010	185	100.196	549	297.3384
20	18/10/2010	205	111.028	596	322.7936
21	19/10/2010	201	108.8616	577	312.5032
22	20/10/2010	229	124.0264	628	340.1248
23	21/10/2010	223	120.7768	692	374.7872
24	22/10/2010	231	125.1096	680	368.288
25	23/10/2010	204	110.4864	567	307.0872
26	24/10/2010	196	106.1536	587	317.9192
27	25/10/2010	221	119.6936	715	387.244
28	26/10/2010	163	88.2808	621	336.3336
29	27/10/2010	220	119.152	600	324.96
30	28/10/2010	182	98.5712	556	301.1296
31	29/10/2010	179	96.9464	620	335.792
32	30/10/2010	159	86.1144	516	279.4656
TOTAL		**6,273 Kilowatt / hour**	**3,398 CO2 Kilogram**	**20,740 Kilowatt / hour**	**11,234 CO2 Kilogram**

Table 7.3: Power Consumption in Kw/h and the induced tons of CO_2 emissions to the atmosphere

Figure 7.13 (below) gives a visual idea of the differences in CO_2 emissions between the Educational and Administrative buildings.

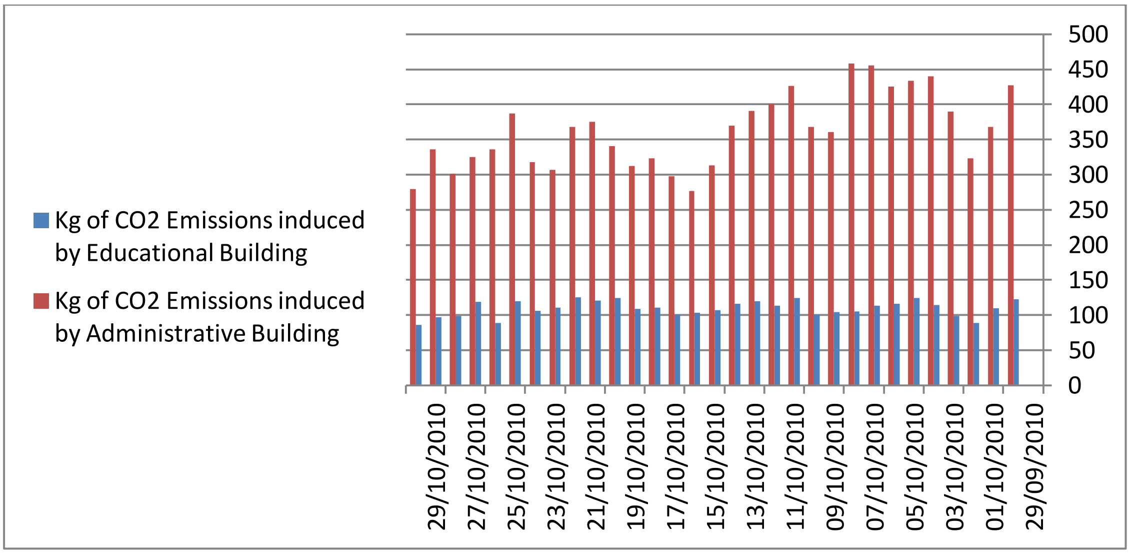


Figure 7.13: Kilogrammes of CO_2 emissions of the two prototypes during the 31 days of the study

7.7.1 The Educational Building

The Educational Building has been designed in a similar fashion to the vernacular buildings in this region. This is observed in the use of the courtyard at the heart of the building.

The courtyard has been designed in proportionate dimensions in order to minimise sun penetration into outdoor spaces within it, and raise the temperature in a significant way - even though the lecture halls are facing the East-West axis. Such orientation usually induces high heat gains.

A comparison between the temperatures in the courtyard and those in the exposed outdoors showed a significant influence on the air temperature of the courtyard. The relatively cooler spaces of the courtyard are definitely affecting factors in reducing the heat gains on the building. However, the research monitored the two prototypes in order to estimate the air conditioning load of each building.

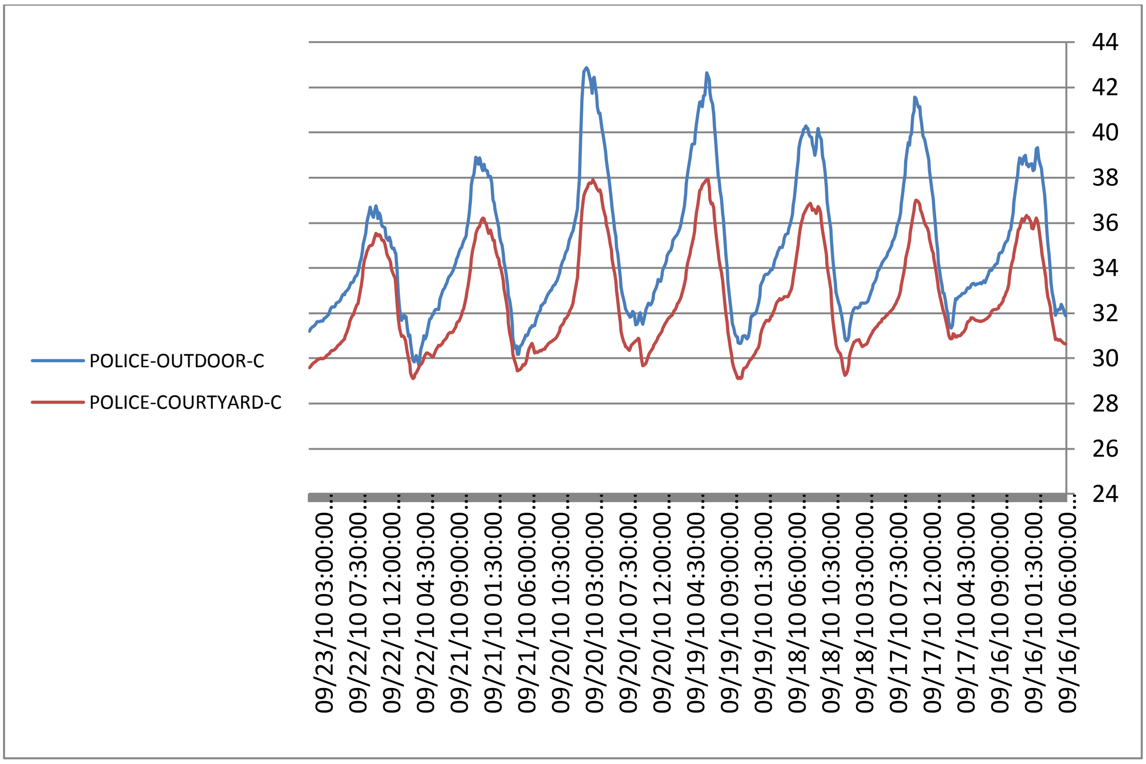


Figure7.14: A comparison between the temperatures of the courtyard and those of the exposed outdoors in the same campus from 16 September 2010 to 23 September 2010.

Figure 7.14 shows that the average temperature of the courtyard at night is around 2˚ less than that of the exposed spaces in the campus. It also shows that the average temperature of the courtyard during the peak hot time of the day is around 3˚-4˚ less than those of the exposed spaces in the campus.

The height of all the indoor spaces, whether they are in the Educational Building or the Administrative Building, is 3.00m. The comparison between the thermal performances of the two prototypes is appropriate due to the fact that both buildings are similar in height and in the use of the same constructional materials.

The total CO_2 emission of the Educational Building was found to be 3,398 kg, over 31 days.

This means that the average daily CO_2 emission of all of the air conditioned area of the Educational Building is (3,398 kg/ 31 days) 110 kg/day.

The total built-up (air conditioned) area of the Educational Building is:

Ground floor area of 780 m² + first floor area of 726 m² = 1,506 m²

This means that the average daily CO_2 emission in the Educational building is (110 / 1,506) = 0.07304 kg/ m².

It also means that the annual CO_2 emissions in kilogrammes per square metre of the Educational Building is (0.07304 X 365) = 26.66 kg/ m².

7.7.2 The Administrative building

The Administrative Building has been designed using modern approaches. All spaces in the offices and the atrium on both floors are fully air-conditioned, see Figure 7.15.

Figure 7.15: Main lobby of the Administrative building

The building is parallel to the Educational building, and it takes the shape of a square plan.

Monitoring the temperature indoors showed that the air conditioning had been on all time. The indoor temperature readings were too close in both buildings due to the fact that both buildings were air conditioned during the day and at night. No relationship was found between the outdoor atmosphere and the indoor one. Slight differences were found between the temperature at night and during the day.

The total CO_2 emissions of the Administrative Building were found to be 11,234 kg, over 31 days.

This means that the average daily CO_2 emissions of all of the air conditioned area of the Administrative Building is (11,234 kg/ 31 days) 362.4 kg/day.

The total built-up (air conditioned) area is:

Ground floor area is (216m² Offices + 336 m² Atrium) = 552m².

First floor area is (423m² Offices + 372m² Void) = 795 m².

The total air conditioned area of the whole building is 1,347 m². This includes the upper space of the atrium.

This means that the average daily CO_2 emissions are (362.4 / 1,347) = 0.269 kg/ m².

However, if the kilogrammes of CO_2 are counted per the usable space only, the calculation will omit the upper void area on the first floor of 372 m², leading us to count the CO_2 emission as (362.4 / 975) = 0.37 kg/ m². This figure will not be included in the research to be conducted.

It also means that the **annual CO_2 emissions in kilogrammes per square metre** of the Administrative Building is (0.269 X 365) = 98.2 kg/ m².

7.7.3 Comparison between monitoring of the Educational and Administrative buildings

The annual CO_2 emissions in kilogrammes per square metre of the Educational Building are 26.66kg/m2 compared to 98.2kg/m2 of the Administrative building.

The ratio of the power consumption in Kw/h and the relevant CO_2 emission to the atmosphere of the Educational Building is (26.66 / 98.2), 27% of those of the Administrative building.

The study also demonstrated that the average temperature of the courtyard at night is around 2˚ less than those of the exposed spaces in the campus. It also shows that the average temperature of the courtyard during the peak hot time of the day is around 4˚ less than those of the exposed spaces in the campus. A strong link has been found due to the fact that using courtyards at the heart of buildings is one of the basic strategies in design that had been applied in the vernacular architecture of this area. These are used to provide healthy indoor environments with high thermal comfort for occupants.

The study showed using a courtyard in the Educational Building with proportionate dimensions led to the minimisation of power consumption and CO_2 emissions respectively, whereas the use of the atrium led to the maximization of power and CO_2 emissions, as in the Administrative Building.

The reasons behind the high levels of energy needed for cooling the Administrative Building are:

a. Lack of wall insulation. Walls are built with concrete block and cement rendering from the outside and gypsum plastering from the inside.

b. The modern attitude of setting low temperatures of air conditioning during summer.

c. The continuous use of air conditioning during the day and at night, even at weekends.

d. Cooling the additional void spaces in the double volume atrium that are not used for any function than aesthetical factors.

e. Ignoring the possible mechanism of the stuck effect to cool spaces and use the atrium as a cooling space by designing ventilation openings that can be opened as needed. This trend is being used in developed countries now and was the basic element in designing the vernacular buildings of the region. However, the steel truss roofing with moderate insulation helped reduce the solar heat gains on the roof.

7.7.4 Conclusions of power monitoring

The two approaches in design demonstrate different ways of energy use. The study concludes the following:

a. Minimising the air conditioning in the usable spaces only, as in the Administrative building, leads to reduced energy in atriums or corridors.

b. It is recommended that indoor settings be raised in general.

c. It is recommended that the temperature of corridors and the atrium be set at 3-4 C˚ higher than the offices and the Educational Building.

d. It is recommended that courtyards be used in small areas that are proportionate to the size of the building in order to keep it shaded and cooled naturally, as in the Educational building.

e. The indoor readings showed that air conditioning was not switched off during the day and at night and even at weekends, leading to a huge waste of energy. Therefore, programmed shutdown systems could be used to ensure the minimisation of waste, in addition to raising public awareness in order to change ‘over-consumption’ attitudes.

f. The most general remark of the project is that there is a huge potential to reduce power consumption if intention is there to do so.

g. It is necessary to engage people and communities in decision-making so that they then strongly adopt implementations.

7.7.5 Monitoring the Outdoor Environment

Five monitors were installed at the same period for five weeks starting from 16 September 2010. Figure 7.16 represents the readings of the first week in both Masdar and the Police Academy.

