Chapter 1: Energy Efficient Refurbishments

1.1 Introduction:

Life cycle of buildings including construction, maintenance during use full life of building and demolition attributes considerable part of total energy consumption. Some researchers show that as much as 40% of annual energy consumption is related to construction and maintenance of built environment. Along with enormous energy consumption buildings also contribute significantly to environmental degradation by means solid waste generation, water and air pollution. One of the effective strategies to mitigate the effect of rapid environmental degradation in most of the cities around the world is to focus on the built environment. Considering that a small percentage of new buildings gets added annually to existing stock (Langston et al 2007), it is the existing building stock which needs attention to improve energy efficiency. According to Mickaityte et al (2008, citing Papadopoulos et al 2002) the energy efficient refurbishment of existing buildings is an important tool for reduction of energy consumption in the building sector , the improvement of prevailing indoor thermal comfort conditions and also improvement of environmental conditions in urban areas. Sitar et al (2006) mentions that principles of sustainable refurbishment are to improve the living conditions and to provide user-friendly spaces, increasing flexibility of the whole building and its parts according to the current and future needs of the inhabitants. The other principles are to decrease the energy use and related operational expenses while to increase use of environment-friendly materials and renewable energy sources. Achieving social and economic satisfaction is also one of the main principles of sustainable refurbishments. Mickaityte et al (2008) has suggested that main results expected from sustainable refurbishments include energy savings, increase of occupant comfort levels, assurance of healthy working environment, extension of building life cycle, economized exploitation of resources and environmental protection.

In a recent publication, Thiemo and Ulrich (2007) suggested that two thirds of office buildings in Europe are currently outdated with façade and mechanical systems older than 30 years. The author highlights dilemma of building owners to satisfy ever changing spatial and technical demand of end users without having to resort to extreme measure such as demolition and re-build, but to adopt appropriate renovation strategies to extend life cycle of the building.

Baldwin (1996, cited in Zavadskas et al 2008) states that main goals of sustainable developments include:

- To minimize global climatic change by way of reduction of CO2 emission to atmosphere. Reduction of energy consumption in buildings is the most effective way to minimize climatic change as it results in reduced CO2 emissions.
- Minimizing waste by recycling and re-use of materials, minimizing waste at source such as construction sites.
- Conserving wild life habitats by avoiding buildings on ecologically sensitive sites. Alternatively limiting the construction to brown field areas and to re-use existing buildings by adapting to new-uses.
- To improve indoor environment quality of the building by better lighting and ventilation, and by avoiding potentially harmful building materials.
- Rationally using non-renewable resources while encouraging use of renewable resources such as solar power, wind, and geo-thermal as sources of energy and use of renewable materials in construction.

The main objectives of sustainable refurbishments are in principle similar that of sustainable developments. Sitar et al (2006) lays down principles of integrated sustainable refurbishment as:

- Improving physical conditions and user-friendliness of spaces in buildings and increasing flexibility of the building so that it may be better adapted for current as well as future uses.
- Decreasing over all energy use in the building and particularly reduction of building operation expenses.
- Harvesting energy through renewable energy sources and increased use of eco-friendly building materials.

Stressing importance of energy efficient refurbishments Papadopoulos et al(2002) states that refurbishment of existing buildings results in reduced energy consumption in buildings with improved indoor thermal and environmental conditions. The author has suggested that in large urban areas energy efficient refurbishment of building may significantly improve environmental conditions of entire area.

1.2 Refurbishment against Demolition and Rebuild:

In the context of existing housing in UK Power (2008) brings out an interesting study which compares demolition & rebuild to refurbishment. The author brings out social, environmental and economic benefits of refurbishment when compared to the process of demolition and rebuild. These benefits include higher rate of re-use and recycling of building materials, optimized use of existing infrastructure, development of regional economy due to local employment generation , reduction of transportation cost and reduced landfill disposal. The author states that these benefits clearly overweigh disadvantages of demolition and rebuild which involves higher capital costs, higher consumption of finite resources, greater transportation costs, higher pollution, noise and disruption. Social benefits of refurbishment include cheaper housing solutions with far lower environmental impact, reuse of existing infrastructure and protection of existing communities and limiting urban sprawl. The supporters of demolition and new build have been advocating that demolition of poorest and oldest buildings will improve the environmental efficiency of the overall stock. This push for demolition and rebuild in UK is mainly driven by Government's goal to reach 60% reduction in total energy use in housing section by 2050.

As per The Economist (2007, cited by Power 2008) UK currently has 24 million housing units. Considering an average annual new build of 200,000 units there will be an addition of approximate 9 million units by 2050. The report highlights that 70% housing stocks in 2050 will be made of housing units which are already built. The report concludes that in order to achieve energy savings of 60% in 2050, the appropriate strategy is energy efficient refurbishment of existing buildings rather than demolition and rebuild. Ireland(2008 , cited by Power 2008) suggests that new homes use four to eight times more resources than a refurbishment of existing home of same area. The author attributes retention of building mass and structural frame to massive savings achieved in refurbishments. As per Power(2008) exhaustion of available landfill sites has restrained demolition and new build process. He states that in UK, demolition of existing buildings is the largest contributor to landfills amounting up to 30% of the landfill by volume.

RCEP Report (RCEP, 2007)suggests that in a time frame of 50 years new homes with high embodied but low operating energy will outperform existing refurbished properties . However in short run ie in a timeframe of 10 years energy efficient refurbishment will result in saving of carbon emissions. Report also suggests that adopting strategies such as incremental improvements in energy performance, better incentives for high quality renovations would help refurbishments to achieve similar performances as new-builds. The German Federal Government's 2007 programme proposes a number of measures including loans, grants and tax incentives to bring all pre-1984 housing to current German new-build standard by 2020.

A recent research carried out in UK (The Empty Homes Agency, 2008) studied embodied energy and operational energy in new builds as well as existing-refurbished homes. For this study six homes were selected of which three were new-builds developed by major builders to 2002 or higher building standards. The objective of the research was to determine embodied and operational energies of new build and refurbished homes over a lifespan of 50 years. The results from the study suggests that over the lifespan of 50 years embodied energy constitutes 35% of total CO2 emitted in new builds, while in refurbishments embodied energy constitutes 7% of total CO2 emission. However average operational CO2 emissions in refurbished homes were 40% higher than average new builds. The most interesting outcome of the study is the lifetime combined CO2 emissions. The graph below shows lifetime CO2 emissions per square meter area for new build and refurbishments. The research clearly demonstrates that over the life span of 50 years, new builds will not have any substantial advantage in terms of reduced CO2 emissions over refurbished homes.

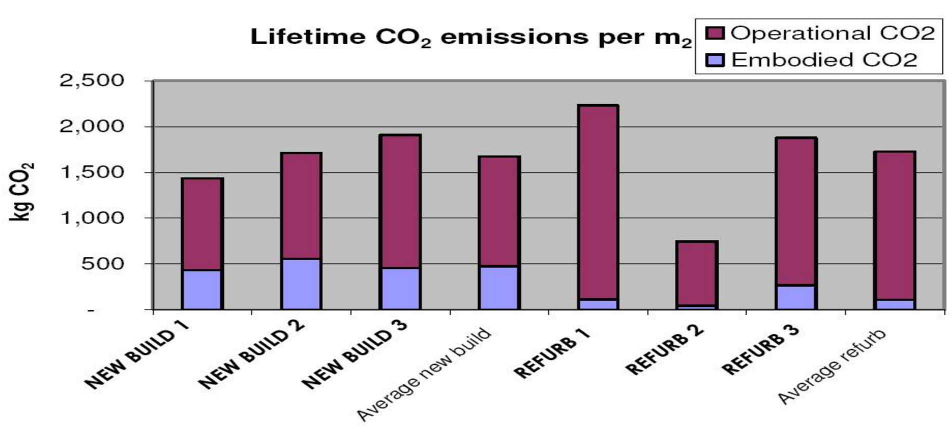


Figure 1: Life Time CO2 Emissions – New Build Vs Refurb (The Empty Homes Agency,2008).

The research carried out by a Stockholm based utility company (Power, 2008) demonstrates that energy savings achieved by use of appropriate insulation materials will payback within the lifespan of the products without any form of economic subsidies. According to this study , six basic energy efficiency improvement measures which will significantly improve energy use of existing homes include insulation roofs, walls, floors , double glazing , damp-proofing and improving heating systems.

According to Power (2008) wider problems of demolition include:

- High cost of demolition followed by providing replacement homes.
- Depreciation of economic values of the neighboring properties. It is generally noticed that the properties earmarked for demolition do not attract any investment or maintenance leading to physical deterioration of neighborhood.
- Displacement of large number of residents until completion of new build, which in some cases may extend up to 10 years. It has been recorded that even in cases of most un-popular older areas proposed for demolition 70% of homes are occupied on average, thus area-based demolition process extremely complex, slow and expensive.
- Large scale demolition of housing effects community facilities such as schools, neighborhood shops, health facilities etc. adversely. Hence local economy suffers due to large scale demolitions.
- Demolition and rebuilding process reduces housing capacity temporarily until new homes are completed. Re-housing existing residents creates extra housing demand.
- The overall timeframe for demolition & rebuild is increased due to requirement of infrastructure renewal following demolition. Even with strong government backing and funding the entire process of housing renewal takes 10-20 years.

In contrast Power (2008) states wider benefits of renewal include:

- In refurbishments structural frame of the existing buildings are retained, and existing infrastructure is preserved and enhanced.
- When compared to new builds, refurbishments are far quicker and less disruptive to the residents. In most cases residents continue to occupy part of housing, even when refurbishments are undergoing. Even if the residents move out temporarily, duration only lasts for months rather than years.
- In most cases refurbishments take place within the existing structures with least exposure to external weather conditions. Hence overall duration of refurbishments are much shorter as compared to new builds.
- Refurbishments generally have positive economic impact on neighboring properties. In most cases it improves property value within the neighborhood.
- Steady housing refurbishments attract investments in community facilities & amenities which will result in upgrading of the area. This also results in upgrading and various underused buildings within the vicinity such as older shops, offices, public buildings and warehouses and brings back economic value to these buildings.

UAE being a young country, majority of currently existing buildings are relatively new. Hence the concept of refurbishment is relatively new to this region. However following Global Financial Crisis in 2008 –new constructions in the region have slowed down and the focus has been shifted to upkeep of the existing building stock efficiently. Since energy efficient refurbishments are relatively new in the region, a requirement for developing suitable body of knowledge was identified during the initial phases of the research. The majority of the literature and data on energy efficient refurbishments currently published are limited to the temperate and cold climates of North America and Europe. Hence intention of the research was to develop validated method for energy efficient refurbishments in UAE. Again to ensure that solution developed is practical and readily applicable, rather than a hypothetical base case an actual existing building was chosen as base building and suitable refurbishment techniques were tested by use of simulation techniques.

Chapter 2: Literature Review

2.1 Introduction:

In this chapter a brief review of various literatures available on Energy efficient refurbishments have been carried out. The first section of the chapter reviews various studies carried out across globe while the second section addresses studies carried out in the middle-east region. The literature review also brings out a comparison of energy policies & regulations in UAE with rest of the world. Inferences from the literature review have been discussed in the last section of the chapter.

2.2 Sustainable Refurbishments: Global Context

Periodic refurbishments have always been part of the building process in order to ensure that habitable spaces are maintained at satisfactory conditions. A number of historic cities have evolved to its current state through the process of cyclic refurbishments of its built environment and infrastructure. However energy efficient refurbishment is relatively new concept surfaced since energy crisis of 1970's. Since then a number of studies have been carried out across the globe to improve energy efficiencies of existing built stock. Some of these studies were aimed at developing analytical frame work to determine refurbishment potential of existing buildings, while the others were aimed at developing appropriate refurbishment techniques.

Zavadskas et al (2008) proposed a sustainable buildings refurbishment decision making model which integrates economic, technical, social and ecological needs of stakeholders and helps to opt for optimum energy efficient refurbishment alternative on the basis of multiple criteria methods application. Building's Refurbishment Knowledge based Decision Support System (BR-DSS) proposed by the author can develop a huge number of alternative refurbishment options, perform multiple criteria analysis on the basis of criteria set up, determine the utility degree and market value and select the optimum solution without any human interference. Kaklauskas *et al* (2007) proposed a knowledge base model for sustainable housing renovation which integrates economic, technical, social and ecological needs of stake holders. The model proposed covers micro and macro environmental conditions as well as building life cycle analysis and can be used for efficient design of renovation projects and for multiple criteria analysis.

A study carried on behalf of International Energy Agency in 2006 (Guertler & Smith 2006) investigates the opportunities for cost effective energy efficient refurbishments of existing high – rise residential buildings in Europe. The study suggests that one in every six residential units in Europe is a high-rise building with 36 millions in total and suggests that energy efficient refurbishments of these units can save up to 28% of their operational energies. One of the main objectives of this study was to assess the current situation of the existing high-rise building stock and to explore the possibilities of integrating energy efficiency improvements into refurbishment cycles of the buildings. The project considered large geographic area covering entire 25 EU nations along with Bulgaria , Romania and Turkey. The large database required for the study was drawn from a number of European sources and particularly from Survey conducted in 2004 by European Housing Ministries.

Total of 28 countries considered for the study were further divided into 3 groups on the basis of climate as warm, moderate and cold countries. Table 1 shows categorization of countries:

Table 1: Categorization of countries (Guertler & Winton 2006)

Heating degree days	EU15 (Countries joined EU before 2004)	**EU10 (Countries joined EU after 2004)**	**AS3 (Accession States)**
≤ 2700 HDD's (Warm Climate)	France, Greece, Italy, Portugal, Spain	Cyprus, Malta	Turkey
2700-3700 HDD's (Moderate Climate)	Belgium, Ireland, Luxembourg, Netherlands, United Kingdom	Czech Republic, Hungary, Slovakia, Slovenia	Bulgaria, Romania
> 3700 HDD's	Austria, Denmark, Finland, Germany, Sweden	Estonia, Latvia, Lithuania, Poland	

In each of the categories mentioned, theoretical base building was considered for assessment of refurbishment potential. In each of the base building applicable energy efficient retrofit measures, energy costs, CO2 emissions were calculated with the Ecofys BEAM model, which was developed by Ecofys for investigation of EU building stock .For each base building input data for BEAM model was derived from a database containing climatic data of the region, building type/size, building age, insulation level, energy supply, energy carrier and emission factors. The model generates out-put data for each base-region including annual investment cost, Cost of conserved energy and simple payback period. The results generated for EU15 warm climate have been discussed here:

Characteristics of the Building stock:

- Of the total building stock approximately 650,000 buildings are multistory residential units with a total of 19.5 million dwelling units.

- Predominant Construction Type – In situ concrete walls, flat concrete roof and concrete floor, single glazed –metal framed windows.
- Energy saving potential of the stock by use of cost effective energy efficient techniques – approx. 25%.

The outcome of BEAM model suggests that refurbishment package saves up to 71.0% of the annual energy consumption. The BEAM model suggests a simple payback period of 2.7 years. Table 2 summarizes outcome of BEAM model.

Table 2: Energy Savings, investment cost and cost of conserved energy

(Guertler & Smith 2006)

	U-value before (W/m²°C)	U-value after (W/m²°C)	Energy saved [kWh/m²a]		Annual investment cost [€/m²a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	2.37	0.46	66.6	35.7%	1.32	2.0	2.8
Roof	3.00	0.39	22.5	12.1%	0.17	0.8	1.1
Floor	2.93	0.47	21.3	11.4%	0.18	0.9	1.2
Windows	4.56	2.64	22.2	11.9%	0.93	4.2	5.8
Package	2.93	0.85	132.6	71.0%	2.61	2.0	2.7

The study arrives at a comparison of energy savings that can be achieved by use of suitable refurbishment techniques in each of the base buildings belonging different categories as per classification in Table 1. Capital costs for refurbishments are determined by a number of factors including standard of energy saving measure being applied, labour costs and material costs in each of the base regions. Capital costs of refurbishments seem to be relatively in higher in EU 15 countries, while costs in AU10 and BS3 countries were moderate as illustrated in Figure 2 & 3. Higher refurbishment costs in EU15 countries are likely to be due higher labour costs in these countries . Refurbishment process generally being labor intensive, often turn out to be expensive in developed countries, where labour costs are higher. Figure 2 & 3 illustrates annual costs of refurbishments across various regions to achieve proposed energy savings.

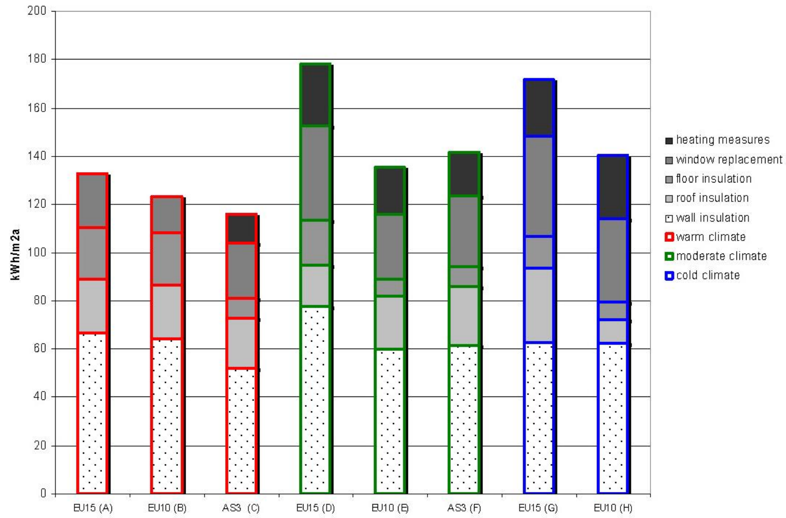


Figure 2 : Energy savings across various categories of buildings considered in the study (Guertler & Smith 2006)

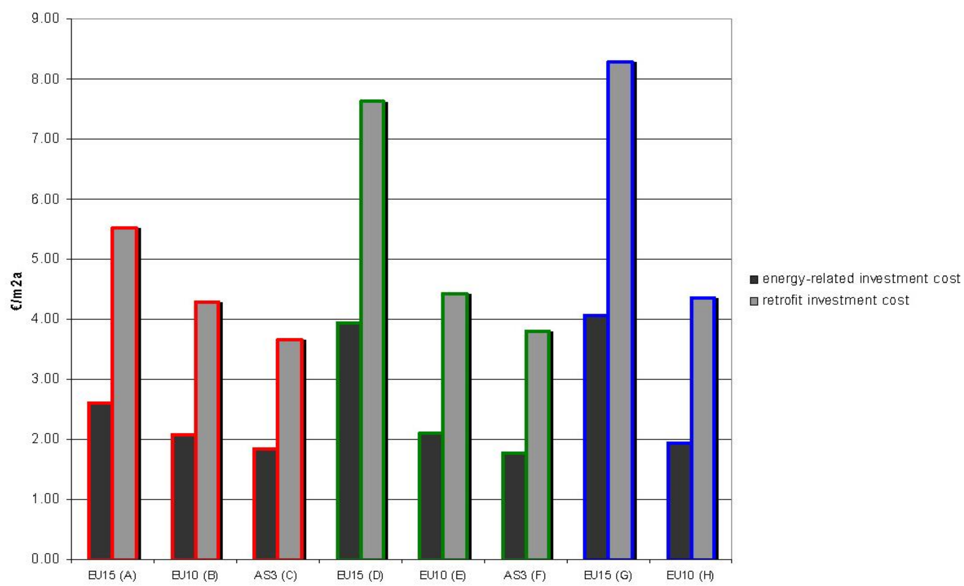


Figure 3 : Annual costs of refurbishments (Guertler & Smith 2006)

Ouyang *et al* (2008) carried out a study of energy saving renovations of existing residential buildings in the city of Hangzhou on the basis of thermal simulation and site investigation. An existing 7 storey residential building in Hangzhou built in the year 1995 was selected as subject building. By use of thermal simulation retrofitting measures were proposed following which economic analysis of the measures were carried out using Life Cycle Cost method. The research methodology included physical investigation of the building, analysis of attributes and variables, development of energy saving renovation measures, thermal simulation followed by economic analysis of renovation measures. In the first phase of the study a detailed site inspection was carried out to assess as built conditions .The site inspection suggested that the thermal transmission values of existing envelope were quite high, much above the current standards for new-builds in the city of Hangzhou. U values of existing single glazed windows were as high as 6.25W/m2k with SC value of 0.8 while U values of external walls and roof were 2.355W/m2k and 3.969W/m2k respectively.

Upon analysis of attributes and variables renovation measures were proposed which included substitution of plastic double windows in place of existing ones, use of curtains/blinds to reduce window SC values, addition of insulation materials for roof and external walls and application of light colored paint to external walls to reduce absorption coefficient. The simulation tool used for assessment of resulting cooling and heating load was DOE-2, only standard simulation programme recommended by Hangzhou Construction Committee. Simulation suggested over all 46% reduction in annual heating and cooling load with total heating and cooling load reduced to 48.77kWh/m2year. In order to validate the simulation total loads of existing building were simulated which then were compared with actual electrical consumption data. It was noticed that simulated and actual consumption data greatly varied, however the researcher factored simulated loads suitably to obtain more realistic energy savings.

A similar study conducted by Storey(2009) in New Zealand demonstrates possibility of renovation of existing office buildings of 1960's and 70's to meet current performance standards by utilization of fraction of resources as compared to the new build. The case chosen for the study was refurbishment of a multistory office building built during 1970's located in 21 Queen Street in the heart of Auckland's Central Business District. Refurbishment strategies used for upgrading the building were mainly intended to serve two purposes. One was amendment to building envelope and addition of floors to increase the leasable area and other was to improve the energy efficiency of the building. Envelope amendment included removal of existing precast concrete panels and replacing them with much lighter full height high performance glazing. Amendment to envelope resulted in increased leasable area in each floor and reduction of envelope load allowed the builders to add another 4 levels to the building. As a result overall leasable area of the building was increased by 92.5%. Strategies to improve energy efficiency of the building included use of energy efficient lighting, chilled beam space conditioning, water saving technologies and incorporation of environment friendly materials. These measures have improved energy performance of the building drastically with energy demand of the renovated building estimated to be at 55.5 kWh/m2/yr which is approximately 42% of the New Zealand Green Building Council benchmark figure of 120kWh/m2/yr (Storey, 2009).

Crawford at el (2002) illustrated through a case study implications of energy efficient refurbishment on over all embodied energy. The case chosen for the study was a single storied detached house of 92 square meter area located in Melbourne- Australia. The house was refurbished by use of renewable resources and non-polluting technologies. Refurbishment included installation of a number of energy saving devices such as solar water heater, photovoltaic panels , improving insulation of the external envelope, use of double glazing in place of single glazed windows, re-use of rainwater for domestic usage etc. The refurbishment also involved few structural alterations by which area of building was increased to 116 sqm. Upon commencement of refurbishment measures embodied energy was re assessed which found to be increased by 63%. However the author suggests that the increased embodied energy will be offset by lower operational energy during the life time of the building.

Studies carried out in Northern Greece (Papadopoulos *et al* 2002) investigated energy saving potential of public and mixed use buildings and developed an acceptable payback time criteria for energy efficient refurbishments. Based on the initial surveys carried out annual specific consumption for space heating in the subject buildings varied between 130-180 kWh/m2 while as per the current regulations this value should have been between 80-110kWh/m2. This convinced the research team that appropriate refurbishment methods may reduce energy consumption substantially. Subject buildings for the study consisted of a group of 42 residential, public and mixed use buildings covering a wide range of age and construction types. The subject buildings were classified in to three categories on the basis of age as pre 1940's buildings, 1940's to 1980's and post 1980's buildings. The first group pre-1940's buildings consisted large public buildings and offices with average annual space heating consumption of 183.5kWh/m2, while the second group 1940's to 80's group consisted of mainly 3-7 storey mixed-use urban buildings with annual space heating consumption of 167.9 kWh/m2, while the third group consisting of post 1980's buildings were better insulated with average annual space heating consumption of 100.4 kWh/m2.

The various factors which determined the energy consumption of each group of buildings were studied which included:

1. Size of the building
2. Building's surface to heated volume ratio
3. Existence of thermal insulation
4. Condition of heating/cooling system

Retrofitting measures proposed by the research team included following measures:

1. Improving insulation of external walls by retrofitting externally 3-5cm thermal insulation layer covered by plaster
2. Improving insulation of the flat roofs by adding externally 5-8 cm thermal insulation layer
3. Replacing old windows with new double –glazed windows
4. Replacement of older burners and boilers by more efficient systems

The study suggests that economic feasibility of above mentioned retrofit measures shall be determined by depreciated payback period of investment. Papadopoulos *et al* (2002) suggested mathematical equations to calculate Depreciated Payback Period (DPP) and Savings to Investment Ration (SIR). DPB provides the investor with an index suggesting how fast the initial investment will be paid off, but not how efficient the investment was. Efficiency of the investment can be determined by savings to investment ratio method as per equation (2).

$$\text{DPP} = -\frac{\ln\left(\left(1-\frac{dCin}{Ft}\right)\right)}{1n(1+d)} \tag{1}$$

$$\text{SIR} = \frac{\sum_{t=1}^{N} Ft/(1+d)^t}{\sum_{t=1}^{N} Ct/(1+d)^t} \tag{2}$$

Where :

DPP : Depreciated Payback Period

Cin : Initial cash out-flow needed for the implementation of the renovation measure

Ft : Value of the energy savings, considered as a cash in-flow for the time period (year t)

d : Capital cost rate

Ct : Total cash out-flow needed for implementation of the renovation measure for the time period (t)

Based on equation (1) & (2) depreciated payback period and savings to investment ratio for each of the subject building was carried out. The results generated for the study as per Table 3 suggests that depreciated payback periods for various building considered varies in the range of 3.6 years to 20.3 years, while savings to investment ratio varies in the range of 0.9 to 3.7.

