Effect of kinetic façades on energy efficiency in office buildings - hot dry climates

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Abstract

In hot dry climates excess solar gain may result in high cooling energy consumption and indoor discomfort; sun control and shading devices is an important aspect of many energy-efficient building design strategies. Advanced CAD systems that integrate computational tools, such as parametric design systems, make possible and explore ways to formulate a responsive building envelope that could interact with sun position. The parametric design provides innovative building envelopes, which are more adaptive and interactive by actively responding to prevailing weather conditions, for enhancing energy performance and indoor thermal comfort levels. This study attempts to examine and evaluate the effect and performance of smart façades in the context of the indoor thermal comfort and energy efficiency. These parameters are achieved by controlling the levels of solar radiation and by calculating shading element sizes for sun control in response to environmental changes. In order to ensure the systems autonomy the semi-transparent PV modules has been used as panel's material. The method is applied to the case study of a reference office building with a fixed glazed façade windows-to-wall ratio in hot arid climate zone of Algeria, in particular the city of Biskra (latitude 34.6N). The results obtained from modeling simulation, using GECO- grasshopper (parametric plug-in for Rhinoceros), shown That kinetic facades equipped with PV modules have greatly influenced in a positive way the indoor air temperature, thermal and visual comfort levels and also, work towards a better environment for the inhabitants instead of simply being the part that separates the interior from the exterior.

Keywords: Kinetic facades, energy efficiency, indoor thermal comfort, Grasshopper, photovoltaic panels, hot dry climates.

1. Introduction

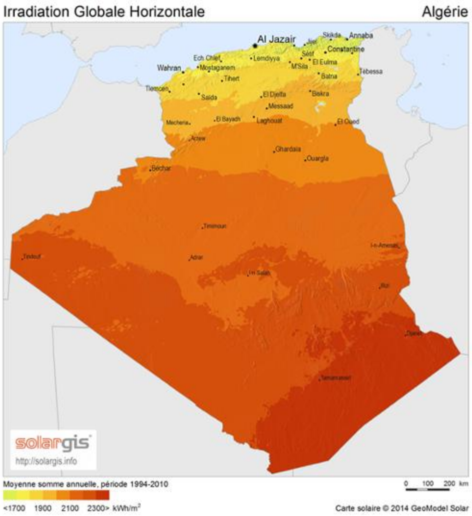
The major global environmental problems facing us at the beginning of the twenty-first century are dominated by the potential and impending risk posed by the greenhouse effect and the resulting impact of climate change. There are also concerns about the damage being inflicted on fragile ecosystems by increasing development and resource extraction, and the depletion of the ozone layer, which allows harmful ultraviolet radiation to penetrate the lower atmosphere. A building envelope separate the outdoor from the sheltered environment, this enclosure can exclude unwanted effects while admitting desirable ones, either passively or actively. The building envelope integrates about 80% of an environmental solution, creating an efficient building that interacts with its surrounding environment [1]; it plays a key role in improving building energy efficiency and indoor comfort for the occupants. The future lies in the use of innovative strategies, based on adaptive solutions for optimizing energy performance, because in the realm of high-performance buildings, the envelope has become the primary site of innovative research and development, We need to believe that architectural skins can be sensitive, interactive extensions of our own bodies and not just protection from nature [2]. Figure 1 illustrate that office buildings commonly use fully glazed façades to reflect a luxurious appearance and to maximize natural light at the expenses of high-energy consumption, due to cooling/heating, they are considered high-energy consumers, as they consume about 25% of the building energy consumption [1]; the increasing preference to use glazed facades in office and public buildings, regardless of the geographical location or climatic region is a major contributor towards the influence of thermo-visual comfort. Automatically this situation leads to an increasing reliance on mechanical air conditioning systems, and the consequential increase in electricity consumption and CO2 emissions. In hot climates, glazed facades are potential sources of undesired solar gain, which cause discomfort and reduce the daylight performance of employees, although solar control glass is to minimize the need for mechanical cooling systems and to eliminate visual disturbance factors, this strategy proved to be insufficient in the arid climatic regions [3].

Creating efficient buildings is a challenge that faces architects nowadays. However, recent developments in computer-aided design programs and digital fabrication have enabled architects to explore new building forms and new treatments of envelopes, in an attempt to solve architectural design problems [4]. Climatic Adaptive Building Shells (CABS) offer potential opportunities for energy savings as well as improvement of indoor environmental quality, by combining the complementary beneficial aspects of both active and passive building technologies into the building envelope.

