Chapter 1: Introduction

1.1 **Global Context**

"There is little time left. The opportunity and responsibility to avoid catastrophic climate change is in your hands," Mr. Ban Ki-Moon said, closing the day-long Summit on Climate Change 2009. The dramatic increase of CO2 and greenhouse gases and the significant decrease of natural absorption of these emissions by the world's forests and oceans have created a call for an emergency plan, where the latest technology, research bodies and geo-engineering strategy should evolve to save our planet (Corner, 2009).

Historically, from Vitruvius, through to William Morris in the 19th century, there has long been an awareness of the effect of buildings, urbanization and industrialization processes on the environment and natural resources. The rapidly growing world energy use of buildings has raised great concerns and the global attention (Wigging and Harris, 2002).

It is well established today that buildings consume almost 40% of the world's energy, 16% of the world's fresh water and 25% of the forest timber, while it is responsible for almost 70% of sulphur oxides and 50% of the CO2 emissions (Bitan 1992, cited in Ghiaus and Inard, 2004). In Europe, about 30% of the total energy consumption is consumed in buildings, a large amount of which is used for heating (Ghiaus and Inard, 2004).

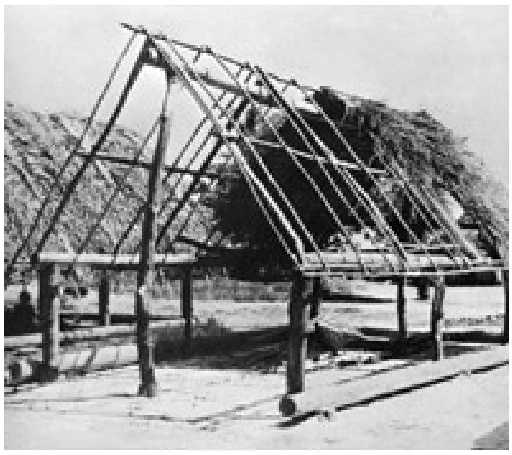
Within the commercial sector, office buildings along with retail have the biggest energy consumption and CO2 emissions. In the USA, offices account for 17% of total non-domestic area and about 18% of the energy use, equivalent to the 3.2% of the total consumption. In Spain, they account for a third of the commercial sector energy consumption and almost 2.7% of total energy consumed and in the UK for 17% of energy consumption and 2% of total energy use. Therefore, it is advisable to start the commercial analysis with office buildings (Lombard, Ortiz and Pout, 2008).

The building façade can account for between 15% and 40% of the total building budget (Hall, 1997 cited in Wigging and Harris, 2002), and may be a significant contributor to the cost of up to 40% more through its impact on the cost of building services (Wigging and Harris, 2002). The choice of material, design and construction of building facades definitely has a major impact on the energy consumption of buildings.

1.2 **Building Envelopes**

Throughout history, building envelopes can be defined as the interface between the interior and exterior environments of buildings. The first human trial to create a building envelope was probably a cave that protected people from various elements and provided some level of privacy and security. Timber or bamboo frames clad with leaves or woven textiles were the main components of the earliest shelters in the warm climates of Africa and Asia, whereas stone, rock and clay were used in other climates.

(a)



(b)

Figure 1.1 (a) A dome shaped hut in Ethiopia combines wall and roof in one material; (b) Timber frame and thatched roof (Arnold, 2009)

Envelopes over time have been used to perform various functions. Some of these functions can be summarized as follows;

- Control of the physical environment factors such as temperature, light, noise, rain, moisture, air infiltration, etc.
- Structural support for the building.
- Fire safety.
- Security.
- Energy conservation.
- Aesthetics.

The basic requirements of building envelopes in responding to diverse functional and climatic demands have remained the same from medieval times to this day. However, the expectations have vastly increased overtime, in terms of both absolute performance and its ability to provide the desired level of control over the external environment. Based on a society's composition and economic conditions, such needs and functions of the exterior envelope choices may vary considerably.

The invention of steel and reinforced concrete created a considerable change in the concepts of the wall and building skin. The exterior wall became a screen and was no longer needed for structural support. However, this structural advantage was accompanied by the drawback of eliminating the heavy mass element that used to be an acoustic and thermal barrier of the external environment. Different types of insulation layers were developed to maximize the performance of the envelopes. Different materials may meet different requirements and serve separate function or some materials may perform multiple functions. More recently the exterior wall has become a major subject of building science studies (Arnold, 2009).

Despite the slow pace of change in the building industry as stated by Selkowitz (2001), the preceding 25 years have seen significant improvements in glass technology. Such improvements produced high quality glass with high performance and properties that have given more flexibility to the window design to fulfill its requirements without compromising the indoor comfort levels. Lee et al. (2004) highlighted that the available high insulating glazing technologies largely resolved the technical problem of controlling heat loss and gain through the window. However, the challenge of managing solar gain, daylight, views and glare is in its early stage.

The extensive use of highly glazed building facades created a more challenging dilemma to the design and manufacturing community. Selkowitz (2001) considered that the current generations of such buildings that are being promoted as energy efficient and environmentally friendly are built on the results of 20-30 years of real advances in the glazing technology, better design tools and more sophisticated building operations. However, they often still fall short of what is needed to make these facades more efficient and cost effective.

The continuous development of curtain wall systems has had a significant influence on building envelope design and architectural trends. The various technical issues related to the envelope industry are being addressed by recent innovations. Growing attention has been paid to the energy consumption of building envelopes, especially after raising the theory of global warming and following the different energy crises in the world. This considerably influenced the R&D efforts in this sector. Lee et al. (2004) tried to justify the market transformation opportunities for emerging advanced façade technologies. The building skin serves a crucial functional role in helping to maintain proper interior environments in extreme external environmental conditions, which create the primary technical challenges of environmental control, including heating, cooling and lighting besides the resources depletion and carbon emissions. The main approach of any traditional design was to provide some degree of static solar control and then rely on the electro-mechanical systems to provide the desired degree of occupant comfort. The significant development of glass technology was a direct reason to facilitate the architectural transformation to highly glazed buildings. Building energy codes and standards have been developed to monitor the construction and reflect societal interest in energy efficient and sustainable designs.

Selkowitz, Aschehoug and Lee (2003) highlighted that there has been a subtle shift from trying to optimize an ideal, static design solution using innovative glazing solutions to making the façade responsive, interactive and even intelligent.

Since climate and occupant needs are dynamic variables, more sophisticated design approaches and technologies have emerged using new high-performance glazing, improved shading and solar control systems, greater use of automated controls and integration with other building systems. Despite many limitations and challenges, various facade technologies and solutions are being developed in the progress towards net zero energy buildings. One relatively new architectural development is the double glass facade that offers a cavity that can provide improved acoustics, better solar control and enhanced ventilation.

Due to the availability of innumerable variations, combinations, and hybrids of building envelope systems, Stout and Garrison (2008) classify the envelopes according to concepts, rather than construction methods or the used materials. The conceptual categories include static, operable, tensile, pneumatic, open and pressurized envelopes.

1.3 **UAE Scenario**

Kazim (2007) addressed the sectoral energy consumption in the UAE in 1998 based on statistics cited from the International Energy Agency (IEA). Figure 1.2 demonstrates that the residential and commercial sectors had almost an equal share of the total primary energy consumption of 16.2% and 15.1%, respectively. Conversely, the transportation sector demonstrated the lowest share of 10.3% of the country's overall energy consumption. However, this percentage is anticipated to double in the next decade due to predicted increase in the population. Without a doubt, the environmental impact of these figures would be very severe especially with respect to carbon emission.

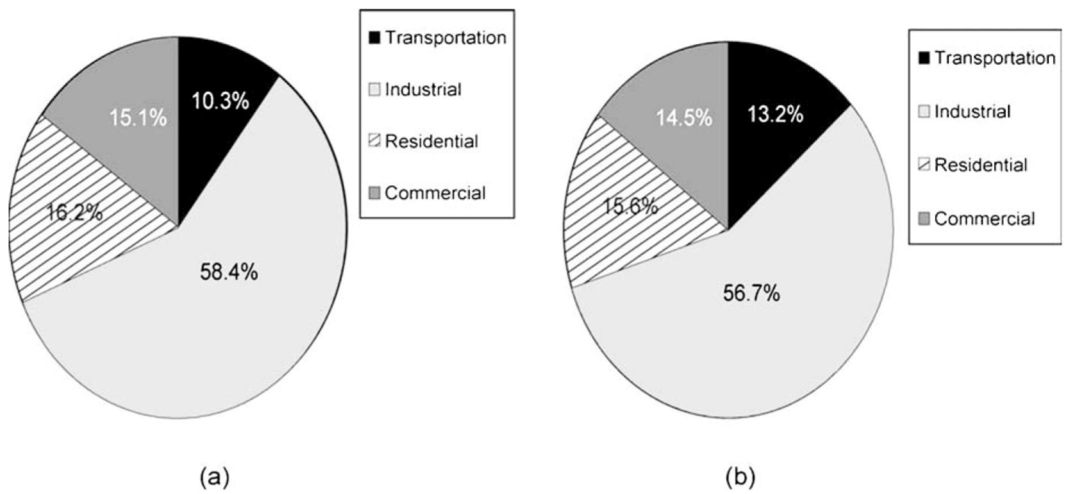


Figure 1.2 UAE's sectoral (a) energy consumption and (b) carbon emission in 1998 (Kazim, 2005:435)

The rapid growth of the UAE and the booming construction have inevitably harmed the environmental situation of the country. The sustainability race that has taken place globally started to cast its shadows on the development polices in the UAE. A wide interest amongst decision makers in the country created a pressure on the market tendency to import relevant technologies to catch up to the demand for environmental solutions and energy efficient developments.

1.4 Motivation

The new challenge is to create more advanced integrated solutions to optimize the energy consumption of building envelopes, acquire the adaptability to the external environmental conditions and address the owner's desire to achieve high levels of occupant comfort. These solutions must be achieved with initially affordable and cost effective solutions and then must operate over long periods with minimal maintenance if they are to be accepted and purchased by building owners (Selkowitz, 2005).

The dynamic facades with intelligent systems were introduced as a solution that has the ability to satisfy the above mentioned concerns. As all new technologies, extensive studies should be undertaken to test the performance of the proposed systems, and investigate the visibility of the adoption of such systems.

The majority of literature and data on performance of Dynamic Façades in terms of thermal, lighting and visual comfort is limited to temperate climates whereas this technology has been rarely studied in hot and humid climates. The lack of academic reference or studies that covers various features of this technology and tests its adaptability with the climatic conditions of UAE created an incentive for the author to carry out this study.

This dissertation presents a simulation study of external automated louvers as one of dynamic façade features. An in-depth analysis will be concentrated on literature and ongoing research in the field of dynamic facades. A prototype dynamic assembly for a typical office space will be proposed and compared to other configurations. The energy consumption of lighting and cooling loads will be the basis of the comparison. These configurations will be examined and simulated under the climatic conditions of Abu Dhabi. The results of will culminate in recommendations to be offered for present development and future studies.

1.5 Dissertation organization

This dissertation is divided into seven chapters as follows;

Chapter one provides a general background of the study, and addresses the need for this study at different levels; global, buildings and facades.

Reviews and discussion of the existing body of literature and previous researches related to the topic of this dissertation are enclosed in chapter two. The literature review defines the intelligent buildings and envelopes that will give a base for good understanding of the logic of dynamic facades. The climatic data of Abu Dhabi is briefed which will give a good understanding of the environmental conditions of the research. The study scope is getting clearer at the last part of this chapter and will be finished off by the aim and objectives.

The next Chapter describes the methodology used in the study. It includes a review and survey of various methodologies used in previous similar studies which constitute the base for the selection of the methodology to be used for this study.

Chapter four includes a description of the base case model and it explains all parameters and factors which are considered in the modeling process. The other selected cases for simulation will be explained in this chapter.

The simulation results of the examined cases followed by discussion and comparative analysis in the context of the findings of other studies are included in chapter five.

Chapter six carries out a brief economic analysis of all the selected cases. This includes estimation of the cost associated of each case and an analysis of the pay back periods. An economic comparison will be discussed to identify the efficiency of each configuration.

The last chapter draws some conclusions based on the results of the study and proposes recommendations for future research in this area.

Chapter 2: Literature Review

2.1 Introduction

A literature search was conducted to determine the current state of knowledge in the field of dynamic façades. In order to have a good understanding of dynamic facade features, it is important to define intelligent buildings and investigate intelligent envelope characteristics. Recently, many studies have been carried out to explore the performance, practicality and viability of adopting such advanced technology. This review focuses on studies related to dynamic louvers and blinds, and partially to dynamic control systems. The most important part of this chapter is the findings of various studies from where the motivation for this research arose.

2.2 Intelligent buildings and dynamic facades

Since its birth in the early 1980s there has been no universal agreement on a definition or terminology for intelligent building. Many definitions have been suggested by various academic and technical bodies. Wigging and Harris (2002) listed more than 30 definitions of building Intelligence and they redefined the intelligent building as:

> "'A building with the ability to know its Configuration, anticipates the optimum dynamic response to prevailing environmental stimuli, and actuates the appropriate physical reaction in a predictable manner. It is expected that the system will strive to exploit the use of natural forces and minimize the need to import energy from non-renewable sources. The truly 'intelligent building' should therefore be endowed with some of the human characteristics that give it the ability to learn, adjust and respond instinctively to its immediate environment in order to provide comfortable internal conditions and use energy more efficiently" (Wigging and Harris 2002:23).

Cardin (1983, cited in Wigging and Harris 2002) described an intelligent building as one which has fully automated building service control systems. The Intelligent Building Institution in the USA (1988, cited in Derek and Clements-Croome 1997) defined intelligent building that integrates and coordinates effectively various systems to maximize technical performance, investment, operating cost savings and flexibility. Kroner (1989) explored another definition of intelligent building from an architectural perspective. He described truly intelligent architecture as performing the following functions;

- Sensing internal and external conditions such as weather and occupancy.
- Remembering information, instructions and previous patterns of use.
- Modifying its physical characteristics and properties in order to respond to internal and external conditions. A building's degree of transparency, thermal resistance, degree of exposure, colour and texture could be changed.
- Communicating information about itself and its performance to the occupant, building owner or maintenance personnel.

Duffy, Eley, Giffone and Worthington (DEGW) Report (1992) described the intelligent building as a productive office concept. Cho and Fellows (2000) reported three phases of the development of intelligent buildings identified in DEGW (1992);

- Automated buildings (1981-1985): buildings which offered highly sophisticated information and communication facilities and systems or had facilities built-in for their installation in the future.
- Responsive buildings (1986-1991): buildings which responded to user requirements at a number of levels, relating to the life-cycles of various elements, such as shells and services.

- Effective buildings (1992-date of issue): buildings which provide a responsive, effective and supportive environment within which the organization can achieve its business objectives.

Wong, Li and Wang (2005) highlighted the fact that many authors started to extend the definition of intelligent buildings to cover their learning ability and performance adjustment. Yang and Peng (2001) as an example proposed more dimensions for intelligent buildings. The performance of intelligent buildings generally falls into four categories; individual comfort, organizational flexibility, technological adaptability and environmental performance. They believed that intelligent building should also be capable of learning, adapting and adjusting performance according to its occupants and the environment as well.

Himanen (2003) collected and classified definitions of intelligent building concepts. He believed that the lack of standard definition of intelligent building was because of it being a new idea and its industry was not yet fully developed. At the beginning of his discussion about the definitions he referred to the descriptions stated by the Intelligent Building Institute Foundation (I.B.I.) in 1989 and other definitions of various organizations to summarize the common factors of intelligent building concepts as follows :

- Intelligent buildings (IBs) provide an effective and productive environment and maximize the performance.
- The needs of the occupants are primary with respect to the building performance.
- The performance will be gained in a cost effective manner with minimum life-time costs.
- In spite of the cost minimizing, the accommodation should be convenient, the management of resources efficient and sustainability should be respected.

- The performance needs will be met by integrating the best available concepts, materials, systems and technologies, architecture and structures.
- The performance can be evaluated by or implemented with environmental friendliness, flexibility and utilization of space, movable space elements and equipment, life cycle costing, comfort, convenience, safety and security, working efficiency, image of high technology, culture, construction process and structure, long term flexibility, and marketability, information intensity, interaction, service-orientation, ability of promoting health (therapeutic), adaptability, reliability (stable and accurate), and productivity (profitability) at correctness of basic technical solutions.

Nikolaou, Kolokotsa and Stavrakakis (2004) addressed the ambiguousness of the intelligence terminology, especially when applied to man-made systems. The authors referred for the term to objects that can react correctly to unforeseen circumstances and learn from the associated response. The concepts of self-correction or fault tolerance are considered as essential elements of "artificial intelligence". Neural networks and fuzzy logic are some of the tools that resemble human intelligence methods to achieve intelligence. According to the authors, Intelligent Building technology generally refers to the integration of four systems:

- Building Automation System (BAS)
- Telecommunications System (TS)
- Office Automation System (OAS)
- Computer Aided Facility Management System (CAFMS)

Figure 2.1 shows the building which was designed by Skidmore, Owings and Merrill in USA that was completed in 1984. This building was agreed to be the world's first intelligent building (Wigging and Harris, 2002).

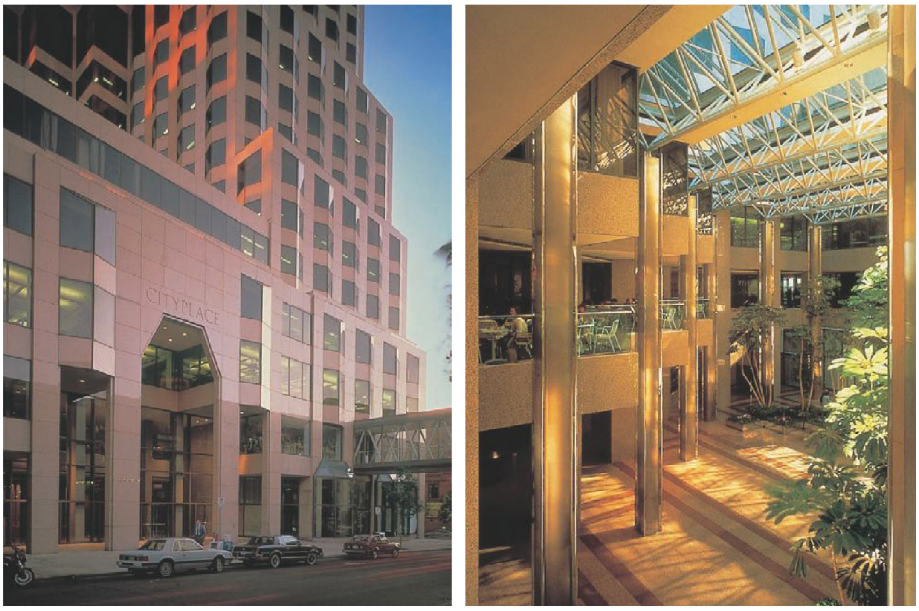


Figure 2.1 Skidmore, Owings and Merrill's office building of 1983 in Hartford, Connecticut, USA (Wigging and Harris, 2002)

A building envelope is an essential part of any building. It is the separation between the interior and the exterior environments of a building which physically protect the indoor environment as well as facilitate its climate control through the control of the air and heat through the building envelope components in a way to achieve a certain level of comfort for the occupants (encyclopedia Wikipedia, 2009). Because buildings are subjected to a wide range of external and internal conditions, with the additional handicap of being unable to relocate themselves to more favorable environments, they too should ideally possess dynamic thermo- regulatory capabilities at the building envelope. These dynamic qualities should yield improved comfort, satisfaction and productivity to its occupant while minimizing the energy cost and the environmental impact to maintain that comfort (Lee and Selkowitz, 1997).

Aschehoug et al. (2005) listed a multitude of definitions and synonyms in the literature for the concept of 'Intelligent Building Envelope'. Table (2.1) includes some of these definitions.

Table 2.1 Definitions and Synonyms of Intelligent Building Envelope adapted from Aschehoug et al. (2005)

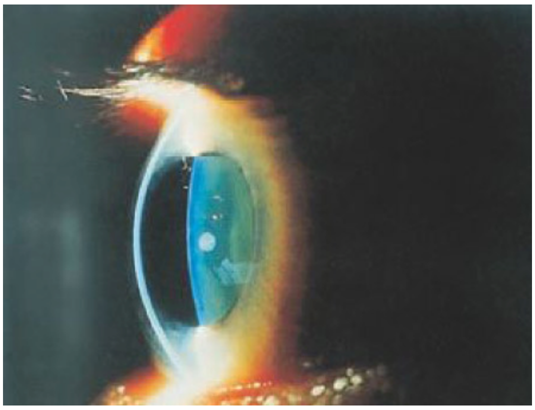
	Terminology	Definition
1	Advanced Facades	Distinguished from conventional ones
2	High-performance Facades	Assuming conventional facades are low-performance
3	Innovative Facades	Conventional facades are per definition no innovations
4	Smart Facades	Implying automated computer-based controls
5	Intelligent facades	Normally understood as identical to “smart”
6	Active Facades	Which only means dynamic in character
7	Interactive Facades	Implying reactions to external situation and user demands
8	Responsive Facades	Normally understood as identical to “interactive”

The authors believe that building envelopes that respond intelligently to the dynamic character of the available external conditions and internal occupant demands should potentially be able to give substantial reductions in energy use and peak power demand.

In addition to the long list of definitions of intelligent skins, Wigging and Harris (2002) developed a further definition as:

> "A composition of construction elements confined to the outer weather-protecting zone of a building, which perform functions that can be individually or cumulatively adjusted to respond predictably to environmental variations, to maintain comfort with the least use of energy. In such a skin, the adaptability of the façade elements is actuated instinctively through self-regulated adjustments to their configuration. Energy flows through the building fabric (in both directions) are autonomically controlled for maximum gain and minimal reliance on imported energy" (Wigging and Harris 2002:23).

In order to have a better understanding of the intelligence concept, many scholars established some biological and intellectual metaphors. Wigging and Harris (2002) highlighted human body intelligent systems, which enable the body to operate in an unconscious and conscious way. The human skin is a good example of adaptation. It adapts to temperature and humidity and can repair itself. A human eye is another example of supreme adaptability. It has a self- adjusting lens that respond to signals from the brain telling it what to look at. A shutter deals with light levels, whereas the automatic lubrications keep the eye moist and clean. An eyelid is a safeguard of the eye through an instantaneous response to the external dangers.



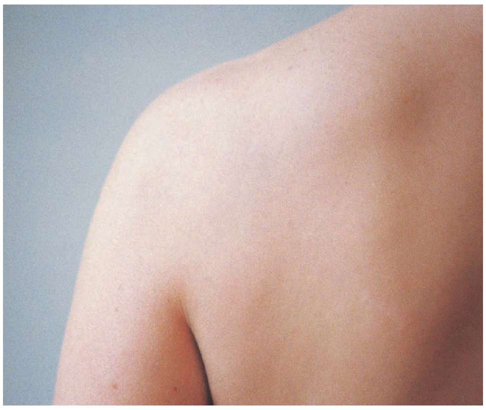


Figure 2.2 Adaptability of Human body. Wigging and Harris (2002)

Recently, the term “Dynamic Facades” started to be used by some scholars for intelligent facades. During the preparation of this study, no specific definition was found for this term. It is basically used to express the dynamic response of the façade to the internal and external environment.

Nikolaou, Kolokotsa and Stavrakakis (2004) considered any building skin that constitutes the screen between the internal and external environment. It adjusts the heat gains and losses to and from the interior spaces through static elements such as building mass or through automated devices. The main environmental elements which have to be regulated by the building envelope are: water, humidity, air, sound, light, view, heat, fire, pollution, safety and security. The more complicated envelope control should have the ability to resolve the conflict between them. To achieve a balance of flow of the above parameters, the building envelope will call for an automatic control to respond to the daily and seasonal variations of the internal and external requirements on one side and the occupant's needs on the other side. Daylight, for instance is desirable, whereas glare is not. Natural ventilation might be required, but noise is not. Solar heat gain might be desired in winter, whereas heat rejection should be considered in hot summers. Moreover, the transparency could be an added value for the views, but could be problematic for privacy. Any static design, no matter how well designed, can not respond to those conflicts, therefore, the adaptability attributes of the dynamic and intelligent facades becomes a necessity.

Kroner (1989) described dynamic buildings, enclosures, interiors and structures that have the ability to rotate, move in and out of the ground, or float on or seek protection below the water. The future dynamic enclosures according to the author are surfaces which have an inherent intelligence to change their physical properties according to programmed instructions or according to instructions given by an occupant. The buildings are no longer limited to predetermined static walls, windows, roofs and skylights. In spite of the futuristic vision which was presented by the author in his article, the current technological revolution has introduced telecommunications, miniaturization, micromechanics, digital systems, technologies and materials that make this vision possible today. Kroner was trying to elucidate the dynamic characteristics that would lead to paradigm shifts in architecture for the future.

Lawrence Berkeley National Laboratory (2009) as shown in Fig 2.3 developed a description for the dynamic façade that enable the building to reduce the lighting and cooling loads by means of solar and daylight controls on real time basis. These controls can also deliver increased comfort, view and amenity to occupants.

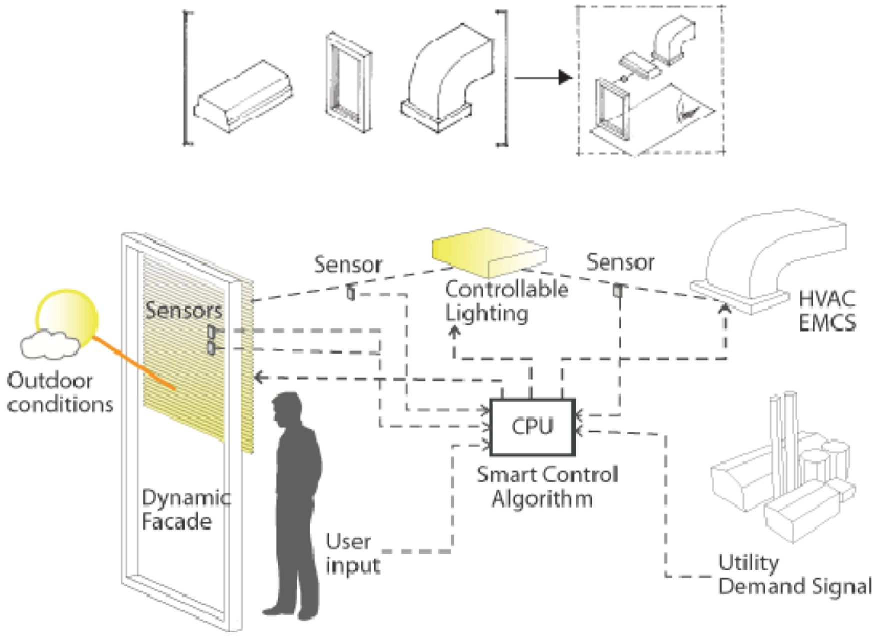


Figure 2.3 Dynamic Façade technology concept. (LBNL, 2009)

Components of Dynamic windows such as switchable electrochromic windows, automated shades and operable windows rely on sensors and smarts control that are networked with HVAC and lighting systems to achieve high performance. Lawrence Berkeley National Laboratory has conducted many field studies and computer simulations to examine this technology. Results indicate significant technical potential for dynamic systems and broad applicability for commercial buildings.

Harrison, Loe and Read (1998) stated that the development and growing refinements of dynamic facades has been a response to the growing awareness of energy conservation whereas previously façades were more or less static. The 1980s saw the emergence of dynamic façade systems that could respond to changing environmental requirements and client needs. It is this property coupled with the potential of computer technology which will differentiate the façades of the future.

Lee and Selkowitz (1997) and Selkowitz (2005) believed that the adaptation of dynamic envelopes offer the potential to achieve a near optimum energy-efficient environment. The dynamic qualities could improve the comfort, satisfaction, and productivity of the occupants while minimizing the energy cost and environmental impact. As a response to the changing conditions, a dynamic façade may be able to respond to an increase in solar heat gain by altering its thermal conductance, by operating a series of shading devices or altering glazing properties.

2.3 Features of Intelligent dynamic Facades

Wigging and Harris (2002) listed the 'genetic characteristics ' of the functional groups that make up intelligent skins. Table (2.2) summarizes the features of intelligent skins.

Table 2.2 Features of Intelligent Skins adapted from Wigging and Harris (2002)

Intelligent Feature	Description
Building Management Systems (BMS)	The brain of the whole system. The BMS is the central processing unit, receiving all of the information from the various sensor outstations and determining the appropriate control response to the actuating elements
Learning Ability	Via Neural networks and algorithms , it provides buildings with the ability to learn their energy status and thermal characteristics
Environmental data	Typical measurements of various environmental data will determine the control decision of intelligent technology
Responsive Artificial Lighting	The ability to deactivate or dim itself in response to adequate sensed natural lighting levels.
Daylight Controllers	Systems operate in response to information provided by sensors that measure outside light and solar intensity, and inside light levels and temperature.
Sun Controllers	Computer algorithms can determine real-time solar angles by the input of time, latitude and longitude data. Computer-controlled blinds, louvers and other protective shades, all of which can be regarded as solar control.
Occupant control	The ability for manual override control which often provided by on-screen control panels

	and hand-held remote control units.
Electricity generators	Generating electricity by renewables. As the intelligent building evolves, it may develop some of the in-built efficiencies of the human body –using every available resource through maximum conservation and recycling
Ventilation Controllers	Ventilation can be automatically regulated for increased effectiveness and greater occupant control by operable elements of the building fabric, such as retractable roofs, motorized windows and pneumatic dampers
Heating and Temperature controllers	Reducing the significant demands for space and water heating through the use of passive solar strategies, provided with more precise motorized control
Cooling Devices	Computer-controlled night-time ventilation for pre-cooling of the thermal mass. Cooled water distribution is optimized in the same way as the heating circuits
Double Skins	In the summer, the double façade can reduce solar gains by the ventilated cavity and stack effect. In the winter, the double façade will act as a buffer zone between the building and the outside, minimizing heat loss, and improving U-values. Intelligent control mechanisms have been used to regulate the admittance of air into the cavity automatically

According to Lee and Selkowitz (1997), the existing dynamic fenestration products include mechanically driven devices to mitigate the thermal or day lighting environment with shading devices. These systems are used to control the day lighting luminance, cooling loads, view and glare. Other dynamic systems are used in certain applications to control air and water flow.

Hayes-Roth (1995) listed the primary functions of intelligent and dynamic systems as;

1- Perception of dynamic conditions of the environment.
2- Reasoning to interpret perceptions, solve problems, draw inferences and determine actions.
3- Action to affect conditions in the environment.

Selkowitz and Lee (1997) briefed the Main components of dynamic and intelligent systems in the following;

- Actuators
- Sensors
- Control logic (Visual, Energy, Season,) which determines what action should be taken under certain conditions.

2.4 Automation and occupant response

The manual operation of the shade is a random and subjective process and does not contribute to reducing energy consumption for cooling and lighting. It has been observed that at least 30% of the people would leave the shades closed during cloudy days where transmitted useful daylight is reduced, and open during clear days where the cooling demands are increased (Tzempelikos, 2007).

Manual operation of windows or shades might work well in small scale buildings like homes whereas in larger buildings with high occupancy and operating design strategy with predictive algorithms, control by occupants must be replaced by more reliable automated controls. Such controls will be fed with data from the various ranges of building sensors. Motors, actuators or dynamic coatings must be reliably activated in response to control system outputs. Building automation systems track and display key system performance and perform recurrent diagnosis over time and report if any fault or errors are detected. The best systems provide building occupant feedback via the web to building operators (Selkowitz and Lee, 2004).

Colaco et al. (2008) assumed that for manual controlled shading devices, the occupants will not use blinds to optimize the quality criteria and energy conservation. They alter the shading position only when they are exposed to extreme discomfort. Skelly and Wilkinson (2001) identified many factors that influence the way in which occupants adjust blinds and most contain a high degree of uncertainty for the building designer. Skelly and Wilkinson (1998) used a wide-ranging literature survey to divide these variables into three main categories;

1- Comfort – no two individuals are alike.
2- Climate – no two days are the same.
3- Context – no two locations are the same.

Blinds have a huge influence on the occupant's perception of the internal environment. Studies have shown that occupant adjustment is largely triggered by a need to alleviate discomfort caused by glare, direct solar penetration or visual intrusion. The factors affecting whether conditions are comfortable or uncomfortable for an individual will vary with location and climate, orientation, building type, exterior obstructions, shading, and interior spatial design, as well as the needs determined by interior visual tasks and the desire of the individual occupant.

Kim et al. (2009) conducted a survey to explore the operation of actual motorized blinds in a 22 story office building in Seoul - Korea. It was found that 82.6% of all motorized blinds did not move. The occlusion index of the stopped blinds of almost opened (0~ 20 %) or almost closed (80~100%) was 39.8% and 33.1%, respectively. Motorized blinds require a higher initial cost than a manual blind, but do not produce better environmental performance. Therefore the application of automated blinds which can be controlled by sensors according to the conditions of external environment is necessary.

2.5 Solar Control and Dynamic Window Shading Devices

Solar radiation plays a key role in the design of buildings. It presents one of the significant sources of potential heat gain of indoor spaces, especially in hot climate zones and summer seasons. However, solar radiation may still cause a source of occupant discomfort in temperate zones. On the other hand, it represents one of the most efficient and abundant source of heating in cold climates. The luminous efficacy of direct and indirect solar radiation makes it the most efficient source of natural lighting. However, the light and heat, which is sent by the sun is not always desired. Thus, the selection and design of a proper shading device is challenging, in terms of making a compromise between heat rejection in hot climates and heat capturing in cold climates , all whilst maximizing daylight and achieving visual comfort.

One of the challenges for the use of daylight in non-domestic buildings is formed by variable and potentially conflicting demands of transparency versus privacy, openness versus insulation and access to daylight versus solar shading. In addition, due to the greenhouse effect, all daylight allowed indoors generates heat. As this heat gain can only partially be avoided by means of solar shading and blocking near infrared radiation, an advisable strategy would be to avoid the admission of superfluous daylight indoors and correspondingly to use the available daylight sources in the most effective manner possible (Wyckmans, 2005).

Larasati (2004) classified shading devices using different criteria. He pointed out that many shading devices have the ability to adjust their orientation using various control strategies to respond to external and internal conditions. The list of shading devices includes:

- Louver overhang
- Sun catcher
- Transparent overhang
- Temporary overhang
- Temporary awning
- Mirror Sloped light shelf
- Precast sloping light shelf
- Dynamic light shelf and sun-catcher,

- Multiple horizontal louver
- Dynamic vertical louver

Dynamic exterior shading devices are more effective than interior shading devices in reducing solar heat gain because they block radiation before it passes through a window (Loutzenhiser et al. 2007 cited in Colaco et al. 2008). It is well recognized that with the use of internal shades, such as blinds or curtains, the short-wave radiation passes through the window glass layers and hits the shade. Some of the radiation will be reflected outside and the rest will be absorbed by the shade, which will heat up and increase the internal room temperature. This process depends significantly on the colour and texture of the shade.

Kim and Park (2009) studied the optimal control of blinds systems which are used in building facades to provide thermal and visual comfort and classified the studies of blind systems with respect to performance into three categories;

1- Static and not optimal
2- Dynamic but not optimal
3- Dynamic and optimal

2.6 Findings of previous studies of Dynamic Systems

The objective of this section is to examine the status of published research on key building parameters: dynamic shading devices and daylighting controls and orientation. Eight scientific papers covering a period from 1994 to 2009 are summarized and discussed. The intention here is to explore the procedures proposed in scientific literature on how the parameters can be tuned for effective utilization of technology and energy saving in office buildings. The discussion of the papers will be followed by a comparison between the results, which will give a better understanding of the subjacent issues and possibly identify critical gaps in knowledge that need to be filled by more studies.

Newsham (1994) examined the impact of manual control of window blinds and electric lighting on building energy consumption. A typical south facing office in Toronto was used for the study. The modeled room was 4.5X7.5X3.0 (m). One third of the south wall was double glazed with clear glass (U value 2.6 W/m^{2}K). An internal window blind excluded 50% of solar gain and 80% of daylight from the room when fully closed. The HVAC system heating and cooling set points were 21°C and 24.5°C respectively. A 500 Lux was provided at desk level. Occupancy of the office was considered from 08:00 to 17:00.

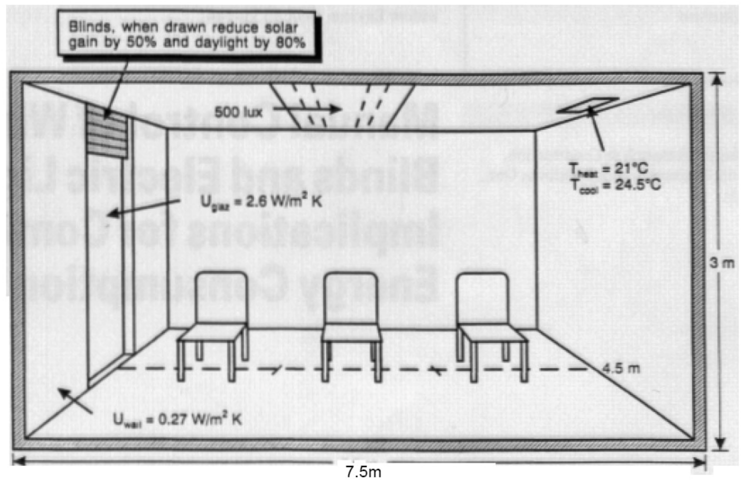


Figure 2.4 Characteristics of the modeled office (Newsham, 1994).

For this study, four blind control strategies were considered:

- Permanent (always closed)
- None (always open)
- Manual (obeying a proposed algorithm)
- 7 months (blinds always closed April - October, and always open November - March)

Two lighting control strategies were considered:

- On for all occupied hours
- Manual control (obeying a proposed algorithm).

Out of 24 simulations carried out in the study, Newsham (1994) concluded for a manual control of blinds and electric lighting an increase of the annual lighting energy by 66%; less cooling energy by 7%, heating energy increase by 17%. Consequently the total of the thermal and lighting energy consumption was increased by 33%.

The effect of slat angle and absorptance on the heating and cooling loads of buildings in Seoul (South Korea) was studied by Cho, Shin and Zaheer-Uddin (1995). The study was carried out by developing a model for the window with inside venetian blinds which was incorporated later into the TRNSYS computer program. The model building floor area was $30m^2$ with a 3 meter high ceiling. The size of the south facing window was 3.0 m by 1.0 m high. Weather data of Seoul was used for the simulations.

The simulation runs were carried out by varying the slat angle from -80° to 80° in 20° intervals. The slat absorptance was kept constant at 0.5. The results showed that the variations of slat angle caused 2-8% change in the heating load compared to the case with zero slat angle, and most of this increase occurred during daytime. The results also showed that the total cooling load of double pane window with venetian blinds was 5-20% less than the case without blinds when the slat angle was varied from -80° to 80°. The results show that the slat angle had a significant effect in reducing cooling loads during the daytime. Figure 2.5 shows the effect of slat angle on the nighttime and daytime cooling loads.

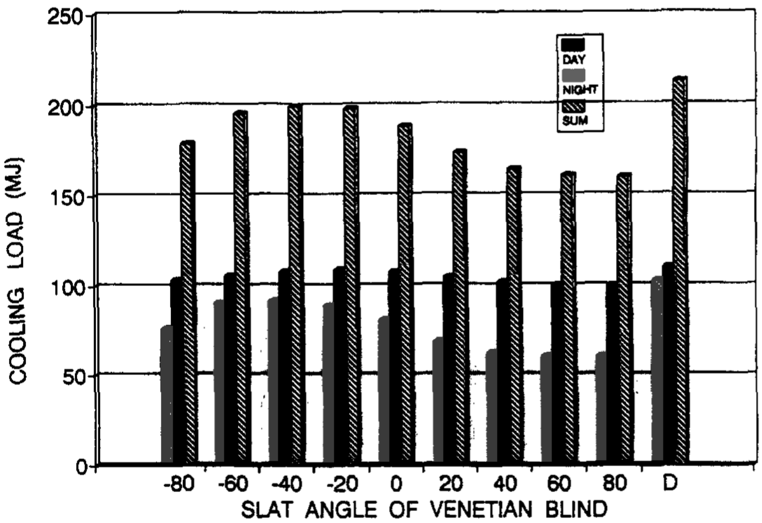


Figure 2.5 Nighttime and daytime cooling loads for 7 days (Cho, Shin and Zaheer-Uddin., 1995)

Lee, DiBartolomeo and Selkowitz (1998) used two full scale offices in Oakland and California to explore the potential energy saving by using an automated venetian blind operating in synchronization with a dimmable electric lighting system to block direct sun, provide the design workplace illuminance and maximize view under realistic weather conditions. The two test rooms were fully furnished with nearly identical building materials of commercial offices. Each test room was 3.71 m wide by 4.57 m deep by 2.68 m high. The southeast facing windows in each room were exposed to the same interior and exterior environment. The existing window system consisted of a 6 mm single-pane, green-tinted glass (glazing properties: Tv=0.75, SHGC =0.46, U-value=6.24 W/m^2 K) with a custom aluminum frame. The window opening was 3.71m wide and 2.74m high with five divided lights ranging in width from 0.61m to 0.67 m. The visible glass area was 7.5 m^2. The window-to-exterior-wall-area-ratio was 0.65. The window was recessed 0.43 m from the face of the building and had 0.13 m deep interior and 0.03 m deep exterior mullions. A 0.127 m wide, curved slat, semi-specular white aluminum venetian blind was fitted in a white painted wood frame and placed 0.127 m away from the interior face of the existing glazing system. The blind covered the entire vertical height of the window and was not retractable, only the angle of the slats could be altered. A small direct current motor drive at the base of the window blind was used to alter blind angle in synchronization with the lighting controls via National Instruments Lab View computer control.

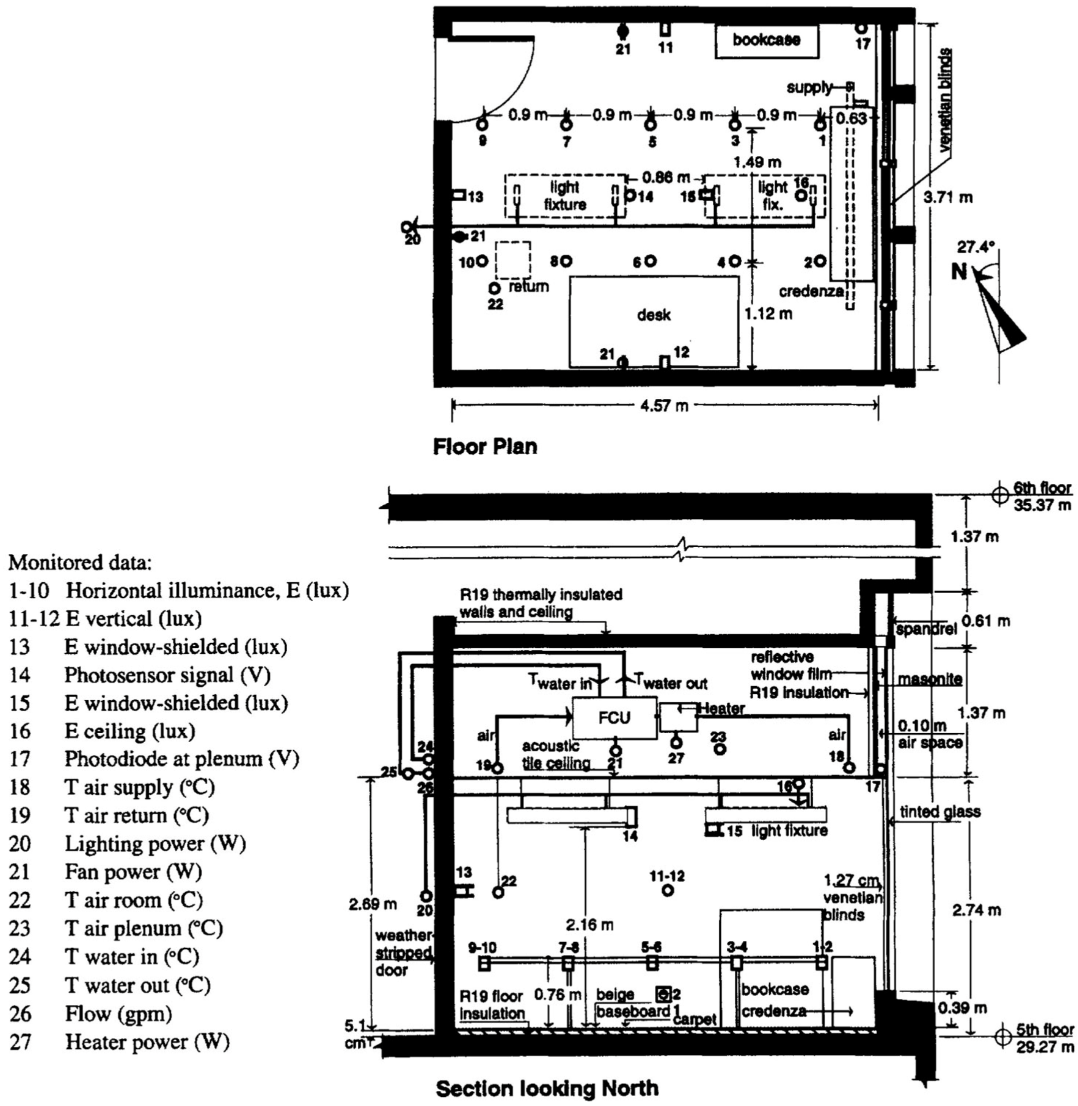


Figure 2.6 Floor plan and section view of full-scale test room (Lee, DiBartolomeo and Selkowitz., 1998).

Lee, DiBartolomeo and Selkowitz (1998) used two systems to illustrate the energy savings of the dynamic systems;

- The Base case system: the venetian blind were set to one of three fixed and static positions (45°, 15 ° and 0 °). For the base case with no day lighting control scenario, the electric lights were set to full power, whereas for the base case with lighting control, the lighting system was designed to supplement the daylight to achieve the desired illuminance of 510 Lux.

- The Prototype system: the venetian blinds were activated every 30 seconds to block direct sun, and maintain the illuminance of 540 to 700 Lux. If no daylight is available, the blinds were set to maximize the view (Horizontal).

The authors concluded that savings with the integration of automated Venetian blinds with day lighting controls ranged from 7% to 15% and 19% to 52% for cooling and lighting loads respectively compared to a static 45°blind angle. With no day lighting control , the dynamic venetian blinds achieved a lighting energy saving of 22-86% against any static blind angle for overcast to clear sky conditions , whereas an average cooling load reduction of 28 ± 5% on clear sky in July against the 0° blind angle

Guillemin and Morel (2001) developed an innovative and self adaptive integrated system for building energy and comfort management. Two rooms (4.75mX3.6mX2.8m) were used for the experiments. The rooms had a south facing window with an area of 5.75m^2 (U-value 1.4 W/m2K).One room was equipped with the integrated dynamic system whereas the other room was equipped with a conventional controller (no automatic blind control, no automatic artificial lighting control and proportional heating controller with saturation). The room controllers were exchanged frequently to reduce the experimental bias due to the room characteristics.

The authors applied fuzzy logic techniques for an automated shading device controller capable of adapting to the user behavior and to the room characteristics. User adaptation was achieved by means of genetic algorithms that optimize the parameters of the fuzzy logic controllers. The function of a shading device was split into two parts depending on the user presence. With the detection of room occupancy, priority was given to visual comfort, while unoccupied priority was given to thermal aspects (heating/cooling energy saving). Four different device categories were considered for the control: the heating/cooling system, the ventilation, the blinds (shading devices) and the artificial lighting.

The integrated system was built on the principle of three nested control loop levels. First loop (Level 1) made the translation from physical values to the appropriate commands of the corresponding device. Second loop (Level 2) incorporated domain knowledge and used adaptive models for realizing a smart global control strategy. The third loop allowed a tuning of the Level 2 rule base using genetic algorithm (GA) for continuous adaptation to the real building and weather data conditions and to the user requirement and wishes with the detection of user presence controller switched to the visual optimization mode. In this mode, the algorithm was divided into two parts. The first part determined a maximum blind aperture in order to avoid glare (using a fuzzy rule base) and the second part tried to find the blind position (below the maximum value) that led to the inside illuminance corresponding to the illuminance set point chosen by the user. When the room was unoccupied for a certain amount of time (typically for 15 minutes at least) the controller switched from the visual optimization to the energy optimization algorithm. Each night, a process of adaptation was undertaken. By the application of GA's, the system learns to adapt itself to the user's behavior and to the parameters of the building and the environment. The most significant quantitative result is the total energy Consumption during the first 94 days of experiments. The Integrated System saved 25% of the total energy comparing to the conventional controller.

Carbonari, Rossi and Romangnoni (2002) studied the optimal orientation of buildings in relation to the type of adopted shading devices and their control logic, in case of adjustable ones. A case study of a room of an office building with two working places was used for this study. Room's dimensions were 6.0 X 5.0 X 3.3 m. All five surfaces of the enclosure were considered to be adiabatic, whereas the sixth wall was external and fully glazed. The external wall was composed from the exterior to the interior as follows; adjustable louvers, double glazing of 4mm thickness with 6mm air gap and internal diffusing blinds.

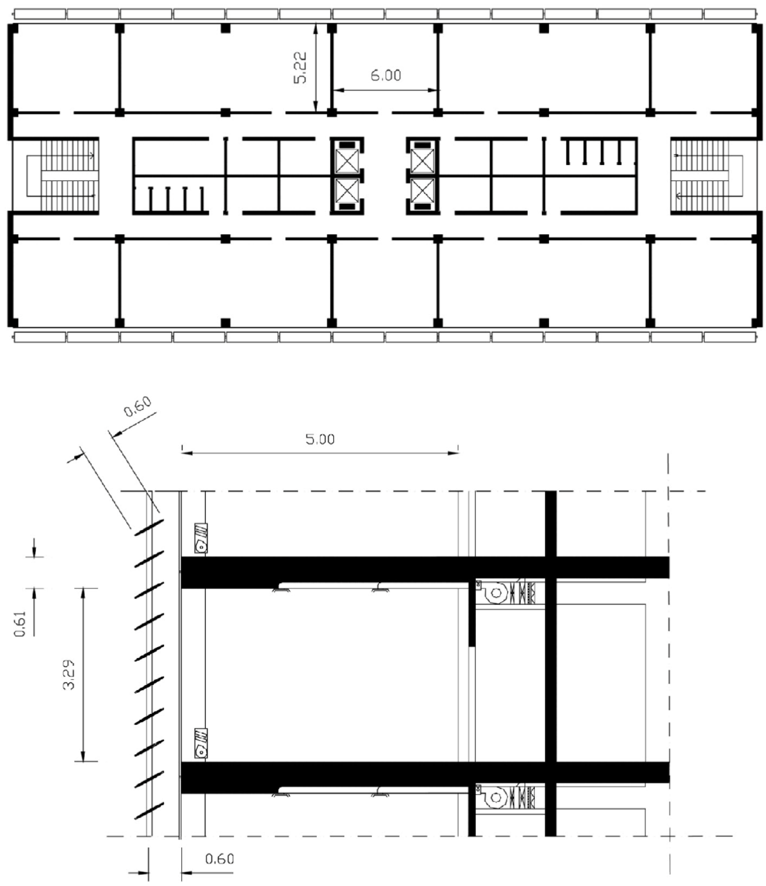


Figure 2.7 Floor plan and section of the office module (Carbonari, Rossi and Romangnoni, 2002)

Three different configurations were analyzed;

- No external shading elements.
- External fixed louvers 45° tilted.
- Automatically adjustable louvers with seasonal control logic which allowed at each time the entrance of the usable solar radiation. In this case the tilt angle was adjusted to achieve an approximated energy balance.

The simulations were performed for three Italian cities; Venice, Rome and Tarapani. Based on the results of the simulations, it was found that the automatic control of louvers tilt angle with seasonal logic was in general the optimal configuration. The benefits of this system were more relevant to the north city where the heating was needed, and became more irrelevant to the south where the fixed louvers seemed to be a bit more relevant due to the fact that both direct and diffuse solar radiation were shielded, and the energy cooling needs were furthermore reduced. The 'no external shading' case was in general the worst configuration.