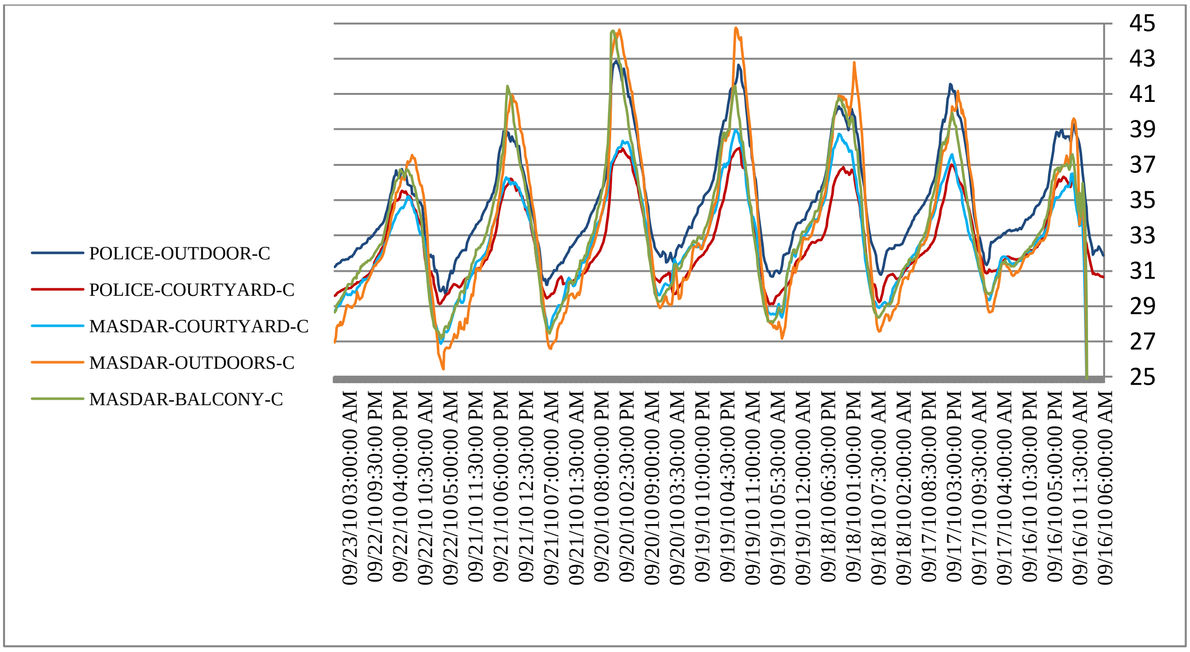


Figure7.16: Week 1- between 16 September 2010 and 23 September 2010 - comparison between all outdoor temperatures C (Masdar and Police Academy)

Figure 7.16 demonstrates the readings of the period between 16 September 2010 and 23 September 2010 and indicates the following:

- The lowest gap in temperatures between the peak of the day and night was seen clearly in the Police Academy courtyard thermal performance (as indicated in red on the above chart). This explains the positive effect of the design strategy on the courtyard environment. Figure 7.17 and Figure 7.18 give impressions about the semi-closed outdoor spaces between the narrow alleyways, which justify the cooler temperatures recorded through the monitoring period.
- The next low gap has been observed in the case of the thermal performance of the courtyard area in Masdar.

Figure 7.17: Shaded narrow outdoor corridors shaded with photovoltaic cells and surrounded by super-insulated walls, the Masdar Institute

- The biggest gap which has been observed is in the difference between the day and night temperature in Masdar outdoor spaces. This is as a result of the specific location of the monitor in a far-exposed space, facing an open desert area.

Figure7. 18: Narrow, relatively cool corridors between buildings in Masdar

- However, the outdoor exposed monitor in the Police Academy building has also recorded a high gap, yet with a lower difference between that and the Masdar exposed monitor. This is because of the relatively green Police Academy compound and its surrounding urban areas compared to the desert-surrounded Masdar compound.

The reason behind the moderate difference in temperature and relative humidity in the Police Academy courtyard when compared to the Masdar building courtyard can be explained as thus:

1. The specific dimensions of the Police Academy courtyard and the proportionate rate of the courtyard length, width and height, have led to the creation of the most moderate temperatures, with minimum gaps between day and night, in the Educational building courtyard.

2. The opposite close ends of the courtyard have created an insulated zone with greenery in the centre when compared with the Masdar building open courtyard. The same, opposite sides are open at the first floor level, which disperse and clear the hot air.

3. The highly-insulated building material of Masdar with a low air conditioning load, compared to the low-insulated walls of the Police Academy building, showed that good thermal performance is relevant to design strategy.

4. The steel truss roofing system with a thin layer of 50mm of polyurethane insulation, and the air layer inside the truss have reduced the impact of roof heat gains on the first floor level of the Educational building. Surprisingly, the same roofing system is used in the Administrative building and yet it consumes almost four times the amount of power than the Educational building does. This leads us on to the impact of the courtyard zone.

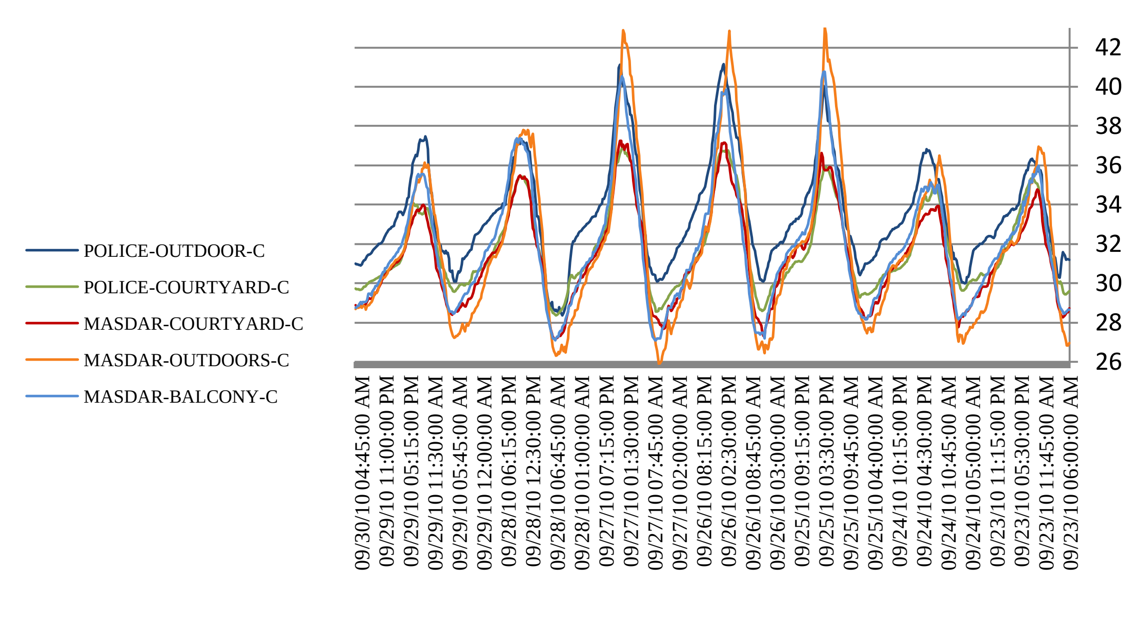


Figure 7.19: Week 2 - between 23 September 2010 and 30 September 2010 - Comparison between all outdoor temperatures (C°), (Masdar and Police Academy buildings)

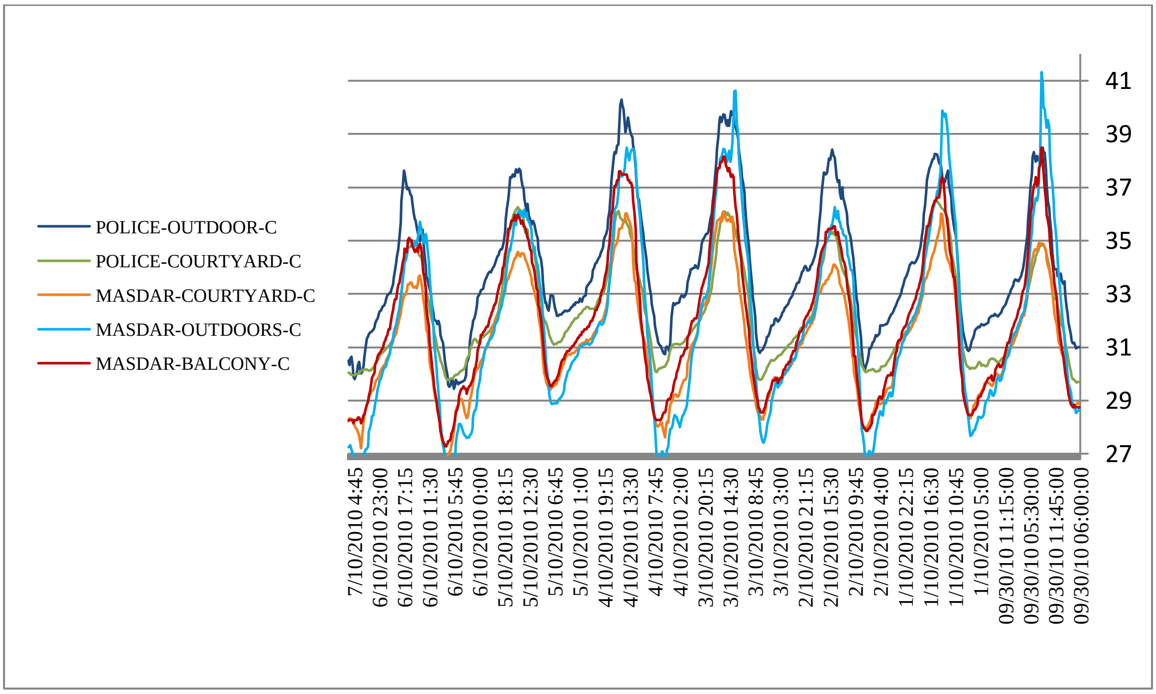


Figure 7.20: Week 3 - between 30 September 2010 and 7 October 2010 -Comparison between all outdoor temperatures (C°), (Masdar and Police Academy buildings)

A remarkable note was that the outdoor temperature readings at night in Masdar (whether in the courtyard, the outdoor space or the balcony) were the lowest at night when compared to those readings of the Police Academy building. This is considered to be the result of the 'open site' desert environment surrounding the Masdar building.

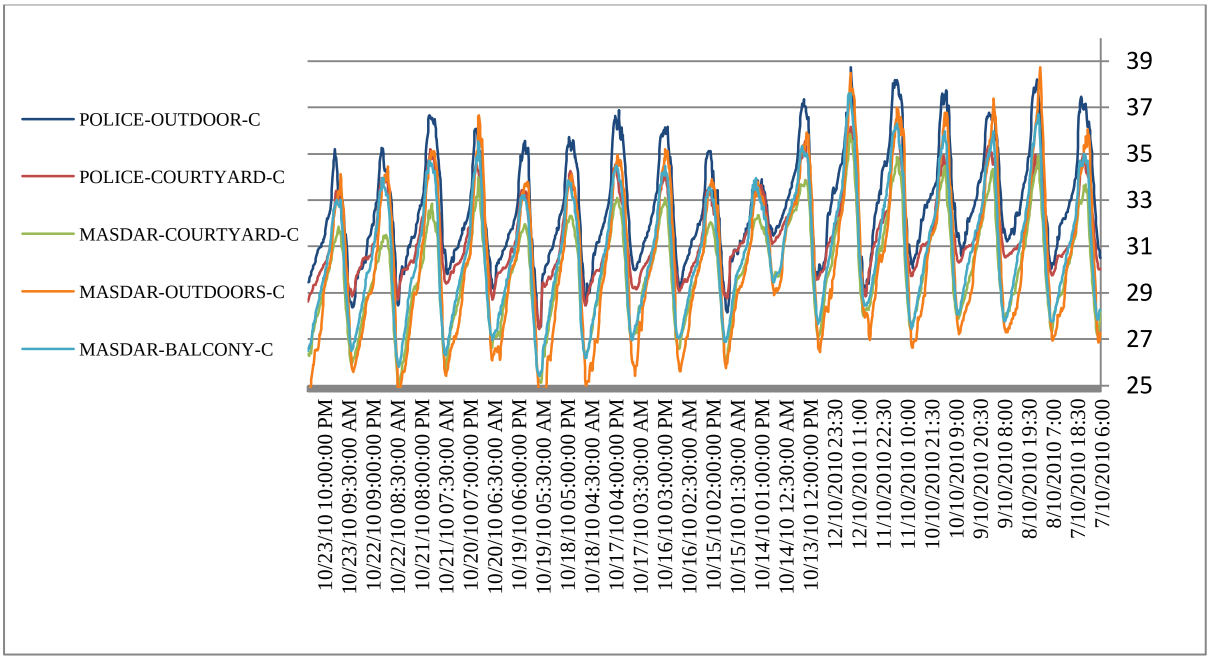


Figure 7.21: Week 4 & 5 - between 7 October 2010 and 23 October 2010 - Comparison between all outdoor temperatures (C°), (Masdar and Police Academy buildings)

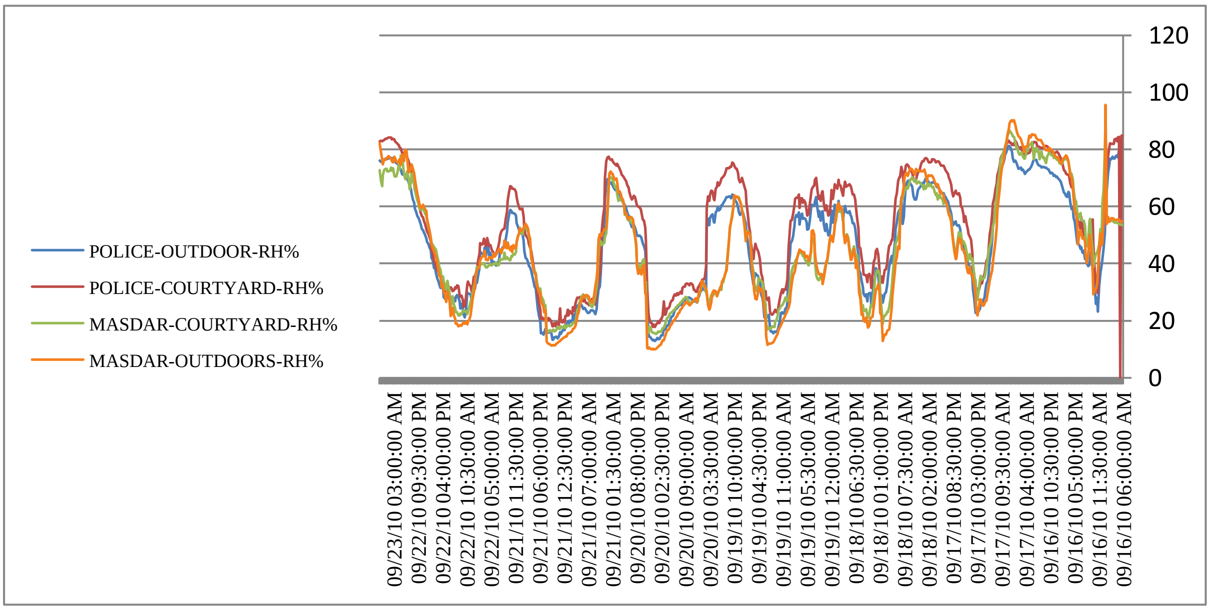


Figure 7 22: Week 1 - between 16 September 2010 and 23 September 2010 -Comparison between all outdoor relative humidity (Masdar and Police Academy buildings)