Figure 1: Office buildings in Biskra, Algeria with curtain wall façades facing west and south. (Photos by authors)

2. Shading strategies and solar control for hot climate

In hot climates region, shading is one of the most important design strategies due to exposure and intense solar radiation; it is not a new approach in architectural solutions. In ancient times, Greeks focused the development of their cities on solar availability, because one of prime solution is the proper design of the building envelope that responds effectively to solar radiation control. Certainly solar control in buildings is important, as it is understanding of how this task can be achieved by the use of adequate shading geometries. Solar control in buildings not only helps to define an energy balance in the envelope, also it can contribute to the reduction of lighting systems by collecting available daylight. Thus, this can contribute to the reduction of electricity consumption. It is understood by building designers that envelopes, which respond to the climate conditions, will automatically lower energy consumption. However, this is not always set in practice [5]. Incoming solar radiation in buildings has strong implications both on visual and thermal aspects. Solar shading systems influence daylight levels in a building and the view to the exterior environment; they also reduce yearly solar gains and modify thermal exchanges through the glazed building envelope. Therefore, shadings, affect the building energy use for lighting, heating and cooling, and the occupants' visual and thermal comfort [6], the properties of a building envelope can relate directly to lighting and cooling energy use. While the percentage of openings on walls can determine the level of daylight on the interior spaces, it can also contribute to solar heat gain if openings are not protected nor geometries and respond to different layers of information. These layers can relate to each other and to the geometry; if one changes, it will affect the whole geometry or parts of it [7], to ensure a positive environmental design outcome, it is important to understand the climate conditions of the particular site where a building will be designed or perhaps redesigned. The type of exterior sun control system is an important point to study for most buildings, in particular for those that are located in extreme environments similar to Biskra's climate and with clear sky predominance as shown in Figure 2. The implementation of a mechanical sun control system has to be studied precisely by including an analysis of several items in relationship to the particular environment in which the system will be placed.



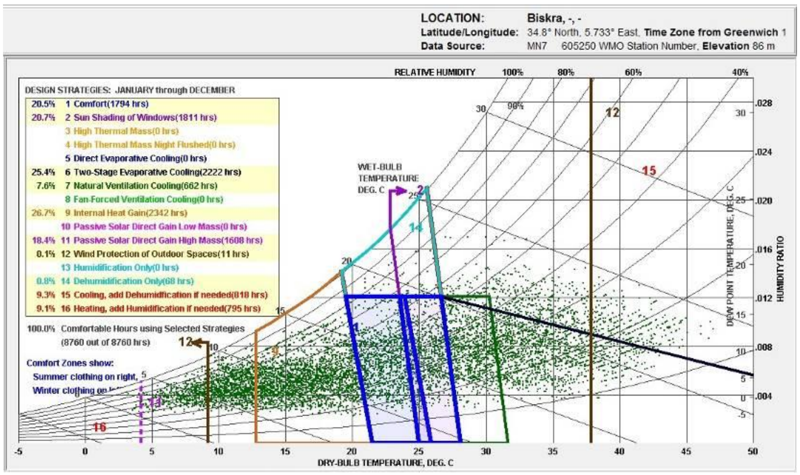


Figure 2: solar radiation map of Algeria (source: Solargis, 2014), 1b Psychometric chart of Biskra weather data from climate consultant 6.0 (source: by authors)

2.1 Responding to solar radiation

Adaptive systems that react to different levels of solar radiation are by far the most seen adaptive façade solution. There are examples of micro, macro and combined systems, but computer controlled macro systems are the most common. The adaptive solar shading systems can take on many different shapes and forms, there are external and internal systems, different kinds of blinds and shutters [8], but also more innovative examples both when it comes to shape and appearance but also in terms of driving mechanism. Whether it is macro or micro, based on natural reactions or computed algorithms, it is especially important to consider the trade-off between solar heat gain and daylight, obviously as they have the same original source the use of shading systems also affects the amount of daylight, that are let into the building [9].

