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A study of the performance of different shading devices in a Southern European Office building

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Abstract
This paper investigates the performance of different shading systems on AVAX Headquarters in Athens. The study consists of two approaches: survey work and environmental modelling. The first one reveals the occupants' preferences for the system, and the simulation displays the quantitative attributes regarding energy demand, occupants' dissatisfaction and daylight factors in different scenarios. The results indicate that the installation of solar shading reduces significantly energy consumption and occupants' dissatisfaction. Adaptive systems reduce further both energy demand and dissatisfaction. The systems' effectiveness in relation to predicted energy consumption and user's response is analysed. In addition, the role of environmental modelling and survey work in architectural design is discussed.

Keywords: solar shading, adaptive, comfort, energy, office

1. Introduction
The main challenge for building designers in the 21st century is the design of low-energy buildings, without reducing comfort. Especially in workplaces, good indoor quality is essential for maximizing employees' productivity (Andreadaki, 2006). Office buildings are responsible for about 2.2 million tonnes of CO_2 per year (Ratcliffe et al, n.d.). As space conditioning and lighting are the most energy intensive systems, the most effective approach to limit CO_2 emissions and maintain comfort, is to reduce solar gains (Simonella et al, 2010). Considering these aspects, the main objective of this study is to explore the performance of adaptive shading systems in offices. The term 'adaptive' is used for both manually and automatically controlled systems.

2. Analysis of the methodology
The study is focused on AVAX Headquarters, a renowned office building in Athens, especially for its adaptive shading system. A conversation with the designers, Tombazis Architects, revealed the current failure of solar shading due to lack of maintenance. Thereafter, the study followed two approaches: the fieldwork and the environmental modelling. The first one displays the qualitative characteristics, whereas the second one reveals the quantitative attributes of the shading devices.

3. AVAX Headquarters
The building (Fig. 1) was constructed in 1998 for the company AVAX S.A. Since 2005, it has hosted a department of the Greek Ministry of Development. The building is located in central Athens (Fig. 2). It has an open view towards the east. The west elevation is shaded by neighbouring buildings, while narrow sides touch adjoining buildings. The gross area of 3050m^2 is distributed on three basement levels, ground floor, and five office floors. The main spaces are situated along the glazed east facade and are separated from the secondary areas by a circulation area.

The solar fins in the east elevation are vertical silk screen printed glass panels. They were designed to be automatically controlled by the BMS and rotated in response to solar radiation. The building envelope consists of fairfaced bricks and enamel coated metal panels. All windows have insulated aluminium frames, are 1.70m high, manually openable, double-glazed with a U-value of 2.8W/m^{2}K.

Figure 1: AVAX Headquarters.

Figure 4.2: AVAX Headquarters in the dense urban fabric of Athens city centre (Google maps, 2013).

4.1 Fieldwork

The building hosts fifty employees. Half of them answered in the provided questionnaires. Working hours are flexible and range from 07:00 to 20:00. Most of the employees work between 09:00-17:00. All of them believe that their productivity would be improved if solar shading was operated properly. Today, they are forced to rotate the fins manually. As an employee states: 'The idea of an adaptive shading system is potentially very good. However, today many problems have arisen due to the fact that it is not working'. 55% of the occupants would prefer to manually control solar shading compared to 45% that would prefer an adaptive system, controlled by the BMS. Finally, it is worth mentioning that most of the occupants find the characterisation of the building as sustainable an oxymoron, as its functions are based on electromechanical equipment.

4.2 Simulation strategy

IES<VE> is used for environmental modelling. The whole building is tested in two cases: 1. no solar shading, 2. fixed solar shading (Fig. 3). The width of solar fins is 30cm and the distance between them is 35cm. For facilitating the process, the angle of slats with respect to the wall of the east facade is in the range of 15°-90°, with increments of 15° (Fig. 4). The results are compared in terms of energy consumption and occupants' dissatisfaction for determining the optimum angle. Thereafter, the office with the highest solar gains, is chosen for evaluating the performance of adaptive solar shading. The 21st day of March, June, September, and December are chosen as representative of extreme and average sky conditions. The following scenarios are tested:

1. no shading,
2. optimum fixed solar shading,
3. automatically adaptive shading system in response to sun position, and
4. manually adaptive shading system in response to occupants' expectations.