Payback period of 8-10 years is generally acceptable for residential and commercial buildings, however a higher depreciated payback period may be acceptable for buildings with large residual useful life. This is particularly applicable in case of 10-20 year old buildings with inefficient design or construction which have 50-60 years of useful residual life. In such cases payback periods up to 20 years may be acceptable as the substantial energy saving is achieved during residual useful life of the building.

Table 3: Summary of Refurbishment measures - Papadopoulos et al (2002)

Building ID Number	Date of construction (year)	Use[a]	Specific heating consumption (kWh/m^2 per annum)	Savings possible (%)	Single interventions[b]				DPB (years)	SIR[c]
					Walls	Roof	Openings	Heating system		
22	1885	PB	194	19.4	×	N.n.	?	N.n.	6.8	N.A.
21	1895	PB	136	18.5	×	✓	?	N.n.	5.9	N.A.
20	1930	PB	121	19.0	?	N.n.	N.n.	N.n.	16.3	N.A.
24	1932	MU	133	28.7	×	✓	N.n.	N.n.	10.1	N.A.
23	1935	PB	154	25.9	?	N.n.	?	✓	12.5	N.A.
8	1952	E	236	51.0	✓	✓	✓	✓	3.6	3.7
38	1952	H	350	38.3	✓	N.n.	✓	N.n.	8.4	3.2
42	1962	MU	149	34.8	✓	N.n.	✓	N.n.	9.0	1.7
18	1963	MU	177	22.4	✓	✓	✓	✓	7.2	2.1
41	1964	MU	357	36.9	✓	✓	✓	✓	5.1	3.2
7	1965	PB	359	28.6	✓	✓	?	N.n.	4.8	2.9
39	1966	E	173	31.2	✓	✓	✓	✓	6.8	3
40	1966	MU	216	28.5	?	?	✓	✓	8.6	2.3
6	1968	PB	119	37.9	✓	✓	N.n.	✓	7.2	2.1
5	1970	MU	152	32.8	✓	✓	?	N.n.	5.5	3.5
4	1972	MU	235	27.8	✓	N.n.	✓	✓	13.8	2.7
19	1972	MU	74	14.3	✓	N.n.	N.n.	N.n.	11.0	2.6
10	1975	MU	236	25.6	?	×	✓	N.n.	7.6	3.4
13	1975	MU	104	21.0	✓	✓	?	N.n.	15.3	2.2
36	1975	MU	202	19.6	✓	✓	✓	✓	6.2	3.4
37	1975	E	201	17.3	✓	×	?	✓	8.3	3.2
12	1976	MU	118	17.6	N.n.	N.n.	✓	✓	16.0	1.8
16	1976	MU	286	37.2	✓	N.n.	✓	✓	8.4	3.3
17	1976	MU	139	14.3	✓	✓	?	N.n.	7.0	2
35	1976	MU	133	21.0	✓	✓	?	✓	6.5	3.2
1	1977	MU	172	31.1	✓	N.n.	?	✓	4.8	3.4
34	1977	MU	121	16.8	✓	N.n.	N.n.	✓	7.1	2.3
3	1978	MU	185	17.4	✓	✓	?	✓	5.5	3.5
14	1978	MU	116	18.3	✓	✓	N.n.	✓	16.1	1.2
32	1978	R	108	12.4	✓	N.n.	N.n.	N.n.	4.9	3.7
33	1978	MU	85	17.3	✓	✓	N.n.	N.n.	6.3	3.3
2	1979	MU	251	24.8	✓	✓	?	✓	15.2	1.3
30	1979	MU	214	7.4	✓	N.n.	?	✓	6.0	3.4
9	1980	MU	141	9.7	✓	N.n.	?	✓	4.8	3.6
29	1980	R	136	4.6	N.n.	N.n.	N.n.	✓	4.5	3.5
31	1980	MU	154	5.9	N.n.	N.n.	?	✓	3.6	3.7
11	1982	MU	126	8.3	N.n.	M.i.	N.n.	✓	16.2	1.9
15	1982	MU	147	21.3	?	✓	?	M.i.	18.1	0.9
28	1985	R	161	12.4	✓	N.n.	N.n.	M.i.	5.5	3.6
25	1986	R	82	1.1	N.n.	M.i.	N.n.	N.n.	20.3	1.5
26	1987	R	101	4.8	N.n.	N.n.	N.n.	M.i.	8.3	3.1
27	1988	R	116	7.8	N.n.	N.n.	N.n.	M.i.	5.2	3.4

[a] PB: public building, public or private services and offices; MU: mixed-use building, residences and services/enterprises/shops; E: educational building; H: hospital; R: residential building.

[b] Symbols (✓): feasible intervention; (?): necessary, but not feasible; (×): not possible to intervene; N.n.: not needed intervention; M.i.: minor interventions.

[c] N.A.: SIR values for buildings older than 70 years cannot be determined.

2.3 Energy Efficient Refurbishments – Regional Context

Energy rich Middle East region were slow in adopting energy efficiency in built environment when compared to western countries. According to current building practices in the region refurbishments are not used as frequently and effectively as in western countries to upkeep the existing buildings. This is partly because of extreme climate in the region which deteriorates the buildings at much faster rate and reduces the life span of buildings. Hence often older buildings are demolished and rebuilt rather than refurbishing them as the building would have reached close to end of its useful life. Availability of abundant and cheap energy also keeps the operational energy costs low, hence offers no incentive for energy efficient refurbishments. It's only since 1990's there has been increased awareness about energy performance the buildings and need for statutory framework to regulate energy efficiencies of the buildings. Kuwait and Bahrain adopted energy codes during mid 90's (Radhi 2009) while emirate of Dubai adopted envelope energy code only in 2003. Though regulatory enforcement of energy codes came into effect late, there have been number of studies carried out in last two decades many of which have suggested need to enforce stricter energy regulations.

A recent study by Ragom(2002) addresses feasibility of energy efficient refurbishment in hot and arid regions such as Kuwait and attempts to justify the cost of implementing effective retrofitting schemes. The study reveals that in places like Kuwait where electricity is highly subsidized by the government, substantial savings can be achieved at national level if retrofitting costs are fully borne by the government. According to Ragom(2002), of the total electricity consumed in Kuwait , residential sector represents 65% of the energy. Most of this energy is consumed for air conditioning. At peak time 70% of total electricity produced is used for Air conditioning while of the total annual production 50% is consumed by Air conditioning system. Hence the main focus of retrofit measures was to reduce cooling loads. In the current study a two storey, rectangular residential building of 172 sqm area was considered as base building .Various retrofit measures were simulated on the base building by using the simulation program DOE-2.1E. Retrofit measures considered were improvisation of wall and roof insulation and use of high-performance glazing in place of existing glazed windows. A number of retrofit options were generated by using various permutations of above retrofit measures and payback periods for each option were calculated. Payback periods were found to be ranging from 32 years to 104 years. However these extremely high payback periods are due to the fact that electricity is highly subsidized in Kuwait. The author brings out the fact that average production cost of electricity in Kuwait is 0.54 US$ /kWh out of which government subsidy is 87% of costs ie 0.47 US$ /kWh , hence the customer pays a flat rate of 0.07 US$ /kWh only. The author suggests that these energy efficient retrofits will be beneficial to Government, considering substantial subsidies will be saved due to reduced energy consumption. It was found that even if the government funds the entire cost of retrofitting, payback period for the investment varies from 5 to 16 years.

A recent paper by Radhi (2009) studied the impact of wall systems and cladding materials on the CO2 emissions and aims to analyze the performance of those systems in order provide a reliable technical database for designers. The wall systems examined included stucco, masonry veneer, aluminium cladding, vinyl cladding and Exterior insulation and finish systems (EIFS). Economic performance, environmental performance, embodied energy and impact on operational energy were estimated for various wall systems using simulation tool. Outcome of the study suggests that, of the various cladding systems investigated EIFS system seemed to be most effective technique to reduce that energy consumption and CO2 emissions. Even in case of refurbishments EIFS can be the most effective strategy to reduce cooling loads and to improve energy performance of the buildings. Another study by Radhi (2010) examines embodied energy payback time (EPBT) for PV panels in UAE. The study suggests that use of PV panels on external envelope reduces transmittance value of the envelope resulting in energy savings, thus effectively reduces EPBT of the panels. The study brings out following outcomes which have practical implications in existing as well as new builds in UAE:

- On the basis of base building used for the research average output of PV panels were estimated to be 89kWh/m2 per year. Energy savings due to reduced cooling load were estimated to be 330kWh/m2 for southern façade.
- Optimal tilt angle for south facing surface in UAE are 24degree due to optimum amount of direct beam solar radiation. However when the tilt angle is 90 degree, western PV façade generates larger output.
- Considering PV panels effectively insulate the exterior envelope such as walls and roofs they can be used as an alternate to external thermal insulation in both new builds and refurbishments.

Sallal *et al* (2010) carried out study on developing a prototype for sustainable housing in UAE by use of Estidama principles. The housing prototype was developed following an integrated process of design and performance evaluation. The study suggested that up to 59% reduction in green house gas emission and utility bills may be achieved in typical Emirati Housing. A recent study by Aboulnaga(2005) examines the efficiencies of external glazing used in various new buildings in Emirate of Dubai. The study examines performance of various buildings in terms of glass type, visible light transmittance, shading coefficient, reflection and relative heat gain. The study suggested that glazing was misused in 70% of the buildings, with daylight factor and day light levels much higher than the accepted levels. The findings of the research are applicable even in case of refurbishments, where sizes of glazed surfaces on external envelope have to be rationalized often to control heat gain/loss and lighting levels.

2.4 Existing Building Stock in Emirate of Dubai :

A brief study of Dubai Statistical Yearbook-2008 published by Dubai Statistical Center brings out a number of interesting facts with reference to existing buildings in emirate of Dubai and their energy consumption pattern. Emirate of Dubai has witnessed robust growth in construction sector since the beginning of past decade; hence sizable existing building stocks are relatively new. Figure 4 & Table 4 indicate the total number of existing housing units in census years 1993,2000, 2003 and 2008 (Dubai Statistical Year Book,2008). Table 4 suggests total number of existing housing units dramatically surged between year 2000 to year 2008.

Table 4 : Year wise- Existing Housing units (Dubai Statistical Year Book , 2008)

Housing Type	**1993**	**2000**	**2003**	**2008**
Flats (in multi storey buildings)	60,099	95,542	141,114	199,136
Independent Villas	14,305	20,846	42,561	56,819
Total	74,404	116,388	183,675	255,955

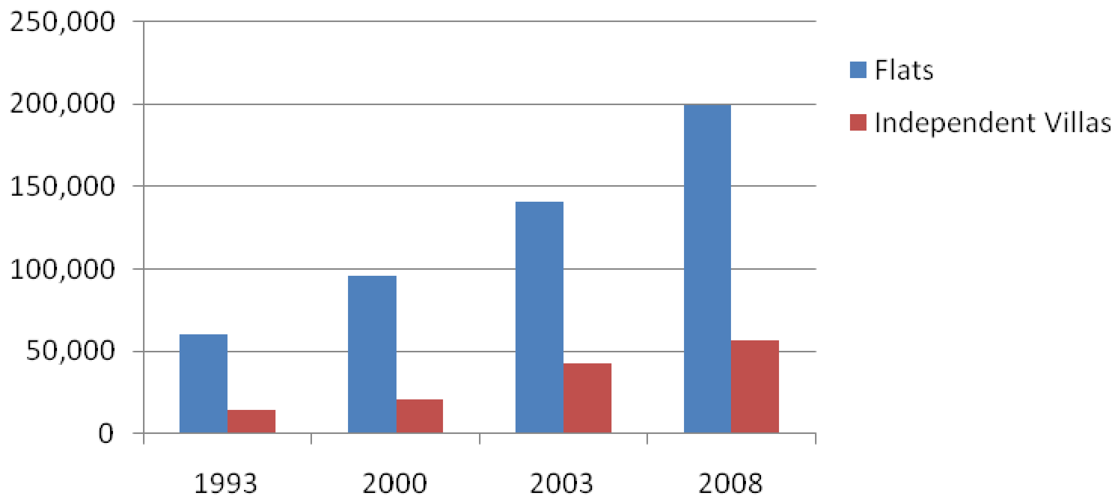


Figure 4 : Year wise-Existing Housing units (Dubai Statistical Year Book , 2008)

Assuming relatively low levels of demolition and rebuild age of the existing buildings were estimated. Figure 5 and Table 5 indicate age of existing housing units during census year 2008.

Table 5 : Age of Existing Housing units (Dubai Statistical Year Book , 2008)

Housing Type	**≥15 year old**	**8-15 year old**	**5-8 year old**	**0-5 year old**
Flats (in multi storey buildings)	60,099	35,443	45,572	58,022
Independent Villas	14,305	6,541	21,715	14,258
Total	74,404	41,984	67,287	72,280
Percentage of existing housing stock in 2008	29.06%	16.40%	26.28%	28.24%

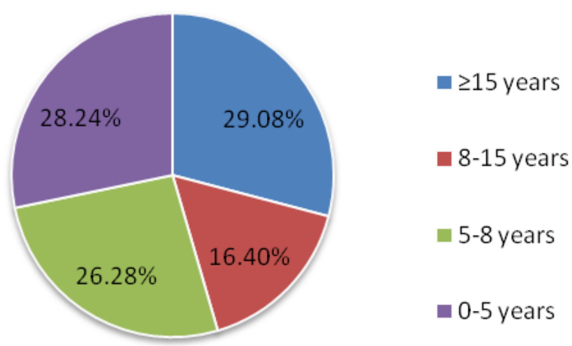


Figure 5 : Age of Existing Housing units (Dubai Statistical Year Book , 2008)

As per Dubai Statistical Year Book (2008) existing number of buildings classified on the basis of building types. Figure 6 and Table 6 indicates various existing building types during census years 1993, 2000 and 2005.

Table 6 : Existing Building Stock (Dubai Statistical Year Book , 2008)

Type of Buildings	**1993**	**2000**	**2005**
Residential Buildings (G+1 Level)	4136	5868	4334
Residential Buildings (Multistory)	2483	4236	8479
Residential Villas	30150	35824	56736
Establishment Buildings*	5240	7370	8221
Total no. of Buildings	42,009	53,298	77,770

Figure 6 : Existing Building Stock (Dubai Statistical Year Book , 2008)

Again assuming relatively low percentage of demolition and rebuild age of buildings were estimated. Figure 7 and Table 7 indicate age of existing building types during the census year 2005.

Table 7 : Age of existing building stock units in the year 2005

(Dubai Statistical Year Book , 2008)

Type of Buildings	**≥13 year old**	**5-13 years old**	**0-5 years old**
Residential Buildings (G+1 Level)	4136	1732	-
Residential Buildings (Multistory)	2483	1753	4243
Residential Villas	30150	5674	20912
Establishment Buildings*	5240	2130	851
Total no. of Buildings	42,009	11,289	24,472
Percentage of Existing Building Stock as of 2005	54.01%	14.51%	31.48%
**(Offices, Shopping, Government , Industrial Buildings, Other Buildings)*			

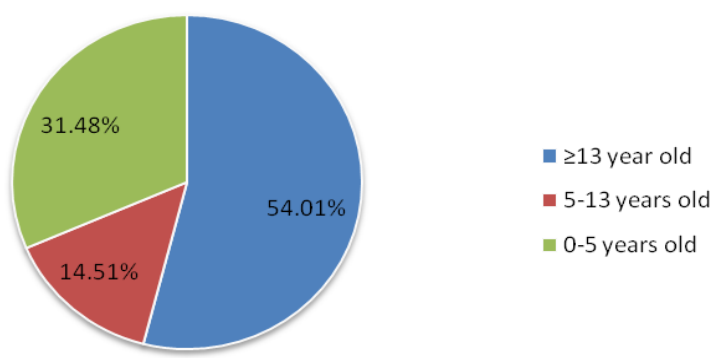


Figure 7 : Age of existing building stock units in the year 2005 (Dubai Statistical Year Book , 2008)

Brief review of age of existing housing stock in Emirate of Dubai suggests that more than 70% of the housing units are less than 15 years old. Considering a sizable new housing units are expected to add to Dubai's existing housing stock during the period 2008-2012, by end of year 2012 percentage of housing units more than 15 years old is likely to reduced further. Between year 2003 and 2008 a total number of 72,280 housing units were added to existing building stock at an annual rate of 14,456 units per year. In terms of percentages approximately 5.6% new housing units were added to existing building stock annually.

This situation is quite unusual when compared to more matured housing markets. A study by Langston *et al* (2007) in Hong Kong suggests that, during the period 2005-2006, a total number of 16,579 new residential units were added to existing building stock, which presents 1.5% of the total housing units. Furthermore a study of age of existing housing units in Hong Kong as per Rating Valuation Department-Hong Kong (2010) suggests that average addition of new housing units in each decade beginning in 1960 – 2000 remained between 10-20%. This suggests an annual addition of 1% to 2% housing units to existing stock. Figure 8 indicates the age of existing housing units as during the year 2000.

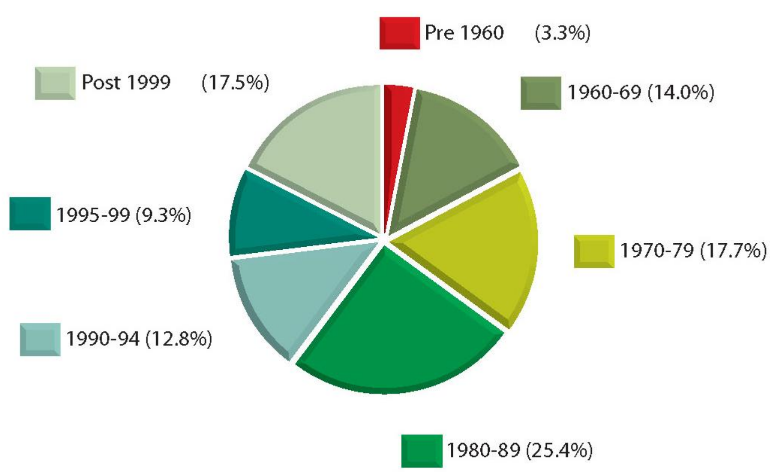


Figure 8 : Age of existing building stock in Hong Kong during year 2006 (Langston *et al* 2007)

In more matured housing markets such as UK addition of new units to existing stock is even gradual. As per Power (2008) new buildings add at most 1% a year to the existing stock in UK. Power (2008) suggests that currently there are around 24 million homes are existing in UK of which 87% are expected to form part of existing building stock even in 2050. As per Housing Condition Survey carried out in 2004, (Department of Communities and Local Government, 2006) age of existing housing stock in UK is as per Table 8.

Table 8 : Age of existing building stock in UK (Power,2008)

Age/Period	**Pre 1919**	**1919-1944**	**1945-1964**	**1965-1974**	**1975-1980**	**1981-1990**	**Post 1990**
	≥85 years	**85 – 60 years**	**59-40 years**	**39-30 years**	**29-24 years**	**23-14 years**	**≤14 Years**
Total No. housing units (in Million units)	4.4	3.6	4.2	3.1	1.3	1.8	1.8
Percentage of Existing Building Stock as of 2005	21.78%	17.82%	20.79%	15.35%	6.44%	8.91%	8.91%

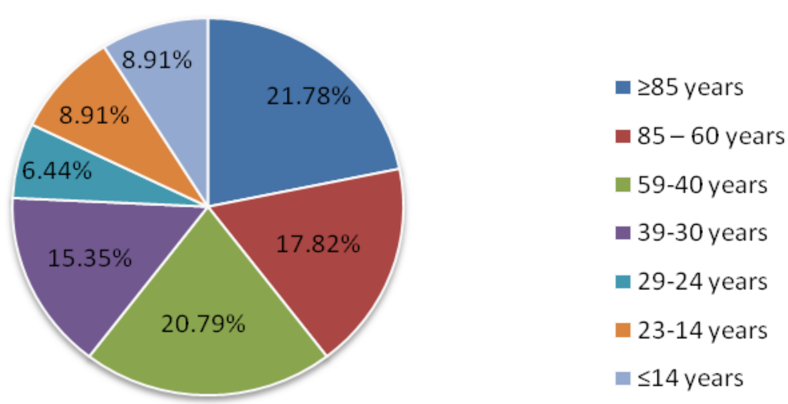


Figure 9 : Age of existing building stock in UK (Power,2008)

Comparison of age of existing building stock of Dubai with UK and Hong Kong data brings out the fact that existing building stock in Dubai is relatively new. Only 29% of existing housing units in Dubai are older than 18 years, while percentage of older buildings is considerably higher in cases of UK and Hong Kong. The fact that Dubai has emerged as a sizable urban center only in the recent decades is main reason for relatively new building stock of Dubai. Again there are no relevant statistical data suggesting average life of buildings in Dubai. In the coming years with maturing housing market, more relevant statistics such as average and expected of life of buildings will be generated.

2.5 Building Regulations – Energy Codes:

2.5.1 Definition – Building energy code is a document used by the regulatory authority to control building design practices in relation to energy efficiencies of the buildings (Radhi 2008). Radhi (2008) has suggested two different approaches to building energy codes, prescriptive and performance. A prescriptive approach to energy code sets a minimum design requirement for key energy use aspects in buildings. Performance based approach sets a target or benchmark for the level of energy performance of the buildings without prescribing the procedure or methods to achieve target benchmark. Energy codes in developed in European countries such as UK during 1970's were prescriptive type where codes enforced minimum standard for health and safety and energy efficiency. Even the current codes of UK such as Energy Efficiency Requirements for new dwellings –Part L (Department of Communities and Local Government, 2007) is a prescriptive type code which is discussed in detail in following paragraphs. Prescriptive type of codes often seem to limit flexibility to building designers as it prescribes design and details of building components. To counter this limitation few of the advanced countries have been trying to move towards whole building energy codes recently.

Local building codes in Gulf region such as Bahrain, Kuwait and UAE are prescriptive type. Analysis of UAE's building code over the period of few years has suggested that building codes were quite pragmatic till recent years; however more comprehensive amendments are being made currently in line with international building codes. To bring out comparison with UAE's building codes with well developed international codes, a brief study of UK's current energy codes are included following which UAE's building codes are discussed in detail.

2.5.2 Building Codes in relation to Energy Performance of Buildings in UK :

The department of Communities and Local Government in UK has made it mandatory for all new and existing buildings since 2008 to have Energy Performance Certification (EPC) while they are being built, sold and being rented. For existing buildings EPC's are intended to inform potential buyer or tenant about energy performance of the buildings. A number of public authorities such as NES, BRE provide training and accreditation for individuals as approved energy assessors. For new builds, building codes have set the minimum design requirements in terms of energy aspects of the buildings. These regulations have undergone a number of revisions over last few years and each new amendment has prescribed stricter energy performance. The latest amendment, Energy Efficiency Requirements for new dwellings –Part L came into effect in April 2006. Highlights of current amendment include (Department of Communities and Local Government, 2007):

- Carbon Emission Reductions: With 2006 as base year emissions at 2010 are set to reduce by 70% and by 50% by year 2013. New builds are set to be carbon neutral by 2016.

- Construction Quality: In order to ensure that as built performance matches design intent a two tier approach adopted. First measure is to consider an additional adjustment factor in design calculations. Second measure is to enforce builders to invest in enhanced site-based quality control system with additional pre-completion testing.
- Lighting: With better insulated external envelopes for dwellings lighting becomes a significant contributor to over all CO2 emissions. Hence the regulations call for high efficiency Domestic Energy Efficient Lighting Scheme.
- Passive Controls: Passive controls of overheating by appropriate orientation, shading design and landscaping design.
- Approved construction details: The building regulations offer design and construction detail solutions to builders in area such as air-leakage, insulation discontinuities etc. Implementation of approved construction details are expected to achieve higher energy savings.
- Amendments to Standard Assessment Procedures (SAP) including :
    - Shift to monthly energy calculations instead of annual calculations considering differences in winter and summer energy performance.
    - Development of new procedures for assessing effects of thermal mass in summer & winter performance calculations and to assess night-cooling ventilation system.
    - Development of new procedures for addressing embodied energy.

Implementation of proposed regulations has been illustrated in the case of 100 square meter detached house (Department of Communities and Local Government 2007) as per Table 9. The applied standards are intended to achieve compliance with 2010 target, which is 25% more energy efficient than 2006 year base case.

Table 9: Proposed regulations for detached housing

(Department of Communities and Local Government 2007)

Element/Detail	Criteria	Construction
Roof	Average U value – 0.14 W/m2	eg: Fully insulated 300mm deep l-beam structure will achieve target 'U' value.
Walls	Average U value – 0.22 W/m2	eg 1 : Masonry wall with 150mm cavity filled with fiber insulation – overall thickness 370mm. eg 2 : Timber frame construction- 89 mm stud with 70mm external insulation – over all thickness 350mm. eg 3: Concrete block with external insulation – overall thickness 300mm.
GF Slab	Average U value – 0.17 W/m2	eg: 150mm expanded polystyrene or equivalent under slab insulation will achieve target value.
Windows and Doors	Average U value – 0.9 W/m2	Eg: High performance triple glazing with soft-coat low e glazing with Argon in-fill.
Thermal bridging allowance	U value – 0.04 W/m2	Can be achieved through improved construction details
Ventilation System	High efficiency	Use of high performance mechanical extract system will ensure higher efficiency.
Air permeability	3 cubic m/hr/sqm at 50Pa pressure difference	Can be achieved by plastering inside surfaces of walls, ceilings and floor.
Hot water central Heating	High efficiency	High efficiency boiler with thermostatic controls . High performance storage cylinder with 75mm insulation.
Lighting	Use low energy fittings	Minimum 70% of rooms with higher lighting demand to have low energy light fittings.