3. Adaptive and kinetic facades

Historically, buildings where designed based on the pre-conditions given by the surrounding environment and together with the available natural resources, creating comfortable spaces in relation to the climate, the term “building skin” in reference to the building’s exterior envelope. Adaptive façade differs from a traditional facade in that it incorporates variable devices whose control adaptability allows the building envelope to act as a climate moderator. By using the facade in this way, we can provide a building ability to respond or benefit from external climatic conditions we mean the ability to accept or reject free energy from the external environment, and as a result reduce the amount of artificial energy required to achieve indoor comfort. If we scan the literature on this type of building envelopes, it is easy to notice they relate to a number of closely associated words such as, “smart”, “intelligent”, “interactive”, “adaptive” or “responsive”, etc. These expressions have been used loosely and interchangeably, creating confusion to their specific meaning and their conceptual relationship to building performance and design [10]. This term exactly relates to the design aims in architecture. Professor William Zuk [11], on the other hand, described the term kinetic, in 1970 in his book Kinetic Architecture, as a field of architecture in which building components or whole buildings have the capability of adapting to change through kinetics in reversible, deformable, incremental and mobile modes. In order to select and review design cases and categorize its’ traits, we start by citing the example done by the Corbusier in 1916 ‘le Mur neutralisant’. In addition, later, after the energy crisis, a suggested wall build up called the ‘the polyvalent wall’ by Mike Davies from 1981 [12]. As shown in Figure 3 Richard Buckminster Fuller used one of the very early examples of an adaptive envelope system in his design of the US Pavilion for the World expo in Montreal in 1967; the dome was constructed from a lattice steel structure with transparent acrylic sheets as façade material. In order to keep the comfort within reasonable levels a computer controlled [9]. Within present-day architecture, there is a rising concern in kinetics. As verified by smart facades, the potentials are for a responsive skin that adapts to varying environment situations and user residence [13], generally the type of building envelopes is defined by three characteristics:

- To manifest the strong correlations to climate and environment with its connotation of indoor environmental conditions and energy efficiency.
- To integrate a particular degree of physical motion or behaviors with the potentials to enhance architectural aesthetics.
- To imply biological metaphors with the idea of optimal performance and access to natural sources

Figure 3: 1a Buckminster Fuller, United States Pavilion, (1967), photo by Rudy Godinez, 1b Bio-tech building at TU Graz, Fertigstellung 2004. Photo by Paul Ott, 1c CJ Research Center's Kinetic Folding Facade 2012 / Yazdani Studio, photo by Andrew Michler

Building shells are located at the boundary between inside and outside, and are therefore subject to a range of variable conditions. Meteorological conditions change throughout the day and the year, and this also applies to occupancy and comfort wishes. Conventional building shells typically have static properties, and no ability to behave in response to these changes. Making the shift to climate adaptive building shells (CABS) offers opportunities to take advantage of the variability that is available and offer a high potential to reduce the energy demand for lighting and space conditioning [14]. At the same time, also a positive contribution to indoor air quality and thermal and visual comfort levels can be expected. Adaptive systems use less energy, offer more occupant control in addition to improved overall space efficiency, Current energy efficient design strategies and technologies of building envelopes have led to significant building energy savings. However, for most climates, the conventional building envelopes with static properties may not be an optimal solution. These representative cases and studies manifest a growing interest in kinetic envelope technologies which are proposed for improving energy performance, indoor comfort, and occupancy interactions with buildings as well [15]. Today there are a great number of façade and envelope technologies that are readily available in the market. However, the decision as to how they are designed, operated, maintained and assessed remains a challenge [16], the number of existing products, built examples, design proposals and research prototypes that appeared in books, patent applications, and journal- and conference papers is relatively limited. Moreover, extensive review papers have not yet been published [14].

4. Parametric design and simulations of kinetic envelope systems

The development in computer technology have improved capacity of handling complex simulation models have enabled more accurate calculations of the energy performance. This can be used as a design tool at an early stage, making it possible to design an optimal envelope, adopted for specific conditions and context. However, the optimization tends to be lame as the many of the input values, for example insulation value that you might want to alter to find an optimum are fixed to one value. Therefore the software cannot truly consider an adaptive envelope but rather optimize the relationship between otherwise static parameters [17]. The computer did not invent parametric design, nor did it redefine architecture or the profession; it did provide a valuable tool that has since enabled architects to design and construct innovative buildings with more exacting qualitative and quantitative conditions. [18] Parametric architecture has been gaining momentum over the past few years. This new design approach involves sketching behaviors in nature quantifying them and introducing them to advanced computational design programs that help architects in exploring new geometries [19] for that parametric design enables the recognition of patterns of geometric behavior and related performative capacities and tendencies of the system. In continued feedback with the external environment, these behavioral tendencies can then inform the ontogenetic development of one specific system through the parametric differentiation of its sub-locations [20], computational tools particularly parametric design can assist refined and dynamic co-ordination of cross-disciplinary intelligence that has been handed out across variety of analytical tools and techniques [21]. Parametric modelling enables simplicity to explore designs by assigning the automatic generation for a category of substitutional design solutions. A change in an input parameter stimulates a synchronized modification in the form, generating alternatives on the form while preserving the tacit consistency of the design [22], Parametric modelling converts this feature of kinetic pattern design into a new and strong expression [23].