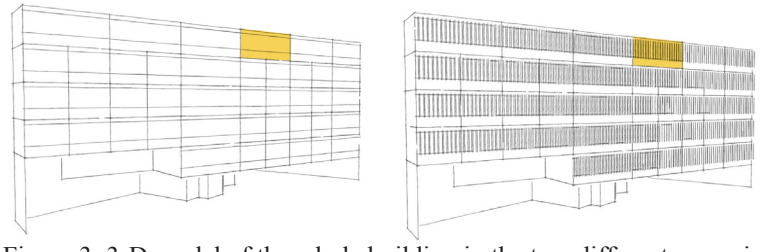

Figure 3: 3-D model of the whole building in the two different scenarios. Office with the highest solar gains 5.3 is depicted with yellow colour.

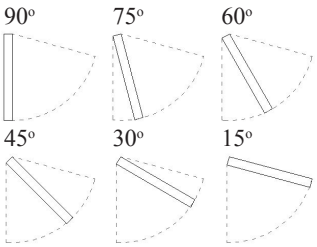

Figure 4: The possible angle of slats.

The adaptive behaviour in the third scenario is based on the solar geometry in Athens (Table 1) and in the fourth scenario on the hypothesis that the shading device is controlled by an employee who is sitting one metre away from the window (Table 2). Obviously, the manual control may be different than the proposed one in this particular scenario.

Table 1: The angle of the solar fins when solar shading is automatically adaptive.

time	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30
March	15°	30°	45°	60°	75°	90°	90°	90°	90°	90°	90°	90°	90°
June	15°	15°	15°	30°	60°	90°	90°	90°	90°	90°	90°	90°	90°
September	15°	30°	45°	60°	75°	90°	90°	90°	90°	90°	90°	90°	90°
December	45°	45°	60°	75°	90°	90°	90°	90°	90°	90°	90°	90°	90°

Table 2: The angle of the solar fins when solar shading is manually adaptive.

time	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30
March	45°	45°	45°	45°	90°	90°	90°	90°	90°	90°	90°	90°	90°
June	30°	30°	30°	30°	90°	90°	90°	90°	90°	90°	90°	90°	90°
September	45°	45°	45°	45°	90°	90°	90°	90°	90°	90°	90°	90°	90°
December	90°	90°	90°	90°	90°	90°	90°	90°	90°	90°	90°	90°	90°

4.3 Analysis model

The building is modelled with some degree of simplification. It consists of the ground floor and five office floors. The CIBSE guidelines are taken as a good practice indication of comfort. The tested office is part of the general model. It has one external wall, facing east. It is 7.20m wide, 4.00m deep and the floor-to-ceiling height is 3.00m. The input data are based on the information gathered in the field work. The office is occupied by two people. Fluorescent lamps are used, which are switched on when daylight illuminance is less than 300 lux. The heating set point temperature is 19°C and the cooling set point temperature is 24°C.

4.4 Design testing and analysis_whole building

The results for the whole building throughout the year, in terms of occupants' dissatisfaction and energy consumption for heating, cooling, and artificial lighting are shown in Table 3. The use of solar shading reduces both total energy consumption and dissatisfaction. The most beneficial shading system is the one that the vertical fins are rotated by 15°. Compared to the first scenario, the optimum system reduces energy consumption by 5.34% and dissatisfaction by 31.73% (Fig. 5). The reduction in energy is not as significant as the decrease in dissatisfaction, because even though there is a reduction in cooling loads, heating and lighting loads are increased.

Table 3: The results of the different scenarios in terms of energy consumption and occupants' dissatisfaction.

Scenario	Energy consumption (MWh)				Occupants dissatisfaction (%)
	Heating load	Cooling load	Lighting gain	Total	
Scenario 1: No shading	10.2	88.1	17	206.1	38.36
Scenario 2: Fixed shading					
1. 15°	12.6	78.6	20.6	195.1	26.19
2. 30°	12.3	79.5	20.6	195.9	27.22
3. 45°	12	80.5	20.4	197.2	28.61
4. 60°	11.8	81.8	20.1	198.7	30.56
5. 75°	11.6	83.2	19.5	200.6	32.98
6. 90°	11.3	84.2	19.2	201.8	34.45

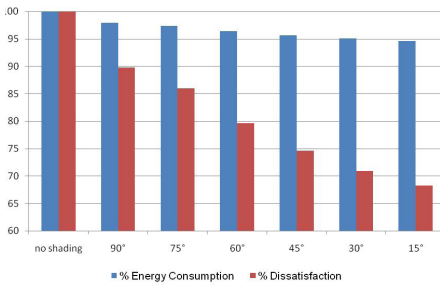

Figure 5: Energy consumption and dissatisfaction expressed as percentage of their maximum values.