2.5.3 UAE- Building Codes:

In UAE each of the emirates has developed their own building codes. Generally there has been no separation of building regulations from envelope energy codes. A part of building regulations prescribed envelope energy standards. In the emirate of Dubai two regulatory authorities have developed building codes over past couple of decades namely Dubai Municipality and Jebel Ali Free Zone Authority. Other jurisdictions such as TECOM have adopted building regulations from either of the authorities. The earliest building regulations reviewed in the current study is “Building and General Civil Work Construction Regulations “Second edition issued by Jebel Ali Free zone authority in the year 1994. Extract from the regulations in relation to energy performance of the building includes:

- Clause 6.1 - 6.4 : Fitness of Materials

  The clause suggests that all building materials should confirm to UAE/Gulf standards, British standards, International standards and or any other standards approved by the authority. The code also prescribes a minimum of twenty year design life for the building.

- Clause 8.1 – 8.6 : Structural Design of Buildings

  The clause prescribes relevant BS codes applicable for building design and construction, minimum design requirements for structural steel and concrete structures.

- Clause 11.1-11.9 : Fire Protection Facilities

  The clause suggests that fire protection design and specifications shall comply with National Fire Codes of USA. The codes seem to be quite elaborate on fire and life safety requirements in buildings.

- Clause 12.1-12.11 : Ventilation and Air Conditioning

  The clauses prescribe that the design and installation of air conditioning and ventilation system shall be as per current ASHRAE guideline and also shall comply to relevant British Standards. The clauses also suggest recommended Air changes for various usages.

- Clauses 15.1-15.4 : Lighting

The codes along appendix-G prescribe the recommended minimum lighting for various usages.

The above versions of the regulations seem to be primitive in defining expected energy performance levels. The mandatory energy efficient aspects such as thermal transmittance values of external envelope, glazing and daylight requirements, shading devices etc haven't been addressed in the regulations. Hence buildings built during this period would have been quite energy in-efficient unless the building designers incorporated high energy efficient feature well above the requirements of building regulations.

Building regulations by Dubai Municipality have been issued as articles, and amendments and addition to these articles are being issued as DM- circulars. As of year 1999 total of 57 articles were issued by Dubai Municipality which formed the Building Regulations. Currently in additional to these articles total of 170 DM- circulars have been issued which combined forms current Dubai Municipality Building Regulations. Other than these building regulations , Dubai Municipality has issued a number of advisory notes on building material specifications and construction details. Advisory notes on building material specification (1995) includes detail specifications and quality aspects of building materials such as concrete aggregates, cement, admixtures and additives for concrete, precast concrete paving blocks and concrete masonry blocks. However properties such as thermal transmittance values, thermal reflectance haven't been addressed. Extracts from current Dubai Municipality regulations in relation to energy efficiency are as per following:

- Article 12 : Natural lighting and ventilation openings , Article 13 : Opening sizes

  Article 12 – stipulates mandatory day light and primary and secondary ventilation in all livable rooms. Article 13 prescribes minimum 10% window area (minimum 10% of overall floor area) for livable rooms and minimum 5% window area for service areas. Minimum of 5% window area has been prescribed for warehouses and workshops.

- Article 26 : Environmental conditions

This article addresses various environmental parameters to be considered in design. The code suggests use of passive design elements to optimise lighting-solar heat gain, and to take advantage of beneficial effects of prevailing wind. The article suggests that appropriate DM- circular shall be referred for specifications of thermal insulation, acoustic insulation, shading coefficients of envelope components.

- Article 50 : Insulation Materials

  The article prescribes requirement of appropriate thermal calculations to be submitted for competent department's approval.'

- Article 54 : Structural Design

  This article prescribes a number of British Standard codes for design of Structural elements.

- Administrative Resolution No.(66) – 2003 : Technical specification for thermal insulation materials. This regulation prescribes thermal transmission values of external envelope and performance criteria for Ventilation, Air Conditioning. Table 10 presents summary of Administrative Resolution No.66.

Table 10: Extracts from Dubai Municipality Administrative Resolution No.66

Item	**Requirements**
External Walls	Locally available thermal insulated blocks shall be used - maximum allowable U value – 0.57 W/m2K
Roof	Allowable U value – 0.44 W/m2K
Glazing	Case 1 – When glazing area is 10% - 40% of external envelope U value – 3.28 W/m2K Shading Coefficient – 0.4 Case 2 - When glazing area is more than 40% U value – 2.1 W/m2K Shading Coefficient – 0.35 Case 3 – Glazing for showrooms etc requiring higher visual transmittance U value – 2.5 W/m2K Shading Coefficient – 0.76
Aluminium Works	Aluminium sections for window/door frames shall be thermally broken.
Air-conditioning	The article prescribes AC units with heat recovery units in accordance with ASHRAE 90.1 & 90.2. AC units have EER values in accordance with ASHRAE standards. Ventilation requirements as per ASHRAE standard 62.
Thermal Insulation Materials	The article includes specifications for all thermal insulation materials and prescribes installation and workmanship.
General guidelines	General guidelines include a number of passive and measures such as building orientation, efficient landscaping, rationalization opening in external envelope, external color and surface treatment.

- Circular No. 161 -2008 : Application of Green Building Standards for Buildings

  This circular addresses various aspects of green buildings such as optimized power consumption, on site power generation, Indoor environmental air quality, efficient water usage, sustainable landscaping using native plants, energy efficient using power saving light fixtures and advanced control systems for lighting and ventilation.

2.6 Comparison of Building Codes:

A review of building regulations development in UAE brings out the fact that until recent years building codes have not explicitly addressed energy efficiency. Administrative resolution no.66 issued in 2003 is one of the first articles which prescribe minimum thermal performance of envelope components. Envelope codes haven't been amended since 2003 and same are being followed as of 2011. Comparison of DM's resolution 66 with current envelope codes of UK (Part-L) brings out the fact that energy codes in UK are much more stringent. Thermal transmittance values of envelope components such as roof, wall , floor and glazed windows are much lower in UK codes which will greatly enhance energy performance of the envelope. Buildings prior to 2003 in Dubai are less likely to be energy efficient as before issuance of article 66, there seem to be no set standards for energy performance of envelope components. Considering about 45.46% of existing housing units were built pre-2003 they are less likely to be complying to current building codes. This group may present an opportunity for energy efficient refurbishments.

2.7 Inferences:

The current chapter started with drawing parallel between various published articles on energy efficient refurbishments in global context to that in regional context. The comparison brings out the fact that energy efficient refurbishment is relatively new concept to the Middle East region while it has been practiced since past few decades in European and Northern American countries. It can also be noticed that in European countries such as UK a good data base of energy performance of existing built stock is maintained, while the same body of knowledge is yet to be developed in this region. Again most of the published works in this region seems to have been originated from individual researchers, while in developed countries similar studies have been carried out by large government or semi-government organisations with large resources spent on research. This visible gap in published works acted as further incentive to carry out the current research.

The second part of the chapter addresses age of existing built stock in UAE, particularly in Dubai on the basis of data base developed by Dubai Statistical Center. In comparison to much matured housing markets such as UK or Hong Kong , Emirate of Dubai seem to be very young housing market with majority of currently existing housing units built in last 15 years. With current data base, it is difficult evaluate life span of different category of buildings in Emirate of Dubai. This again calls for developing a suitable and structured data base with accurate information about existing built stock. Though Dubai Statistical Center established in 2006 has been publishing a data base in the form of Statistical Year Books, detailed information about existing buildings and their energy consumption pattern needs to be included.

The last part of the chapter draws a comparison between building codes and regulations with developed country such as UK with local building codes. The study particularly brings out the fact that prescriptions for energy performance of the envelope components in the buildings have been introduced only recently by Dubai Municipality, while this was mandatory in UK regulations since few decades. Though recent Building Codes introduced by Abu Dhabi is more comprehensive a detailed analysis of these codes are not included, as the current study primarily focuses on refurbishment of existing buildings in Emirate of Dubai.

2.8 Aims & Objectives of the Research:

Literature review carried out highlights the fact that, though energy efficient refurbishments are very commonly and effectively used in Europe and North American countries, it is very rarely used in this region. Hence the main aim of the research was to determine if refurbishment can be used effectively to improve energy efficiency of existing buildings in this region. Further aims of the study were to determine particular refurbishment techniques that are most effective when applied to existing buildings. Energy saving potential of various refurbishment techniques is to be evaluated followed by economic analysis to determine payback periods.

In line with these aims, particular objectives of the research have been listed:

1. To determine if energy efficient refurbishment is a feasible option for existing buildings by use of case study. The objective was to choose an existing case and apply suitable refurbishment techniques and to evaluate over all energy savings that can be achieved.

2. To determine various refurbishment techniques which are most suited for this region. Though a number of different refurbishment techniques have been in use around the world, not all of them may be suitable for in this region. Hence it was intended to scrutinize various commonly used techniques and to determine most effective and practical strategies for this region.

3. To determine energy saving potential of each of the refurbishment strategy. The objective was to quantify percentage energy saving that may be achieved by application of various selected techniques. To ensure that results generated are realistic, each refurbishment strategy shall be applied to the base building in isolation and corresponding energy saving shall be assessed.

4. To determine cost effectiveness of various refurbishment techniques, and to evaluate payback period for various refurbishment strategies.

Chapter 3: Refurbishment Techniques

As the building gets older, various building components gets degraded which will result in increased operational energy consumption. A timely refurbishment of building components such building envelope, mechanical & electrical systems will not only extend the useful life of building but also improves energy efficiency of the building. Baker (2009) has suggested a number of techniques that may be used in energy efficient refurbishment of existing buildings. The suggested techniques find application in both cold and warm climates. Various techniques have been discussed in the initial part of the chapter, followed by recommendations for effective strategies suited for UAE.

The refurbishment techniques have been classified on the basis of areas of application.

3.1 Floors: A non insulated ground floor may allow considerable amount of heat transfer with the soil below effectively increasing cooling or heating load of the building. The effect of floor insulation will be significant on over all energy performance for low height buildings with smaller foot prints. Simple construction practices to improve the insulation values of the ground floor slab include:

3.1.1 Load bearing insulation above existing slab with reinforced screed top covering:

The above method is one of the simplest techniques to insulate the existing floors. It is suggested that a rigid insulation of 50-100 mm on existing floor slab covered with screed thickness of up to 75 mm may significantly increase the insulation along with beneficial effect of contributing to the thermal mass.

3.1.2 Load bearing insulation above existing floor slab with light weight decking above:

This type flooring insulation layer isolates thermal mass of the building from floor finish. An advanced version of the same type of refurbishment is to have access flooring with a rigid or non rigid insulation below. Along with primary intent of increasing the insulation of the flooring, access flooring also creates opportunities for under floor ventilation and also IT installations.

3.2 Walls : The main contributions of wall insulation includes heat retention in cool conditions, heat exclusion in warm conditions and prevention of solar gains due to direct solar radiation. In conventional non-insulated constructions U value of external opaque walls may vary from 1 – 5 W/sqm deg C. An appropriate insulation technique used as a refurbishment measure may reduce the transmittance value up to 0.2 W/sqm deg C. The application of insulation may be external or internal depending on individual cases.

3.2.1 External Insulation: The external insulations have beneficial effect of protecting the structure from direct solar radiation thus reducing cooling loads, providing weather proofing to degraded external wall. Properly applied external insulation may eliminate most of the cold bridges. Techniques for external insulations includes following:

3.2.1.1 Rigid Insulation material fixed to wall with render top coat

3.2.1.2 Metal framing on external wall with non structural insulation in voids finished with render on a support layer such as metal lath.

3.2.1.3 Metal framing on external wall with non structural insulation in voids with rigid cladding on top.

3.2.1.4 Composite engineered cladding which offers weathering, insulation and structural support on existing external skin.

3.2.2 Internal Insulation:

Insulation may be applied on the internal face of the envelope especially when the buildings are of historic importance where alteration of the external façade by way applying external insulation may not be acceptable. Internal insulation decouples internal environment from the thermal mass of the building, thus beneficial effect of thermal mass may be lost. It is suggested that internal insulation may lead to cold bridges especially where floor slab meets external walls. Cold bridges often lead to interstitial condensation. A vapour barrier may be incorporated on the warm side of the insulation layer to overcome interstitial condensation. Various techniques of internal insulation application include:

3.2.2.1 Rigid insulation material fixed to wall with render or plaster board top coat.

3.2.2.2 Framing fixed onto the internal side of the wall with voids filled with non-structural insulation. The outer skin may of plaster board or cladding panel.

3.3 Roofs : In warmer climates roof surfaces generally receive maximum direct solar radiation thus can be major cause of overheating. In cooler climates roofs can be a source of large heat loss through convection and through high radiant losses to the night sky. Refurbishments may be necessary for roofs due unsatisfactory exclusion of precipitation or due to poor thermal performance. Roof insulations may be categorized as per the following on the basis of opportunities for insulation.

3.3.1 Roofs with accessible attic spaces: This type of construction with access to underside of roof is generally found in traditional buildings, where roof may be insulated by providing a thick layer of non rigid insulation at underside of the roof. This treatment will result in high standards of insulation at minimum cost. Baker (2009) suggests that application of 300 mm fiberglass insulation layer below a tiled roof will reduce overall U value of the construction from 2.5 W/sqm deg K to 0.1W/sqm deg K , which is a drastic reduction. One of the practical strategies to avoid condensations in insulated attic spaces is to well ventilate the spaces, thus keeping the moisture away.

3.3.2 Insulating solid roof with insulation above water proofing:

One of the most simplest and practical techniques of insulating existing solid roof finds wide application in energy efficient refurbishments. In this method slabs of rigid insulation are cut and laid on existing waterproofing membrane, with top layer of concrete tiles or gravel. This method offers a number of advantages including well protection to water proofing membrane below, least disturbance interior spaces during installation and also minimizing chances of cold bridges.

3.3.3 Insulation between water proof membrane and structural deck:

When the existing water proofing membrane on roof is badly damaged it presents an opportunity to incorporate rigid insulation layer between structural deck and water proofing membrane. However considering waterproofing membrane is exposed to direct solar radiation, membrane may get damaged due to extreme heat.

3.3.4 Roofing – Other Techniques:

During refurbishment of roofs a number of other parameters related to the roof construction may be altered to improve energy performance including surface reflectance of roofing material, use of low-emissivity membrane and use of green roofs and roof ponds. In warmer climates with high solar radiation thermal performance of the roof may be greatly improved by varying surface reflectance of the roofing material. By increasing surface reflectance of roofing material solar heat gain factor of the roof may be reduced. Baker(2009) suggests that simply by applying a white coloured paint coating on non insulated steel corrugated roof reduces its solar heat gain factor from 7.6% to 3.7%. Similarly by application of a white paint coat which has high surface reflectance on 150 mm thick concrete slab may reduce the solar heat gain factor from 9.1% to 4.1%. Baker(2009) has also suggested that a number of new paints are available in the market which reflect most of incident near infrared radiations even when the coating is colored with the over thermal performance significantly better that conventional white paint. In hot and arid regions such as ours, where overheating is the main problem use of high reflectance surface treatment shall be favored as it reduces solar transmittance as well as protects the roof material from degradation due to reaching high temperature. On a macro scale use of high reflectance roofing material reduces Urban Heat Island effect. Another effective technique to reduce heat gain from the roofs is to use of low emissivity membrane such as aluminium foil in the roof cavity which will re-radiate heat transmitted through radiation.

Earlier researches have indicated that Thermal mass of the building have a beneficial effect on thermal performance of the building in both cold and warmer climates (Guertler & Winton 2006). Roof insulations in refurbishments alters the thermal mass of the building. In cases where the roof is insulated internally, thermal mass of the building gets disjoined from the interior environment, thus ruining beneficial effect thermal mass to the interior spaces. However when insulation is applied externally in contributes positively to the thermal mass of the building. Strategies such as green roofs and roof ponds can be used in roof refurbishments however recent studies have shown that conductivity of wet soil is quite high hence addition of planters on roof may not necessarily increase the insulation value of roof, however thermal mass of roof increases.

3.4 Windows and glazed openings: Upgrading of glazing is one of the most commonly used refurbishment technique. Upgrading or modifying glazed openings in a refurbishment may involve replacement of glazing material, reduction or enlargement of openings and installation of a external or internal shading system. The concepts of high performance day lighting in refurbishment projects has been well illustrated in Technical Monograph of Revival which is a five year project funded by European Commission's fifth framework – "ENERGIE" programme.

3.4.1 Glazing – Types and Energy Performance:

The main purpose of provision of windows or glazing openings in buildings is to provide appropriate levels of daylight into interior spaces. In cooler climates it may be prudent to have duel function to windows where in both light and heat may be gained. However in warmer climates intent will be to allow visible spectrum of lighting into interior spaces while screening off excess heat. The recent developments in glazing technology have made this possible. U Values of modern glazing systems using low-emissivity surfaces with inert gas infill may be as low as 1.0 W/Sqm deg K which is only fraction of conventional single glazing(Baker,2009). Also this type of high performance glazing may be developed to have selective transmission to radiation where in visible part of light spectrum is transmitted while invisible spectrum of light mainly constituting heat waves are filtered. Previous studies have suggested that the radiation incident on glazing partly gets reflected, partly absorbed and partly transmitted. For normal clear glazing reflected component is about 15% of total incident radiation, however value increases significantly once angle of incidence increases beyond 60 degree. Normal clear glazing transmits up to 80% of incident radiation while about 5% of radiation gets absorbed. It may be noted that most commonly used glazing types such as tinted glass and reflective glass have quite different performance. A tinted glass contains pigments which increases absorption. Because of presence of pigments transmittance value of tinted glass is reduced typically from 40% to as low as 10% (Baker,2009). The glass gets heated due to absorbed component and heat is transmitted partly to interior and partly to exterior due to convection and radiation. In case of reflective glazing a thin metallic or semi conducting coating is provided which increases the reflectance of the glass. Hence reflective glazing reduces the transmittance due to reflection and does not lead additional heat absorption to interior space as energy gets reflected. Considering both reflective and tinted glazing reduces the transmittance considerably "High Performance" glazing was developed which transmits significant portion of visible light spectrum while blocks invisible spectrum of light consisting of infra-red and ultra-violet radiations. Thus light transmitted through high performance glazing has higher luminous efficacy.

3.4.2 Low emissivity Glazing: Low emissivity glazing consists of a thin layer of electrically conducting layer applied to internal layer of glass. Generally low e coating is used in double glazing with outer layer of glazing protecting the low-e surface. The gap between the glazing layers is filled by air of heavy inert gas such as argon to reduce convective heat transfer. The low e coat reflects long wave heat radiation. In summers outer layer of glass directly exposed to solar radiations absorbs heat and reradiates them as long wave radiations to inside layer of glass. Low e coating present on inside glass layer reflects the long wave radiation, hence heat gain to interior space is minimized. In winters long wave radiations emitted by interior space is reflected back to interiors by low e coating minimizing heat loss. Thus low emissivity glazing will be beneficial to both in summers as well as winters. Application of low e coating reduces transmittance – U value of glass assembly considerably. As illustrated in Revival Technical Monograph (2008) typical U value of 2.8W/sqm deg K for normal double glazing may be reduced to 1.8 W/sqm deg K when internal low e coat is applied. The U value may be reduced further to 1.0 W/sqm deg K when the gap between the layers is filled with inert gas such as Argon which reduces the convective heat transfer. The recent developments is glazing technology have resulted in new types of glazing which respond to changing external environmental conditions (Aboulnaga,2005). Photo chromic glazing alters transmittance of lighting in line with incident lighting levels. Similarly thermo chromic glazing are provided with coating of thermo chromic materials which alters the transmittance value of glazing by responding to external temperature. Another type of dynamic transmittance glazing is electro chromic glazing which incorporates liquid crystal systems. These liquid crystals respond to electrical field, hence their properties may be modulated by controlling electrical field. Hence by modulating the electrical filed transmittance value of the glazing may be altered.

3.4.3 Framing and Support System:

Lighting and Thermal transmittance of windows is not only governed by the glazing panel but also by framing system. The light transmission through windows is reduced due to obstruction caused by the window frames. Due to width of the frame the extent of obstruction increases with angle of incidence of light. Again surface finish or reflectance of the frame has an effect on light transmission. Framing of glazed windows can have a large impact on overall transmittance value of the window assembly. Baker (2009) has illustrated a case where aluminum framing increases U value of the glass from 5.6W/deg C sqm to an average U value of 9.5W/deg C sqm for entire window assembly. Though the framing forms relatively smaller portion of the entire area of window assembly observed significant raise in U value is due to ‘fin effect’ of the framing and very high thermal conductance of aluminium. At 237W/m deg K it is has 50 times higher transmittance value than a normal single glazing panel. Through a material such as wood has much lower transmittance value , in the order of 0.15 W/m deg K aluminium is still preferred as framing material for windows due to its high strength and ability to extrude aluminium with highly complex sections suited for supporting glazed panels. U value of the aluminium frames are reduced by introduction of thermal seals. UPVC is another material which has been used quite successfully to replace aluminium as framing material due to its low thermal conductivity. (about 0.2W/m deg C). However UPVC is associated with disadvantages such as vulnerable to UV degradation, greater environmental impact due to higher embodied CO_2 and difficulty in recycling.

Baker's (2009) study of U values for glazing & framing combinations for pane size 1.2m X 1.2m. Table 11 indicates that over all U value of glazing + frame varies significantly due to choice of frame type.

Table 11 : U-value of glazing + framing systems (Baker 2009)

Glazing + framing system	U-value of glazing material	U-value of glazing + framing
Double glazing Aluminium	2.8	3.1
Double glazing Aluminium with thermal break	2.8	3.0
Double glazing low-e inert gas Aluminium	1.5	2.7
Double glazing low-e inert gas Aluminium with thermal break	1.5	1.9
Double glazing low-e inert gas Timber	1.5	1.8

Double glazing low-e inert gas Timber with thermal break	1.5	1.5

3.4.4 Refurbishment of glazed openings:

Most frequently used energy efficient refurbishment techniques in relation of glazed openings have been listed below:

3.4.5 Glazing Replacement: Most effective strategy to improve energy performance of the envelope. Generally existing single glazing is replaced by double or double low e glazing. The main advantage due the glazing replacement is reduced heat gain in warm season and reduced heat loss during cooler season. In cases of refurbishments of historic buildings where it may not be feasible to replace original glazing with frame – a suitable strategy will be to apply a low e coating on glass panel which will reduce U value to some extent. According to Revival Technical Monograph(2008) U value of existing single glazing may be reduced from 6W/sqm K to 4 W/sqm K by application of one layer of hard ceramic low-e coating.

3.4.6 Modifying apertures:

While considering existing building stock for refurbishment, buildings which are over glazed with single glazing layer presents opportunities to modify apertures. It is generally noticed that few of the modern buildings built in 1950's onwards have been provided with excess amount of glazing with poor thermal performance often resulting in over heated interiors. Modification of apertures could be effective strategy in such cases as it will reduce overall glazing area thus reduces the heat gain. Since existing glazing may be replaced by opaque envelope with U values as low as 0.2 W/sqm K it will have significant impact on overall U value of the envelope. According to Revival Technical Monograph(2008) if the 70% of double glazing of a façade is reduced to 35% with an opaque material with U value of 0.2W/sqm K , the average U value of the original aperture would be reduced from 2.8W/sqm K to 1.5 W/sqm K. The report suggests following as rules of thumb while reducing apertures of exiting openings:

- Sill heights should be maintained at 1 m or less.
- Generally upper portion of the glazing is effective in uniform distribution of light in the interiors, hence shall not be modified.
- Horizontal distance between glazed openings should not exceed 3 m.

In some parts of the building where lighting levels are lower than acceptable levels new windows may be included on the external walls to ensure adequate daylight to interiors. Single storey buildings and top floors of buildings provide opportunities to incorporate skylights which will help to achieve uniform distribution of lighting in interior spaces.

3.4.7 Shading Devices:

In refurbishments often shading devices are used to regulate solar gains and to control glare. Shading devices that may be retro-fitted during refurbishment are mainly of following category – external , internal and inter-pane (Guertler & Smith 2006). External shading devices are very effective in minimizing thermal gains and the heat absorbed by the shading devices are re-emitted to external environment in case of external shading devices. External shading devices may be of one of the following types - over hangs, louvers, fins, blinds and perforated screens. By comparison internal shading devices are relatively less expensive and easier to install, hence are often preferred in refurbishments. Louvers and roller blinds of translucent material are most commonly used type of internal blinds. In case of horizontal internal louvers the use of high reflective material coating on top surface of louvers will direct incident light upwards towards the ceiling ensuring uniform distribution of illumination. Internal louver systems are generally retractable enabling the users to allow maximum daylight during hours of limiting daylight availability. Roller blinds are another form of internal shading devices which is a preferred solution in retrofitting due to low cost and simple installation process. Both louvers and roller blinds transmit considerable amount of heat absorbed to interior spaces , hence in warmer climates it is preferred to use high reflectance material for the shades so that greater proportion of radiation are reflected out through glazing.

3.5 Atria and Double Skins:

Atrium is a large open space with glazed envelope situated within a building. Researches carried out in 1970's have illustrated energy saving potential of the atria and have suggested that carefully designed atrium space can reduce overall energy consumption of the building. Moreover Architectural potential of such enclosed spaces have made atrium a very popular feature among architects. Atria are particularly effective in cooler climates as they may save considerable heating load if designed efficiently. Atria may be integrated in refurbishments as well if the building provides such opportunities. In refurbishments atria will be cost effective when parent building provides the primary support structure for the atrium envelope.

3.5.1 Principles and Energy Performance of Atria

The performance of the atrium depends on properties of the skin or envelope and the geometry of the atrium and surrounding enclosure. The external walls of the parent building enclosed by the atrium envelope which separates atrium space from the parent building is termed *Separating Wall*. The ratio of separating wall area to atrium floor area is measure of protectivity of the atrium and higher the ratio higher the protectivity. The ratio of overall conductance of the separating wall to conductance of external atrium envelope determines energy performance of the atrium. The figure xx illustrates three cases of atria with differing protectivities.