5. Methodology of research

In order to explore different variations of shading designs, and their effects on both radiation protection and daylight utilization, this study employs parametric design that allows parameterized manipulation of geometry to generate and settle exterior sun screen designs. There are multiple performance criteria in shading design. Ecotect and Radiance software are simulation tools identified as candidates for performance assessment of design variations in terms of radiation exposure, daylight utilization and energy consumption. All of them can be connected to Rhino through different Grasshopper plug-ins.

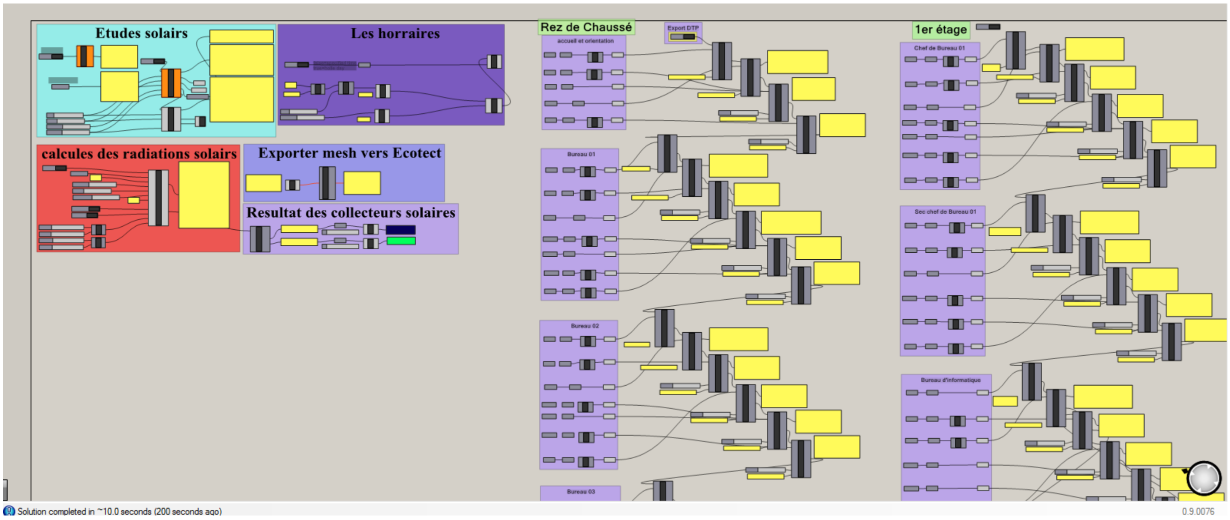


Figure 4: the parametric definition for the office building and the kinetic facade system (source: by authors)

The Research work was divided into two consecutive phases illustrated in Figure 5. The first stage focuses on the analysis of thermal comfort performance before using the kinetic façade. The second stage represents a thermal comfort and day lighting simulation using parametric tools for kinetic hexagonal-patterned facade to achieve the near optimum thermal and visual comfort adequacy. In this case, the types of motion of hexagonal units are changed with the sun movement during the day and the whole year. The first type of motion is opening Variation, which varies by controlling the levels of solar radiation and by calculating shading element sizes for sun control in response to environmental changes. In order to ensure and maximize day lighting performance, the semi-transparent PV modules have been used as panel's material for the whole facade. The simulation process allows us to choose the optimum design among these alternatives. This could be achieved through visualizing how kinetic facade systems coupled with PV modules, work in relation to the indoor space and to predict the final performance in the early design stage.

To achieve a dynamic system that is updated on an hourly basis the Rhinoceros /Grasshopper model is linked to Autodesk Ecotect via a plugin called GECO [24]. GECO facilitates real-time data exchange between both software packages. The solar path can be traced/imported into the Rhinoceros model through Grasshopper’s parametric engine; changes in solar position/angle directly affect the models response. This allows for more complex panel systems or other large quantities of variable shading components to be automated and animated.

GECO allows Ecotect to import geometry from Rhinoceros and calculate building performance, thermal values, solar radiation and energy consumption. This allows users to perform complete conceptual design and mass modelling in Rhinoceros with the benefit of seeing design changes in real time and make faster more decisions that are informed, see Figure 4.