4.4 Design testing and analysis_office

The simulation results for the tested office are summarised in Table 4.

Table 4: The results of the different scenarios in terms of energy consumption and occupants' dissatisfaction on the 21st of March, June, September and December.

Scenario	21 March					21 June				
	Energy consumption (kWh)				Occupants dissatisfaction (%)	Energy consumption (kWh)				Occupants dissatisfaction (%)
	Heating load	Cooling load	Lighting gain	Total		Heating load	Cooling load	Lighting gain	Total	
Scenario 1: No shading	0.036	0.233	0.892	1.167	9.69	0	32.438	0	32.438	28.01
Scenario 2: Fixed shading (15°)	1.931	0	2.454	4.385	6.46	0	22.438	2.073	24.511	22.8
Scenario 3: automatically adaptive shading system	1.903	0	1.273	3.176	6.26	0	23.883	0.075	23.958	24.32
Scenario 4: manually adaptive shading system	1.731	0	1.198	2.929	5.92	0	25.348	0.075	25.423	21.89

Scenario	21 September					21 December				
	Energy consumption (kWh)				Occupants dissatisfaction (%)	Energy consumption (kWh)				Occupants dissatisfaction (%)
	Heating load	Cooling load	Lighting gain	Total		Heating load	Cooling load	Lighting gain	Total	
Scenario 1: No shading	0	16.477	0.374	16.851	21.00	0.095	0.345	1.646	2.086	9.42
Scenario 2: Fixed shading (15°)	0	10.609	3.179	13.788	17.55	0.215	0	5.838	6.053	5.65
Scenario 3: automatically adaptive shading system	0	10.794	0.958	11.752	18.38	0.349	0	3.518	3.867	5.66
Scenario 4: manually adaptive shading system	0	11.276	0.823	12.099	18.02	0.781	0	2.994	3.775	5.58

On the 21st of March, the first scenario is the most beneficial in terms of energy consumption. This is attributed to the fact that the presence of shading device increases the need for artificial lighting and heating. However, dissatisfaction is nearly twice as much as in the rest scenarios. On the 21st of June, the first scenario is arguably the worst both in terms of energy consumption and dissatisfaction, due to the high amounts of undisturbed solar radiation that enters the building. The rest scenarios present nearly equivalent rates of energy consumption and dissatisfaction, while it is remarkable the lighting need for the fixed shading scenario. On the 21st of September, the overview is essentially analogous to the one of the 21st of June. *No shading* is the most disadvantageous in both energy consumption and dissatisfaction. The presence of solar shading reduces not only the energy consumption by 20-30% (depending on the scenario), but also the dissatisfaction by 12-16% compared to Scenario 1. On the 21st of December, the most energy intensive scenario is the *fixed shading* due to the extremely high lighting gains. The best scenario in terms of energy is *no shading*, however it is poor regarding occupants' dissatisfaction.

Daylight analysis

The daylight analysis is performed with a CIE standard overcast sky, only on the 21st of December and June at 10.00 and 14.00, due to software limitations. The simulation results are summarised in Table 5 and are useful for comparing the different angles at different times during the day. In December, the average values of daylight illuminance are almost satisfactory for office activities only in the first scenario. In June the average values of daylight illuminance are satisfactory excluding the results given with fixed solar shading. However, as the maximum levels in the first scenario are extremely high, the use of solar shading is non-negotiable.

Table 5: The results of daylight analysis for the four scenarios.