The concept of a dynamic window system was studied by Athenitis and Tzemplikos (2002). An out door test-room in Montréal of 2.3m wide X 2.7 m wide X 2.4 m high was used to present a methodology for detailed daylighting numerical simulation of an office space with a dynamic window system. The window consisted of integrated motorized blinds. The window was double glazed with low emissivity coating and highly reflective motorized aluminum louvers integrated between two panes; its dimensions was 1.08m X 1.08m. The louver's width was 35mm and 6mm thick and could rotate in both directions (180°) with a fixed vertical positions (i.e. could not retract). Several sensors were employed to measure radiation and daylight.

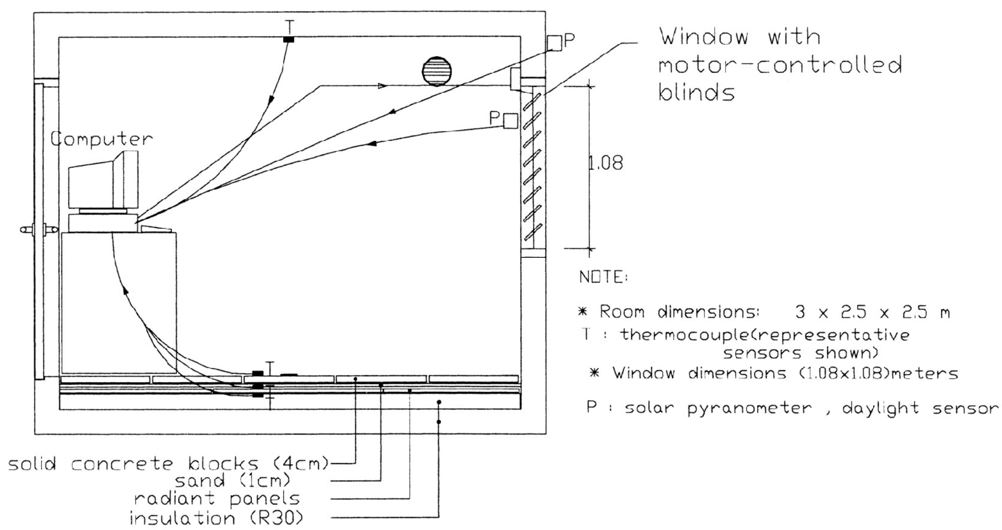


Figure 2.8 Section through the office module (Tzemplikos and Athenitis, 2002)

Based on the experimental measurements in an outdoor test room, Tzemplikos and Athenitis (2002) developed daylight transmittance equations for a dynamic window system, as a function of sky conditions (clear and overcast sky), blind tilt angle and angle of solar incidence. The energy savings using the above mentioned methodology might exceed 75% for overcast day and 90% for clear sky days, comparing with the case of no daylighting/dimming control. A proper control of the blinds blocked direct solar radiation and reduced glare. In case of partly cloudy days, the building automation system determined the type of the sky conditions at regular times based on the exterior sensors

Ochoa and Capeluto (2008) explored the influence of incorporating intelligence in buildings in hot climates from the perspective of energy consumption and user comfort with an emphasis on lighting. An office module was studied in the city of Haifa, which was located at the Mediterranean basin to analyze the influence of active features and passive design. Three variation series were evaluated against the base case facing west with no shading and switched on lighting during working hours. The base case module was 7.0 X 7.0 X 2.6m except for one case where the module was 10 m deep in order to test the influence of building depth. The external wall was made of concrete blocks with U value of 0.75 W/(m^2 °C). The initial windowpane was 12mm with clear double-glazing.

The three tested variation series were;

1- Base case plus an addition of active features (reflective radiation/glare control blinds operating automatically at a fixed angle, stepped lighting controls, low emissivity glass and forced ventilation).
2- Base case plus adding intelligent passive design strategies features (fixed shading, stepped lighting controls, low emissivity glass, etc.).
3- Use of mix of passive and active intelligent features.

Despite the wide range of cases presented in this article, only simulation results of the external blinds using different control strategies and the use of electrical control are discussed. Table 2.3 presents a list of some results of simulations.

Table 2.3 Characteristics of selected simulation cases

Case	Orientation	Glazing	Blinds/ Activation by	Light Control	Night Ventilation	Yearly Energy Performance** (kW/m2)	% of Energy Reduction to the basecase
1	West*	Double Glazing Clear	None	Always on	No	61	-
2	West	Double Glazing Clear	External/Glare+ Radiation	Always on	No	42	31.1%
3	West	Low Emmisivity	External/Glare+ Radiation	Stepped	Fan with setpoints	35	42.6%
4	West	Double Glazing Clear	External/Fixed	Stepped	No	40	34.4%
* The basecase							
** An approximation figure extracted from the charts including (Cooling,Heating,lights and fans)							

The results in Table 2.3 show that there was an energy reduction of approximately 31.1% due to the use of external blinds which were activated by glare and radiation. Adding the use of low emissivity glass and stepped lighting control with a night ventilation approach increased the energy reduction by 42.6% compared to the base case.

Kim and Park (2009) tried to address the difference between static vs. dynamic control of interior and exterior blind systems in office buildings. They developed a test model room with a rectangular space 2.8m(H), 3m(W) and 6m (D) , which was an assumed parameter of a typical office floor. The test room had south facing window and consisted of double glazing. The blind system was considered to be inside or outside the test room with a 0.5 reflectivity of the slats and 25mm separation of slats. Each of the following angles 0 ° , 45 ° , 90 ° and 135 ° was assumed to be a manual slat angle in addition to the base case ‘no blind’ was included.

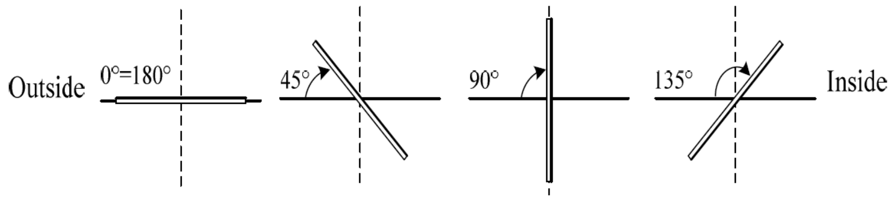


Figure 2.9 Angle of blind slat (Kim and Park, 2009)

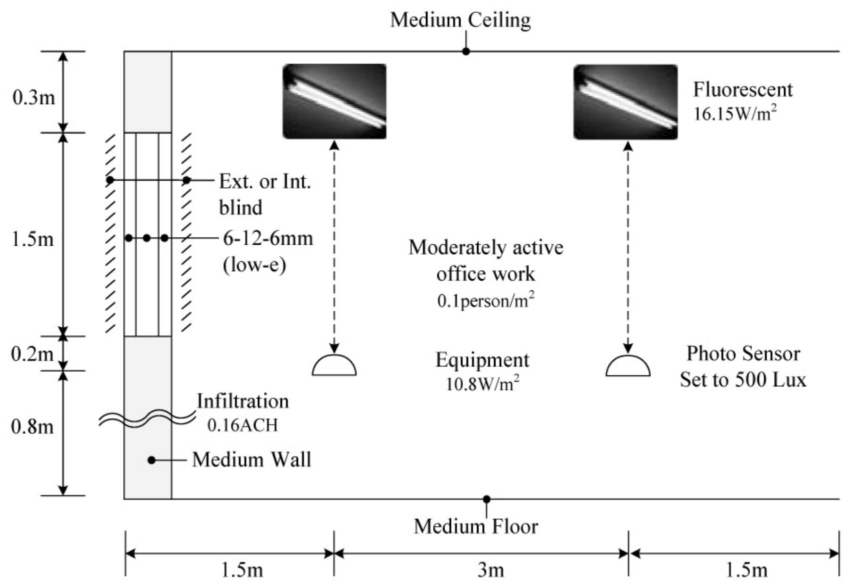


Figure 2.10 Simulation model (Kim and Park, 2009)

The simulation runs were conducted under clear sky conditions located in Seoul in Korea. The optimal control simulation runs were made for different seasons (interior/exterior) and daylighting control (with vs. without). The results of the simulation for the studies cases are summarized in table 2.4.

Table 2.4 Results of Simulation adapted from Kim and Park (2009)

Case	Blind Position	Orientation	Daylight control	Optimal Angle	Energy Savings (compared to manual control of blinds)
1	External	South	Yes	0°-10° or 160°-180°	0.4 - 8.2%
2	External	South	No	90° daytime & 0° Nighttime	0.6 - 26.6%
3	External	West	Yes	Varies	Not mentioned by the author
4	External	West	No	Varies	4.1 - 32.7%
5	Internal	South	Yes	0° to 20° daytime & 180° Nighttime	22.9 - 41.1%
6	Internal	South	No	150°-180°	9.1 - 18.2%
7	Internal	West	Yes	0°-30° or 150°-180° Daytime & 90° Nighttime	10.4 - 35.2%
8	Internal	West	No	0°-40° Daytime & 90° Nighttime	6.7 - 16.9%

It was found that the energy performance of blind systems can be significantly improved by applying daylighting control. In other words, ‘manual control with daylighting control’ can perform better than ‘optimal control with no daylighting control’ except for the slat angle of 90°. In the case of daylighting control, a horizontal slat angle of around 0° was the best for energy savings, regardless of the season. Careful integration of the three factors (seasons, position, and daylighting control) and operation of blind systems helped blind systems act as a true energy saver as well as environmental controller.

Establishing a comparative analysis of the studies above require relationships between two or more variables and the documentation of differences and similarities in a systematic approach. The quantifications of the relationships between them are essential to the value of the study (Carpi and Egger, 2008). Due to the fact that each study was conducted in different settings under specific conditions, the comparison between the results of the various cases undertaken in these studies is not appropriate. However, some parameters that play a key role in the results of the studies are summarized as follows;

- Geographical location and statistical weather data.
- Orientations (North, West, South and East).
- Window configuration (dimension, materials, position, etc.)
- Types of tested blinds or louvers (position, size, angle, control strategies, etc.).
- Use of lighting control strategies.

In general an analysis can be drawn based on the following factors that correspond to this research:

Use of lighting control:

The use of various lighting control methodology was examined in various researches. Tzemplikos and Athenitis (2002) concluded a high percentage of lighting energy saving (92% for clear days) whereas Kim and Park (2009) achieved approximately 90% reduction of lighting energy for the summertime and around 77% in a typical winter day. According to these studies and others, the use of lighting control methodology has a potential of high electrical energy savings.

Use of static blinds or louvers:

Fixed external blinds with stepped light control were studied by Ochoa and Capeluto (2008). They detected an overall energy saving approximately 35% of the base case without blinds and lighting control whereas Kim and Park (2009) found out that the use of static fixed external blinds achieved an energy saving of 22%, 21%, 27% & 37% for the angles 0°, 45°, 90° and 135°, respectively compared to the base case when no day light control was used. After applying a day light control for both the base case and the case with blinds, the saving was registered 0% to 7% for the same angles. It is important to highlight here that the use of daylight control achieved a considerable reduction of energy to the base case (approximately 37%).

Use of dynamic systems:

Testing the dynamic systems was found to achieve a good percentage of energy savings. Lee, DiBartolomeo and Selkowitz (1998) concluded that the prototype dynamic system achieved a daily lighting energy saving range from 22% to 86% compared to the base case with static blinds (at any angle). This saving varied based on the availability of daylight in clear and overcast days. The cooling loads were noticed to be reduced by approximately 28% by the prototype compared to the base case with static horizontal blind. Guillemin and Morel (2001) predicted a 25% reduction of energy due to the integrated dynamic system comparing to the conventional system (no automatic blind control, no automatic artificial lighting control). The use of proper control strategy for the blinds is vital to achieve a reasonable saving of the energy consumption. The study, which was undertaken by Newsham (1994) showed that the use of blind system itself without a proper control strategy would not contribute to energy savings.

2.7 Challenges of Dynamic Systems

Dynamic facades today are characterized by three key features: systems integration, dynamic operation and changing life-cycle performance issues. The process of developing any new technology faces many challenges that need to be addressed. Selkowitz, Aschehoug and Lee (2003) and Wigging and Harris (2002) discussed some of these challenges.

1. *Initial cost of the façade hardware :*

   In the majority of cases, such innovative facades and advanced technologies including the automation and control systems will add to the initial cost when compared a base case with conventional facades. Sometimes, part of the initial cost will be offset by other design changes such as reducing the size of the chillers or eliminating the need for conventional shades due to the use of dynamic ones. The additional cost of the dynamic system raises many questions concerning the viability of such systems.

2. *More developed automation and controls for optimal operations*

   Especially in large buildings, more advanced reliable predictive algorithms and automated controls must be developed to ensure a successful implementation of dynamic skin systems. Motors, actuators or dynamic coatings must activate reliably in response to control system outputs.

3. *Better simulation , design and operation tools*

   Unlike the conventional facade design, the dynamic facades must be studied at the early stages of the design using advanced simulation tools, where a virtual model is created and analyzed. A new degree of tool integration is required to allow a proper link between the thermal, lighting, ventilation systems in the same model. These tools must be updated and developed to adapt with the fast technological pace.

4. *More Field testing of design concepts and technologies*

   Due to the nonexistence of the perfect modeling tools, mock-ups and test rooms are imperative to give a good level of performance, where the human factors and other variables in the real world are considered.

5. *Maintenance of dynamic facades*

   With the automated skins, and moving parts, comes a greater susceptibility to breakdown, and a resultant need for increased maintenance, which might have an impact on the cost. This is one of the main reasons for the slow acceptance of the market for these systems. The ability of a building to examine itself regularly and provide a regular report about its status and if there is any problem to be addressed is one of the smart building features.

2.8 Abu Dhabi - UAE climate

Abu Dhabi is the capital of UAE, and the seat of federal government. Abu Dhabi’s geographical coordinates are 24° 28' 0" North, 54° 22' 0" East. It is the largest of seven emirates comprising the UAE, occupying more than 80% of the country’s total land mass and featuring a coastline that stretches over 700 kilometers. Nearly 200 islands fall under the Abu Dhabi territory .Abu Dhabi holds 9% of the world’s proven oil reserves and almost 5% of the world’s natural gas, which gives it one of the highest gross domestic products (GDP) per capita in the world. Abu Dhabi has grown to be a cosmopolitan metropolis. Its rapid development and urbanization, coupled with the relatively high average income of its population, has transformed Abu Dhabi, making the city more Westernized than most other Arab cities. Today the city is the country's center of political, industrial activities, and a major cultural and commercial centre due to its position as the capital (Wikipedia, 2009) and (Abu Dhabi Government, 2009).

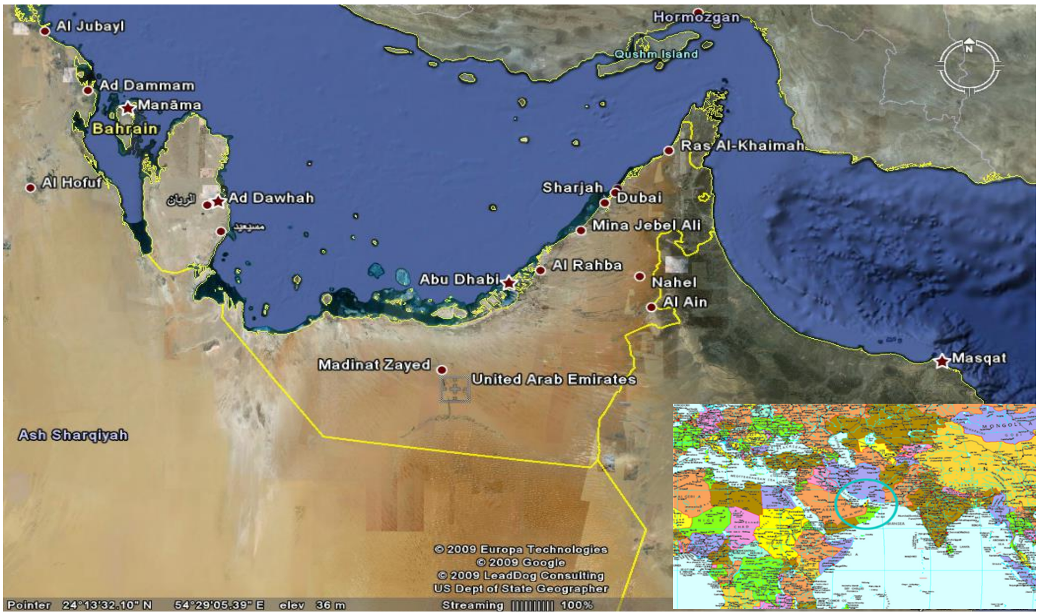


Figure 2.11 UAE map (Google Earth, 2009)

Climatic analysis

Temperature

Statistical data extracted from IES_VE weather database shows a fluctuating temperature over the course of a year in Abu Dhabi. August is the hottest month where the temperature would hit over 45 °C. December, January and February are the winter months whereas June, July and August are the summer months.

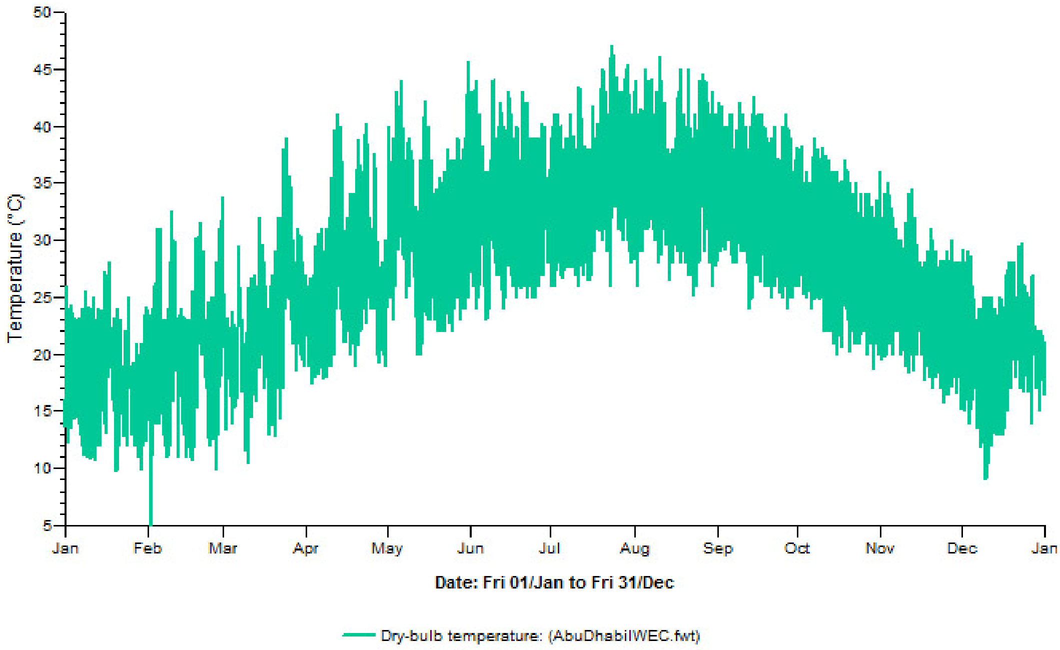


Figure 2.12 Abu Dhabi Annual temperature (IES-VE Database)

Relative Humidity

Humidity in Abu Dhabi is highest in winter months. The humidity graph shows that it may reach up to 100% at certain hours in certain days.

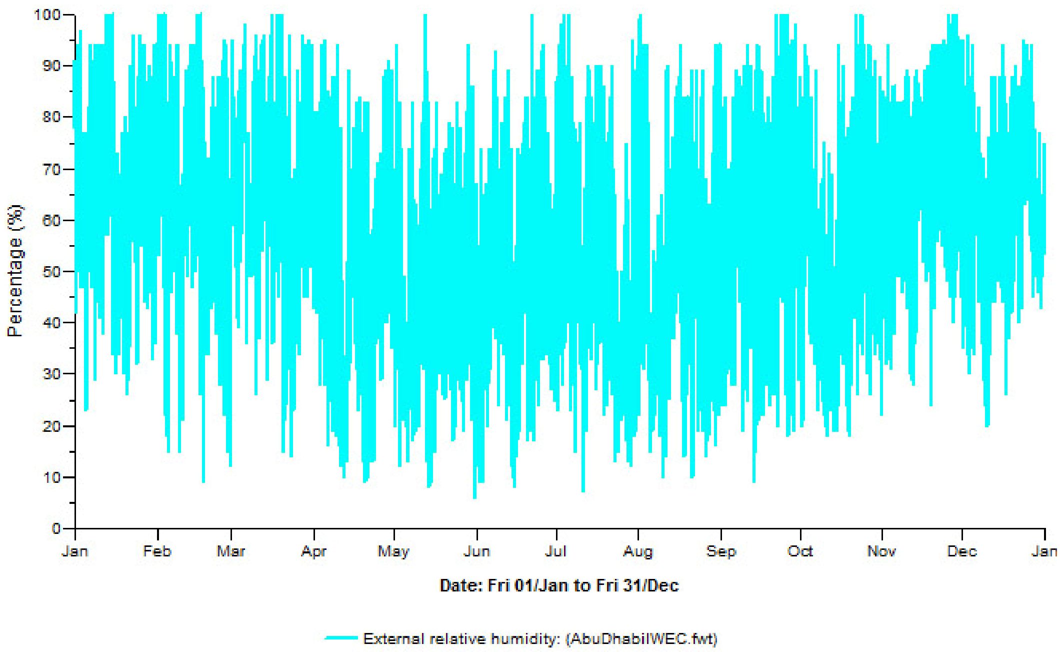


Figure 2.13 Abu Dhabi Annual Humidity (IES-VE Database)

Precipitation

Rainfall is relatively low in Abu Dhabi with an average number of rainy days about 12 days annually .The Average yearly rainfall, of about 89mm, comes mainly in February and March.

Table 2.5 Statistical data of precipitation in Abu Dhabi (World Metrological Organization, 2009)

Month	Mean Total Rainfall (mm)	Mean Number of Rain Days
Jan	3.9	0.8
Feb	42.0	3.5
Mar	24.8	3.9
Apr	7.3	1.4
May	Trace	0.0
Jun	0.0	0.0
Jul	Trace	0.0
Aug	0.1	0.1
Sep	Trace	0.0
Oct	0.0	0.0
Nov	1.8	0.2
Dec	9.0	2.1

Solar radiation

The direct solar radiation is high during the whole year. It reaches up to 967W/sqm. Islam et al. (2009) recorded the daily mean and monthly average direct beam radiation values higher in the months of April, May and June, whereas comparatively lower values were found in July and August and the winter season.

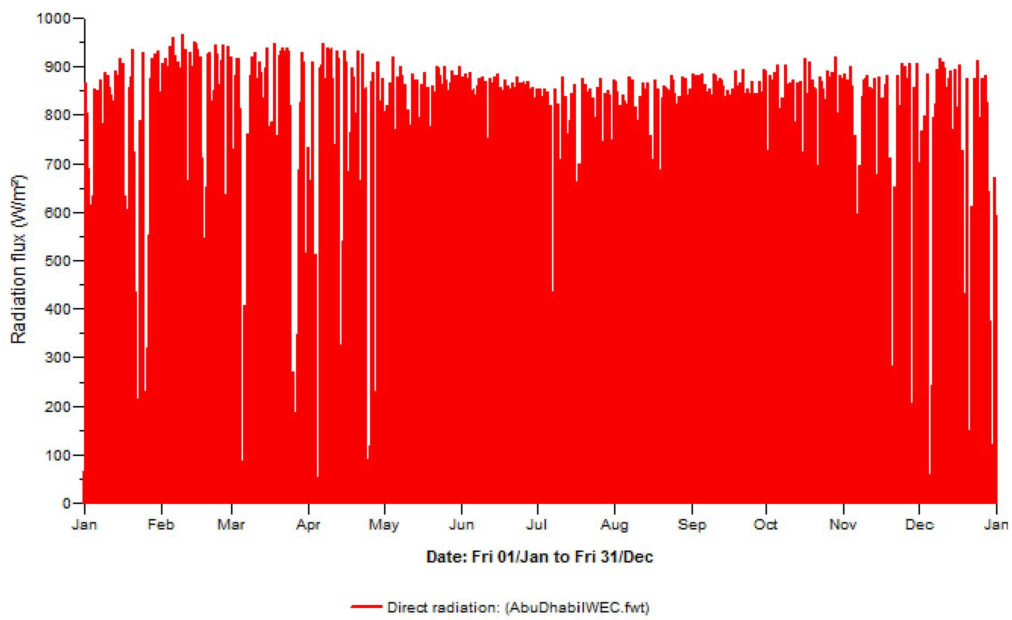


Figure 2.14 Abu Dhabi Annual direct solar radiation (IES-VE Database)

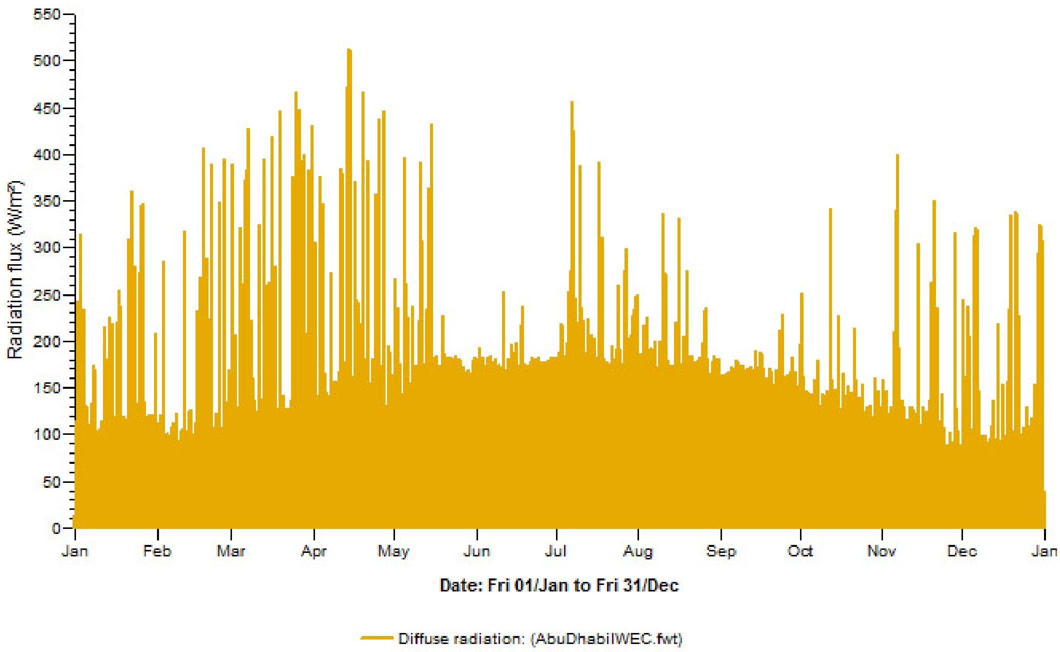


Figure 2.15 Abu Dhabi Annual diffused solar radiation (IES-VE Database)

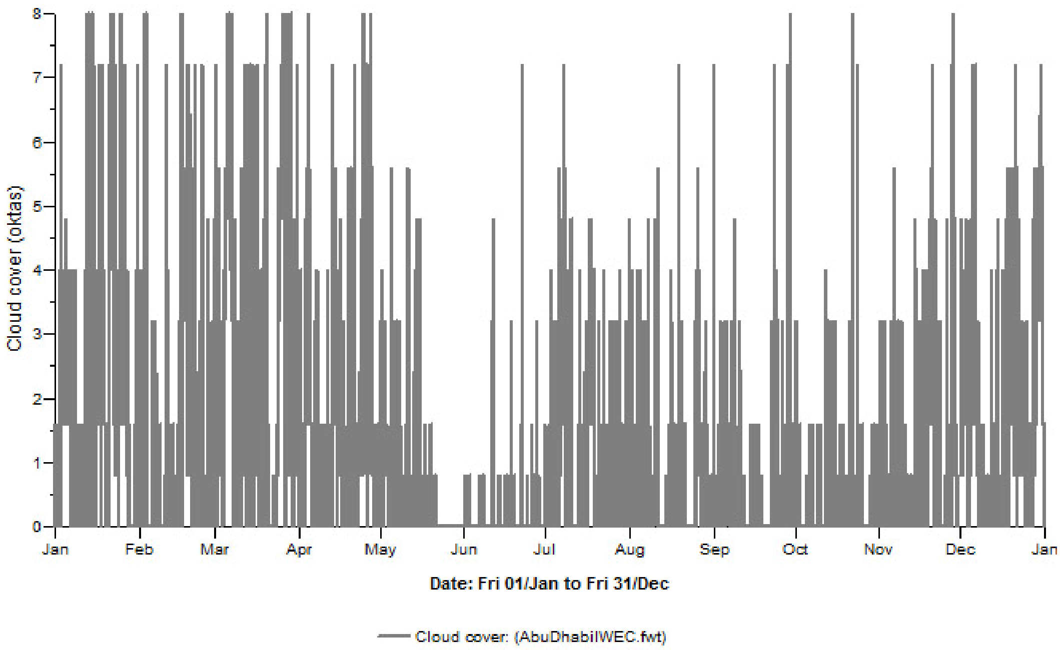


Figure 2.16 Abu Dhabi Annual cloud cover (IES-VE Database)

Wind speed and direction

The prevailing wind is from North West direction with an average speed between 2 m/s to 6 m/s. Figure 2.18 shows a maximum wind speed of 24m/s registered in January.

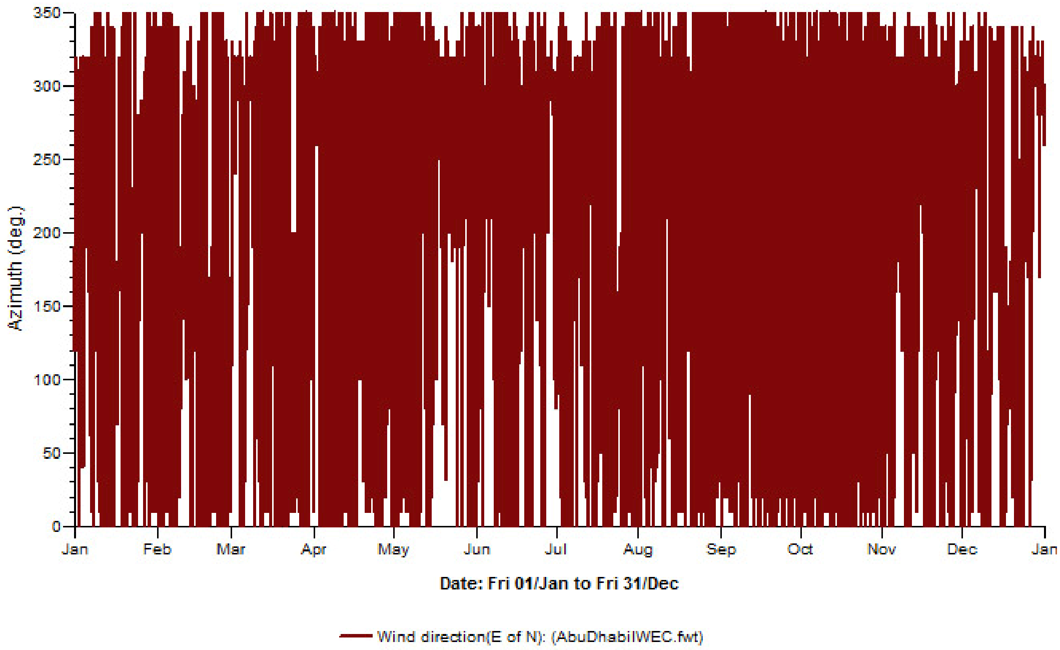


Figure 2.17 Abu Dhabi Annual wind direction (IES-VE Database)

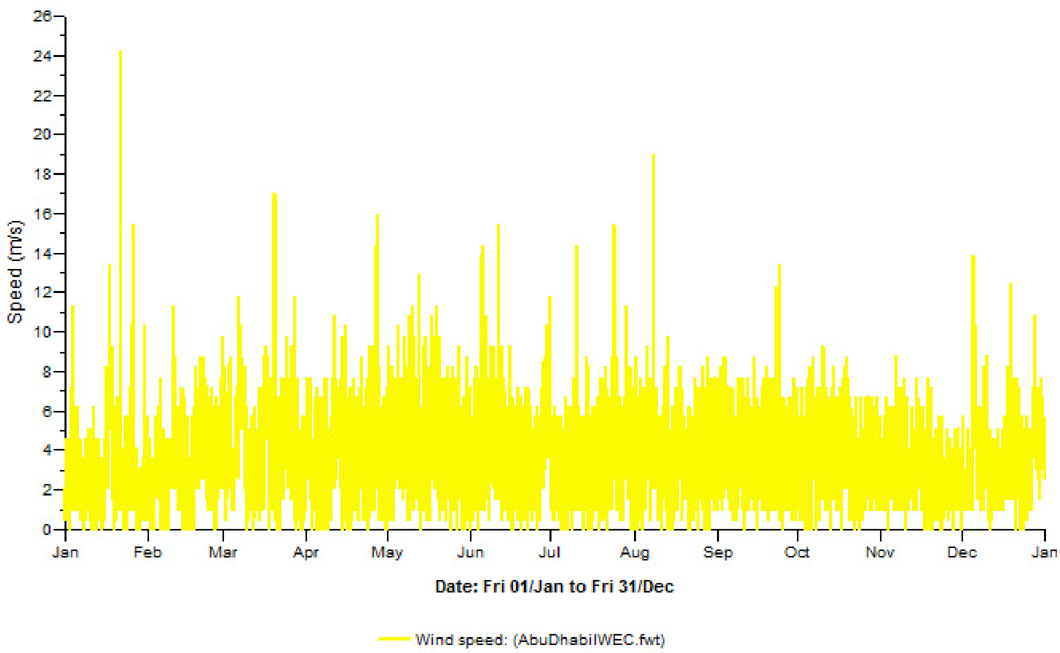


Figure 2.18 Abu Dhabi Annual wind speed (IES-VE Database)

2.9 Dynamic Facades in UAE

Since the establishment of the UAE, the federal government used the country's oil wealth for country growth and improvement the life of citizens, thus achieving significant progress in a very short time. Aboul Naga and Elsheshtawy (2001) highlighted the fact that the building industry in the UAE, particularly in Abu Dhabi Emirate, is forming a large portion of the economy. During the development process, a rapid growth within the Gulf area witnessed active construction that, in some instances, neglected the impact on the environment and human activities.

Radhi (2009) addressed the potential impact of global warming on the UAE. The change in atmospheric pollution and increases in Green House Gas emissions were the main reasons behind the tendency of the climate of UAE to get warmer. This tendency will have an impact on the built environment and the energy use in buildings. Radhi revealed that The Environment Agency of Abu Dhabi and the Ministry of Energy stated that temperatures in the UAE regions could increase while precipitation levels could significantly decline by the end of the 21st century.

Several ongoing projects in the country are planned to mitigate the potential impact of climate change. As the largest state of the United Arab Emirates, Abu Dhabi has initiated mage projects for advancing sustainable energy technology to address climate change. With plans to be a world leader especially in solar power, the emirate is set to complete the entire Zero-Carbon Masdar City by 2015. To ensure an appropriate implementation of the new vision, local building regulations such as Estidama in Abu Dhabi have been developed to ensure its sustainability goals and aspirations are well rounded. Its main focus is to influence the rapidly changing built environment. The implementation of such regulations has created a major incentive for various energy technology providers abroad to offer their solutions to improve the construction industry and develop energy efficient buildings (Urban Planning Council, 2009).

Bahaj, James and Jentsch (2008) believe that a radical change of built forms in the near future appears unrealistic in spite of the desire for such change from a sustainability perspective. Therefore, advanced glazing and solar control technologies are vital to develop an energy efficient strategy of highly glazed buildings and improve the current situation. The authors gave an overview of some potential glazing and façade technologies that might be beneficial to improve the current standards in this part of the world.

The booming construction technology and the energy initiatives in the country have been an incentive for some technology providers to promote the dynamic façade as a state of the art technology for energy efficient designs. The good performance that has been achieved in other parts of the world, especially USA and Europe has been used to support their promotion. Somfy for instance, is a collective group of companies and brands with a worldwide presence in over 53 countries. Motorization and Automatic solar control of openings and closures in homes and buildings are their core business. Its wide range Animeo Solution enables the control of all the window coverings and dynamic shadings automatically through sensors responding to positions according to the actual time, changes in weather conditions and their orientation towards the sun. Somfy's specific controls for Management of Dynamic Façades (MDF) allow the optimized control of a façade's visual and thermal flux, using automated sun shading. Recently, some of the dynamic features have been installed in iconic projects in the UAE (Somfy, 2009).

During the preparation of this study, no academic evidence has been found to test the dynamic features such as the dynamic louvers under the climatic conditions of UAE. The majority of the materials that have been collected to address the viability of these advanced systems locally are promotional reports and studies, which belong to the available suppliers of the dynamic facades in the local market.

2.10 Problem statement

The concept of dynamic facades through installing controllable elements on the building envelope is not new; however, the ability of such systems to work reliably and effectively is a far greater challenge. The shift from static conventional facades to dynamic and responsive facades has been accompanied by many studies undertaken by organizations and academic bodies to explore the performance of these technologies against various parameters such as thermal, lighting, ventilation, control, occupant comfort, operation, management and cost effectiveness. Various studies as discussed earlier have shown that appropriate dynamic shading design and control, linked with simultaneous control of electric lighting and HVAC components, could significantly reduce lighting and cooling loads, while maintaining good thermal and lighting indoor conditions.

The majority of the literature and data on performance of Dynamic Façades in terms of thermal lighting and visual comfort is limited to temperate and cold climates of North America and Europe. The lack of studies on the application of intelligent and dynamic facades in hot and humid climates is well known in contrast to the growing body of knowledge in relation to cold climates. This can be referred to the mainstream in energy conscious design for hot regions that gives the priority to passive design techniques rather than the active approaches in achieving the thermal comfort. The recent growing awareness of the global crisis concerning climate change and its potential impact on all countries has created the stimulation for the adaptation of such advanced façade technology. The implementation of dynamic features in the UAE has an experimental approach especially with the unavailability of the local academic reference of such systems.

The growing demand for state-of-the-art office facilities in these geographic areas validates the study of suitable active based climatic technologies. However, replicating solutions developed for cold climates and other regions creates a high risk of irrelevancy to the local climatic and geographical conditions, and might ultimately lead to high energy consumption levels and troublesome working conditions. On the contrary, any proposed technology for this area should be based on proven building physics principles and relevant studies.

Varieties of dynamic façade features are available in the current industry catalogues, and some of them have been listed earlier in this chapter. Dynamic external louvers are some of the elements that have been examined in the West for their energy performance. The results as elaborated in similar studies show a promising future for this façade feature if tested under the climate of Abu Dhabi.

The lack of validated information about dynamic façade louvers in UAE has created the incentive to initiate this study and to investigate the viability and efficiency of these systems. The purpose of this research is to explore through simulation methodology the energy performance of dynamic façade louvers in office buildings in Abu Dhabi and to examine their efficiency against various parameters. The intent is to establish a comparison between the use of dynamic louvers and the static ones with a light control. Shading Coefficient Values of glass as a measure of solar energy entering through the glass has an impact on the overall performance of the dynamic louvers. This study tries to create a relationship between the Shading Coefficient Value of the glass and the energy performance of the dynamic window with louver configuration. Moreover, this study will carry out an exploration of the possible impact on the energy consumption of the dynamic louvers with the location of lighting sensor and its distance from the window.

2.11 Aim and Objectives

The aim of this research can be simplified and summarized as follows
'To make a valuable contribution to the academic knowledge about some aspects of the dynamic facades and to push/rectify the market tendency in the adoption of such technologies'

Some objectives have been set to facilitate achieving the main aim of this research. These objectives are;

- Understanding the functional logic of the intelligent and dynamic fenestration systems.
- Exploring system adaptation to suit local conditions.
- Identifying and quantify the benefits of using dynamic louvers.
- Studying various configurations with different variables (Shading Coefficient Value of the glass, electrical photo sensor location, and slat angles of the louvers) for the dynamic window.
- Exploring the optimal fixed angle of the louvers for different orientation under the climatic conditions of Abu Dhabi.
- Studying the visibility of using the automated louvers.
- Energy modeling to predict and estimate energy consumption based on the studied parameters.
- Evaluating the viability of Dynamic louver fenestration systems by means of economic analysis.

Chapter 3 : Research Methodology

3.1 Defining research parameters

A basic office module layout is created and maintained for the entire study. Some variables will be manipulated to explore multiple configurations to evaluate the efficiency of dynamic louvers in a typical office building in Abu Dhabi. Energy consumption values will be the main outcome of this study, and it will be used as a base for the comparisons. Brief descriptions of the main variables that will influence the main outcome are defined as follows;

- Position of lighting sensor: This sensor will be used to measure the available daylight in the space and linked to luminaries to provide additional artificial lighting to achieve the desired level of illuminance at the work plane.

- Glass Shading Coefficient (SC): This value affects the total solar heat transmittance of glass. Changing this value has an impact on the day lighting as well as on the cooling loads and eventually on the performance of the dynamic louvers.

- Slat tilt Angle of Louvers: Lighting and cooling loads of the space is affected by adjusting the slat angle.

- Orientation: This variable will be tested independently for all configurations. All cases will be examined during the daytime on four pre-selected days in the year.

A description of the office module and the selected configurations will be detailed further in chapter four of this dissertation.

3.2 Review of Methodologies of previous work

In this part of the dissertation, a review is conducted of research methodologies undertaken by other scholars, which are related to the subject of this study. An emphasis will be on the reasons for the selection of the various methodologies in order to establish the most suitable options for this study.

Experimental Studies

Lee, DiBartolomeo and Selkowitz (1998) explored through an experimental study the potential energy saving offered by automated Venetian blinds operating in synchronization with controlled artificial lighting. A 14-month observation in the field was used for the collection of lighting and cooling energy loads as well as weather data by means of scientific dataloggers. The field of the two private offices was pre-prepared with all equipment and hardware such as lamps, photo sensors, data logging station, mechanical equipments, etc. that were required to conduct the study. The data collected from various sensors were tabulated and reformatted in charts and tables to find out the energy efficiency of dynamic versus static systems.

Kim et al. (2009) followed an experimental approach to evaluate the environmental performance of automated venetian blinds. The test rooms were equipped with the required measuring tools such as lux and radiation meters and thermocouples to measure the actual indoor and outdoor illuminance and radiation as well as the temperature. A survey was conducted in the first part of this study to define the frequency of the operation of actual motorized blinds.

Simulation Studies

A simulation methodology was used by Kim & Park (2009) to address the difference between static versus dynamic control of interior and exterior blind systems in office buildings. A whole building simulation tool (Energy Plus) was used in conjunction with MATLAB optimization toolbox to solve the optimal control of the blind systems. A review of previous works was used to identify the problem and highlight the gap in published literature, which constitutes the incentive for the author to conduct the research. The simulation results were presented in the form of charts and tables to draw the inferences for the study.

The effect of slat angle and absorptance on the heating and cooling loads of buildings in Seoul (South Korea) was studied by Cho, Shin and Zaheer-Uddin (1995) via a numerical model which was developed and evaluated using the TRNSYS computer simulation tool to examine the effect of changing the slat parameters. Carbonari, Rossi and Romangnoni (2002) utilized three computer codes for the simulation process to study the optimal orientation of buildings in relation to the type of adopted shading devices and their control logic. The first code (Ener-Lux) calculated the hourly values of solar gain and daylight level inside the room. The second code (Midas) simulated hour by hour the dynamic thermal behavior of the room taking into consideration the solar and internal gains utilizing the artificial lighting from the first code. The last code calculated thermal comfort indexes. Ochoa and Capeluto (2008) used the computer simulation engine (Energy Plus) to explore the influence of incorporating intelligence in buildings in hot climates. Heating, cooling, lighting and glare were studied to assess three series of intelligent features; Passive, active and a mix of both design strategies. Many other studies carried out by Song, Kim, M. and Kim, J., (2005), Newsham (1994) , Tzemplikos and Athenitis (2002) and Guillemin and Morel (2001) used simulation methodology to study various aspects of intelligent shading devices and lighting controls.

Most of the literature reviewed during the preparation for this study followed similar methodologies based on experimental field studies and computer simulations. Some of the advantages and disadvantages of both methodologies are summarized in Table 3.1.

Table 3.1 Advantages and disadvantages of simulation and field study methodologies

Characteristics	Simulation Study	Field Experimental Study
Reliability	+	-
Replicability	+	-
Cost	+	-
Subject to Disturbance and errors	+	-
Use of Resources	+	-
Control of Variables	+	-
Easy to conduct	+	-
Time	+	-
Reality	-	+
Validity	-	+
Understanding future behavior	+	-
Ability to scale objects	+	-

(+) Advantage
(-) Disadvantage

3.3 Research Design and Methodology

The investigations outlined in the previous section show that in similar studies to this one, two methodologies were mainly used; experimental and simulation. The simulation methodology has been selected for this quantitative research. The main reasons for this selection are summarized as follows;

- Time limitations: Field studies require long periods of monitoring and observations that is beyond the time available for this study.
- Cost limitation: Considerable expenses are usually associated with field studies.

The research has been carried out in two parts. The first part consists of a literature review of dynamic façade systems .The second part is based on simulation methodology.

Method 1: Literature Review

A thorough review was conducted to explore the literature on related topics that provide the necessary background to understand dynamic fenestration systems and their performance. Some case studies are presented to highlight the application of dynamic façade features internationally and in the United Arab Emirates. The research design, data classification and methodologies of similar studies are also reviewed. However, the findings of this review will be used to highlight a gap in the knowledge in the field of dynamic façades that will be used to frame the research problem and shape its aim and objectives. Most of the literature review is covered in chapter two of this dissertation.

Method 2: Simulation

Simulation is an approximate method to obtain information about the performance of a certain object in a certain setting or environment. This can be achieved via numerical or computer models, or from measurements made from an analogous environment. Smith (1999) defined simulation as the process of designing a model of a real or imagined system and conducting experiments with that model. The main objective of this process is to understand the behavior of the system or evaluate strategies for the operation of the system through assumptions, mathematical algorithms and relationships. As mentioned before, this method is cost effective and if done properly, can stand for real systems. Smith (1999) proposed a definite process for creating, developing, validating, operating, and analyzing the results of simulations. The main steps of this process;

- Define problem space

- Define conceptual model
- Collect input data
- Construct software model
- Verify, Validate, and Accredit the Model.
- Design Experiments.
- Execute Simulation.
- Collect Output Data.
- Document Results.
- Analyze Data.
- Expand Model

3.4 Selection of Simulation Tool process

It took the author two months to find the right simulation tool that has the ability to simulate the dynamic façade features, and examine the parameters that are manipulated to test dynamic louvers. Pre-requisites were identified to be satisfied by the simulation software.

- Ability to model the dynamic louvers at different angles.
- Reliable software with validation certificates.
- Capability to link the HVAC and Lighting system through control criteria based on the internal and external environmental conditions.
- Ability to set up schedules and profiles for the operation of the space.
- Graphic User-Friendly Interface (GUI).
- Smooth learning curve especially for a scholar with an architectural background.

During this period many professionals and software makers were contacted to identify software that met the above-mentioned prerequisites. Many papers that include an up-to-date comparison of the features and capabilities of many building energy simulation programs were studied to support the selection of the simulation tool. Crawley et al. (2005) conducted a comparison between the major twenty simulation tools. Fourteen tables were presented to demonstrate the variety of approaches and solutions presented by these programs. The IES-VE software achieved a high score as a capable, comprehensive and integrated solution.

Table 3.2 Part of simulation tools comparison Table no.2, Crawley et al. (2005)

Table 1 ***Zone Loads*** (11 of the 21 rows from Table 2 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																				
▪ Dependent on temperature	X	X					P		X		X	X	X		X	X	X	X		X
▪ Dependent on air flow	X						X		P		X		X		X			X		E
▪ Dependent on surface heat coefficient from CFD									E		E		X							
▪ User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing																				
▪ Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
▪ Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
▪ User-specified minimum and maximum			X	X		X	X		X	X		X	X	X	X			X	X	
▪ User-specified steady-state, steady-periodic or fully dynamic design conditions			X									X	X	X				X	X	X

Attia et al. (2009) established a comparison between ten different building performance simulation tools as architect friendly program. A comparative survey was used to register the preference of usability among architects. IES-VE Scored the highest with 85%. The strength of IES-VE can be realized in its user friendly GUI and its template driven approach. Figure 3.1 shows the ranking of the ten tools.

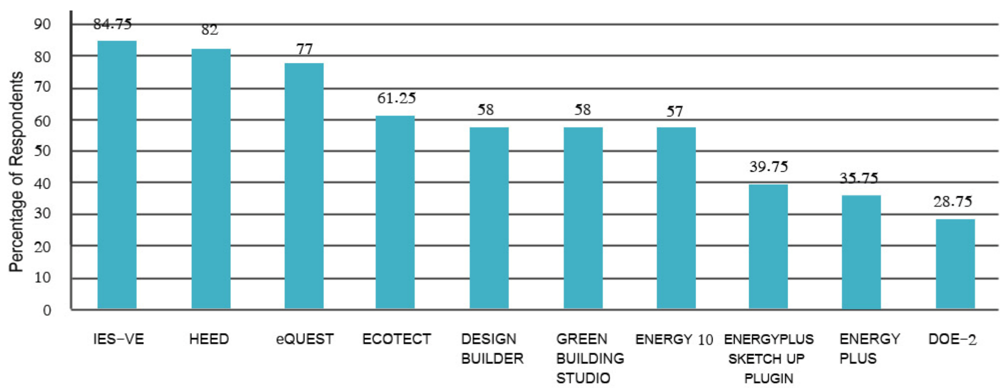


Figure 3.1 Ranking the ten tools, Attia et al. (2009)

Eventually, and after examining much available software and exploring their capabilities, IES-VE was selected to be used in this study. Although this software does not meet all the predefined prerequisites, being a user friendly software with a Graphic Interface, it can be used with some extra effort to model dynamic louvers and set up thermal and electrical parameters.

3.5 Integrated Environmental Solutions- Virtual Environment (IES-VE).

This software as a dynamic simulation package helps architects and engineers design more environmental integrated and sustainable buildings. The advantage of a product like IES-VE is that it provides a good environment for the detailed evaluation of buildings and system designs and helps architects to study the effects of their design directly, make alterations, develop the design, and improve it to achieve the desired energy optimization levels. It consists of some modules that can simulate any life cycle activity associated with a building. The IES-VE performance analysis software suite allows architects and engineers to facilitate a sustainable design process by offering quantitative feedback on the environmental performance of different design options (IES, 2009).

The separate <VE> product levels provide options suitable for different design stages and user experience, while the integrated nature of the suite allows the interrelationships between energy use, CO_2 emissions, solar, lighting, airflow and system design to be taken into account and analyzed. Users can now uniquely undertake analysis directly from a Google SketchUp™ or Autodesk® Revit® model if desired as IES has created integrated plug-ins to these programs.
IES-VE is an integrated suite of applications linked by a common user interface (CUI) and a single integrated Data Model (IDM). This software includes the following modules;

• ModelIT: Geometry creation and editing
• ApacheCalc: Loads analysis
• ApacheSim: Thermal analysis
• MacroFlo: Natural ventilation
• Apache HVAC: HVAC systems simulation
• SunCast: Solar Shading analysis
• MicroFlo: CFD simulation system
• FlucsPro/Radiance: Lighting design
• DEFT: Model optimization
• LifeCycle: life-cycle energy and cost analysis
• Simulex: building evacuation

The author attended several seminars conducted by IES representatives and became familiar with its components. Eventually, a student copy was procured online on 15 June 2008. The software Package contains all of the features of a full version of IES in addition to a complete manual. The one year license duration was adequate to learn the software and complete this study.

3.6 Validity and Reliability

There are several threats to validity that might arise during the execution of any research and affect the outcomes of the study. The potential source of threats to validity of this type of quantitative research has been identified and manipulated to ensure a proper response to such threats. The use of literature and simulation methodology in this research influenced the type of these threats. The following points describe the potential threats to validity and some measures undertaken by the author to prevent these threats from occurring.

- The software validity (IES-VE): This issue concerns how close the computer simulation is to reality. This software has been validated and approved by the Communities and Local Government (CLG) and other relevant bodies. More information about this software and its validity can be obtained from the IES website www.iesve.com .

- The capability of the author to use the software: The author considered some measures to ensure the model validity and to gain confidence in using the software to conduct this research.