The other factor influencing performance of the atria is the extent of direct solar radiation penetrating on atria envelope. The ratio of south facing glazing to non –south facing glazing is termed as Solarity of the atrium which is a determining factor for solar gain. These parameters Protectivity and Solarity together determines thermal performance of the atrium to a large extent.

3.5.2 Thermal performance in Winter and Summer:

Well designed atrium spaces can reduce the heating load of the buildings in winter. Atrium spaces with good solarity will absorb reasonable amount of solar radiation during winter thus raising the air temperature within the atrium. This will result in reduced heat loss via separating wall which will effectively reduce heating load of the over all building. The fresh air supply for the building may be obtained from atrium which is pre-heated already, reducing ventilation heat load. Baker(2009) has presented an interesting study of predicted monthly temperature of an unheated atrium for varying glazing ratios for sunny and non-sunny days. The study also shows predicted air temperatures when the glazed surface is replaced by insulated opaque envelope.

In summer due to increased heat gain in the atrium space the parent building may suffer from conductive and ventilation heat gains. Due to stratification of air within the atrium lower part of atrium may remain cool but upper parts are likely to be heated up, thus causing a large heat transfer to upper floors of building. By shading the atrium envelope effectively and by inducing a sufficient air circulation within the atrium space negative effects of atrium may be mitigated. Glazing exposed to direct solar radiation may be shaded by use of movable shading. To induce sufficient air circulation within the atrium space , stack effect may be effectively used by allowing passage for air entry at the bottom of the atrium at ground level and by providing ventilation outlets on top of the atrium. Baker(2009) has suggested that an openable area of around 10% of the solar glazing area shall be sufficient to induce vertical air circulation within the atrium space.

3.6 Use of Double Skins in Refurbishments:

Double skins find application in both new buildings as well in refurbishments. In refurbishments double skin can be cost effective in projects which will require upgrading of glazed facades with intricate and expensive detailing. The energy saving potential of the secondary skin increases if the primary envelope is highly glazed and poorly insulated. Double skins are distinguished from double glazing by use of a gap of 0.3m – 1.5m between primary and secondary glazing envelope. The secondary skin not only improves the thermal insulation of the overall envelope but also provides a suitable location of shading devices. It also provides an opportunity to have controlled ventilation between outside, void and interior of the building. The thermal benefits of the double skin are similar to atrium spaces ie reduced conductive and infiltration losses and possibilities of ventilation pre-heating. However in warmer climates poorly designed double skins are prone to over-heating. In warmer climates the cavity between the skins are provided with shades to avoid direct solar radiation on inner skin. Combination of shading devices, openable panels to control ventilation along with intelligent control system can make the skins sensitive to changing weather pattern. However due to high cost of large glazed surfaces, shading, support structure along with intelligent control system often makes technique one of the most expensive item in refurbishments.

3.7 Mechanical Services and Controls:

In contemporary buildings in it generally noticed that condition and efficiency of mechanical services and controls has a significant impact on overall energy performance of the building. Considering life span of mechanical equipments is shorter than that of the building envelope it requires frequent maintenance and upgrades, hence presents opportunities to improve efficiencies. Though it is difficult to generalize it is often noticed that upgrading mechanical equipments will tend to be more cost effective as compared to improving the fabric performance. A number of earlier studies have suggested that large savings may be achieved in terms of operational cost by modest investment in upgrading mechanical systems, hence such refurbishments will have rapid payback period. Main components of mechanical services include Air conditioning and Lighting both of which have been dealt separately.

3.7.1 Air Conditioning:

In cooler climates main component of air conditioning is heating hence, efficiency of boilers is one of the main factor which determines energy efficiency of the mechanical systems. Boiler efficiency is the ratio of useful heat output of to the boiler to calorific value of fuel input. Older boilers use heavyweight heat exchangers with efficiency as low as 45 percent. In comparison modern boilers which use improved heat exchangers and better controls may achieve seasonal efficiencies as high as 85 percent (Baker ,2009). Efficiency of the heating system may also be improved by upgrading heat distribution, sizing and positioning of heat emitters. Fans and pumps used in circulation warm air or water consumes considerable amount of energy and often can be as large as or larger than heating energy. Refurbishment provides an opportunity to replace the pumps/fans to more efficient equipments or to incorporate more efficient strategies such as variable speed drives which regulates flow by varying speed.

In warmer climates main air-conditioning requirement is cooling. The conventional strategy for mechanical cooling is to use mechanical central chillers which produce chilled water. This chilled water is circulated around the building to various emitters such as fan coil units, cooled floor or ceiling which transfer the coolth to the air around. Efficiencies of such installations mainly depend on the type of compressors used and efficiency of the coolant circulation system. Mechanical chillers may use either wet cooling towers, dry cooling towers or by use of ground cooling to extract heat from the building. Wet cooling towers are known to have high efficiencies however are associated with Legionnaire's disease when not maintained well. Fan driven dry cooling tower's are safer from health perspective due to removal of moist however they are not as efficient as wet cooling towers. Use of absorption chillers can be very efficient when high grade heat is available. Absorption chillers use heat rather than electricity in the process of cooling water or refrigerant. Often absorption chillers are used along with combined heat & power systems (CHP) where the additional heat generated in the power generation process may be used by chillers.

3.7.2 Artificial Lighting:

Artificial lighting contributes significantly to over all energy consumption of the building particularly in the case of non-domestic buildings such as offices and commercial buildings. A number of earlier researches have suggested that a careful balance of natural and artificial lighting will result in a optimum and most energy efficient lighting. The overall lighting energy consumption also depends on the efficiency of the artificial lighting system itself. Efficiency of the light fixtures and illuminance level and distribution are the two potential areas to achieve higher energy efficiency especially in refurbishments. Luminous efficacy of a light fixture is defined as the ratio of luminous energy measured in lumens to the power consumed. Luminous efficacy of fluorescent tubes(T5, T8) and LED lights are much higher as compared to conventional lights such as tungsten pendent lights, halogen lights (Guertler & Smith 2006).. Hence one of the effective strategies in energy efficient retrofits is to replace low efficacy lighting by high efficacy lighting that may save considerable energy. Rationalizations of illuminance levels and distribution is another area that may result in significant savings. As per conventional lighting design norms large areas such as open offices are provided with medium to high level of uniform illuminance. However in actual, higher illuminance may be required in specific areas within the space such as desks or work stations in an open office while a medium level of illuminance may be sufficient in rest of the office area. An effective solution in this case may be to reduce the ambient illumination to entire space while to use task lights on desks or work stations.

3.8 Inferences:

Various refurbishment strategies discussed in this chapter can be further classified as passive and active refurbishment strategies. Refurbishment techniques which improve the energy efficiency without use of active energy can be defined as passive refurbishment strategy. External wall, floor & roof insulation, glazing replacement, shading devices, atria and double skin can be classified as passive techniques while improving efficiencies of air conditioning and artificial lighting can be classified as active techniques. Among passive techniques floor, roof & wall insulation, glazing replacement & shading devices is suited for both cold and warm climates while atria and double skin are more suited for regions with cold climate. Techniques such as external insulation to walls and roofs not only improve the energy efficiency of the building, but also increases life of the external envelope. Due to extreme climatic conditions, external envelope of building in UAE , deteriorates relatively faster hence application of external insulation layer to either walls or roof will improve the life of external envelope. Therefore external insulation application is one of the most suited refurbishment techniques that may be used to improve energy efficiency of the existing buildings in this region. Refurbishment techniques in relation to external windows ie glazing replacement and application of shading devices are effective in hot climate as suitably selected glazing and shading devices can considerably reduce solar heat gain. Upgrading Air conditioning and use efficient lighting can save considerable energy. However these active refurbishments will require a conditional survey of the existing mechanical equipments and rigorous analysis before refurbishment strategies can be suggested. Hence the current study will focus only on suitable passive refurbishment strategies.

Chapter 4: Research Methodology:

The current study is aimed at assessing energy efficient refurbishment potential of existing building stock in Emirate of Dubai and to develop appropriate refurbishment techniques. The scope of study is limited to office buildings only, considering large number of office buildings have been built in UAE during the past few decades. As per Dubai Statistical Year Book (2008) , as of year 2008 office and commercial buildings form 10.56% of the total existing buildings. This is considerable part of the existing built stock; hence it was decided focus on this sector. Next phase of the study was selecting the appropriate research methodology. Upon study of various research methodologies a combination of case study method and simulation & modeling method was found to be most suited for the current research.

4.1 Case Study Method:

As per definition of Yin (1994) a case study is an empirical inquiry that investigates a contemporary phenomenon or setting within its real –life context, especially when the boundaries between phenomenon and the context are not clearly evident. Case study involves studying a case in relation to the complex dynamics with which it intersects. General characteristics of case study as defined by Groat & Wang (2002) are:

1. A focus on either single or multiple cases studied in their real life contexts.
2. The capacity to explain casual links.
3. The importance of theory development in research design phase.
4. A reliance on multiple sources of evidence with data needing to converge in a triangulating fashion.
5. Power to generalize the theory.

Yin further explains the uniqueness of case study research method stating that case study's strength is its capacity to generalize to theory much the same way as "single experiment " can be generalized to a theory, which intern can be tested through other experiments. Case study method can be based on quantitative data or it may have a theory driven focus.

4.1.1 Typology of Case Study:

Case study could be of different type based on purpose of research. Purpose of the case study method could be to develop or to test a theory. Typology of the case study ie whether it is explanatory, descriptive or exploratory or combination of these will depend on purpose of research or the research question. Case studies can accumulate the data or evidences from a variety of sources such as archives, oral history, interviews, and surveys, formal and spatial analyses. According Yin (1994) typology of case study methods can be

1. Linear – Analytic case study: A typical article format beginning with problem statement, literature review, analysis and results.
2. Chronological – A study based on narrative sequence.
3. Theory building- A study in which sequence of chapters depends on logic of theory development.
4. Un-sequenced – A case study in which sequence is not important, hence chapters could be interchanged.

4.1.2 Single or Multiple case design:

Choice between single and multiple case design will depend on nature of theoretical question or research question involved and the role of replication in testing and confirming the study outcomes. A single case study is generally used to investigate a phenomenon involving multiple and highly complex factors. In case of a theoretical question with narrower scope in which factors of importance may vary from one case to another multiple case design might be appropriate. In multiple case studies every case shall serve a specific purpose within overall scope of inquiry. Multiple cases are similar to multiple experiments which follows “replication” logic. Yin also explains that “replication logic” as applied to case study can be literal or theoretical replication. A literal replication is a case study that tests precisely the same outcomes, principles or predictions established by initial case study, while a theoretical replication is a case study that produces contrasting results but for predictable reasons. Strengths and weakness of case study method as explained by Groat & Wang (2002) as per following:

Strengths	**Weakness**
1. Focus on the embeddedness of the case in its context.	Potential for over complication.
2. Capacity to explain casual links.	Causality likely to be multi-faceted & complex.
3. Richness of multiple data sources.	Challenge of integrating many data sources in coherent way.
	Replication required in other cases.
4. Ability to generalize to theory.	Difficult to do well , fewer established rules and procedures than other designs.
5. Compelling & convincing when done well.	

In the current research aim of the research is to determine the refurbishment potential of existing buildings, hence it is prudent to employ a case study approach, where an existing building can be chosen as base case. Considering base case will be studied in its real life context the results generated may be generalized. Following selection of base case, application of refurbishment techniques may be tested by use of experimental methods or by simulation methods. In experimental methods the researcher varies the value of the independent variable and determines the effect of the same on dependent variable. Experimental method as applicable to current research will involve erection of suitable refurbishment technique which can be considered as independent variable, followed by evaluation of net energy savings which can be considered as dependent variable. Experimental method can be resource and time intensive process, hence simulation and modeling methods were preferred.

4.2 Simulation and Modeling Research:

Simulation research is an approach where in real-world phenomenon's are studied by use of replication. According to Grout & Wang (2002) Simulation research is a study which involves controlled replications of real world contexts or events for the purposes of studying dynamic interactions within that setting. Data collected from a simulation research based on dynamic interactions of replications can be used in the real-world context. Simulation research can yield information about dangerous conditions without placing researcher or subject in harm's way. This research approach is particularly useful when dealing with questions of scale and complexity. The current advancements in computer based simulations can simulate tiny forces between atoms of a molecule to a gigantic urban scale where in transportation networks can be simulated. Simulation research is also used in testing of materials where in building materials and components undergo tests replicating real world stresses. As per Carno and Brewer (1973 – cited by Wang 2002) simulation research is useful both in developing theory as well as testing theory. They have suggested that simulation research can be used to test a hypothesis or a logical explanatory system by simulating or enacting conceptual system in an empirical venue. Clipson (1993) has classified simulation models as iconic, analog , operational and mathematical. In the first two of the models which is iconic and analog deals with physical systems such as testing of materials or product while operational models are based on users interaction within physical context. Mathematical models are slightly complex simulations where systems of numerical coding represent real-world relationships in quantifiable abstract values.

4.2.1 Strengths and weakness of Simulation and modeling approach:

One of the main strengths of simulation research is to capture complexity of real world behavior without having to limit the number of variables as in the case experimental research. Simulation techniques can also be used for predicting future behavior of subjects. Among the weaknesses of the approach main item is vagueness in defining completeness of the replication. This weakness is more pronounced in operational simulation methods where in bringing the aspect of spontaneity similar to real-life situations is quite difficult. Another main drawback of the approach is the cost and time required to produce complex simulations. Cost may be so high that it may be impossible.

4.3 Selection of Simulation Tool :

Literature reviews carried out in the initial stage suggested that various simulation tools were used with different degree of success in similar studies. A similar research carried out by Jinlong *et al* (2008) to study energy saving renovations of existing residential buildings in the city of Hangzhou used the simulation tool DOE-2. However in the above research upon validation of the tool by comparing simulated building electrical load with actual electrical consumption data a huge discrepancy was noticed. This study stresses the importance of validation of simulation tool. Ragom (2002) used DOE-2.1 as simulation tool for developing suitable refurbishment strategies for existing housing in Kuwait. However the simulation tool is not validated in the above study.

Another study carried out by Radhi (2009) on impact of wall systems and cladding materials on the CO2 emissions used BEES as simulation tool. Another study carried out the same author (Radhi, 2009) to determine potential impact of global warming on UAE residential buildings used Visual DOE program as simulation tool. Visual DOE programme is a sophisticated simulation tool which has been developed to provide energy performance assessment as close as possible to the real performance of the building throughout its life cycle. To verify credibility of Simulation tool and base-case modeling, simulated energy consumption were compared with actual monthly utility bills. Marginal differences in the range of 3.7% to 4.0% were noticed in actual and simulated energy consumptions which establish credibility of simulation tool.A recent study on impact of external louvers on energy consumption of the building in UAE by Hammad & Abu-Hijleh (2010) has used IES as simulation tool successfully.

Based on author's familiarity with simulation tools , and availability of the tools ECOTECT and IES were considered. A detail study and both tools were conducted in the initial stage of simulation. Criteria which were used to evaluate suitability of the simulation tool included Usability, Intelligence, Interoperability, Process Adaptability and Accuracy (Attia , 2011) .

Comparison of the tools has been included in Table 11a.

IES tool has clear edge over ECOTECT mainly due to the accuracy in results. Hence it was decided to adopt IES for the simulation.

Simulation Tool Matrix		
Criteria	**IES-VE-6.2**	**ECOTECT**
General	IES-VE is a plug in for Sketch up, allows modeling of whole building , annual energy and carbon usage.	ECOTECT primarily can be used to develop concept design, however it includes various simulation functions. Main strength of the tool is visual impact , while lack of accuracy is the main weakness.
Usability	**High** - Usage is simple with a restrained set of options, facilitating data input and navigation. The tool incorporates inbuilt quality assurance features and process of feeding the data is quick and easy. However the output information is not suitable for decision making as output lacks visual presentation and includes mainly tabular information.	**High** - Very user friendly with adaptable interfaces. The out put is very visual hence aids decision making process.
Intelligence	**Medium**- Tool allows alternatives comparison. Various inputs for AC, solar gain, Shading, Ventilation, Materials, Room internal thermal conditions etc. can be fed into the model. However some of the embedded hidden default values cannot be altered.	**Medium**-Tool can display and animate parameters such as shadows, reflections, solar radiation , hourly/monthly cooling& heating loads etc. However the tool does not allow alternative comparison and confirmation of code compliance.
Interoperability	**Medium**-The modeling can be developed in IES or can be imported from sketch up, Revit, AUTO CAD 3D.	**Medium** - The modeling can be developed in ECOTECT or can be imported from sketch up, 3D Studio, AUTO CAD 3D.
Process Adaptability	**Medium**-The tool can be adopted in different stages of design process. Tool Can be used in design development as well as in evaluating design performance.	**Medium** - The tool is suitable for Concept/Initial design development only.
Accuracy	**High**-IES APACHE Thermal Analysis is a core thermal design and energy simulation component, which has been tested with ASHRAE Standard 140.	**Low**- lacks energy analysis option. Tool's thermal simulation results, does not fully reflect reality which is one of the main draw-backs of the tool.

Table 11a : Simulation Tool Matrix (Attia , 2011)

4.4 Research Methodology:

As stated in section 2.8 main aim of the research was to determine, if refurbishment can be used effectively to improve energy efficiency of existing buildings in UAE. Further aims were to determine effective refurbishment strategies that can be applied to existing buildings, along with economic analysis to determine payback period for each of the strategy. To ensure that solutions generated have practical application, a case study approach was preferred where various refurbishment strategies will be tested on an existing building. As stated in section 3.8 only passive refurbishment strategies will be tested on selected base building and resulting energy consumption will be determined by use of simulation. Again as stated in section 3.8 passive strategies chosen were:

1. External wall insulation
2. Roof insulation
3. Glazing replacement
4. Incorporation of shading devices

In order to determine effect each of the selected strategies on the base building model shall be simulated by applying the strategy and net energy consumption shall be determined. Difference in estimated energy consumption between base case and simulation upon application of refurbishment technique will determine effective energy saving achieved. Next step would be to determine the payback period for each refurbishment strategy. Simple payback period of each strategy is calculated by:

Simple Payback Period = Total cost of refurbishment/Annual cost saving (3)

Net annual energy saving upon application of refurbishment strategy multiplied by unit energy cost will determine net annual cost saving. While total cost of refurbishment for each strategy shall be determined on the basis of market surveys.

Various steps in the research can be summarised as per following:

1. Stage A-Sample Selection:

.i Reconnaissance Survey to indentify buildings suitable for the study.

.ii Comparison of the buildings identified in reconnaissance survey and selection of base building for the study.

2. Stage B – Data Collection

.i Field monitoring or observational survey of the base building, Data collection of the base building via as built drawings.

3. Stage C – Development of Refurbishment strategies & Economic Analysis

.i Development of suitable refurbishment technique using Simulation tools.

.ii Economic analysis of refurbishment strategy developed.

.iii Discussion of results and Conclusions

Chapter 5: Refurbishment Strategies & Simulation:

5.1 Stage A- Sample Selection

5.1.1 Reconnaissance Survey: Aim of the reconnaissance survey is to shortlist potential buildings for the study. The broad criteria for selection of the building were age of the building, size of the building, availability of as built drawings and performance data. Considering energy codes were introduced in Emirate of Dubai in the year 2003, the offices built prior to this date are less likely to have efficient envelope and efficient MEP systems. Hence office buildings built prior to year 2003 were targeted. Access to the building for field inspection, availability of as built information were also other criteria considered while selection of the buildings for the study. Another criteria was to choose buildings fully owned and occupied by a single owner. This will ensure that utility data can be easily accessed as such buildings are provided with single utility meter. On the basis of reconnaissance survey three office buildings were considered to be suitable for the study.

1. HSBC branch Office in Burdubai
2. HSBC branch Offices in Jebel Ali
3. HSBC Corporate Offices in Dubai Internet City

5.1.2 Selection of base building: On the basis of initial field survey brief comparison of the selected sample buildings conducted. Upon initial screening HSBC – Burdubai branch was chosen as the representative sample as the building was older than the rest and was due for a general refurbishment. The building presented an opportunity for integrating energy efficient refurbishment with general refurbishment cycle. Table 12 presents summary of comparison.

Table 12 : Comparison of Selected building

Item	Building	Year of completion	Usage	No. of Floors	Information available
1.	HSBC-Burdubai	1995	Retail / Offices	B+G+5	As built drawings , 4 year utility bill data available
2.	HSBC- Jebel Ali	2003	Retail/offices	G+4	As built drawings , 4 year utility bill data available
3.	HSBC- DIC	2002	Corporate Office	G+2	As built information were not available.

5.2 Stage B - Data Collection :

5.2.1 Location: HSBC Burdubai branch is located in historical quarter of Dubai, facing the Dubai Creek. The building is located in densely populated commercial area with 4-5 story commercial/retail buildings around. The building is approached through Al-suq road on south side of the building. The north façade of the building faces the Dubai creek. Eastern and western façades of the building are well protected by closely located buildings, while northern and southern facades are fully exposed to solar radiation. However proximity of the creek alters micro climate to some extent with northern façade receiving constant breeze throughout the day.

Figure .10 – Location Map of HSBC Burdubai Branch (Google Map, 2011)

5.2.2 General Description of the Building:

The building has been provided with a basement –part of which is used for parking while rest for mechanical plant rooms etc. A dedicated transformer for the building is located at basement floor. Ground and Mezzanine floor of the building are being used for retail banking. First to forth floors are being used as offices, while the penthouse at fifth floor level consists of guest rooms and conference facilities. At the time of the visit it was noticed that Third and Fourth floors were partly used and remaining area's in these two floors were reserved for expansion. Mechanical rooms are located above the penthouse with dedicated room for electrical panels. Southern and Northern side of the façade have large glazed windows providing reasonable amount of natural daylight to interiors while there are limited number of glazed openings provided on eastern and western facades. Two number vertical transportation cores with lifts and staircase located on eastern and western side connects various floors.

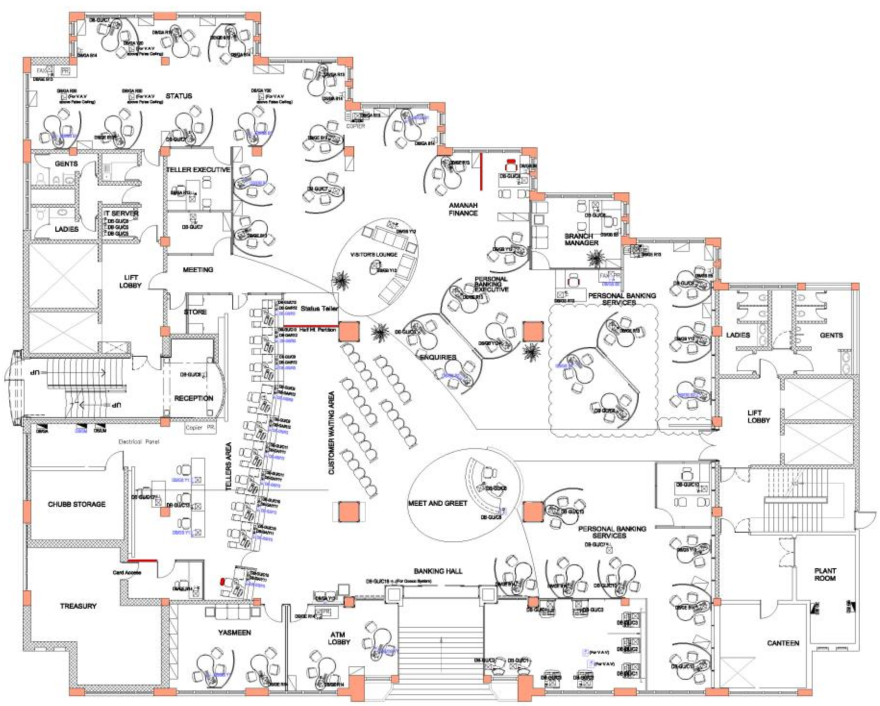


Figure .11 – Ground Floor Plan HSBC Burdubai Branch (HSBC As Built Drawings , 2011)

Figure 12 – South Elevation facing Al-suq Road.(Personal photograph , 2011)

Figure 13 – West & East Elevations (Personal photograph,2011)

Figure 15 – North Elevation(Personal photograph , 2011)

5.2.3 Structural System:

A conventional RCC framed building with columns at 4.8m x 4.8m structural grid. The external walls are built of block works finished with render. The floors are made of hollow core concrete slabs. Two number vertical transportation cores made of RC shear walls are located on East and West side offers stability to the structure.

5.2.4 Building Services:

A dedicated 1600 kVA transformer located in the basement floor provides sufficient power for the entire building. Part of the basement floor is reserved for fire water tanks and garbage room while remaining is reserved for parking. The offices have been provided with floor boxes at regular grids which provide power supply and data connectivity to computers and other equipments. Table 13 which represents "Consolidated Load Schedule" which is prepared on the basis of load schedules for each of the floor obtained from as-built drawings. Main intention of producing consolidated load schedule was to determine average lighting load and average equipment load which are essential inputs for simulation. Upon review of the load schedule it has been noted that small power for equipments and computers form considerable part of the overall load. Average equipment load is estimated to be around 39.08 kw/m2. The Ground and First Floor areas have specialized lighting as they are customer facing areas, while second, third, fourth and fifth floors have 600 x 600 recessed modular florescent lights. Average lighting load has been estimated to be approx 28.08 kw/m2. HVAC system consists of two no. air cooled chillers located on roof supplying chilled water with 2 no. AHU's located in each floor. Supply air is provided to each of the offices via diffusers connected to air handling units via ducts.

