474: Lighting and Thermal Performance of Innovative Shading Devices: New Insights into their Aesthetics and Control in a Mediterranean Climate.

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Abstract With a view towards minimising energy demand for cooling and artificial lighting in buildings, this paper evaluates innovative shading devices and how they can balance a generous degree of control mastering seasonal natural light with thermal gains in a typical Mediterranean climate such as Malta. The study evaluates the potential success (or failure) of such shading devices, from both their aesthetic and functional perspectives, as part of a passive design strategy adopted by the architect. Through environmental design and solar geometry, experimental simulations were generated in architectural science modelling software package Ecotect© developed by Andrew Marsh. Moreover a novel computer model termed Solar Control© was developed by the authors in order to assist architects at an early stage during design.

Keywords: energy, comfort, solar gains, natural lighting, shading devices, orientation.

1. Introduction

In architectural design openings satisfy two major physiological and psychological needs: they permit the entry of natural light and ventilation while creating a visual link with the exterior. Daylight brings about a sense of respite and well being influencing people's mood. However visual comfort is only achieved when the perceptive facilities of the human brain can operate without distractions. Incorrect distribution of light intensity, glare and poor colour matching inhibit perception. Moreover interesting external views provide a considerable psychological benefit to the occupiers.

Effective solar and daylight control measures are usually introduced within the exterior skin of the architectural fabric. The building skin has a foremost role as the transition space between the inside and the outside and while offering protection from various weather elements, it also transmits a design message. Aesthetic and cultural functions of a façade are just as important. Thus the actual skin could be an aesthetic and cultural transmitter, as well as an environmental statement often verifying a building's basic use. The glazed area, position of openings and the degree of control over lighting and thermal gains within a building are therefore synonymous to its success. On a more humane scale, equally important are comfort levels, both visual and thermal. Hence the need for solar control over glazed openings.

2. Aims of the Study

Through environmental design and solar geometry, experimental simulations were generated using software modelling. An Ecotect© lighting and thermal simulation package[i] was used. Separately, a novel computer program was developed by Herman Calleja, running on a customised Microsoft Excel©, including graphical representation of output results. Results were assessed and analysed on three case studies.

The study further evaluates the potential success (or failure) of shading devices, typically designed through gut feeling or experience only, from both their aesthetic and functional perspectives, as part of a passive design strategy adopted by the architect.

3. Climate Overview

Malta, located at latitude 35"52'N experiences a typical Mediterranean high insolation exposure with a solar altitude at 79°C above the horizon in summer on 21 June and a winter low altitude sun at 31°C in winter on 21 December[ii].

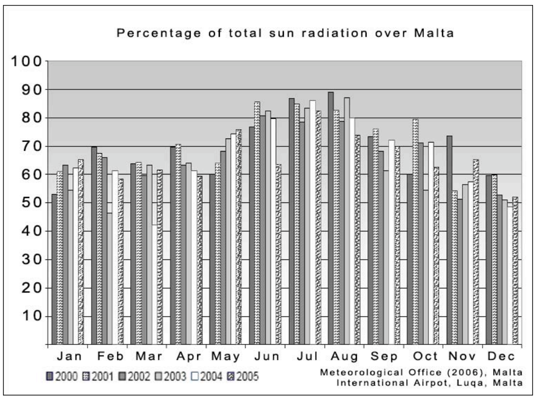

Fig 1.Percentage of total sun radiation over Malta

Solar radiation is very intense during the summer period especially since minimal cloud cover is experienced, if any. However in winter although the direct sunlight availability is reduced due to a higher cloud cover, a high amount of diffused radiation is present. Subsequently winter diffused light combined with a low altitude sun may be a persistent source of glare.

4. Methodology

Three local case studies were selected and analysed using *Ecotect©* illustrating daylighting indices, illuminance levels, insolation levels, diurnal and seasonal shading patterns. Various leading software packages available in the field of solar control were compared. *Doe-2* and *Energy10* were reviewed as very accurate but produce a limited visual representation. *EnergyPlus* obliges input and output values in an ASCII format thus requiring a supporting platform. Finally *Ecotect©* was chosen in order to analyse the case studies namely due to the accurate calculations it produces while being very user friendly and generating high quality illustrations. The fine merger of these three benefits makes *Ecotect©* a very useful and widespread architectural design tool.