  1- The model was frequently reviewed by an IES technical advisor. Several sessions were organized to check the modeling process as well as to confirm that all steps and parameters undertaken by the author were the correct way to build up the model specified in the next chapter. Finally , the model was completed and finalized after the verification by the technical advisor,

  2- The base model described in the next chapter has been modeled through another software (HAP 4.41). A mechanical engineer in Atkins was given complete measurements and description of the base case model. The results of the simulations are compared to the results carried out by the author via IES software. The validation model will be included in the last section of chapter four.

Chapter 4 : Building the Simulation Model

4.1 Model Description

A base case or generic model is necessary to establish this parametric simulation study. All design features of the model were studied in a way to represent the prevalent practice of construction in the Emirate of Abu Dhabi. Commonly used parameters and constructions materials in Abu Dhabi have been adopted to build the model. The following part consists of a description of the model as well as its parameters.

4.1.1 Office Module

To study the impact of dynamic louvers on the energy consumption in offices, a simulation model was developed that represents a typical office room in Abu Dhabi. The model room has a rectangular shape of 4.0m (Width), 8.0m (Depth) and 2.7m (Height). The room is assumed to have a perimeter location in a typical office building, and has one window on the external façade which is 3.0m Wide and 2.7m High. The window is assumed to be flush with the external façade as part of a curtain wall assembly. Nine louvers of 3.5mX0.3mX0.03m with a vertical spacing of 0.3m are assumed to cover the window at a distance of 0.1m from the external face of the façade. Figure 4.1 shows the setting out of the proposed office module.

There is no definite design for offices. The design varies depending on many factors. The selected shape and dimension of the proposed module was based on an assumption to represent a commonly used two-desk office space.

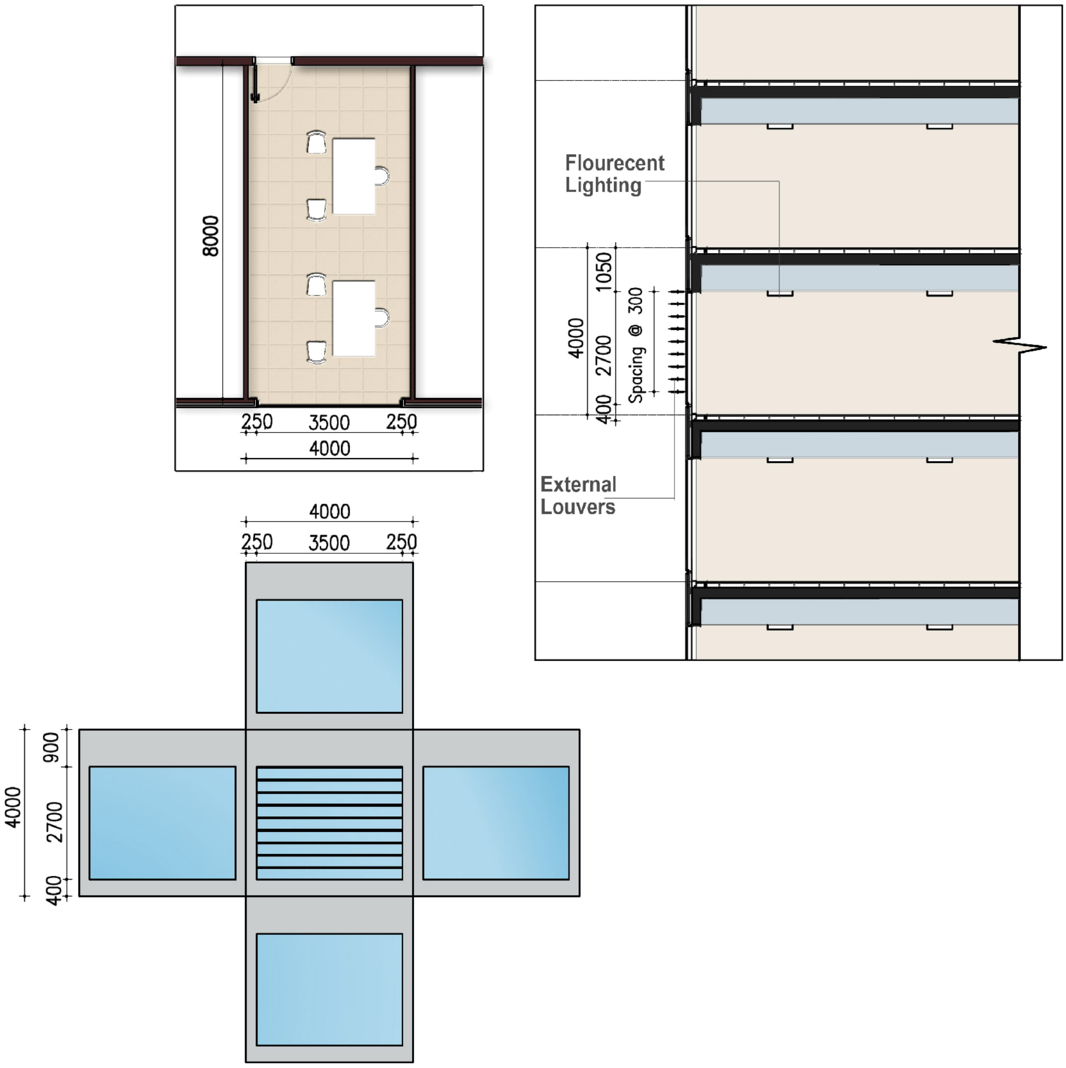


Figure 4.1 Floor Plan , Elevation and wall section of simulation Office Module (South Orientation)

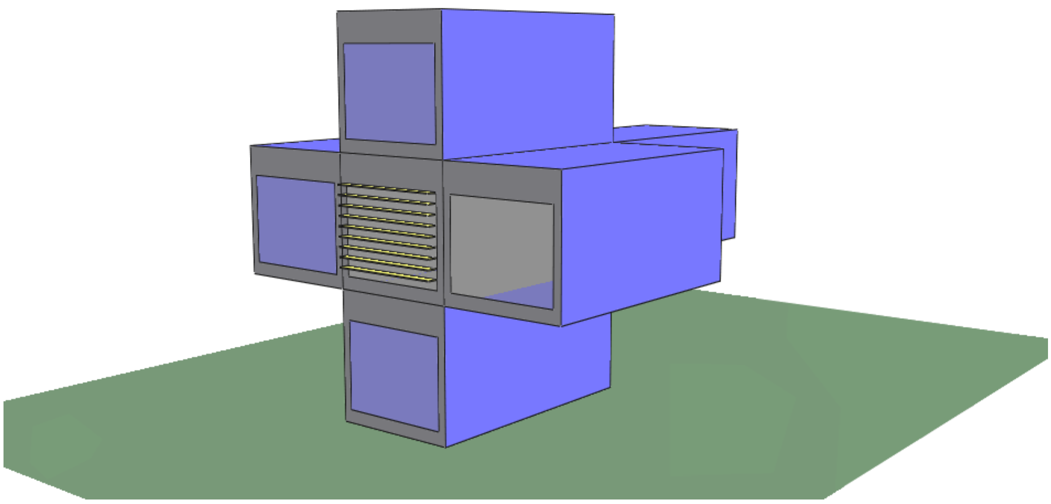


Figure 4.2 IES Simulation Model (South Orientation)

For the simulations of south and west orientations, vertical louvers will be used instead of the horizontal with similar configuration of the model. Figure 4.3 shows the setting out of the model for east and west

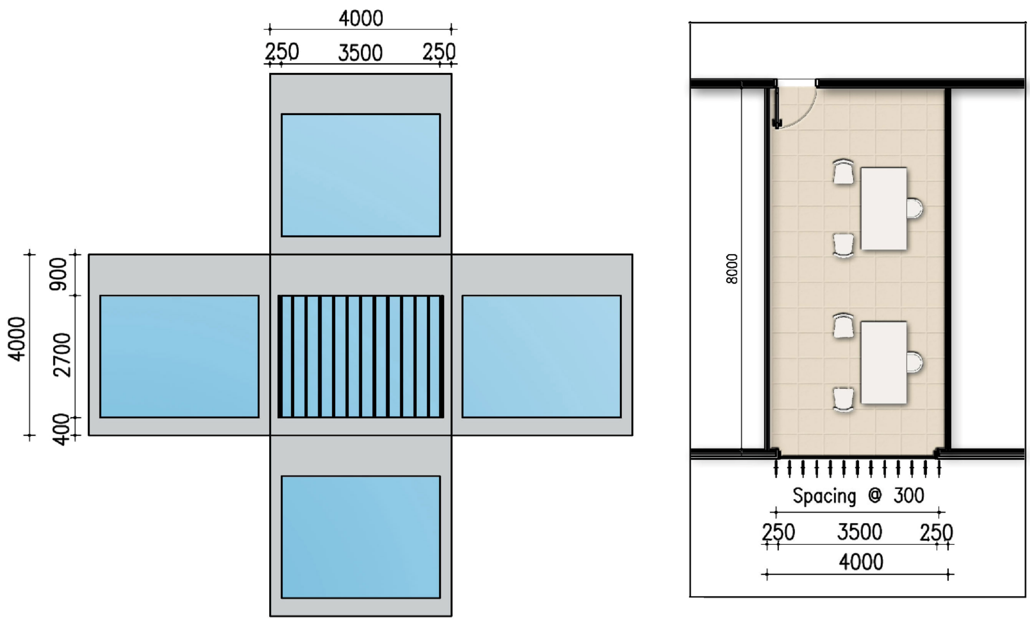


Figure 4.3 Floor Plan , Elevation and wall section of simulation Office Module(East & West Orientation)

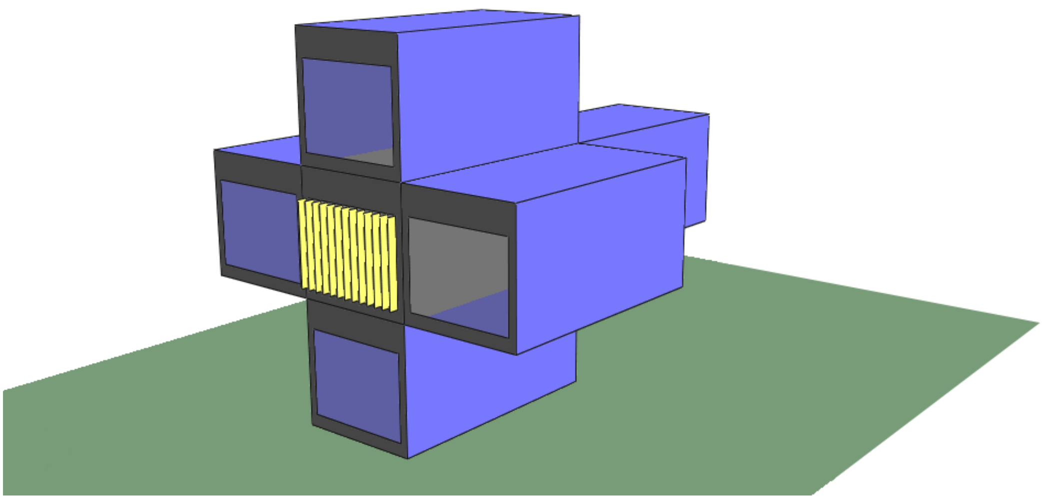


Figure 4.4 IES Simulation Model (East & West Orientation)

4.1.2 Module Finishes

The facility consists of one office room that was furnished with building materials and furniture to imitate a commercial office-like environment in Abu Dhabi. IES-VE Constructions Database provides facilities for viewing and editing constructions used in the thermal applications. Any construction defines the thermal properties of a building element such as a wall, ceiling or window, which consists of a number of layers with thermal and surface properties and some other properties used in thermal simulations and analysis. The purpose of the Constructions Database is to assemble a set of constructions for use in the project. Accurate construction data is critically important for the integrity of the thermal model. Table 4.1 shows the chosen material finishes of the model, which are available from the IES-VE material database.

Table 4.1 Simulation Model Construction Materials

	Material	Thickness (M)	Density (kg/m^2)	Conductivity (W/m.K)	Category	CIBSE U-Value (W/m^2.K)
External Walls	Aluminium	0.004	2800.00	160.00	Metals	0.3932
	Cavity	0.10	-	-	-	
	Polyurethane Boards	0.05	30.00	0.03	Insulating Materials	
	Concrete Block (Heavy Weight)	0.10	2300.00	1.63	Concretes	
	Plaster (Light Weight)	0.02	600.00	0.16	Plaster	
Internal partitions	Plaster (Light Weight)	0.02	600.00	0.16	Plaster	1.1101
	Aerated Concrete Block	0.10	750.00	0.24	Concretes	
	Plaster (Light Weight)	0.02	600.00	0.16	Plaster	
Internal Ceiling/ Flooring	Wilton Carpet	0.01	0.01	0.06	Carpets	0.9421
	Aluminium	0.004	2800.00	160.00	Metals	
	Cavity	0.10	-	-	-	
	Screed	0.05	1200.00	0.41	Screed & Renders	
	Cast Concrete (Dense)	0.25	2100.00	1.40	Concretes	
	Cavity	0.10	-	-	-	
	Aluminium	0.004	2800.00	160.00	Metals	
Doors	Pine (20% Moist)	0.040	419.00	0.14	Timber	2.1608
	Material	**Thickness (M)**	**Transmittance**	**Outside Reflectance**	**Inside Reflecance**	**CIBSE Net U-Value (W/m2.K)**
External Glazing	Pilkington K 6mm	0.006	0.44	0.33	0.15	1.95
	Cavity	0.012	-	-	-	
	Clear Float 6MM	0.006	0.663	0.33	0.27	
	Glass Total Shading Coefficient : 0.41					

4.1.3 HVAC and Lighting assumptions

The room was assumed to accommodate medium density occupancy, Two work stations with two computers of 370 (W) and two adults with Maximum Sensible Gain 90.0 W/Person. The room was configured with off-continuously heating whereas the cooling profile was turned on continuously. The internal temperature was set to be constant at 24 °C whereas the room infiltration was set to 0.25 Air Change per Hour (ACH) .

500 Lux was selected for general office work based on IESNA standards (Block, 2000). In order to test the effect of the location of a lighting sensor on the results and the efficiency of the dynamic louvers, the simulations will be carried out with two positions of the light sensor; at 2m and 4m distance from the external window as shown in Figs 4.5 and 4.6. The sensor is linked to fluorescent luminaries fixed on the ceiling at 2.7 m high where the installed power density 2.2W/m2/100Lux. If the daylight illuminance on the work space exceeds 500 Lux on the desk level at 0.85m above the finished floor level, the fluorescent light will be switched off. If not, the sensor provides enough electric energy to maintain 500 Lux.

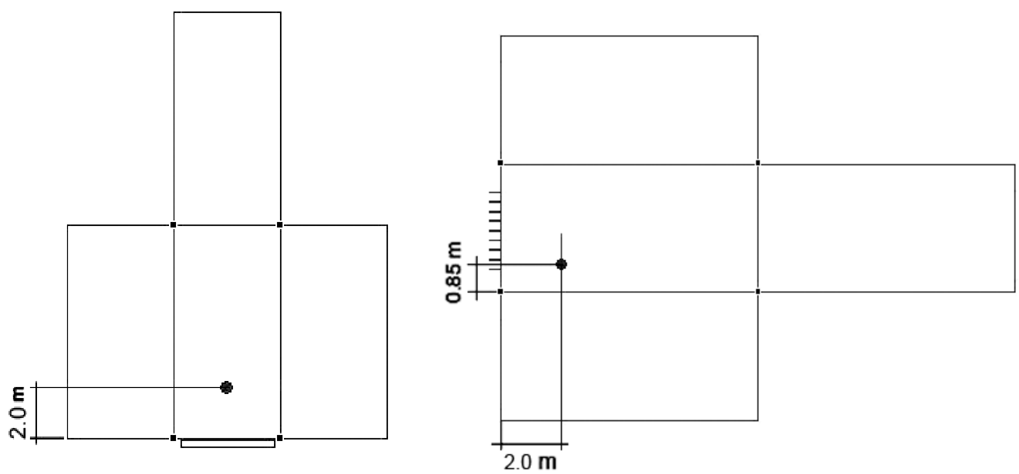


Figure 4.5 Plan and side elevation of lighting sensor @ 2.0m from window

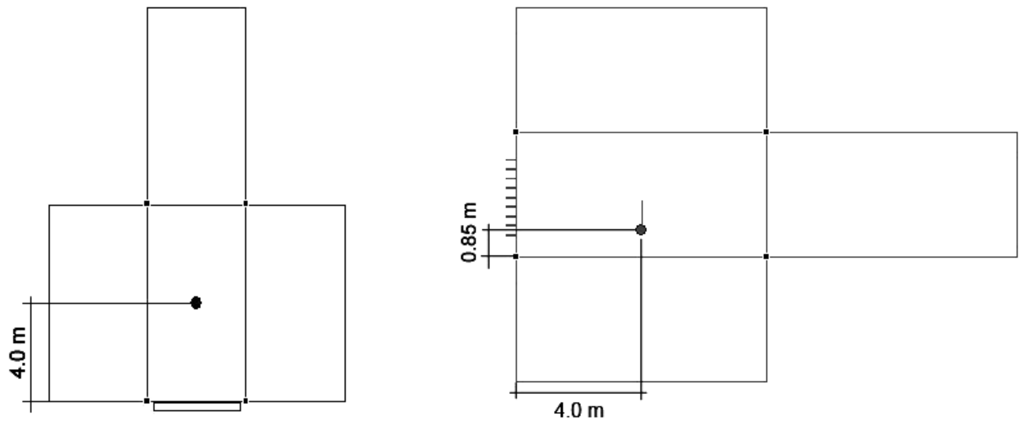


Figure 4.6 Plan and side elevation of lighting sensor @ 4.0m from window

The U-value of the glass is maintained equal to 1.95 W.k/m2 whereas the shading coefficient will be set for two values; 0.41 and 0.746 as detailed later in the configuration of the cases. Fixing the U-value and changing the shading coefficient will affect the light transmission of the glass that will vary the daylight illuminance transmitted to the office space.

4.1.4 Louver Control Strategy

As mentioned in chapter two, there are many control strategies for the dynamic louvers. Generally, they can be divided into two main categories, manual and automatic. Many algorithms are being developed to set up strategies to control shading devices. Louvers and blinds can be adjusted to respond to various climatic parameters such as Glare, Solar gain, views outside, architectural decoration, etc.

Testing the various control strategies is out of the scope of this study. The main intention here is to find out the maximum potential energy saving that can be achieved due to the use of automated louvers against the fixed and alternative configurations that will be detailed later in this chapter. Therefore, the proposed control strategy will be based on the overall energy consumption and has the capability of changing the louvers slat angle to the positions where the energy consumption is optimized. This means that the dynamic louvers slat angle is moved to a certain angle at a specific time where the overall lighting and HVAC energy consumption is at the minimum. The optimal slat angle will be manually selected based on hourly basis simulations for the examined angles.

4.1.5 Weather Data

APLocate database is one feature of IES-VE software. This database consists of extensive hourly weather data for various cities in the world. The current study adopts weather data contained in this database to represent the prevailing local climatic conditions of Abu Dhabi. Each weather file has hourly values of dry-bulb and wet-bulb temperature, direct normal and horizontal diffuse solar radiation, solar altitude and azimuth, wind speed and direction, cloud cover and atmospheric pressure.

4.1.6 Orientation and Time

All selected cases are tested and simulated against three orientations; East, South and west. Shading the north facing facades in the latitude of Abu Dhabi is not effective since it receives very little direct solar radiation in the early morning and before the sunset.

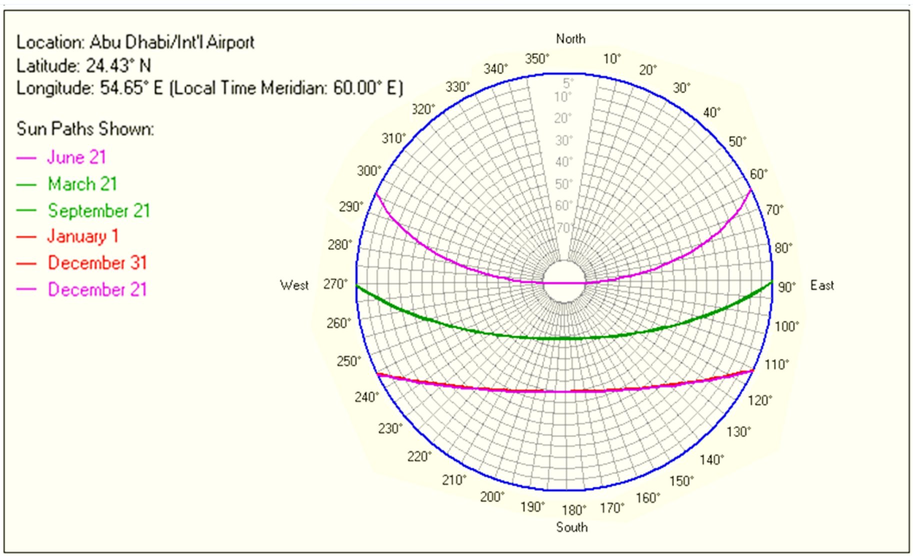


Figure 4.7 Sun Path Diagram of Abu Dhabi (IES Database)

Four days were selected to represent the whole year. These days were; 20 December, 20 June, 20 September and 21 March. The main reasons for the selection of these days:

- Date of solstices and equinoxes or close to them.
- Clear sky conditions where the installation of Dynamic louvers are more effective. Overcast skies reduce solar radiation and ultimately affect negatively the performance of dynamic louvers.
- Should not fall in the weekend days where the office is in non operation time.

Achieving both targets was successful for the selected days in March, June and September, whereas overcast skies were detected in the whole month of December. The selected day in this month has relatively fewer clouds comparing to other day close to solstices. The results were registered on hourly basis from 5.30 until 20.30.

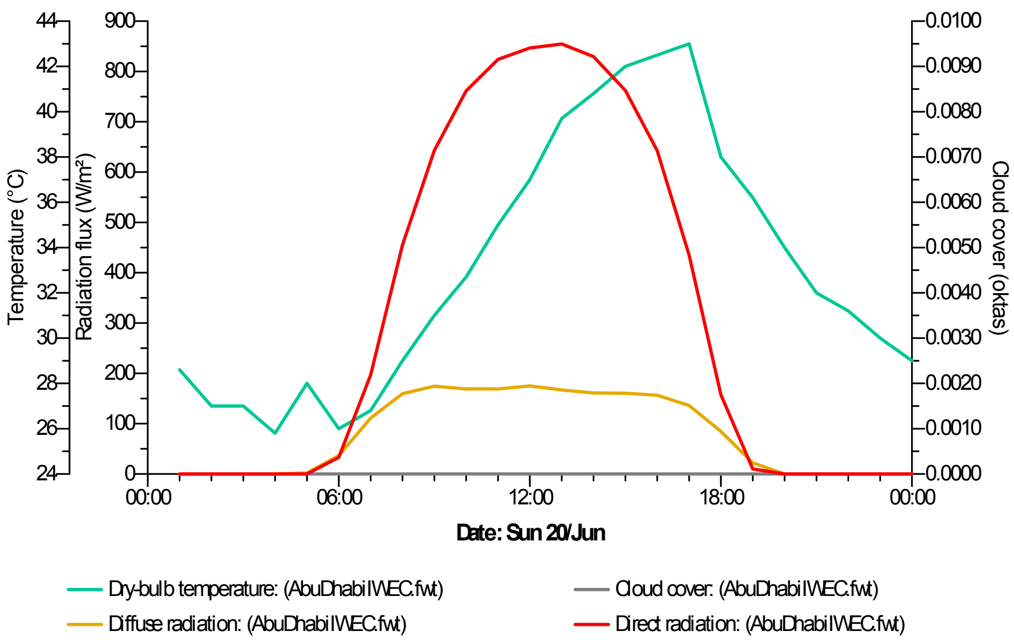


Figure 4.8 June 20 Weather Data of Abu Dhabi (from IES-VE Weather Database)

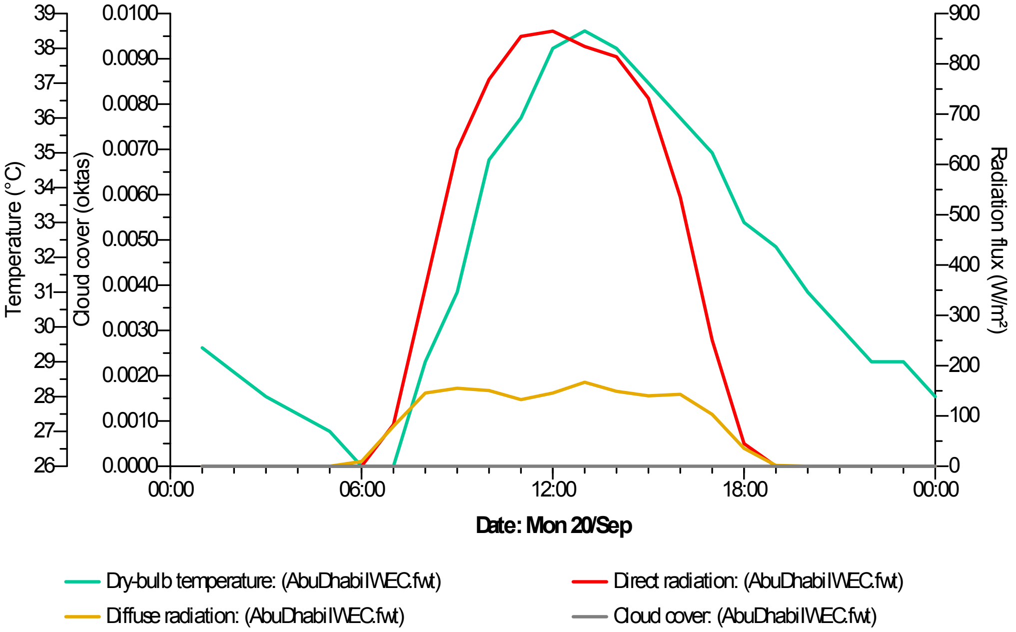


Figure 4.9 September 20 Weather Data of Abu Dhabi (from IES-VE Weather Database)

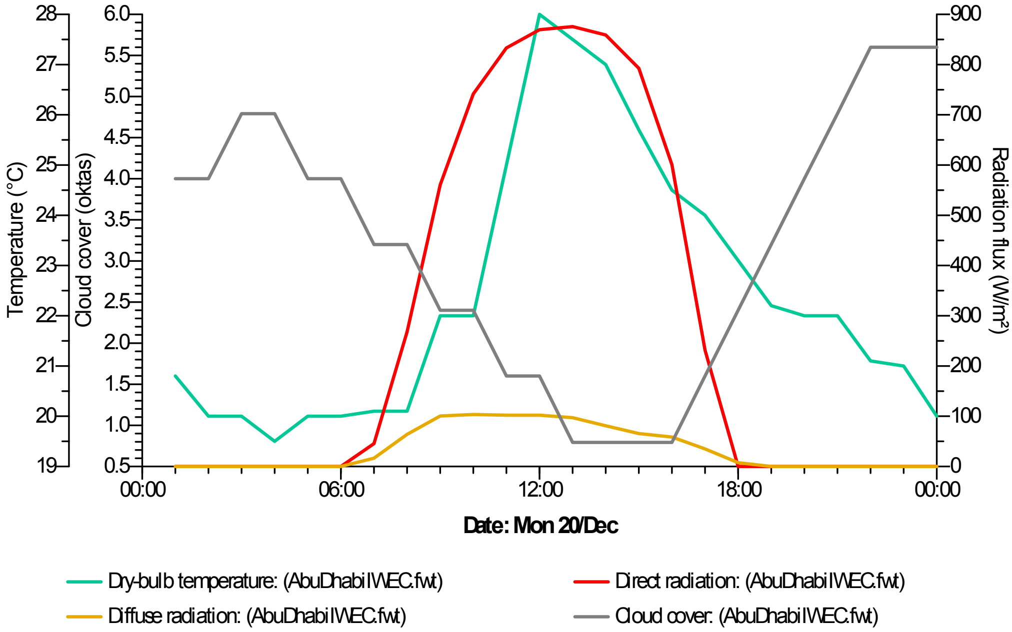


Figure 4.10 December 20 Weather Data of Abu Dhabi (from IES-VE Weather Database)

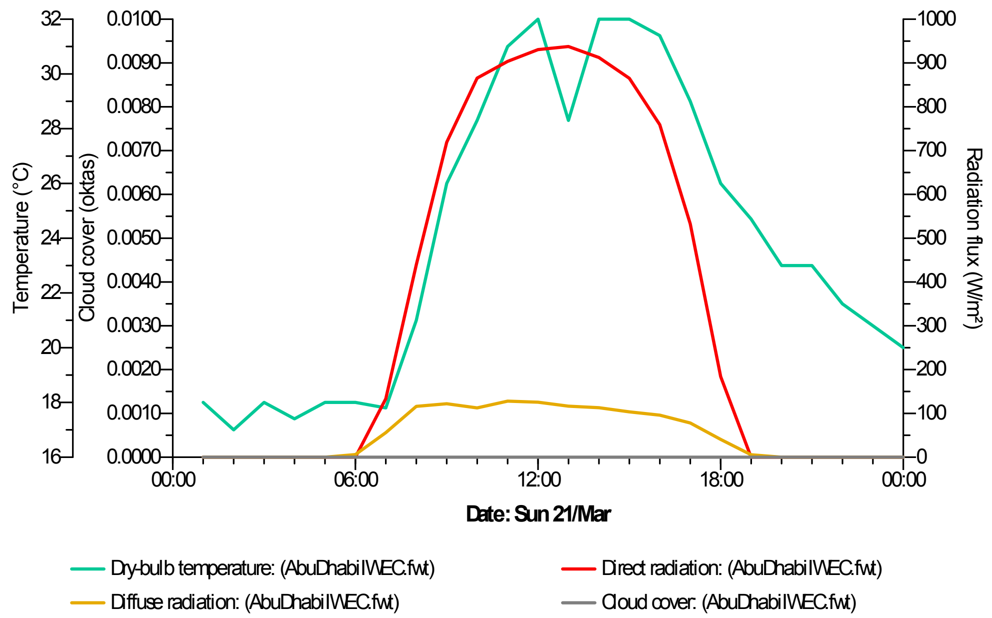


Figure 4.11 March 21 Weather Data of Abu Dhabi (from IES-VE Weather Database)

4.1.7 Operation Profiles

A profile specifies time variation over a year. It is usually used to schedule HVAC and lighting systems, specify the timing and define the time-varying-set-points of various parameters. It is assembled from daily, weekly and annual profiles. The operation profiles of this study are defined and created by APpro of IES-VE program. The common patterns of operation in offices in Abu Dhabi will be used as the basis of the assumptions of the profiles of this study. Office operations are assumed to run from 8.00am to 6.00pm during the weekdays, and closed down during the weekends (Friday and Saturday). Therefore, two daily profiles are created as follows;

Daily Profiles:

The first Daily profile, which is named Dimming Daily Profile activates the dimming sensor when the room illuminance of the office module (e1) is less than 500 lux as per the formula (ramp(e1,0,1,500,0)) . This formula is suitable for applying as a dimming profile controlling lighting gain as a function of available daylight. It modulates the lighting gain as a function of the illuminance on the working plane, e1. The value of the profile falls from 1 at zero illuminance to zero at illuminance 500 lux, after that remaining constant at this value (IES-VE User Guide, 2009).

One more daily profile is created to activate the lighting of the office room and assigned to people and computers from 7:00 am to 7:00 pm to cover the proposed office operation timing. This profile is named Daily Operation Profile.

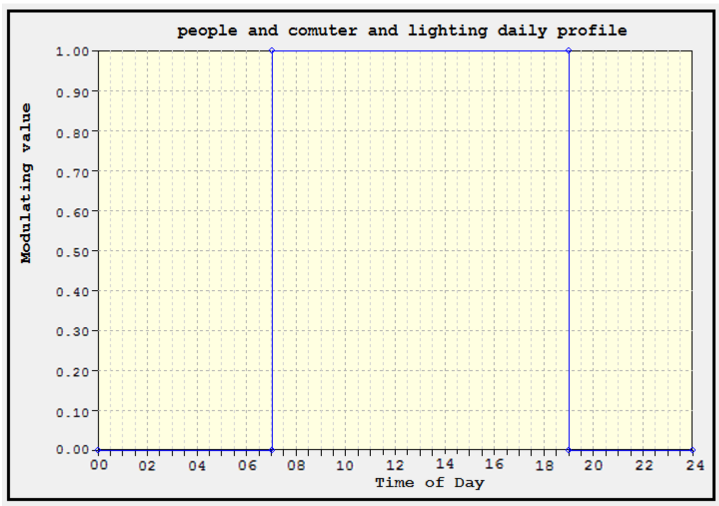
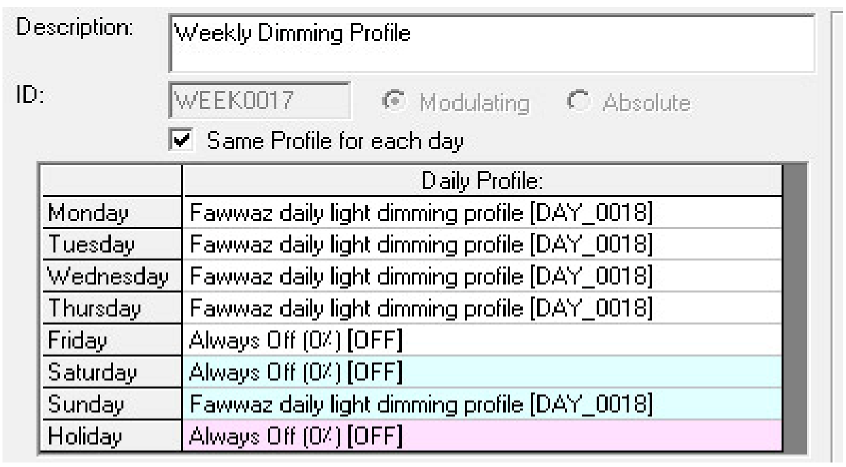


Figure 4.12 Daily Operation Profile

<u>Weekly Profiles:</u>

The daily profiles are used to create two weekly profiles; the first weekly profile is assumed to use the dimming daily profiles continuously through weekdays, and be off continuously during the weekends. This profile is named Weekly Dimming Profile.



Description: Weekly Dimming Profile

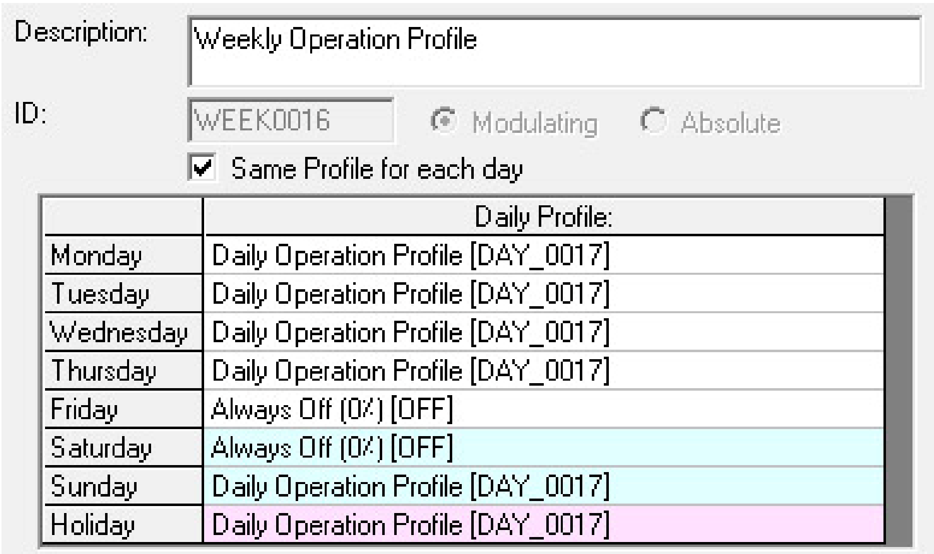
ID: WEEK0017 Modulating Absolute

Same Profile for each day

	Daily Profile:
Monday	Fawwaz daily light dimming profile [DAY_0018]
Tuesday	Fawwaz daily light dimming profile [DAY_0018]
Wednesday	Fawwaz daily light dimming profile [DAY_0018]
Thursday	Fawwaz daily light dimming profile [DAY_0018]
Friday	Always Off (0%) [OFF]
Saturday	Always Off (0%) [OFF]
Sunday	Fawwaz daily light dimming profile [DAY_0018]
Holiday	Always Off (0%) [OFF]

Figure 4.13 Weekly Dimming Profile

The daily profile that represents the office operation on weekdays was created to activate the lighting and HVAC systems during the weekdays and deactivate these systems over the weekends. This profile is named Weekly Operation Profile.



	Daily Profile:
Monday	Daily Operation Profile [DAY_0017]
Tuesday	Daily Operation Profile [DAY_0017]
Wednesday	Daily Operation Profile [DAY_0017]
Thursday	Daily Operation Profile [DAY_0017]
Friday	Always Off (0%) [OFF]
Saturday	Always Off (0%) [OFF]
Sunday	Daily Operation Profile [DAY_0017]
Holiday	Daily Operation Profile [DAY_0017]

Figure 4.14 Weekly Operation Profile

Annual Profiles:

No assumption is considered for this profile due to its minor impact on the overall results.

4.2 Simulation cases configuration

Different scenarios have been studied in order to examine the energy efficiency of dynamic louvers. The variation of the cases was made through manipulating the following parameters:

- Daylight control
- Slat Angle
- Orientation
- Shading coefficient
- Sensor location

To have a better understanding of the simulation of various cases and to establish comparative analysis, the simulation configuration has been divided into three groups based on the orientation; south, east and west. Within each group the simulations will be carried out for the four selected days a year. Table 4.2 show a matrix of the simulation cases.

Table 4.2 Matrix of Simulation Cases

Matrix of Simulation Cases									
		Shading Coefficient 0.41 &					**Shading Coefficient 0.746**		
		Base case	Lighting Sensor @ 2m		Lighting Sensor @ 4m		Base case	Lighting Sensor @ 2m	
			With Lighting Control	Louvers Angles with 20° interval	With Lighting Control	Louvers Angles with 20° interval		With Lighting Control	Louvers Angles with 20° interval
Group (1): South Façade Simulations									
	December	X	X	X	X	X	X	X	X
	March	X	X	X	X	X	X	X	X
	June	X	X	X	X	X	X	X	X
	September	X	X	X	X	X	X	X	X
Group (2): East Façade Simulations									
	December	X	X	X					
	March	X	X	X					
	June	X	X	X					
	September	X	X	X					
Group (3): West Façade Simulations									
	December	X	X	X					
	March	X	X	X					
	June	X	X	X					
	September	X	X	X					

Based on the matrix in Table 4.2, a description of the main scenarios for simulation will be presented in the following sections.

4.2.1 Base case

The base case scenario is established with no lighting control and no shading devices. This case represents the business as usual case for a typical office design in Abu Dhabi. The lighting is assumed to be continuously operated during the proposed office operation timing. This scenario will be simulated in the selected four days and for the three orientations; east, south and west. This case will be examined against two shading coefficients.

4.2.2 Base case with lighting control and no external louvers

In this case a dimming lighting sensor is added to the base case model at a distance of 2m/4m from the external window. No external louvers are considered for this assembly. The main objective for this case is to find out the contribution of the lighting sensor to the energy consumption at its two positions. With glass shading coefficient of 0.41, the simulations will be undertaken for the three orientations and in four days whereas the simulations will be carried out for the south orientation in the four days for the glass with shading coefficient of 0.746.

4.2.3 Fixed and dynamic Louvers with lighting control

The previous case will be modified by adding the external dynamic louvers in addition to the lighting control. The simulation runs are conducted for the following louver slat angles; -80°, -60°, -40°, -20°, 0°, 20° , 40°, 60° and 80° as shown in Fig 4.15. This case will be examined in the four days for the three orientations. As mentioned before, the total energy consumption is estimated for the various angles.

The angle that has the minimum energy consumption at a certain time is considered to be the optimal angle and represents the optimal dynamic louvers at that time. Based on the results of the simulation of the angles, the optimal fixed louver angle will be concluded and compared against the base case. The simulation of the dynamic louvers will be tested against the two positions of the sensors.

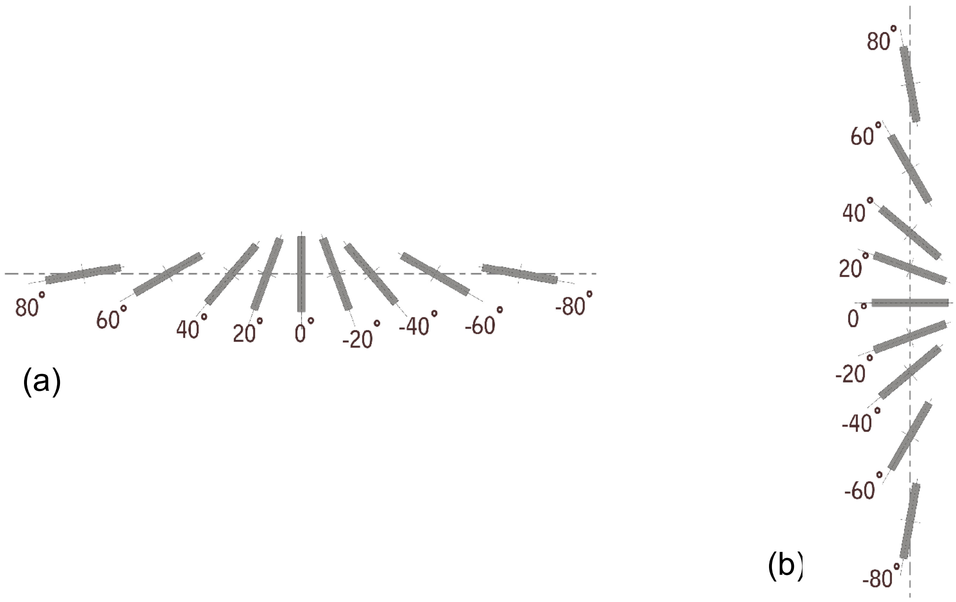


Figure 4.15 (a) Angles of vertical louver slats (b) Angles of horizontal louver slats

4.3 Key study considerations

- It is not the intent of this study to calculate annual, monthly or daily energy consumption for the above-mentioned cases. The energy consumption will be registered on an hourly basis for a certain period and the summation will be produced for each case just to make a comparison between the cases. This method will present a acceptable level of accuracy due to its hourly readings.

- In this work, the office room represents a typical office space in an office building. It is surrounded by offices from all sides; left, right, top and below. No shadows from surrounding buildings are considered. The context and urban morphology of the geographical site and its urban shading profile are ignored.

- This study gives the maximum results of the effect of dynamic louvers on the energy consumption except in December where the weather data shows an overcast sky during the whole month.

- Due to the absence of sunlight during nighttime, the louvers will have negligible effect on the energy consumption of the space; therefore, the focus of this study will be limited to hours from 5:30 until 20:30 that cover the daytime hours during all seasons.

- The study is conducted for a typical office space as detailed previously. Any change of the configuration of this space may lead to a change in the results of the simulations, which will definitely affect the performance of dynamic louvers.

- Material surface properties including surface reflections have been considered constant for all cases. Therefore, this factor will not have impact on the correctness of the results.

- It is out of the scope of this study to investigate parameters such as human comfort or visual quality that might be affected due to the use of dynamic louvers. However, this study is limited to explore the Impact of dynamic louvers on the hourly energy consumption of a typical office.

4.4 Modeling Process

- Building the model: The model was constructed using the ModelIT that is the model building component of IES_VE. Only the louvers were created in separate files and attached to the main model file as obstructions.

- Defining the model parameters: Building Template Manager, Constructions Database and APLocate are used to define Room parameters, construction materials, location and weather data, respectively.

- Lighting sensor: Radiance lighting simulation component is used to position the lighting sensor in its place at a distance of 2m / 4m from the window at the centerline of the office room. The "Apache" button will produce a model.ill file for use in the ApacheSim Radiance link.

- Project profiles: Profiles Database (APpro) is used to set up the profiles of lighting system. Light luminaries are linked to the variation (operation) and dimming profiles.

- Cuncast: This component is used to perform shading analysis and solar insolation for the obstructions, windows and openings. This analysis is carried out every time the louvers obstruction file is changed or if there is any change in the orientation. The results of this simulation are linked to the Apachesim before running the simulations.

- Simulations: ApacheSim is used to carry out the simulations. In this component, a link can optionally be created to Suncast and Radiance to incorporate the effect of shading devices as well as the lighting sensor profiles. Results from ApacheSim are viewed using the Vista component.

4.5 Model Validation

A basic Model validation was conducted to verify the results obtained from the base case model and compared to the results of the same model using HAP 4.41 thermal simulation tool. A mechanical engineer in Atkins (Multi Discipline engineering firm) was given all measures and parameters that were considered to build up the model using the IES by the Author. The model used for the comparison was the base case that was descried previously in this chapter with shading coefficient (0.746). The ASHREA Loads calculation tool of IES was used to obtain the cooling loads of the base case during the peak hours in June and December. These loads were compared to the cooling loads obtained from HAP 4.41. The reason for the selection of this type of results was the similarity of calculation criteria by both tools.

Figure 4.16 and 4.17 show the cooling loads by both tools in June and December. It is observed that the loads follow the same trend. However there is a small difference between the two readings .This could be accounted for the different precision measures that are accepted in addition to the slightly different weather data for Abu Dhabi used by both tools. HAP as an example doesn't take values of more than two decimals whereas IES accepts more than 5 decimals. These results exhibit confidence to the author's proficiency in using the software which is vital to conduct this research.

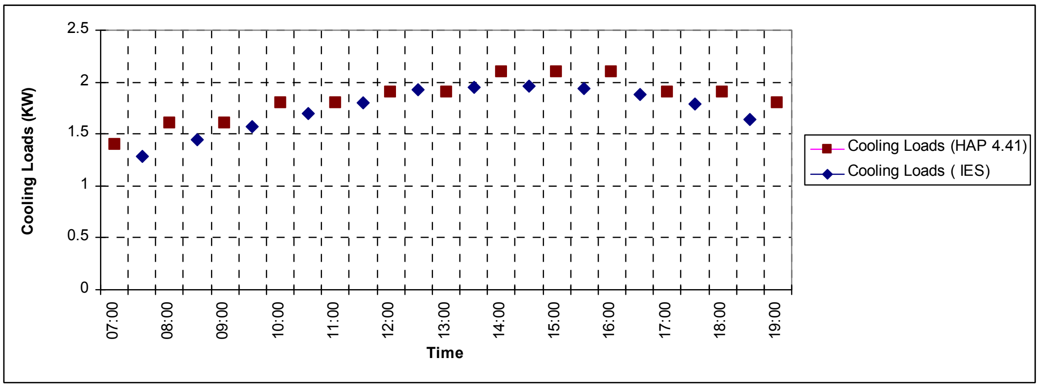


Figure 4.16 IES and HAP cooling loads in June

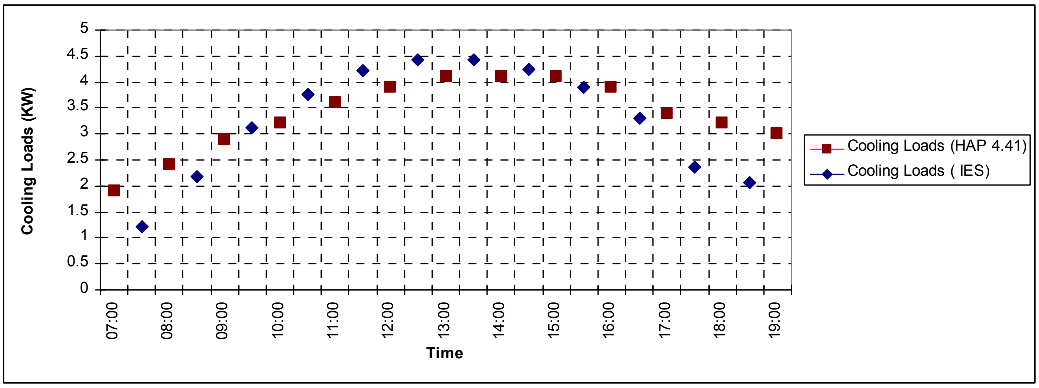


Figure 4.17 IES and HAP cooling loads in December

Chapter 5: Results and Discussion

This chapter describes the results obtained from more than 220 simulation runs for the configurations outlined in the previous section. The simulations are grouped according to orientations, and are presented on that basis. Because the simulation tables and charts comprise many pages, this chapter provides only a glimpse of the wealth of information in the tables. Detailed results are enclosed with the first set of simulations of the south oriented facade in the selected day in December. However, most of the charts and tables have been moved to Appendices and cross references are provided wherever relevant. The results are followed by a discussion of the findings in the context of other studies described in the literature review. The last section of this chapter includes a summary and a general comparison between the simulation results of all configurations of the south , east and west orientations.

5.1 South Façade Simulations

5.1.1 Glass Shading Coefficient 0.41 and lighting sensor @ 2m

December:

The results show that lighting control strategy caused an energy saving (22.33%) whereas the case with dynamic louvers has achieved a significant saving of the hourly energy consumption (42.22%) compared to the base case scenario. The case with louvers at an angle of 20° has the maximum reduction of 41.1% of the energy among all other angles. Therefore, it has been considered as the optimal fixed angle in the selected day in December. It can be seen that the energy reduction because of this angle is close to the percentage achieved by the dynamic louvers case. Figure 5.1 shows the energy consumption of all configurations in the selected day in December.

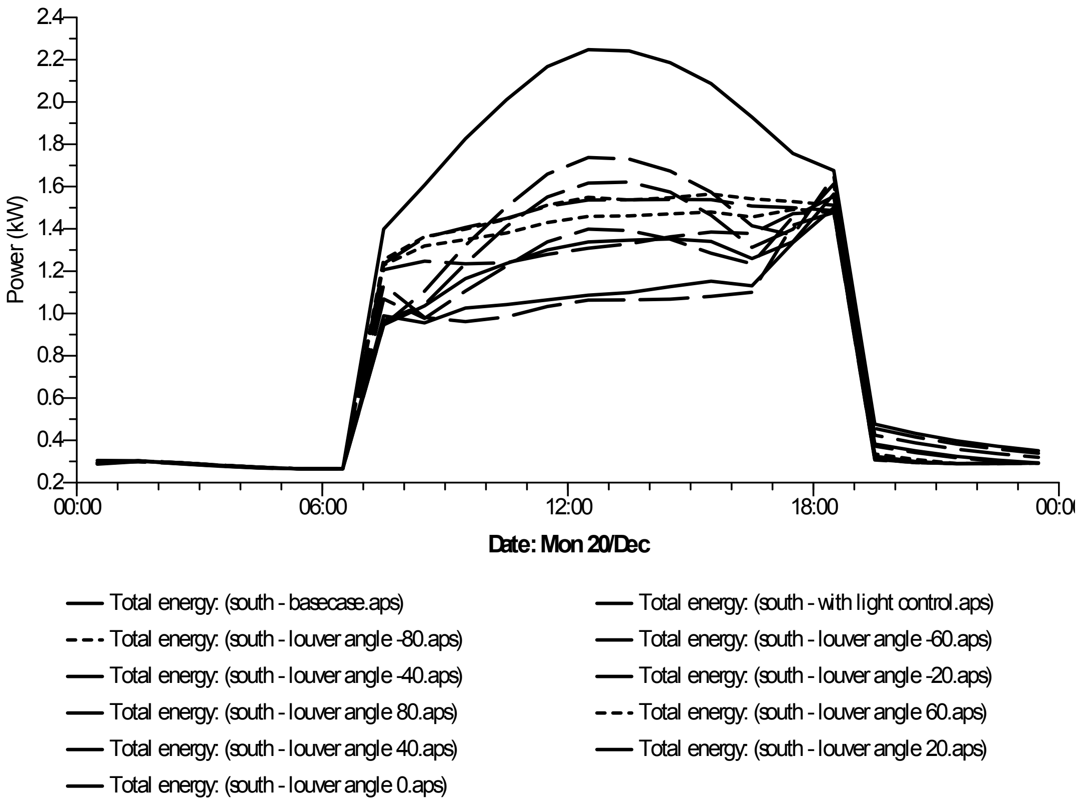


Figure 5.1 Total Energy Consumption of all scenarios for the south oriented facade in 20 December

The potential energy savings due to the dynamic louvers with lighting control rely substantially on lighting and cooling loads. The reduction of these loads is roughly proportional to the degree of the static louver's openness and its relation to solar position. To clarify, the cooling loads and lighting energy of the base case, the case with lighting control and the cases with various angles are presented in separate charts (see Fig 5.2 and Fig 5.3).