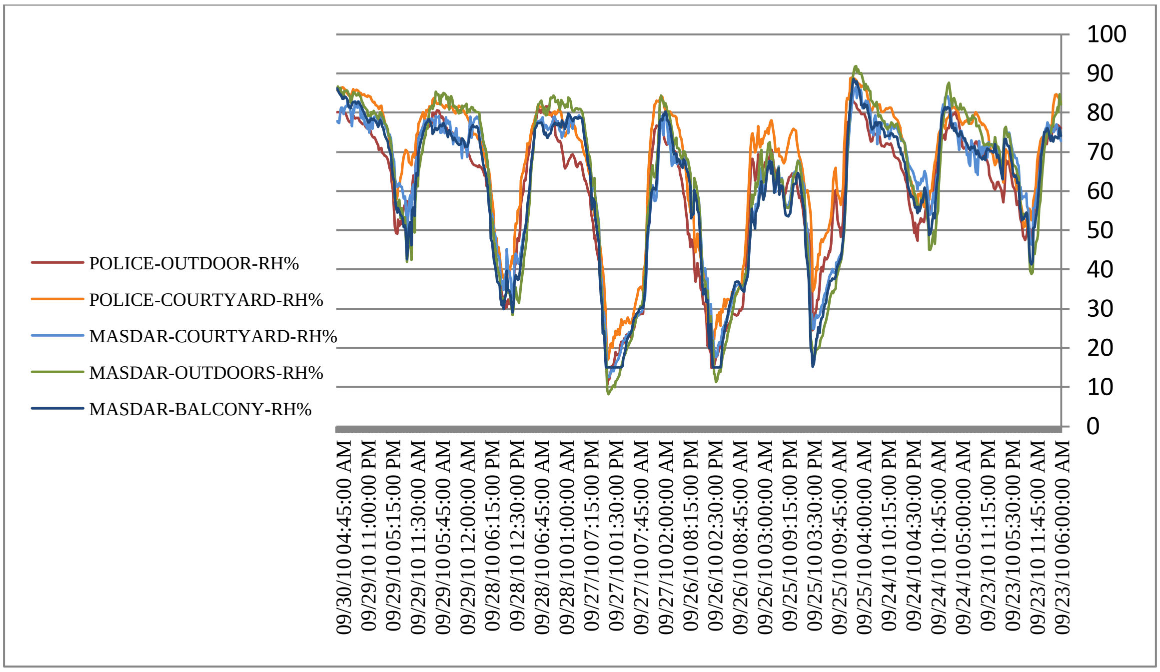


Figure7. 23: Week 2 - between 23 September 2010 and 30 September 2010 -Comparison between all outdoor relative humidity (Masdar and Police Academy buildings)

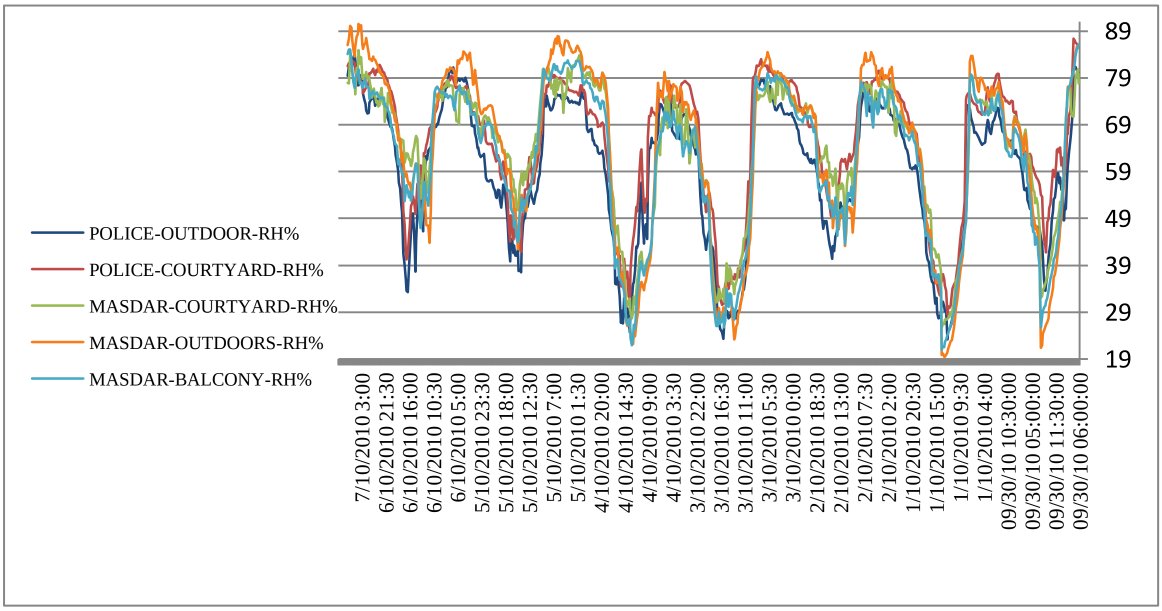


Figure7. 24: Week 3 - between 30 September 2010 and 7 October 2010 -Comparison between all outdoor relative humidity (Masdar and Police Academy buildings)

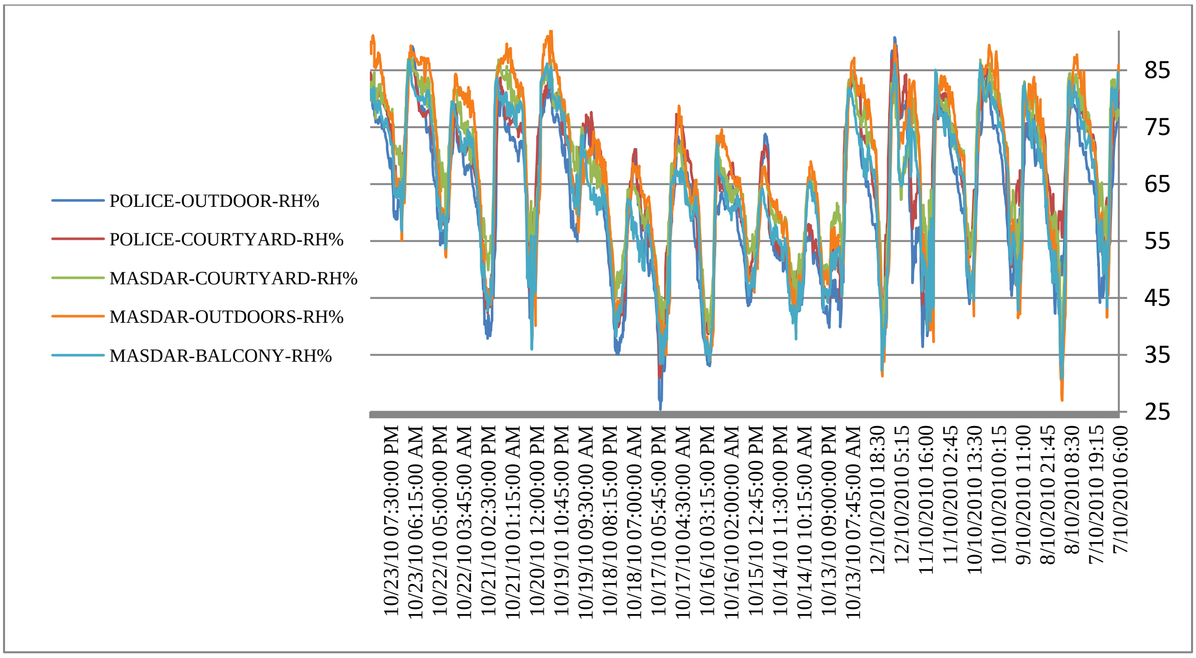


Figure 7.25: Weeks 4 & 5 - between 7 October 2010 and 23 October 2010 - Comparison between all outdoor relative humidity (Masdar and Police Academy buildings)

The relative humidity diagram for indoor environments has not been outlined as these were all similar due to similar indoor temperatures. However, the outdoor relative humidity showed the following;

1- The readings were strongly interlinked with the outdoor temperatures. This meant that during the peak highest temperatures during the day the relative humidity dropped. The opposite happens at night - with the lowest outdoor temperatures, the relative humidity goes up.

2- It is also observed that due to the 'open site', desert-facing location of the outdoor monitors in the Masdar building, the highest gap between day and night readings were recorded. This meant that generally the highest relative humidity was recorded at night, and the lowest during the day.

Figures 7.26-7.34 represent the readings of each research, carried out separately throughout the full period of investigation between 16 September and 30 October 2010. With each Figure, the estimated lowest and highest readings are recorded.

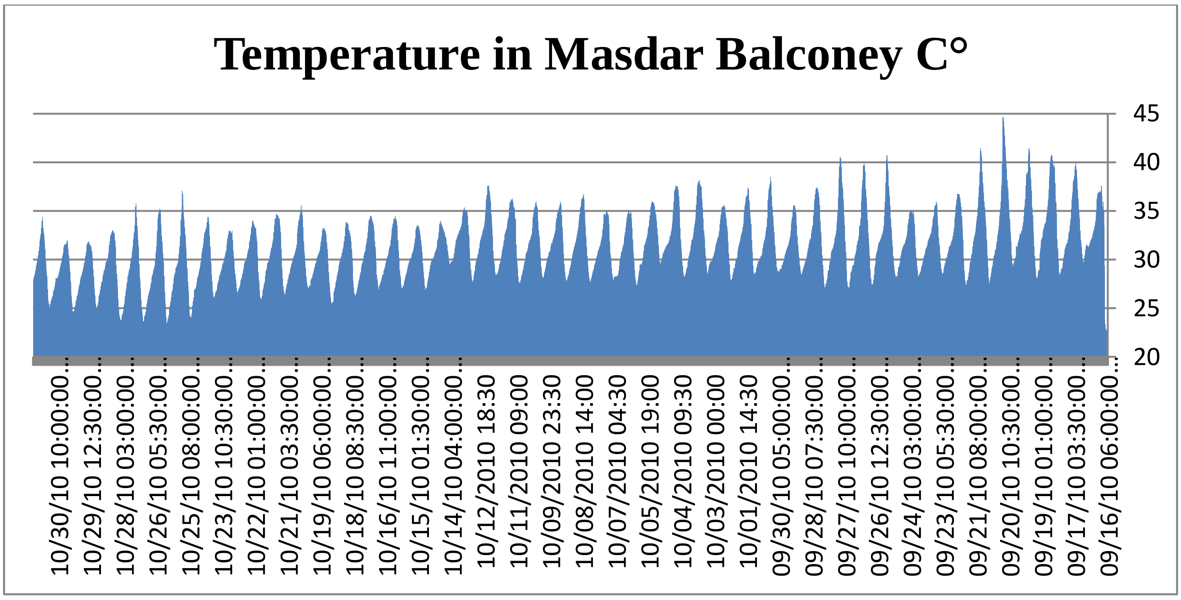


Figure 7.26: Temperature on the Masdar Balcony (C°)

The estimated highest temperature on the Masdar Balcony was 45C° and the lowest was 25C°.

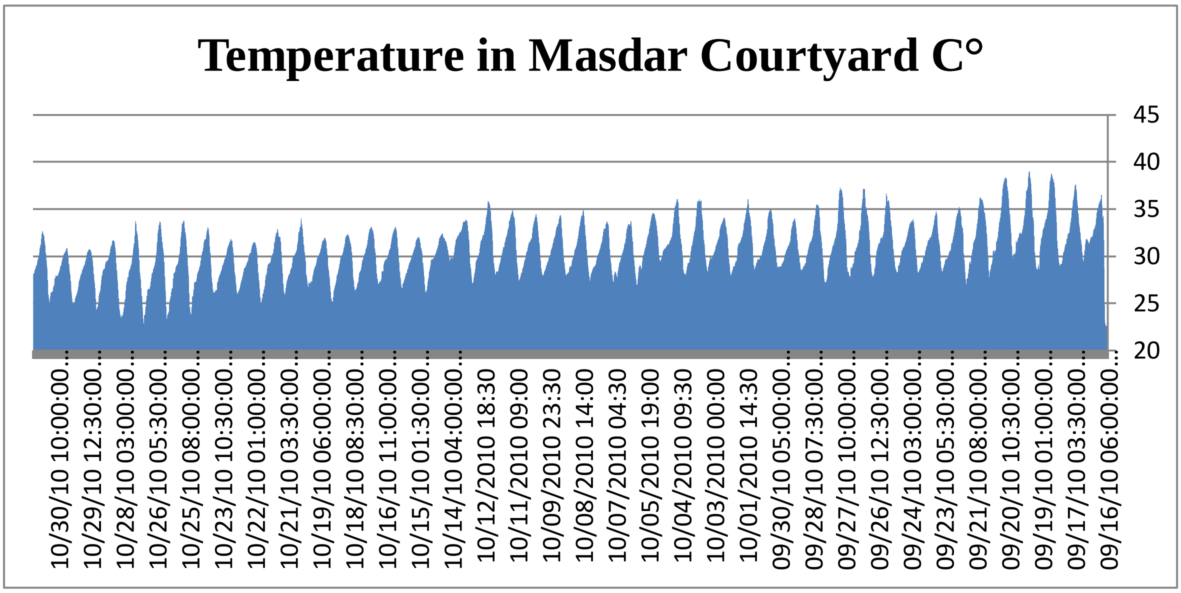


Figure 7.27: Temperature in the Masdar Courtyard (C°)

The estimated highest temperature in the Masdar Courtyard was 38C° and the lowest was 23C°.