During the study *Solar Control*, a Microsoft Excel© built-in program, was designed as a tool to assist architects at an early design stage. The program only requires the user to input a few parameters, namely orientation and dimensions of a rectangular window and its overhang, the site latitude and longitude, the time of use and the glazing type being used. *Solar Control* works out a complex graph representing the shadow pattern and calculates the shaded area in order to produce the values required to run further program equations. The program further calculates the heat transmitted through the glass due to temperature differences, as well as direct and diffused solar radiation.

Using mathematical geometry *Solar Control* calculates the angle of incidence of the sun starting from standard declination angle and altitude derivation equations. The Declination being calculated as follows:

$$Dec = 23.45*\sin[(Julian\ Day+284)*360/365]$$ [iii][1]

The Solar Constant: the intensity of extraterrestrial solar radiation I_{Sn} is considered as a constant of 1353Wm^{-2}. [iv] While the intensity of direct solar radiation on a surface normal to the solar beam, I_{Dn}, is then calculated as

$$I_{Dn} = I_{Sn} * T_{D}.m$$ [v][2]

where T_D is the atmospheric transmissivity factor and m being a correction factor[vi]. The intensity of direct solar radiation on a vertical plane, I_{Dv}, is calculated by:

$$I_{Dv} = I_{Dn} *\cos(HSA)*\cos(Alt)$$ [vii][3]

where *H* is the Horizontal Shadow Angle and *Alt* is the Altitude. The diffused solar radiation on a vertical plane, I_{dv}, is calculated by:

$$I_{dv} = (0.2710 - 0.2939\ T_D)*I_{Sn}*\cos(Alt)$$ [viii][4]

Heat gained through temperature difference:

$$Qc= UA(To-Ti)$$ [5]

Heat gained due to Direct and Diffused solar radiation:

$$Qt= (I_{Dv}\ A_S\ \lambda_1 + I_{dv}\ A\ \lambda_2)$$ [ix][6]

Where U is the air to air thermal transmittance of the glass surface;
A is the total area of glass surface;
A_S is the total area of glass under direct sunlight;
To is the outside air temperature;
Ti is the inside air temperature.
λ_1 is the transmissivity of glass for direct solar radiation.
λ_2 is the transmissivity of glass for diffused solar radiation. The value assumed was 0.70W/m^{2}K.
The program allows the user to get both visual observations of the shading pattern for a given shading device and numeric values of how much an opening would be exposed hence giving cooling load requirements indications for any environmental control system.

5. Case Studies

From a set of six, three domestic local case studies were short listed. These were run through *Ecotect©* and analysed. The case studies provided solar control, exploiting different approaches: traditional means, tradition re-interpretation, and the application of a new architectural language respectively, namely;

1. A traditional structural vaulted roof in a private villa (incorporating light shafts);
2. A reinterpretation of the Maltese traditional horizontal louvers (*persjani*) as a façade concept for a development of eight interlocking apartments;
3. A fragmented innovative concrete shading screen in a seaward housing development.

In the projects analysed, digital and physical models were utilised during the design process in order to simulate the shading patterns expected. On the other hand, various solar control applications in the projects were also the result of the respective architects' intuition *without* any shading calculations. The results obtained were very close to what the architect expected. However deficiencies did occur; shortcomings could have been anticipated if a basic solar and daylight analysis tool was utilized during the early design stage. Deficiencies included overexposed areas, gloomy (poorly lit) corners, glare and maintenance access.