Figure 5.2 shows the effect of closing the louver angle on lighting demand. It can be seen that the base case, as expected, consumes the maximum lighting energy whereas the case with lighting control is the most energy efficient scenario. The louvers at any angle cause obstructions to daylight passing to indoor office space that increase the lighting energy consumed by luminaries. Closing the slat angle of the louvers upward or downward reduces the amount of light transmitted to the space and ultimately increases the lighting demand. It reaches the maximum value at an almost closed angle of 80° or -80°. The dimming lighting control achieved lighting energy saving (95.2%) compared to the base case without lighting control. This value is close to the lighting energy saving (92%) that was concluded by Athienitis and Tzempelikos (2002) with dimming methodology on clear days. That study was carried out for an office space in Montréal, and the authors employed multiple light sensors to measure daylight. This can justify the slight difference between the two values.

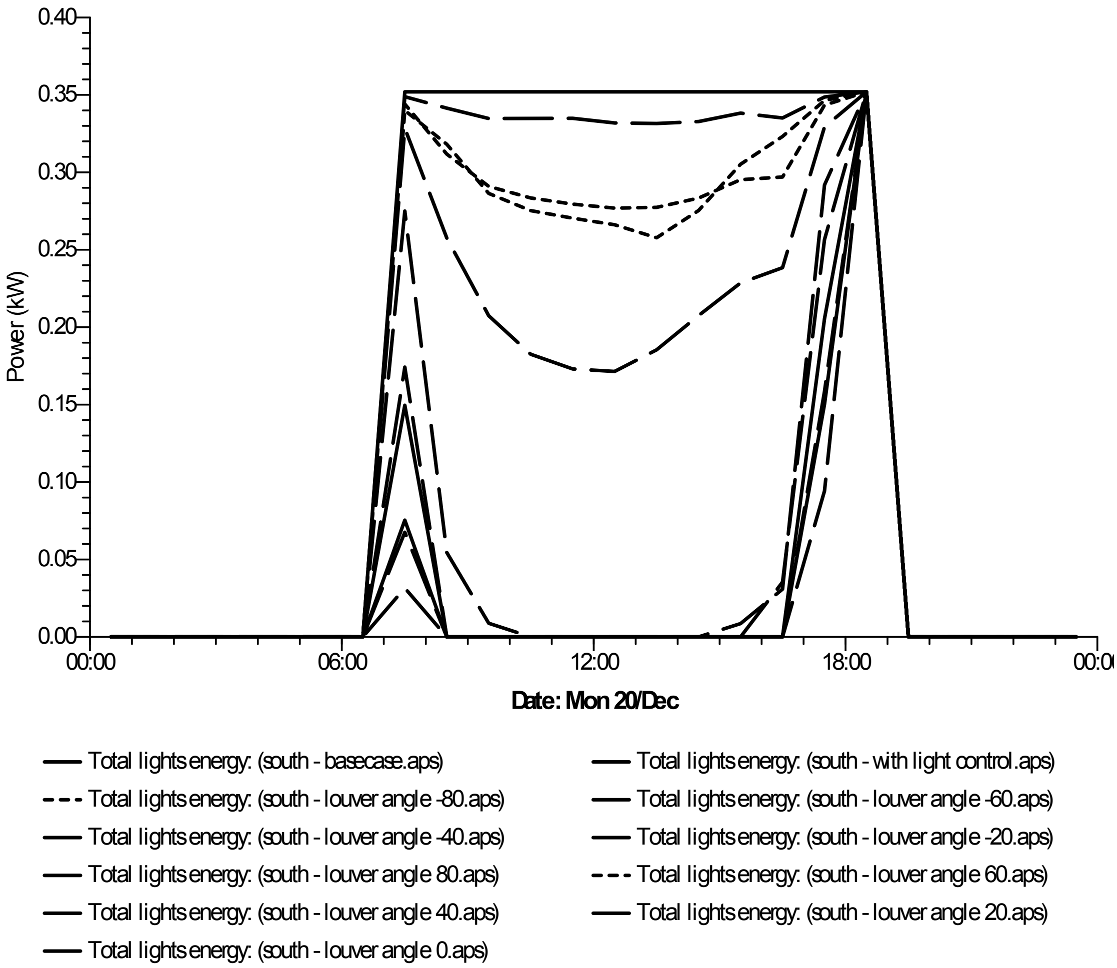


Figure 5.2 Lighting loads of all scenarios for the south oriented facade in 20 December

Referring to the system cooling energy loads in Fig 5.3, it shows that the case of louvers has considerably reduced the cooling demand. This reduction of cooling depends on the slat angle of the louvers. The maximum reduction is noticed at 20° and that is considered to be the optimal angle with respect to cooling loads. From a cooling perspective, however, the minimum energy consumption was supposed to occur at the most closed angle of -80° or 80° where the solar radiation was blocked due to louvers. This did not happen and is most properly due to the reduction of illuminance levels that caused an increase of lighting demand. This increase generated an extra internal heat gain dissipated from the lighting fixtures that raised the demand of the cooling system as shown in Fig 5.2. Therefore, the optimal energy consumption is a balance between the lighting and HVAC loads.

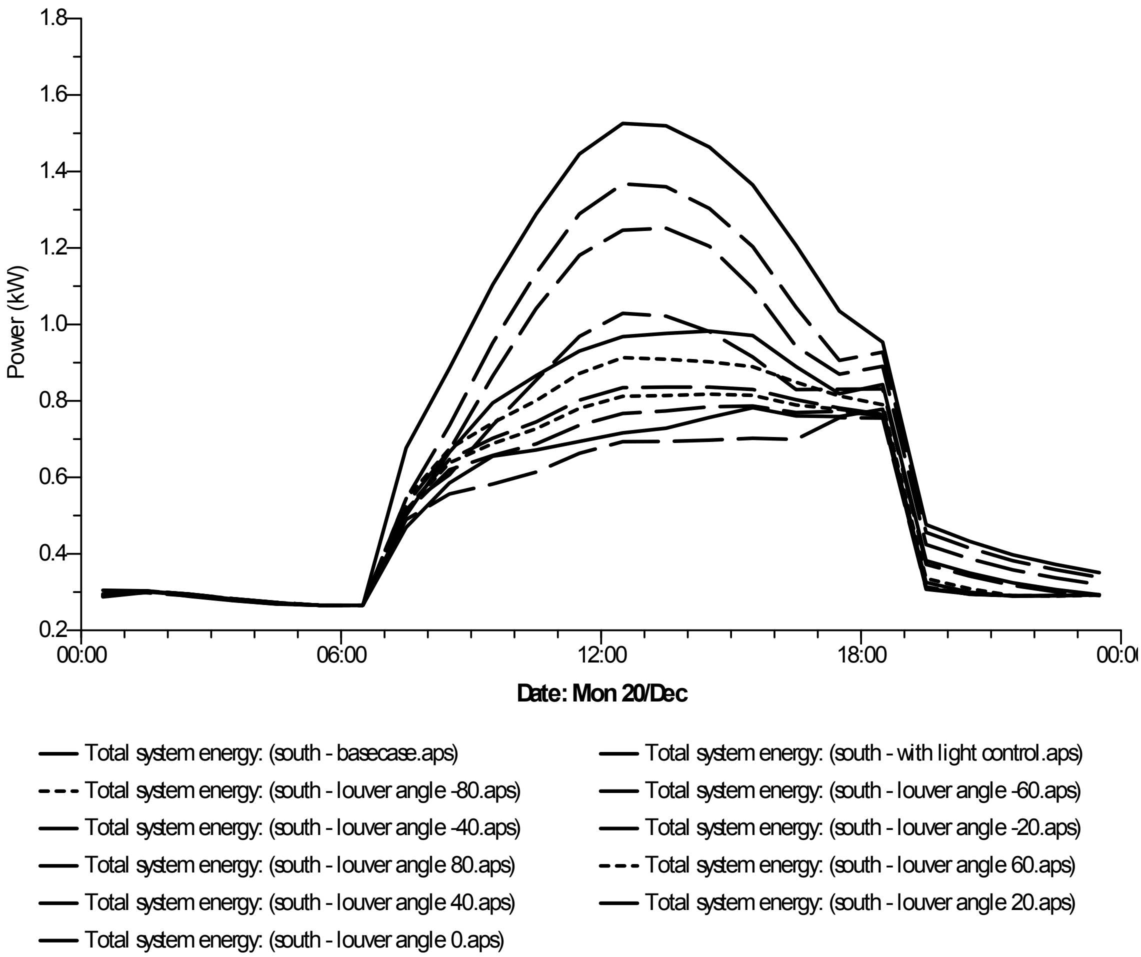


Figure 5.3 Cooling loads of all scenarios for the south oriented facade in 20 December

As explained previously, the shading devices are not effective in the absence of solar radiation. Therefore the optimal slat angles within the period from the sunrise to the sunset are only considered. Any change to optimal slat angle out of this period does not have value for this study. The weather file shows that the sunrise in the day in December starts at 7:05 in the morning whereas the sunset is observed at 17:33. The optimal louver slat angle in Fig 5.4 shows a steady angle at 20° during daytime. Slight change to this angle occurs in the morning and late evening hours. At 7:30 in the morning, the slat angle -20° has the optimal value of energy consumption where the daylight is maximized and the solar radiation is blocked. Consequently, the lighting is switched off as shown in Fig 5.2. As soon as the solar altitude rises, the indoor space will be subject to more heat due to the direct solar radiation that goes through this angle. As a result, the optimal angle has been changed to the position of 20° where the solar radiation is blocked and daylighting is still allowed to enter the indoor space. The optimal angle is maintained at 20° until evening hours. The difference in energy consumption at 17:30 for the louver slat angle 20º and 0º is approximately 0.083 KW which is minimal and does not move the optimal angle far away from the angle 20º especially given that the tested angles are at 20º intervals. The data shown in Fig 5.4 is obtained from Table 5.1.

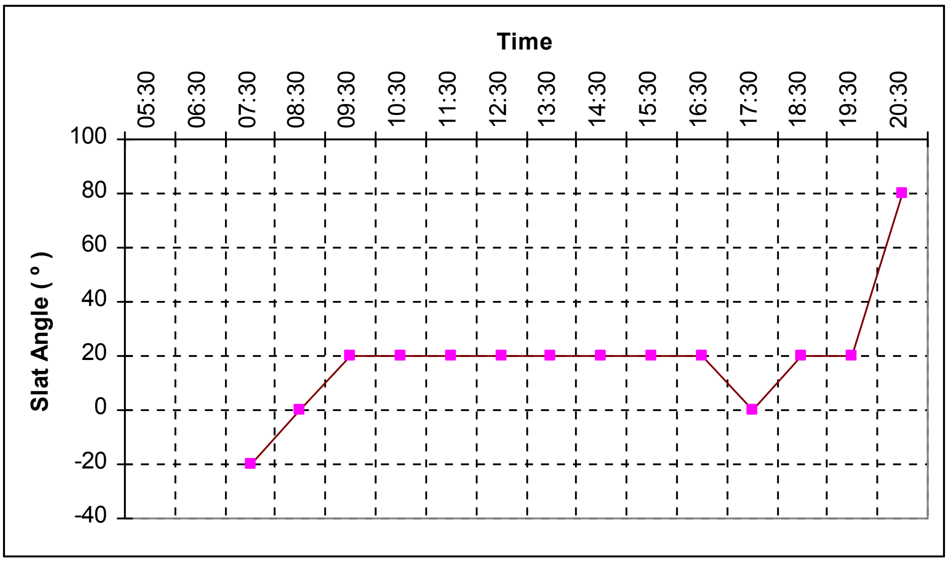


Figure 5.4 Optimal louver slat angle of the south oriented facade in December from 7:30 to 20:30

Figure 5.5 shows the energy consumption of various scenarios tabulated in Table 5.1. The case of dynamic louvers has the minimum energy consumption whereas the base case has the largest. The effect of louvers on the energy consumption is evident during the mid daytime.

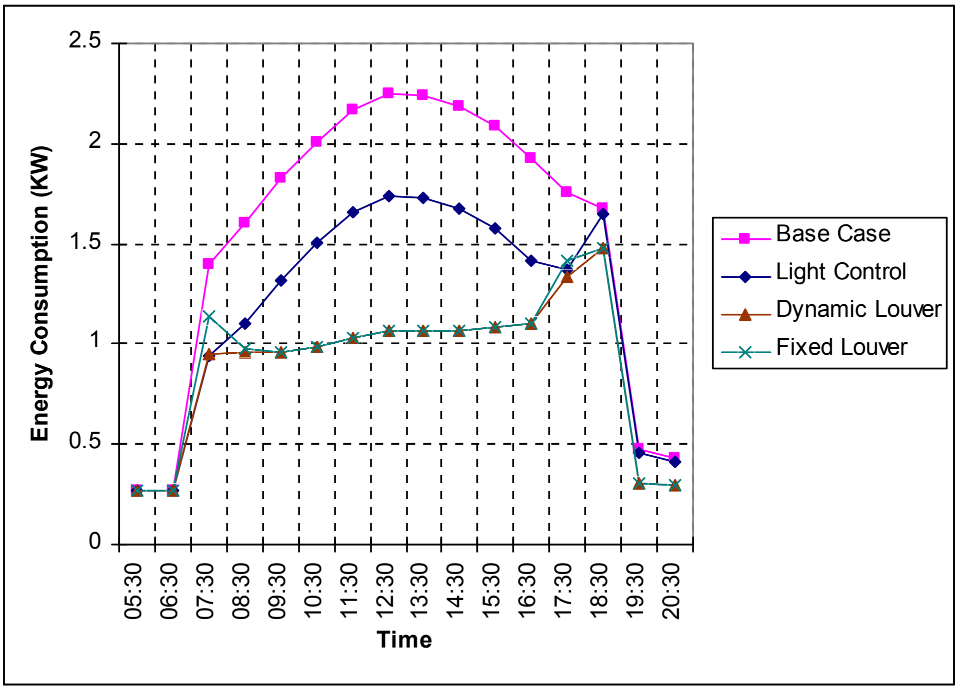


Figure 5.5 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 5:30 to 20:30

Table 5.1 Hourly energy consumption of the south oriented façade in 20 December from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (20º)
20 – DECEMBER	05:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	06:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	07:30	1.39878	0.9452	1.25434	1.06856	0.96605	0.94608	0.98882	1.1344	1.20656	1.2288	1.23528	32.43%	32.36%	18.90%
	08:30	1.6072	1.10555	1.36273	0.97663	1.0416	1.03565	0.95538	0.98117	1.24738	1.31949	1.35804	31.21%	40.56%	38.95%
	09:30	1.82613	1.32158	1.39891	1.10618	1.23513	1.1646	1.02543	0.96116	1.23478	1.34916	1.40685	27.63%	47.37%	47.37%
	10:30	2.0106	1.50382	1.44594	1.22402	1.41151	1.23615	1.04157	0.98372	1.23987	1.38064	1.44967	25.21%	51.07%	51.07%
	11:30	2.16763	1.65904	1.5121	1.33846	1.55082	1.30029	1.06379	1.03299	1.27927	1.42988	1.50678	23.46%	52.34%	52.34%
	12:30	2.2476	1.73751	1.54921	1.39882	1.61635	1.33792	1.08612	1.06323	1.30834	1.4588	1.53653	22.69%	52.69%	52.69%
	13:30	2.24136	1.73	1.5367	1.39162	1.62157	1.34647	1.09839	1.06392	1.32907	1.46141	1.53758	22.81%	52.53%	52.53%
	14:30	2.18555	1.67313	1.54751	1.35127	1.57415	1.35246	1.12677	1.06726	1.36215	1.47104	1.53886	23.45%	51.17%	51.17%
	15:30	2.08681	1.57348	1.56449	1.28477	1.46427	1.34071	1.15214	1.08068	1.38503	1.47977	1.53795	24.60%	48.21%	48.21%
	16:30	1.92873	1.41462	1.542	1.23499	1.31249	1.25958	1.13056	1.10002	1.37784	1.45606	1.50805	26.66%	42.97%	42.97%
	17:30	1.75675	1.36992	1.52917	1.45687	1.39817	1.33891	1.33439	1.41771	1.47187	1.4914	1.4999	22.02%	24.04%	19.30%
	18:30	1.67551	1.64944	1.51186	1.55319	1.61229	1.56478	1.50021	1.47703	1.48276	1.48537	1.48674	1.56%	11.85%	11.85%
	19:30	0.47638	0.45601	0.33536	0.3722	0.42407	0.38196	0.32512	0.3072	0.31009	0.31207	0.31325	4.28%	35.51%	35.51%
	20:30	0.43275	0.41516	0.30898	0.34176	0.38746	0.34993	0.29956	0.29531	0.29477	0.29442	0.29421	4.06%	32.01%	31.76%
	Total	**24.57222**	**19.0849**	**18.92974**	**16.62978**	**18.14637**	**16.48593**	**14.65869**	**14.49624**	**17.06022**	**18.14875**	**18.74013**	**22.33%**	**42.22%**	**41.01%**
				Optimal Dynamic Slat Angle				**14.19771**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

Note: When optimal case is not assigned, all readings are similar and can be used as optimal case

March:

The simulations of the selected day of March show an optimal slat angle of -20° during the majority of daytime and this registers a change from what has been concluded for December. Figure 5.6 shows a swift change of the optimal angle at 6:30 due to a negligible change in the energy consumption. The total hourly energy saving that is achieved with the optimal angle is 37.96 % which is almost similar to the reduction made by the dynamic configuration 38%. The dimming light control reduced the energy consumption of the base case by 26.9%. Appendix A includes a full tabulation and charts of the simulations carried out for this month.

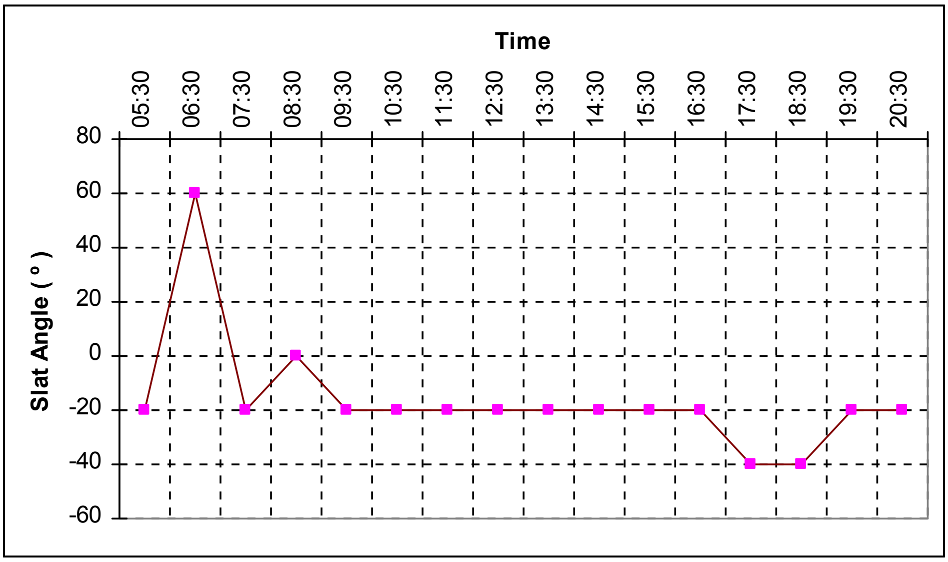


Figure 5.6 Optimal louver slat angle of the south oriented facade in March from 5:30 to 20:30

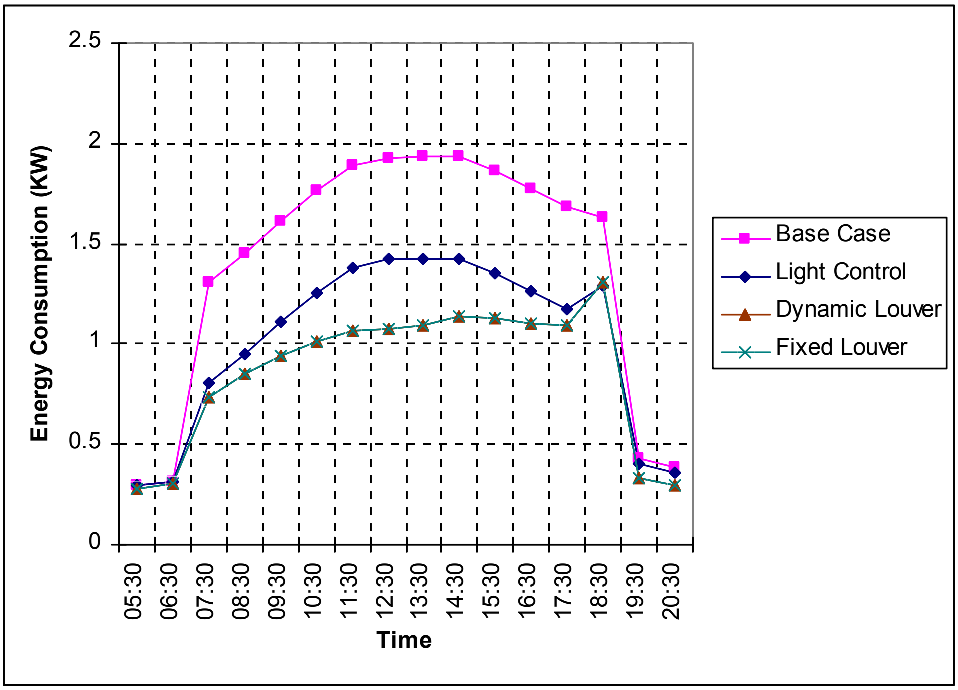


Figure 5.7 Hourly energy consumption of all scenarios of the south oriented facade in 21 March from 5:30 to 20:30

June:

Figure 5.8 shows that the optimal louver slat angle of the selected day in June is -40°. This angle is maintained optimal during the whole time from 7:30 to 20:30 with a slight change at 18:30. The result of simulations for the south oriented façade in this month registered an interesting observation. The energy saving that is produced for the case with daylight control is similar to what can be achieved in other cases with optimal fixed louvers or dynamic configuration as shown in Fig 5.9. This can be justified by observing the low solar gain of the base case in Fig 5.10. The solar altitude during June where the solar path is zenithal at noon is high. This suggests that the louvers at this time of the year have low performance with respect to their impact on cooling loads. However, the louvers might be beneficial for other reasons that will not be investigated in this research. Appendix A includes a full tabulation and charts of the simulations carried out for this month.

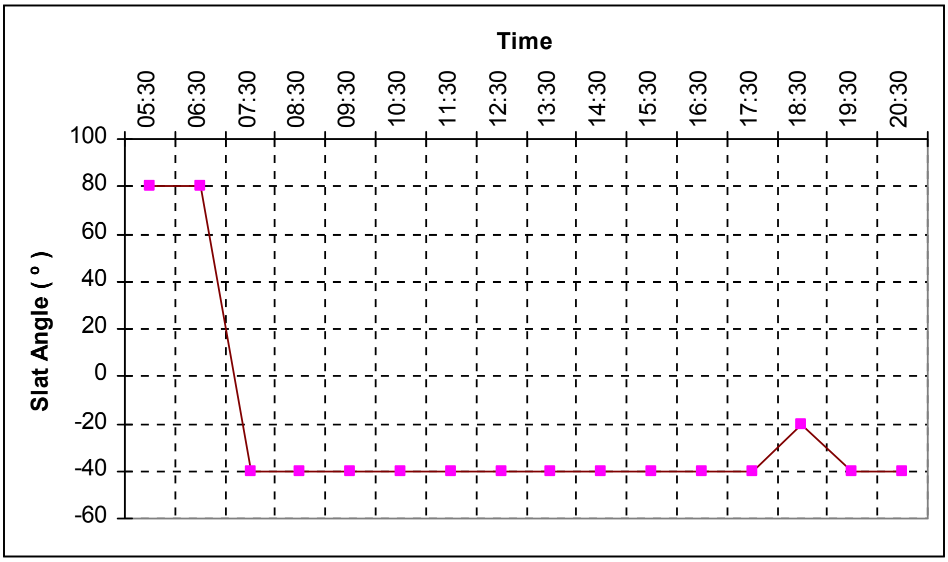


Figure 5.8 Optimal louver slat angle of the south oriented facade in 20 June from 5:30 to20:30

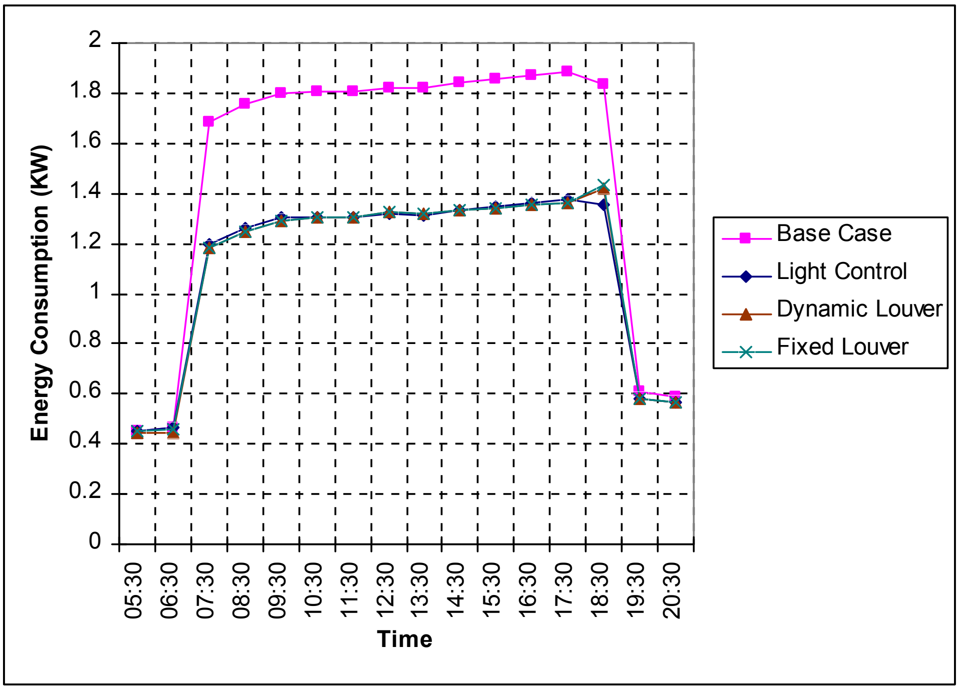


Figure 5.9 Hourly energy consumption of all scenarios of the south oriented facade in 20 June from 5:30 to 20:30

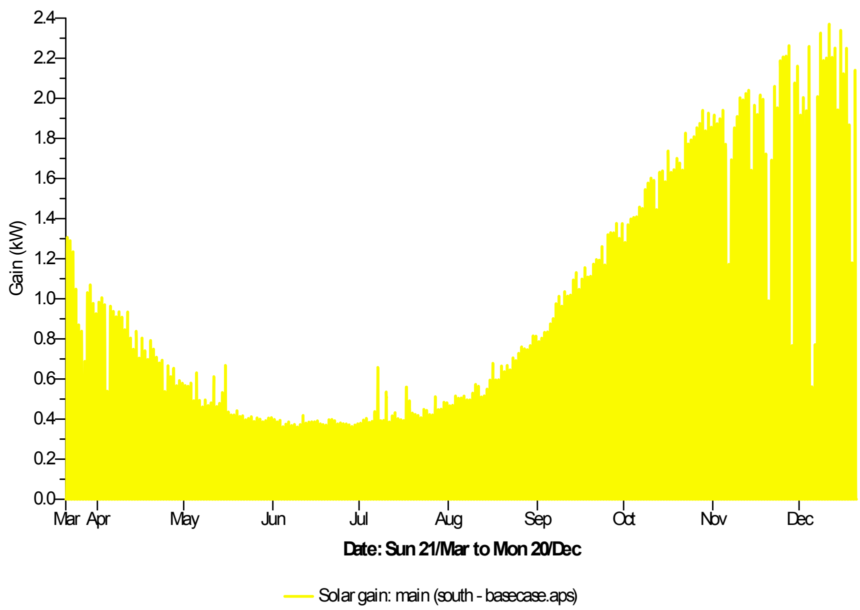


Figure 5.10 Annual solar gain of the base case of the south oriented facade

The cooling loads of the full day in June were estimated and compared to the results obtained by Cho, Shin and Zaheer-Uddin (1995) as shown in Fig 5.11. A wide range of factors that could influence the cooling loads such as the latitude difference between Korea and Abu Dhabi, climatic conditions and time can justify the tendency variation of cooling loads with respect to slat angles. It is important to highlight here that the negative angles of their model corresponds to the positive in this study.

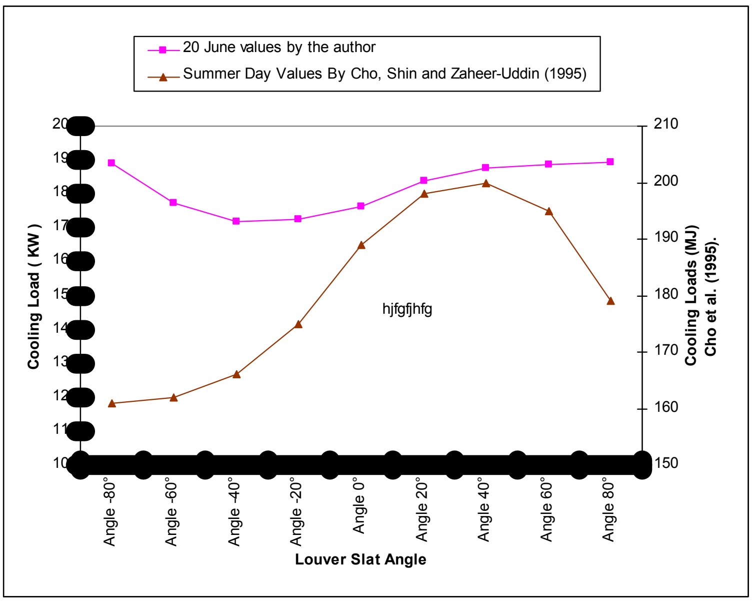


Figure 5.11 Full day cooling loads in 21 June

September:

The simulations of the selected day of September do not show a consistent optimal angle over the course of daytime. This angle keeps changing although a tendency is observed at angle -40° (see Fig. 5.12). The detailed tabulation of the simulation that can be found in Appendix A shows that the optimal fixed angle for this day in September is -40° with an energy reduction of 30.64% compared to the base case. This percentage is almost the same as what can be achieved by the dynamic configuration. Figure 5.13 shows an energy saving that can be achieved with both configurations exceeds the saving due to the use of lighting control only compared to the energy consumption of the base case.

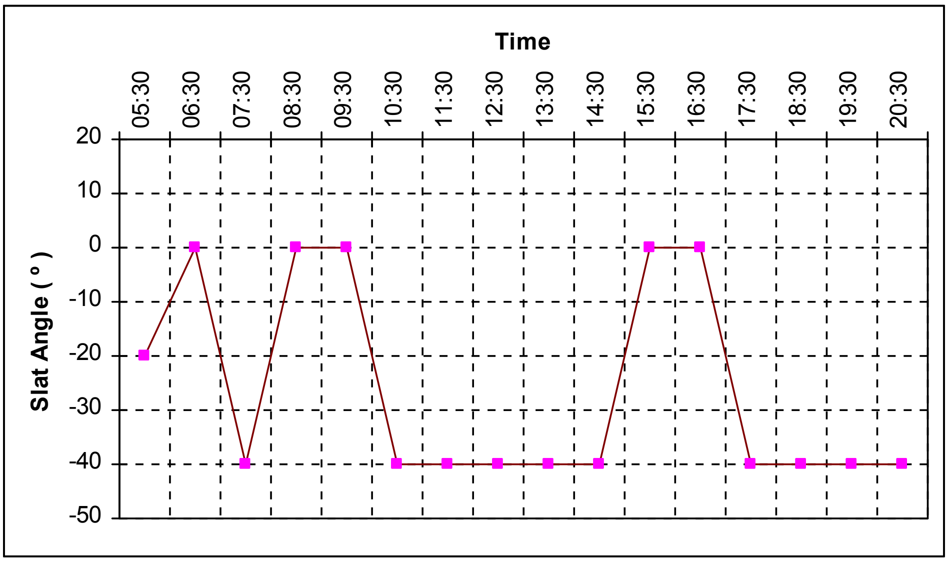


Figure 5.12 Optimal Louver Slat angle of the south oriented facade in 20 September from 5:30 to 20:30

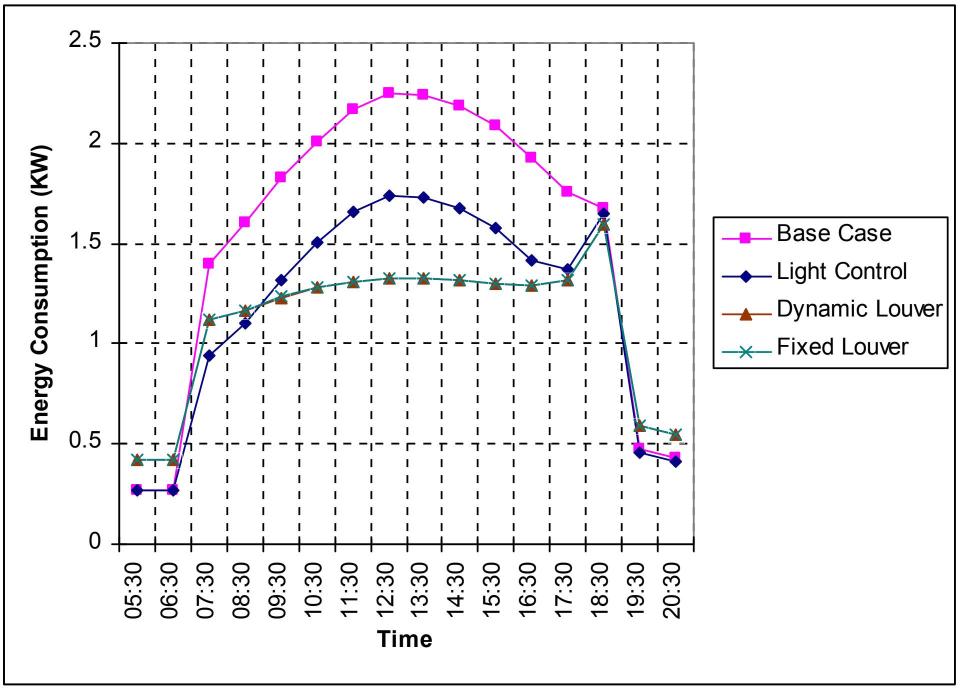


Figure 5.13 Hourly energy consumption of all scenarios of the south oriented facade in 20 September from 5:30 to 20:30

Summary:

Figure 5.14 is a summary chart showing the energy saving contribution by the various configurations of the South oriented façade with glass shading coefficient of 0.41 and sensor location 2m distance from the window. Results are concluded from the simulation of the cases for the selected four days from 5:30 to 20:30. Comparing with an office space where neither light control nor louvers are available (lights are on continuously during operation time), the energy saving of the dynamic louvers achieved the maximum value (34.02 %). The louvers with fixed angles of -20° and 0° have the next rating at 31.36% and 31.28% respectively. Therefore, the optimal angle is considered to fall between these two angles for the whole year. When applying the dimming methodology of the light control, the energy saving reaches to 24.4%.

The complete tabulation of the data shown in Fig 5.14 can be found in Appendix A.

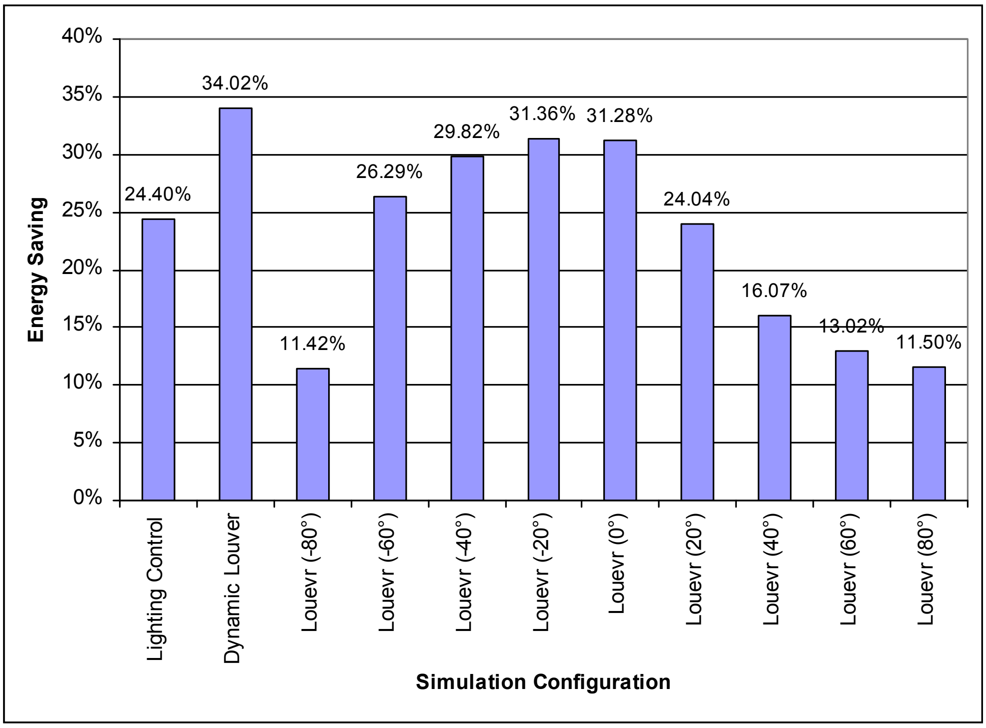


Figure 5.14 Total hourly energy saving of the south oriented façade compared to the base case for the four selected days in December, March, June and September

5.2.2 Glass Shading Coefficient 0.41 and lighting sensor @ 4 meters

Moving the sensor a distance of 4 meters from the window as expected reduced the energy saving due to the use of dimming methodology as well as the louvers. Figure 5.15 shows a summary chart of the energy saving contribution by the various configurations of the South oriented façade with glass shading coefficient of 0.41 and sensor location 4m distance from the window. Results are concluded from the simulation of the cases for the selected four days from 5:30 to 20:30. The dimming lighting control achieved energy saving up to 20.13 % whereas the installation of dynamic louvers cut down the energy consumption by 28.85 % of the energy consumption of the base case. The optimal fixed louver slat angle is maintained at (-20°) with energy saving of 25.49%. Moving the sensor inside the space reduced the day light illuminance available in the space, and this calls for more energy consumption by the lighting fixtures that effects the total energy consumption. The HVAC system was not affected by the movement of the lighting sensor apart from the extra heat dissipated from the lighting fixtures that required more cooling to compensate for this increate in temperature. The complete tabulation of the data shown in Fig 5.15 can be found in Appendix B.

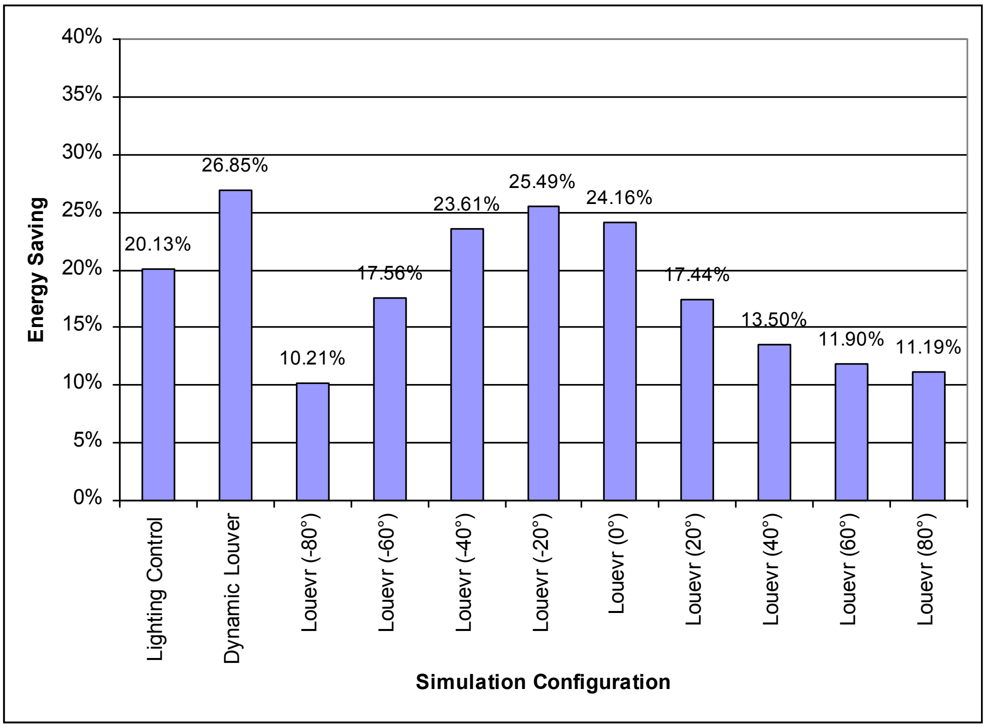


Figure 5.15 Total hourly energy saving of the south oriented façade compared to the base case in December, March, June and September

5.2.1 Glass Shading Coefficient 0.746 and lighting sensor @ 2 meters

Increasing the shading coefficient while maintaining the sensor position at 2 meters from the window consumes more energy by the base case of approximately 11% compared to the same case with shading coefficient 0.41. However, the energy consumption of the dynamic louvers compared to the base case with high shading coefficient is reduced by

37.73%. Due to the similar energy saving that is observed for the three fixed angles (-20°, 0° and 20°), the optimal angle is considered to fall between the angles (-20° and 20°) for this case. Applying the control light case without louvers has energy saving up to 21.63%. The primary modes of heat transfer through the glass are by conduction, convection and radiation. The U-Value of the glass measures the thermal conductivity only. This justifies the increase in the energy consumption when the shading coefficient increased. The solar heat is still allowed to pass through the glass by radiation and convection especially as the former has increased due to the higher visible light transmittance value. Increasing the shading coefficient is advantageous with respect to the artificial lighting consumption, but it works negatively to increase the cooling loads. The pattern of the optimal louver slat angle is maintained similar of cases with glass shading coefficient 0.41.The complete tabulation of the data shown in Fig 5.16 can be found in Appendix C.

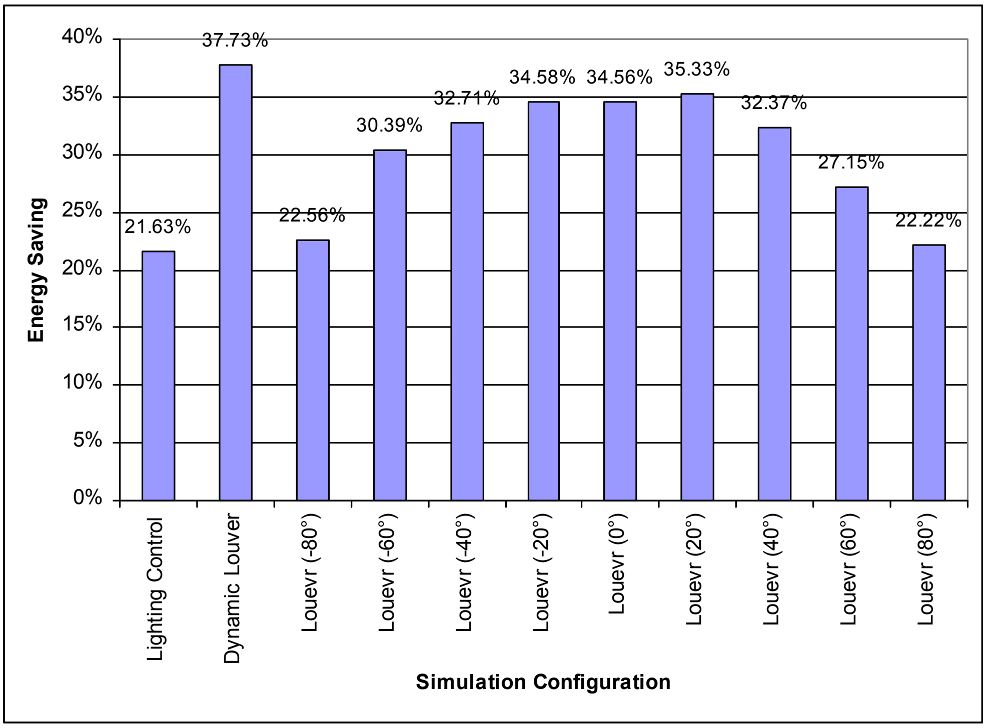


Figure 5.16 Total hourly energy saving of the south oriented façade compared to the base case for the four selected days in December, March, June and September

5.2 East Façade Simulations

5.2.1 Glass Shading Coefficient 0.41 and lighting sensor @ 2 meters

Appendix D contains detailed tables and charts of the simulation undertaken for the east oriented façade with a glass shading coefficient of 0.41 and sensor location 2m distance from the window. The results show that the optimal louver angle concluded in December, March, June and September is 0°, 20°, -20° and 20° respectively. The detailed charts of the optimal angles for the selected four days do not show a regular tendency to have a consistent optimal angle. It keeps changing over the course of the daytime.

The energy consumption charts of the four months show that the case with louvers performs better than the case with lighting control only in the morning hours whereas in the afternoon the case of lighting control achieves more energy saving as shown in December Fig 5.17. This can be understood by looking at the drop in solar gain and cooling loads for the base case of the east façade in the selected day in December (see Fig 5.18). This drop in solar gain is associated with the incident solar radiation and the position of the east façade with respect to solar path that cause a reduction in the cooling energy, which reduces considerably the performance of the louvers and gives preference to maximizing the lighting in the space. This ultimately reduces the need for artificial lighting.

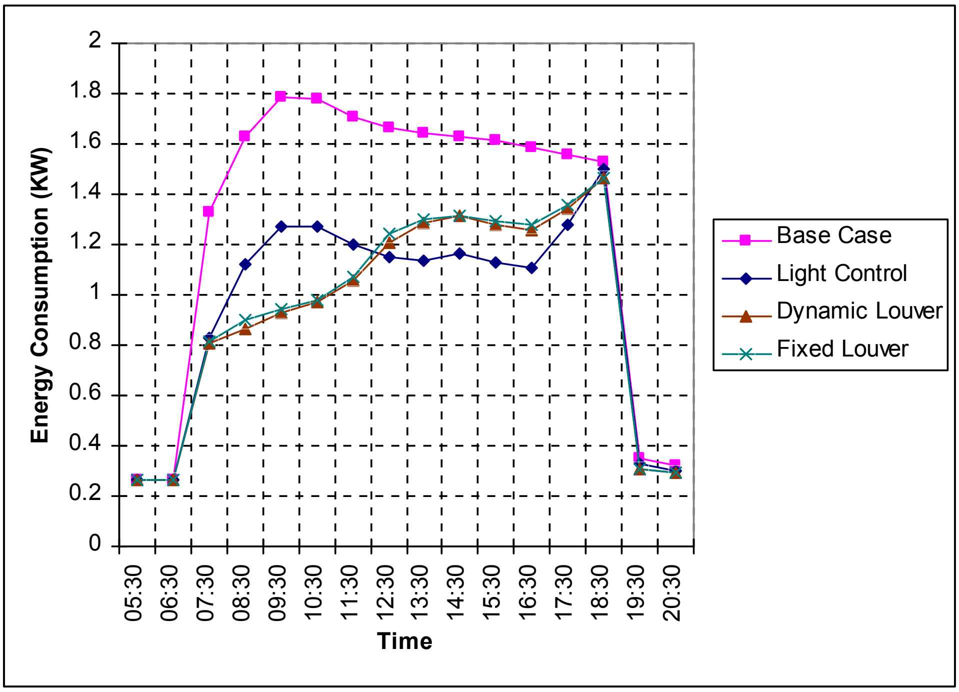


Figure 5.17 Hourly energy consumption of all scenarios of the east oriented facade in 20 December from 5:30 to 20:30

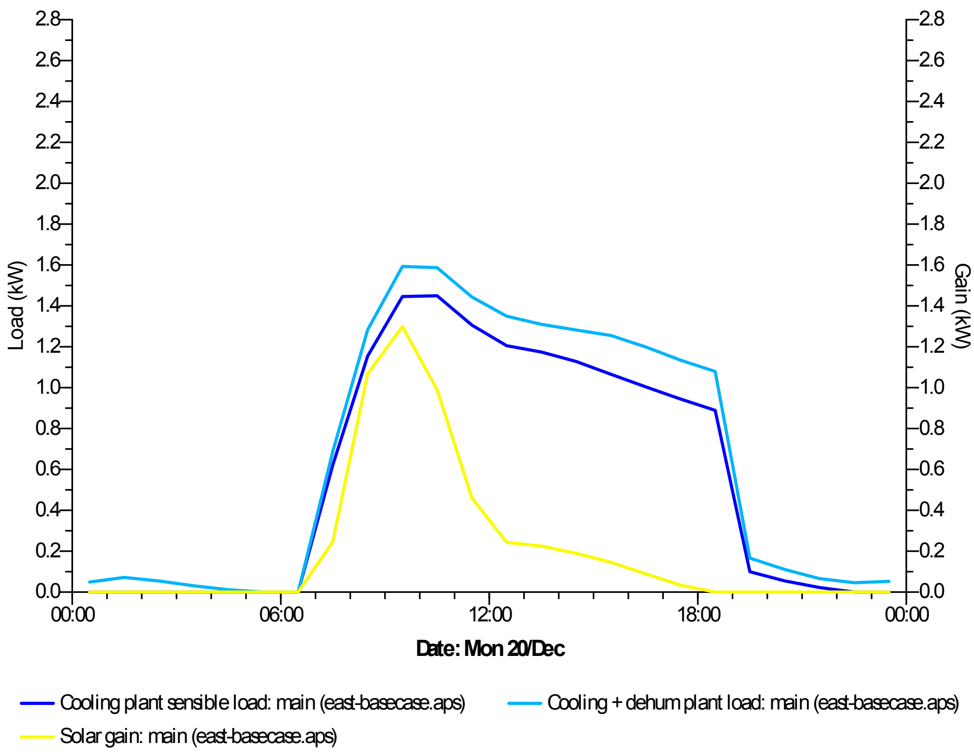


Figure 5.18 Solar gain and cooling loads of the base case for the east oriented facade in 20 December

The overall energy consumption of the four days shows that the optimal angle falls between 20° and -20° which achieves a reduction in energy from 25.21% to 26.08% compared to the base case. Figure 5.19 is a summary chart showing the energy saving by the various configurations. The results do not show much improvement in the energy consumption due to dynamic louvers when compared to the use of lighting control only. The difference is only 4.12% of the energy consumption of the base case. This reduction of energy is close to what can be achieved by the optimal louver angle (20°). Appendix D includes the complete tabulation of the data shown in Fig 5.19.

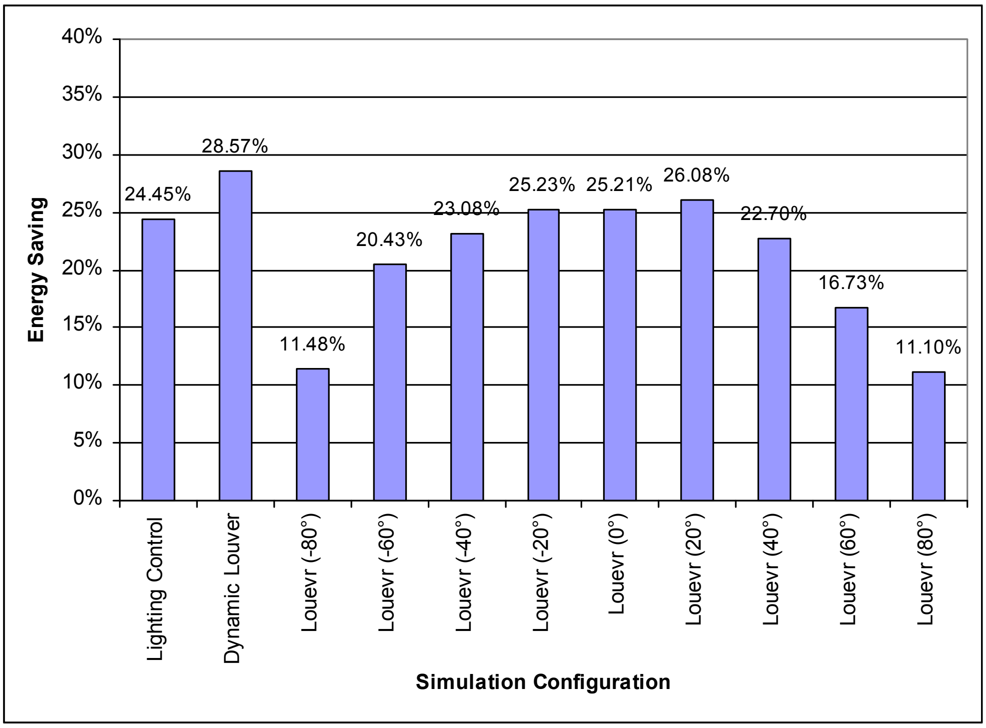


Figure 5.19 Total hourly energy saving of the east oriented façade compared to the base case for the four selected days in December, March, June and September

5.3 West Façade Simulations

5.3.1 Glass Shading Coefficient 0.41 and lighting sensor @ 2 meters

The results of simulation for the west oriented facade show that the optimal louver angle concluded in December, March , June and September is 0° , -20°, 20° and -20° respectively. What is interesting in these results is that the optimal angle of this façade is the mirror of that of the east oriented façade for the same month. The detailed charts of the optimal angles for the four selected days do not show a consistent optimal angle in spite of a frequent tendency to certain angles.