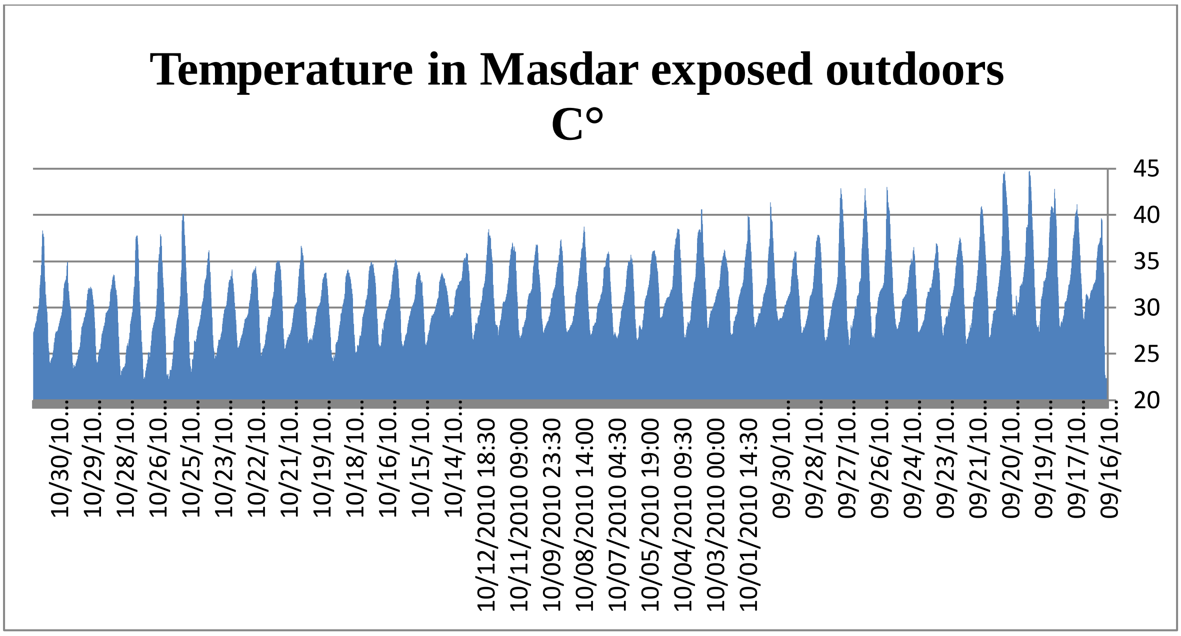


Figure 7.28: Temperature in the Masdar exposed outdoors areas (C°)

The estimated highest temperature in the Masdar exposed outdoors areas was 45C° and the lowest was 22C°.

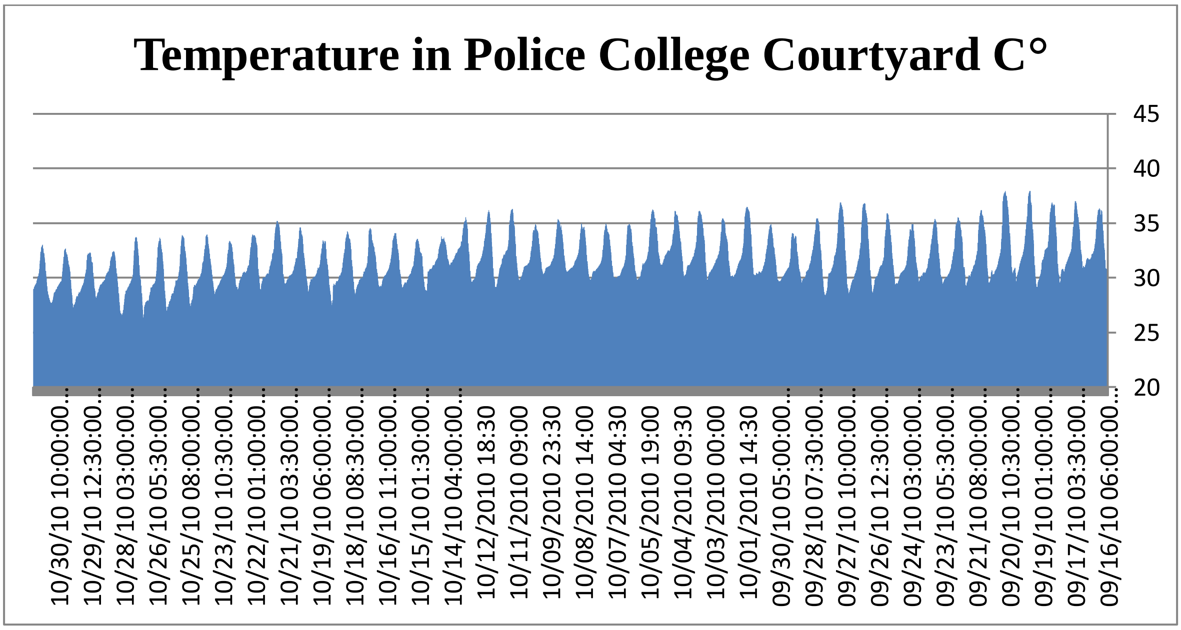


Figure 7.29: Temperature in the Police Academy Courtyard (C°)

The estimated highest temperature in the Police Academy Courtyard was 37.5C° and the lowest was 27C°.

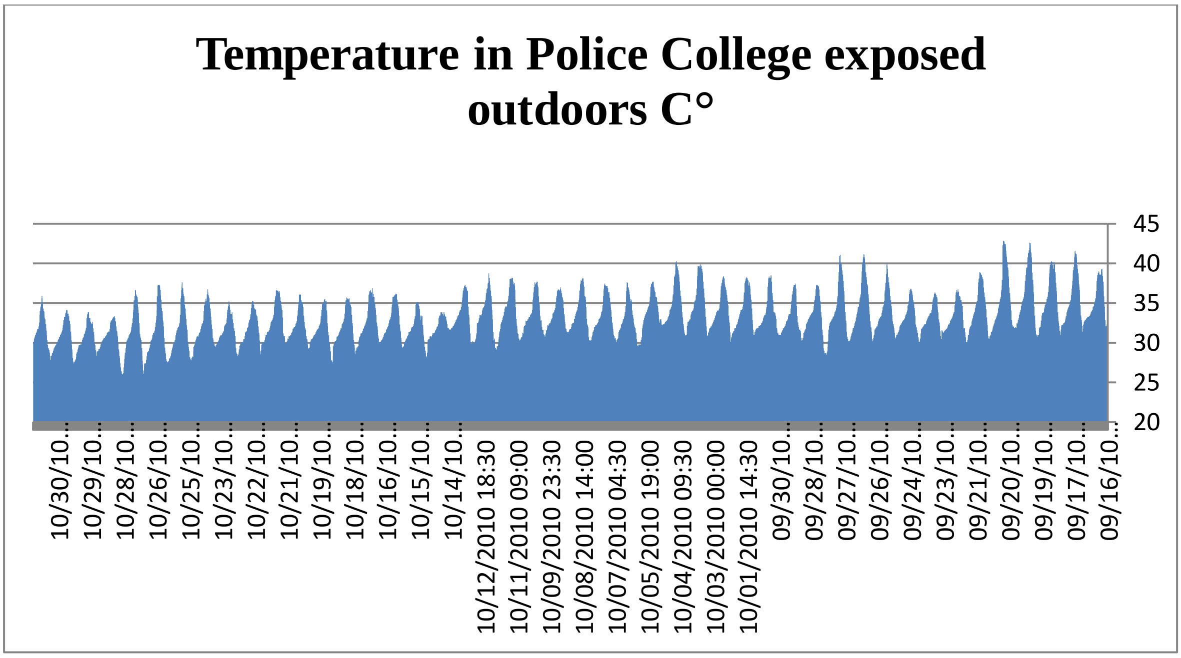


Figure 7.30: Temperature in the Police Academy exposed outdoors areas (C°)

The estimated highest temperature in the Police Academy exposed outdoors areas was 42C° and the lowest was 26C°.

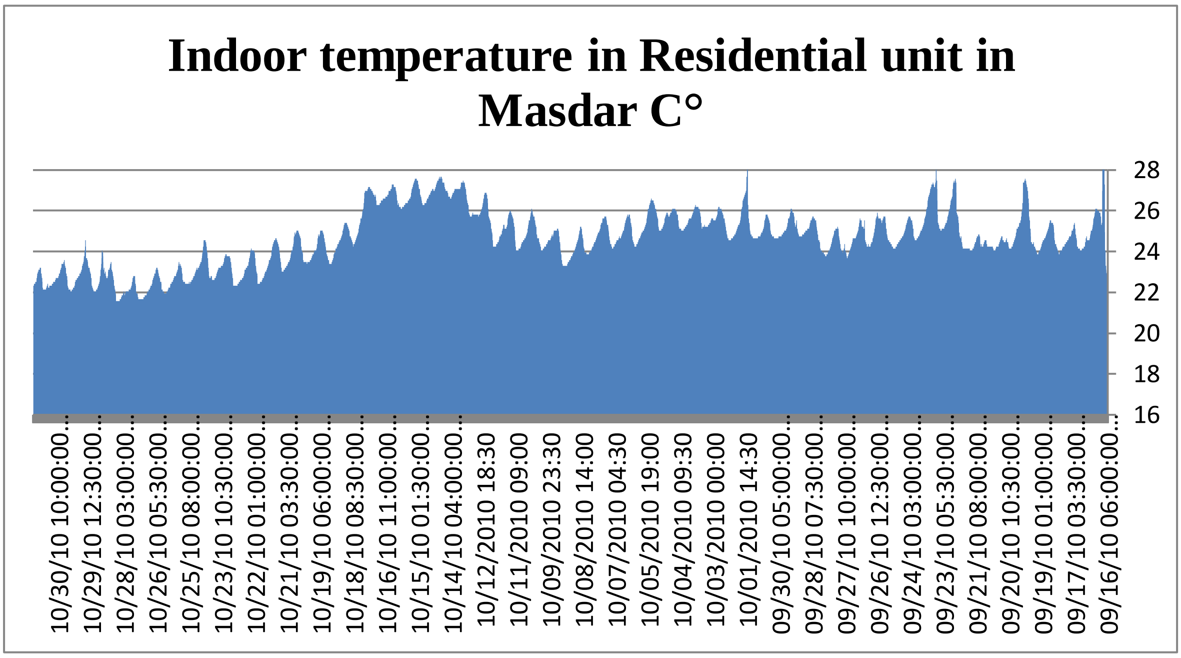


Figure7.31: Indoor temperature in the Residential unit in the Masdar building (C°)

The estimated highest indoor temperature in the Residential unit in the Masdar building was 28C° and the lowest was 21.5C°.

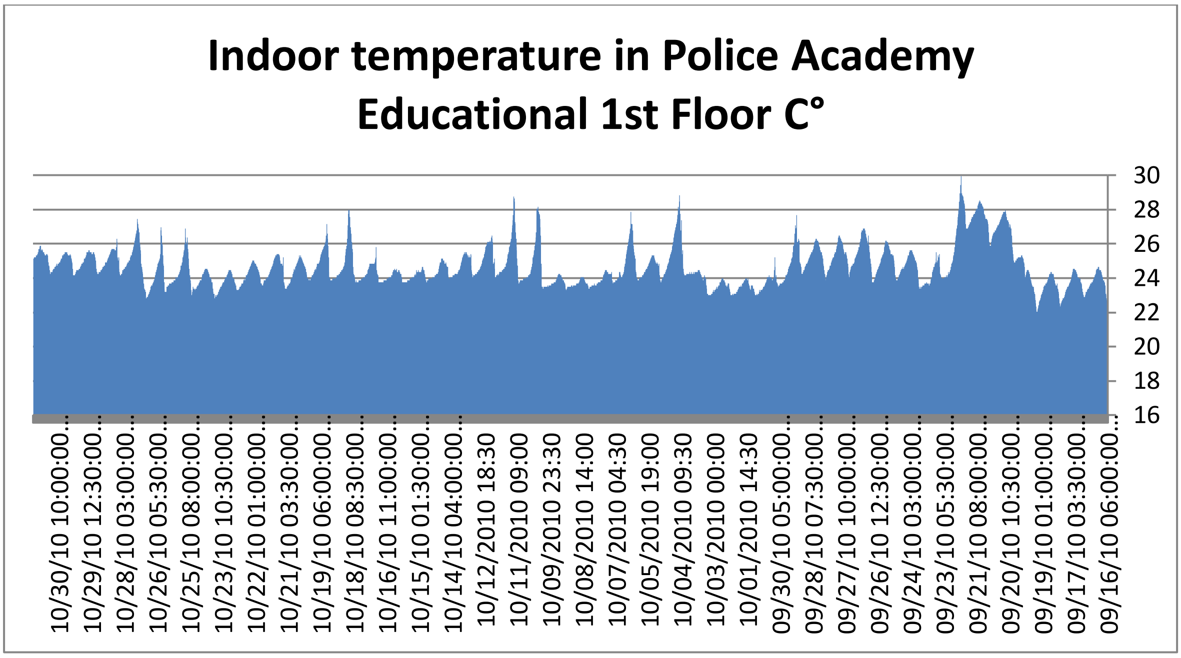


Figure 7.32: Indoor temperature in the Police Academy Educational building, 1st Floor (C°)

The estimated highest indoor temperature in the Police Academy Educational building on the 1st Floor was 30C° and the lowest was 23C°.