6. Results

In the first case study, the vaulted structure proved to be very well lit with the exception of having overexposed areas with spots in excess of 4000W/h of insolation during the summer period, while in a particular habitable room the natural lighting level was below 300Lux during daytime, this being below the CIBSE code.[x]

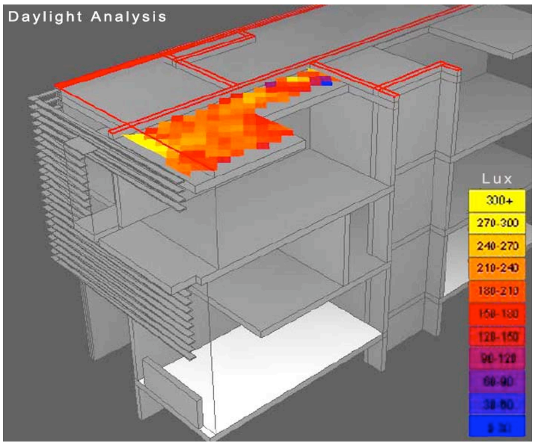

Fig 2. Lighting Analysis of louvered apartments

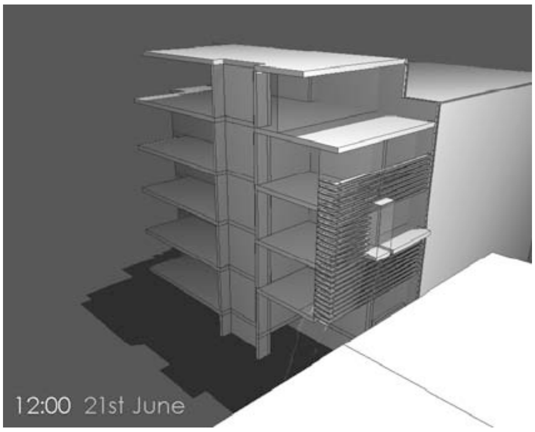

Fig 3. A Figure of the summer shading analysis

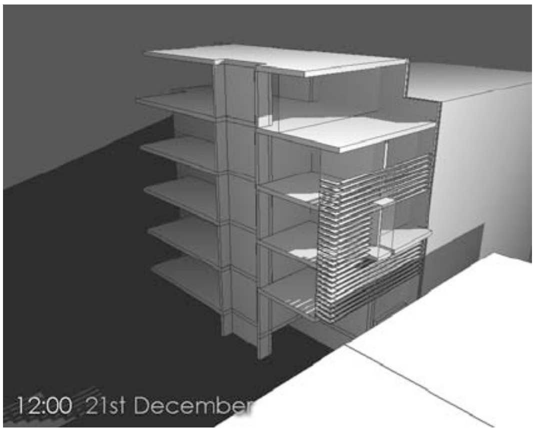

Fig 4. A Figure of the winter shading analysis

Computer modelling substantiated the effectiveness of the deep louvered façade as a means of solar control at the top levels while permitting the entry of the low winter sun. However digital simulation of the louvered apartments, situated in a relatively contained urbanistic environment, predicted low average daylight levels at the lowest two storeys. Some frontal spaces achieved an average natural illuminance of 250lux, deemed unsatisfactory[xi].

For the third case study, a south-facing, seaward housing development, various studies were carried out during design stage including both physical modelling and shadow studies. Wide overhanging balconies in conjunction with the fragmented screen (inspired by Paul Rudolph's Florida houses) proved to be a very effective solar control design though glare problems could arise due to over exposure in some areas. However some smaller apartments achieved lower lighting levels, as they enjoyed less glazed frontal area.