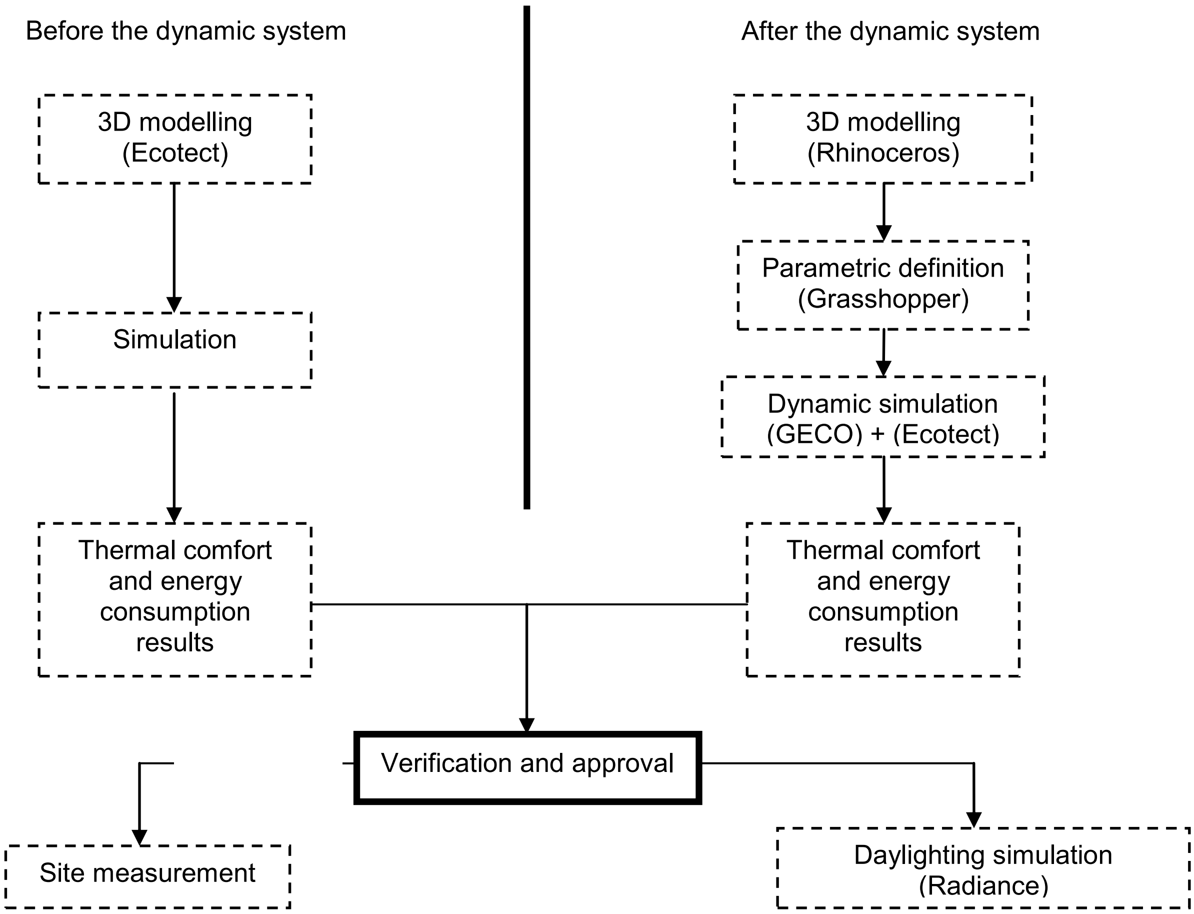


Figure 5: Workflow schema showing development process.

5.1 Case study

The case study chosen is an office building with a large curtain wall façades situated in the city of Biskra; located in the south-eastern part of Algeria (latitude 34.6N), it is characterized by:

• A hot and dry summer the diurnal temperature difference is important reaching 18 C.

• A short winter period characterized by a cold night.

According to the climatic zones distribution of Algeria, Biskra belongs to the zone D, which belongs to the pre-Sahara and Sahara desert, these regions described by an average maximum temperature reaches 41C° in summer as shown in Figure 6. Solar radiation is very intense in summer with a daily average of 5962 Wh/m² for a horizontal surface, during the month of July [25].