Table 13 - Consolidated load schedule

Levels	Lighting Load (in kW)	Equipment load (in kW)	AHU/VAV (in kW)	Water Heater (in kW)	Chiller (in kW)	Lift (in kW)	Pump (in kW)	Chilled Water Pump (in kW)	Condensing Unit (in kW)	Total (kW)	Area of Floor(carpet area) (in sqm)	Lighting Load per unit Area (kW/m2)	Load per Unit Area(75%) (kW/m2)	Peak Occupancy (occupants)	Occupancy rate (m2/person)
Basement	11.5	10	8							29.5	1032	11.14	7.27	5	206.4
Ground	56.35	35	8	3						102.35	1032	54.60	25.44	140	7.4
Mezzanine	36.75	47.5	8	3						95.25	1032	35.61	34.52	156	6.6
1 Floor	23	45.8	8	3						79.8	1032	22.29	33.28	120	8.6
2 Floor	23	45.8	8	3						79.8	1032	22.29	33.28	120	8.6
3 Floor	23	45.8	8	3						79.8	1032	22.29	33.28	50	20.6
4 Floor	23	45.8	8	3						79.8	1032	22.29	33.28	50	20.6
Pent House	23	31.5	8	3						65.5	688	33.43	34.34	50	13.8
Roof	2	2			627	82	5	55	110	883					
Total	221.6	309.2	64	21	627	82	5	55	110	1494.8	7912			691	
Average Lighting Load 28.08kw/m2			Average Equipment Load 39.08kw/m2							Average Occupancy rate - 11.45m2 (per occupant)					

5.3 Envelope characteristics of the Building:

External walls of the building are built of non-insulated concrete blocks with render and paint finish on both sides. Considerable part of the external envelope is formed by non-insulated RC columns, beams and shear walls which increases the overall U value of the envelope significantly. Over all area of the external walls is 3,721 sqm. Net U value of the external walls is estimated to be 2.38 W/m2K on the basis of as built drawings and material submittals. One third of the external envelope is made of glazed windows, with total area 1691 sqm. Existing glazing is made of double glazed panels with 6mm thick internal and external glazing with

12mm air-gap in between. U value of the existing glazing is 3.23 W/m2K on the basis of as built drawings. There are no shading devices provided for windows, hence large surfaces of glazing on southern and northern façade of the building are well exposed to direct solar radiation. Roofs are standard built-up roofs consisting layers of RC roof slab, light weight concrete layer, water proofing membrane, Insulation board layer, geo-textile membrane followed by concrete pavers on top. Net U value of roof construction is estimated to be 0.69 W/m2K. Basement floor consists of non-insulated concrete slab. Though the base building chosen for study has been built a decade before mandatory enforcement of envelope energy codes in emirate of Dubai, it is noted that its thermal performance of glazing and roof of the base building is quite close to current energy codes while that of external walls is too excessive. Table 14 summarizes base building description along with thermal characteristics of its envelope.

Table 14 : External Envelope – U Values (As built drawings , 2011)

Item	**Building Description**	
1.	No. of Floors	9 floors. Basement + Ground+ Mezzanine+ 4 floors + penthouse + plant rooms on roof.
2.	Floor Area	7,912 sqm.
3.	Volume	39,432 cubic meters
4.	Height	35.5 m from GL.
5.	External Wall Area	3721 sqm
6.	External Glazing Area	1691 sqm
7.	Roof Area	1287 sqm
8.	External wall – U value	2.38 W/m2K
9.	Glazing – U value	3.23 W/m2K
10.	Roof – U value	0.69 W/m2K

5.4 Development of Refurbishment Strategy:

In order to develop practical energy efficient refurbishments the current research uses simulation methods. One of the main strengths of simulation research is to capture complexity of real world behavior without having to limit the number of variables as in the case conventional experimental research. Simulation tools considered for the study were Ecotect and IES. Based on the thorough review of both tools and upon review of other similar researches, it was decided use IES as it is better suited for similar type of studies. The first process was to validate the tool, to ensure that simulation results are well in agreement with real world situation.

5.5 Validation Methodology:

In order to validate the simulation tool a model of the building was developed on the basis of as built information. Model was developed on IES with external fenestrations precisely matching the existing building. Appropriate materials were assigned to each of the building components matching the existing, so that buildings thermal behavior may be precisely simulated. Thermal conditions inclusive of room conditions, HVAC system, Internal gain and air-exchanges were simulated in line with actual. Upon completion of the model, it was simulated using Apache Sym to estimate electrical load and monthly energy consumption. These simulated monthly energy consumption were then compared with actual as measured energy monthly energy bills. Comparison of simulated monthly energy consumption values with as measured monthly energy bills suggests a good accuracy of the simulation. Figures 16, 17 and 18 indicate base building model developed in IES.

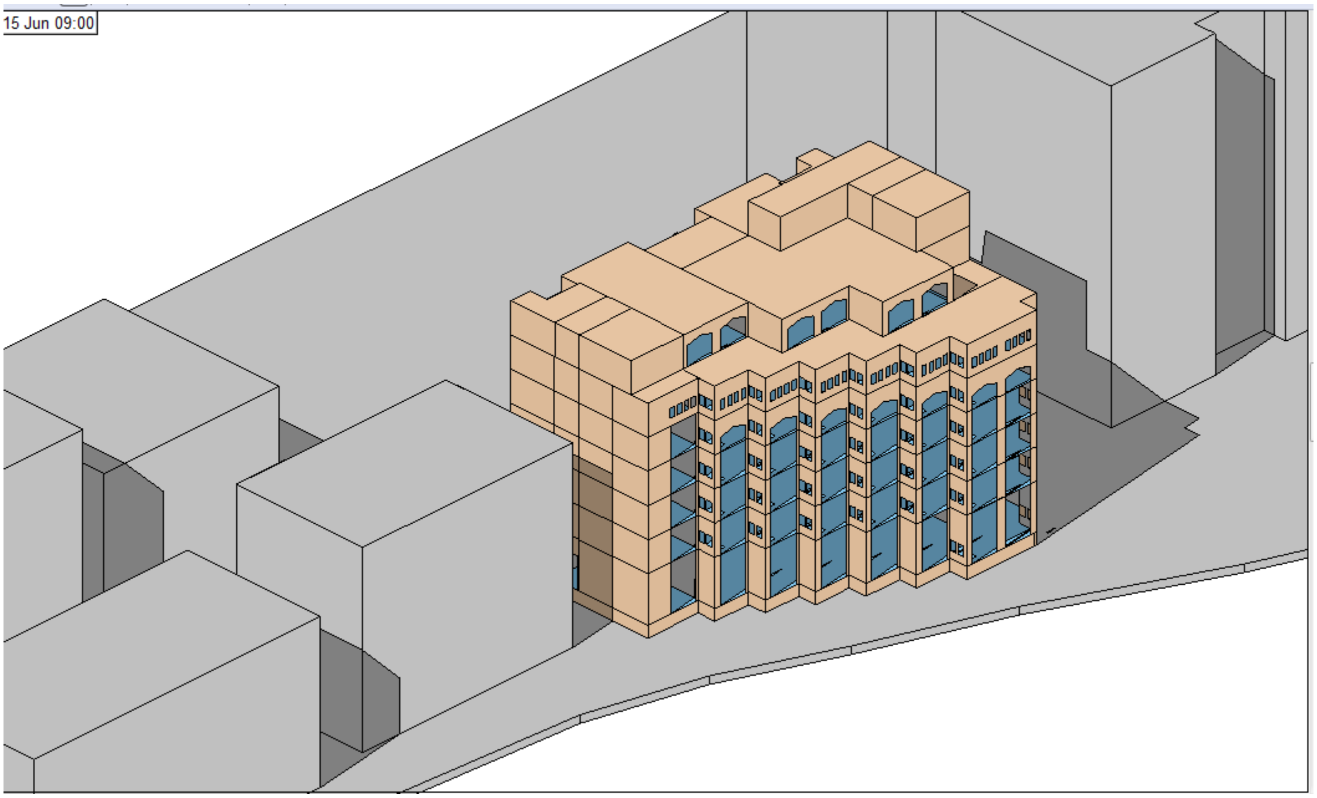


Figure 16: Base Building Model -Northern Façade (IES –VE 6.2)

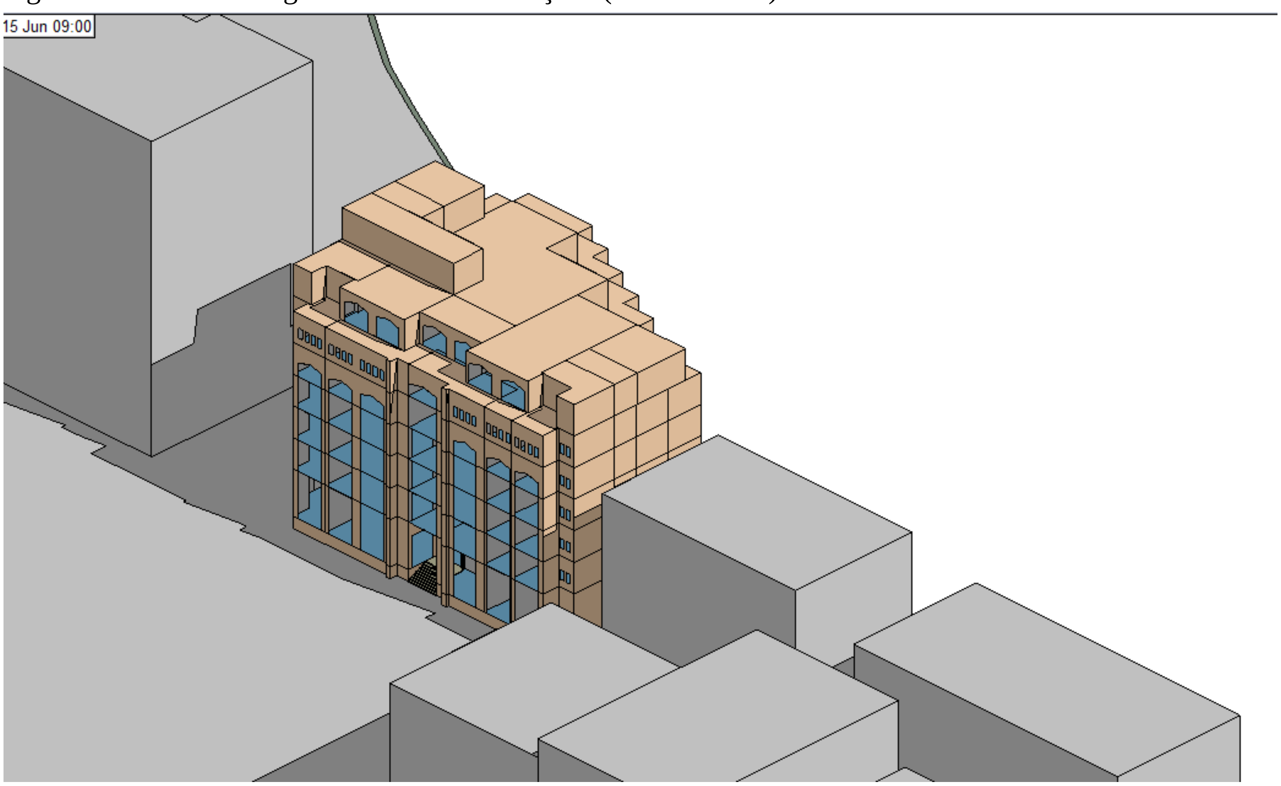


Figure 17: Base Building Model -Sothern Façade (IES –VE 6.2)

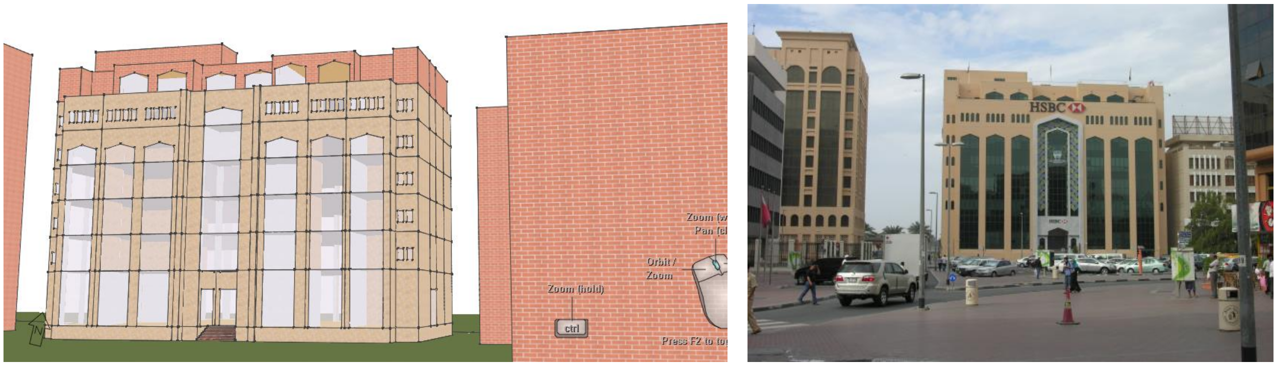


Figure 18 – Southern façade at ground level – IES model and the actual photograph for comparison (Personal Photograph 2011)

Figure A.1 and A.2 in Appendix A indicate daily and weekly usage profiles developed on the basis of actual operations. Figure A.3 to A.15 in Appendix A indicate construction templates for envelope and internal building components, Room conditions and Internal gains considered in the base model. Upon completion of the base model, it was simulated using plug in 'Apache Thermal Calculation' simulation tool. Out puts of the simulation includes heating –cooling, lighting and equipment loads, energy consumption and carbon emissions. Figure 19-22 indicate the simulation outputs.

Figure 19 indicates Chiller Loads. Diurnal peak Chiller load output reaches maximum during the month of August reaching unto 420 kWh. and minimum during month of February with peak minimum load of 130kWh. Figure 20 indicates the monthly chiller energy consumption. As expected month of August consumes maximum monthly energy – 186.67 MWh and least energy for chillers is consumed in the month of January -31.49 MWh. Total estimated annual chiller energy consumption is 1268.34 MWh. which forms 38.32% of total annual building energy consumption.

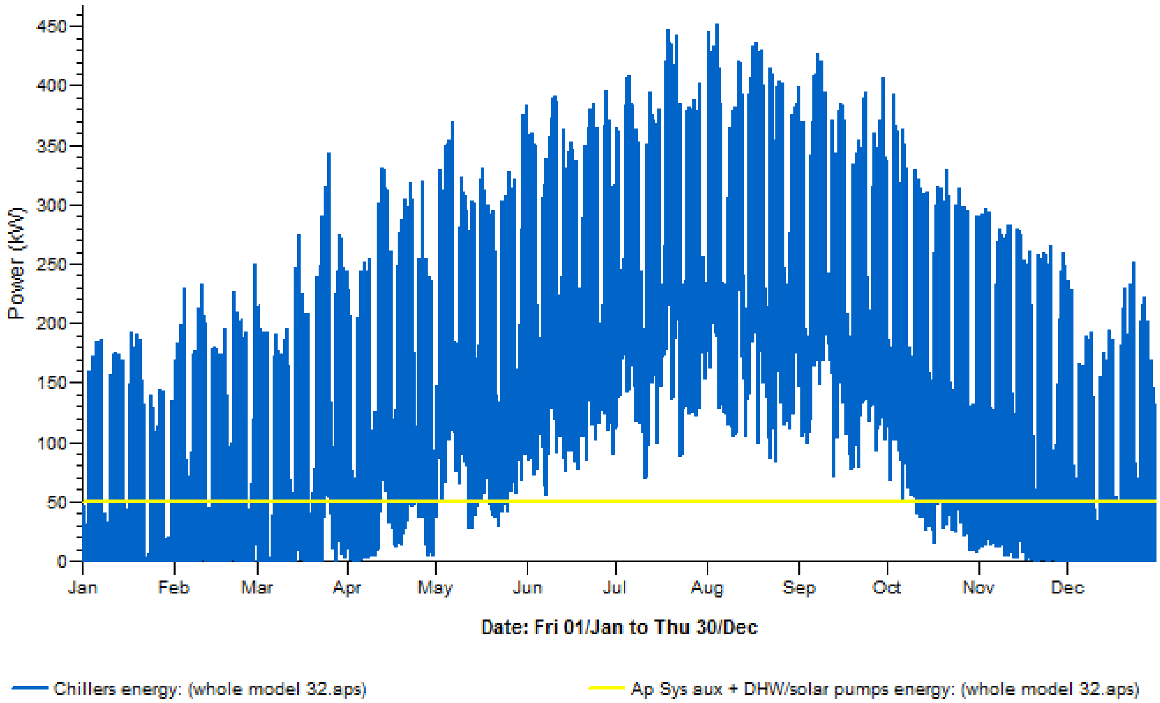


Figure 19 – Chiller Loads (IES-VE 6.2)

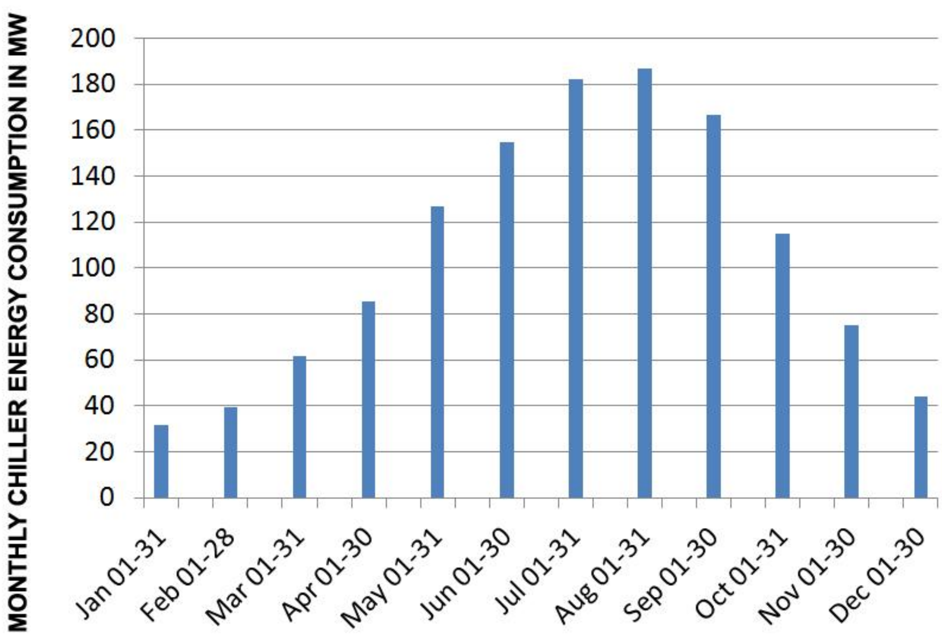


Figure 20 – Monthly chiller energy consumption (IES-VE 6.2)

Figure 21 and 22 represents total lighting loads and energy consumption .Total lighting load remains constant at 195 kWh throughout the year. Monthly energy consumption varies in a narrow range between 47 MWh to 54 MWh as illustrated in Figure 22. Lack of automated lighting control seems to the reason for constant lighting loads. The graphs suggest that irrespective of varying daylight levels artificial lighting remains constants. This presents an opportunity to incorporate daylight sensors in the retrofit which may result in optimization of artificial lighting.

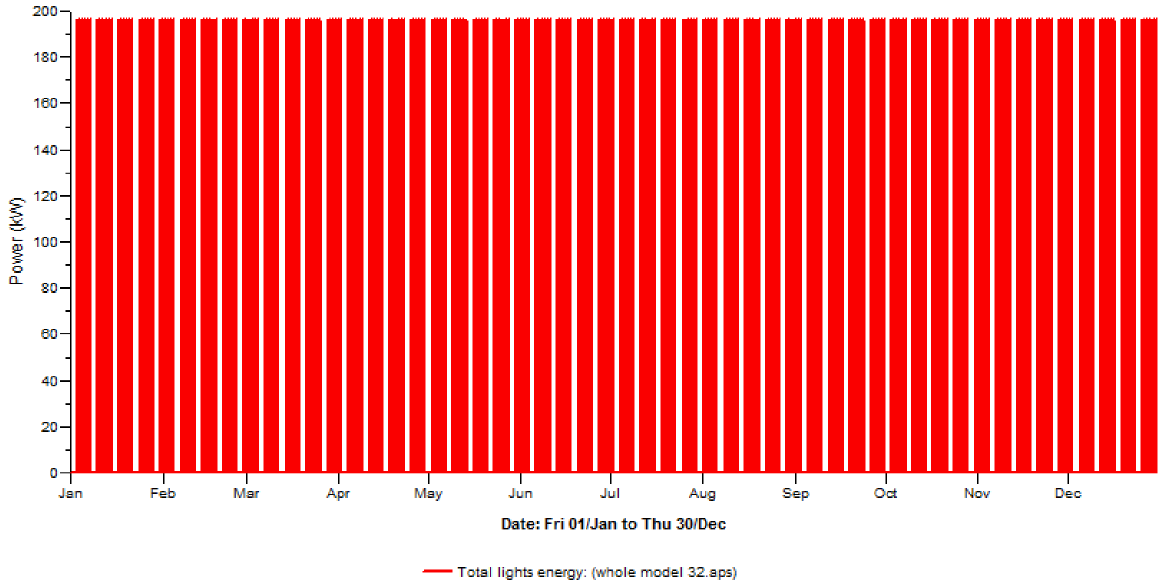


Figure 21 – Lighting Loads (IES-VE 6.2)

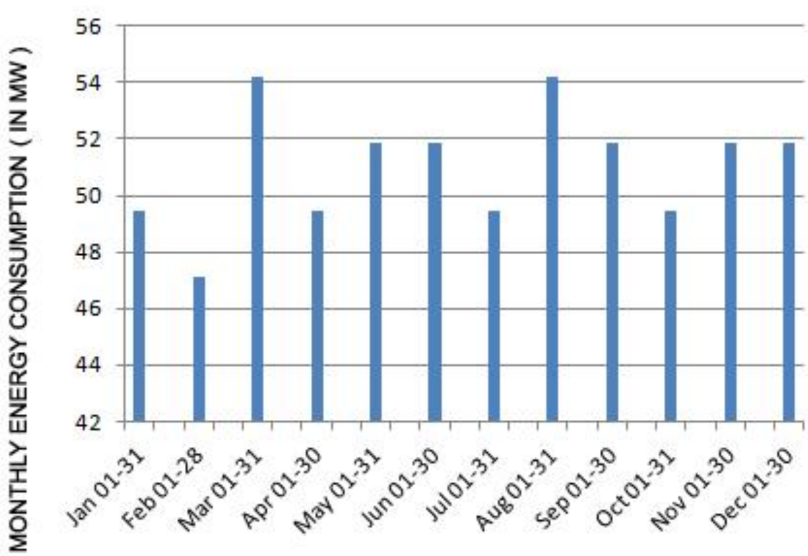


Figure 22 – Monthly lighting energy consumption (IES-VE 6.2)

Figure 23 and 24 represents equipment load and monthly equipment energy consumption. The equipment load appears to remain constant at around 195kWh throughout the year. However

Monthly equipment energy consumption varies in narrow range as per figure 24.

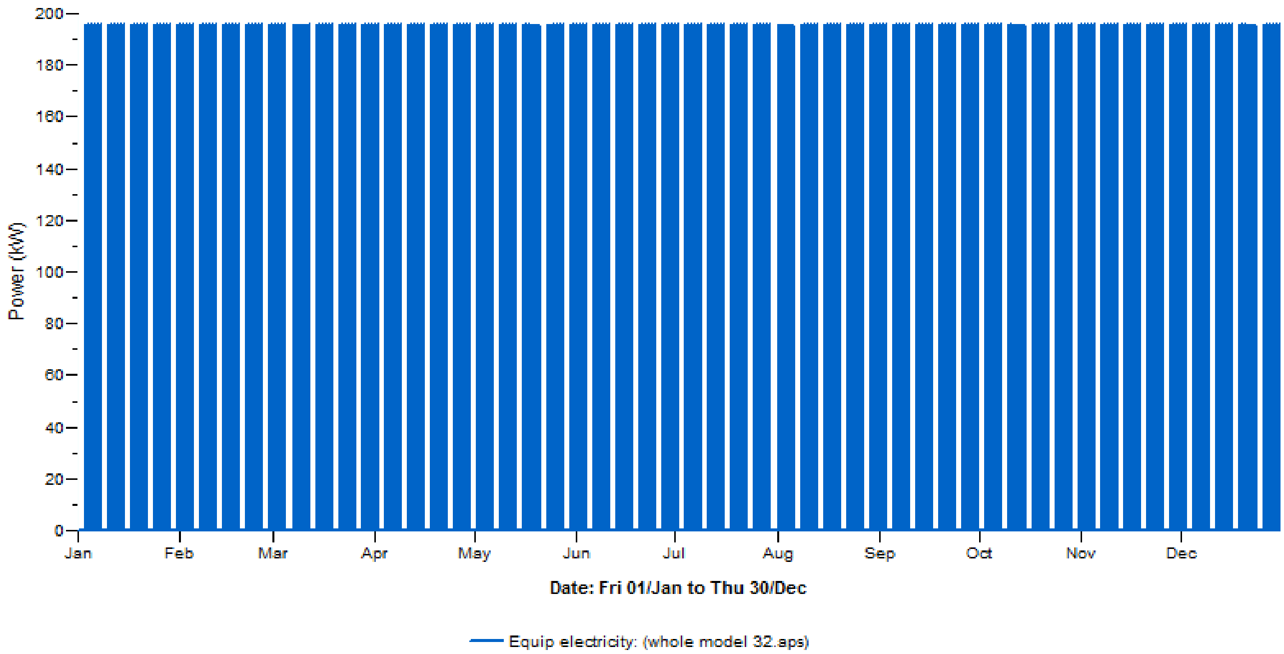


Figure 23 – Equipment Loads (IES-VE 6.2)

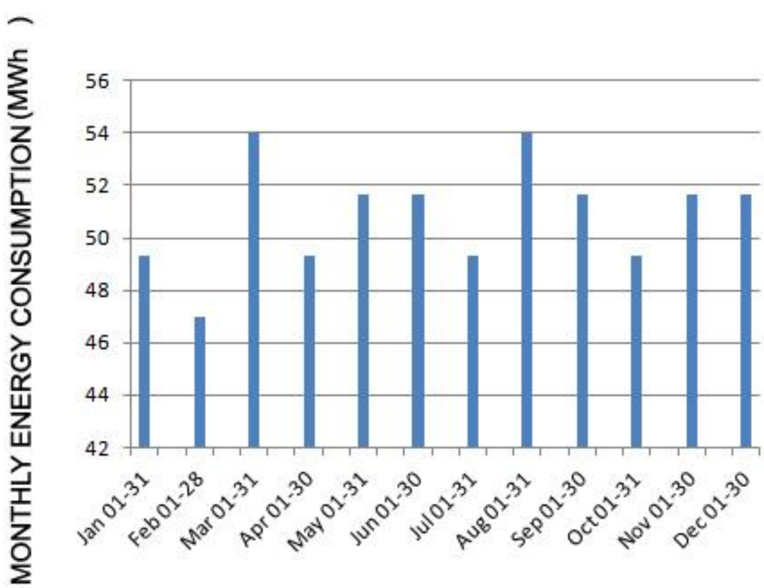


Figure 24 – Equipment Energy Consumption (IES-VE 6.2)

Figure 25 indicates combined electrical loading, while Table 15 indicates combined monthly energy consumption. Combined electrical loading peaks during the month of August, during which peak electrical load has been estimated to be 1012 kWh. Combined monthly energy consumption varies significantly across the year with maximum of 388.14 MWh consumption in August while minimum of 176.99 MWh is achieved in the month of January. From table 15 it can be noted that of the total annual energy consumption 38.32% is due to Chillers, 13.22% is due to Auxiliary systems and pumps , 18.50% is due to artificial lighting , 18.45% is due to equipment load while remaining 11.51% is due lift, water supply pumps and misc. items.