The charts of the four months show a reverse pattern of energy consumption to what was observed for the east oriented façade. The case of lighting control only tends to perform better than the case with louvers in the morning hours whereas the louvers achieve a better saving in the afternoon hours. A similar justification of the east oriented façade applies here. Figure 5.20 shows an example of the energy consumption pattern for the various configurations of west façade.

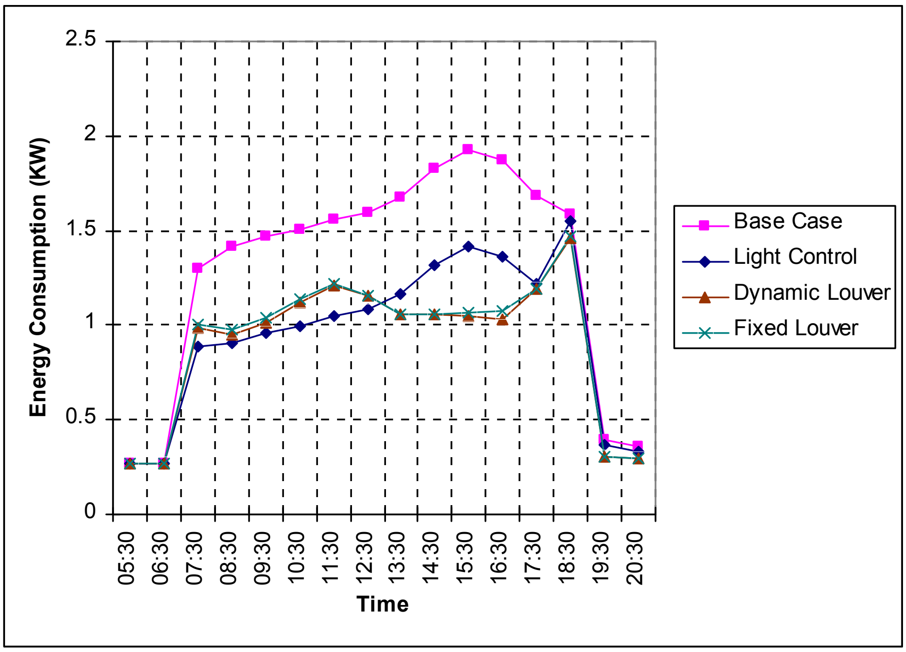


Figure 5.20 Hourly energy consumption of all scenarios of the west oriented facade in 20 December from 5:30 to 20:30

The west oriented façade configurations perform similar to the east façade configurations. The use of lighting control only achieved 25.19% of the base case. The configuration with dynamic louvers improves the performance and makes a reduction of 30.31% of the base case. Figure 5.21 shows that the louvers angle (20°) is the optimal angle of the four selected days with energy reduction of 25.97%. The complete tabulation of this figure can be found in Appendix E.

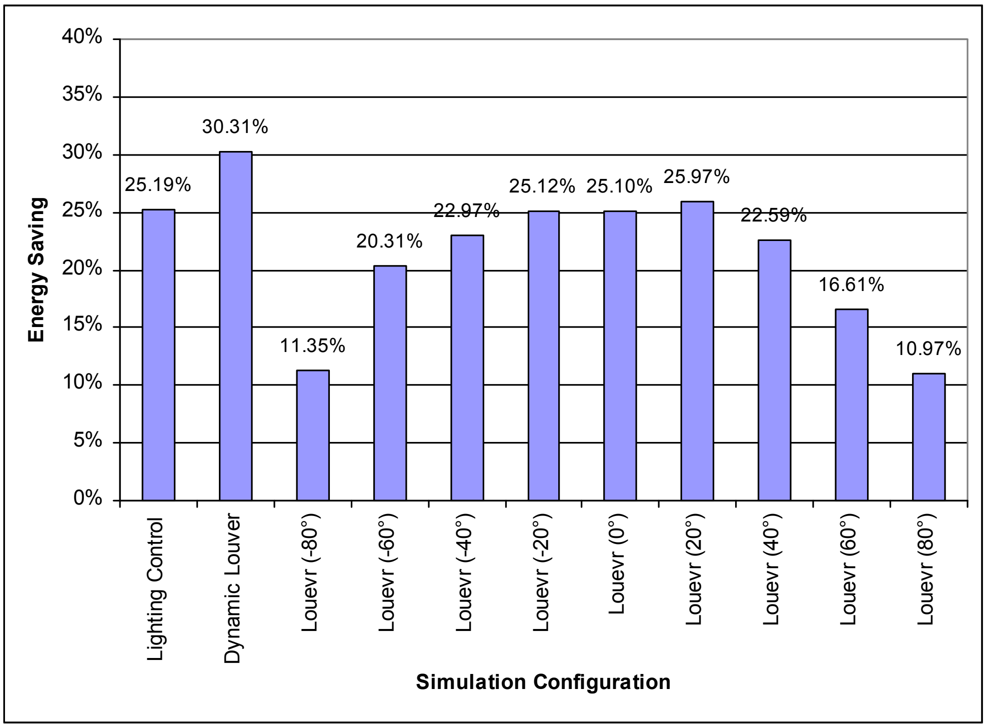


Figure 5.21 Total hourly energy saving of the west oriented façade compared to the base case for the four selected days in December, March, June and September

5.4 General Discussion

In the previous sections of this chapter, the results of simulation of various configurations were discussed based on their orientation. In this section a general discussion evaluates the results of all orientations. This will help to create a broad picture of the performance of dynamic louvers.

The optimal louver angle with respect to overall energy consumption highly depends on a balance between the solar gain and the amount of day light illuminance available at the work plane that will be collected by the lighting sensor. This angle can be identified at a certain moment by adding the lighting demand and HVAC loads required to cool the space at that moment. The amount of daylight in the space is dependent on the position of the sun with respect to the façade orientation. For instance, the south oriented façade achieved less lighting demand in December rather than in June. This can be justified due to the solar altitude in June.

Dimming control is always advantageous compared to the case without lighting control methodology, regardless of the presence of louvers. With daylighting control, any presence of daylight will be captured by the light/Lux sensor and an immediate reduction of lighting energy will occur depending on the amount of available light. On the other hand, less use of artificial light will result in reduction of the heat dissipated from the luminaries and ultimately the cooling loads will be less.

The most effective way to reduce the solar load on a fenestration is to intercept direct radiation from the sun before it reaches the glass (ASHRAE, 2005). For this reason, it should be noted that the louver position is one of the important energy saving factors. On the other hand, the louvers might have a negative impact on the overall energy consumption of the space as explained for the east and west oriented facades. The louvers could create obstructions to daylight without being advantageous from the cooling perspective.

Figure 5.22 shows a comparison between the performances for all scenarios for the three orientations; south, east and west with a shading coefficient of 0.41 and sensor position at 2 meters from the window. It is important to note here that the percentages given in the chart are for all scenarios over the base case of that orientation. As shown in the chart, the optimal louver slats tilt angle varies from -20° to 20° regardless of the orientation. This gives an indication for the most appropriate fixed louver angle that can be used to fix louvers in the city of Abu Dhabi.

The energy saving that can be achieved for the east and west facades are almost the same with slight preference to the east oriented façade. The use of dimming light control achieves a good percentage of saving and sometimes performs better than using fixed louvers with almost closed angles. The maximum percentages are achieved for the south oriented façade. The case of dynamic louvers with light control is always the best scenario although the percentage of saving is close to what can be achieved by using the optimal fixed louver angle.

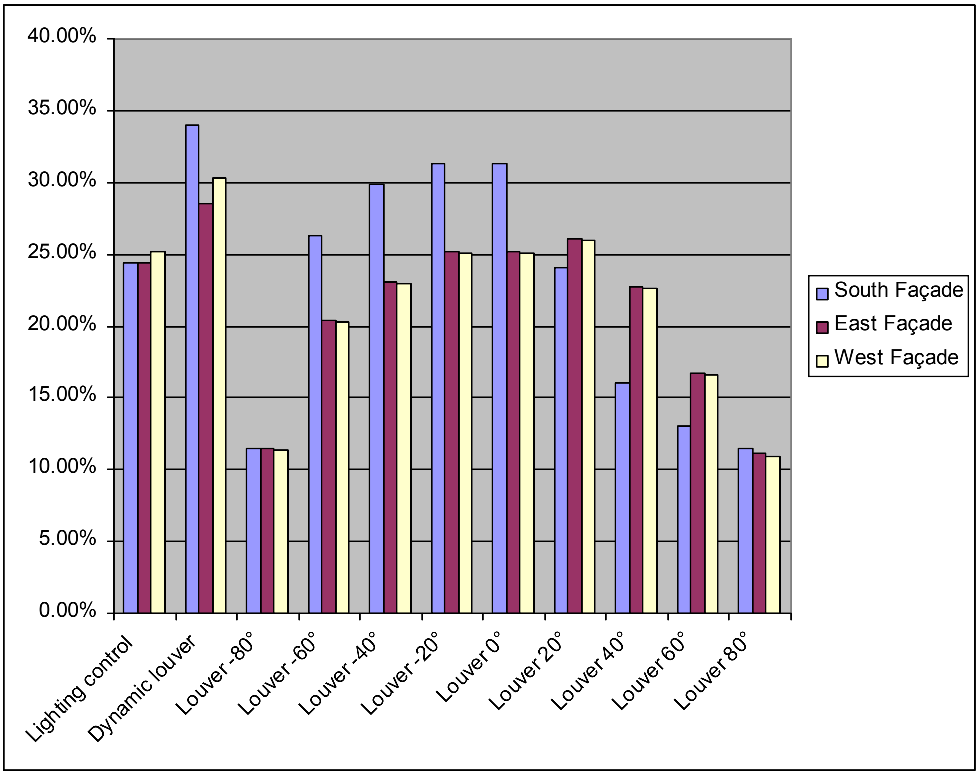


Figure 5.22 Total hourly energy saving of East oriented façade compared to the base case for the four selected days in December, March, June and September

Keeping the light sensor close to the window might be misleading, especially when one sensor is installed as shown in this study. The light distribution might not be uniform as explained when the sensor was moved away from the window due to the large contrast in daylight levels between the front and back of the room. Therefore, the best way is to design the number of luminaries required for the space and link each one directly to a sensor below it. This will ensure consistent Illuminance levels at the work plane.

The dynamic system and shading devices not only affect the energy consumption, but also might have an impact on other parameters which are of high importance to ensure a proper operation of the space as well as achieving a sufficient level of occupants comfort. Identifying the best louver angles by referring to the energy consumption may not be sufficient unless certain measures are considered to mitigate the undesired glare and heterogeneous distribution of illuminance on the work plane. Using certain angles for the louvers might be beneficial for the uniformity of illuminance and controlling glare, others could work negatively. In general, the use of shading devices causes an obstruction to natural daylight. Figure 5.23 shows the illuminance levels at the work plane of the south oriented façade in the selected day in December under sunny sky conditions. The areas of red in the visuals illustrate points greater than 1000 lux and therefore likely to be direct sunlight passing between the louvers .The visuals show that the sun azimuth at this time produces high illuminance levels for the upward louver angles and reduces significantly at the closed louver slat angle.

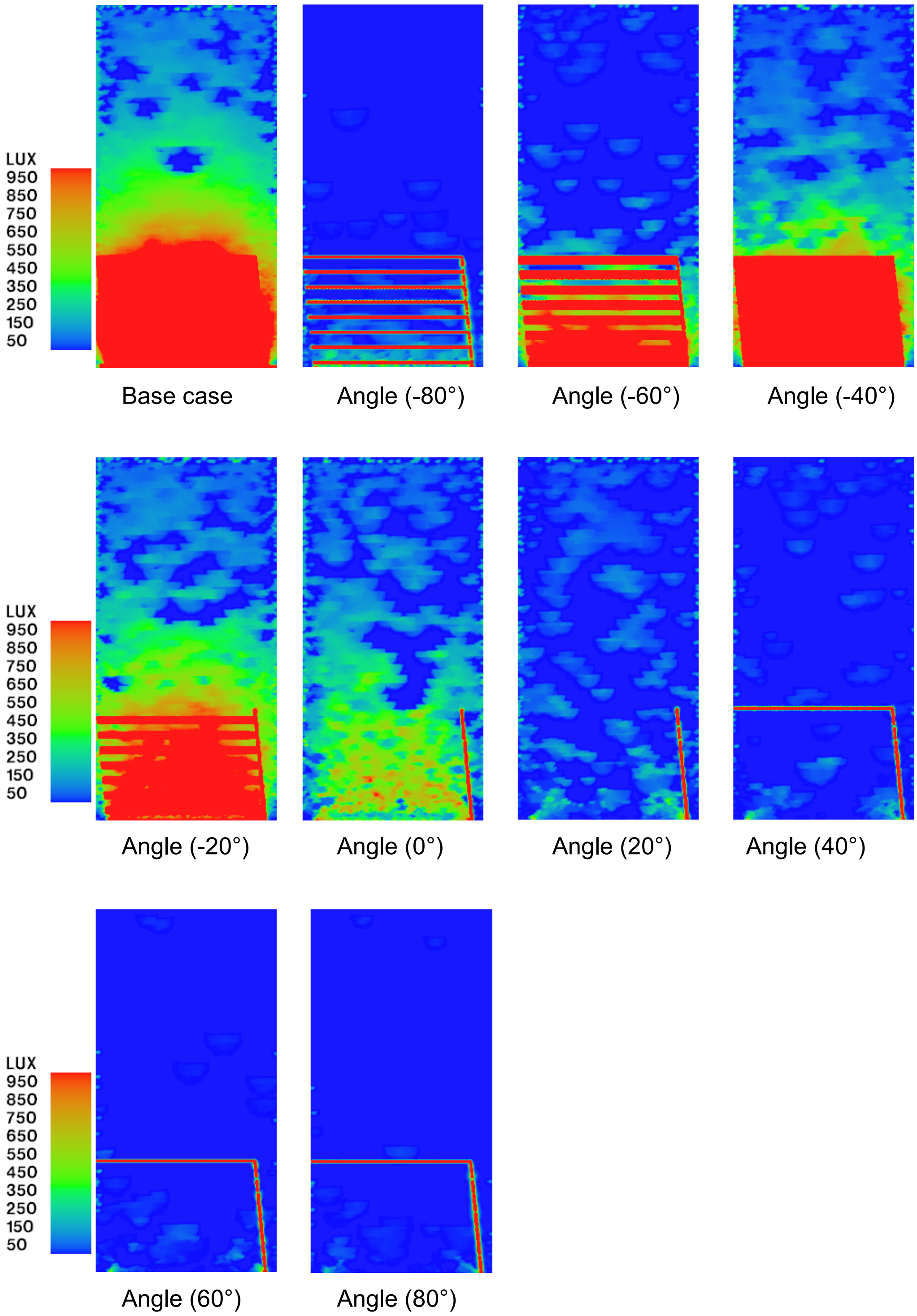


Figure 5.23 Illuminance levels at work plane in 20 December at 12:00

Glare is caused by either or both the excessive luminance values in the field of view and too high luminance contrasts. Windows can have a high luminance that gives a strong contrast from inside to outside, potentially causing glare. The strongest luminance source is the Sun, and if this in the field of view then glare is inevitable. Figure 5.24 shows some selected visuals for glare at the work plane in the selected day in December under sunny conditions. The use of external louvers is always beneficial for reducing the glare levels compared to the base case with no louvers.

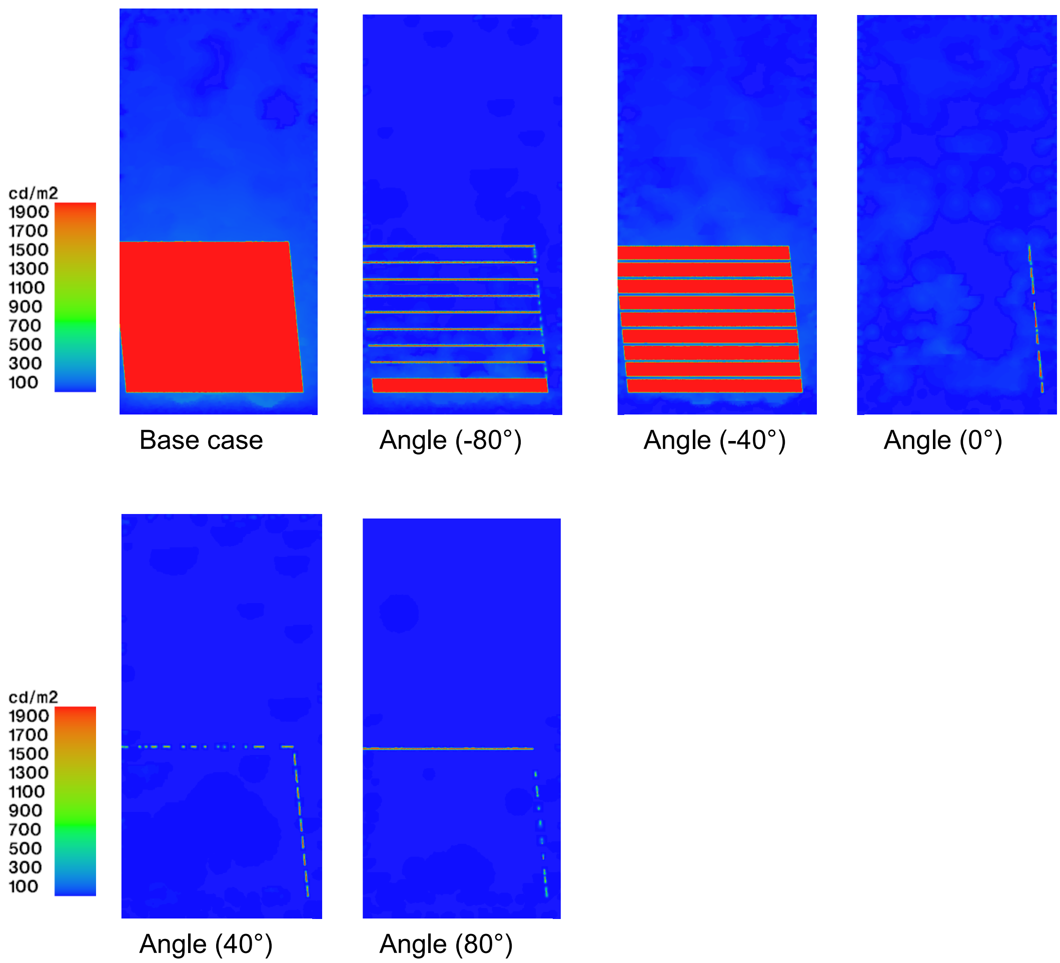


Figure 5.24 Glare levels at work plane in 20 December at 12:00

Many simulations were carried out to study the glare levels that can be produced for the optimal louver slat angles for the four selected days. It was found that the use of external louver reduces significantly the glare values at the work plane to acceptable levels although high values of glare were observed between the louver slats. Figure 5.25 and 5.26 as examples show the glare values for the optimal louver slat angles in June and March at 12:00.

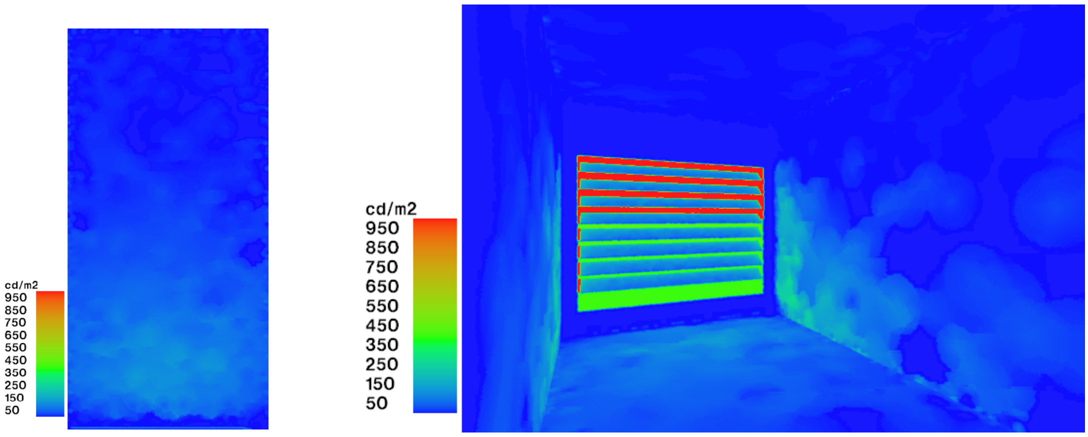


Figure 5.25 South oriented façade glare levels in 20 June at 12:00 for the optimal louver slat angle (-40°)

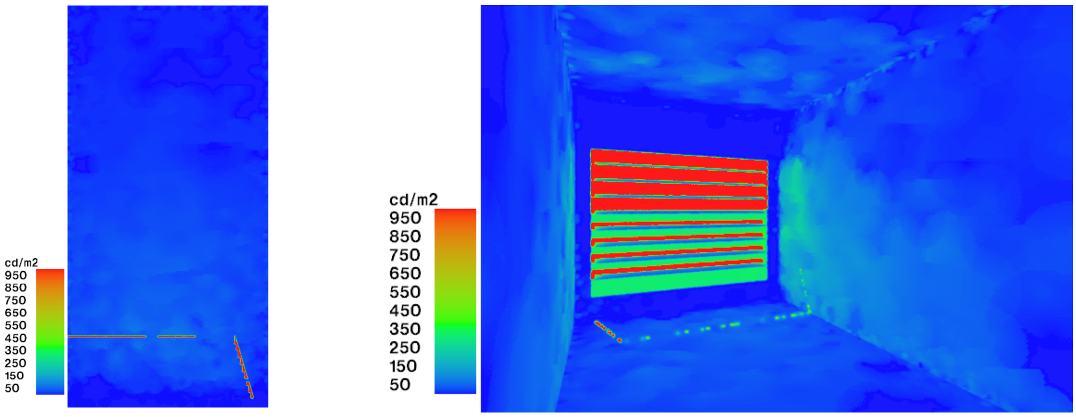


Figure 5.26 South oriented façade glare levels in 21 March at 12:00 for the optimal louver slat angle (-20°)

Increasing the shading coefficient could be advantageous for the lighting consumption, but on the other hand may lead to more cooling demand due to the increased heat gain. This suggests that any combination of fenestration elements should be studied independently and the energy consumption has to be evaluated to decide the optimal configuration that suites the climatic conditions and the space orientation.

The percentages of energy saving that can be achieved for the selected cases does not necessarily indicate a preference for any solution unless an economic study is carried out where these percentages are linked to the cost of each configuration . This will give a better understanding of the viability of each case. In the next chapter, an economic analysis will be presented in the context of the current market rates of Abu Dhabi.

Chapter 6: Economic Analysis

Economic analysis is the most frequently used method for evaluating the effectiveness of a new system and determining if a business opportunity is possible, practical and viable. It is also common to call it a cost/benefit analysis. Its main and simple procedure is to determine the benefits and savings that are expected from a candidate system and compare them with costs. The system is viable if benefits outweigh costs where the decision is made to implement the system. This chapter presents an economic analysis and appraisal of dynamic versus static louver fenestration systems compared to the cost of the base case described in the previous sections with a glass shading coefficient of 0.41 and sensor location at 2 meters from the window. The purpose of the analysis is to explore the viability of such solutions. The analysis is based on the results of the simulation of the pre-described configurations of the south oriented façade only. The potential energy savings of such configurations come from:

- Capital cost savings from reduction of peak cooling load (chiller size).
- Operational cost savings from reduction in cooling energy demand.
- Operational cost savings from reduction in peak cooling demand (penalties).
- Operational cost savings from reduction in electricity for lighting (if lighting control is used).

6.1 Inputs for the Study

All cost assumptions are based on Abu Dhabi rates of the local market at the time of conducting this research. The results are not necessarily applicable to any other place or in different time. For this analysis, the following rates and assumptions are used:

- The cost of electricity is AED 0.15/KWhr

- The positive impact of any reduction of the peak cooling demands on the capital cost of cooling system resizing is not included in this study.
- The annual operational maintenance of all systems is assumed to be an average of 7% of the initial capital cost as advised by the specialist.
- The electricity consumption by the lighting control or the motorization assembly is minimal; therefore it will be ignored in this study.

6.2 Annual Energy Consumption of all configurations

The main objective of this section is to estimate the energy consumption percentage compared to the base case for a typical week. This percentage will be multiplied by the annual energy consumption of the base case, which will give the annual energy consumption of all configurations. To estimate the energy consumption of a typical week, certain steps are followed;

Step 1: the average energy consumption of a full day (cooling system, equipments and lighting separately). This has been estimated by adding the energy consumption for the daytime of weekdays to the energy consumption for the nighttime of the base case. As explained previously in chapter four, the potential saving in the lighting and cooling loads due to the installation of lighting control methodology, fixed louvers or the dynamic assembly are negligible at nighttime. In fact the lighting loads are zero at this time because the office is out of operation.

Step 2: the energy consumption of typical weekends was estimated for the base case. During weekends, the office is out of operation, so there is no lighting demand, and the cooling loads have low values. It was assumed that the contribution of various configurations on energy saving during the weekend is very minimal, therefore, the consumption of the base case was used to represent these days. To test this assumption, the energy consumption of one weekend days in March for the base case was compared to the consumption for the optimal louvers angle (-20º) in these two days. It was found that the energy saving percentage due to the fixed louvers was 1.5%, and this percentage would be much less when the energy consumption of full week is considered. This result supports the assumption. Four weekends in (March, June, September and December) were selected. Their energy consumption was averaged to have a typical weekend's energy consumption.

Step 3: the energy consumption that was concluded for a typical week for all configuration was used to get the percentage of saving over the base case. The overall energy consumption for the cooling system, equipment and lighting was obtained from the simulations of full year for the base case. Finally, the energy consumption of all configurations was calculated. Table 6.1 summarizes the final calculations. The detailed calculation tables can be found in Appendix F.

Table 6.1 Annual energy consumption

	Base case	Light control	Fixed Louvers (-20º)	Dynamic louvers
Anuual System and Equipment consumption (KWh)	7337.3	6859.7	6393.6	6212.5
Annual Lighting consumption (KWh)	1098.2	53.1	84.9	81.0
Net annual System, Equipment and Lighting consumption (KWh)	8435.5	6912.8	6478.5	6293.5
Cost of net Annual energy (AED)	**1265.3**	**1036.9**	**971.8**	**944.0**
Percentage of reduction in energy consumption compared to the base case	**0**	**18%**	**23%**	**25%**
Cost saving over the Base Case (AED)	**–**	**228**	**294**	**321**

6.3 Capital cost estimation of all configurations

The direct and indirect costs were assumed based on quotations and data received from some system providers in the local market. Due to the unavailability of manufacturers to provide quotations for the entire proposed dynamic system, a rough estimation was based on various quotations obtained through telephone calls, emails and official offers. In fact, precise costing of such a complicated system requires detailed information, which takes long time and technical knowledge. The rough costing that was obtained is just to give an idea about the potential payback period for external dynamic louver system. Table 6.2 summarizes the extra capital cost estimation for all configurations compared to the base case. This estimation was averaged for a medium size building and normalized to suit the size of the studied office space.

Table 6.2 Capital cost estimation

	Light control	**Fixed Louvers**	**Dynamic louvers**
Dimming light components	1775	1775	1775
Aluminum Louvers	0	14742	14742
Motorization	0	0	1800
system integration	0	0	1150
Sub Total	1775	16517	19467
Maintenance (7%)	124.25	1156.19	1362.69
Sub Total	**1899.25**	**17673.19**	**20829.69**

Some quotations received from suppliers can be found in Appendix F.

6.3 Results

The simple Pay-back period method was used to estimate the payback timeframe of the studied configurations according to the following formula.

$$Y = \frac{CF_0}{A}$$ (Krarti, 2000, eq. 3.29)

Y: Payback Period CF_0: Initial investment   A: Annual net saving

The calculations of energy savings and the capital cost of all configurations are used as the input data in the simple Payback formula. Table 6.3 summarizes the Payback period results. It is important to note that the Pay-back period is estimated for the systems regardless of the cost of the base case system as this is equal in all configurations.

Table 6.3 Pay-back Period of all configurations

	Light control	**Fixed Louvers**	**Dynamic louvers**
Pay-Back Period (year)	8.3	60.2	64.8

The results show that the investment of static or dynamic systems is economically unviable whereas the adoption of light dimmers is more economic. The high cost of the louvers and the cheap prices of electricity in this part of the world were the direct reasons for such results. To clarify, the payback period of louver fenestration systems will reduce considerably to approximately 20 years if the cost of electricity is raised to AED 0.45/KWhr.

Chapter 7: Conclusions and Recommendations

In this research, Dynamic louvers as a component of dynamic facades were studied and their impact on the overall energy consumption was investigated under the climatic conditions of Abu Dhabi city. A literature review was conducted to establish a concrete base for the research. The findings from this literature review led to identify the objectives of this research. A simulation model was created for all tested configurations. The results of simulations were used to determine the potential energy savings of this system compared to the base case with and without lighting control and static louvers at various angles. An economic analysis was carried out to explore the viability of adapting the dynamic system in the local market of Abu Dhabi.

7.1 Conclusions

The use of dynamic louvers with the dimming light methodology achieved the maximum reduction among other scenarios, although by small margin in many cases. The percentage of reduction compared to the base case was found to be more for the south oriented façade rather than other orientations. It was found that the dynamic system achieved a maximum reduction of energy consumption of approximately 34.02%, 28.57% and 30.31% for the south, east and west orientation, respectively. The simulations that were carried out for the static horizontal louvers at various angles showed that the optimal angle fell between -20° and 0° for the south oriented façade and the saving was 31.28% over the base case. The vertical louvers at an angle of 20° achieved a maximum reduction over the base case for the east and west oriented façade with a percentage of 26.08% and 25.97%, respectively.

The installation of dimming methodology for lighting is always advantageous. It was found that the potential energy saving for the south, east and west oriented façade was 24.4%, 24.45% and 25.19% respectively.

The potential energy saving due to the use of louvers at the east and west façade is very minimal compared to the base case with a dimming light only. This raises the question of the wisdom of using the external louvers for the east and west orientations if lighting dimmers will be used anyway. However, the use of louvers is beneficial compared to the base case in the absence of the dimming control.

The performance of the proposed dynamic system has to be studied for any change of the glass parameters such as shading coefficient and the U-Value. The optimal value of the energy consumption is a balance between the heat gain and the visible light transmittance. Any change to glass parameters might affect lighting demand positively, but an increase in cooling loads might occur. Therefore a careful integration of any proposed dynamic system and glass properties can help to act as a true energy saver as well as an environmental controller.

This study addressed the potential contribution of external louvers in reducing the glare levels that the space might be exposed to due to the high illuminance levels. The glare simulations that were carried out for some of the optimal angles during the four selected days showed that these angles always experience acceptable levels of glare at the work plane and some high levels of glare were detected between the louvers slats which cause uncomfortable visual spots when looking directly at the window.

The economic analysis that was carried out for the south oriented façade did not prove to be economically viable investment of the static or dynamic louver systems. It has to be considered that the high construction costs and the low prices of electricity are some of the factors that affect the viability of such systems. A life cycle analysis of all systems if conducted would give a better evaluation from a sustainability perspective

7.2 Recommendations for future research

Following the development of dynamic louver systems and exploring the performance of this scheme under certain conditions, many other opportunities for future studies are highlighted as follows:

- The proposed control strategy for the louvers is based solely on energy consumption regardless of any impact that might occur on other parameters. The results of the proposed system can be further studied in the context of human comfort and visual quality.

- The properties of louvers on energy consumption can provide a broad area of study. The width, number, profile and surface reflectance of louvers might have more benefits in reducing energy consumption.

- Another system can be proposed and studied in a way to combine the virtues of daylighting and solar heat rejection for the studied area. This suggests having a louver configuration that can be retracted and stored to allow the maximum daylight when no direct solar radiation is detected. On the other hand it can be expanded at an adjustable louver angle when shading is desired to reduce heat gain.

- Glare is a very important factor to be considered in the design of office spaces. The excessive rates of glare especially at the perimeter spaces might produce uncomfortable areas. Although a preliminary study was conducted to explore the impact of the proposed dynamic system on glare levels, a detailed study might be beneficial to have a better evaluation and solutions can be proposed to mitigate this effect.

- A single light sensor was used in this research. The ideal situation as explained previously is to have multiple sensors based on the number of luminaries required to lighten the space with 500 lux. This will ensure a more uniform distribution of light and maintain the 500 lux all over the space.

- The high cost of proposed aluminum louvers was a direct reason for the unfeasible results of static or dynamic louver fenestration systems. However, these results might be positively changed if alternative material is explored such as PVC louvers. This option if studied has to be accompanied by an investigation of other factors such as the durability and resistance to climatic conditions in order to address the overall performance of such option.

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Appendix A

South Façade Simulations

Glass Shading Coefficient 0.41 and lighting sensor @ 2 meters

Table A.1 Hourly energy consumption of the south oriented façade in 20 December from 20:30 to 8:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (20°)
20 – DECEMBER	05:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	06:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	07:30	1.39878	0.9452	1.25434	1.06856	0.96605	0.94608	0.98882	1.1344	1.20656	1.2288	1.23528	32.43%	32.36%	18.90%
	08:30	1.6072	1.10555	1.36273	0.97663	1.0416	1.03565	0.95538	0.98117	1.24738	1.31949	1.35804	31.21%	40.56%	38.95%
	09:30	1.82613	1.32158	1.39891	1.10618	1.23513	1.1646	1.02543	0.96116	1.23478	1.34916	1.40685	27.63%	47.37%	47.37%
	10:30	2.0106	1.50382	1.44594	1.22402	1.41151	1.23615	1.04157	0.98372	1.23987	1.38064	1.44967	25.21%	51.07%	51.07%
	11:30	2.16763	1.65904	1.5121	1.33846	1.55082	1.30029	1.06379	1.03299	1.27927	1.42988	1.50678	23.46%	52.34%	52.34%
	12:30	2.2476	1.73751	1.54921	1.39882	1.61635	1.33792	1.08612	1.06323	1.30834	1.4588	1.53653	22.69%	52.69%	52.69%
	13:30	2.24136	1.73	1.5367	1.39162	1.62157	1.34647	1.09839	1.06392	1.32907	1.46141	1.53758	22.81%	52.53%	52.53%
	14:30	2.18555	1.67313	1.54751	1.35127	1.57415	1.35246	1.12677	1.06726	1.36215	1.47104	1.53886	23.45%	51.17%	51.17%
	15:30	2.08681	1.57348	1.56449	1.28477	1.46427	1.34071	1.15214	1.08068	1.38503	1.47977	1.53795	24.60%	48.21%	48.21%
	16:30	1.92873	1.41462	1.542	1.23499	1.31249	1.25958	1.13056	1.10002	1.37784	1.45606	1.50805	26.66%	42.97%	42.97%
	17:30	1.75675	1.36992	1.52917	1.45687	1.39817	1.33891	1.33439	1.41771	1.47187	1.4914	1.4999	22.02%	24.04%	19.30%
	18:30	1.67551	1.64944	1.51186	1.55319	1.61229	1.56478	1.50021	1.47703	1.48276	1.48537	1.48674	1.56%	11.85%	11.85%
	19:30	0.47638	0.45601	0.33536	0.3722	0.42407	0.38196	0.32512	0.3072	0.31009	0.31207	0.31325	4.28%	35.51%	35.51%
	20:30	0.43275	0.41516	0.30898	0.34176	0.38746	0.34993	0.29956	0.29531	0.29477	0.29442	0.29421	4.06%	32.01%	31.76%
	Total	**24.57222**	**19.0849**	**18.92974**	**16.62978**	**18.14637**	**16.48593**	**14.65869**	**14.49624**	**17.06022**	**18.14875**	**18.74013**	**22.33%**	**42.22%**	**41.01%**
				Optimal Dynamic Slat Angle				**14.19771**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

Note: When optimal case is not assigned, all readings are similar and can be used as optimal case

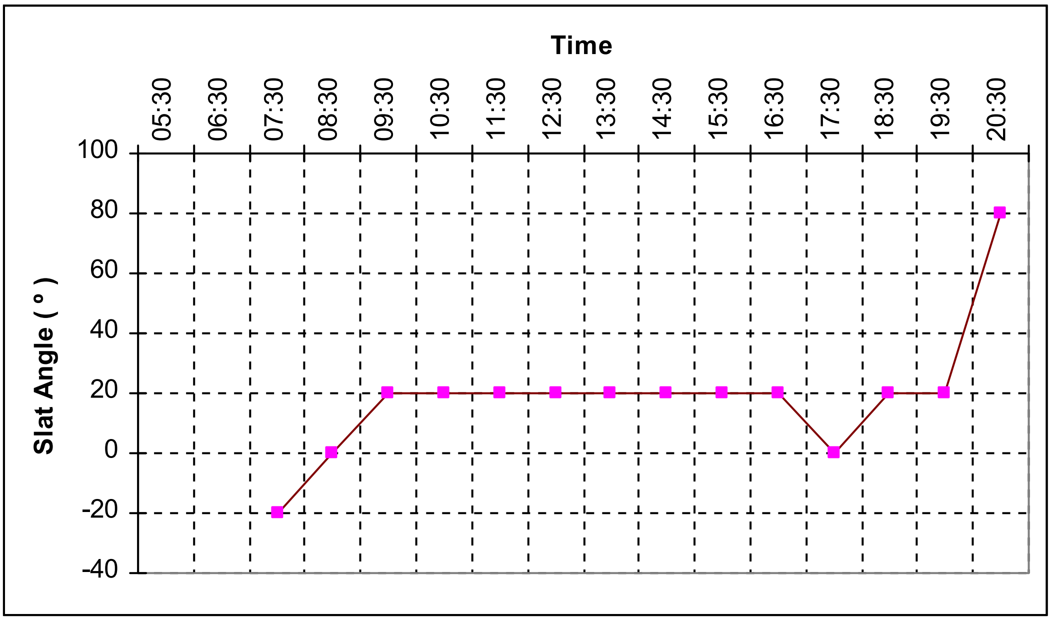

Figure A.1 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 7:30 to 20:30

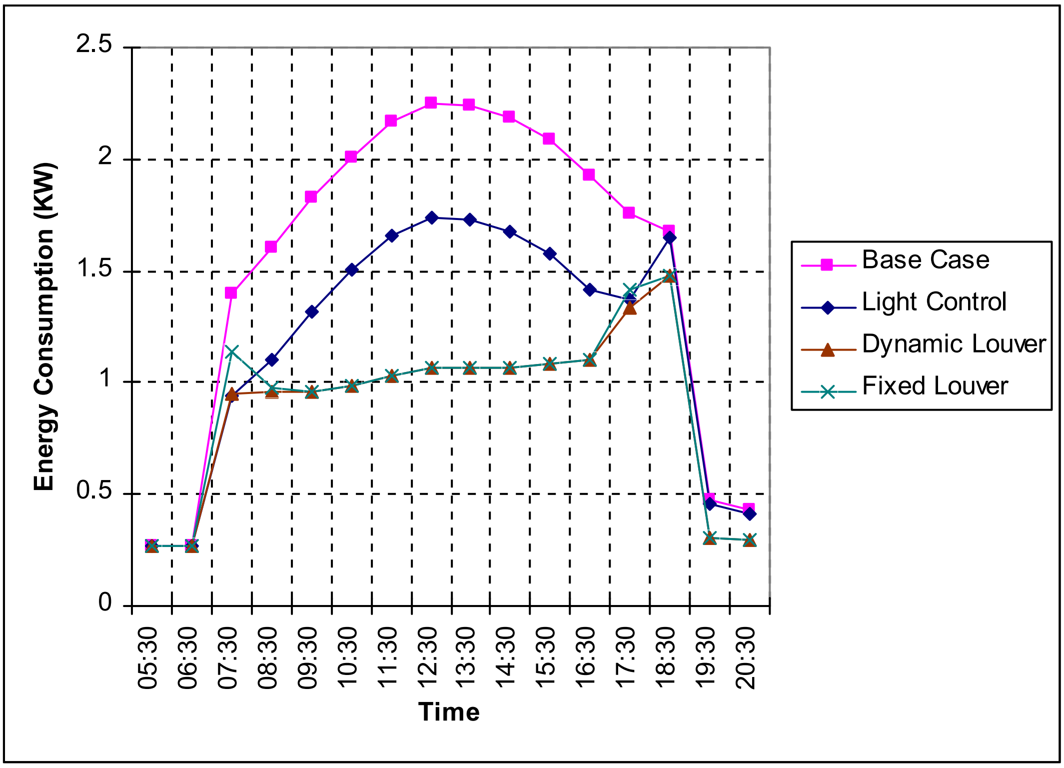

Figure A.2 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 7:30 to 20:30

Table A.2 Hourly energy consumption of the south oriented façade in 21 March from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-20º)
21 – MARCH	05:30	0.29465	0.29271	0.28147	0.28946	0.27541	0.27462	0.27506	0.27637	0.27746	0.27777	0.27797	0.66%	6.80%	6.80%
	06:30	0.31522	0.31457	0.30763	0.31127	0.3068	0.30649	0.30612	0.30596	0.30598	0.3059	0.30591	0.21%	2.96%	2.77%
	07:30	1.30462	0.80719	1.2009	0.89128	0.74103	0.73807	0.80331	1.04616	1.16003	1.19937	1.21222	38.13%	43.43%	43.43%
	08:30	1.45151	0.9516	1.29842	0.92096	0.85903	0.85107	0.8502	1.08769	1.23619	1.29278	1.32282	34.44%	41.43%	41.37%
	09:30	1.61086	1.1079	1.42327	1.06511	0.95251	0.94451	0.94563	1.13868	1.32423	1.39037	1.42836	31.22%	-396.63%	41.37%
	10:30	1.76091	1.25561	1.50613	1.18996	1.01714	1.01274	1.01606	1.20375	1.39566	1.46257	1.5057	28.70%	42.49%	42.49%
	11:30	1.88625	1.37769	1.57447	1.29074	1.06866	1.0659	1.07347	1.23397	1.44121	1.53071	1.57255	26.96%	43.49%	43.49%
	12:30	1.93069	1.42192	1.59124	1.32396	1.07878	1.07642	1.09964	1.24024	1.46528	1.54858	1.59011	26.35%	44.25%	44.25%
	13:30	1.93591	1.42581	1.59985	1.32992	1.09402	1.09176	1.10834	1.25826	1.49205	1.56136	1.59844	26.35%	43.60%	43.60%
	14:30	1.93275	1.42155	1.63248	1.3377	1.13862	1.13565	1.13918	1.28456	1.53858	1.59237	1.63402	26.45%	41.24%	41.24%
	15:30	1.86429	1.35211	1.61967	1.28784	1.13505	1.12929	1.13088	1.29895	1.5298	1.58602	1.62521	27.47%	39.43%	39.43%
	16:30	1.77444	1.26142	1.60216	1.21815	1.11193	1.10395	1.11254	1.33533	1.51359	1.57202	1.59879	28.91%	37.79%	37.79%
	17:30	1.68384	1.17012	1.56506	1.32104	1.08897	1.09201	1.17683	1.36339	1.49804	1.54019	1.55384	30.51%	35.33%	35.15%
	18:30	1.62961	1.29272	1.54624	1.47051	1.30883	1.31227	1.39296	1.48039	1.51756	1.53032	1.53393	20.67%	19.68%	19.47%
	19:30	0.42701	0.40225	0.36412	0.38434	0.33273	0.33031	0.33221	0.34058	0.34849	0.35064	0.35189	5.80%	22.65%	22.65%
	20:30	0.38108	0.36155	0.3259	0.34489	0.29932	0.29709	0.29831	0.30523	0.31199	0.31383	0.31495	5.12%	22.04%	22.04%
	Total	**22.18364**	**16.21672**	**19.43901**	**15.97713**	**13.80883**	**13.76215**	**14.06074**	**16.19951**	**18.35614**	**19.0548**	**19.42671**	**26.90%**	**38.00%**	**37.96%**
				Optimal Dynamic Slat Angle				**13.75421**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

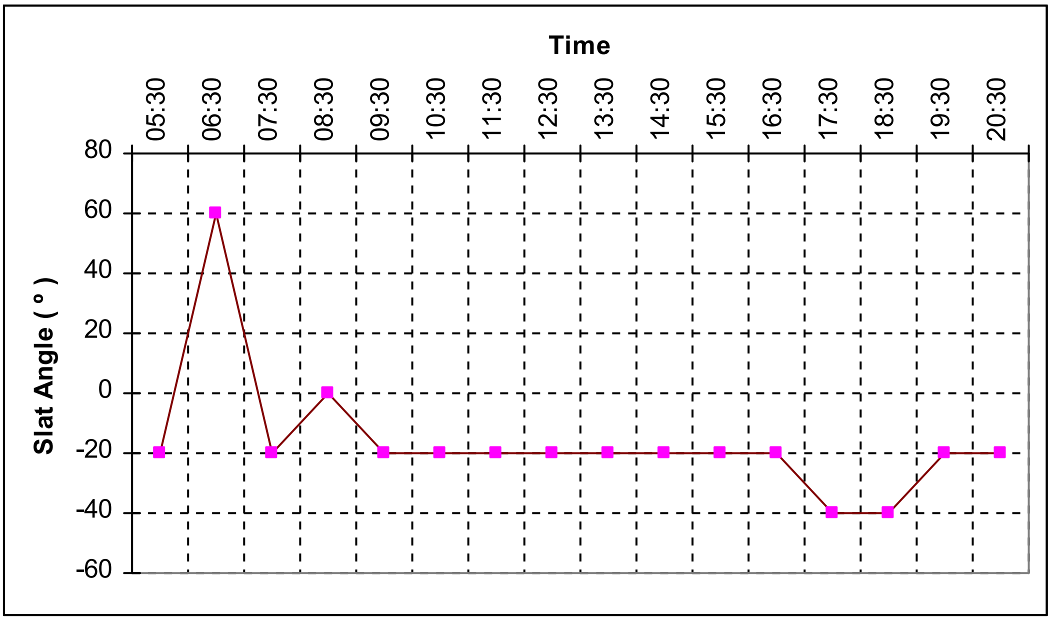

Figure A.3 Hourly energy consumption of all scenarios for the south oriented facade in 21 March from 5:30 to 20:30

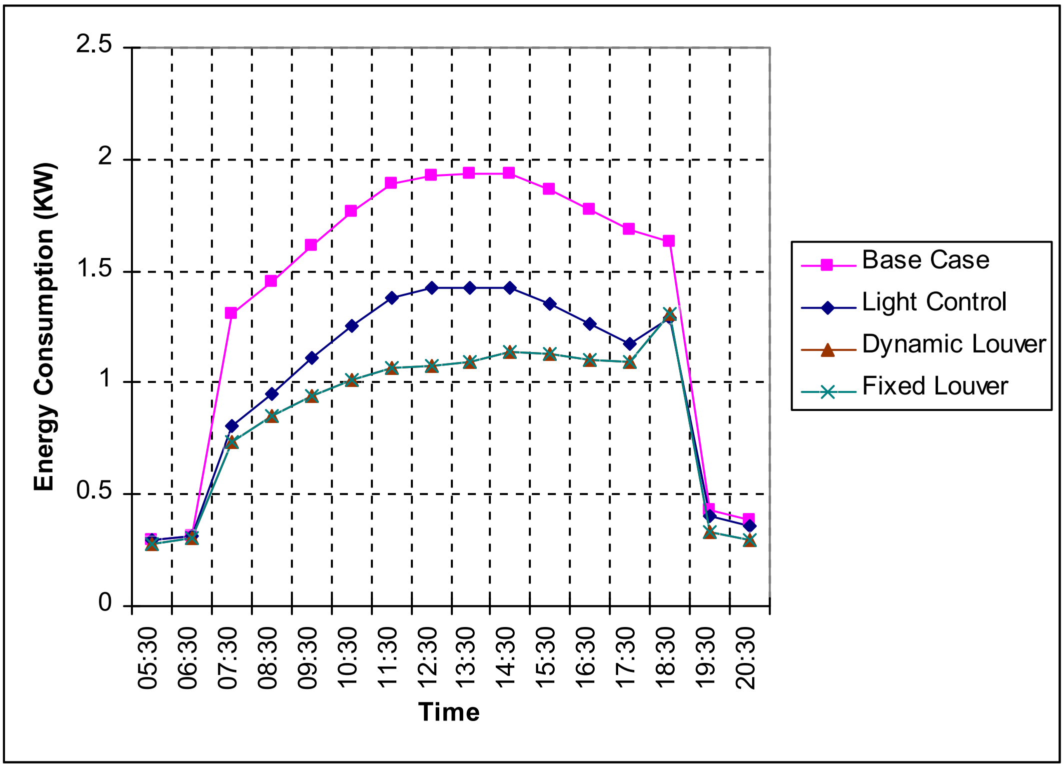

Figure A.4 Hourly energy consumption of all scenarios for the south oriented facade in 21 March from 5:30 to 20:30

Table A.3 Hourly energy consumption of the south oriented façade in 20 June from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				-80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-40°)
20 – JUNE	05:30	0.45361	0.4519	0.44765	0.44818	0.44869	0.4488	0.44822	0.44766	0.44726	0.44702	0.44695	0.38%	1.47%	1.08%
	06:30	0.46604	0.46439	0.44974	0.45322	0.45538	0.45549	0.45309	0.45029	0.44856	0.44769	0.44743	0.35%	3.99%	2.29%
	07:30	1.68635	1.19944	1.63985	1.24409	1.18444	1.18455	1.2228	1.50294	1.57117	1.63242	1.64721	28.87%	29.76%	29.76%
	08:30	1.75913	1.26297	1.71013	1.30151	1.24893	1.24904	1.29143	1.5647	1.64671	1.70051	1.72275	28.20%	29.00%	29.00%
	09:30	1.8008	1.30117	1.76231	1.40775	1.29355	1.29365	1.40377	1.62659	1.72065	1.75684	1.77863	27.74%	28.17%	28.17%
	10:30	1.80577	1.30345	1.78608	1.48869	1.30326	1.30356	1.48516	1.65891	1.74628	1.77954	1.79955	27.82%	27.83%	27.83%
	11:30	1.80596	1.30147	1.79253	1.53046	1.30425	1.34072	1.47868	1.63944	1.76441	1.79255	1.80797	27.93%	27.78%	27.78%
	12:30	1.82194	1.31563	1.80375	1.54543	1.32615	1.39918	1.49768	1.63845	1.79405	1.81746	1.82894	27.79%	27.21%	27.21%
	13:30	1.81831	1.31048	1.80859	1.54548	1.32107	1.3945	1.52035	1.63928	1.78208	1.80766	1.82333	27.93%	27.35%	27.35%
	14:30	1.83956	1.33043	1.82542	1.52692	1.33154	1.35268	1.49412	1.66297	1.78571	1.81694	1.83589	27.68%	27.62%	27.62%
	15:30	1.85851	1.34827	1.83048	1.49041	1.34328	1.34476	1.45679	1.68633	1.7794	1.82122	1.8416	27.45%	27.72%	27.72%
	16:30	1.87455	1.36334	1.82943	1.45573	1.35251	1.35368	1.42669	1.68841	1.77722	1.82647	1.84386	27.27%	27.85%	27.85%
	17:30	1.88639	1.37434	1.8386	1.50648	1.35964	1.36062	1.47205	1.70941	1.79618	1.83606	1.84956	27.14%	27.92%	27.92%
	18:30	1.83448	1.35819	1.80339	1.60372	1.43241	1.42038	1.58546	1.72949	1.78211	1.80142	1.80707	25.96%	22.57%	21.92%
	19:30	0.60846	0.58186	0.59611	0.58407	0.57762	0.5781	0.58294	0.59063	0.59382	0.59485	0.5953	4.37%	5.07%	5.07%
	20:30	0.58748	0.56831	0.57895	0.56945	0.56472	0.56524	0.56863	0.5746	0.57728	0.57815	0.57855	3.26%	3.87%	3.87%
	Total	**23.90734**	**17.83564**	**23.50301**	**19.70159**	**17.84744**	**18.04495**	**19.38786**	**21.8101**	**23.01289**	**23.4568**	**23.65459**	**25.40%**	**25.44%**	**25.35%**
				Optimal Dynamic Slat Angle				**17.82572**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