			21 December			21 June		
Scenarios	Location | Time	Quantity	Values min	avg	max	Values min	avg	max
1. No shading	Office 5.3 (10pm)	Dayligh factor	0.6%	2.8%	8.0%	0.6%	2.9%	8.0%
		Daylight illuminance	37 lux	189 lux	523 lux	96 lux	451 lux	1243 lux
	Office 5.3 (14am)	Dayligh factor	0.6%	2.9%	8.0%	0.6%	2.9%	8.0%
		Daylight illuminance	46 lux	222 lux	632 lux	105 lux	495 lux	1364 lux
2. Fixed shading (15°)	Office 5.3 (10am)	Dayligh factor	0.0%	0.5%	5.9%	0.0%	0.5%	5.9%
		Daylight illuminance	0.05 lux	31 lux	393 lux	0.41 lux	72 lux	923 lux
	Office 5.3 (14am)	Dayligh factor	0.0%	0.5%	5.9%	0.0%	0.5%	5.9%
		Daylight illuminance	0.07 lux	37 lux	470 lux	0.47 lux	79 lux	1013 lux
3. Automatically adaptive shading	Office 5.3 (10pm)	Dayligh factor	0.0%	1.2%	6.1%	0.0%	0.5%	5.9%
		Daylight illuminance	0.84 lux	81 lux	407 lux	0.41 lux	72 lux	923 lux
	Office 5.3 (14am)	Dayligh factor	0.0%	1.4%	5.3%	0.1%	1.4%	5.3%
		Daylight illuminance	0.31 lux	111 lux	421 lux	9 lux	247 lux	910 lux
4. Manually adaptive shading	Office 5.3 (10am)	Dayligh factor	0.0%	1.4%	5.3%	0.0%	0.7%	5.9%
		Daylight illuminance	0.24 lux	93 lux	352 lux	0.53 lux	116 lux	916 lux
	Office 5.3 (14am)	Dayligh factor	0.0%	1.4%	5.3%	0.1%	1.4%	5.3%
		Daylight illuminance	0.31 lux	111 lux	421 lux	9 lux	247 lux	910 lux

5. Conclusions

5.1 Comparison of the four scenarios

1. No shading system: The main advantage is the zero financial cost. In addition, the minimum heating and lighting loads appear in this case. Furthermore, the average values of daylight illuminance are quite satisfactory. However, absence of solar shading results in high cooling loads and daylight illuminance values especially in June. Therefore, this scenario yields the highest percentages of dissatisfaction.

2. Optimum fixed shading system: The main benefits consist of low cooling loads and lower financial cost compared to adaptive shading systems. According to a survey in the Greek market, its installation cost is 66% lower compared to automatically adaptive solar shading. In addition, a fixed system has minimal maintenance and no operating costs. However, it results in low illuminance levels, increasing lighting gains. Finally, it hardly fulfils occupants' expectations for large time intervals.

3. Automatically adaptive shading system: Systems controlled via a sun sensor contribute to energy savings more effectively, reducing significantly cooling loads. However, they may not satisfy everyone. Therefore, the percentage of dissatisfaction is not as low as it is in the case of a manually adaptive system. Apart from that, they are expensive solutions with high costs for installation, operation and maintenance.

4. Manually adaptive shading system: The main advantages are related to occupants' satisfaction. Usually the percentages of dissatisfaction are the lowest compared to the rest scenarios. In addition, its cost is 46.7% lower than the cost of an automatically adaptive system. However, their operation can cause conflicts among the occupants. For this reason, users should be aware of the system's benefits in order to operate it optimally. Even though the manually adaptive systems seem to have more benefits than disadvantages the selection of the optimum scenario is not straight forward. For this reason a summary table is presented below (Table 6).

Table 6: A summary table for the four scenarios.

	Scenario 1: No shading	**Scenario 2:** Fixed shading	**Scenario 3:** Automatically adaptive shading	**Scenario 4:** Manually adaptive shading
fieldwork	−	?	−	+
simulation	−	±	±	±

? no information
\+ positive
− negative

5.2 Discussion about survey work and environmental modelling

Survey work was a very useful tool for understanding the occupants' preferences, which are usually expressed in terms of predetermined limits of environmental factors. However, there are physiological and psychological factors, which influence the way that every individual perceives comfort. Occupants expect to control their environment in order to respond to discomfort (Nicol et al, 2012). Moreover, fieldwork revealed the need for active and positive relationships between design teams, building managers and occupants for achieving proper functioning of the building's systems.

Environmental modelling unfolded the quantitative characteristics of solar shading in relation to energy consumption, daylight levels and dissatisfaction. As the daylight analysis was accomplished for specific time points, a general conclusion about the performance of adaptive systems with respect to daylight cannot be obtained. The results regarding energy are more reliable, as they are based on objective inputs, such as: weather data, solar geometry, material properties and building geometry. Nevertheless, the outputs about occupants' dissatisfaction depend on certain comfort criteria without taking into account psychological parameters, humans' expectations and needs. Therefore, the study of human reactions is necessary for optimising the simulation software. Additionally to this, the software lacks capabilities to predict the performance of adaptive components. The user must assume the adaptive behaviour and test it manually, usually for specific days during the year.

In this context, fieldwork emerges as a necessary process for evaluating different design alternatives. It should precede the environmental modelling in order for the inputs to be based on actual statistical data. In this way occupants' preferences and expectations are introduced in the design process.

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