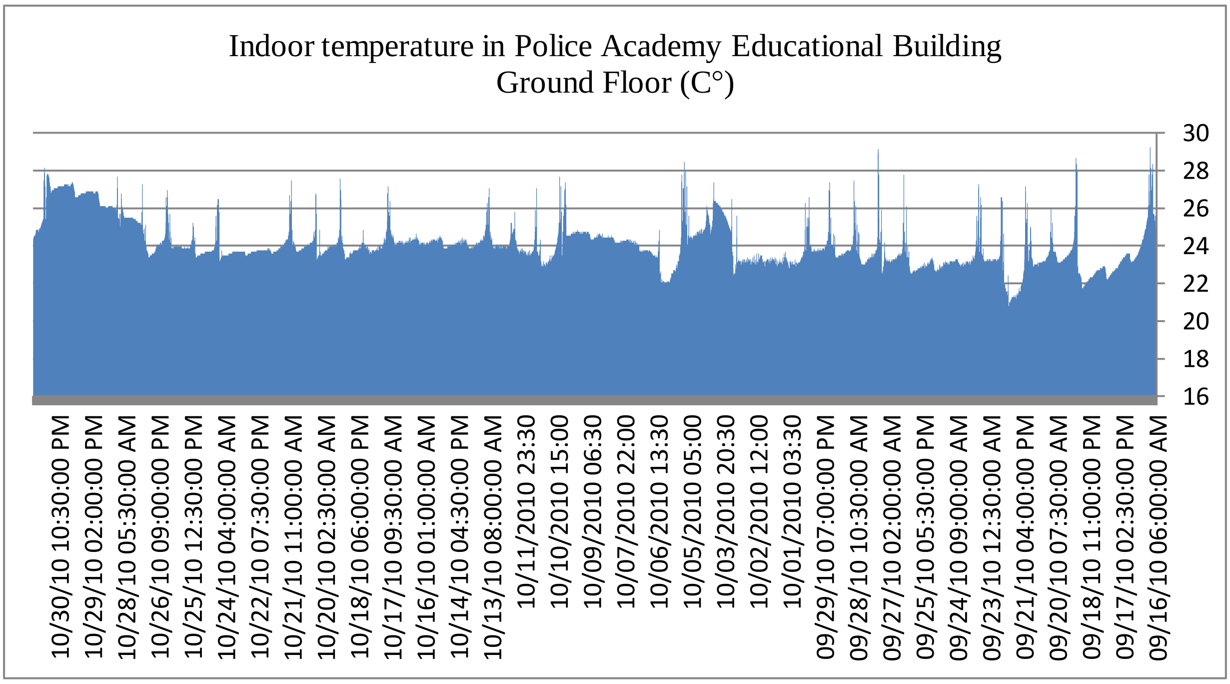


Figure 7.33: Indoor temperature in the Police Academy Educational Building, ground floor (C°)

The estimated highest indoor temperature in the Police Academy Educational Building on the ground floor was 29C° and the lowest was 21C°.

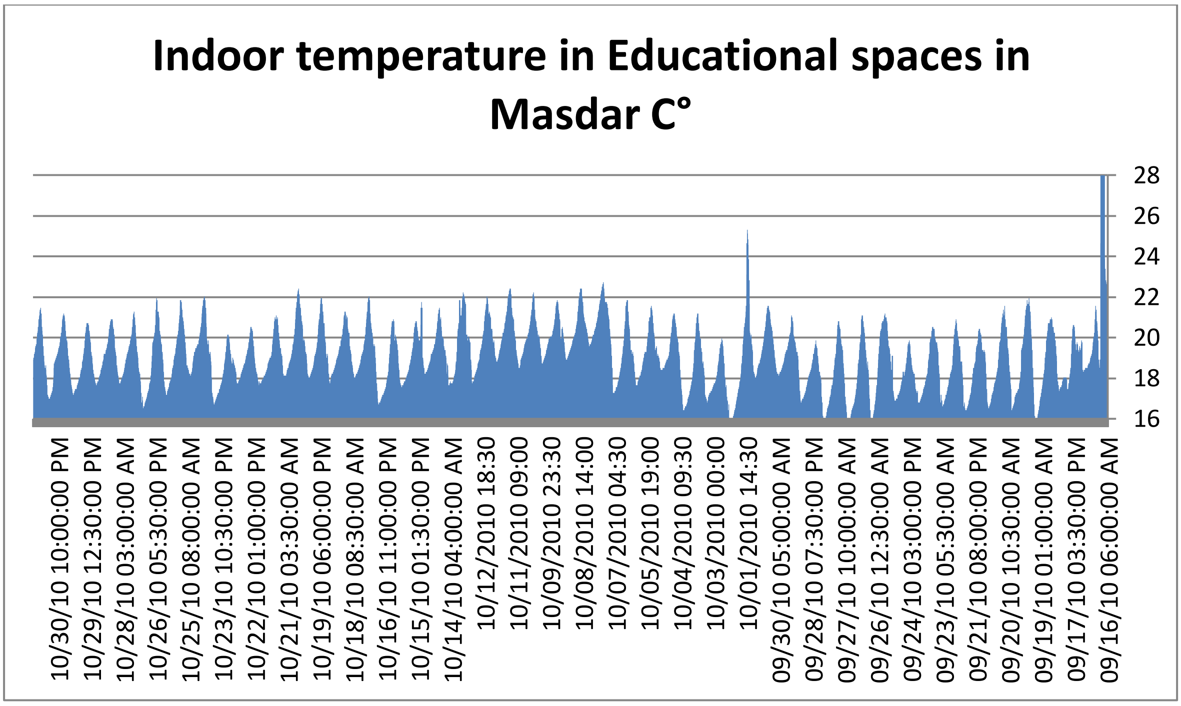


Figure 7.34: Indoor temperature in Educational spaces in the Masdar building (C°)

The estimated highest indoor temperature in Educational spaces in the Masdar building was 25C° and the lowest was 16C°. It is considered unreasonable to have indoor temperatures of as low as 16C° in the Masdar Educational building lecture halls. It was anticipated that higher indoor temperatures would apply in all Masdar premises in order to induce the highest possible change in attitude among Masdar students – and then to apply such an experiment nationally. But the results showed the opposite.

Location	Rounded Highest C°	Rounded Lowest C°	Temperature difference between day and night C°
Masdar Balcony	45	25	20
Masdar courtyard	38	23	15
Masdar exposed outdoors areas	45	22	23
Police Academy Courtyard	37.5	27	10.5
Police Academy exposed outdoors areas	42	26	16
Indoors - residential unit in the Masdar building	28	21.5	6.5
Indoors - Police Academy Educational building, ground floor	29	21	8
Indoors - Police Academy Educational building, 1st floor	30	23	7
Indoors - Temperature in educational spaces in the Masdar building	25	16	9

Table 7.4: Highest and lowest temperatures recorded in the investigated buildings

The following observations have been made with regard to Table 7.4:

1. The Masdar building courtyard and the Police Academy building courtyard recorded 38C° and 37.5C° temperatures respectively. This means that low budget buildings with a good design strategy could result in a similar microclimate if not better than high quality and budget projects, as is the case with Masdar.

2. Masdar outdoors areas are closer to the desert surroundings, temperatures are higher during the day than those of the Police Academy building and lower than those of the Police Academy building at night. It is therefore the differences between daytime and night time temperatures in the Police Academy building which recorded a relatively smaller gap, in the case of the Police Academy.

An average of the charts in Figure 7.24 to Figure 7.32 has been extracted. These have been listed in ranking order in the below table.

No.	Location of readings	Average C°	Average RH%
1.	Masdar educational spaces - indoors	19.1	68%
2.	Police Academy Educational building, ground floor – indoors	24	35.6%
3.	Police Academy Educational building, 1st floor – indoors	24.6	39.8%
4.	Masdar residential unit, 1st floor - indoors	24.6	57%
5.	Masdar courtyard	30.5	61.8%
6.	Masdar exposed outdoors areas	31	61.3%
7.	Masdar balcony	31.2	58.7%
8.	Police Academy courtyard	31.6	63%
9.	Police Academy exposed outdoors areas	33	58%

Table 7.5: Average temperatures and relative humidity during the whole period of recording.

Table 7.5 demonstrates the following findings about the average temperatures and relative humidity during the same period of time:

1. Generally the indoor temperatures ranged from 19.1C to 24.6C.

2. Outdoor temperatures ranged from 30.5C to 33.0C.

3. A lowest average temperature of 19.1C was recorded in the educational indoors of Masdar. Two reasons have been seen to induce this: the energy efficient building envelope (?) of the Masdar Educational building, which reduces heat gains, and the air conditioning system provided.

4. The exceptionally low relative humidity has been recorded in both indoor spaces of the Educational Police Academy, due to the conventional air conditioning system, as it absorbs the indoor humidity.

5. Similar indoor temperatures have been recorded in the Police Academy building and Masdar building residential unit monitored spaces (between 24C°) and 24.6

C°.) This was seen to be a result of the air conditioning system in the poorly-insulated buildings of the Police Academy, as opposed to the energy-efficient, sophisticated insulated indoors of the Masdar building residential indoor spaces, with limited air-conditioning.

6. Close readings of both the Masdar courtyard (30.5 C°), and the Police Academy courtyard (31.6 C°), based on similar design strategies of the isolated courtyard in the Police Academy Educational building and the narrow corridors of the Masdar complex.

7. Two degrees in temperature were found between an average of 33 C° in exposed areas in the Police Academy building, as opposed to 31 C° in the Masdar building exposed outdoors areas. This was considered to be a reflection of the 'open space', 'outside the city' location of the Masdar complex, with highly opened ventilation rates leading to the cooling of the outdoor space.

8. A very general observation is that the higher the temperature is, the lower the relative humidity is, except in the air conditioned indoor spaces.

Table 7.5 has been translated into two diagrams - one for the average temperature readings and the other for the average relative humidity readings, see Figure 7.35 and Figure 7.36.

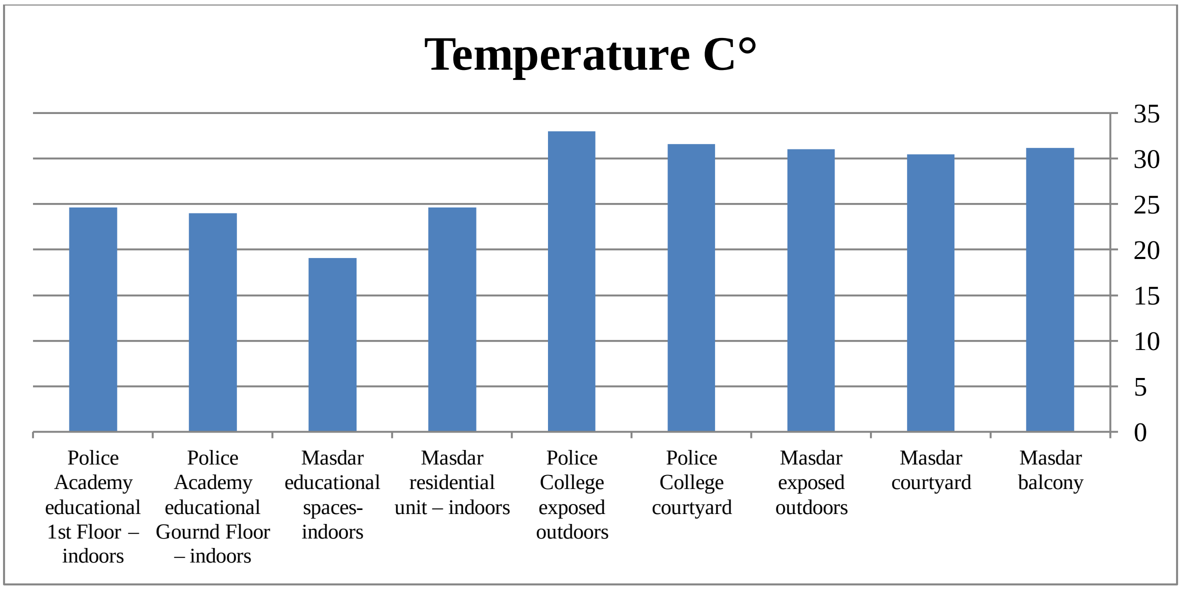


Figure7.35: Average temperatures of all monitored spaces

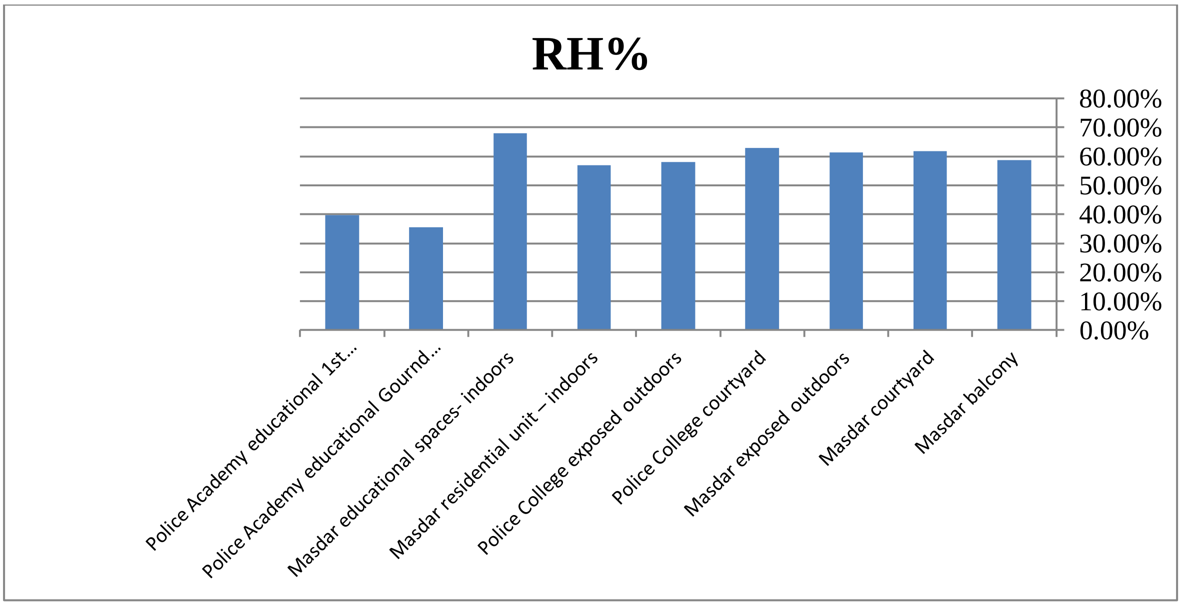


Figure 7.36: Average relative humidity of all monitored spaces

7.8 Power monitoring in May 2011

Power consumption readings of the residential unit in the Masdar building monitored in fall 2010 were supposed to be submitted by Masdar. However, because of technical abnormality, it was understood later that there was no possibility of extracting those specific readings from the system.