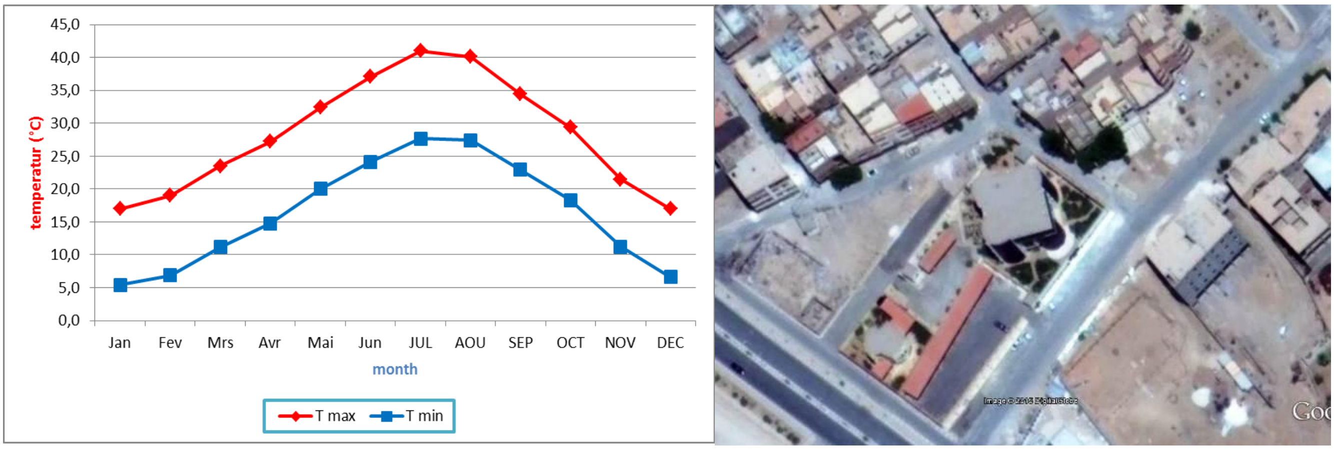


Figure 6: 1a average maximum temperature of Biskra – Algeria, 1b the position of the office building in the urban context (source: Google earth, 2016)

For this study, we chose a typical office building with a 60% of double glazing curtain walls, in the external façade. The building spreads over an area of 859 m² and, it has four floors as shown in Figure 7. The activities on the inside split of 58 workspace, we find that the entire building is equipped with an air conditioning, unless circulation spaces that are naturally ventilated. These caused huge electricity consumption in the summer due to the direct heat gain from the glazed facades, the interviewed persons showed a complete dissatisfaction regarding indoor thermal comfort, this condition led to a drop in work production, the entire building conception has not taken any solar control measure in the design phase.

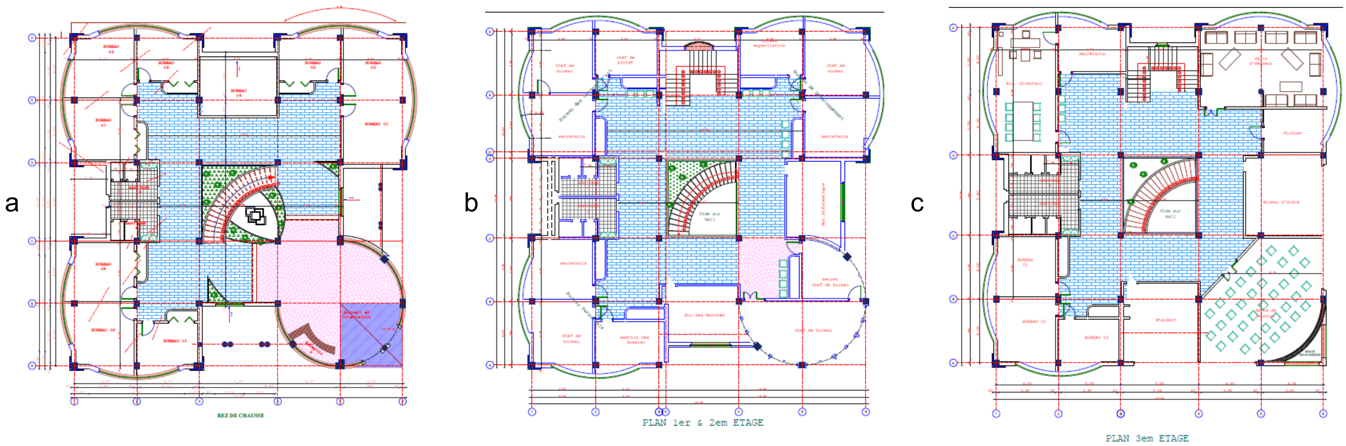


Figure 7: 1a first floor, 1b second & third floor, 1c forth floor for the office building (source: by authors)

6. Results and discussion

The results showed that after the integration of a dynamic sun protection system, as a second skin, we minimize exposure to direct radiation of 17.9% illustrated in Figure 8. Which directly influence in a positive way the thermal and visual comfort levels, this dynamic shading system contribute to a significant reduction of the energy consumption reaching 43%, with a decreasing of indoor air temperature ranging between 4.0 C° to 4.8 C°. In addition, the integration of photovoltaic cells into the kinetic façade has a positive contribution in producing electricity that generate the amount 6000 kW / month.