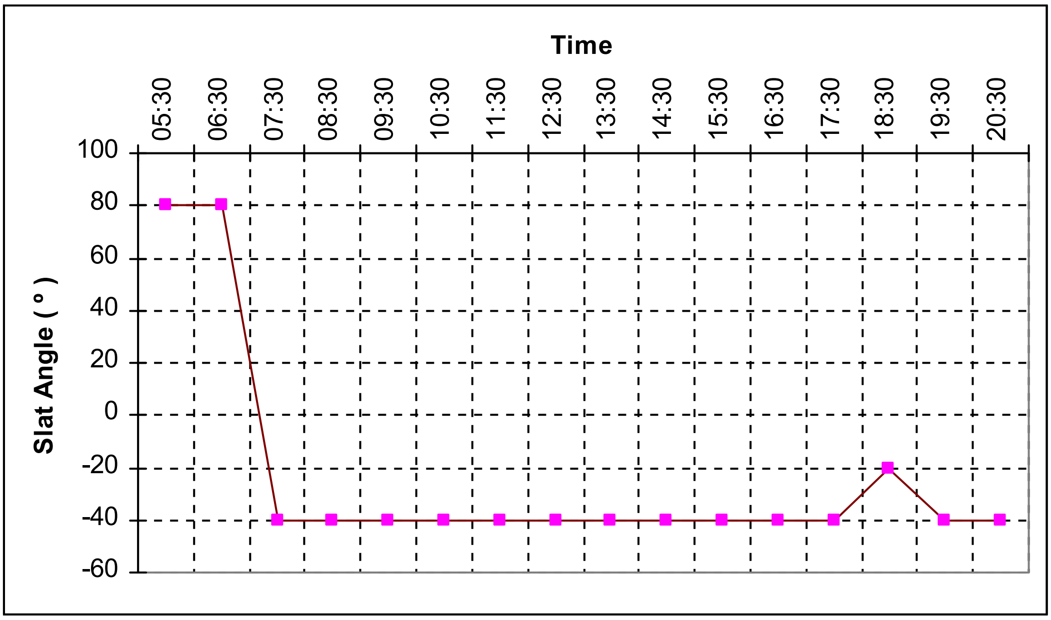

Figure A.5 Hourly energy consumption of all scenarios for the south oriented facade in 20 June from 5:30 to 20:30

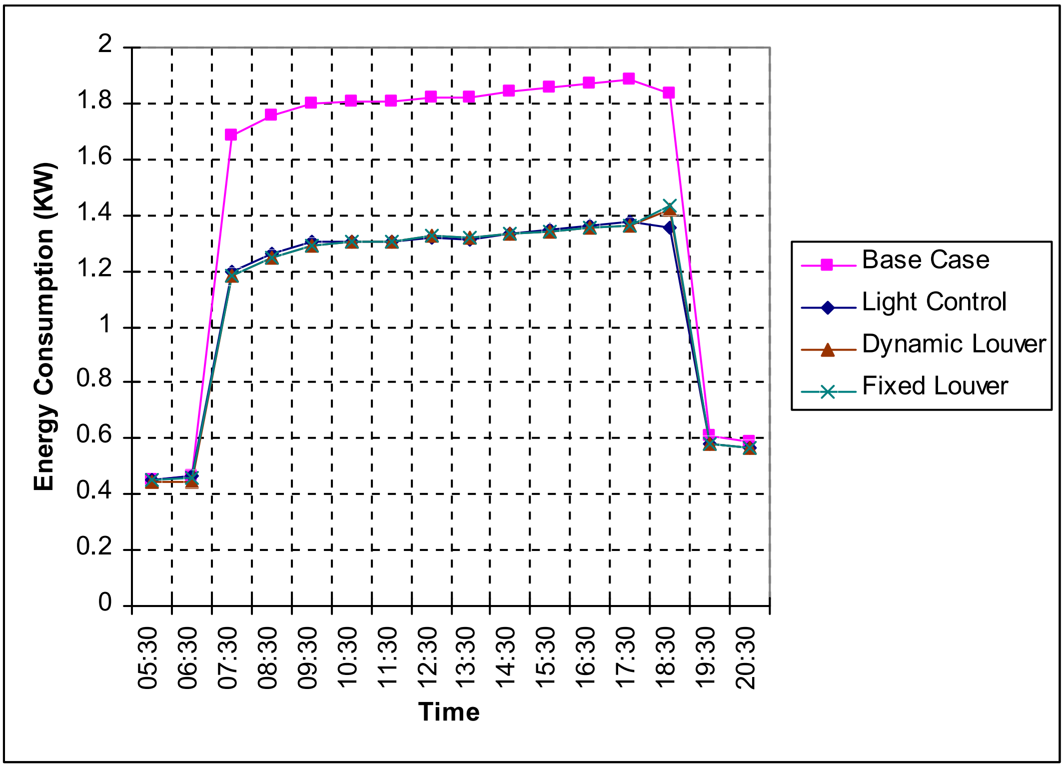

Figure A.6 Hourly energy consumption of all scenarios for the south oriented facade in 20 June from 5:30 to 20:30

Table A.4 Hourly energy consumption of the south oriented façade in 20 September from 5:30 to 20:30
(Shading coefficient 0.41, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				-80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-40°)
20 – SEPTEMBER	05:30	0.45047	0.44425	0.43403	0.43166	0.42426	0.42419	0.42476	0.4276	0.42932	0.42996	0.43025	1.38%	5.83%	5.82%
	06:30	0.45011	0.44433	0.42678	0.42679	0.42101	0.42094	0.42013	0.42111	0.42173	0.42185	0.42197	1.28%	6.66%	6.47%
	07:30	1.64476	1.1541	1.5762	1.15314	1.12057	1.12062	1.15161	1.42912	1.53311	1.57194	1.58941	29.83%	31.87%	31.87%
	08:30	1.73012	1.23053	1.617	1.17808	1.16908	1.16921	1.16608	1.40751	1.55071	1.60931	1.63653	28.88%	32.60%	32.43%
	09:30	1.85501	1.3522	1.70023	1.26364	1.2327	1.23305	1.23167	1.46335	1.60724	1.67421	1.70583	27.11%	33.60%	33.55%
	10:30	1.98027	1.47498	1.78337	1.34495	1.28206	1.28283	1.28841	1.50298	1.66018	1.73586	1.76304	25.52%	35.26%	35.26%
	11:30	2.06851	1.56119	1.82518	1.39967	1.3078	1.30865	1.3398	1.50365	1.70639	1.77342	1.80152	24.53%	36.78%	36.78%
	12:30	2.11521	1.60621	1.83809	1.43123	1.32547	1.32768	1.33968	1.52483	1.72918	1.80003	1.83247	24.06%	37.34%	37.34%
	13:30	2.10805	1.59765	1.83725	1.4293	1.33001	1.33397	1.33848	1.54019	1.73234	1.80171	1.83606	24.21%	36.91%	36.91%
	14:30	2.04676	1.53522	1.81543	1.39121	1.31918	1.3203	1.32218	1.51996	1.72056	1.78416	1.81443	24.99%	35.55%	35.55%
	15:30	1.96224	1.44971	1.77076	1.33916	1.29537	1.29594	1.29522	1.51037	1.69008	1.75727	1.78587	26.12%	33.99%	33.99%
	16:30	1.91032	1.39693	1.77069	1.31546	1.2912	1.29152	1.2891	1.58033	1.6886	1.75622	1.77863	26.87%	32.52%	32.41%
	17:30	1.88364	1.36951	1.7906	1.48179	1.3199	1.32834	1.44335	1.68166	1.74181	1.77814	1.78769	27.29%	29.93%	29.93%
	18:30	1.85106	1.58523	1.78711	1.70055	1.5962	1.60447	1.67164	1.7479	1.76777	1.77655	1.77949	14.36%	13.77%	13.77%
	19:30	0.66244	0.63853	0.61449	0.60471	0.58756	0.58771	0.58882	0.59756	0.60247	0.60434	0.60512	3.61%	11.30%	11.30%
	20:30	0.61196	0.59251	0.57021	0.56218	0.54726	0.54731	0.54803	0.55534	0.5596	0.56121	0.5619	3.18%	10.57%	10.57%
	Total	**25.33093**	**19.43308**	**23.15742**	**18.45352**	**17.56963**	**17.59673**	**17.85896**	**20.41346**	**22.14109**	**22.83618**	**23.13021**	**23.28%**	**30.67%**	**30.64%**
				Optimal Dynamic Slat Angle				**17.5624**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

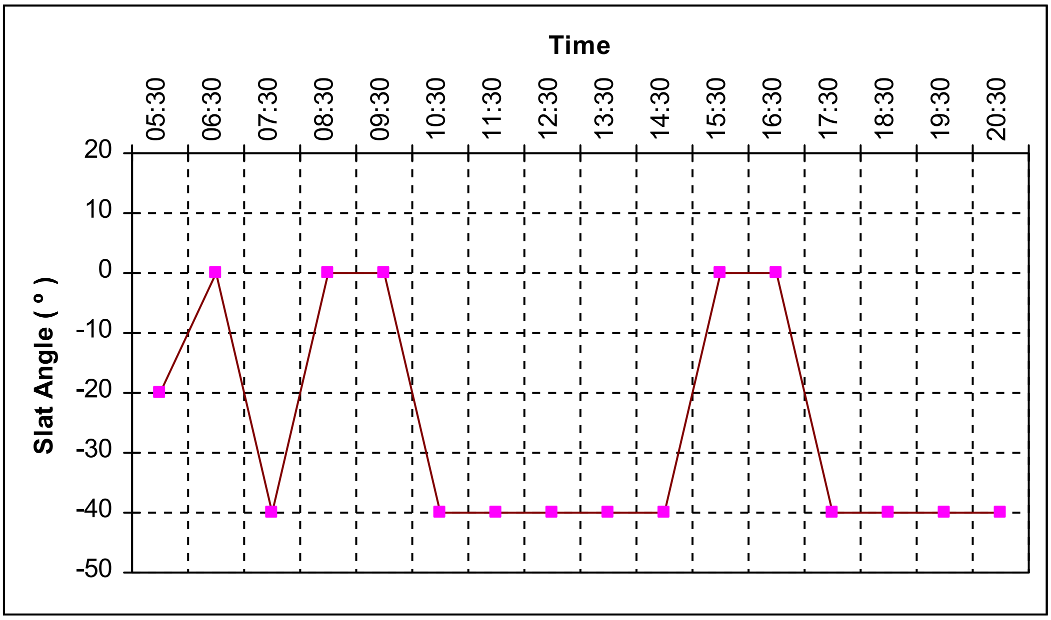

Figure A.7 Hourly energy consumption of all scenarios for the south oriented facade in 20 September from 5:30 to 20:30

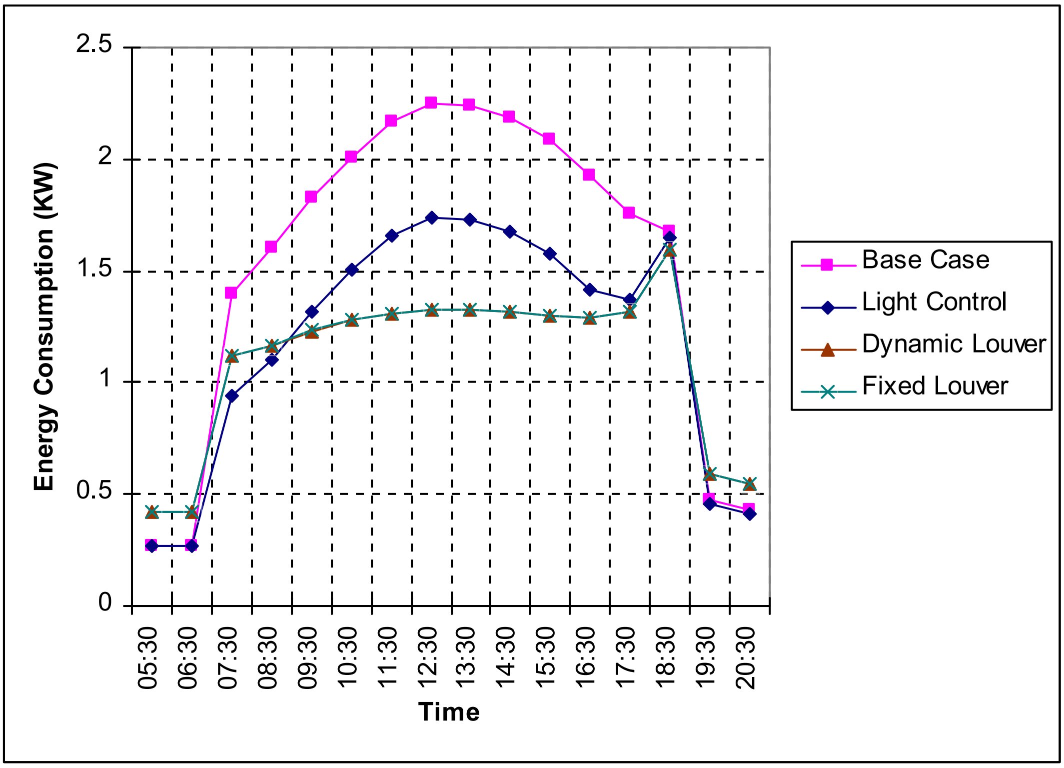

Figure A.8 Hourly energy consumption of all scenarios for the south oriented facade in 20 September from 5:30 to 20:30

Table A.5 Summary of energy savings of the south oriented façade in the four selected days from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

Summary of Energy savings of South Façade Simulations (Shading Coefficient = 0.41 & sensor distance = 2m)(KW)												
Date & Time	**Base case**	**Lighting Congtrol**	**Dynamic louver**	**Louver Angle**								
				-80º	-60º	-40º	-20º	0º	20º	40º	60º	80º
20 Dec (5:30 - 20:30)	24.57222	19.0849	14.19771	18.92974	16.62978	18.14637	16.48593	14.65869	14.49624	17.06022	18.14875	18.74013
21 March (5:30 -20:30)	22.18364	16.21672	13.75421	19.43901	15.97713	13.80883	13.76215	14.06074	16.19951	18.35614	19.0548	19.42671
20 June (5:30 - 20:30)	23.90734	17.83564	17.82572	23.50301	19.70159	17.84744	18.04495	19.38786	21.8101	23.01289	23.4568	23.65459
20 Sept (5:30 - 20:30)	25.33093	19.43308	17.5624	23.15742	18.45352	17.56963	17.59673	17.85896	20.41346	22.14109	22.83618	23.13021
Total	95.99413	72.57034	63.34004	85.02918	70.76202	67.37227	65.88976	65.96625	72.91931	80.57034	83.49653	84.95164
Percentage of Total energy saving over the Base case		**24.40%**	**34.02%**	**11.42%**	**26.29%**	**29.82%**	**31.36%**	**31.28%**	**24.04%**	**16.07%**	**13.02%**	**11.50%**

Appendix B

South Façade Simulations

Glass Shading Coefficient 0.41 and lighting sensor @ 4meters

Table B.1 Hourly energy consumption of the south oriented façade in 20 December from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 4 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (0°)
20 – DECEMBER	05:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	06:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	07:30	1.39878	1.15187	1.27054	1.28833	1.253	1.14678	1.15188	1.20397	1.22428	1.2363	1.23819	17.65%	18.02%	17.65%
	08:30	1.6072	1.10922	1.39319	1.30897	1.11712	1.04468	1.10044	1.2651	1.32522	1.35907	1.36751	30.98%	35.00%	31.53%
	09:30	1.82613	1.32379	1.45739	1.34934	1.23958	1.16713	1.11472	1.2798	1.3734	1.40914	1.42316	27.51%	38.96%	38.96%
	10:30	2.0106	1.50566	1.51112	1.389	1.41512	1.23825	1.15677	1.31839	1.41888	1.44749	1.46608	25.11%	42.47%	42.47%
	11:30	2.16763	1.66061	1.5828	1.44665	1.55391	1.30211	1.20415	1.38477	1.47675	1.50073	1.52165	23.39%	44.45%	44.45%
	12:30	2.2476	1.73888	1.62145	1.48692	1.61904	1.3395	1.21278	1.41554	1.49891	1.53288	1.55505	22.63%	46.04%	46.04%
	13:30	2.24136	1.73121	1.62443	1.49717	1.62395	1.34787	1.20609	1.41435	1.49763	1.53497	1.55537	22.76%	46.19%	46.19%
	14:30	2.18555	1.6742	1.61642	1.49296	1.57627	1.35371	1.29116	1.43455	1.50827	1.53805	1.55506	23.40%	40.92%	40.92%
	15:30	2.08681	1.57445	1.60376	1.52228	1.46619	1.34183	1.27352	1.41757	1.48846	1.52732	1.54782	24.55%	38.97%	38.97%
	16:30	1.92873	1.42439	1.57158	1.53161	1.44909	1.29641	1.26982	1.42643	1.49305	1.5136	1.52626	26.15%	34.16%	34.16%
	17:30	1.75675	1.57894	1.53822	1.5811	1.6143	1.50835	1.45962	1.48525	1.50016	1.50396	1.50454	10.12%	16.91%	16.91%
	18:30	1.67551	1.65349	1.51437	1.56414	1.61778	1.56823	1.50717	1.49121	1.48883	1.48801	1.48744	1.31%	11.22%	10.05%
	19:30	0.47638	0.45821	0.33753	0.38107	0.42769	0.38415	0.33065	0.31684	0.31492	0.31433	0.31385	3.81%	34.12%	30.59%
	20:30	0.43275	0.417	0.31089	0.34953	0.39053	0.35177	0.30432	0.29444	0.29419	0.29418	0.29419	3.64%	32.02%	29.68%
	Total	**24.57222**	**19.53236**	**19.48413**	**18.71951**	**18.89401**	**16.92121**	**16.11353**	**17.67865**	**18.43339**	**18.73047**	**18.88661**	**20.51%**	**34.86%**	**34.42%**
				Optimal Dynamic Slat Angle				**16.006**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

Note: When optimal case is not assigned, all readings are similar and can be used as optimal case

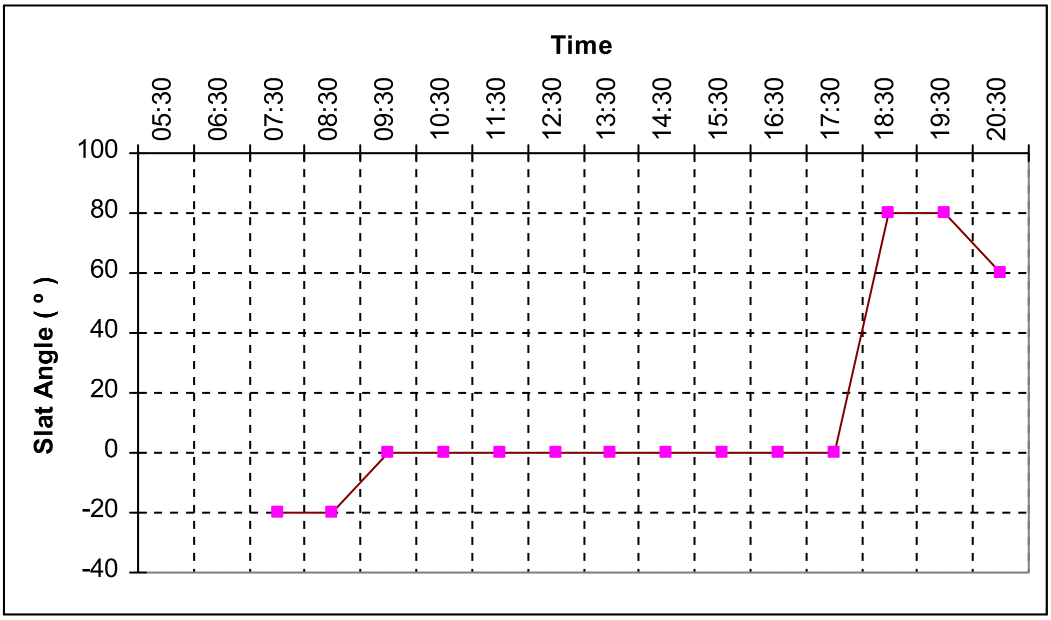

Figure B.1 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 7:30 to 20:30

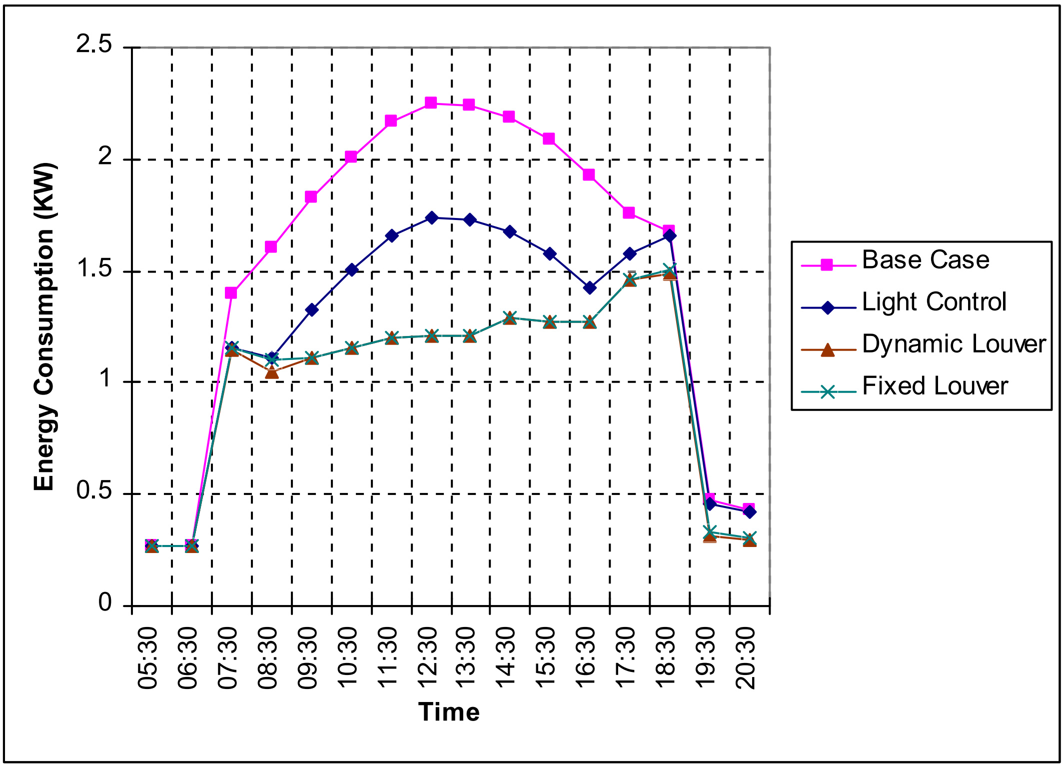

Figure B.2 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 7:30 to 20:30

Table B.2 Hourly energy consumption of the south oriented façade in 21 March from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 4 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				-80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-40º)
21 – MARCH	05:30	0.29465	0.29304	0.28167	0.2906	0.27599	0.27553	0.27629	0.2773	0.27782	0.27794	0.27802	0.55%	6.49%	6.33%
	06:30	0.31522	0.31468	0.30771	0.31166	0.30701	0.30683	0.30658	0.30631	0.30611	0.30597	0.30593	0.17%	2.95%	2.60%
	07:30	1.30462	0.93234	1.23162	1.22534	1.03672	0.95615	1.01295	1.13384	1.19204	1.21287	1.21957	28.54%	26.71%	20.53%
	08:30	1.45151	0.95425	1.35149	1.29442	0.92073	0.98691	1.08338	1.22086	1.30053	1.32582	1.33761	34.26%	36.57%	36.57%
	09:30	1.61086	1.10976	1.45767	1.33775	0.9575	1.09299	1.21752	1.33643	1.40255	1.42944	1.43972	31.11%	40.56%	40.56%
	10:30	1.76091	1.2572	1.54562	1.36591	1.0212	1.1741	1.31674	1.42216	1.48428	1.50575	1.51601	28.61%	42.01%	42.01%
	11:30	1.88625	1.38012	1.61719	1.41928	1.07365	1.22978	1.38422	1.48338	1.55216	1.56986	1.58093	26.83%	43.08%	43.08%
	12:30	1.93069	1.4231	1.63718	1.44066	1.08178	1.25408	1.3916	1.49474	1.56997	1.58865	1.59773	26.29%	43.97%	43.97%
	13:30	1.93591	1.42687	1.64972	1.45425	1.09666	1.27844	1.41434	1.51205	1.58324	1.60182	1.61074	26.29%	43.35%	43.35%
	14:30	1.93275	1.4225	1.67715	1.51163	1.14098	1.30714	1.46365	1.55427	1.61256	1.63517	1.64575	26.40%	40.97%	40.97%
	15:30	1.86429	1.38251	1.66094	1.5677	1.13717	1.30893	1.44525	1.54417	1.60296	1.62479	1.63542	25.84%	39.00%	39.00%
	16:30	1.77444	1.36876	1.62888	1.60221	1.1806	1.3175	1.41849	1.51744	1.57485	1.5967	1.6067	22.86%	33.47%	33.47%
	17:30	1.68384	1.40148	1.58195	1.58925	1.39467	1.35765	1.41706	1.50445	1.54601	1.5562	1.56265	16.77%	19.37%	17.17%
	18:30	1.62961	1.50529	1.55224	1.58001	1.48647	1.44897	1.46862	1.508	1.52935	1.53409	1.53685	7.63%	11.08%	8.78%
	19:30	0.42701	0.40825	0.36568	0.39587	0.33925	0.34046	0.34481	0.34922	0.35158	0.35201	0.35234	4.39%	20.55%	20.55%
	20:30	0.38108	0.3655	0.32724	0.35422	0.30393	0.30509	0.30885	0.31261	0.31464	0.315	0.31532	4.09%	20.25%	20.25%
	Total	**22.18364**	**16.94565**	**19.87395**	**18.74076**	**14.75431**	**15.94055**	**17.27035**	**18.47723**	**19.20065**	**19.43208**	**19.54129**	**23.61%**	**34.20%**	**33.49%**
				Optimal Dynamic Slat Angle				**14.59768**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

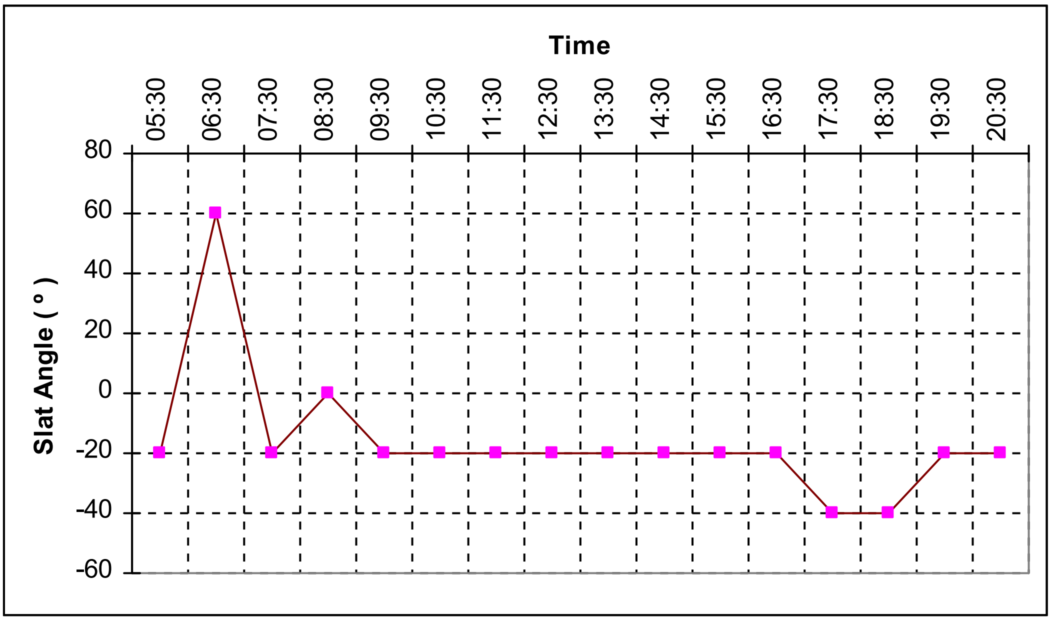

Figure B.3 Hourly energy consumption of all scenarios for the south oriented facade in 21 March from 5:30 to 20:30

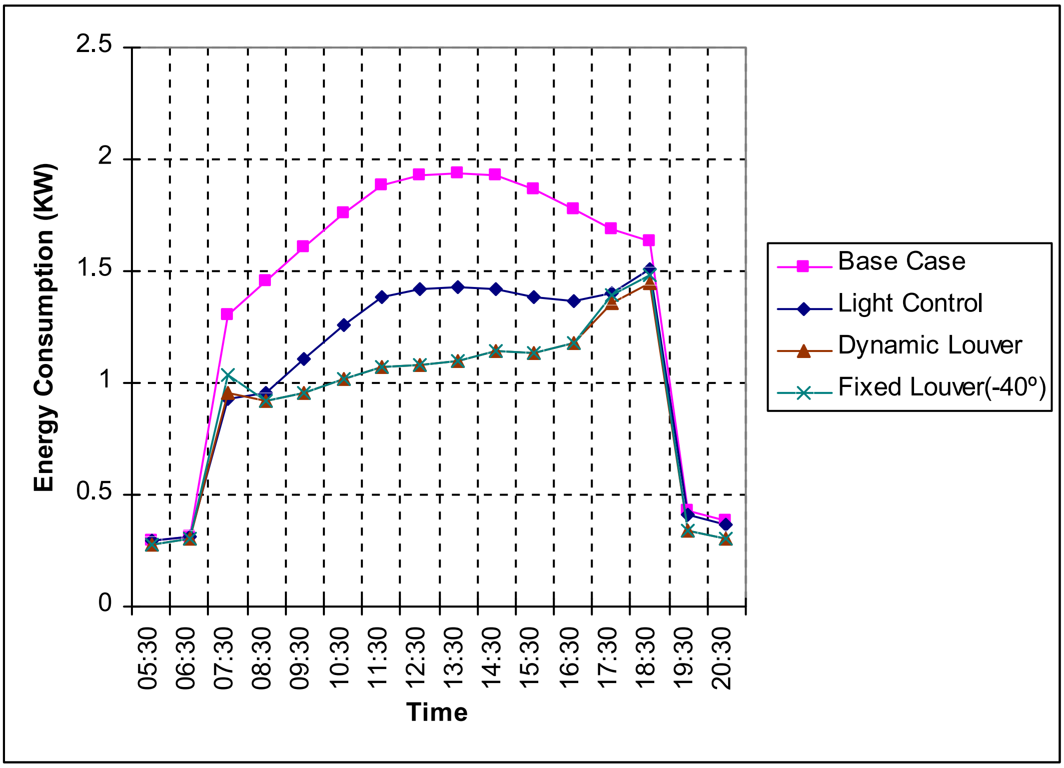

Figure B.4 Hourly energy consumption of all scenarios for the south oriented facade in 21 March from 5:30 to 20:30

Table B.3 Hourly energy consumption of the south oriented façade in 20 June from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 4 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-20º)
20 – JUNE	05:30	0.45361	0.45259	0.4477	0.44916	0.44988	0.44963	0.44882	0.4479	0.44733	0.44705	0.44696	0.22%	1.47%	0.88%
	06:30	0.46604	0.46505	0.44979	0.45417	0.45653	0.4563	0.45367	0.45052	0.44862	0.44772	0.44744	0.21%	3.99%	2.09%
	07:30	1.68635	1.27678	1.65561	1.62701	1.52664	1.38103	1.42791	1.54594	1.60513	1.64103	1.65136	24.29%	18.11%	18.11%
	08:30	1.75913	1.33547	1.72735	1.69161	1.58019	1.46046	1.48328	1.61908	1.67397	1.71395	1.72626	24.08%	16.98%	16.98%
	09:30	1.8008	1.4468	1.7812	1.74088	1.62951	1.54381	1.57494	1.70695	1.7335	1.76966	1.78162	19.66%	14.27%	14.27%
	10:30	1.80577	1.52402	1.79948	1.7543	1.65621	1.59116	1.63674	1.7408	1.75965	1.79152	1.80261	15.60%	11.88%	11.88%
	11:30	1.80596	1.56926	1.80594	1.75957	1.66859	1.62044	1.66348	1.74472	1.78139	1.80129	1.81057	13.11%	10.27%	10.27%
	12:30	1.82194	1.60106	1.81762	1.7675	1.69625	1.65435	1.69736	1.7684	1.80776	1.82459	1.83157	12.12%	9.20%	9.20%
	13:30	1.81831	1.58615	1.82106	1.77161	1.7021	1.64281	1.69239	1.75917	1.79622	1.81722	1.82646	12.77%	9.65%	9.65%
	14:30	1.83956	1.56669	1.83632	1.78758	1.70145	1.636	1.68885	1.75993	1.80636	1.8296	1.84004	14.83%	11.07%	11.07%
	15:30	1.85851	1.52224	1.84444	1.79949	1.71143	1.61601	1.65616	1.74476	1.80711	1.83331	1.84597	18.09%	13.05%	13.05%
	16:30	1.87455	1.48205	1.8505	1.81452	1.70481	1.59299	1.62834	1.73027	1.8097	1.83393	1.84972	20.94%	15.02%	15.02%
	17:30	1.88639	1.52166	1.85647	1.83063	1.72483	1.60268	1.65591	1.74563	1.81873	1.8432	1.85342	19.33%	15.04%	15.04%
	18:30	1.83448	1.61765	1.81013	1.79554	1.7337	1.65774	1.68897	1.75081	1.78733	1.80432	1.80804	11.82%	9.63%	9.63%
	19:30	0.60846	0.59333	0.59678	0.59803	0.5955	0.59108	0.59138	0.59347	0.5947	0.59523	0.59546	2.49%	2.86%	2.86%
	20:30	0.58748	0.57594	0.57949	0.58012	0.57806	0.57479	0.5752	0.57697	0.578	0.57847	0.57867	1.96%	2.16%	2.16%
	Total	**23.90734**	**20.13674**	**23.67988**	**23.22172**	**22.11568**	**21.07128**	**21.5634**	**22.68532**	**23.2555**	**23.57209**	**23.69617**	**15.77%**	**11.91%**	**11.86%**
				Optimal Dynamic Slat Angle				**21.05975**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

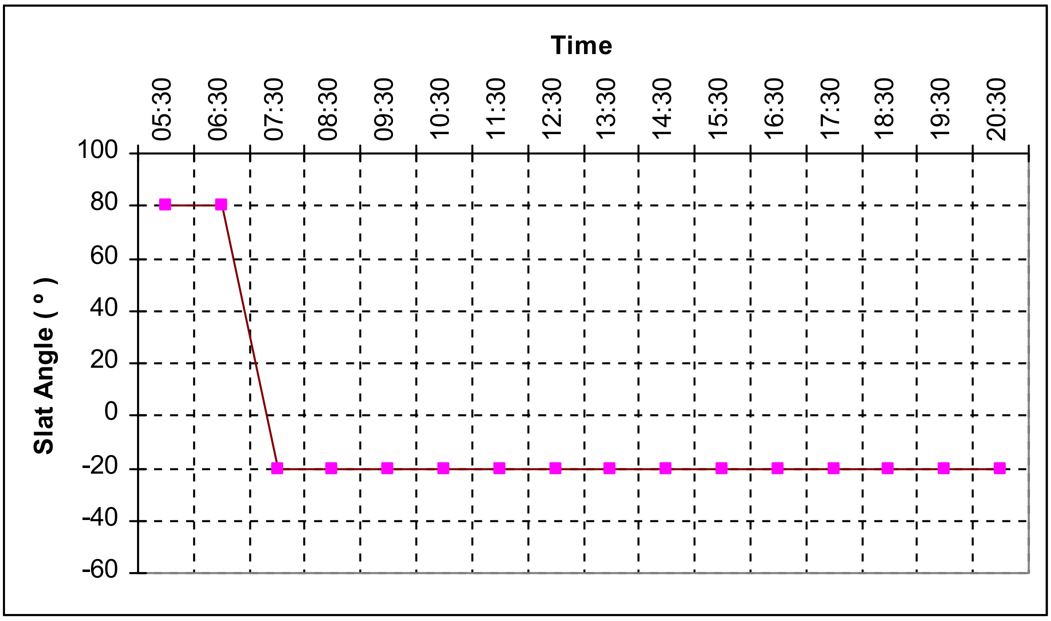

Figure B.5 Hourly energy consumption of all scenarios for the south oriented facade in 20 June from 5:30 to 20:30

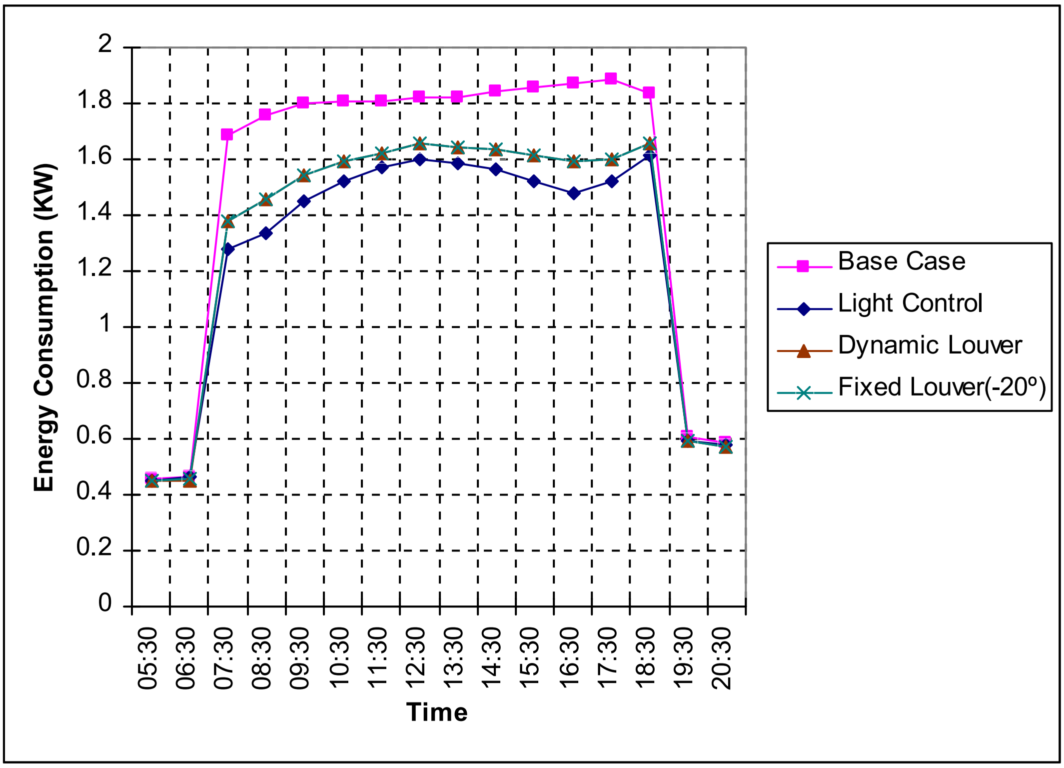

Figure B.6 Hourly energy consumption of all scenarios for the south oriented facade in 20 March from 5:30 to 20:30

Table B.4 Hourly energy consumption of the south oriented façade in 20 September from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 4 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-40°)
20 – SEPTEMBER	05:30	0.45047	0.44505	0.43441	0.43344	0.42579	0.42638	0.4276	0.42927	0.43	0.43024	0.43035	1.20%	5.48%	5.48%
	06:30	0.45011	0.44507	0.42713	0.42843	0.4224	0.42297	0.42276	0.42267	0.42236	0.42211	0.42207	1.12%	6.23%	6.16%
	07:30	1.64476	1.21841	1.60113	1.52793	1.39182	1.30909	1.33813	1.47226	1.56198	1.5883	1.59538	25.92%	20.41%	15.38%
	08:30	1.73012	1.2318	1.65507	1.43149	1.30233	1.29685	1.34584	1.50495	1.60613	1.6353	1.64825	28.80%	25.04%	24.73%
	09:30	1.85501	1.35319	1.73345	1.36175	1.24852	1.38841	1.46319	1.616	1.67832	1.70466	1.71916	27.05%	32.69%	32.69%
	10:30	1.98027	1.50385	1.80279	1.35345	1.2856	1.48611	1.57281	1.69266	1.74554	1.76832	1.77879	24.06%	35.08%	35.08%
	11:30	2.06851	1.61684	1.84686	1.40459	1.31079	1.53881	1.63122	1.73003	1.78582	1.80694	1.81568	21.84%	36.63%	36.63%
	12:30	2.11521	1.62133	1.87633	1.43542	1.32807	1.51431	1.64109	1.73992	1.80508	1.82931	1.84063	23.35%	37.21%	37.21%
	13:30	2.10805	1.59908	1.88288	1.43294	1.3323	1.49841	1.63224	1.74176	1.80939	1.83148	1.84486	24.14%	36.80%	36.80%
	14:30	2.04676	1.54916	1.85319	1.42194	1.32502	1.48893	1.6053	1.72316	1.78578	1.8108	1.82414	24.31%	35.26%	35.26%
	15:30	1.96224	1.46006	1.81632	1.49565	1.39257	1.44168	1.5387	1.67711	1.74401	1.78036	1.79377	25.59%	29.03%	29.03%
	16:30	1.91032	1.43862	1.80398	1.63471	1.52407	1.44707	1.51879	1.6657	1.74303	1.77319	1.78525	24.69%	24.25%	20.22%
	17:30	1.88364	1.58596	1.80291	1.75483	1.65864	1.5751	1.61746	1.72424	1.76755	1.78498	1.79013	15.80%	16.38%	11.94%
	18:30	1.85106	1.74966	1.79204	1.78319	1.74122	1.71124	1.72613	1.76187	1.7725	1.77933	1.78019	5.48%	7.55%	5.93%
	19:30	0.66244	0.64318	0.6158	0.61205	0.59479	0.59648	0.5991	0.60322	0.6048	0.60525	0.60546	2.91%	10.21%	10.21%
	20:30	0.61196	0.5957	0.57132	0.56806	0.55271	0.55437	0.55669	0.56022	0.5616	0.562	0.56219	2.66%	9.68%	9.68%
	Total	**25.33093**	**20.05696**	**23.51561**	**20.07987**	**18.83664**	**19.69621**	**20.63705**	**22.06504**	**22.82389**	**23.11257**	**23.2363**	**20.82%**	**26.74%**	**25.64%**
				Optimal Dynamic Slat Angle				**18.55758**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

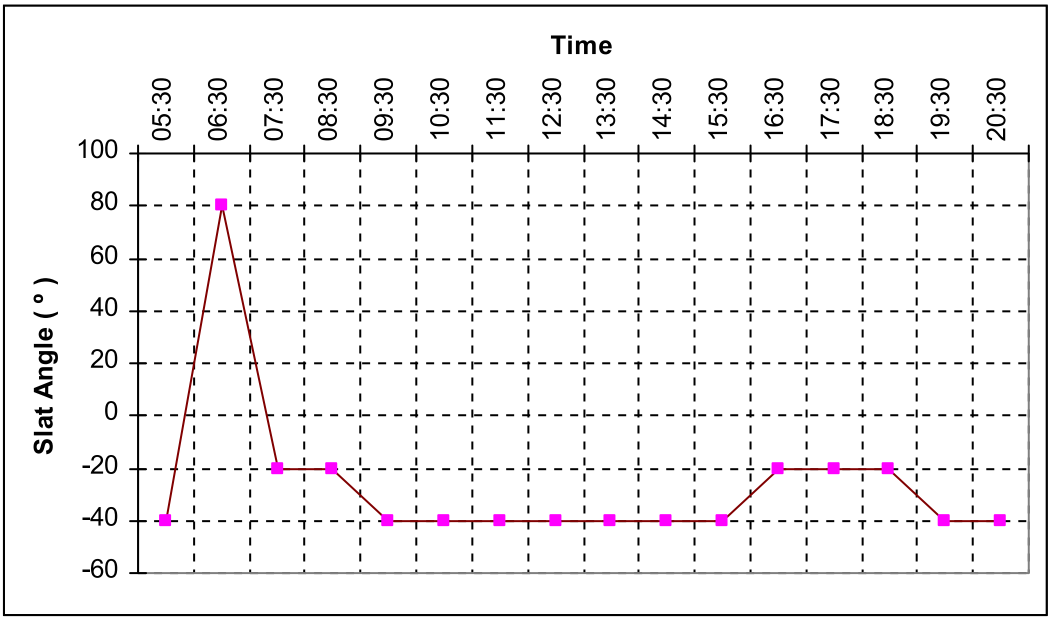

Figure B.7 Hourly energy consumption of all scenarios for the south oriented facade in 20 September from 5:30 to 20:30

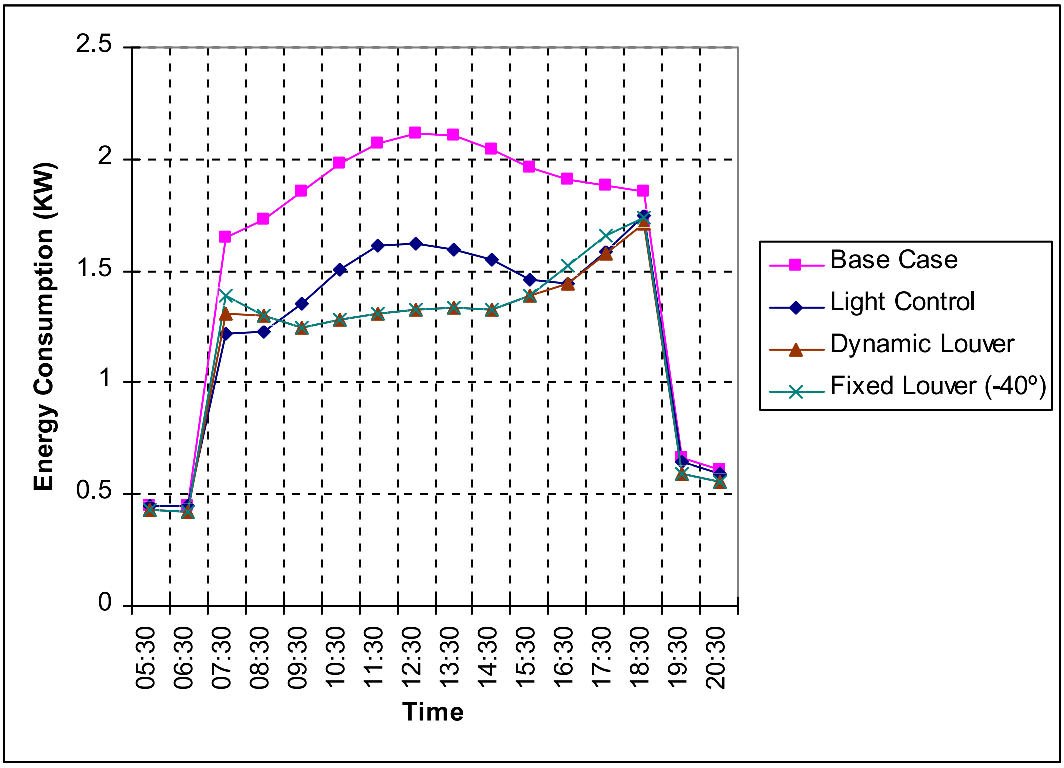

Figure B.8 Hourly energy consumption of all scenarios for the south oriented facade in 20 September from 5:30 to 20:30

Table B.5 Summary of energy savings of the south oriented façade in the four selected days from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 4 meters)

Summary of Energy savings of South Façade Simulations (Shading Coefficient = 0.41 & sensor distance = 4m) (KW)												
Date & Time	**Base case**	**Lighting Congtrol**	**Dynamic louver**	**Louver Angle**								
				-80º	-60º	-40º	-20º	0º	20º	40º	60º	80º
20 Dec (5:30 - 20:30)	24.57222	19.53236	16.006	19.48413	18.71951	18.89401	16.92121	16.11353	17.67865	18.43339	18.73047	18.88661
21 March (5:30 - 20:30)	22.18364	16.94565	14.59768	19.87395	18.74076	14.75431	15.94055	17.27035	18.47723	19.20065	19.43208	19.54129
20 June (5:30 - 20:30)	23.90734	20.13674	21.05975	23.67988	23.22172	22.11568	21.07128	21.5634	22.68532	23.2555	23.57209	23.69617
20 Sept (5:30 - 20:30)	25.33093	20.05696	18.55758	23.15742	18.45352	17.56963	17.59673	17.85896	20.41346	22.14109	22.83618	23.13021
Total	95.99413	76.67171	70.22101	86.19538	79.13551	73.33363	71.52977	72.80624	79.25466	83.03063	84.57082	85.25428
Percentage of Total energy saving over the Base case		**20.13%**	**26.85%**	**10.21%**	**17.56%**	**23.61%**	**25.49%**	**24.16%**	**17.44%**	**13.50%**	**11.90%**	**11.19%**

Appendix C

South Façade Simulations

Glass Shading Coefficient 0.746 and lighting sensor@ 2 meters

Table C.1 Hourly energy consumption of the south oriented façade in 20 December from 5:30 to 20:30 (Shading coefficient 0.746, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (20º)
20 – DECEMBER	05:30	0.28889	0.2833	0.26522	0.26522	0.2673	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	1.93%	8.19%	8.19%
	06:30	0.28444	0.27923	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	1.83%	6.76%	6.76%
	07:30	1.47919	1.03314	1.30222	1.14115	1.04929	1.03017	1.05122	1.18081	1.24337	1.26244	1.26717	30.16%	30.36%	20.17%
	08:30	1.81056	1.31182	1.42377	1.08505	1.19588	1.19996	1.06314	1.04471	1.29048	1.35713	1.39233	27.55%	42.30%	42.30%
	09:30	2.19719	1.69508	1.49525	1.30072	1.53511	1.4109	1.15987	1.0291	1.29207	1.40151	1.45488	22.85%	53.16%	53.16%
	10:30	2.52193	2.01726	1.57183	1.49967	1.84492	1.52032	1.16392	1.05797	1.30606	1.44311	1.50827	20.01%	58.05%	58.05%
	11:30	2.77449	2.26774	1.65784	1.67202	2.06358	1.59755	1.16261	1.10738	1.3478	1.49579	1.57024	18.26%	60.09%	60.09%
	12:30	2.8973	2.38884	1.70428	1.75794	2.15929	1.6416	1.17748	1.13708	1.37695	1.52518	1.60127	17.55%	60.75%	60.75%
	13:30	2.88472	2.37481	1.69092	1.74428	2.16961	1.65959	1.20254	1.13982	1.39973	1.52959	1.60343	17.68%	60.49%	60.49%
	14:30	2.77971	2.26858	1.68969	1.66822	2.08101	1.67289	1.25713	1.14521	1.43357	1.53907	1.60286	18.39%	58.80%	58.80%
	15:30	2.58724	2.07508	1.68242	1.53915	1.86839	1.64965	1.30482	1.15949	1.4488	1.53911	1.59253	19.80%	55.18%	55.18%
	16:30	2.28649	1.77345	1.62507	1.40763	1.58315	1.49854	1.27051	1.17846	1.43187	1.50062	1.5484	22.44%	48.46%	48.46%
	17:30	1.96629	1.58045	1.58159	1.56378	1.56127	1.47149	1.41101	1.46547	1.50692	1.52053	1.52686	19.62%	28.24%	25.47%
	18:30	1.82586	1.80071	1.55132	1.63443	1.73519	1.65604	1.54742	1.5069	1.50682	1.50708	1.50715	1.38%	17.47%	17.47%
	19:30	0.60543	0.58591	0.36987	0.4427	0.53013	0.46036	0.36564	0.33071	0.33081	0.33117	0.33123	3.22%	45.38%	45.38%
	20:30	0.54568	0.52889	0.33975	0.40404	0.48058	0.41871	0.3353	0.30481	0.30495	0.3053	0.30534	3.08%	44.14%	44.14%
	Total	**29.73541**	**24.26429**	**20.21626**	**19.39122**	**22.38992**	**19.41821**	**16.00305**	**15.31836**	**17.75064**	**18.78807**	**19.3424**	**18.40%**	**49.17%**	**48.48%**
				Optimal Dynamic Slat Angle				**15.11318**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