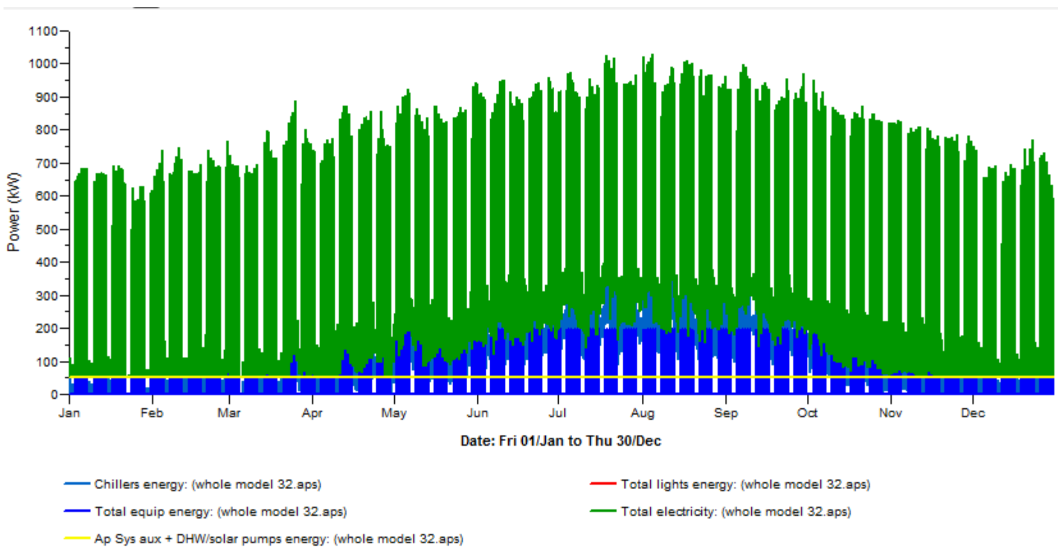


Figure 25: Combined energy consumption.(IES VE-6.2)

Table 15 : Combined energy consumption.(IES VE-6.2)

	Chillers energy (MWh)	Ap Sys aux + DHW/solar pumps energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Lights electricity (MWh)	Equip electricity (MWh)	Total energy (MWh)
	whole model 32.aps	whole model 32.aps	whole model 32.aps	whole model 32.aps	whole model 32.aps	whole model 32.aps
Date						
Jan 01-31	31.4968	37.2609	9.4490	49.4725	49.3211	176.9993
Feb 01-28	39.4319	33.6550	11.8296	47.1166	46.9725	179.0050
Mar 01-31	61.6461	37.2609	18.4938	54.1842	54.0184	225.6031
Apr 01-30	85.2296	36.0590	25.5689	49.4725	49.3211	245.6507
May 01-31	126.8863	37.2609	38.0659	51.8283	51.6698	305.7107
Jun 01-30	154.4293	36.0590	46.3288	51.8283	51.6698	340.3145
Jul 01-31	182.0572	37.2609	54.6171	49.4725	49.3211	372.7282
Aug 01-31	186.6765	37.2609	56.0029	54.1842	54.0184	388.1424
Sep 01-30	166.5074	36.0590	49.9522	51.8283	51.6698	356.0163
Oct 01-31	114.8640	37.2609	34.4592	49.4725	49.3211	285.3774
Nov 01-30	75.1610	36.0590	22.5483	51.8283	51.6698	237.2660
Dec 01-30	44.0227	36.0590	13.2068	51.8283	51.6698	196.7859
Summed total	1268.4088	437.5157	380.5226	612.5164	610.6425	3309.5996

In order to validate the simulation tool, simulated mothly totals were compared with mothly utility bills. Mothly utility bills for year 2007 to 2010 otained from client's building maintetence records were as per Table 16.

Table 16: Actual Monthly Electricity Consumption – units MWh (Utility bills)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
2007	297,730	268,488	275,065	302,470	320,131	411,714	409,075	423,336	418,495	381,376	367,278	329,885	4205043
2008	295,893	251,537	299,009	291,315	329,702	346,085	441,241	435,344	398,591	397,068	367,247	310,154	4163186
2009	310,874	241,276	247,995	309,017	308,387	325,988	390,420	404,670	363,878	447,006	334,127	339,740	4023378
2010	216,093	228,456	172,174	313,026	256,561	269,381	290,624	312,538	305,322	303,515	277,835	263,575	3209100

As per figure 26 it can be noted that annual consumption gradually reduced from year 2007 to 2009; however a significant reduction has been observed in the year 2010. The reason for reduction between 2009 -2007 seems to be gradual reduction in occupancy levels, as advised by the end user. While sharp reduction in energy readings in the year 2010 is due to replacement of existing chillers by high efficiency chiller. Hence year 2010 has been considered as base year for validating the simulation tool.

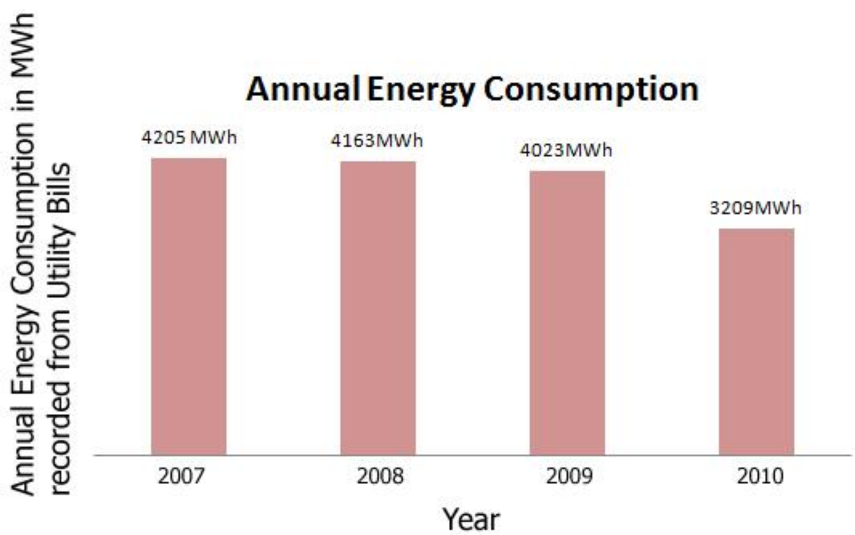


Figure 26: Annual Electricity Consumption (Utility bills)

Upon review of monthly consumption for the year 2010, it has been noted that energy consumption value for March seem to be significantly lower than monthly average value for

March in the previous years, while energy consumption for April-2010 is significantly higher than monthly average for April. This is possibly due to inconsistency in date of energy meter reading. The Table 17 below indicates corrected monthly totals for year 2010 with March and April monthly totals corrected on the basis of previous monthly averages for the same months.

Table 17 – Corrected Monthly energy consumption for year 2010

2010 (Corrected)	216,093	228,456	231,245	253,955	256,561	269,381	290,624	312,538	305,322	303,515	277,835	263,575	**3209100**

Figure 27 & 28 brings out comparison of simulated energy consumption with actual energy consumption. Figure 28 indicates that simulated monthly energy consumption varies in the range of + 22% to -33% with reference to actual monthly energy consumption. Generally it has been noticed that during summer months simulated monthly totals seem to be higher than actual measured values, while in the winter simulated monthly totals seem to be lower than the actual monthly consumption. The lower than anticipated monthly totals in summer can be explained due to reduced occupancy rates in summer as relatively large portion of occupants will be engaged in annual leaves during summer. Commonly noticed user behavior such as keeping the windows open during winter months while air-conditioning is switched on leading to increased cooling load, could be one of the reasons for higher than anticipated monthly energy consumption in winter months. However simulated annual energy consumption differs from the actual by only 3 %. The variation of simulated monthly totals with reference to actual energy consumption is within the acceptable range which confirms the validity of the simulation tool for developing appropriate refurbishment techniques.

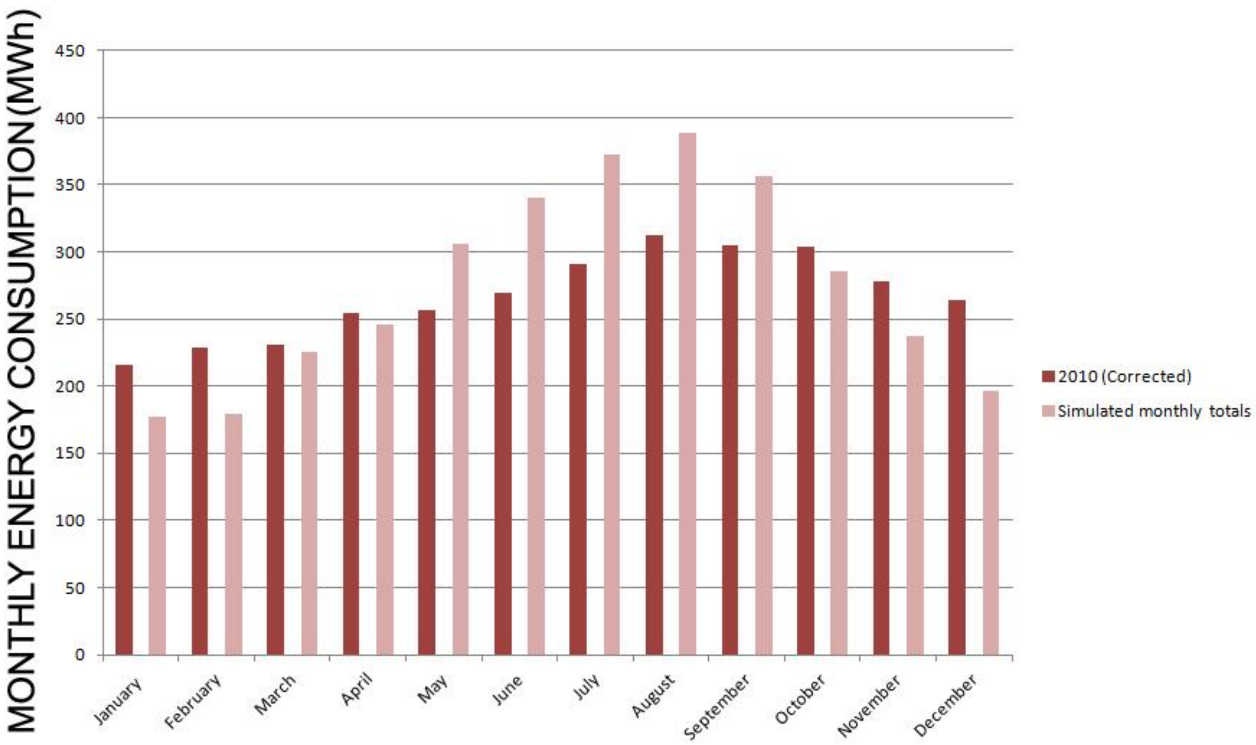


Figure 27 : Actual monthly energy consumption Vs Simulation

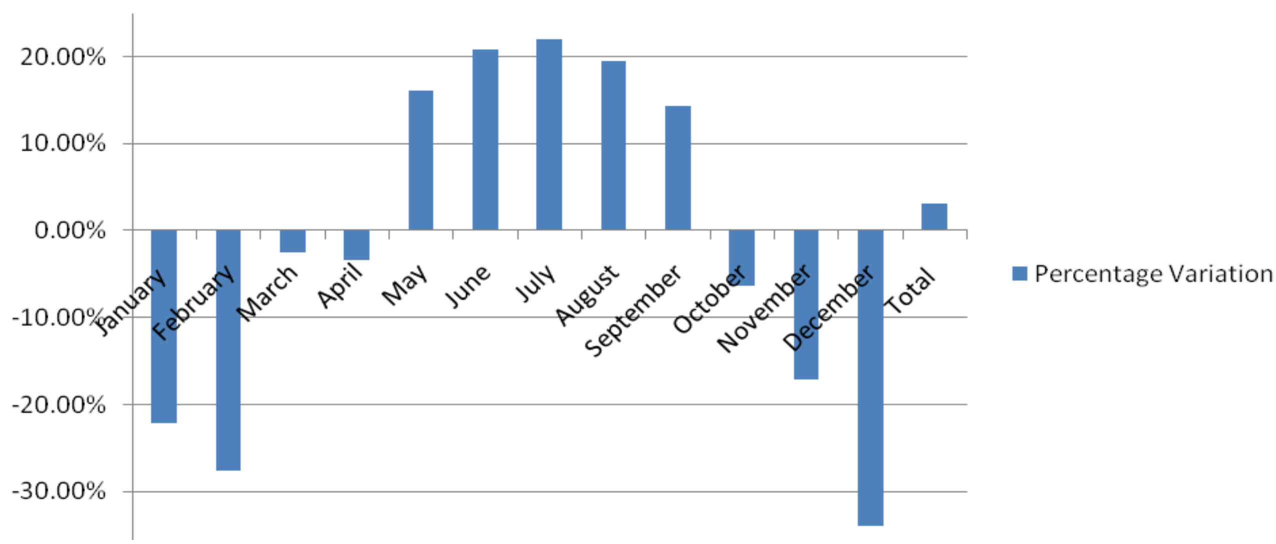


Figure 28: Variation of simulated monthly energy consumption compared to actual consumption.

In a similar research carried out by Ouyang et al (2008) in the city of Hangzhou – China the intent was to determine economic viability of energy saving renovation measures applied to an existing multistory residential apartment. The simulation tool used in the study was DOE-2. To validate the simulation tool heating and cooling loads of the base building were determined using simulation, and later simulation output were compared with actual energy consumption. Figure 28a indicates actual heating and cooling load Vs simulation output. Even though a drastic discrepancy is noticed between actual and simulated values, author explains the discrepancies by use of reasons such as life style aspects of occupants which aren't accounted in simulation, changing clothing pattern in accordance to seasons and other cultural aspects which are not fully considered in simulation.

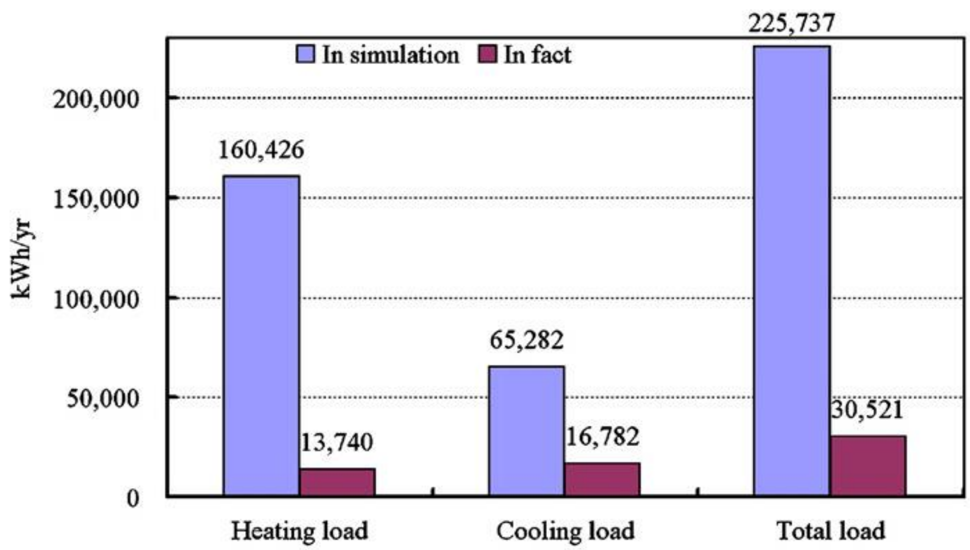


Figure 28a: Simulated Vs Actual energy consumption (Ouyang et al, 2008)

Another study carried out by Radhi (2010) explores use of façade integrated photovoltaic system cladding for commercial buildings in UAE. The author has adopted a case study approach, where PV panels were applied on a existing G+2 commercial building and resulting energy consumption was determined using simulation. Simulation tool used for the study was Energy-10. The simulation tool was validated by determining actual operational energy of the base building via simulation , and then comparing these values with actual energy bills. Figure 28b suggests brings out the comparison between actual and simulation energy consumptions. It can be noted that, despite of minor differences over-all pattern of simulated and actual energy consumptions seems to be good agreement.

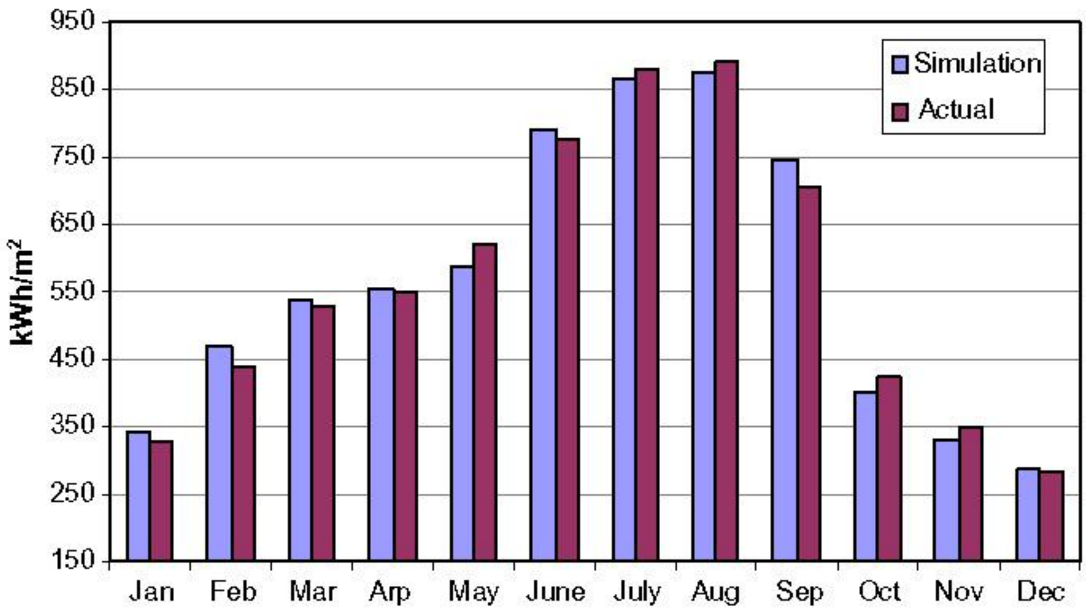


Figure 28b: Simulated Vs Actual energy consumption (Radhi ,2010)

Figure 28a and 28b illustrate two contrasting cases of simulation validation process. In the first case huge discrepancies have been noticed in simulated and actual energy consumption, while the second case simulated values are in good agreement with actual energy consumption. It shall be noted simulation tool and process can be validated as long as discrepancies in simulation are well explained.

Table 18 : Monthly carbon emissions (IES VE6.2)

	Total lights CE (kgCO2)	Total equip CE (kgCO2)	Total system CE (kgCO2)	Total elec. CE (kgCO2)
	whole model 32.aps	whole model 32.aps	whole model 32.aps	whole model 32.aps
Date				
Jan 01-31	25577	25499	40433	91509
Feb 01-28	24359	24285	43902	92546
Mar 01-31	28013	27928	60696	116637
Apr 01-30	25577	25499	75925	127001
May 01-31	26795	26713	104544	158053
Jun 01-30	26795	26713	122434	175943
Jul 01-31	25577	25499	141624	192701
Aug 01-31	28013	27928	144729	200670
Sep 01-30	26795	26713	130552	184060
Oct 01-31	25577	25499	96464	147540
Nov 01-30	26795	26713	69158	122667
Dec 01-30	26795	26713	48230	101738
Summed total	316670	315703	1078691	1711064

Table 18 indicates monthly CO2 emissions, measured in kg CO2 due to lighting, equipments, HVAC system and total electrical load.

5.6 Simulation and Application of Refurbishment Strategies:

As stated in section 3.8 only passive refurbishment strategies will be applied and resulting energy consumption will be determined by simulation. Passive strategies that will be applied are:

1. External wall insulation
2. Roof insulation
3. Glazing replacement
4. Incorporation of shading devices

5.6.1 Strategy 1 – Application of EIFS for external walls.

Considering existing external walls do not comply with current building regulations, it is one of the first area where refurbishment has been proposed. Application of External Insulation & Finish Systems can be an effective strategy to improve the thermal performance and longevity of the external envelope. Benefits of using EIFS include improved thermal performance, superior and durable external finish, control of condensation and improved acoustic performance. Considering EIFS is an externally applied insulation system, application may commence even when the building is being occupied.

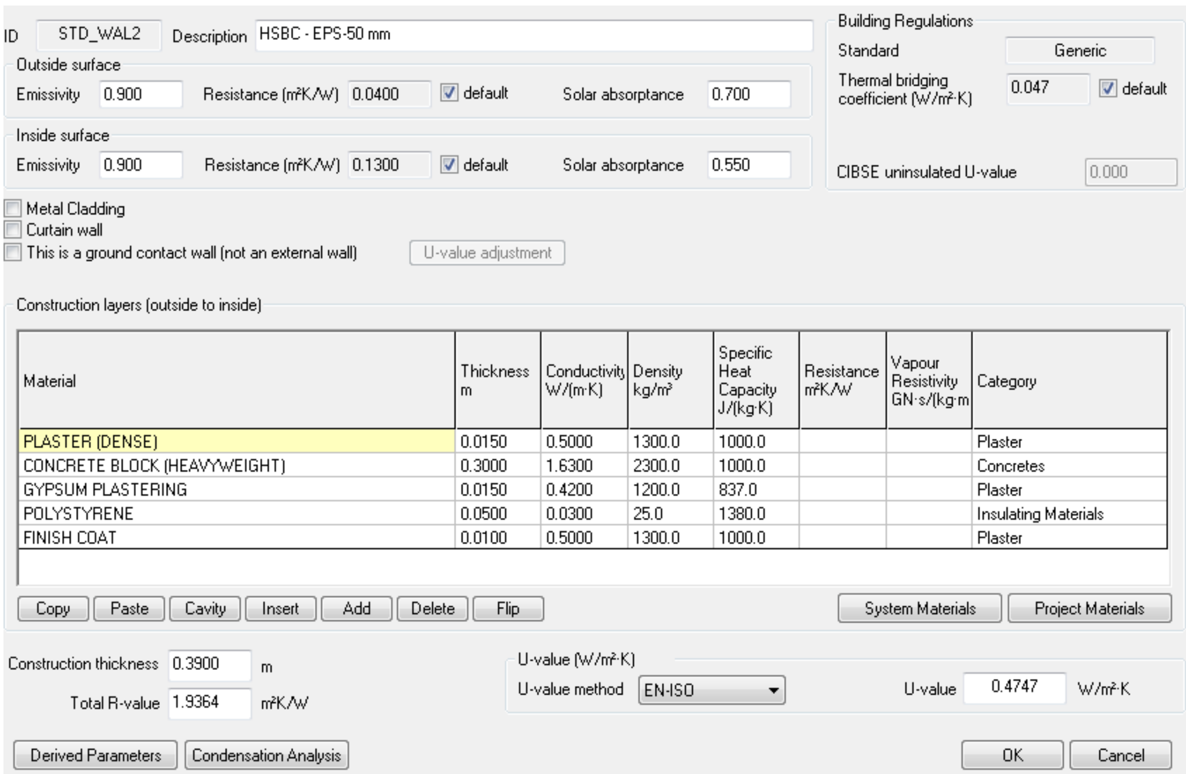
The EIFS systems consists of expanded polystyrene boards fixed onto existing wall by use of adhesive, and further fastened by mechanical fastener and finished with basecoat, fiberglass mesh and finishing coat. Thickness of polystyrene board may be varied to achieve required transmittance value. Polystyrene boards of thickness 50mm, 75 mm , 100 mm and 150 mm were applied to external walls and resultant effect were simulated. Table 15 indicates IES template for roof construction with 50 mm thick EIFS cladding. In this case wall will consist of 15 mm internal plaster, 300 mm concrete block, 15 mm thick external plaster, 50 mm thick polystyrene insulation board and 10 mm thick finish coat. Upon feeding these values to IES construction template , net U value for the wall assembly is generated. In the current case the net U value generated is 0.4747 W/m2K , which complies with current Dubai Municipality thermal regulations. Rest of the criteria for simulation including remaining construction, room conditions, systems, internal gains and air exchange templates are maintained as per the base case. Simulation is run using Apache –thermal calculation and simulation tool which generates a number of results of which monthly energy consumption has been presented in Table 20.