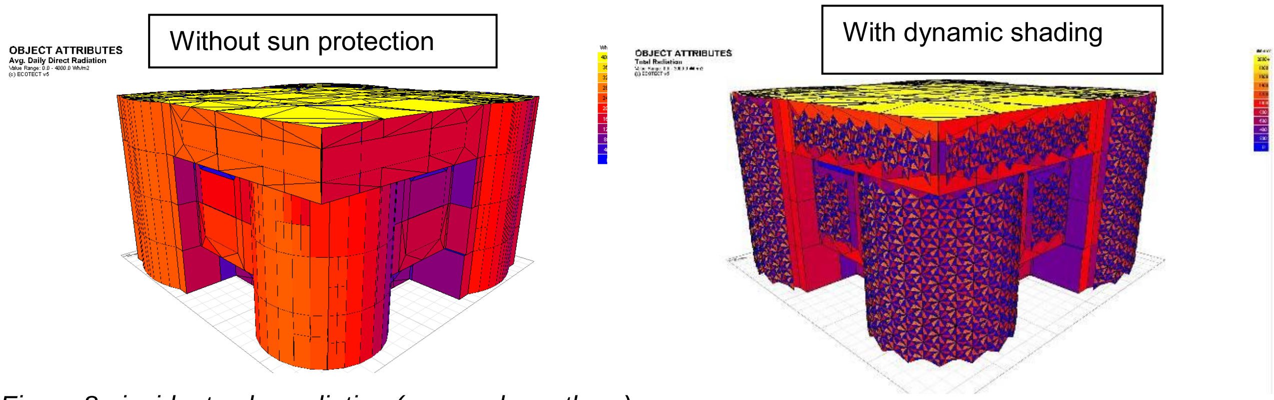


Figure 8: incident solar radiation (source: by authors)

For the thermal comfort part, to calculate the overheating zone we adopted the adaptive comfort in ASHRAE 55–2010 intended to office [26], where the comfort limit is ranged between 22.9° - 26.9°.

After analysis, the results obtained, showed that the overheating period begin from April to October which cover all the hour working from 8 am to 17 pm. The dynamic shading system was programmed according to cited overheated period. The system work independently for each facade according to the need of protection, related to the work hours. As shown in figure 9, after installing the dynamic shading system, the overheating area was reduced and the comfort hours are increasing by 360 hours, as shown in Figure 9.

Without shading

					la moyenne horaire des température /TMY3 -Annee 2005 /Biskra							
mois/heure	Jan	Fev	Mar	Avr	Mai	Juin	Jui	Aou	Sep	Oct	Nov	Dec
00:00	8,1	10,2	14,8	18,5	23,0	27,2	31,7	30,9	25,0	21,3	13,6	9,4
01:00	8,0	10,1	14,6	18,4	22,3	26,4	31,4	30,6	24,8	21,3	13,5	9,3
02:00	7,9	9,9	14,5	18,3	22,0	26,1	31,1	30,4	24,2	21,1	13,3	9,2
03:00	7,8	9,8	14,4	18,2	22,0	25,8	31,0	29,6	24,1	21,1	13,3	9,1
04:00	7,7	9,8	14,3	18,1	22,1	25,8	30,4	29,5	24,1	21,1	13,2	9,0
05:00	7,6	9,7	14,2	18,1	22,0	25,6	30,3	29,5	24,4	21,0	13,1	9,0
06:00	7,6	9,6	14,2	18,9	25,3	29,8	34,9	31,2	24,8	21,0	13,1	8,9
07:00	7,5	9,6	17,2	22,7	28,7	34,0	38,6	36,3	28,1	23,6	13,2	8,9
08:00	12,2	14,2	21,2	25,6	30,9	36,1	41,0	39,3	31,4	26,3	18,8	14,1
09:00	16,3	18,4	23,6	26,9	32,0	36,8	42,0	40,7	33,5	28,3	22,9	17,9
10:00	18,8	20,6	24,9	27,5	32,5	37,3	41,9	41,2	34,5	30,2	24,8	20,1
11:00	20,4	21,7	25,3	27,7	32,2	36,6	41,5	41,1	34,6	31,1	26,2	21,3
12:00	20,9	22,0	26,0	28,3	31,5	35,9	40,3	40,7	34,6	31,5	26,4	21,6
13:00	20,7	22,2	26,2	28,3	30,9	35,5	39,5	40,2	34,3	31,0	26,7	21,4
14:00	21,4	23,1	27,2	29,0	31,6	36,2	40,4	40,6	34,6	31,2	27,2	21,8
15:00	20,4	22,5	27,1	29,1	31,7	36,2	40,8	40,5	34,3	30,4	25,6	20,4
16:00	16,5	20,1	25,4	27,9	31,0	35,7	40,4	39,6	33,1	28,6	21,9	17,0
17:00	10,5	15,5	21,7	25,1	29,2	33,8	38,2	37,1	30,3	24,8	15,8	11,3
18:00	9,7	11,8	17,2	21,8	27,4	32,0	35,9	34,5	27,3	23,4	15,0	10,8
19:00	9,4	11,5	16,6	19,9	25,6	29,5	33,1	32,1	27,0	23,0	14,6	10,5
20:00	9,2	11,3	16,1	19,6	25,0	29,1	32,7	31,8	26,7	22,5	14,4	10,4
21:00	9,0	11,1	15,7	19,5	24,7	28,8	32,4	31,6	26,2	22,0	14,2	10,2
22:00	8,8	10,9	15,4	19,1	24,3	28,4	32,1	31,3	25,6	21,7	14,1	10,0
23:00	8,3	10,4	15,0	18,8	23,7	28,2	32,0	31,2	25,2	21,4	13,7	9,6