Note: When optimal case is not assigned, all readings are similar and can be used as optimal case

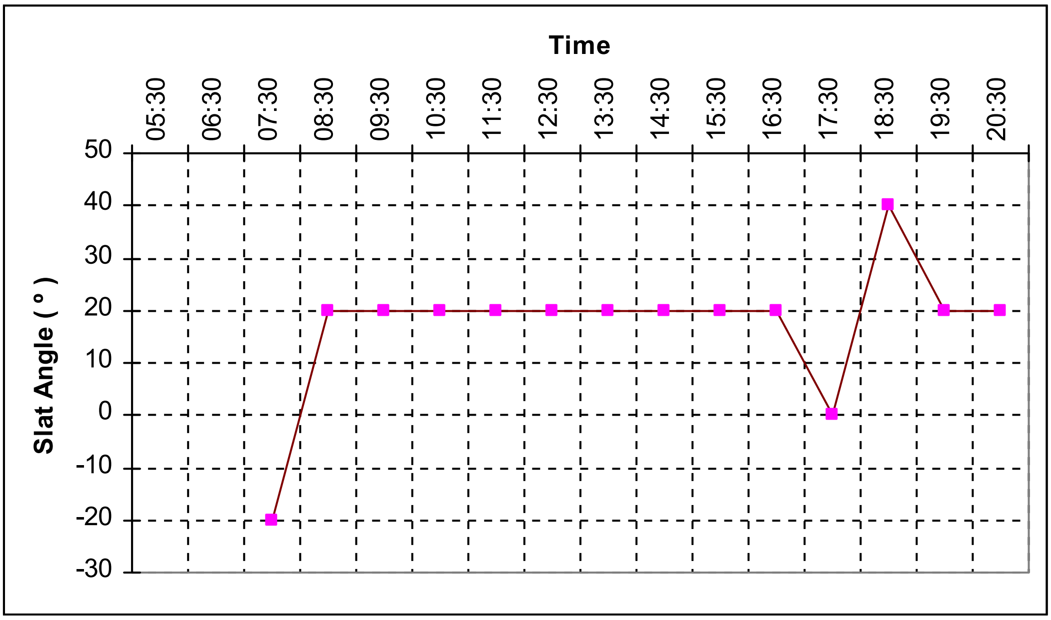

Figure C.1 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 7:30 to 20:30

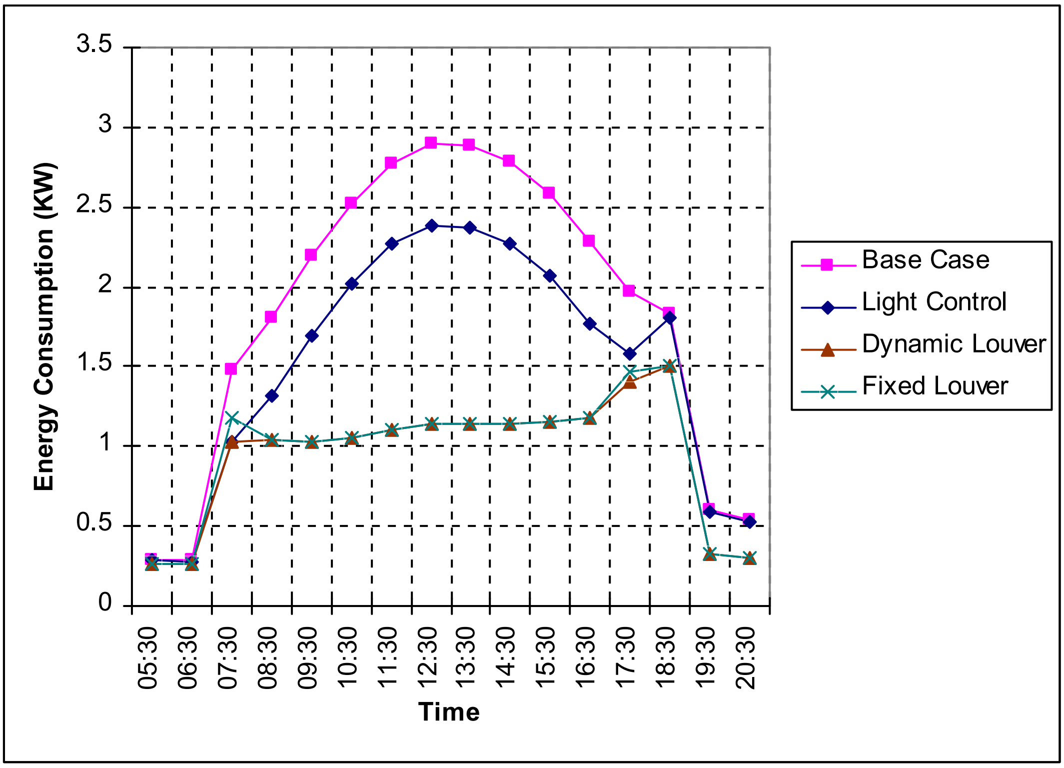

Figure C.2 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 5:30 to 20:30

Table C.2 Hourly energy consumption of the south oriented façade in 21 March from 5:30 to 20:30 (Shading coefficient 0.746, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-20º)
21 – MARCH	05:30	0.30795	0.30753	0.29227	0.30525	0.28661	0.28563	0.28545	0.28582	0.28624	0.28617	0.28616	0.14%	7.31%	7.25%
	06:30	0.32698	0.32654	0.31339	0.31959	0.3142	0.31384	0.31271	0.31153	0.31089	0.31049	0.31037	0.13%	5.08%	4.02%
	07:30	1.39201	0.90339	1.25619	0.96464	0.80011	0.79565	0.8532	1.09029	1.20243	1.24008	1.25197	35.10%	42.84%	42.84%
	08:30	1.58636	1.08871	1.36595	1.02445	0.94089	0.92873	0.92147	1.15085	1.29409	1.34765	1.37589	31.37%	41.91%	41.46%
	09:30	1.81689	1.31588	1.51641	1.22519	1.04817	1.03568	1.03152	1.21792	1.39878	1.46183	1.49757	27.58%	43.23%	43.00%
	10:30	2.0499	1.54634	1.62568	1.40968	1.12024	1.11395	1.11326	1.29584	1.4838	1.54785	1.58875	24.57%	45.69%	45.66%
	11:30	2.23901	1.73331	1.71481	1.55503	1.17608	1.17265	1.17762	1.33382	1.53802	1.62513	1.66523	22.59%	47.63%	47.63%
	12:30	2.31498	1.80758	1.73927	1.60821	1.18444	1.18174	1.20486	1.34214	1.56435	1.64559	1.68581	21.92%	48.95%	48.95%
	13:30	2.3139	1.80507	1.74697	1.6108	1.2009	1.19828	1.21436	1.36105	1.59201	1.65915	1.69472	21.99%	48.21%	48.21%
	14:30	2.27088	1.76084	1.76827	1.5924	1.24601	1.24197	1.24301	1.38464	1.63545	1.6867	1.7263	22.46%	45.31%	45.31%
	15:30	2.13507	1.62398	1.73394	1.49543	1.23681	1.22761	1.22579	1.38927	1.61652	1.67001	1.70699	23.94%	42.59%	42.50%
	16:30	1.97022	1.45823	1.68924	1.3682	1.20016	1.1872	1.19167	1.40905	1.58346	1.63928	1.66415	25.99%	39.74%	39.74%
	17:30	1.81945	1.30668	1.62662	1.42249	1.15458	1.15518	1.23592	1.41718	1.54828	1.58828	1.60062	28.18%	36.54%	36.51%
	18:30	1.72977	1.39379	1.59134	1.54552	1.35485	1.35733	1.43527	1.51889	1.55349	1.56477	1.56755	19.42%	21.67%	21.53%
	19:30	0.50706	0.48316	0.40058	0.44559	0.36812	0.36495	0.36517	0.37105	0.37721	0.37831	0.37893	4.71%	28.03%	28.03%
	20:30	0.45152	0.43281	0.3582	0.399	0.33063	0.32775	0.32751	0.33223	0.33744	0.33835	0.33891	4.14%	27.47%	27.41%
	Total	**25.23195**	**19.29384**	**20.73913**	**18.29147**	**14.9628**	**14.88814**	**15.13879**	**17.21157**	**19.32246**	**19.98964**	**20.33992**	**23.53%**	**41.08%**	**40.99%**
				Optimal Dynamic Slat Angle				**14.86724**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

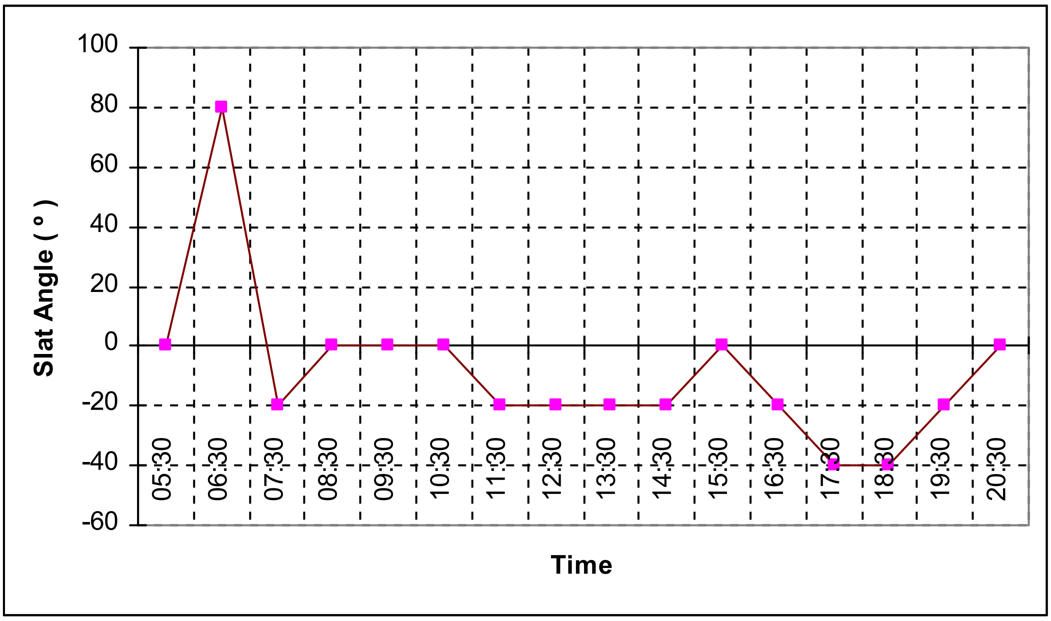

Figure C.3 Hourly energy consumption of all scenarios for the south oriented facade in 21 March from 5:30 to 20:30

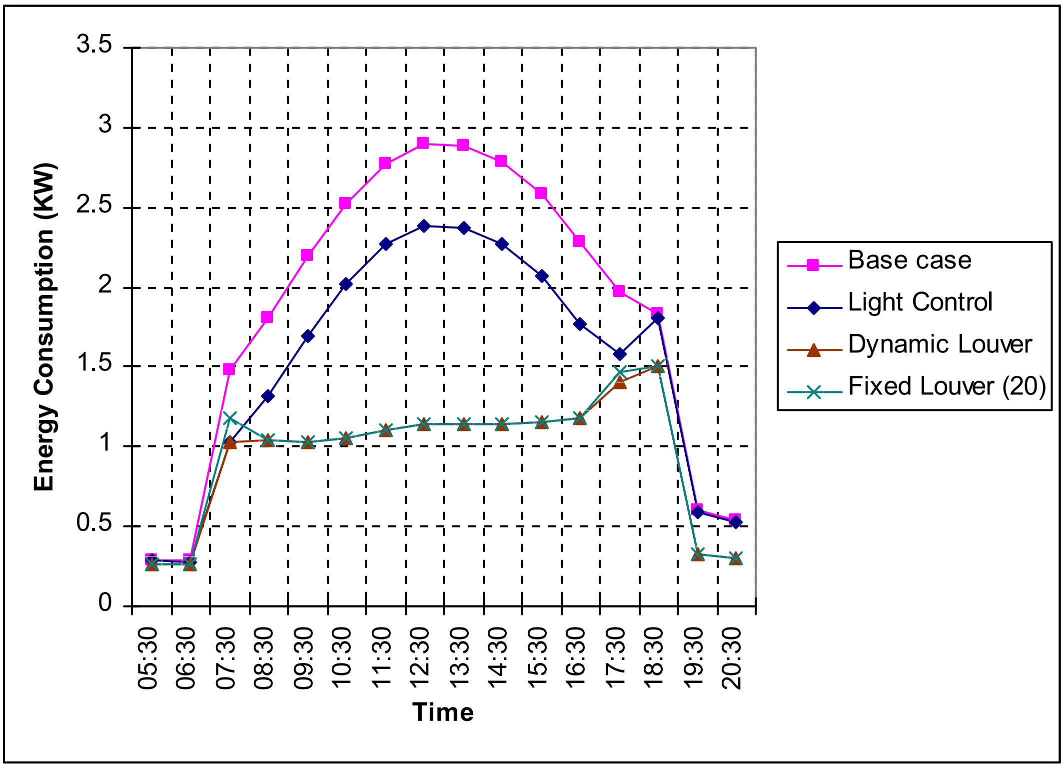

Figure C.4 Hourly energy consumption of all scenarios for the south oriented facade in 20 December from 5:30 to 20:30

Table C.3 Hourly energy consumption of the south oriented façade in 20 June from 5:30 to 20:30 (Shading coefficient 0.746, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-40°)
20 – JUNE	05:30	0.47237	0.47066	0.45876	0.46142	0.46319	0.46332	0.46144	0.45926	0.45789	0.45719	0.45699	0.36%	3.26%	1.94%
	06:30	0.50254	0.50089	0.46813	0.47668	0.48174	0.48188	0.47636	0.46969	0.46566	0.46369	0.46311	0.33%	7.85%	4.14%
	07:30	1.74883	1.26192	1.67192	1.28469	1.22989	1.23004	1.26302	1.53666	1.60101	1.66041	1.67466	27.84%	29.67%	29.67%
	08:30	1.841	1.34484	1.75756	1.3586	1.31151	1.31166	1.34807	1.61398	1.69159	1.7433	1.76492	26.95%	28.76%	28.76%
	09:30	1.89359	1.39396	1.82334	1.4777	1.36855	1.36869	1.4733	1.68933	1.77934	1.81359	1.83482	26.39%	27.73%	27.73%
	10:30	1.90569	1.40337	1.85841	1.56876	1.38772	1.38805	1.56487	1.73273	1.81657	1.84816	1.86768	26.36%	27.18%	27.18%
	11:30	1.91241	1.40792	1.87377	1.61875	1.39659	1.43312	1.56677	1.72217	1.84394	1.87056	1.88554	26.38%	26.97%	26.97%
	12:30	1.94165	1.43534	1.89298	1.64194	1.42977	1.50461	1.59977	1.73539	1.88792	1.90987	1.92092	26.08%	26.36%	26.36%
	13:30	1.93071	1.42287	1.89602	1.63972	1.41967	1.49335	1.61511	1.72888	1.86862	1.89273	1.90797	26.30%	26.47%	26.47%
	14:30	1.95021	1.44108	1.90925	1.61819	1.42724	1.44851	1.58542	1.74861	1.86799	1.8976	1.91609	26.11%	26.82%	26.82%
	15:30	1.96601	1.45577	1.90694	1.57552	1.43345	1.43504	1.54177	1.76474	1.85389	1.89384	1.91367	25.95%	27.09%	27.09%
	16:30	1.9748	1.46359	1.89458	1.53068	1.43314	1.43441	1.50139	1.75566	1.84002	1.88715	1.90392	25.89%	27.43%	27.43%
	17:30	1.97092	1.45887	1.88891	1.56636	1.42503	1.42611	1.53166	1.76174	1.84417	1.88197	1.89487	25.98%	27.70%	27.70%
	18:30	1.89513	1.41884	1.83886	1.64622	1.47899	1.46703	1.6278	1.76648	1.81591	1.8337	1.8389	25.13%	22.59%	21.96%
	19:30	0.64895	0.62235	0.62159	0.61372	0.60974	0.61027	0.61257	0.61709	0.61839	0.61851	0.6187	4.10%	6.04%	6.04%
	20:30	0.61882	0.59965	0.59968	0.59312	0.59015	0.59073	0.59233	0.59605	0.5974	0.59764	0.59785	3.10%	4.63%	4.63%
	Total	**25.17363**	**19.10192**	**24.3607**	**20.67207**	**18.88637**	**19.08682**	**20.36165**	**22.69846**	**23.85031**	**24.26991**	**24.46061**	**24.12%**	**25.12%**	**24.98%**
				Optimal Dynamic Slat Angle				**18.84958**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

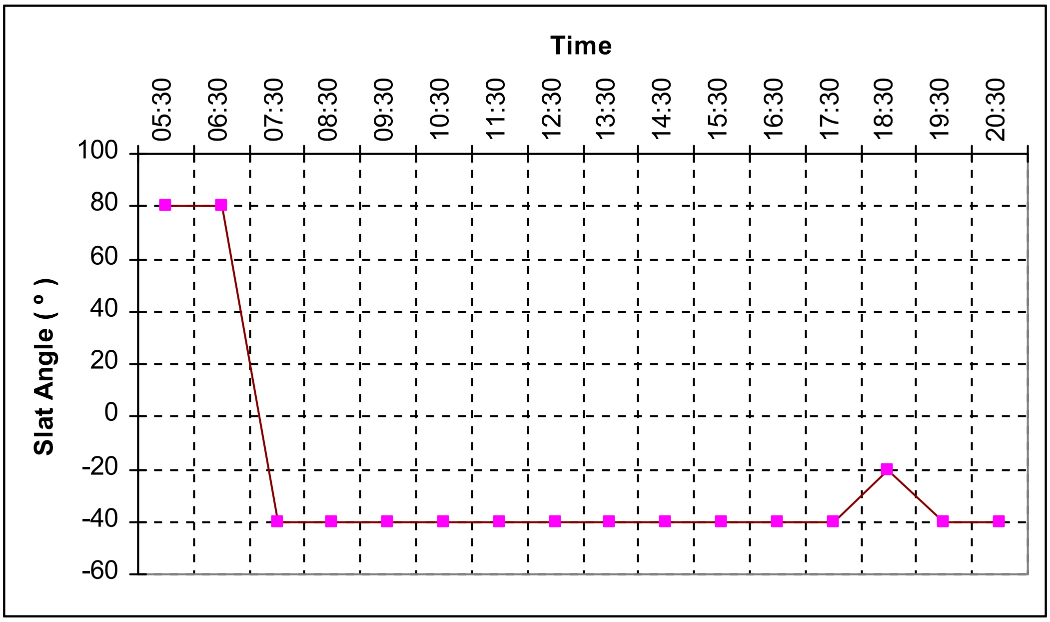

Figure C.5 Hourly energy consumption of all scenarios for the south oriented facade in 20 June from 5:30 to 20:30

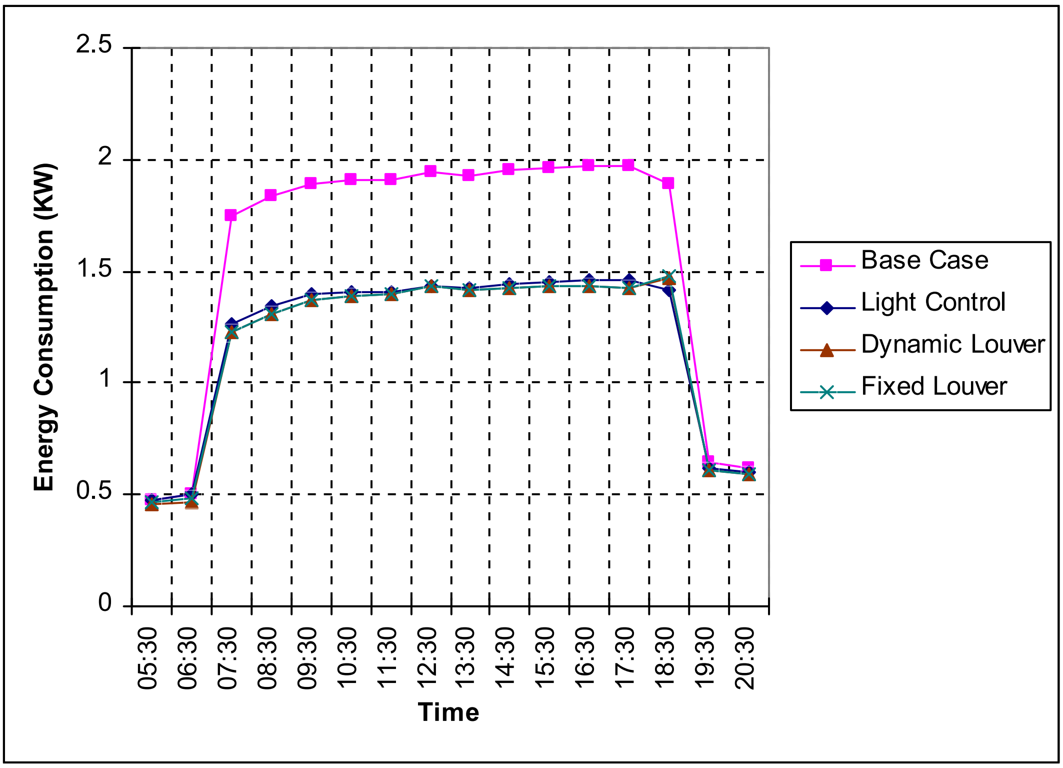

Figure C.6 Hourly energy consumption of all scenarios the south oriented facade in 20 June from 5:30 to 20:30

Table C.4 Hourly energy consumption of the south oriented façade in 20 September from 5:30 to 20:30
(Shading coefficient 0.746, lighting sensor @ 2 meters)

South-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-40°)
20 – SEPTEMBER	05:30	0.47612	0.4699	0.44517	0.44561	0.43412	0.43416	0.43427	0.43646	0.43768	0.43804	0.43818	1.31%	8.82%	8.82%
	06:30	0.48706	0.48129	0.4423	0.44714	0.43868	0.43873	0.43614	0.43487	0.43403	0.43342	0.43327	1.18%	11.04%	9.93%
	07:30	1.71089	1.22023	1.60488	1.19036	1.15725	1.15749	1.18436	1.45667	1.55737	1.59454	1.61135	28.68%	32.36%	32.36%
	08:30	1.8434	1.34381	1.66801	1.24056	1.22705	1.22744	1.21928	1.45441	1.59327	1.64956	1.67555	27.10%	33.86%	33.44%
	09:30	2.03728	1.53447	1.77966	1.36103	1.30694	1.30774	1.30231	1.52888	1.66865	1.73322	1.76321	24.68%	36.08%	35.85%
	10:30	2.23845	1.73316	1.88988	1.47944	1.36645	1.36805	1.37095	1.58207	1.73583	1.80936	1.83496	22.57%	38.96%	38.96%
	11:30	2.38249	1.87518	1.9505	1.56111	1.39626	1.39809	1.42872	1.59021	1.79009	1.85538	1.88233	21.29%	41.39%	41.39%
	12:30	2.45297	1.94398	1.97207	1.60473	1.41722	1.42133	1.4331	1.6158	1.81727	1.88643	1.91793	20.75%	42.22%	42.22%
	13:30	2.43429	1.92388	1.96941	1.59878	1.4253	1.43218	1.43471	1.63344	1.82229	1.88965	1.92266	20.97%	41.45%	41.45%
	14:30	2.32881	1.81726	1.93421	1.54001	1.41367	1.41593	1.41513	1.60924	1.80615	1.86744	1.89598	21.97%	39.30%	39.30%
	15:30	2.17854	1.66601	1.8663	1.45593	1.38163	1.38295	1.37831	1.58832	1.76375	1.82844	1.85535	23.53%	36.73%	36.58%
	16:30	2.0665	1.55312	1.84074	1.40156	1.36273	1.36361	1.35629	1.64121	1.74496	1.81014	1.83124	24.84%	34.37%	34.06%
	17:30	1.99425	1.48012	1.83884	1.54293	1.37069	1.37954	1.49047	1.72355	1.78015	1.81465	1.82337	25.78%	31.27%	31.27%
	18:30	1.9313	1.66548	1.82174	1.7444	1.62999	1.63859	1.70348	1.77675	1.79451	1.80218	1.80458	13.76%	15.60%	15.60%
	19:30	0.72615	0.70223	0.64216	0.63938	0.61275	0.61318	0.61298	0.61994	0.62351	0.62464	0.62504	3.29%	15.62%	15.62%
	20:30	0.66778	0.64833	0.59444	0.59252	0.5691	0.56941	0.56902	0.57484	0.57796	0.57894	0.57929	2.91%	14.79%	14.78%
	Total	**27.95628**	**22.05845**	**24.26031**	**19.84549**	**18.50983**	**18.54842**	**18.76952**	**21.26666**	**22.94747**	**23.61603**	**23.89429**	**21.10%**	**33.89%**	**33.79%**
				Optimal Dynamic Slat Angle				**18.48218**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

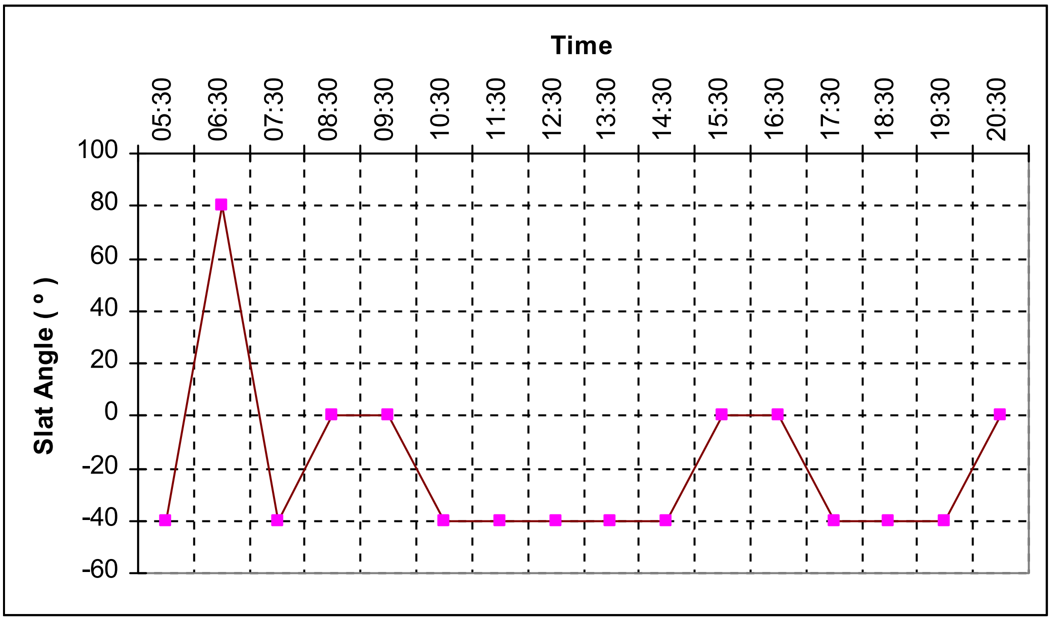

Figure C.7 Hourly energy consumption of all scenarios for the south oriented facade in 20 September from 5:30 to 20:30

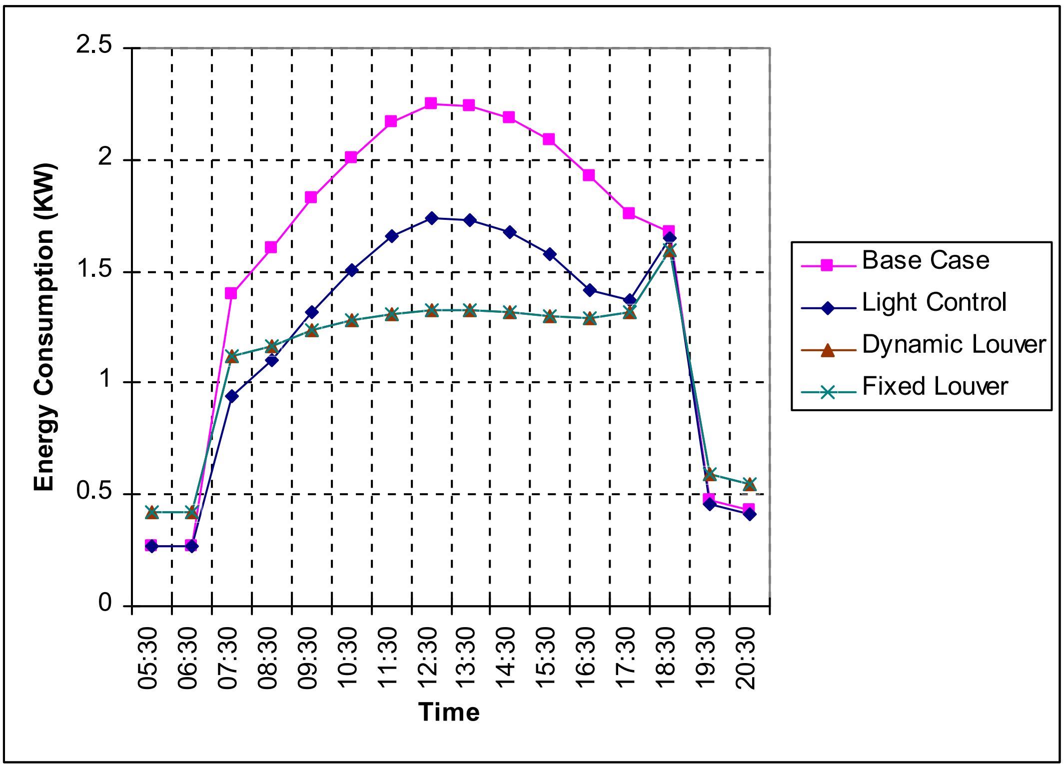

Figure C.8 Hourly energy consumption of all scenarios for the south oriented facade in 20 September from 5:30 to 20:30

Table C.5 Summary of energy savings of the south oriented façade in the four selected days from 5:30 to 20:30
(Shading coefficient 0.746, lighting sensor @ 2 meters)

Summary of Energy savings of South Façade Simulations (Shading Coefficient = 0.746 & sensor distance = 2m) (KW)												
Date & Time	**Base case**	**Lighting Congtrol**	**Dynamic louver**	**Louver Angle**								
				-80º	-60º	-40º	-20º	0º	20º	40º	60º	80º
20 Dec (5:30 - 20:30)	29.73541	24.26429	15.11318	18.5558	16.87133	16.12276	15.239	15.08533	15.13012	16.31745	17.92755	18.62417
21 March (5:30 - 20:30)	25.23195	19.29384	14.86724	19.14453	17.01213	16.99315	16.83212	16.39446	15.81344	16.32302	17.76003	19.14594
20 June (5:30 - 20:30)	25.17363	19.10192	18.84958	23.30161	21.06093	19.8776	19.41435	20.17518	20.29173	20.90219	21.77971	23.43945
20 Sept (5:30 - 20:30)	27.95628	22.05845	18.48218	22.71384	20.30609	19.7482	19.22858	19.07925	18.67284	19.56119	21.28281	22.86615
Total	108.09727	84.7185	67.31218	83.71578	75.25048	72.74171	70.71405	70.73422	69.90813	73.10385	78.7501	84.07571
Percentage of Total energy saving over the Base case		**21.63%**	**37.73%**	**22.56%**	**30.39%**	**32.71%**	**34.58%**	**34.56%**	**35.33%**	**32.37%**	**27.15%**	**22.22%**

Appendix D

East Façade Simulations

Glass Shading Coefficient 0.41 and lighting sensor @ 2 meters

Table D.1 Hourly energy consumption of the east oriented façade in 20 December from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

East-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (0°)
20 – DECEMBER	05:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26526	0.26523	0.26522	0.26522	0.00%	0.00%	0.00%
	06:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	07:30	1.33168	0.83116	1.21461	1.00112	0.86562	0.80731	0.81772	0.85498	1.04194	1.16507	1.21295	37.59%	39.38%	38.59%
	08:30	1.62857	1.12213	1.30767	0.97219	1.05434	0.98872	0.90282	0.86575	0.9417	1.201	1.33147	31.10%	46.84%	44.56%
	09:30	1.78364	1.27499	1.33743	1.09823	1.16457	1.02448	0.94289	0.92563	0.94585	1.24387	1.38119	28.52%	48.10%	47.14%
	10:30	1.78071	1.27031	1.41305	1.1274	1.10274	1.00919	0.97926	0.97217	1.11316	1.32973	1.42913	28.66%	45.41%	45.01%
	11:30	1.70892	1.1971	1.49649	1.1753	1.09123	1.05922	1.06875	1.13861	1.29523	1.45201	1.50106	29.95%	38.02%	37.46%
	12:30	1.66199	1.14898	1.5351	1.45219	1.23733	1.20641	1.24261	1.26833	1.38858	1.50131	1.54213	30.87%	27.41%	25.23%
	13:30	1.64208	1.13799	1.54698	1.48949	1.37378	1.28851	1.29679	1.30804	1.41055	1.50197	1.54442	30.70%	21.53%	21.03%
	14:30	1.62805	1.16214	1.54532	1.49785	1.40358	1.31515	1.31399	1.3161	1.40988	1.49932	1.54043	28.62%	19.29%	19.29%
	15:30	1.61482	1.12614	1.53664	1.48662	1.39363	1.29801	1.29039	1.28189	1.38961	1.48686	1.53357	30.26%	20.62%	20.09%
	16:30	1.58686	1.10992	1.51262	1.4659	1.36802	1.27545	1.27667	1.25784	1.36843	1.47023	1.50943	30.06%	20.73%	19.55%
	17:30	1.55449	1.28202	1.49327	1.47181	1.43438	1.35854	1.35542	1.34587	1.4123	1.46825	1.4885	17.53%	13.42%	12.81%
	18:30	1.52683	1.50114	1.48192	1.49106	1.49095	1.47532	1.46646	1.46306	1.46845	1.47536	1.47694	1.68%	4.18%	3.95%
	19:30	0.34826	0.3275	0.30927	0.31718	0.31746	0.30681	0.30495	0.30496	0.30522	0.30651	0.30703	5.96%	12.44%	12.44%
	20:30	0.32048	0.30234	0.29499	0.29455	0.29469	0.29544	0.29617	0.29641	0.2961	0.29562	0.29548	5.66%	8.09%	7.59%
	Total	**20.64782**	**15.3243**	**18.5558**	**16.87133**	**16.12276**	**15.239**	**15.08533**	**15.13012**	**16.31745**	**17.92755**	**18.62417**	**25.78%**	**27.75%**	**26.94%**
				Optimal Dynamic Slat Angle				**14.91759**							

15.08533

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

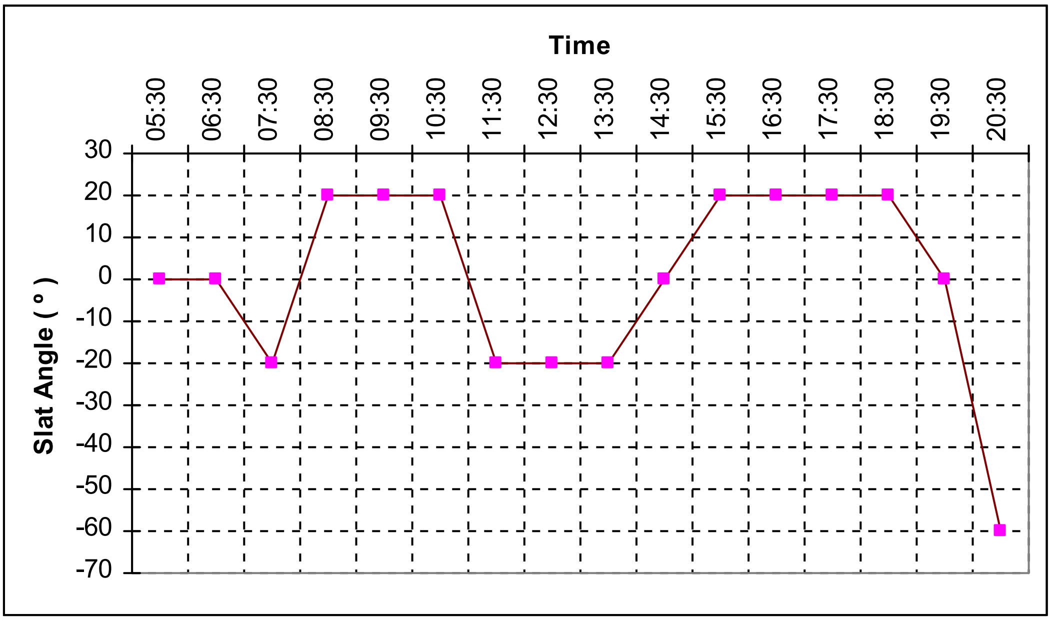

Figure D.1 Hourly energy consumption of all scenarios for the east oriented facade in 20 December from 5:30 to 20:30

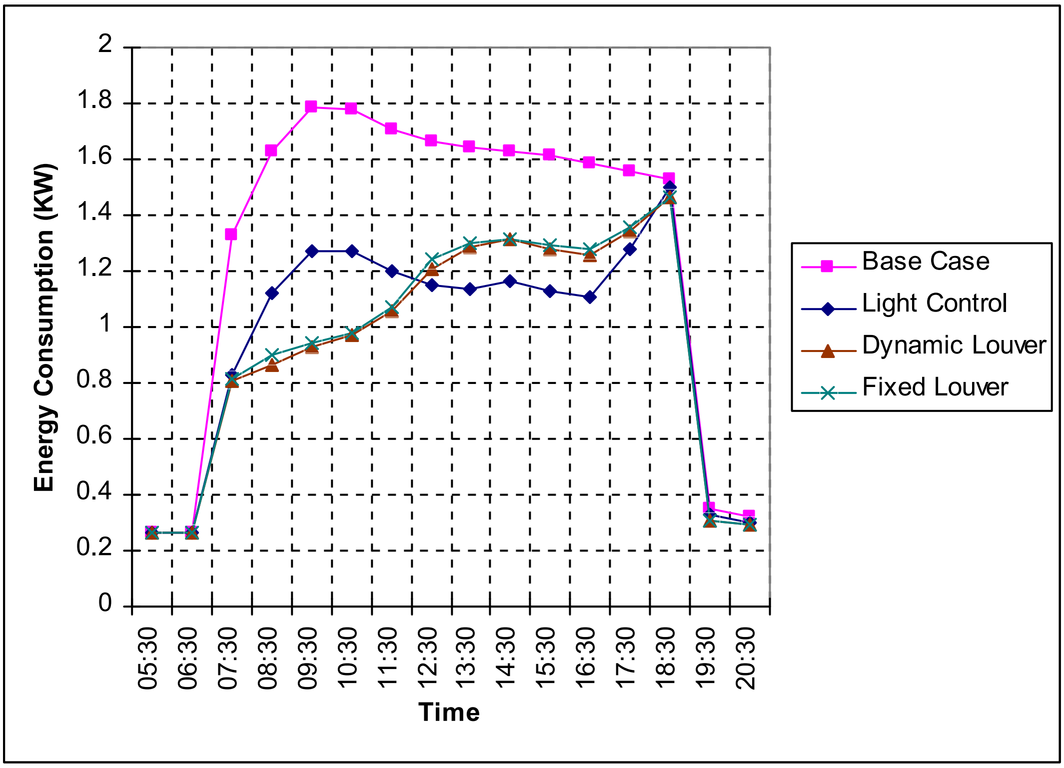

Figure D.2 Hourly energy consumption of all scenarios for the east oriented facade in 20 December from 5:30 to 20:30

Table D.2 Hourly energy consumption of the east oriented façade in 21 March from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

East-Façade														
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (20º)
21 – MARCH	05:30	0.29313	0.29125	0.2777	0.28181	0.28649	0.28856	0.28512	0.2804	0.277	0.27634	0.27662	0.64%	5.73%	4.34%
	06:30	0.32714	0.3265	0.30595	0.30937	0.31425	0.31905	0.31977	0.31386	0.30909	0.30644	0.30549	0.20%	6.62%	4.06%
	07:30	1.49531	1.00524	1.16335	0.81944	0.84843	0.92451	0.92053	0.83884	0.77511	0.92683	1.18468	32.77%	48.16%	43.90%
	08:30	1.83663	1.33734	1.25892	0.95132	1.08845	1.23813	1.15157	1.00329	0.89365	0.95405	1.27378	27.19%	51.34%	45.37%
	09:30	2.0076	1.50513	1.35409	1.10402	1.28465	1.39182	1.22019	1.05874	0.97341	1.11749	1.35673	25.03%	51.51%	47.26%
	10:30	1.97838	1.47351	1.45118	1.22984	1.32601	1.29574	1.17337	1.07651	1.05245	1.30227	1.45042	25.52%	46.80%	45.59%
	11:30	1.84638	1.33952	1.56441	1.20332	1.2331	1.21124	1.16188	1.17075	1.26542	1.45924	1.54299	27.45%	37.07%	36.59%
	12:30	1.71686	1.22296	1.58387	1.24689	1.22931	1.24894	1.26912	1.33071	1.42024	1.52365	1.57324	28.77%	28.40%	22.49%
	13:30	1.70194	1.26092	1.59849	1.55113	1.45816	1.42339	1.41762	1.41166	1.48469	1.55628	1.59602	25.91%	17.06%	17.06%
	14:30	1.73066	1.26833	1.63263	1.57847	1.49688	1.45298	1.44681	1.43033	1.51146	1.59251	1.631	26.71%	17.35%	17.35%
	15:30	1.71503	1.20641	1.62132	1.55724	1.46391	1.39489	1.39776	1.36495	1.47478	1.57294	1.62188	29.66%	20.41%	20.41%
	16:30	1.68726	1.17523	1.58981	1.51932	1.41207	1.29453	1.30341	1.26613	1.42175	1.5267	1.5936	30.35%	24.96%	24.96%
	17:30	1.64319	1.13027	1.54895	1.48316	1.38489	1.25198	1.257	1.23547	1.37625	1.49228	1.55167	31.21%	24.81%	24.81%
	18:30	1.60545	1.27536	1.52993	1.49836	1.46552	1.38936	1.38365	1.37169	1.43705	1.49895	1.52939	20.56%	14.56%	14.56%
	19:30	0.40791	0.38373	0.35036	0.35768	0.3692	0.37191	0.36135	0.34754	0.34305	0.34512	0.3475	5.93%	15.90%	14.80%
	20:30	0.36544	0.34646	0.31357	0.32076	0.33183	0.33509	0.32531	0.31257	0.30762	0.30894	0.31093	5.19%	15.82%	14.47%
	Total	**22.35831**	**16.54816**	**19.14453**	**17.01213**	**16.99315**	**16.83212**	**16.39446**	**15.81344**	**16.32302**	**17.76003**	**19.14594**	**25.99%**	**31.13%**	**24.72%**
				Optimal Dynamic Slat Angle				**15.39854**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

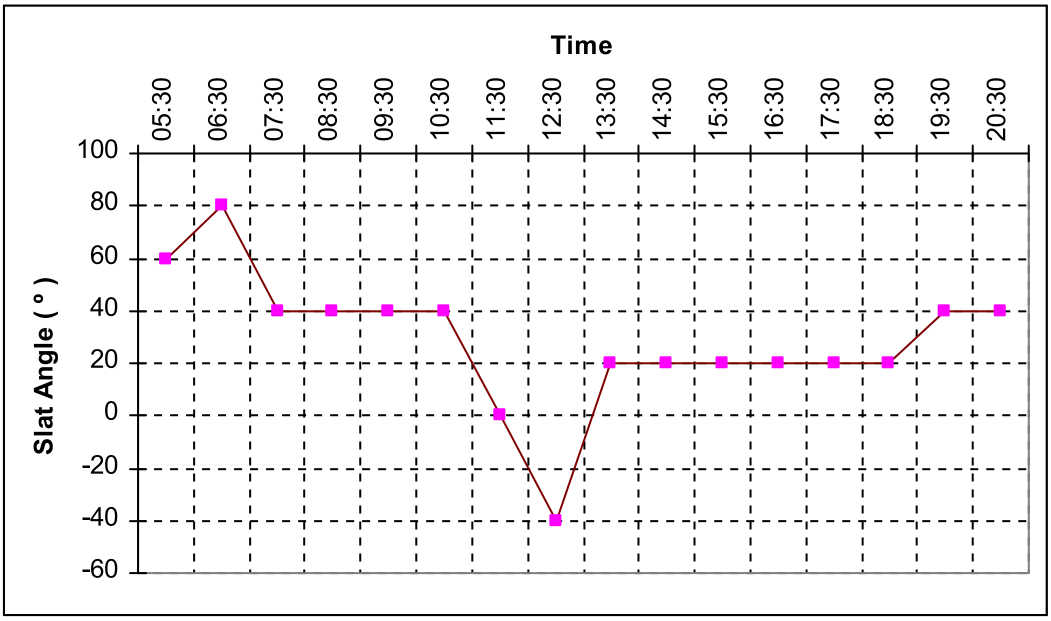

Figure D.3 Hourly energy consumption of all scenarios for the east oriented facade in 21 March from 5:30 to 20:30

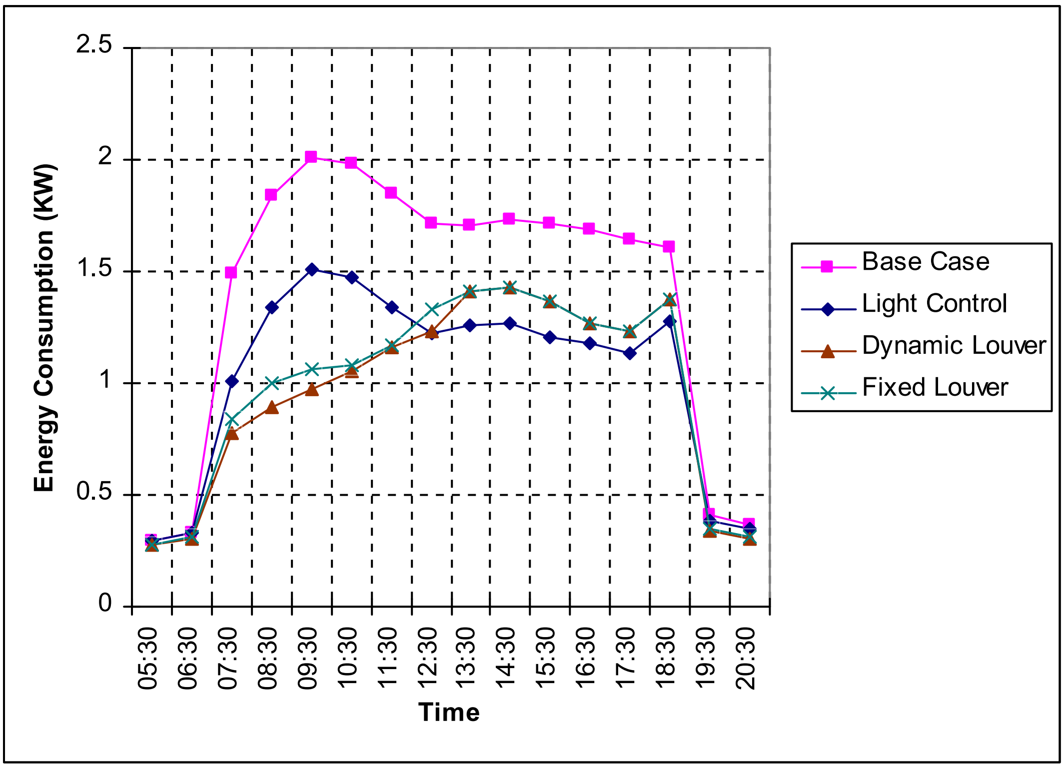

Figure D.4 Hourly energy consumption of all scenarios for the east oriented facade in 21 March from 5:30 to 20:30

Table D.3 Hourly energy consumption of the east oriented façade in 20 June from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

East-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-20°)
20 – JUNE	05:30	0.47898	0.47728	0.44924	0.45052	0.45356	0.4591	0.46634	0.46742	0.46036	0.45377	0.44926	0.35%	6.21%	4.15%
	06:30	0.55633	0.55468	0.45008	0.45344	0.45907	0.47826	0.50556	0.52764	0.50057	0.47238	0.45176	0.30%	19.10%	14.03%
	07:30	1.94245	1.45554	1.57308	1.18875	1.20549	1.26316	1.3421	1.39228	1.30678	1.23141	1.59415	25.07%	38.80%	34.97%
	08:30	2.17817	1.68201	1.63089	1.25867	1.31112	1.41056	1.53963	1.57146	1.43677	1.3234	1.6682	22.78%	42.21%	35.24%
	09:30	2.25811	1.75847	1.69817	1.33782	1.39207	1.50433	1.64294	1.62728	1.48821	1.42342	1.73271	22.13%	40.75%	33.38%
	10:30	2.17357	1.67124	1.7555	1.5246	1.40956	1.4992	1.60524	1.56227	1.45993	1.58497	1.76332	23.11%	35.15%	31.03%
	11:30	2.00518	1.50068	1.79027	1.66784	1.46077	1.42669	1.47595	1.46504	1.55918	1.7001	1.78983	25.16%	28.85%	28.85%
	12:30	1.90976	1.40344	1.8051	1.71195	1.56453	1.47289	1.5042	1.5392	1.66641	1.76189	1.80542	26.51%	22.88%	22.88%
	13:30	1.89708	1.38924	1.81577	1.72384	1.60377	1.5345	1.55156	1.57914	1.68203	1.77833	1.82034	26.77%	19.11%	19.11%
	14:30	1.90911	1.39997	1.8325	1.73139	1.60827	1.51915	1.55017	1.55715	1.68188	1.78049	1.83734	26.67%	20.43%	20.43%
	15:30	1.92015	1.4099	1.83739	1.71424	1.57126	1.4403	1.47495	1.47491	1.65144	1.76717	1.8443	26.57%	24.99%	24.99%
	16:30	1.92974	1.41853	1.83874	1.69384	1.52529	1.38137	1.39745	1.39829	1.58326	1.77068	1.84563	26.49%	28.42%	28.42%
	17:30	1.93625	1.4242	1.84223	1.70679	1.53454	1.38199	1.39886	1.40109	1.57694	1.78111	1.84883	26.45%	28.63%	28.63%
	18:30	1.87988	1.39498	1.80151	1.72277	1.60412	1.46056	1.51436	1.52307	1.65397	1.76433	1.80688	25.79%	22.31%	22.31%
	19:30	0.65011	0.62322	0.59903	0.5953	0.59464	0.59818	0.61067	0.61045	0.6054	0.60164	0.59922	4.14%	7.99%	7.99%
	20:30	0.62595	0.60671	0.58211	0.57917	0.57954	0.58411	0.5952	0.59504	0.58906	0.58462	0.58226	3.07%	7.47%	6.68%
	Total	**26.25082**	**20.17009**	**23.30161**	**21.06093**	**19.8776**	**19.41435**	**20.17518**	**20.29173**	**20.90219**	**21.77971**	**23.43945**	**23.16%**	**28.04%**	**26.04%**
				Optimal Dynamic Slat Angle				**18.88892**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