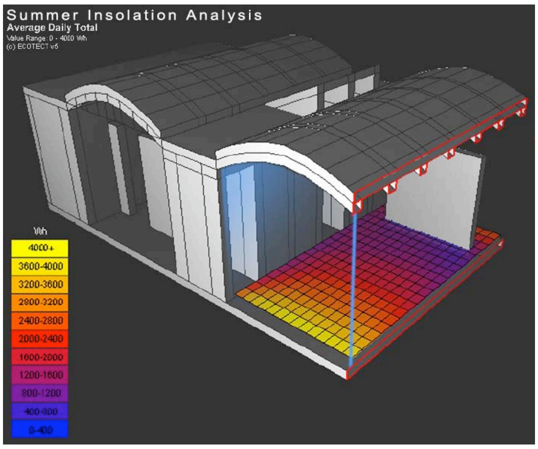

Fig 5. Summer Insolation within the vaulted villa

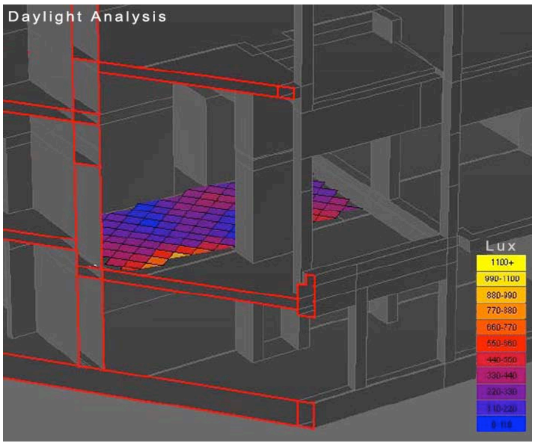

Fig 6. Lighting Analysis of the apartments clad with a concrete fragmented screen

7. Findings

The study underlines the importance of site orientation for known solar exposures with respect to seasonal changes with time and its influence on the indoor environment. The first measure of control is at an urban design scale. The urban armature defines the orientation of most buildings and may influence the composition of a building. The massing, the construction method and the materials selected also influence the solar performance of practically any edifice.

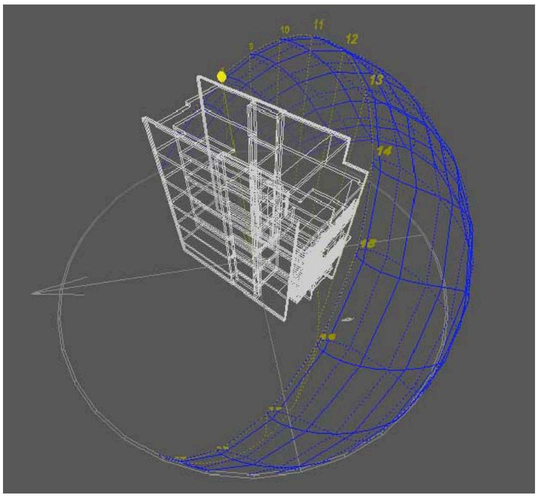

Fig 7. Local Sun trajectory studied monthly

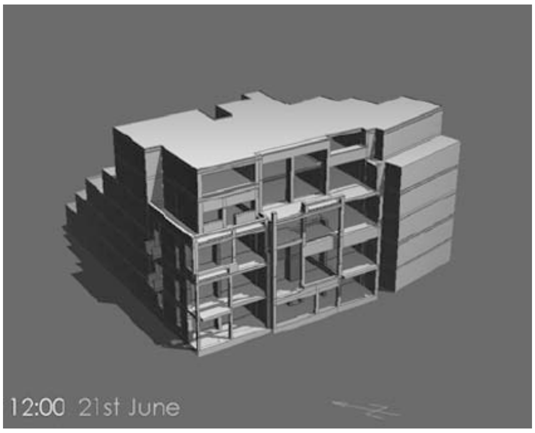

Fig 8. A Figure of the Summer shading analysis of the concrete screen shaded apartments

Fig 9. A Figure of the Winter shading analysis illustrating the shallow winter sun in Malta

South facing facades tend to be very prone to overheating in summer due to the high levels of insolation. The traditional thick building fabric and the use of high internal spaces used to offer a high amount of thermal mass buffer. However nowadays due to ever decreasing land availability and the site-size limitations thinner and lighter methods of construction are being applied. However some other efficient traditions are still being applied or re-interpreted as is the case of the horizontally-louver (‘*persjana’)* and loggias.

Horizontal louvers (fixed) and projecting terraces performing as overhangs are two minimalistic re-interpretations of the traditional *persjana* and loggia (portico) respectively. Having a high noon sun angle of 78.63° on the summer solstice and a very low noon winter solstice angle of 31.36° makes horizontal shading a very effective solar control, obstructing overhead direct sunlight in summer, while permitting the entry of the shallow sun in winter.