Results as per Table 20 suggests that monthly energy consumption for chillers has been reduced as compared to base model simulation while monthly energy consumption due to auxiliary system and pumps, lighting and equipments remain same as the base model. Nett energy saving is obtained by : Summed Total energy (base model) – Summed Total energy (50mm EIFS). Hence total savings achieved is 3309.59 MWh – 3158.63 MWh = 150.96 MWh.

Percentage of energy saving = Nett saving / Summed total energy (base model)

ie 150.96 / 3309.59 = 4.56 % .

Table 19 : Construction Template-50 mm thick EIFS Cladding (IES VE6.2)



Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
PLASTER (DENSE)	0.0150	0.5000	1300.0	1000.0			Plaster
CONCRETE BLOCK (HEAVYWEIGHT)	0.3000	1.6300	2300.0	1000.0			Concretes
GYPSUM PLASTERING	0.0150	0.4200	1200.0	837.0			Plaster
POLYSTYRENE	0.0500	0.0300	25.0	1380.0			Insulating Materials
FINISH COAT	0.0100	0.5000	1300.0	1000.0			Plaster

Table 20 : Monthly Energy savings with 50 mm thick EIFS Cladding (IES VE6.2)

	Chillers energy (MWh)	Ap Sys aux + DHW/solar pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
	whole model 34.aps	whole model 34.aps	whole model 34.aps	whole model 34.aps	whole model 34.aps
Date					
Jan 01-31	37.0422	37.2609	49.4725	49.3211	184.2086
Feb 01-28	43.0108	33.6550	47.1166	46.9725	183.6577
Mar 01-31	61.5277	37.2609	54.1842	54.0184	225.4489
Apr 01-30	77.5793	36.0590	49.4725	49.3211	235.7054
May 01-31	110.4954	37.2609	51.8283	51.6698	284.4026
Jun 01-30	133.9013	36.0590	51.8283	51.6698	313.6285
Jul 01-31	157.9960	37.2609	49.4725	49.3211	341.4491
Aug 01-31	161.8889	37.2609	54.1842	54.0184	355.9185
Sep 01-30	146.7399	36.0590	51.8283	51.6698	330.3188
Oct 01-31	102.6117	37.2609	49.4725	49.3211	269.4496
Nov 01-30	71.8134	36.0590	51.8283	51.6698	232.9141
Dec 01-30	47.6732	36.0590	51.8283	51.6698	201.5317
Summed total	1152.2797	437.5157	612.5164	610.6425	3158.6335

Figure B.1 to Figure B.7 under Appendix B indicates IES input templates with various EFIS cladding suggested above along with corresponding simulation outputs. Results of the simulation have been discussed under Chapter 6 .

5.6.2 Strategy 2 – Glazing

Existing glazed windows/openings may be replaced by high performance, low e coated double glazing. The thermal transmittance value of existing glazing is 3.2256 W/m2K. As per Dubai Municipality Administrative Resolution No.(66) – 2003 , the thermal transmittance external glazing shall be 3.28 W/m2K. Hence the glazing complies with current energy codes. However a number of high performance glazing are available, which can further improve the energy performance of the external envelope. The existing glazing has been replaced by more energy efficient glazing and resulting cooling loads have been simulated. In the last option existing glazing has been replaced by triple glazing complying to current UK standards and resulting cooling loads have been simulated.

Table 21: Glazing Types (Sun guard glass, 2011)

Type	Product	Ext. glazing	Int. Glazing	Transmission			Reflectance			U-Value (W/sqmC)		Solar Heat Gain Coefficient
				Visible Light %	UV %	Solar Energy %	Visible Light out %	Visible Light in %	Solar energy out%	Winter Night time	Summer Daytime	
Option 1 Sun Guard Super Neutral Clear	SNX 62/67	Clear	Clear	57	0	20	10	11	23	1.54	1.42	**0.27**
Option 2 Sun guard Super Neutral Dark Green	SN54	Green	Clear	37	0	13	9	16	6	1.54	1.48	**0.21**
Option 3 Sun Guard Super Neutral Gray	SN 54	Gray	Clear	25	0	10	6	16	8	1.54	1.48	**0.19**
Option 4 Triple Glazing	-	-	-	41	4	15	9	17	8	0.90	0.90	-

Template 21 to Template 28 under Appendix C indicates IES input templates with various glazing options suggested above along with corresponding simulation outputs. Results of the simulation have been discussed in Chapter 6.

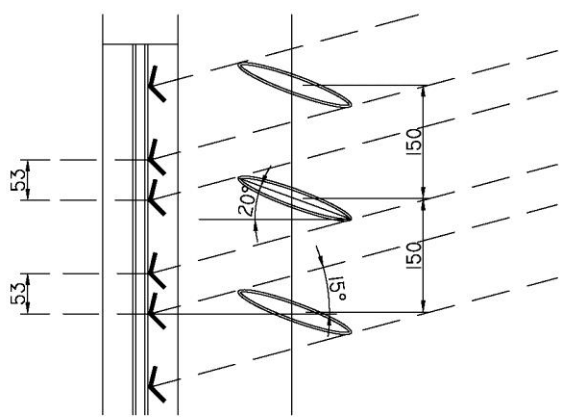
5.6.3 Strategy 3 – Roof retrofit:

Existing roof is built up of reinforced concrete slab with thermal insulation and water proofing above. Construction consists of 250 mm thick RC slab of, 150mm light weight foam concrete, 5 mm thick water proofing membrane, 50 mm insulation boards, 2 mm thick geo textile layer followed by 50 mm thick precast concrete slabs. The net heat transmission value of the roof is 0.6923. This value is 60% higher than the current energy codes in Dubai. Most effective and economical strategy to improve thermal performance of the roof is to replace the existing insulation boards with high quality insulation boards. Considering insulation boards are loosely laid below precast concrete slabs, insulation board replacement involves lifting up of precast concrete slabs and geo-textile layer and replacing the existing insulation boards by high performance insulation boards. Existing 50 mm thick insulation board has been replaced by 75 mm , 100 mm, 125 mm and 150 mm thick insulation boards and resulting energy consumptions have been simulated. In the last option 150mm thick cellular polyurethane boards are used and resulting yearly energy consumption has been simulated. Template 29 to Template 38 under Appendix D indicates IES input templates with various glazing options suggested above along with corresponding simulation outputs. Results of the simulation have been discussed in Chapter 6.

5.6.4 Strategy 4 – Shading Devices:

Large glazed windows present on South and North façade of the building have no shading devices hence contributes to considerable direct solar heat gain. Absence of any form of shading, presents an opportunity to explore possibilities of incorporating external type shading devices. Simple but effective form of external shading devices are metal louvers which may be fixed on the external side of the glazed windows. For optimum performance dynamic louvers shall be used which vary their tilt angle in response to incident solar radiation. However dynamic louvers are relatively expensive and they will require complex control systems to continuously alter the tilt angle of the louver, hence for simplicity of application fixed angle louver were chosen. Parameters which will determine the efficiency of the fixed angle louvers are size of louver, tilt angle, spacing between the louver and surface characteristics. In order to minimize the number of variables aluminum louvers of 160mm size which are readily available in local market were used at fixed tilt angle.

A recent study carried out by Hammad and Abu-Hijelh (2010) suggests that external louvers on south façade with a fixed angle of -20 deg. can save up to 31.36% total energy consumption. In line with outcome of this study it was decided to fix the tilt angle at -20 deg. The only variable then will be the louver spacing, by varying which transmission factor of the louver varies. The louvers spacing were set at 150mm, 200 mm and 250 mm and resulting transmission factor were determined which then were fed to IES template. Figure 29 illustrates transmission factor calculation for louver spacing 150mm and angle of radiation incidence 15 degree.



ANGLE OF INCIDENCE- 15 DEGREE
TRANSMISSION FACTOR=
AREA OF GLAZING RECEIVING DIRECT RADIATION / TOTAL GLAZED AREA
ie 53/150 = 0.36

Figure 29 : Transmission factor computation

Template 39 to Template 45 under Appendix E indicates IES input templates with 150mm, 200mm and 250 mm louver spacing with corresponding simulation outputs. Results of the simulation have been discussed in Chapter 6.

5.7 Simulation –Test Matrix :

Simulations in relation to various retrofit measures discussed under section 5.61- 5.64 have been summarized in the form of Figure 30-Simulation Test Matrix. Base case simulation represents simulation carried out with envelope parameters same as as-built envelope. The output of base case simulation is the net annual energy consumption . Comparison of simulated base-case consumption with utility bills as per section 5.5 validates the simulation tool and base-model. Following validation, simulation1 to simulation 15 have been carried out , where in value of the one of parameters were altered while remaining were maintained as base case values. Hence each of the simulation will determine effect on one parameter alone, on the net energy consumption. For example in Simulation 1 , the external wall has been provided with 50mm thick EIFS cladding , while rest of the parameters were maintained same as that of the base case. Hence upon simulation, the effect 50mm thick EIFS cladding alone on the energy consumption of the base building may be determined. Results generated in each of the 16 simulations have been discussed and further analyzed in chapter 6.

Simulation Test Matrix				
Simulations	**External Wall**	**Glazing**	**Roofing**	**Shading Devices**
Base Case Simulation	**As Built-200 mm Solid block**	**As Built - U value**	**As Built with 50 mm insulation**	**As built-no shading device**
Simulation 1	With 50 mm thick EIFS cladding			
Simulation 2	With 75 mm thick EIFS cladding			
Simulation 3	With 100 mm thick EIFS cladding			
Simulation 4	With 150 mm thick EIFS cladding			
Simulation 5		U Value 1.54, SHGC 0.27		
Simulation 6		U Value 1.54, SHGC 0.21		
Simulation 7		U Value 1.54, SHGC 0.19		
Simulation 8		Tripple Glazing - U Value 0.9		
Simulation 9			75 mm insulation	
Simulation 10			100mm insulation	
Simulation 11			125mm insulation	
Simulation 12			150 mm insulation	
Simulation 13				Fixed Al. Louver - spacing 150 mm
Simulation 14				Fixed Al. Louver - spacing 200 mm
Simulation 15				Fixed Al. Louver - spacing 250 mm
Optimum case 1- Max. Energy Savings	With 150 mm thick EIFS cladding	Tripple Glazing - U Value 0.9	150 mm insulation	Fixed Al. Louver - spacing 150 mm
Optimum case 2- Min. Payback Period	With 50 mm thick EIFS cladding	U Value 1.54, SHGC 0.19	125mm insulation	Fixed Al. Louver - spacing 250 mm

Figure 30 – Simulation Test Matrix

Chapter 6 . Results and Discussion

This section summarizes the results obtained from various simulation runs for the refurbishment options outlined in the previous section, followed by an economic analysis of each case. The simulations generate estimated annual energy consumption for each of the refurbishment strategy applied. The difference between simulated energy consumption and base case energy consumption presents net annual energy savings for respective strategy. Net savings in energy costs then, can be estimated by multiplying Annual energy savings by unit energy cost. In order to determine the simple payback period for each refurbishment option, cost of the refurbishment measures were determined on the basis of prevailing market rates in the region. Simple payback period then determined using the equation:

Simple Payback Period = Total Cost of Refurbishment/Annual Energy Cost Savings (3)

6.1 External Wall cladding:

As briefed under section 5.6.1 EIFS cladding of thickness 50mm, 75mm, 100mm and 150 mm were applied and the models were simulated. Computation of Payback period as illustrated below:

Case 1 : Expanded polystyrene thickness 50 mm

Annual energy consumption with 50mm thick EIFS cladding as per Appendix B , Template 14

3,158.63 MWh.

Base case Annual Energy Consumption as per Table 12(Chapter 5) 3,309.59 MWh.

Net Saving in Energy: 3309.59-3158.63 = 150.96 MWh.

Net saving in Cost: Saving in Energy x Unit cost of Energy

Unit cost of Energy as per DEWA current tariff (Dubai Electricity & Water Authority 2011)

38 fils /kWh + 6.8 fil fuel surcharge ~ 45 fil/kWh.

Cost of 1 MWh electricity = 45 fils X 1000 = AED 450.

Net cost saving : 150.96x150 = AED 67,932.

Supply and installation of cost of 50 mm thick EIFS cladding = AED 120/m2. (Sovis 2011)

Total Cost of cladding : Area of cladding x unit cost ie 120 x 3721 = AED 446,520.

Simple Payback period calculated using equation(|3) : 446,520 / 67,932 = 6.6 years.

Application of EIFS cladding on external walls will result in saving of up to 5.28% of operational energy of the building as illustrated in Table 22. Payback period seems to be least when 50 mm thick polystyrene board backed EIFS cladding is used. Most of the commercially available EIFS systems in UAE offer a warranty of 10 to 15 years, hence useful life of the EIFS cladding system in UAE climate can be estimated to be 15-20 years which is more than twice of the payback period. Again by integrating EIFS application with general maintenance cycle of the building, payback periods may be significantly reduced.

Table 22: External Wall cladding with various cladding thickness with corresponding simple payback period.

Strategy 1- External Wall Cladding Replacement				
EPS Cladding Thickness	50mm(Option 1)	75mm(Option 2)	100mm(Option 3)	150mm (Option 4)
Annual Energy Consumption (MWh)	3,158.63	3147.7	3141.58	3134.96
Annual Energy Savings (MWh)	150.96	161.89	168.01	174.63
Annual Energy Saving (percentage)	4.56%	4.89%	5.08%	5.28%
Annual Cost Savings (in AED)	67,932	72,851	75,605	78,584
Net Cost of EIFS Cladding (AED per sqm)	120	130	140	153
Total cost of claddding in AED (External Wall area -3721 sqm)	446,520	483,730	520,940	569,313
Simple Payback Period (years)	6.6	6.6	6.9	7.2

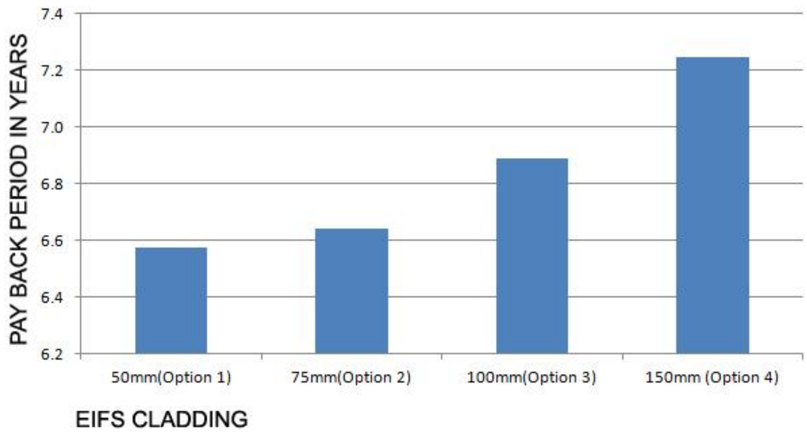


Figure 31 : Payback Periods for EIFS cladding

Table 23 further analyses net energy savings and simple payback periods due increased thickness of EIFS cladding. As per the table, application of 50 mm thick EIFS cladding will result in annual energy saving of 150.96 MWh as compared to the base case with annual cost saving of AED 67,932. Cost incurred for application of the cladding is AED 446,520 and simple payback period is 6.6 years. Increasing the EIFS cladding thickness by another 25 mm will result in additional annual energy saving of 10.93MWh and additional annual cost saving of AED 4,919. Additional cost incurred for increasing cladding thickness by 25 mm is AED 37,210 and the payback period for additional investment is 7.6 years. Increasing the cladding thickness by another 25mm (total thickness 100mm) will result in additional annual energy saving of 6.12MW and additional annual cost saving of AED 2,754. Additional cost incurred for increasing cladding thickness is AED 37,210 and the payback period for the additional investment is estimated to be 13.5 years. It can be noted that further increase in cladding thickness will substantially increases payback period for additional investment. In other words returns on investment diminishes for incremental investments. Hence it may be concluded that optimum returns are achieved for cladding thickness of 50mm.

Table 23: External Wall cladding with incremental cladding thickness with corresponding simple payback period.

External Wall Cladding Replacement - Incremental costs and Payback periods					
EPS Cladding Incremental Thickness	50mm(Option 1)	(+)25 mm (total 75 mm)	(+)25mm(Total 100mm)	(+)25 mm (total 125mm)	(+)25mm (total 150mm)
Annual Energy Consumption (MWh)	3,158.63	3147.7	3141.58	3137.67	3134.96
Incermental Annual Energy Savings (MWh)	150.96	10.93	6.12	3.91	2.71
Incermental Annual Energy Saving (percentage)	4.56%	0.33%	0.18%	0.12%	0.08%
Incremental Annual Returns (in AED)	0	4,919	2,754	1,759	1,220
Incermental Cost of EIFS Cladding (AED per sqm)	120	10	10	7	6
Investement in AED (Incremental)	0	37,210	37,210	26,047	22,326
Simple Payback Period in years (Incremental)	0.0	7.6	13.5	14.8	18.3

The external envelope of the building consists of block work with render and acrylic based external paint finish. According to recent researches carried out in Netherlands (Blom et al 2010) maintenance frequency of external paints in temperate climate is 6 years. Extreme climate of Gulf demands shorter maintenance frequency, however it is reasonable assume a 5 year maintenance frequency for external paints. As per current market prices in UAE, acrylic based external painting will cost AED 20 – 30 (Sovis, 2011) per square meter. By matching maintenance cycle of the external paint with EIFS cladding will reduce net cost of EIFS cladding. Table 24 suggests reduced cost of cladding along with reduced payback periods, by integrating EIFS application with maintenance cycle of external painting.

Table 24 : Reduced net cost and simple payback period.

Strategy 1A- External Wall Cladding Replacement-Integrated with maintenance cycle				
EPS Cladding Thickness	50mm	75mm	100mm	150mm
Annual Energy Consumption (MWh)	3,158.63	3147.7	3141.58	3134.96
Annual Energy Savings (MWh)	150.37	161.3	167.42	174.04
Annual Energy Saving (percentage)	4.54%	4.87%	5.06%	5.26%
Annual Cost Savings (in AED)	67,667	72,585	75,339	78,318
Net Cost of EIFS Cladding (AED per sqm)	90	100	110	122
Total cost of claddding in AED	334,890	372,100	409,310	453,962
Simple Payback Period (years)	4.9	5.1	5.4	5.8

Application of EIFS cladding mainly reduces the cooling load of the building. EIFS cladding will not have any impact lighting load, equipment load and auxiliary load. This can be illustrated by comparing energy consumption pattern of base case with simulated energy consumption upon application of EIFS cladding. As per Table 24a it can be noted that application of EIFS cladding reduces cooling load by 9.15 % to 11.79%.

Table 24a : Net reduction in Cooling Load due to EIFS application

Simulation	Chiller Energy	Auxilary Sustems Energy	Fans/Pumps/Lift/Misc	Lighting Energy	Equipment Energy	Total Energy	Total Savings in Chiller load	% Savings in Chiller Load
Base Case	1268.4	437.52	380.52	612.51	610.64	3309.59	NA	NA
EIFS 50 mm	1152.28	437.52	345.68	612.51	610.64	3158.63	116.12	9.15%
EIFS 75 mm	1143.87	437.52	343.16	612.51	610.64	3147.7	124.53	10.81%
EIFS 100mm	1139.16	437.52	341.76	612.51	610.64	3141.59	129.24	11.30%
EIFS 150mm	1134.07	437.52	340.22	612.51	610.64	3134.96	134.33	11.79%

Net reduction in cooling load due to EIFS application as illustrated in Table 24a is comparable to similar other studies carried in the region. Studies carried out by Ragom (2002) in Kuwait suggested that incase of G+1 floor residential villa in Kuwait, application of external insulations with U value 0.56W/m2K & 0.378W/m2K resulted in net reduction of cooling loads by 17.28% and 19.10% respectively. Though in the current case net projected net savings seem to slightly lower, it may be explained by use of following criteria:

1. Lower volume/floor area to external wall ratio : It is to be noted that in the base building floor area to external wall ratio is likely to be lower than the case of villa , as the base building has relatively larger and deeper floor area.

2. Adjacent Buildings: The base building is located in a densely developed urban area with tall buildings on Eastern and Western side of the building, which protects the building from direct solar radiation during morning and evenings. To determine shading effect of adjacent buildings the base-model was simulated by detaching the shading profile results of which has been included in Appendix B, Figure B.7 and Figure B.8. Simulation results suggest that net reduction cooling load caused by surrounding buildings is 6.28%. Considering East and West facades of

the building consist mainly blank walls which will receive EIFS cladding – effectiveness of EIFS cladding on these walls will be slightly reduced.

6.2 Refurbishment Measure 2 – Glazing Replacement:

As briefed in section 5.6.2 existing glazing has been replaced by high efficient double and triple glazing and the model were simulated, results of which have been tabulated in Table 20. Total Area of glazing replacement – 1691 square meters. For the cost analysis it has been assumed the existing aluminium sections will be retained in place, and only glazing and glass fixing beads will be replaced. Cost of double glazing in UAE varies from AED 200 – AED 250 per square meters (Sovis ,2011) excluding aluminium framing. Cost of triple glazing varies from AED 300-AED 350 per square meter.

As illustrated in Table 25, replacement of existing glazing by high efficiency double glazing will result in saving of up to 3.71% of operational energy, while use of high efficiency triple glazing will result in savings of up to 4.93% of operational energy. Simple payback period is least (7.35 years) when high efficiency double glazing –Option 3 is used. According to Blom et al (2010) useful life of glazing used in external envelope of building is 25 years while aluminium framing for the windows has a useful life of 40-50 years. Hence useful life of glazing approximately 2.5 times simple payback period. Considering the external glazing is 15 year old, it is left with another useful life of 10 years. It is imminent that glazing will have to be replaced in next 10 years, hence associated energy savings will act as additional incentive for the stake holders to consider replacement now.

Table 25 : Glazing replacement with corresponding simple payback period.

Strategy 3-Roofing Retrofit					
Roofing - Insulation Board Thickness	75mm(Option 1)	100mm(Option 2)	125mm(Option 3)	150mm(Option 4)	150mm (Polyeurethane Board-Option5)
Annual Energy Consumption (MWh)	3,270.81	3,268.25	3,266.67	3,264.94	3,258.91
Annual Energy Savings (MWh)	38.78	41.34	42.92	44.65	50.68
Annual Energy Saving (percentage)	1.17%	1.25%	1.30%	1.35%	1.53%
Annual Cost Savings(in AED)	17,451	18,603	19,314	20,093	22,806
Cost of roof insulation (AED per sqm)	45	60	75	90	95
Total cost of roof insulation (for total roof area of 1287 sqm)	57,915	77,220	96,525	115,830	122,265
Simple Pay Back Period (years)	3.3	4.2	5.0	5.8	5.4

Table 25a suggests net reduction in cooling load of the building due to glazing replacement. A comparison of base case energy consumption pattern with simulated energy consumption upon glazing replacement brings out net reduction in cooling load of the building. It can be noted that cooling load reduces in the range of 3.16 % to 9.89% due to various glazing replacements considered.

Table 25a : Net reduction in Cooling Load due to Glazing replacement

Simulation	Chiller Energy	Auxilary Sustems Energy	Fans/Pumps/Lift/Misc	Lighting Energy	Equipment Energy	Total Energy	Total Savings in Chiller load	% Savings in Chiller Load
Base Case	1268.4	437.52	380.52	612.51	610.64	3309.59	NA	NA
Glazing Option1	1228.26	437.52	368.47	612.51	610.64	3257.4	40.14	3.16%
Glazing Option2	1184.43	437.52	355.33	612.51	610.64	3200.43	83.97	6.62%
Glazing Option3	1174.06	437.52	352.22	612.51	610.64	3186.95	94.34	7.44%
Glazing Option4	1143.01	437.52	342.9	612.51	610.64	3146.58	125.39	9.89%

6.3 Refurbishment Measure3 – Roof Retrofit:

As briefed in section 5.6.3, thermal performance of the existing roof is improved by replacing existing roof insulation boards by high efficiency roof insulation boards.

Total area of roof/terrace is 1287 square meters. Cost involved in retrofit is mainly cost of insulation boards being replaced, while the workmanship shall be relatively low considering insulation boards are dry laid on roof below the layer of concrete paving tiles. As illustrated in Table 26, roof insulation replacement will result 1.17 % to 1.53% of savings in annual operational energy with simple payback periods varying between 3.3 years to 5.4 years. Figure 32 demonstrates effect of varying insulation thickness on payback period. The figure suggests that increase in insulation thickness from 75mm to 150 mm results in only marginal increase in energy savings. It is to be noted that overall U value of the roof built up with 75 mm thick polystyrene board will be 0.5638 W/m2K while with 100 mm polystyrene board net U value of the roof will be 0.4755 W/m2K as illustrated in Appendix D- Template 30 and 32.

However as per Dubai Municipality Thermal regulations minimum U value for the roofs shall be 0.44 W/m2K. Hence roof retrofit with 75 and 100 mm thick expanded polystyrene boards do not comply with current local authority regulations. Only when roof insulation board thickness is increased to 125 mm thick overall U value of the roof assembly drops down to 0.4111W/m2K which is within the DM requirements.

Table 26 : Roofing retrofit with corresponding simple payback period.