As a result of this, new power consumption monitoring was planned to take place in May 2011. It was very important to install meters in the Police Academy building and to make sure that Masdar readings could be extracted. It was also very important to take the readings before summer. In order to take power readings and utilise them for average power consumption for a full year, it was very important to avoid monitoring during summer or winter. Monitoring in a relatively moderate temperature would provide the option of an annual average as shown below in Figure 7.35.

A hypothetical approach to study the implications of the financial and environmental costs has been established. Three indicators of costs are to be investigated:

1- The initial cost of each prototype by implementing comparisons in AED/ m^2.

2- The running cost of each prototype to be measured by AED/ m^2.

3- The environmental costs of CO_2 emissions that are induced by the different design strategies of each prototype, to be measured by kilogrammes of CO_2/m^2.

The research showed that a diversity of elements interfere with the effect on the financial and environmental costs. These were seen to be:

1- Initial costs

2- Running costs

3- Maintenance

4- Inflation of the national economy

5- Interests of any financial cost over time

6- Depreciation of buildings

7- Anticipated changes of energy prices on local and global scales

8- Power consumption and CO_2 emissions, respectively

However, in order to steer the research into a more concise and controlled mathematical methodology, and after consulting accountants regarding analysis of the investigated factors, it was decided to calculate the following only:

1- Initial costs while adding interest and inflation over 20 years

2- Running costs over 20 years while adding interest and inflation

3- Carbon dioxide emissions over 20 years

The more the oil reserve is limited, the higher energy prices will rise, globally. This applies to the period of the next 25 years, which will be part of the above calculations. However, it was decided to consider power prices as stable in order to simplify the results. The aim of the study is the comparative analysis that is going to be translated into percentages. Therefore, as the oil, power and energy prices go up it will apply to all cases of all prototypes, resulting in the same ratios and calculations of any future financial cost.

Different obstacles faced regarding the recording process of power consumption:

1- Within Masdar, the new compound was under construction. Therefore, it was necessary to investigate whether the power readings covered the power consumption of the residential unit used, in addition to the consumption of power for construction. It was confirmed that these readings covered the meters of those already being used in the buildings only.

2- Within the Police Academy, a big compound of educational, training and residential buildings share the same power monitors. Therefore, two monitors in two prototypes were fixed: the educational building and the administrative building.

3- The average monthly temperatures in Abu Dhabi are shown in Figure 7.37. The average temperature over 12 months has been calculated to be 27.6C°. Based on these figures, it was decided to use the power readings of the study during May as an average for the year.

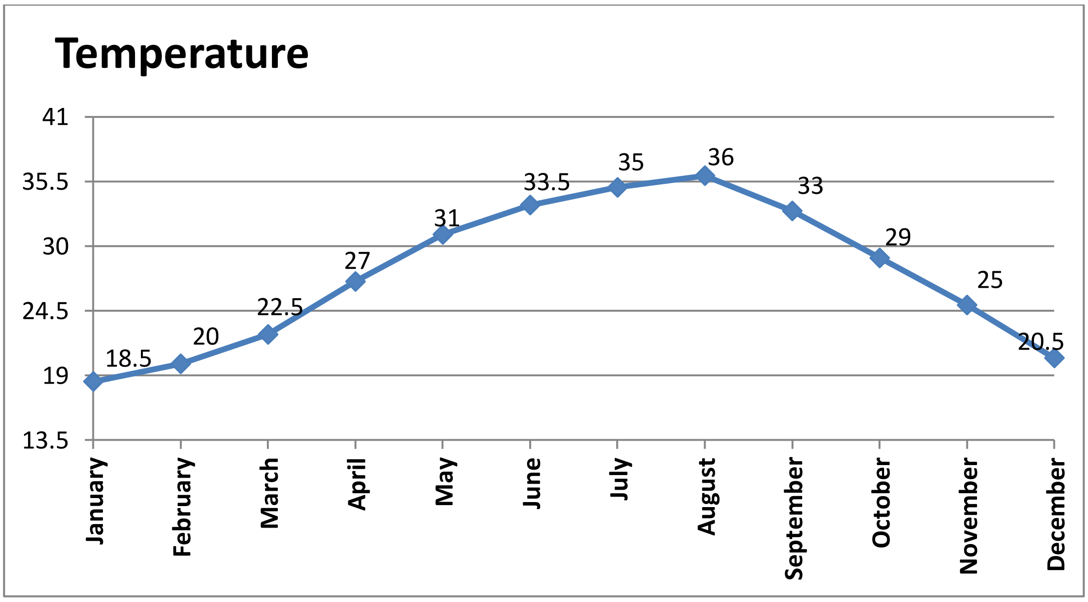


Figure7.37: Annual Average Temperature in the UAE
Source: National Centre for Meteorology in Abu Dhabi, 2011

Based on the above figure, published by the National Centre for Meteorology in Abu Dhabi, it was decided to consider the temperatures of October and May as the annual average for the 12 months of the year.

The current price of kWh is 0.05 AED/ kWh. However its actual cost to the government is 0.27 AED/ kWh (price obtained from a direct contact over the phone with an Abu Dhabi distribution company). It was therefore decided to consider the cost of kWh as 0.27 AED/ kWh.

To translate power consumption in kWh into kilogrammes of carbon dioxide, all monitor readings shall be multiplies by 0.5416 kgCO2/kWh. (see Table 7.2)

The most accurate rates of inflation and interest were sought in order to apply them into the Excel calculations. However, after discussing the matter with a local specialised accountant it was decided to consider inflation as 3% and the interest rate as 6%.

n	Date	Police Academy Administrative Building		Police Academy Educational building		Masdar building Residential unit	
		Reading	Kw/h consumption	Reading	Kw/h consumption	Reading	Kw/h consumption
1	7-May-2011	61692	465	28177	206	1557	4
2	8-May-2011	62157	407	28383	209	1561	0
3	9-May-2011	62564	768	28592	426	1561	0
4	10-May-2011	63332	559	29018	205	1561	40
5	11-May-2011	63891	595	29223	238	1601	5
6	12-May-2011	64486	638	29461	230	1606	7
7	13-May-2011	65124	632	29691	218	1613	8
8	14-May-2011	65756	503	29909	194	1621	10
9	15-May-2011	66259	145	30103	153	1631	8
10	16-May-2011	66404	175	30256	143	1639	7
11	17-May-2011	66579	609	30399	235	1646	9
12	18-May-2011	67188	537	30634	199	1655	9
13	19-May-2011	67725	507	30833	230	1664	9
14	20-May-2011	68232	520	31063	218	1673	10
TOTAL			**7,060**	**TOTAL**	**3,104**	**TOTAL**	**126**

Table 7.6: Power consumed between 4 May and 20 May 2011 by Masdar residential unit and the Police Academy Administrative and Educational buildings

Table 7.6 showed that the total power consumed throughout the 14 days of investigation by all three prototyped areas listed above, will be used in the following way:

1. Divide the power consumed in two weeks by the total area of the space, in order to get power consumption per square meter.
2. The power consumption per square meter will be divided by 14 in order to get the daily power consumption.
3. The daily power consumption will be multiplied by 0.27 in order to find the daily power cost (to the government) in AED.
4. The daily power consumption will be multiplied by 0.5416 in order to find the daily amount of kilogrammes of CO_2 to be emitted into the atmosphere, per square meter.

The results of the above mathematical procedures will be listed in Table 7.7 that combines all three results, in order to consider the results and make comparisons.

	Police Academy Administrative Building	Police Academy Educational building	Masdar building Residential unit
Initial cost price in AED/m^2	4,000 AED/ m^2	4,000 AED/ m^2	6,600 AED/ m^2
Total consumption (during the 2 weeks of investigation)	7,060 kW/h	3,104 kW/h	126 kW/h
Area investigated	1,347 m^2	1,506 m^2	60 m^2
Kw/h consumption per m^2 (full period of 2 weeks)	5.24 kW/h/ m^2	2.06 kW/h/ m^2	2.1 kW/h/ m^2
Daily kW/h consumption (above readings divided by 14)	0.37 kW/h/ m^2	0.15 kW/h/ m^2	0.15 kW/h/m^2
Monthly consumption in kW/h per m^2	11.23 kW/h per m^2	4.42 kW/h per m^2	4.50 kW/h per m^2
Monthly running cost in AED/m^2, calculated at cost price of 0.27 AED/m^2	3.032 AED/ m^2	1.193 AED/ m^2	1.215 AED/ m^2
Monthly CO_2 emissions in kg(s)/m2, calculated at 0.5416 kg of CO_2 /kW/h	6.082 kg(s)/ m^2	2.394 kg(s)/ m^2	2.437 kg(s)/ m^2
CO_2 emissions by the end of 20 years	1,459.68 kg of CO_2/ m^2	574.56 kg of CO_2/ m^2	584.88 kg of CO_2/ m^2

Table 7.7: Total readings investigated during the second period of time, between 7 May and 20 May 2011

The above table was produced based on the following procedures:

Point 1:

A study was undertaken in the local market of Abu Dhabi. The price of 4,000 AED per square meter was seen to be the most suitable for the Police Academy Administrative and Educational buildings. Facts like using window type and split air-conditioning were taken into consideration. A market study was also undertaken to determine the effects of the steel truss roofing covered with steel cladding, which covered both indoor spaces and cantilevers (see Figure 7.9.)

The Masdar building residential unit cost per square metre was provided by using a table listing all prices for different building categories. However, the amount of 200AED was added in to cover the cost of the district cooling, as provided by Masdar staff, (to be attached in the Appendix).

Point 2:

The power consumption readings in kW/h were measured by two monitors installed in each one of the investigated buildings on the Police Academy building site, as in Appendix?

However, Masdar readings of the power consumption of a typical residential unit on the ground floor have been extracted from the table provided by Masdar, (to be attached in the Appendix).

The monitoring period covered the same 14 days from 7 May to 20 May 2011. The average temperature in May as seen in Figure 7.14 is close to the annual average temperatures.

Point 3:

The area investigated was measured from CAD files of all three prototypes. This included only the indoor air conditioned area. In the Administrative building the area with double the volume space in the middle of the building was multiplied by two based on the fact that the air conditioned space height (6.00m) was double the normal room’s height of (3.00 m) height (see Figure 7.11.)

A typical residential unit in the Masdar building was measured from CAD files.

Point 4:

The total power consumption of the two specific weeks measured in Point 2 has been divided by each area. As found in Point 3, this resulted in the power consumption of each building type over 14 days. This was measured by kW/h/m2.

Point 5:

The above results of the power consumption in each prototype over 14 days have been divided by 14 in order to get the power consumption of each building type in one day only.

Point 6:

The daily power consumption of the three building types was multiplied by 30 in order to get the approximate monthly power consumption. It was decided to choose the later cost calculation tables (Table 7.8, 7.9 and 7.10) on a monthly basis over 20 years (240 months) in order to minimise the size of the tables (to be attached in the Appendix).

Point 7:

Figures from Point 6 were multiplied by 0.27 AED/ m^2, which is the cost of each kW/h to the Government of Abu Dhabi. The results gave the monthly running cost in AED/m2 in each building type investigated. In the Masdar building, the power running cost is 1.215 AED per each square meter, as shown in the below table, extracted from the original, (to be attached in the Appendix).

MASDAR RESIDENTAIL UNIT			Monthly Inflation	0.25%
			Monthly Interest	0.50%
			Annual Inflation 3%	Annual Interest 6%
Month	Initial cost of Construction of 1 m^2	Monthly running cost	After interest	After inflation
1	AED 6,600.00	AED 1.215	AED 6,634.22	AED 6,650.81
240	AED 40,293.88	AED 1.215	AED 40,496.57	AED 40,597.81

Table 7.8: Cost of each square meter of the Masdar building residential unit after 20 years of occupation

The Police Academy Educational building recorded similar rates, even less than the Masdar building's power consumption readings. The running cost is 1.193 AED per each square meters, as shown in the below table extracted from the original, (to be attached in the Appendix).

POLICE ACADEMY EDUCATIONAL			Monthly Inflation	0.25%
			Monthly Interest	0.50%
			Annual Inflation 3%	Annual Interest 6%
Month	Initial cost of Construction of 1 m^2	Monthly running cost	After interest	After inflation
1	AED 4,000.00	AED 1.193	AED 4,021.20	AED 4,031.25
240	AED 24,725.64	AED 1.193	AED 24,850.47	AED 24,912.59

Table 7.9: Cost of each square meter of the Police Academy Educational Building after 20 years of occupation.

The Police Academy Administrative building recorded the highest rates of power consumption readings and consequently, running costs, in AED. The running cost is found to be 3.032 AED/m2, as shown in the below table extracted from the original, (to be attached in the Appendix).

POLICE ACADEMY ADMINISTRATIVE			Monthly Inflation	0.25%
			Monthly Interest	0.50%
			Annual Inflation 3%	Annual Interest 6%
Month	Initial cost of Construction	Monthly running cost	After interest	After inflation
1	AED 4,000.00	AED 3.032	AED 4,023.05	AED 4,033.10
240	AED 25,954.39	AED 3.032	AED 26,087.21	AED 26,152.42

Table 7.10: Cost of each square metre of the Police Academy Educational Building after 20 years of occupation

Point 8:

The monthly power consumed by each square metre in each building type, investigated as shown in Point 6, has been multiplied by 0.5416 kg of CO_2 /kW/h, in order to calculate the monthly kilogrammes of CO_2 resulted from running each one square metre of each building.

Point 9:

The final monthly figure of CO_2 emissions of each building type, as shown in Point 8, was multiplied by 240 in order to calculate the number of CO_2 emissions in kilogrammes from each square metre, in each building type, after 20 years.