Moreover after several experiments it was shown that an effective pitch between a series of horizontal louvers should not be more than 0.9 x louver width. However in order to achieve a better performance in August and due to the fact that high temperatures are starting earlier in spring 0.7 x louver width gives a much better performance without compromising the daylight levels and the entry of the winter sun.

Fig 10. The seaward concrete screen during construction

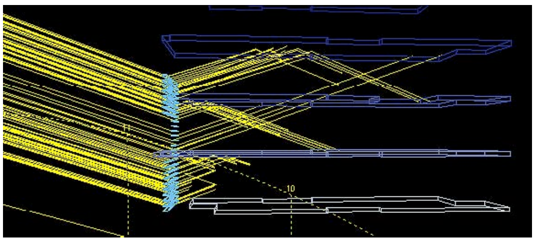

Fig 11. A Figure depicting the study of advanced lighting reflection using Ecotect©

8. Discussion

As shown in the results of the case studies obtained through computer modelling, the façade performance could be very close to what the architect expected without prior digital modelling. However deficiencies that could have been avoided did indeed occur. This further proves the need of computer assistance and simulation as a concept is being developed.

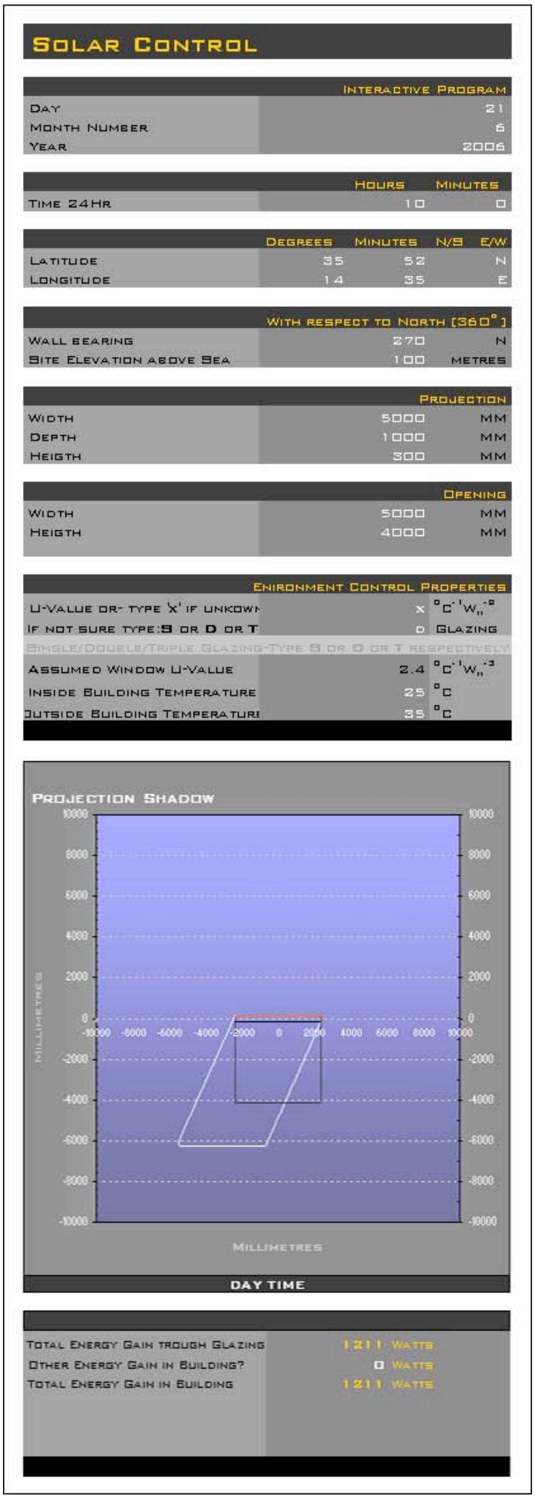

Fig 10. A User Screen shot of Solar Control©

A real-time assistance package such as the program developed during the study, *Solar Control*, provides the possibility to test out various design options with a minimal time consuming methodology.