Strategy 3-Roofing Retrofit					
Roofing - Insulation Board Thickness	75mm(Option 1)	100mm(Option 2)	125mm(Option 3)	150mm(Option 4)	150mm (Polyeurethane Board-Option5)
Annual Energy Consumption (MWh)	3,270.81	3,268.25	3,266.67	3,264.94	3,258.91
Annual Energy Savings (MWh)	38.78	41.34	42.92	44.65	50.68
Annual Energy Saving (percentage)	1.17%	1.25%	1.30%	1.35%	1.53%
Annual Cost Savings(in AED)	17,451	18,603	19,314	20,093	22,806
Cost of roof insulation (AED per sqm)	45	60	75	90	95
Total cost of roof insulation (for total roof area of 1287 sqm)	57,915	77,220	96,525	115,830	122,265
Simple Pay Back Period (years)	3.3	4.2	5.0	5.8	5.4

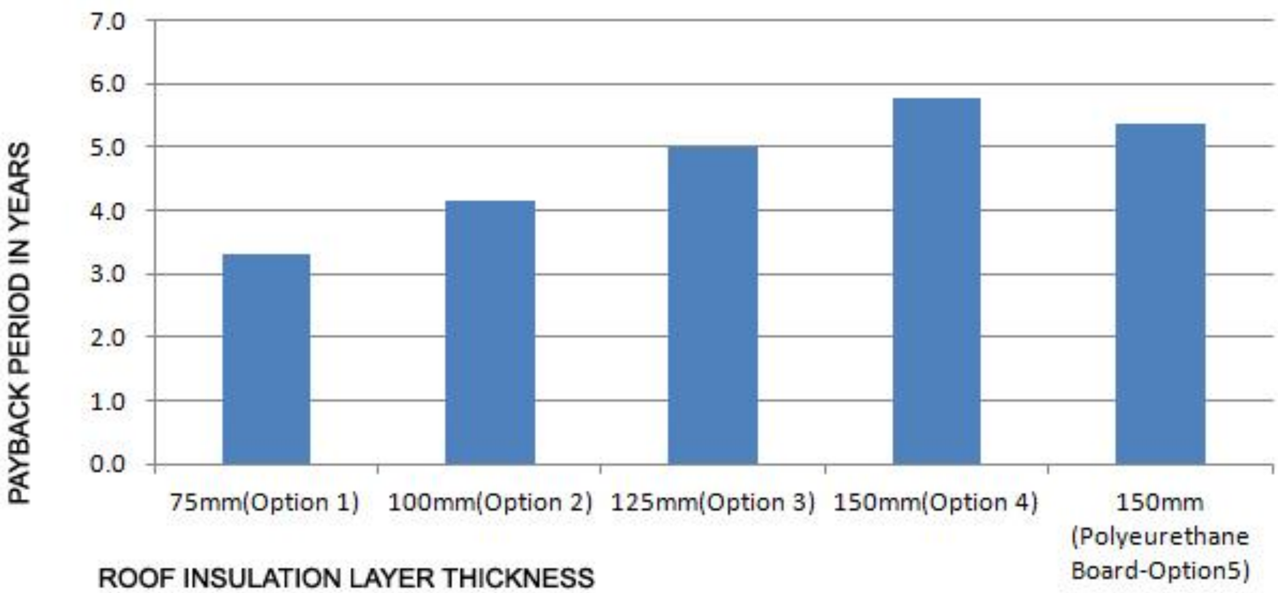


Figure 32 : Payback Periods for Roofing retrofit

Table 27 indicates effect of incremental thickness of roof insulation on net energy savings and payback periods. As per the table, application of 75mm thick roof insulation layer will result in a annual energy saving of 38.78MWh with annual cost saving of AED 17,451. Estimate cost of roof retrofit is AED 57,915 and payback period is 3.3 years. Increasing the insulation thickness by 25 mm will result in additional annual energy saving of 2.56MWh and additional annual cost saving of AED 1,152. Additional investment for increasing cladding thickness by 25 mm is AED 19,305 and the payback period for additional investment is 16.8 years. Increasing the insulation thickness by another 25mm (total thickness 125mm) will result in additional annual energy saving of 1.58MW and additional annual cost saving of AED 711. Additional cost incurred for increasing cladding thickness is AED 19,305 and the payback period for the additional investment is estimated to be 27.2 years. Further increasing the insulation by another 25mm (total thickness 150mm) will result in additional annual energy saving of 1.97MW and additional annual cost saving of AED 887. Additional cost incurred for increasing cladding thickness is

AED 19,305 and the payback period for the additional investment is estimated to be 21.8 years. As payback period on incremental investments are more than 20 years it is economically not attractive. However as per statutory requirements minimum thick of insulation board that will result in acceptable U value for the roof assembly is 125 mm, hence return on investment is optimum for 125 mm thick insulation board.

Table 27 : Roofing retrofit with incremental insulation thickness with corresponding simple payback period.

Roofing Retrofit-Incremental costs and payback periods				
Roofing - Insulation Board Incremental Thickness	75mm(Option 1)	(+) 25 mm(total 100mm)	(+) 25 mm(total 125mm)	(+) 25 mm(total 150mm)
Annual Energy Consumption (MWh)	3,270.81	3,268.25	3,266.67	3,264.70
Incremental Annual Energy Savings (MWh)	38.78	2.56	1.58	1.97
Incremental Annual Energy Saving (percentage)	1.17%	0.08%	0.05%	0.06%
Incremental annaul returns (in AED)	17,451	1,152	711	887
Cost of roof insulation (Incremental value-AED/sqm)	45	15	15	15
Incremetal investment cost (in AED)	57,915	19,305	19,305	19,305
Simple Pay Back Period in years (incremental)	3.3	16.8	27.2	21.8

A recent research carried out by Kellenberger and Althuas (2008) suggests that useful life of expanded polystyrene as 25 years, in temperate climate. Useful life of polystyrene boards is likely to be lower in this region due to extreme climate, hence can be assumed to be between 15-20 Years. Hence the useful life of the material is approximately 3-4 times simple payback period which is an economically favorable condition for replacement of insulation material. Considering the roof insulation is 15 year old already and it is left with a useful life of 5 years only. It is imminent that insulation material shall be replaced in next 5 years; hence additional energy savings that will be achieved will act as incentive to replace the insulation boards now.

Table 27a indicates net reduction in cooling load due roofing retrofit. It can be noted that cooling load is reduced in the range of 2.35 % to 3.11% due to application of suggested roofing retrofit measures.

Table 27a : Net reduction in Cooling Load due to Roofing Retrofit

Simulation	Chiller Energy	Auxilary Sustems Energy	Fans/Pumps/Lift/Misc	Lighting Energy	Equipment Energy	Total Energy	Total Savings in Chiller load	% Savings in Chiller Load
Base Case	1268.4	437.52	380.52	612.51	610.64	3309.59	NA	NA
75 mm Insulation	1238.57	437.52	371.57	612.51	610.64	3270.81	29.83	2.35%
100 mm Insulation	1236.61	437.52	370.97	612.51	610.64	3268.25	31.79	2.51%
125mm Insulation	1235.16	437.52	370.93	612.51	610.64	3266.76	33.24	2.62%
150mm Insulation	1234.05	437.52	370.22	612.51	610.64	3264.94	34.35	2.71%
150mm Cellular Polyeurethane Insulation	1228.96	437.52	368.69	612.51	610.64	3258.32	39.44	3.11%

Studies carried out by Ragom (2002) in Kuwait suggested that incase of G+1 floor residential villa in Kuwait, application of external roof insulation with U value 0.56W/m2K & 0.378W/m2K resulted in net reduction of cooling loads by 2.01 % and 2.83% respectively. The predicted energy savings in the current case is comparable to results of above study.

6.4 Refurbishment Measure 4 – Shading devices :

As briefed under section 4.44 external aluminium louvers with spacing 150mm, 200mm and 250 mm were applied to the base model and each case were simulated. Resulting annual energy consumption along with cost of external louver application and resulting payback periods have been indicated in Table 28 .

Table 28: Application of external Aluminium louvers with corresponding Simple payback periods.

Strategy 4- Use of fixed Aluminium Louvre (Louvre tilt angle -20 deg)			
Louvre Spacing	150mm(Option 1)	200mm(Option 2)	250mm(Opion 3)
Annual Energy Consumption (MWh)	3,095.90	3108.5	3123.5
Annual Energy Savings (MWh)	213.69	201.09	186.09
Annual Energy Saving (percentage)	6.46%	6.08%	5.62%
Annual Cost Savings (in AED)	96,161	90,491	83,741
Cost of Aluminium Louvers (AED per sqm)	300	250	200
Total cost of Louvers in AED (Total Area 1691 SQM)	507,300	422,750	338,200
Simple Payback Period (years)	5.3	4.7	4.0

Total area of glazing area in the building is 1691 square meters, of which significant part is on the south façade. As briefed in section 4.44 fixed tilt angle – aluminium lovers were applied to all 4 facades. The simulation results suggest that an annual energy savings of 5.62%, 6.08% & 6.46% can be achieved by use of Aluminium louvers (160 mm size) with 250mm, 200 mm and 150 mm spacing respectively. In order to determine simple payback periods – cost of Aluminum louvers were determined on the basis of current market prices in Emirate of Dubai. Simple payback periods are estimated to be 5.2 years, 6.0 years and 6.8 years respectively. Of the cases considered least payback period has been achieved when Fixed Aluminum louvers with 250mm spacing are used. Useful life of Aluminium louvers is relatively long; hence replacement may not be required in life span of the building. Table 28 a indicates net reduction in cooling load only, due to application of aluminum louvers. It can be noted that cooling load is reduced in the range of 11.28 % to 12.96% due to application suggested aluminum louvers.

Table 28 a: Net reduction in Cooling Load due to Roofing Retrofit

Simulation	Chiller Energy	Auxilary Sustems Energy	Fans/Pumps/Lift/Misc	Lighting Energy	Equipment Energy	Total Energy	Total Savings in Chiller load	% Savings in Chiller Load
Base Case	1268.4	437.52	380.52	612.51	610.64	3309.59	NA	NA
Louver Spacing 150mm	1103.99	437.52	331.2	612.51	610.64	3095.86	164.41	12.96%
Louver Spacing 200mm	1113.71	437.52	334.13	612.51	610.64	3108.51	154.69	12.20%
Louver Spacing 250mm	1125.33	437.52	337.59	612.51	610.64	3123.59	143.07	11.28%

A recent study carried out by Hammad and Abu-Hijelh (2010) in Abudhabi , suggests that fixed angle external louvers can save up to 31.36%, 26.08% and 25.97% cooling load on South, East and West façade respectively. The net reduction cooling load in current case seems to be considerably lesser as compared to above outcome. The main reason for the inconsistent results seems to be the varying glazing to floor area ratios in the base buildings. In the first case approximate glazing to floor area ratio is 40%, while in the current case this ratio is only 21.37%- which seems to be main reason for lower savings in cooling load. However it shall be noted that installation of louvers is likely reduce natural lighting through the windows, hence likely to increase artificial lighting requirement, study of which has been excluded in the current research.

6.5 Summary:

Multiple refurbishment strategies can be deployed in the base building to achieve optimum energy savings. Of the various refurbishment strategies considered in section 5.1 – 5.4 reductions in annual energy consumption is cumulative for External cladding and Roof retrofit when strategies are implemented simultaneously, however combined net reduction due to glazing replacement and shading devices are not cumulative. In order to determine combined effect of refurbishment strategies, model shall be re-simulated upon applying selected refurbishment measures.Table 29 suggests summary of refurbishment strategies along with simple payback period and net energy savings.

Table 29: Summary of Refurbishment strategies with net energy saving and simple payback period for each options.

	Refurbishment Strategy		Option 1	Option 2	Option 3	Option 4	Option 5
1	External Cladding Replacement	Net energy saving	4.56%	4.89%	5.08%	5.28%	
		Simple payback period(in years)	6.30	6.60	7.00	7.40	
2	External Glazing Replacement	Net energy saving	1.58%	3.30%	3.71%	4.93%	
		Simple payback period(in years)	18.51	9.74	9.45	9.49	
3	Roofing Retrofit	Net energy saving	1.17%	1.25%	1.30%	1.35%	1.53%
		Simple payback period(in years)	4.30	5.30	6.40	7.40	6.90
4	Fixed Aluminium Louvers	Net energy saving	6.46%	6.08%	5.62%		
		Simple payback period(in years)	6.80	6.00	5.20		

6.5.1 Maximum Energy Savings:

In this approach each strategies resulting in maximum energy savings have been considered. As illustrated in Table 30 following combination of retrofit measures results in maximum energy savings:

External cladding : Option 4 – 150 mm thk EIFS cladding.

External glazing replacement: Option 4 – triple glazing.

Roofing retrofit: Option 5- 150 mm thk Polyurethane board .

Fixed Aluminium louvers: Option 1- Fixed aluminum louvers with 150 mm spacing.

Table 30: Summary of Refurbishment strategies – Maximum Energy Savings

	Refurbishment Strategy		Option 1	Option 2	Option 3	Option 4	Option 5
1	External Cladding Replacement	Net energy saving	4.56%	4.89%	5.08%	5.28%	
		Simple payback period(in years)	6.30	6.60	7.00	7.40	
2	External Glazing Replacement	Net energy saving	1.58%	3.30%	3.71%	4.93%	
		Simple payback period(in years)	18.51	9.74	9.45	9.49	
3	Roofing Retrofit	Net energy saving	1.17%	1.25%	1.30%	1.35%	1.53%
		Simple payback period(in years)	4.30	5.30	6.40	7.40	6.90
4	Fixed Aluminium Louvers	Net energy saving	6.46%	6.08%	5.62%		
		Simple payback period(in years)	6.80	6.00	5.20		

Upon application of above refurbishment strategies, the model was simulated results of which have been indicated in Table 31. As per the table it can be noted that :

Total Lighting Energy – 612.51 MWh

Total Equipment Energy – 610.64 MWh

Total Chiller Energy – 888.91 MWh

Aux. Systems Energy – 437.51 MWh

Ap. Systems Heat rej. Fans/pumps Energy – 266.67 MWh

Total Energy – 2816.25 MWh.

Upon comparing the results with base case results -Table 15 it can be noted that net reduction in annual operational energy will be:

Total energy (base case) – Total energy (simulated – max. energy savings)

ie 3309.59 MWh – 2816.25 MWh = 493.34 MWh which is 14.90% savings in annual operational energy consumption.

Total cost of energy savings = Net energy saving x Unit energy cost (4) ie 493.34 x AED 350 = AED172,669.

Total investment cost from table 22, 25, 26 and 28 = AED 1,739,998.

Simple payback period as per equation (3) will be = 1,739,998 / 172,669 = 10.07 years.

Table 31: Simulated monthly energy consumption upon application of retrofit measures as per Table 30.

	Total energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Chillers energy (MWh)	Ap Sys aux + DHW/solar pumps energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)
	max returns.aps	max returns.aps	max returns.aps	max returns.aps	max returns.aps	max returns.aps
Date						
Jan 01-31	175.6453	49.4725	49.3211	30.4553	37.2609	9.1366
Feb 01-28	171.7848	47.1166	46.9725	33.8779	33.6550	10.1634
Mar 01-31	209.7531	54.1842	54.0184	49.4541	37.2609	14.8362
Apr 01-30	211.6359	49.4725	49.3211	59.0644	36.0590	17.7193
May 01-31	247.7604	51.8283	51.6698	82.3089	37.2609	24.6927
Jun 01-30	271.8755	51.8283	51.6698	101.7836	36.0590	30.5351
Jul 01-31	294.1969	49.4725	49.3211	121.6481	37.2609	36.4945
Aug 01-31	308.2046	54.1842	54.0184	125.1856	37.2609	37.5557
Sep 01-30	288.6511	51.8283	51.6698	114.6881	36.0590	34.4064
Oct 01-31	235.8737	49.4725	49.3211	76.7842	37.2609	23.0352
Nov 01-30	211.1834	51.8283	51.6698	55.0976	36.0590	16.5293
Dec 01-30	189.6831	51.8283	51.6698	38.5589	36.0590	11.5677
Summed total	2816.2478	612.5164	610.6425	888.9066	437.5157	266.6720

Further comparison of results under Table 31 with base case results as per Table 15 brings out the fact that, combined effect of the suggested refurbishment measures will have no impact on total lighting and equipment energy consumption, while chiller energy consumption reduces drastically. Total reduction in chiller energy consumption :

1268.40 MWh – 888.91 MWh = 379.49 MWh .

Percentage reduction in cooling energy will be 29.91%, which is a significant saving.

6.5.2 Minimum payback Period:

In this approach each strategy resulting in least payback period has been considered**.** As illustrated in Table 31 following combination of retrofit measures results in minimum payback period:

External cladding: Option 1 – 50 mm thk EIFS cladding.

External glazing replacement: Option 3 – double glazing.

Roofing retrofit: Option 3- 125 mm thk extruded polystyrene board.

Note: Though payback periods are lesser for roof retrofit option 1 & 2 with 50 mm thick and 75 mm thick extruded polystyrene board insulations respectively, net U value of the roof assembly in both cases do not comply with local authority requirements. Hence Option 3 has been considered as optimum case.

Fixed Aluminium louvers : Option 3 - Fixed aluminum louvers with 250 mm spacing.

Table 32: Summary of Refurbishment strategies – Minimum Payback Period

	Refurbishment Strategy		Option 1	Option 2	Option 3	Option 4	Option 5
1	External Cladding Replacement	Net energy saving	4.56%	4.89%	5.08%	5.28%	
		Simple payback period(in years)	6.60	6.60	6.90	7.20	
2	External Glazing Replacement	Net energy saving	1.58%	3.30%	3.71%	4.93%	
		Simple payback period(in years)	14.4	7.57	7.35	7.38	
3	Roofing Retrofit	Net energy saving	1.17%	1.25%	1.30%	1.35%	1.53%
		Simple payback period(in years)	3.30	4.20	5.00	5.80	5.40
4	Fixed Aluminium Louvers	Net energy saving	6.46%	6.08%	5.62%		
		Simple payback period(in years)	5.30	4.70	4.00		

Upon application of above refurbishment strategies, the model was simulated results of which have been indicated in Table 32. As per the table it can be noted that:

Total Lighting Energy – 612.51 MWh

Total Equipment Energy – 610.64 MWh

Total Chiller Energy – 944.03 MWh

Aux. Systems Energy – 437.51 MWh

Ap. Systems Heat rej. Fans/pumps Energy – 283.21 MWh

Total Energy – 2887.91 MWh.

Upon comparing the results to base case results as per Table 15 it can be noted that net saving is annual operational energy will be:

3309.59 MWh – 2887.91 MWh = 421.68 MWh which is 12.74% savings in annual operational energy consumption.

Total cost of energy savings as per equation(4) will be

421.68 x AED 350 = AED147, 588.

Total investment cost from table 22, 25, 26 and 28 = AED 1,287,085.

Simple payback period as per equation (3) will be = 1,287,085 / 147,588 = 8.72 years.

Table 33: Simulated monthly energy consumption –Least payback period criteria

	Chillers energy (MWh)	Ap Sys aux + DHW/solar pumps energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
	least payback period	least payback period	least payback period	least payback period	least payback period	least payback period
Date						
Jan 01-31	29.6100	37.2609	8.8830	49.4725	49.3211	174.5464
Feb 01-28	33.5487	33.6550	10.0646	47.1166	46.9725	171.3567
Mar 01-31	50.4940	37.2609	15.1482	54.1842	54.0184	211.1051
Apr 01-30	62.9787	36.0590	18.8936	49.4725	49.3211	216.7245
May 01-31	89.3748	37.2609	26.8124	51.8283	51.6698	256.9460
Jun 01-30	110.3118	36.0590	33.0936	51.8283	51.6698	282.9621
Jul 01-31	131.5466	37.2609	39.4640	49.4725	49.3211	307.0651
Aug 01-31	135.2794	37.2609	40.5838	54.1842	54.0184	321.3263
Sep 01-30	122.7364	36.0590	36.8209	51.8283	51.6698	299.1142
Oct 01-31	82.0259	37.2609	24.6077	49.4725	49.3211	242.6879
Nov 01-30	57.4564	36.0590	17.2369	51.8283	51.6698	214.2500
Dec 01-30	38.6674	36.0590	11.6002	51.8283	51.6698	189.8240
Summed total	944.0300	437.5157	283.2091	612.5164	610.6425	2887.9084

Total reduction in chiller energy consumption:

1268.40 MWh – 944.03 MWh = 324.37 MWh .

Percentage reduction in cooling energy will be 25.57%.

Chapter 7 . Conclusions & Recommendations

7.1 Conclusions

The results of the simulation discussed in chapter 6 suggest that passive strategies used in refurbishments will result in substantial operational energy savings with acceptable paybacks on investment. Each of the refurbishment strategy can be optimized to maximise the returns. In the case of refurbishment Measure 1 – External wall cladding, EIFS cladding of thickness 50mm, 75mm, 100mm and 150mm were tested by use of simulation tool IES V6. As per the simulation results- corresponding reductions in cooling loads were 9.15%, 10.81%, 11.30% and 11.79% respectively. The corresponding overall annual operational energy savings were 4.56%, 4.89%, 5.08%, 5.28% respectively. Upon computation of simple payback periods on the basis of market rates, payback periods for 50mm, 75mm, 100 mm and 150 mm thick EIFS cladding were found to be 6.6, 6.6, 6.9 and 7.2 years respectively. Hence 50 mm thick EIFS cladding results in optimum returns.

With reference to glazing replacement, the simulation results suggest that glazing systems with lower U value, and SC values result in higher energy savings. Of the various glazing replacement options considered, Glazing Option 3 (Sun Guard – Super Neutral Gray) with U value 1.48 W/m2K and SC 0.19 results in optimum returns with a payback period of 7.35 years. Considering a limited no. of glazing configurations have been tested, the results generated cannot be considered as optimum glazing configuration. A wide range of glazing from various manufacturers shall be tested in order to determine the optimum glazing replacement solution.

The third retrofit measure tested were roofing retrofit, where existing roof insulation layers were replaced and the model was simulated to determine the net energy savings. It is to be noted that existing roof consisted of 50mm thick insulation layer resulting in a net U value of 0.69W/m2K for the roof built-up. Existing roof insulation layer was replaced by extruded polystyrene boards of thickness 75mm, 100mm and 125mm and 150mm and the model was simulated for each case. As per the simulation-results corresponding reductions in cooling loads were 2.35%, 2.51%, 2.62% and 2.71% respectively. The corresponding overall annual operational energy savings were 1.17%, 1.25%, 1.30% and 1.35% respectively. Upon computation of simple payback periods on the basis of market rates, payback periods for 75mm, 100 mm , 125mm and 150 mm thick roof insulation were estimated to be 3.3, 4.2, 5.0 and 5.8 years respectively. Hence optimum returns was achieved at 75mm thick roof insulation boards with payback period of 3.3 years, however net U value of the roof assembly with 75mm thick roof insulation is estimated to be 0.5638 W/m2K which does not comply with current local authority regulations. Only when the roof insulation is 125mm thick over all U value of the roof build up complies with local authority requirements, hence 125mm thick roof insulation can be considered as optimum insulation thickness.

The last retrofit measure tested were application of external shading devices, where fixed aluminium louvers were installed at 150mm, 200mm and 250mm spacing and respective energy consumption were simulated. The simulation results suggested that cooling loads up to 12.96%, 12.20% and 11.28% can be reduced respectively. Overall savings in annual operational energy were 6.46%, 6.08% and 5.62% respectively with simple payback periods of 6.8, 6.0 and 5.2 years. Hence of the cases considered fixed aluminium louvers at a spacing of 250mm presents optimum case with least payback period on investment.

Discussions under section 6.5.1 suggests that a combination of retrofit measures selected on the basis of maximum annual energy savings will result in 29.91% reduction in cooling load and

14.90% savings in annual operational energy. Combined investment for the suggested retrofit strategies is estimated to be AED 1,739,998 with simple payback period of 10.07 years.

As per section 6.5.2 combination of retrofit measures selected on the basis of minimum payback period will result in 25.57% reduction in cooling load and 12.74% savings in annual operational energy. Combined investment for the suggested retrofit strategies is estimated to be AED 1,287,085 with simple payback period of 8.72 years. The suggested payback period of 8.72 years can be considered to be acceptable period, especially in this region where energy costs are relatively low. Considering energy is highly subsidized in UAE, and energy costs are likely to go up in the near future, which will reduce the payback periods further.

7.2 Recommendations & Suggestion for Future Study:

Results from the study conclude that substantial energy savings can be achieved in existing buildings by application of various refurbishment strategies. Economic analysis further concludes that these refurbishment applications are economically feasible with acceptable payback periods. However refurbishment strategies developed are case specific hence cannot be by blindly applied to other cases without appropriate study of each case.

Again, in the current study a limited number of alternatives have been tested for each of the refurbishment strategy before optimum case has been suggested. For example in the case Roof retrofit - 75 mm, 100mm , 125 mm and 150 mm thick polystyrene boards were considered and optimum case were determined by use of simulation followed by economic analysis. The study does not consider other type of roof insulations such as internal insulation boards, liquid applied roof insulation systems etc which may result in better insulation and may result in lower payback period. Hence in order to arrive at optimum roofing refurbishment it is essential to test a wide range of roof refurbishment techniques. Similarly in the case of external shading devices, the current study considers 160mm aluminium louvers at fixed angles with 150mm, 200mm and 250mm internal spacing. For simplification of study only louver spacing has been considered as variable while rest of the parameters such as size of louver, tilt angle, surface characteristics of the louvers etc. are kept constant. However in order to determine the optimum louver configuration it is essential to test each of these parameters separately. Hence each of the refurbishment strategies may be studied separately to determine most optimum confirmation.

Again the current study limits its scope of passive refurbishment strategies only, while a number of active strategies such as refurbishment of chillers & HVAC systems, lighting replacement, application of intelligent lighting and HVAC control systems etc. can substantially reduce operational energy consumption with acceptable payback periods. Hence further studies can be carried out particularly focusing active refurbishment strategies.

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