7.9 Chapter summary

The original design of the research was based on choosing two case studies: a sustainable building like Masdar and conventional buildings like the Police Academy Educational and Administrative buildings.

The three approaches in design demonstrate different types of energy use. The Masdar image of low power consumption, high awareness among its students and cost effectiveness of the project was the reason behind choosing it for this study. Therefore, the questionnaire for Masdar students contained some added questions based on living in a sustainable development. Responses from Masdar students were not consistent - some of them did match expectations and some did not, as discussed in the results of the questionnaires.

It was found that the power consumption of the Masdar building residential unit was similar to that of the Police Academy Educational building. Yet the initial cost of building per square metre of Masdar is around 6,600AED, compared to 4,000AED for the Educational Building.

Based on the similar constructional details of the two buildings, it was originally expected that both the Educational and Administrative buildings of the Police Academy would have similar power readings and thermal performance, in terms of the indoor temperature.

Monitoring the power consumption led to significant findings regarding the thermal performance of the Educational building. The significant difference between the power readings of the two buildings in the Police Academy compound created few doubts about the possibility that the Educational building might be partially air conditioned and not throughout the day and night, hence it consumes less power than the Administrative building.

The indoor temperature monitor readings were checked and discussed with the maintenance team and it was confirmed that the air conditioning is usually switched on a 'full-day basis' and at weekends in order to keep all electronic appliances and computers safe from high temperatures.

The study concludes the following:

h. Minimising the air-conditioning to the usable spaces only as in the Administration building leads to reduced energy consumption in atriums or corridors.

i. It is recommended that indoor settings be increased generally.

j. It is recommended that the temperature of corridors and the atrium be set at 3-4C° higher than that of the offices and lecture halls.

k. It is recommended that courtyards be used in small areas that are proportionate to the size of the building, in order to keep it shaded and cooled naturally, as in the case of the Educational building.

l. The indoor readings showed that air conditioning was not switched off all day and night and even at weekends, resulting in a huge waste of energy. Therefore, a programmed shutdown system could ensure that any energy waste is minimised.

m. The most general remark of this project is therefore that there is huge potential to reduce power consumption if intention is there to do so.

CHAPTER EIGHT:

Conclusions and recommendations

8.1 Conclusions

8.1.1 Review of initial research objectives

This research aimed to investigate whether achieving sustainable buildings in Abu Dhabi would be cost-effective. The government is setting the foundation to establish a sustainable city of the future. However, the question in this study is; will the funds to be allocated for this approach be practical, refundable and profitable?

The study examined the impact of all affecting, relevant and pertinent contexts that influence the thermal performance, occupant perception of buildings, power consumption and the environmental sustainability. These contexts are:

- Historical origins of the sustainability problems. The study established links between the current global sustainability problems and its beginnings in the Industrial Revolution and the Victorian Era.
- A holistic approach to examining the current sustainability problems in the World. The analysis was based upon categorising problems in two categories; human activities leading to environmental defects, and environmental defects induced by human activities.
- The study investigated the local vernacular architecture and its specific design approach. The ancestors of this area put profound effort into understanding, dealing with and considering the environmental, cultural, religious, sustainable, energy efficient design and security issues. Great lessons can be learned from the local wisdom in building philosophy and techniques.
- The final context of the literature review is the study of the evolvement of Abu Dhabi City from its establishment to its many faces of urban history. This chapter helped in deciding upon the most suitable approach for suggesting practical strategies.

All above areas of study have directly affected the steering approach in the field study (Chapter VII) toward choosing the appropriate tools in investigation in order to proof the hypothesis, as shown in the Methodology Chapter VI.

Chapter I introduced the general elements relevant to the establishment of a future sustainable city in Abu Dhabi. All above mentioned context elements have been introduced in a holistic way. A brief examination of the best possible solutions which could be outcomes of this study were examined.

The city has witnessed a revolution by all means in the building industry, infrastructure, and landmark constructions. A range of factors have been examined in order to colour the city in an early stage of its development with a special identity.

- These included shifting the concept of Abu Dhabi as a city allocated for the service of cars into a pedestrian-oriented shaded city, accompanied by a holistic design for the urban furniture by providing seats, green shades and green parks.
- Unify city direction signage, which is currently not user-friendly.
- Design and implement sustainable integrated public transport systems.
- Establish foundations for a sustainable building environment

8.1.2 Conclusions of Chapter VII; Field study and Results Analysis

The design of the research is based on choosing two case studies; a sustainable prototype such as Masdar Institute of Technology and the Educational and Administrative buildings in Abu Dhabi Police Academy.

The three buildings with three approaches in design demonstrate different types of energy use. Masdar's image of low power consumption, high awareness of its students and the cost-effectiveness of the project was the reason behind choosing it for this study. The questionnaire addressed Masdar students, and asked some additional questions based on living in a sustainable development. Responses from Masdar students were not consistent; some of them did match the expectations and some did not, as discussed in the results of the questionnaires.

It was found that the power consumption of the Masdar building residential unit was similar to that of the Police Academy Educational building. Yet, the initial cost of building a square metre in the Masdar building is around 6,600AED, compared to 4,000AED in the Educational Building.

Based on the similar construction details of the two buildings, it was originally expected that both the Educational and Administrative buildings of the Police Academy would have similar power readings and thermal performance of the indoor temperature.

Monitoring the power consumption led to the significant findings of the thermal performance of the Educational building. The significant difference between the power readings of the two buildings in the Police Academy compound created few doubts about the possibility that the Educational building might be partially air conditioned, hence it consumes less power than the Administrative building.

The indoor temperature monitors readings were checked and the issue was discussed with the maintenance team in the Administration Building and it was confirmed that the air conditioning is usually switched on a 'full-day basis' and throughout the weekend, in order to keep all electronic appliances and computers safe from high temperatures.

The study concludes the following:

a. Minimising the air conditioning to the usable spaces only as in the Administration building leads to a reduction in energy used in atriums or corridors.
b. It is recommended that the indoor settings be increased generally.
c. It is recommended that the temperature of the corridors and the atrium be set at 3-4 C° higher than that of the offices and lecture halls.
d. It is recommended to use courtyards in small areas that are proportionate to the size of the building in order to keep it shaded and cooled naturally, as in the case of the Educational building.
e. The indoor readings showed that air conditioning was not switched off during the day or at night and even at weekends, leading to huge waste of energy. Therefore, a programmed shutdown system could ensure the minimization of waste.
f. The most general remark of the project is that there is a huge potential to reduce power consumption if the intention is there to do so.

8.1.2.1 Carbon dioxide findings

Monitoring the indoor CO_2 levels in the Masdar and Police Academy Educational buildings for two weeks in October 2010 gave similar readings, with low levels of CO_2 that ranged between 440 ppm and 540 ppm. These rates are considered to be healthy. Normal levels range between 700 ppm and1000 ppm. No further investigation was carried out in the field study.

8.1.2.2 Thermal performance findings

The readings included in the monitoring period in October 2010 covered indoor monitoring, outdoor monitoring and relative humidity.

8.1.2.2.1 Indoor temperature findings

All the indoor spaces monitored were air conditioned. Therefore, temperatures were similar in most of the spaces in the Masdar building and in the two monitored buildings in the Police Academy. The only exception was in the readings of the lecture hall in the Masdar building. The average indoor temperatures in Masdar accommodation and Police Academy accommodation range from 24.0 C° to 24.6 C°, however the average temperature of the lecture hall was found to be 19.1 C°. The average difference is over 5 C°.

The highest indoor temperature was 25C° and the lowest was 16C°. It is considered unreasonable to have indoor temperatures of as low as 16C° in the Masdar building lecture hall. It was anticipated that higher temperatures indoors would apply in all Masdar premises in order to induce the highest change of attitude possible between Masdar students, and in order to apply such an experiment nationally. Yet, the result was the opposite of what had been anticipated.

8.1.2.2.2 Outdoor temperature findings

Outdoor temperatures ranged from 30.5C° to 33.0 C°. The analysis focused on the exterior temperature due to the big differences in outdoor air temperature in the investigated areas. The lower the gap between daytime and night time temperatures, the more improved the thermal performance.

- The lowest gap in temperatures between the peaks of day and night was seen clearly in the police courtyard thermal performance. This explains the positive effect of the design strategy on the courtyard environment.
- The next low gap was observed in the courtyard area in the Masdar building.
- The biggest gap was observed in the Masdar building outdoor areas. This is as a result of the specific location of the monitor in the far-exposed space, facing an ‘open’ desert area.

The outdoor temperature readings showing the best thermal performance, and the lowest temperatures recorded were in the courtyard of the Police Academy Educational building. The reason behind the relatively cooler difference in temperature and relative humidity can be explained as thus:

- The specific dimensions of the Police Academy courtyard and the proportionate rate of the courtyard length, width and height, have led to the creation of the most moderate temperatures with minimum gaps between day and night in the Educational building courtyard. This has been accompanied by the total shading of the corridors of the 1st floor.
- Also, the opposite close ends of the courtyard have created an insulated zone with greenery in the centre. The same, opposite sides are open at the first floor level, which disperse and clear the hot air.
- The Educational building lecture halls surrounding the courtyard created a thermal insulation zone that kept the solar heat from overheating the courtyard spaces. This shows that good thermal performance is relevant to good design strategy.

8.1.2.2.3 Relative Humidity findings

All relative humidity levels indoors were similar due to the use of air conditioning.

The readings were strongly interlinked with the outdoor temperatures. This meant that during the peak highest temperatures during the day the relative humidity dropped. The opposite happened at night - with the lowest outdoor temperatures, the relative humidity goes up.

It was also observed that due to the ‘open site’ facing the desert location of the outdoor monitors in the Masdar building, the highest gap between day and night readings were recorded. This meant that relative humidity at night was accompanied by the lowest relative humidity during the day.

8.1.2.3 Power monitoring findings

Power consumption was monitored over two periods. In October 2010 it was not possible to conduct power monitoring in the Masdar building, subsequently the monitoring was done only in the Police Academy building. However, in May 2011 power monitoring was conducted in both the Masdar and Police Academy buildings.

The monitoring of October 2010 showed that the annual CO_2 emissions in kilogrammes per square metre of the Educational Building were 26.66kg/m2 compared to 98.2kg/m2 in the Administrative building.

The ratio of the power consumption in Kw/h and the relevant CO_2 emission to the atmosphere of the Educational Building is 26.66/98.2, 27% of that of the Administrative building.

The thermal performance study also demonstrated that the average temperature of the courtyard at night is around 2C° less than that of the exposed spaces on the campus. It also shows that the average temperature of the courtyard during the peak hot time of the day is around 4C° less than that of the exposed spaces in the campus. A strong link has been found due to the fact that using courtyards at the heart of buildings is one of the basic strategies in design that has been applied in the vernacular architecture of this area. These used to provide a healthy indoor environment with high thermal comfort for their occupants.

The study showed that using a courtyard in the Educational Building in proportionate dimensions led to the minimisation of power consumption and CO_2 emissions respectively, whereas the use of the close atrium led to the maximisation of the power and CO_2 emissions, as was the case with the Administrative Building. The reasons behind the high levels of energy needed for cooling the Administrative Building are:

a. Lack of wall insulation. Walls are built with concrete block and cement rendering from outside and gypsum plastering from inside.
b. The modern attitude of setting low temperatures of air conditioning during summer.
c. The continuous use of air conditioning during the day and at night, and even at weekends.
d. Cooling the additional void spaces in the double volume atrium that are not used for any other function than aesthetical factors.
e. Ignoring the possible mechanism of the stuck effect to cool spaces and using the atrium as a cooling space by designing ventilation openings that can be opened as needed. This trend is being used in developed countries now and was the basic element in designing the vernacular buildings of the region.
f. The steel truss roofing with moderate insulation helped to reduce the solar heat gains on the roof.

The result of the monitoring in May 2011 gave the following results. The power consumption of the Masdar building residential unit is similar to that of the Police Academy Educational building. Yet the initial cost of the Masdar building per square metre is around 6,600AED compared to 4,000AED for the Educational Building.

Based on the similar construction details of the two buildings, it was originally expected that both the Educational and Administrative buildings of the Police Academy would have similar power readings and thermal performance of the indoor temperature.

Masdar building residential unit			**Monthly Inflation**	0.25%
			Monthly Interest	0.50%
			Annual Inflation 3%	**Annual Interest 6%**
Month	**Initial cost of Construction of m²**	**Monthly running cost/m²**	**After interest**	**After inflation**
1	AED 6,600.00	AED 1.215	AED 6,634.22	AED 6,650.81
240	AED 40,293.88	AED 1.215	AED 40,496.57	AED 40,597.81
Police Academy Educational building			**Monthly Inflation**	0.25%
			Monthly Interest	0.50%
			Annual Inflation 3%	**Annual Interest 6%**
Month	**Initial cost of Construction of m²**	**Monthly running cost/m²**	**After interest**	**After inflation**
1	AED 4,000.00	AED 1.193	AED 4,021.20	AED 4,031.25
240	AED 24,725.64	AED 1.193	AED 24,850.47	AED 24,912.59
Police Academy Administrative building			**Monthly Inflation**	0.25%
			Monthly Interest	0.50%
			Annual Inflation 3%	**Annual Interest 6%**
Month	**Initial cost of Construction of m²**	**Monthly running cost/m²**	**After interest**	**After inflation**
1	AED 4,000.00	AED 3.032	AED 4,023.05	AED 4,033.10
240	AED 25,954.39	AED 3.032	AED 26,087.21	AED 26,152.42

Table 8.1: Results of 24 months calculations of the cost of each square meter in the three examined projects

The above table demonstrates that the cost of one square metre after 20 years (including initial cost, running costs, 6% interest and 3% inflation) will be as follows:

1. AED 24,912.59 in the Police Educational building
2. AED 26,152.42 in the Police Administrative building
3. AED 40,597.81 in the Masdar building residential unit

The above rates show that the Masdar building residential units are not cost-effective, even though their running costs and CO_2 emissions are similar to those of the Police Academy

Educational building (the cost-effective prototype). The reason for this is the high initial cost.