The use of digital modelling and simulation is a fairly widespread issue in the field of solar control. Software is in a state of rapidly ongoing development and improvement. Today leading light design offices rely mostly on special software packages in order to create the desired solar control and natural light penetration pattern. In some cases highly advanced offices even create their own software packages or plug-ins. Major architectural firms incorporate or work collectively with multidisciplinary teams which offer expertise in the field of natural lighting. A highly successful team illustrating this upcoming trend is the team at Buro Happold in the U.K. which was visited during the research. The practice composed of different bodies as the LiT, specializing on daylighting and the CoSA, dedicated to solar control systems offer combined consultancy to leading architectural firms.

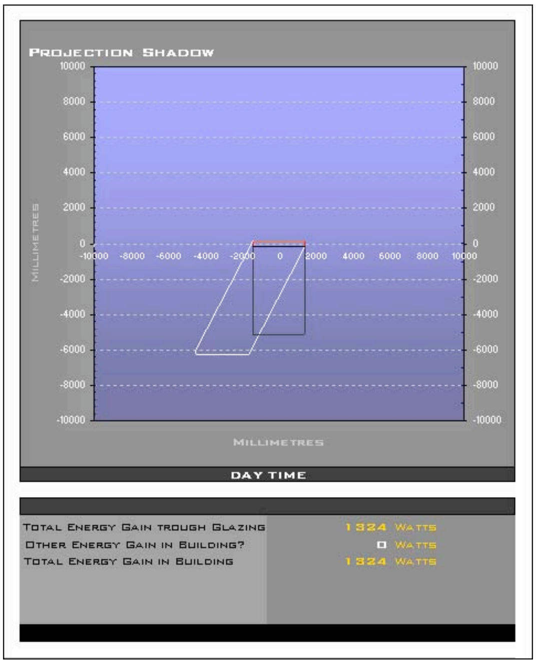

Fig 10. Instant shadow mask rendering as one adjusts the dimensions and properties of an opening and its respective shading system in Solar Control©

9. Application and Limitations

Presently the program is applicable only for rectangular openings within a vertical plane however this is the most typical case for standard glazed openings. Considering the high summer altitude in the context of a Mediterranean Climate horizontal shading devices prove to be a very successful means of solar control and hence the relevance of the program.

10. Conclusions

One of the essential findings of running *Solar Control* is that for horizontal fixed louvers, pitch needs to be between 0.7-0.9 x louver width. Although this may prove to be a simple rule of thumb, experimentation can never be overemphasised in design.

Giving a basic visual representation of shading masks the program is ideal for multiple trials and error tests,; this is most beneficial for early design stages. The program is set in a very user-friendly Microsoft Excel© environment without the need of inputting any technical drawings. No special training is required and is hence ideal for mature established architects and first time users, including students. Furthermore all the calculation process is available and accessible within a parallel running spreadsheet. The steps are very well documented within the program making the project an open source package, promoting further research and open to new additions.

11. Scope for Further Research

Though the mathematical backbone to calculate the solar shading geometry has been developed, the software is still in its pilot stage. The software is to be developed to include vertical and irregular shading devices, openings within a tilting envelope, internal space volume, lux levels, and to handle more complex geometries. The program might be even re-scripted and transposed to parametric design software, such as Bentley© Generative Components© whereas further geometries could be explored through scripting procedures.

Moreover as new technologies are widening the availability of construction options while digital architecture is also leading to further geometry exploration, it is of utmost importance that the progression during design stage is simultaneous with the process of solar gain analysis. Thus the use of parametric software within the field of thermal simulation, and solar and lighting control could be a very powerful link that needs to be explored further. A successful experiment[xii] within the same field has been undertaken by Kaustuv De Biswas who successfully linked the upcoming mentioned parametric design software, Generative Components©, with Ecotect©.

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[x] CIBSE Code for Interior Lighting (1994).
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[xii] http://www.smartgeometry2008.com/