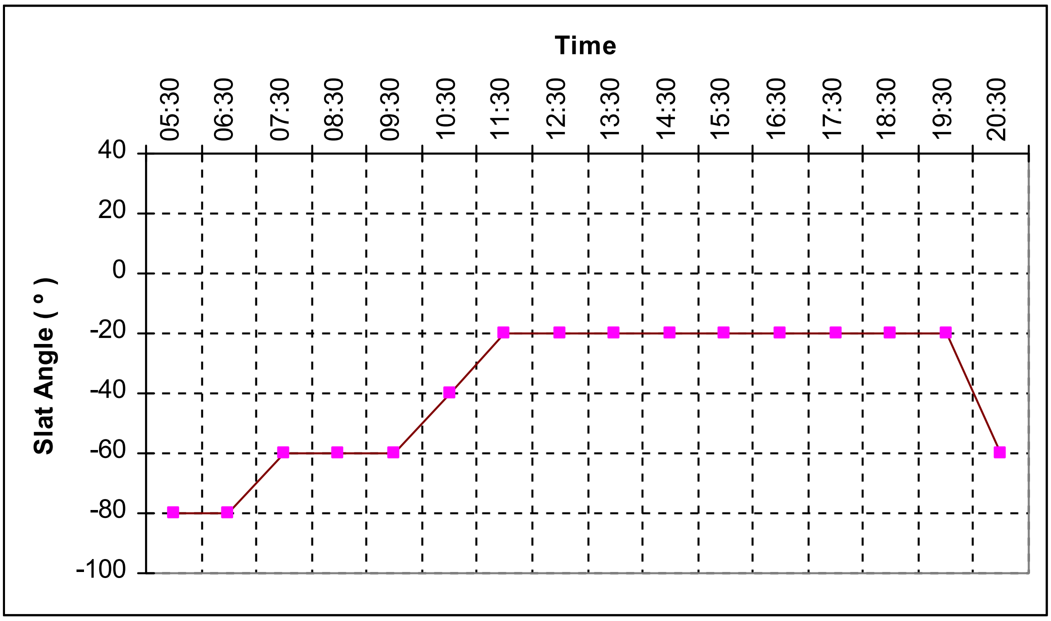

Figure D.5 Hourly energy consumption of all scenarios for the east oriented facade in 20 June from 5:30 to 20:30

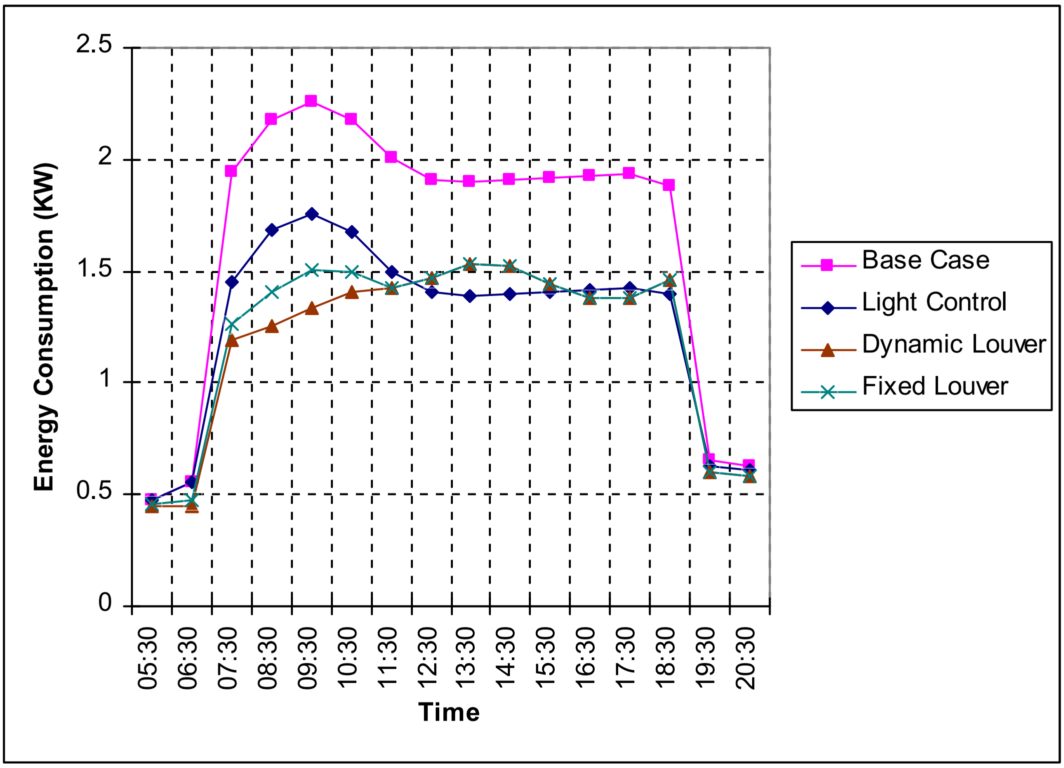

Figure D.6 Hourly energy consumption of all scenarios for the east oriented facade in 20 June from 5:30 to 20:30

Table D.4 Hourly energy consumption of the east oriented façade in 20 September from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

East-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (20º)
20 – SEPTEMBER	05:30	0.44711	0.44086	0.42898	0.43057	0.43415	0.43576	0.43285	0.42822	0.42671	0.42732	0.42835	1.40%	4.56%	4.22%
	06:30	0.45856	0.45277	0.42106	0.42512	0.43199	0.43762	0.43786	0.42939	0.42406	0.42149	0.42035	1.26%	8.33%	6.36%
	07:30	1.78533	1.29465	1.53394	1.14289	1.17703	1.22589	1.24291	1.18991	1.14751	1.31655	1.56348	27.48%	35.98%	34.07%
	08:30	2.02672	1.52712	1.55235	1.22434	1.31927	1.43032	1.40015	1.29162	1.20897	1.25487	1.59235	24.65%	40.35%	34.91%
	09:30	2.15411	1.65129	1.6083	1.33291	1.4611	1.554	1.45088	1.33105	1.26029	1.3717	1.64858	23.34%	41.49%	32.17%
	10:30	2.11722	1.61191	1.7046	1.46628	1.49071	1.48407	1.40313	1.33379	1.3246	1.56863	1.72307	23.87%	37.44%	29.59%
	11:30	1.98142	1.4741	1.78476	1.44802	1.40682	1.39718	1.36986	1.36639	1.51055	1.70377	1.78323	25.60%	31.04%	29.00%
	12:30	1.91276	1.40375	1.81327	1.50544	1.41517	1.39767	1.42336	1.47968	1.61636	1.75246	1.81803	26.61%	26.93%	26.01%
	13:30	1.90033	1.38992	1.82085	1.73558	1.59484	1.50298	1.52602	1.52052	1.65573	1.76342	1.82744	26.86%	20.91%	16.08%
	14:30	1.88247	1.37091	1.80291	1.71806	1.58441	1.48035	1.48936	1.4818	1.63062	1.74196	1.8045	27.17%	21.36%	15.83%
	15:30	1.85903	1.34649	1.77156	1.66088	1.51153	1.35686	1.36881	1.34552	1.51591	1.69181	1.77331	27.57%	27.62%	18.69%
	16:30	1.85782	1.34442	1.76192	1.63597	1.47235	1.31294	1.30648	1.29465	1.44237	1.66332	1.77053	27.63%	30.31%	20.75%
	17:30	1.85659	1.34245	1.77435	1.67782	1.5657	1.39343	1.41052	1.39054	1.55467	1.70296	1.77966	27.69%	25.10%	15.67%
	18:30	1.83118	1.55494	1.77316	1.73852	1.7099	1.64501	1.65195	1.64115	1.69487	1.74773	1.77352	15.09%	10.38%	6.62%
	19:30	0.64609	0.62198	0.60239	0.60317	0.60794	0.60825	0.60342	0.59482	0.5948	0.59866	0.60131	3.73%	7.94%	5.90%
	20:30	0.59831	0.57878	0.55944	0.56052	0.56529	0.56625	0.56169	0.55379	0.55317	0.55616	0.55844	3.26%	7.54%	5.52%
	Total	**25.31505**	**19.40634**	**22.71384**	**20.30609**	**19.7482**	**19.22858**	**19.07925**	**18.67284**	**19.56119**	**21.28281**	**22.86615**	**23.34%**	**27.51%**	**26.24%**
				Optimal Dynamic Slat Angle				**18.35103**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

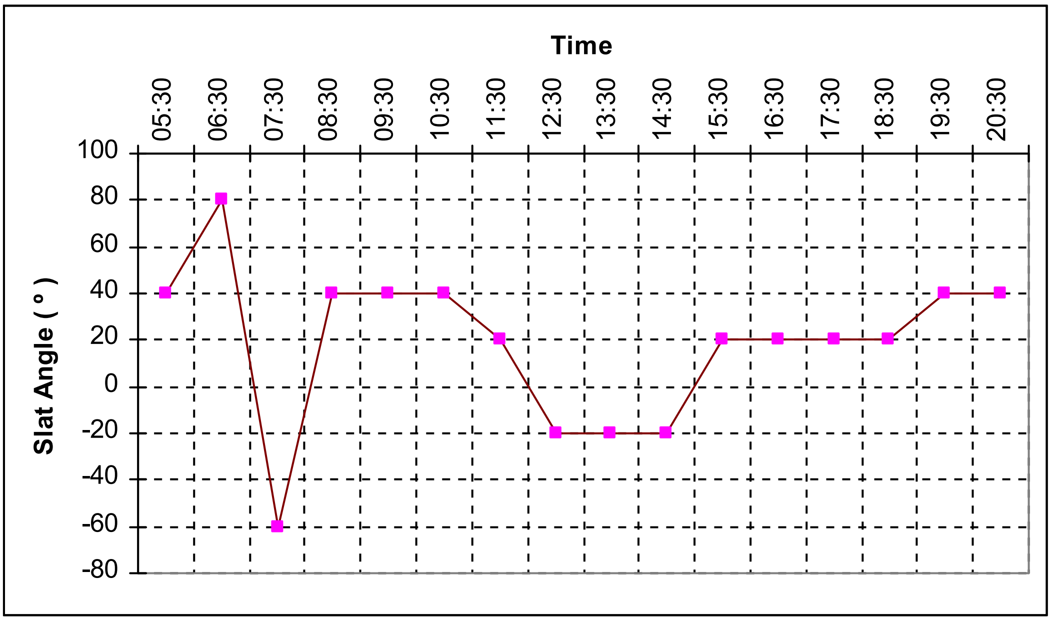

Figure D.7 Hourly energy consumption of all scenarios for the east oriented facade in 20 September from 5:30 to 20:30

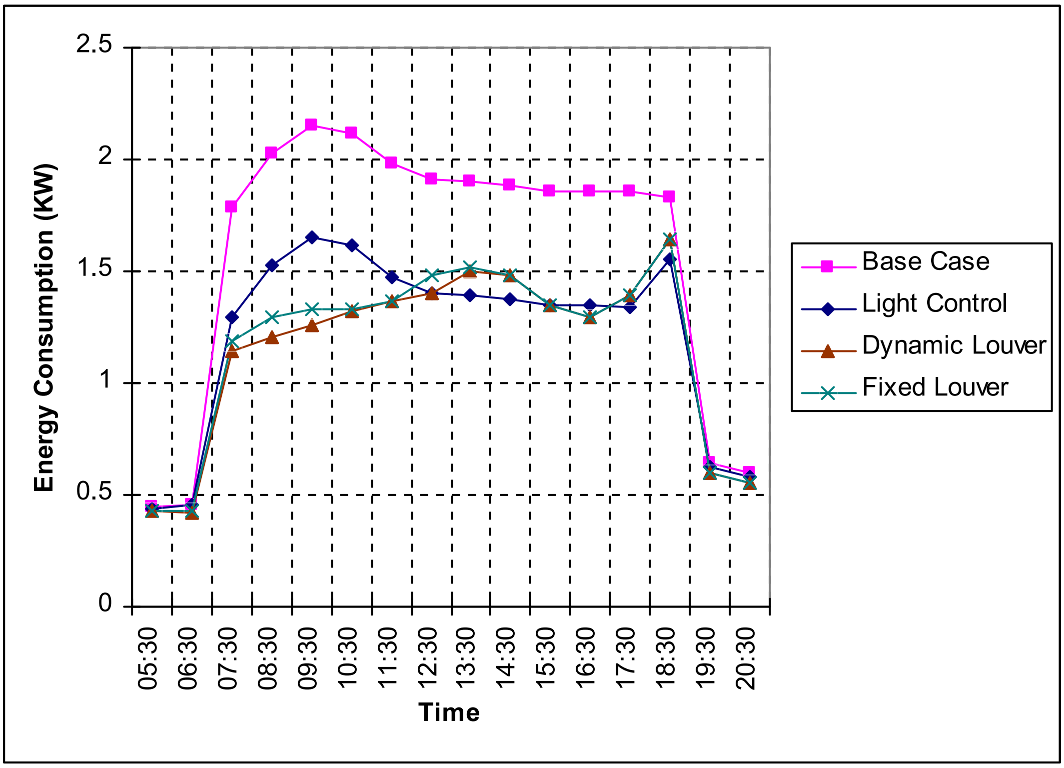

Figure D.8 Hourly energy consumption of all scenarios for the east oriented facade in 20 September from 5:30 to 20:30

Table D.5 Summary of energy savings of the east oriented façade in the four selected days from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

Summary of Energy savings of East Façade Simulations (Shading Coefficient = 0.41 & sensor distance = 2m) (KW)												
Date & Time	Base case	Lighting Congtrol	Dynamic louver	Louver Angle								
				-80º	-60º	-40º	-20º	0º	20º	40º	60º	80º
20 Dec (5:30 - 20:30)	20.64782	15.3243	14.91759	18.5558	16.87133	16.12276	15.239	15.08533	15.13012	16.31745	17.92755	18.62417
21 March (5:30 - 20:30)	22.35831	16.54816	15.39854	19.14453	17.01213	16.99315	16.83212	16.39446	15.81344	16.32302	17.76003	19.14594
20 June (5:30 - 20:30)	26.25082	20.17009	18.88892	23.30161	21.06093	19.8776	19.41435	20.17518	20.29173	20.90219	21.77971	23.43945
20 Sept (5:30 - 20:30)	25.31505	19.40634	18.35103	22.71384	20.30609	19.7482	19.22858	19.07925	18.67284	19.56119	21.28281	22.86615
Total	94.572	71.44889	67.55608	83.71578	75.25048	72.74171	70.71405	70.73422	69.90813	73.10385	78.7501	84.07571
Percentage of Total energy saving over the Base case		**24.45%**	**28.57%**	**11.48%**	**20.43%**	**23.08%**	**25.23%**	**25.21%**	**26.08%**	**22.70%**	**16.73%**	**11.10%**

Appendix E

West Façade Simulations

Glass Shading Coefficient 0.41 and lighting sensor @ 2 meters

Table E.1 Hourly energy consumption of the west oriented façade in 20 December from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

West-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (0º)
20 – DECEMBER	05:30	0.26522	0.26522	0.26522	0.26522	0.26524	0.26526	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	06:30	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.26522	0.00%	0.00%	0.00%
	07:30	1.29665	0.88876	1.21571	1.15134	1.07833	0.98332	1.00704	1.02659	1.12992	1.20863	1.22676	31.46%	24.16%	22.34%
	08:30	1.41479	0.90903	1.34265	1.23369	1.10059	0.94639	0.97743	1.00571	1.17291	1.30516	1.35286	35.75%	33.11%	30.91%
	09:30	1.46839	0.96009	1.39854	1.29056	1.15193	1.00983	1.04018	1.0502	1.22725	1.35563	1.4065	34.62%	31.23%	29.16%
	10:30	1.50328	0.99313	1.44214	1.3539	1.23387	1.12109	1.1409	1.13668	1.27971	1.40479	1.45161	33.94%	25.42%	24.11%
	11:30	1.55687	1.04521	1.50197	1.42088	1.30104	1.21396	1.21504	1.2095	1.30796	1.4597	1.51135	32.86%	22.31%	21.96%
	12:30	1.59612	1.08323	1.53657	1.4483	1.3083	1.23094	1.15162	1.17816	1.20735	1.18156	1.5337	32.13%	27.85%	27.85%
	13:30	1.67924	1.1653	1.54019	1.43351	1.25188	1.1601	1.06148	1.06697	1.0799	1.11094	1.53499	30.61%	36.79%	36.79%
	14:30	1.82954	1.31473	1.53036	1.39422	1.17773	1.07102	1.06038	1.08337	1.15025	1.22477	1.51627	28.14%	42.04%	42.04%
	15:30	1.92889	1.41333	1.51272	1.34801	1.09255	1.04874	1.06704	1.1507	1.28927	1.23375	1.49482	26.73%	45.63%	44.68%
	16:30	1.87697	1.36076	1.49314	1.35124	1.11484	1.03069	1.07196	1.17894	1.26148	1.16211	1.48864	27.50%	45.09%	42.89%
	17:30	1.68022	1.2218	1.48607	1.43336	1.36539	1.23603	1.19252	1.2016	1.25141	1.28552	1.49605	27.28%	29.03%	29.03%
	18:30	1.58159	1.552	1.47846	1.47327	1.46531	1.46113	1.47061	1.49437	1.5197	1.50734	1.48553	1.87%	7.62%	7.02%
	19:30	0.39065	0.36797	0.30757	0.30599	0.30492	0.30494	0.30569	0.31905	0.34023	0.33024	0.31152	5.81%	21.95%	21.75%
	20:30	0.35456	0.33488	0.29534	0.29575	0.29623	0.29644	0.29592	0.29488	0.31124	0.30311	0.29465	5.55%	16.90%	16.54%
	Total	**20.6882**	**15.14066**	**18.61187**	**17.46446**	**15.77337**	**14.6451**	**14.58825**	**14.92716**	**16.05902**	**16.60369**	**18.63569**	**26.81%**	**30.36%**	**29.49%**
				Optimal Dynamic Slat Angle				**14.4067**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

Note: When optimal case is not assigned, all readings are similar and can be used as optimal case

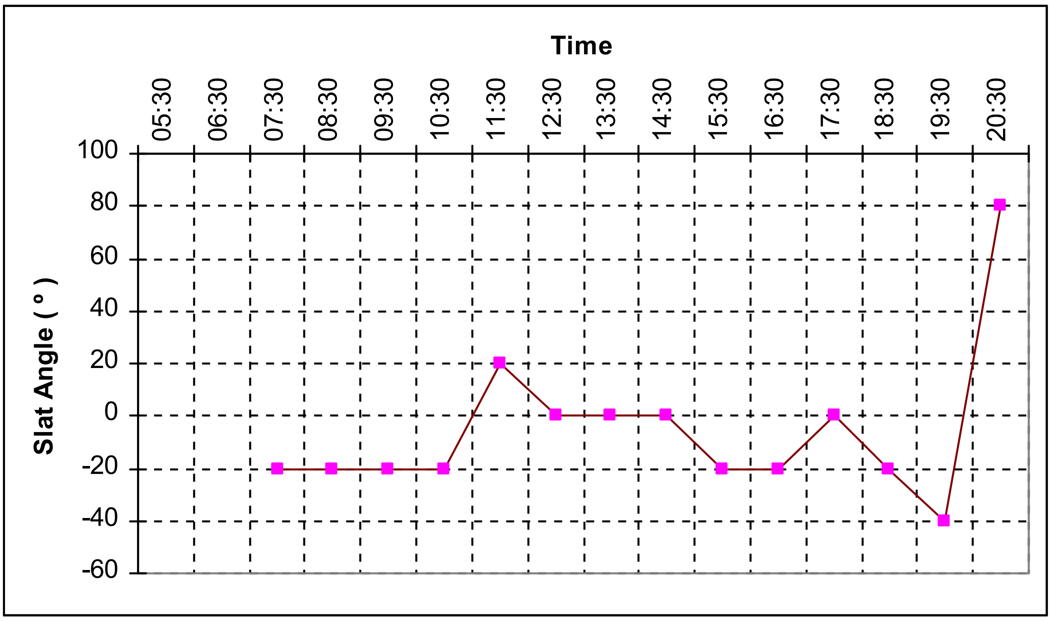

Figure E.1 Hourly energy consumption of all scenarios for the west oriented facade in 20 December from 5:30 to 20:30

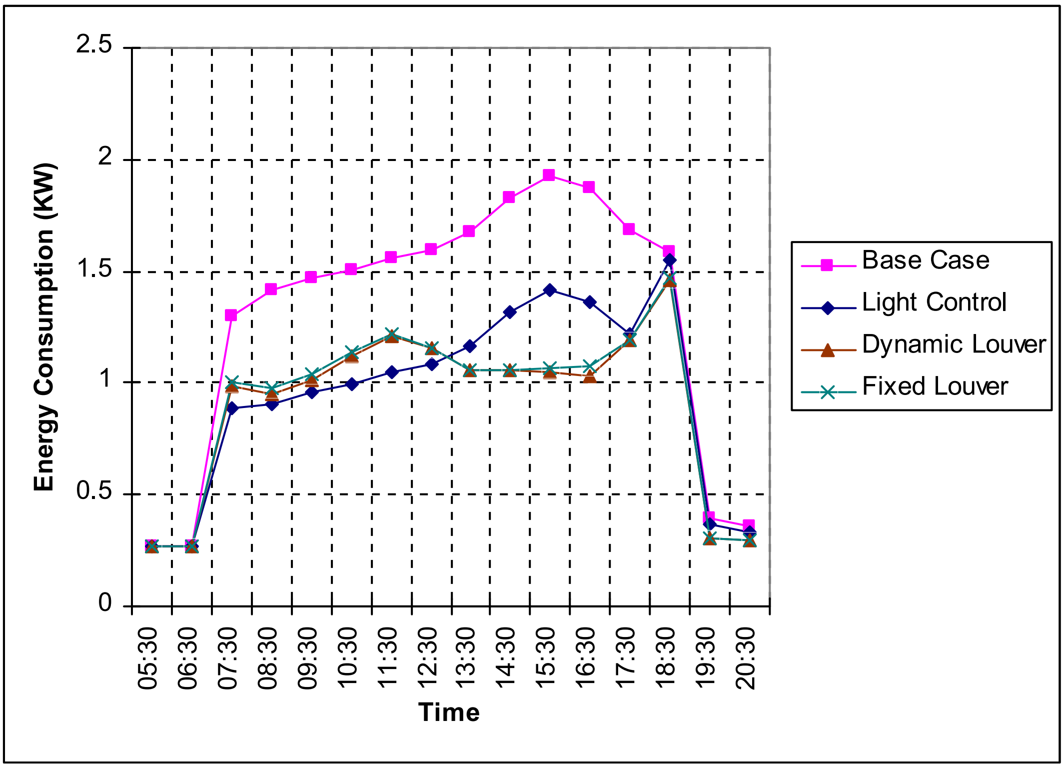

Figure E.2 Hourly energy consumption of all scenarios for the west oriented facade in 20 December from 5:30 to 20:30

Table E.2 Hourly energy consumption of the west oriented façade in 21 March from 5:30 to 8:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

West-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				- 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-20°)
21 – MARCH	05:30	0.30034	0.29851	0.27675	0.27596	0.27699	0.28128	0.28863	0.29375	0.29011	0.28318	0.27762	0.61%	8.12%	6.35%
	06:30	0.31693	0.31635	0.30557	0.30578	0.30652	0.30827	0.31087	0.31249	0.31107	0.30833	0.30585	0.18%	3.58%	2.73%
	07:30	1.31401	0.82267	1.20327	1.08144	0.91787	0.78046	0.8074	0.83185	1.01309	1.1531	1.21238	37.39%	40.60%	40.60%
	08:30	1.42218	0.92319	1.31812	1.18786	1.0244	0.88761	0.92288	0.9292	1.11445	1.26774	1.32763	35.09%	37.59%	37.59%
	09:30	1.49976	0.99756	1.42145	1.33016	1.19772	1.10849	1.1455	1.14809	1.29023	1.38226	1.4288	33.49%	26.09%	26.09%
	10:30	1.55751	1.05746	1.49788	1.427	1.31555	1.25234	1.27492	1.28361	1.39722	1.46647	1.50443	32.11%	19.59%	19.59%
	11:30	1.61153	1.12782	1.56077	1.49429	1.39041	1.33375	1.34423	1.34533	1.44813	1.52378	1.56775	30.02%	17.24%	17.24%
	12:30	1.62234	1.12108	1.57465	1.50433	1.35162	1.3071	1.24336	1.21658	1.26618	1.23221	1.57871	30.90%	25.01%	19.43%
	13:30	1.73038	1.22099	1.59105	1.46903	1.24506	1.19368	1.13508	1.1498	1.1711	1.17528	1.59803	29.44%	34.40%	31.02%
	14:30	1.96824	1.45764	1.6098	1.40915	1.16704	1.1698	1.21576	1.2896	1.36036	1.36607	1.62317	25.94%	40.71%	40.57%
	15:30	2.13592	1.62427	1.58096	1.28599	1.15425	1.19964	1.32889	1.49117	1.45854	1.30241	1.58935	23.95%	45.96%	43.83%
	16:30	2.16716	1.65462	1.54726	1.18683	1.14219	1.24531	1.40637	1.54519	1.40263	1.2577	1.55066	23.65%	47.30%	42.54%
	17:30	1.99173	1.47843	1.51752	1.23778	1.10914	1.19745	1.32316	1.36354	1.25565	1.32918	1.5298	25.77%	44.31%	39.88%
	18:30	1.75139	1.27623	1.52057	1.43255	1.32953	1.2008	1.24603	1.2787	1.28232	1.48811	1.53047	27.13%	31.44%	31.44%
	19:30	0.48065	0.45322	0.34846	0.3418	0.34375	0.36205	0.3971	0.41929	0.3993	0.37007	0.35193	5.71%	28.89%	24.67%
	20:30	0.42268	0.40244	0.31195	0.30652	0.30827	0.32442	0.3539	0.37326	0.35666	0.3309	0.31496	4.79%	27.48%	23.25%
	Total	**22.29275**	**16.23248**	**19.18603**	**17.27647**	**15.58031**	**15.15245**	**15.74408**	**16.27145**	**16.81704**	**17.23679**	**19.29154**	**27.18%**	**33.98%**	**32.03%**
				Optimal Dynamic Slat Angle				**14.71758**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

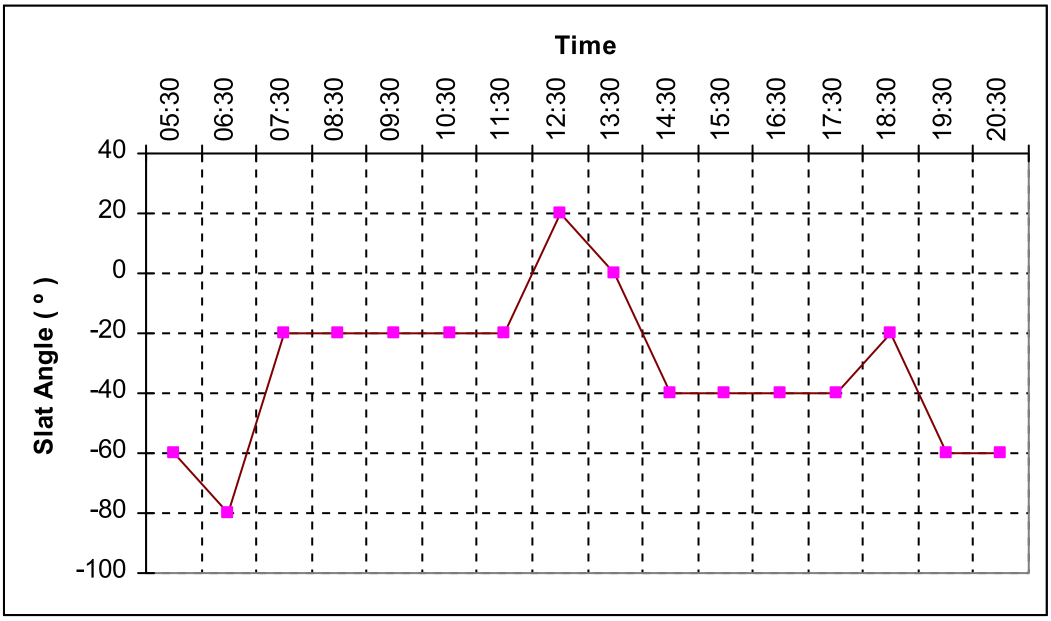

Figure E.3 Hourly energy consumption of all scenarios for the west oriented facade in 21 March from 5:30 to 20:30

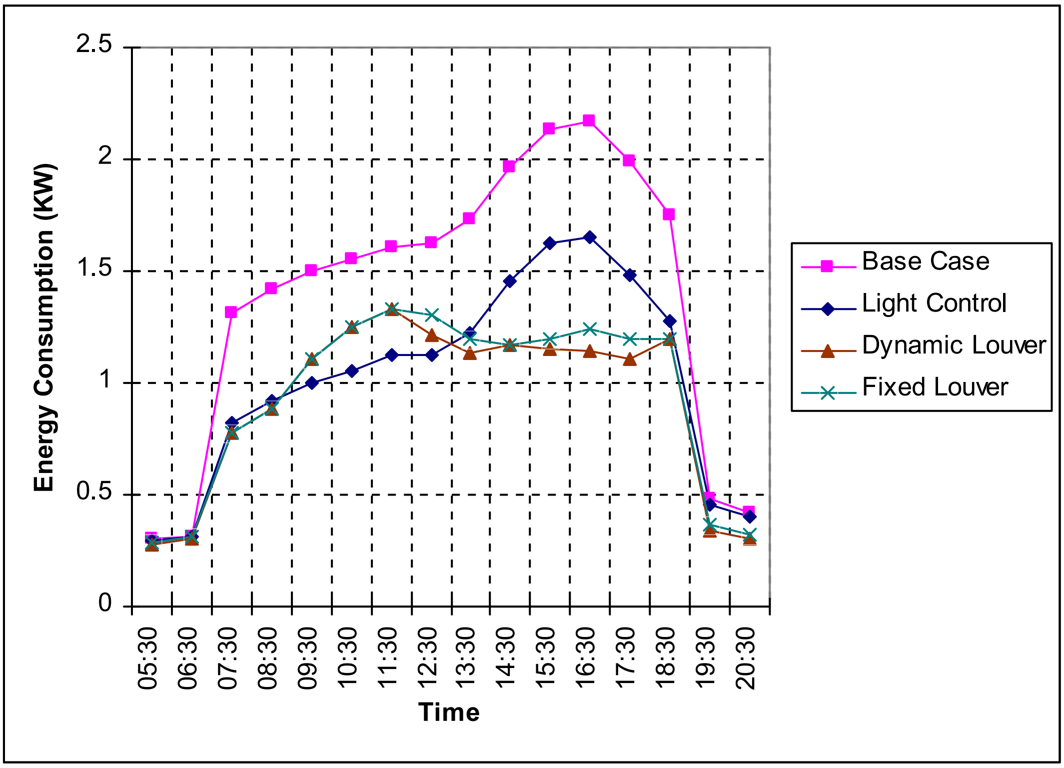

Figure E.4 Hourly energy consumption of all scenarios for the west oriented facade in 21 March from 5:30 to 20:30

Table E.3 Hourly energy consumption of the west oriented façade in 20 June from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

West-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80°	– 60°	– 40°	– 20°	0°	20°	40°	60°	80°	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (20°)
20 – JUNE	05:30	0.48715	0.48544	0.45004	0.45519	0.46359	0.47358	0.47266	0.46302	0.45532	0.451	0.44926	0.35%	7.78%	4.95%
	06:30	0.49749	0.49583	0.45073	0.45735	0.46649	0.47663	0.47607	0.46676	0.45872	0.45334	0.44988	0.33%	9.57%	6.18%
	07:30	1.71596	1.22905	1.63823	1.4879	1.32495	1.20219	1.20199	1.19291	1.30678	1.54822	1.64109	28.38%	22.79%	30.48%
	08:30	1.78713	1.29096	1.7133	1.56279	1.39668	1.26576	1.2656	1.25703	1.3954	1.62047	1.71856	27.76%	21.85%	29.66%
	09:30	1.82738	1.32773	1.76903	1.65517	1.50631	1.35482	1.37803	1.36256	1.51565	1.69756	1.77559	27.34%	17.57%	25.44%
	10:30	1.83107	1.32874	1.79141	1.69767	1.56462	1.45895	1.475	1.47122	1.60073	1.7383	1.79667	27.43%	14.55%	19.65%
	11:30	1.82958	1.32507	1.797	1.70753	1.56527	1.47926	1.47783	1.49259	1.63135	1.74743	1.8013	27.58%	14.45%	18.42%
	12:30	1.83732	1.331	1.79924	1.69813	1.51814	1.42036	1.39842	1.44089	1.61158	1.72135	1.80004	27.56%	17.37%	21.58%
	13:30	1.93935	1.4315	1.79529	1.64906	1.42105	1.40598	1.42269	1.40218	1.49406	1.66383	1.79453	26.19%	26.73%	27.70%
	14:30	2.1316	1.62246	1.776	1.53101	1.45867	1.53543	1.57967	1.49671	1.42872	1.5819	1.79341	23.89%	31.57%	29.78%
	15:30	2.27582	1.76557	1.75018	1.43087	1.52407	1.64621	1.66997	1.54438	1.44419	1.4866	1.78287	22.42%	33.03%	32.14%
	16:30	2.31277	1.80155	1.75301	1.44146	1.55154	1.68842	1.66583	1.53219	1.42954	1.45786	1.79016	22.10%	32.91%	33.75%
	17:30	2.21218	1.70012	1.78504	1.42792	1.51551	1.62105	1.57301	1.4739	1.40122	1.575	1.81402	23.15%	31.49%	33.37%
	18:30	2.01253	1.49974	1.77597	1.42481	1.40085	1.4511	1.42266	1.3886	1.44905	1.66023	1.79065	25.48%	27.90%	31.00%
	19:30	0.7106	0.68242	0.5996	0.60209	0.62366	0.65289	0.64493	0.616	0.59752	0.59392	0.59811	3.97%	12.23%	13.31%
	20:30	0.67031	0.65082	0.5827	0.58589	0.60404	0.6278	0.62303	0.59917	0.58265	0.57847	0.58148	2.91%	9.89%	10.61%
	Total	**26.07824**	**19.968**	**23.22677**	**20.81484**	**19.90544**	**19.76043**	**19.74739**	**19.20011**	**19.80248**	**21.57548**	**23.37762**	**23.43%**	**28.32%**	**26.37%**
				Optimal Dynamic Slat Angle				**18.69262**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

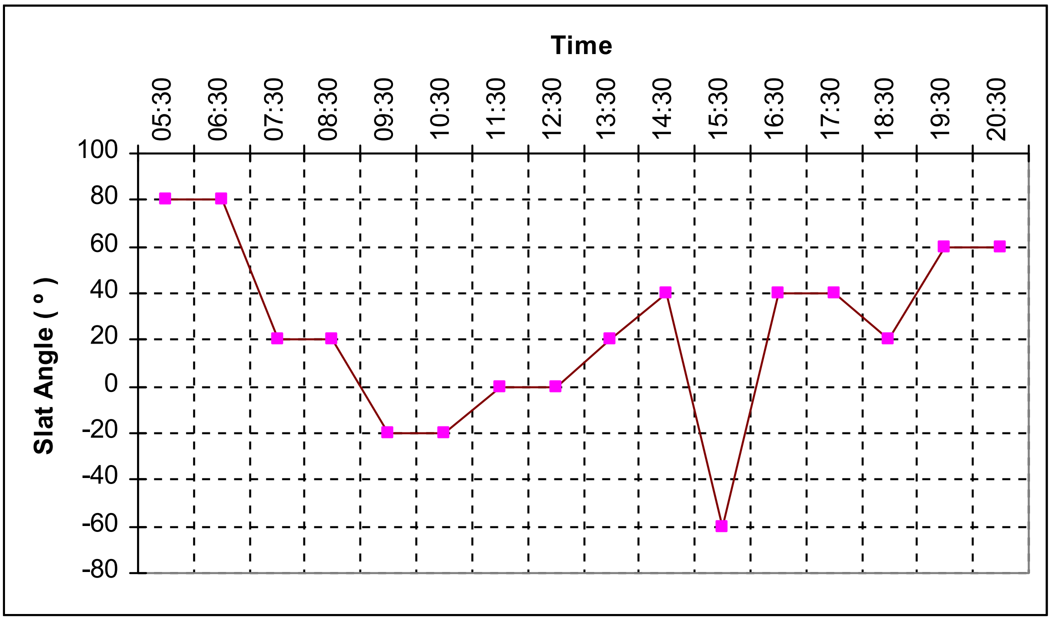

Figure E.5 Hourly energy consumption of all scenarios for the west oriented facade in 20 June from 5:30 to 20:30

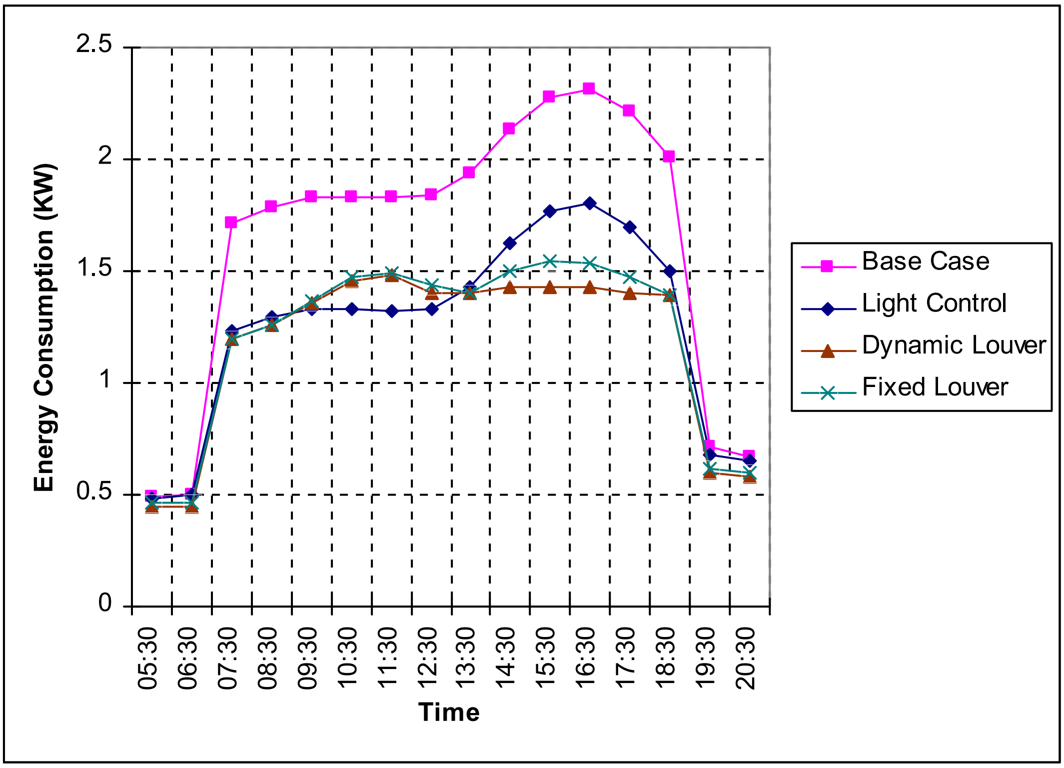

Figure E.6 Hourly energy consumption of all scenarios for the west oriented facade in 20 June from 5:30 to 20:30

Table E.4 Hourly energy consumption of the west oriented façade in 20 September from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

West-Façade															
Date	Time	E.C. of Base Case (KW)	With Light Control (KW)	Hourly Energy Cosumption of Louvers Case at fixed slat angle (KW)									% of Energy Saving Over Base Case		
				– 80º	– 60º	– 40º	– 20º	0º	20º	40º	60º	80º	With Light Control	Optimal Dynamic Louver Slat Angle	Optimal Fixed Louver Slat Angle (-20º)
20 – SEPTEMBER	05:30	0.45949	0.45298	0.42912	0.42794	0.42874	0.43297	0.44059	0.44471	0.44024	0.43411	0.42975	1.42%	6.87%	5.77%
	06:30	0.45828	0.45225	0.42118	0.42142	0.4231	0.42763	0.43494	0.43864	0.43388	0.42717	0.42169	1.32%	8.10%	6.69%
	07:30	1.64741	1.15652	1.57618	1.4315	1.25505	1.12283	1.13219	1.13408	1.28642	1.49007	1.58658	29.80%	31.84%	31.84%
	08:30	1.70214	1.20234	1.62907	1.47574	1.29162	1.16657	1.17352	1.17637	1.35946	1.53318	1.63502	29.36%	31.46%	31.46%
	09:30	1.75984	1.25684	1.69909	1.5852	1.43002	1.2768	1.29965	1.30824	1.5025	1.6276	1.70178	28.58%	27.45%	27.45%
	10:30	1.80362	1.29815	1.75761	1.67234	1.55115	1.44988	1.45219	1.46892	1.59569	1.70795	1.76125	28.03%	19.61%	19.61%
	11:30	1.82887	1.3214	1.7932	1.71668	1.59935	1.51035	1.50628	1.51226	1.61768	1.7468	1.79971	27.75%	17.64%	17.42%
	12:30	1.86107	1.35192	1.8118	1.71113	1.52364	1.40385	1.37177	1.36953	1.41734	1.67519	1.81822	27.36%	26.41%	24.57%
	13:30	1.98884	1.47829	1.81164	1.64467	1.3759	1.3551	1.36867	1.39505	1.41938	1.61159	1.82333	25.67%	31.86%	31.86%
	14:30	2.15563	1.64395	1.34261	1.34373	1.34138	1.36734	1.4312	1.53331	1.54846	1.44825	1.3533	23.74%	37.77%	36.57%
	15:30	2.23804	1.72538	1.3033	1.30856	1.32717	1.40271	1.52249	1.62822	1.52988	1.407	1.31062	22.91%	41.77%	37.32%
	16:30	2.19193	1.67842	1.6913	1.29929	1.33904	1.42201	1.53607	1.56454	1.46042	1.3921	1.71859	23.43%	40.72%	35.13%
	17:30	2.03979	1.52555	1.74379	1.45421	1.34174	1.37771	1.44476	1.43809	1.38222	1.34894	1.75609	25.21%	34.22%	32.46%
	18:30	1.90681	1.47684	1.7649	1.68294	1.60777	1.46228	1.48934	1.51876	1.58265	1.69405	1.77017	22.55%	23.31%	23.31%
	19:30	0.69412	0.66738	0.59892	0.59488	0.59752	0.60905	0.63086	0.63991	0.62653	0.61009	0.60063	3.85%	14.30%	12.26%
	20:30	0.63709	0.61636	0.55661	0.55342	0.55572	0.56602	0.58446	0.59258	0.5811	0.56669	0.55808	3.25%	13.13%	11.16%
	Total	**25.37297**	**19.30457**	**21.93032**	**20.32365**	**18.98891**	**18.3531**	**18.81898**	**19.16321**	**19.78385**	**20.72078**	**22.04481**	**23.92%**	**29.09%**	**27.67%**
				Optimal Dynamic Slat Angle				**17.9924**							

Optimal Energy Consumption Case

Optimal Dynamic Slat Angle

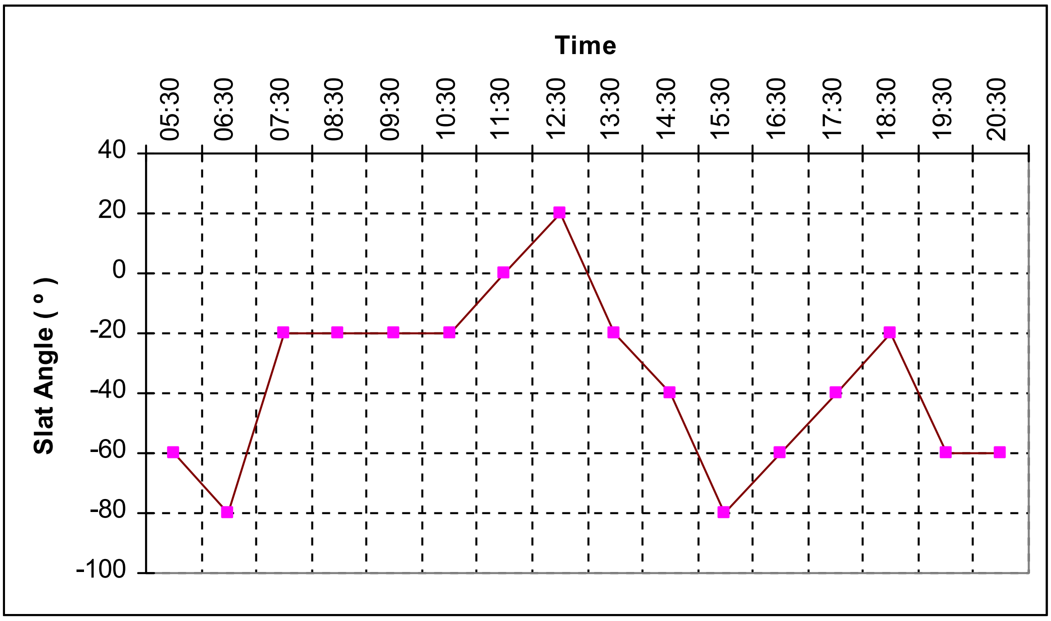

Figure E.7 Hourly energy consumption of all scenarios for the west oriented facade in 20 September from 5:30 to 20:30

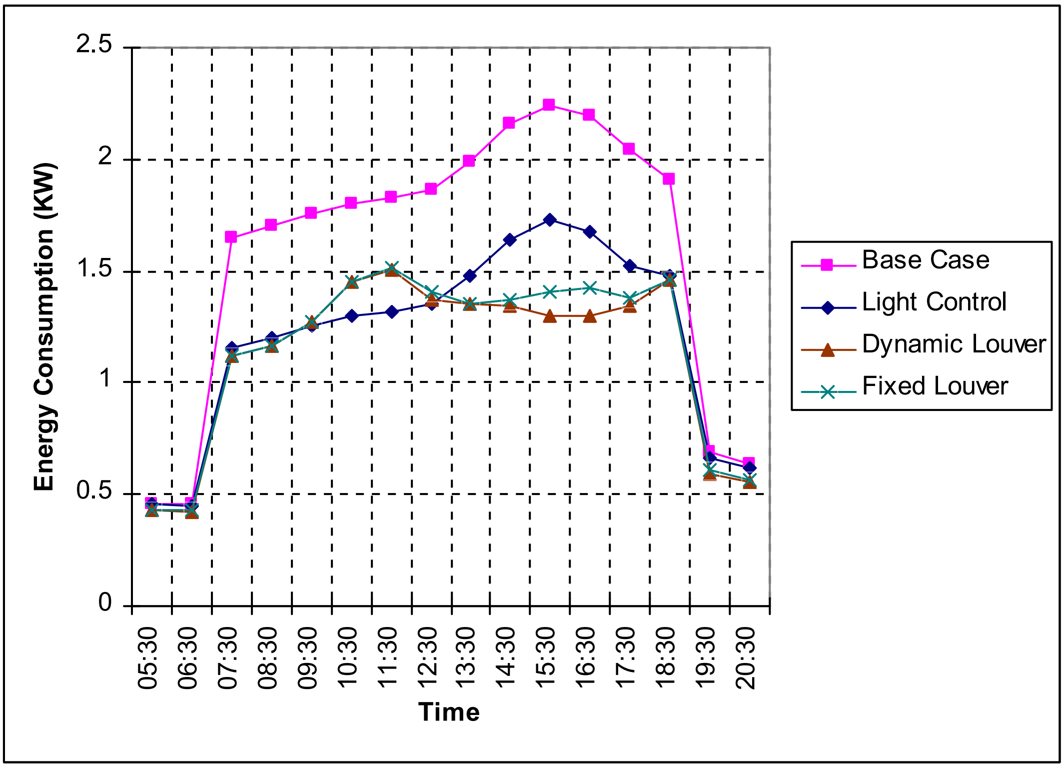

Figure E.8 Hourly energy consumption of all scenarios for the west oriented facade in 20 September from 5:30 to 20:30

Table E.5 Summary of energy savings of the west oriented façade in the four selected days from 5:30 to 20:30 (Shading coefficient 0.41, lighting sensor @ 2 meters)

Summary of Energy savings of West Façade Simulations (Shading Coefficient = 0.41 & sensor distance = 2m) (KW)												
Date & Time	Base case	Lighting Congtrol	Dynamic louver	Louver Angle								
				-80º	-60º	-40º	-20º	0º	20º	40º	60º	80º
20 Dec (5:30 - 20:30)	20.6882	15.14066	14.4067	18.5558	16.87133	16.12276	15.239	15.08533	15.13012	16.31745	17.92755	18.62417
21 March (5:30 - 20:30)	22.29275	16.23248	14.71758	19.14453	17.01213	16.99315	16.83212	16.39446	15.81344	16.32302	17.76003	19.14594
20 June (5:30 - 20:30)	26.07824	19.968	18.69262	23.30161	21.06093	19.8776	19.41435	20.17518	20.29173	20.90219	21.77971	23.43945
20 Sept (5:30 - 20:30)	25.37297	19.30457	17.9924	22.71384	20.30609	19.7482	19.22858	19.07925	18.67284	19.56119	21.28281	22.86615
Total	94.43216	70.64571	65.8093	83.71578	75.25048	72.74171	70.71405	70.73422	69.90813	73.10385	78.7501	84.07571
Percentage of Total energy saving over the Base case		**25.19%**	**30.31%**	**11.35%**	**20.31%**	**22.97%**	**25.12%**	**25.10%**	**25.97%**	**22.59%**	**16.61%**	**10.97%**

Appendix F

Economic Analysis

Table F.1 Average energy consumption calculation of a typical weekday

	Base case	**Light control**	**Fixed Louvers (-20°)**	**Dynamic louvers**
System and equipment energy consumption of the four design days (daytime)	79.1	71.754	64.584	61.799
System and equipment energy consumption of the four design days (nighttime)	13.006	13.006	13.006	13.006
Percentage of system & equipment energy compared to base case	-	92.0%	84.2%	81.2%
Lighting energy consumption of the four design days (daytime)	16.896	0.817	1.306	1.246
Lighting energy consumption of the four design days (nighttime)	0	0	0	0
Percentage of lighting energy consumption compared to the base case	-	4.8%	7.7%	7.4%

Table F.2 Average energy consumption calculation of a typical full week

	Base case	**Light control**	**Fixed Louvers (-20°)**	**Dynamic louvers**
Average system and equipment energy consumption in 5 weekdays (KWh)	115.1325	105.95	96.9875	93.50625
Average system and equipment energy consumption in 2 weekend days (KWh)	25.94375	25.94375	25.94375	25.94375
Total system & equipment energy consumption for a typical full week (KWh)	141.07625	131.89375	122.93125	119.45
Pecentage of system and equipment energy consumption compared to the base case	-	93.5%	87.1%	84.7%
Average lighting energy consumption for weakdays (KWh)	21.12	1.02125	1.6325	1.5575
Average lighting energy consumption in weakends (KWh)	0	0	0	0
Total lighting energy consumption of a typical full week (KWh)	21.12	1.02125	1.6325	1.5575
Pecentage of lighting energy consumption compared to the base case	-	4.8%	7.7%	7.4%

Table F.3 Annual energy consumption calculation

	Base case	**Light control**	**Fixed Louvers (-20°)**	**Dynamic louvers**
Annual system and equipment energy consumption (KWh)	7337.3	6859.72	6393.59	6212.53
Annual lighting energy consumption (KWh)	1098.2	53.10	84.89	80.99
Total energy Consumption (KWh)	**8435.5**	**6912.83**	**6478.48**	**6293.52**

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QUOTATION

TO: **WS Atkins**

ATTN: **Fawwaz Hammad**

PROJECT		**REF**	GST/210110/R0
DATE	21/1/2010	**PAGE**	1 OF 1

SYSTEM	Lighting Control System	**CURRENCY**	AED
DELIVERY	4-6 Weeks	**WARRANTY**	One Year
PAYMENT	30 Days PDC	**VALIDITY**	30 Days

ITEM	QYT	MODEL	DESCRIPTION	UNIT PRICE	AREA COVERING	COST PER AREA
1	1	DUS804C	PRESENCE AND LUX DETECTOR	800	1.00	800.00
2	1	DDBC 320 DALI	3 CHANNEL DALI DIMMING	3600	48.00	75
3	1	DDMC 802	8 CHANNEL MULTIPURPOSE CONTROOLER	2400	8.00	300
4	1	DDCM 102	BLIND CONTROL CARD	400	1.00	400
5	1	DDRC1220-FR	12 CHANNEL RELAY CONTROLLER	3600	12.00	300
TOTAL						1,875.00

* FOR SWITCHITNG ON AND OFF USE 1+5
* FOR DIIMING ONLY USE 1+2
* FOR DIMMING AND BLIND CONTROL USE 1+2+3+4

We look forward to your immediate response.
Best regards

Mohammad Abdulqader
Project Engineer

Figure F.1 Quotation obtained for the cost of lighting and blind controls