These results propose that there is room for financial saving and less environmental impact if buildings like the Police Academy Educational building were built with more thermal insulation and a similar strategy of using the courtyard at the heart of the building.

8.1.2.4 Questionnaire findings

8.1.2.4.1 Sustainable awareness

Similar responses were recorded in most of the questions answered by the two groups. This was not expected at the beginning when designing the questionnaire. It was thought that Masdar students would have a higher environmental knowledge and awareness.

Different rates were recorded, and no one out of the two parties has consistently shown a full awareness and understanding of environmental issues such as the link between the natural environment and planet resources, global warming, energy conservation, ecosystems, the impact of people's engagement on the environment, and governmental obligation in raising public awareness.

Students showed a similar interest in studying sustainability at a rate of 89%. Positive responses mean that the basis is there for a sustainable change in attitude, and that the government and communities should invest in that direction.

When addressing links between the natural environment and deforestation and desertification, building industry and greenhouse gases, Masdar students were observed to have a slightly higher awareness than the PA students.

The questionnaire results showed that there is a need to convince people that air conditioning has a damaging potential in terms of their health and the planet. Most of the students were not ready to exchange air conditioned spaces with other types of cooled spaces that provide relatively higher temperatures and less convenience.

8.1.2.4.2 Impressions

All 11 questions of this section showed that PA students have better impressions of sustainability values and their essential nature than Masdar students. Gaps in responses range from slight to big differences. Questions covered issues like the design of environmentally friendly buildings, potential financial savings, environmental savings, sustainable design effects on environmental education, national health savings, planet resources savings, less CO_2 emissions, a better green image for the UAE, and being part of future co-operation and investment by the UAE in sustainability. Most of the responses of PA students showed a high commitment to being part of the national momentum toward sustainability, especially with regard to better awareness.

8.1.2.4.3 Heritage appreciation

Gaps in responses between the two groups showed non-consistent answers. Areas investigated were whether local heritage deserved to be seen, being interested in learning more about ancestors' living environments, and whether students preferred indoor environments which were closer to the heritage buildings. Most of the two groups thought that there were no links between the buildings they were using and the local heritage. Current buildings did not make students feel closer to local heritage. All results showed a definite need for the media to raise the awareness of the value of the heritage of this region.

8.1.2.4.4 National responsibilities

More students from the PA than Masdar showed an interest in building their houses on a sustainability basis. Police Academy students answered more positively to questions like 'is it patriotic to be environmentally sensible, publicly engaged, and to become more careful with natural resources for the sake of the UAE?' These questions showed that the nation is ready to enter a new sustainable era.

8.1.3 Hypothesis review

The results of the field study showed that it is cost-effective to shift the growth of the city from being regular and environmentally unsustainable into an environmentally sustainable development.

The cost analysis of power consumption in kW/h and the relevant carbon dioxide emissions of buildings with different design strategies for over twenty years, demonstrated the effectiveness of the vernacular solutions in this specific environment.

The best of the three prototypes has been the Educational building in the PA. Even though the building has poor insulation, the specific design with the courtyard at the heart of the building in specific ratios, led to the minimisation of the cost of running and cooling the building.

The study showed that imported design strategies with no link to the local heritage led to poor links between local communities and the current built environment.

8.2 Contribution to knowledge

That whilst development of Abu Dhabi is moving towards a new architectural style, to become to truly Environmentally (& Economically) Sustainable City, no previous research has established that vernacular approaches are not fully incorporated in these developments.

8.3 The main key-findings:

1. It was found that vernacular architecture was sustainable.
2. Abu Dhabi has been strongly influenced by ‘imported’ urban planning methods.
3. This has led to less appreciation of sustainability by Abu Dhabi inhabitants, as shown by the impressions of the students who filled in the questionnaires.
4. Local sustainable buildings can be built with low budgets by using the vernacular knowledge of this region.
5. It is found that Masdar buildings have a low rate of power consumption, yet are not cost-effective.
6. Constructing a sustainable building does not mean that it has to be wholly sustainable building, as is the case with Masdar. This means that there is a profound need to correct the vision of sustainable architecture.
7. The questionnaire findings were that there is a profound need to raise public awareness, in order to create a sustainable new national pattern of consumption.

8.4 Proposed strategies for the city of Abu Dhabi

8.4.1 Redesign building regulations in line with vernacular essence

Building regulations in developed countries with cold weather enforce applying setback from the section border in order to:

a. Get maximum heat gains.
b. Get maximum views and to have the indoor space interact with that of the outdoor.
c. Get maximum natural lighting.
d. Get maximum natural ventilation.

Building regulations in this region follow the same regulations of developed countries which have cold weather and open societies. Therefore, the following phenomena appear in this region:

e. Detached housing leads to maximum heat gains, overheated buildings and loads of air conditioning and power consumption in buildings.
f. Wide windows towards the outside negatively affect privacy, leading to curtains being closed most of the time.
g. Closed windows negatively affect natural lighting and natural ventilation.

As discussed in Chapter IV, the vernacular buildings responded to the environmental, social, religious and economical conditions of this region. This has been reflected as follows:

h. Compact buildings attached to and protecting each other avoid extreme heat gains.
i. Minimum windows towards the outside (except the diwan), in order to preserve privacy.
j. Maximum windows towards the courtyard to enjoy natural lighting.
k. Maximum opening provides maximum natural ventilation.
l. A small shaded courtyard helps cool the spaces and shelter one side at a time during the day, so there is always shade.
m. Limited greenery in the middle is sustainable because it needs less water and maintenance.

n. The focal point of the building is greenery at the heart of the courtyard and maybe the fountain in the centre represents a social gathering centre.
o. Barajel work on the stuck effect mechanism helps ventilate and cool the whole building

All of the above demonstrate that the basis of the building regulations of this area are built on a foundation of the same building regulations of other nations who have a different culture and live in a different environment.

A research firm might have to be established in order to rewrite building regulations in accordance with local requirements regarding the environment, culture, mentality and economy. Investigation might have to cover a range of issues, such as buildings' setback policies.

8.4.2 Redesign Estidama to enforce specific sustainable applications

In Estidama Pearl Rating Systems, all compulsory items (R-items) do not include specific ratios of insulation. Insulation was mentioned in the credit points, which are not compulsory, meaning that credits can be obtained through other items while ignoring the insulation presence. High R-value insulation systems in a building envelope, as in roofs, walls, and glazed areas might need to be made compulsory.

Using a high rate of insulation would sharply reduce the size and initial cost of the air conditioning system of the building, respectively.

It is essential to modify the rating system of Estidama to ensure the requisite items are the most powerful ones, as in the case of insulation.

Other compulsory items that might need to be reviewed are enforcing water fixtures in terms of a specific flow rate, for instance enforcing a maximum of two Litres/minute. Exceptions can be made for specific cases.

It is essential that a national study be carried out regarding on the effect of the high e-film values that cover almost all glazed areas in the UAE and have s real benefits in terms of reducing the heat gains in buildings. The UAE residents and nationals usually have a severe Vitamin D deficiency. Therefore, a national study might need to investigate links between e-film layers and health problems, in order to find the best solutions.

8.4.3 Establish a national data centre for sustainable materials in the market

Establish a specialised analysis centre for building a national library of the local and exported sustainable building materials. A full classification of:

1. Structural materials
2. Finishing materials and their effect on human health and the natural environment
3. Desert and drought landscaping plants, materials and systems
4. Furniture and furnishing materials
5. Energy-efficient air conditioning systems and ventilation systems
6. Plumbing accessories and water fixtures
7. Lighting and power equipments
8. Shaded parking and walkways materials
9. Any other updated new building material or technology

8.4.4 Establish strategies to promote utilising sustainable building materials

There is a need to establish a strategy to encourage the use of more sustainable building materials, whether these are environmentally friendly, recyclable, requiring less embodied energy, or local materials requiring less transport.

The strategy should investigate any potential to encourage people to choose sustainable materials instead of its counterpart of non-sustainable materials. This can be done by enforcing specific acts which give incentives to users of sustainable materials, or imposing limitations or taxes on users of non-sustainable materials.

8.4.5 Instigate national initiatives to retrofit existing building stock toward sustainability

New regulations have direct effects on future buildings. This applies to the Estidama Pearl Rating System. The system implemented will make significant changes. For example, if a research body looks at 2015 in terms of the volume of sustainable change in Abu Dhabi buildings, the ratio might be negligible when compared to the total size of Abu Dhabi buildings.

To make a profound change regarding sustainability, it is essential to draw policies to retrofit Abu Dhabi buildings in a designed and studies sequence. State subsidies and financial support can create a revolutionary shift toward sustainability in Abu Dhabi.

8.4.6 Promote local industry for insulating materials

The current industry concerning building materials in the UAE is huge. However, the immense need for sustainable materials, especially insulating materials, can be invested in building local industry to provide high quality insulation materials which are suitable for the specific environment of the UAE and local areas. These all make the product sustainable, especially if it is made from environmentally friendly raw materials.

The industry should also be used in terms of low flow water features, in order to produce sustainable, high quality local features which save water.

8.4.7 Promote pilot projects to raise public awareness of sustainability

Sustainable awareness can be enhanced by pioneering sustainability projects in which the government encourage the community to understand and use them for their low environmental and financial impact.

As people realise the importance of sustainability in terms of a general consumption pattern in life generally, and in the building industry specifically, it is expected that they will take the lead in terms of reducing resources’ exhaustion.

1. As an example, a case-study of a small neighbourhood with compact housing and central gardens in the courtyard of each house, would help in terms of exploring possibilities of applying energy-efficient techniques within modern housing

schemes. Low power consumption, good thermal comfort, a healthy indoors, and the enjoyment of a full private courtyard garden will be good ways in which to spread sustainability awareness among occupants of these houses.

2. Enhancing public transport will reduce individual trips and therefore CO_2 emissions. Also, this will encourage more walking among city inhabitants, leading to better health, which is a sustainable value as it raises GDP and minimises national health costs. This is being proposed by the UPC, however it may need quick implementation.

3. A policy should be designed so that it uses the media and any other influential resource to raise awareness of a new culture of less consumption among people.
4. The government might have to take the lead in order to reveal the negative impact of exaggerated house floor area sizes on financial burden, social relations, family interaction and the environmental awareness of all family members. Big houses and the exacerbated burdens of having more maids, servants and drivers are negatively affecting cultural habits, family solidarity and a new generation’s ethics.
5. The above are just examples of the areas in which the government can change people’s behaviour regarding a sustainable society.

8.4.8 Introduce sustainability education in the primary curriculum

1. Global warming and greenhouse gases should be part of the science curriculum in primary schools.
2. Encourage community gardening in schools, with adults and children sharing gardening exercises to teach students to grow their own organic food.
3. Classified garbage shoots for recycling, so that students understand the value of recycling (part of the curriculum).
4. Another example might be school building that included all techniques of sustainable design. Parents, when they attend the school, can then witness for themselves the health benefits and sustainable indoors environments.

Creativity has no limits, especially when the good intentions of the nation and the government are present in order to enable profound sustainable change.

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11. Appendices

All the Appendix items are located in the attached CD.

All 11.2 HOBO Readings can be opened by using the attached HOBO Software.

11.1 **Microsoft Excel files;**

11.1.1 CO_2 Loggers Readings

11.1.2 Masdar – Balcony C&RH

11.1.3 Masdar – Courtyard C&RH

11.1.4 Masdar – Exposed Outdoor C&RH

11.1.5 Masdar – Power Readings- 3rd, May 2011

11.1.6 Masdar- Power Readings, 17th, April 2011

11.1.7 Masdar – Residential Unit C&RH

11.1.8 Police Academy- Exposed Outdoors C&RH

11.1.9 Police Academy- Educational Building- Courtyard C&RH

11.1.10 Police Academy- Educational Building- Indoor 1st.F. C&RH

11.1.11 Police Academy- Educational Building- Indoor G.F. C&RH

11.1.12 Power Readings- 7th-20th May, 2011 of all three prototypes

11.1.13 Power Readings- 10th -23rd May, 2011 of Police Academy

11.1.14 Locations of Monitors

11.2 **HOBO Readings;**

11.2.1 CO2 Readings

11.2.2 Masdar – Exposed Outdoor C&RH

11.2.3 Masdar – Balcony C&RH

11.2.4 Masdar – Indoor Educational C&RH

11.2.5 Masdar – Indoor Residential C&RH

11.2.6 Masdar – Outdoor Courtyard C&RH

11.2.7 Police College- Indoors Educational – 1st.F. C&RH

11.2.8 Police College- Indoors Educational – G.F. C&RH

11.2.9 Police College – Outdoors Courtyard C&RH

11.2.10 Police College – Outdoors Exposed Landscape C&RH

11.3 **Twenty years cost calculations**

11.3.1 Twenty 20 years calculations of the cost of m2 in Masdar Residential Unit

11.3.2 Twenty years calculations of the cost of m2 in Police Academy Educational Building

11.3.3 Twenty years calculations of the cost of m2 in Police Academy Administrative Building

11.4 **Miscellaneous files;**

11.4.1 Comments of Masdar Students on the Questionnaires

11.4.2 Comparison – Outdoors of Masdar and Police Academy 2010, C&RH

11.4.3 General Comparison- 7^{th} -24^{th} October, 2010

11.4.4 General Comparison 24^{th} – 31^{st} October, 2010

11.4.5 General Comparison 30^{th} September – 7^{th} October, 2010

11.4.6 General Estimation of Initial construction costs of one meter in Masdar (as received from Masdar)

11.4.7 Power Readings of Police Academy Buildings – October, 2010

11.4.8 Questionnaire results –Police Academy –Arabic (as received)

11.4.9 Questionnaire results –Police Academy –Arabic (translated)