With the dynamic shading

					la moyenne horaire des température /TMY3 -Annee 2005 /Biskra							
mois/heure	Jan	Fev	Mar	Avr	Mai	Juin	Jui	Aou	Sep	Oct	Nov	Dec
00:00	8,1	10,2	14,8	18,5	23,0	27,2	26,9	26,7	25,0	21,3	13,6	9,4
01:00	8,0	10,1	14,6	18,4	22,3	26,4	26,8	26,4	24,8	21,3	13,5	9,3
02:00	7,9	9,9	14,5	18,3	22,0	26,1	26.7	26,4	24,2	21,1	13,3	9,2
03:00	7,8	9,8	14,4	18,2	22,0	25,8	26,6	25,6	24,1	21,1	13,3	9,1
04:00	7,7	9,8	14,3	18,1	22,1	25,8	26,4	25,4	24,1	21,1	13,2	9,0
05:00	7,6	9,7	14,2	18,1	22,0	25,6	26,3	25,5	24,4	21,0	13,1	9,0
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07:00	7,5	9,6	17,2	22,7	25,7	30,0	34,6	31,3	26,1	23,6	13,2	8,9
08:00	12,2	14,2	21,2	24,6	26,5	32,1	37,0	34,8	27,4	26,3	18,8	14,1
09:00	16,3	18,4	23,6	21,9	28,0	32,8	38,0	36,5	29,5	26,0	22,9	17,9
10:00	18,8	20,6	24,9	23.7	28,3	33,3	37,8	37,2	30,1	26,2	24,8	20,1
11:00	20,4	21,7	25,3	23.6	28,1	32,6	37,5	37,1	30,3	27,1	26,2	21,3
12:00	20,9	22,0	26,0	24.1	27,4	31,9	36,3	36,4	30,5	27,5	26,4	21,6
13:00	20,7	22,2	26,2	24.0	26,9	31,5	35,8	36,2	30,3	27,0	26,7	21,4
14:00	21,4	23,1	27,2	24.6	27,3	32,2	36,4	36,7	30,7	27,2	27,2	21,8
15:00	20,4	22,5	27,1	24,3	27,0	32,2	36,5	36,5	33,1	26,4	25,6	20,4
16:00	16,5	20,1	25,4	23,7	26,8	31,7	36,4	35,1	29,6	24,6	21,9	17,0
17:00	10,5	15,5	21,7	24,1	25,1	29,8	34,1	33,1	26,7	22,8	15,8	11,3
18:00	9,7	11,8	17,2	21,8	25,0	28,0	31,5	30,3	24,4	22,4	15,0	10,8
19:00	9,4	11,5	16,6	19,9	24,7	26,5	29,8	28,1	25,1	22,0	14,6	10,5
20:00	9,2	11,3	16,1	19,6	24,4	26,1	28,5	27,7	26,6	22,5	14,4	10,4
21:00	9,0	11,1	15,7	19,5	24,0	26,8	28,3	27,5	26,2	22,0	14,2	10,2
22:00	8,8	10,9	15,4	19,1	23,9	26,4	27,5	27,3	25,6	21,7	14,1	10,0
23:00	8,3	10,4	15,0	18,8	23,7	27,2	26,9	26,8	25,2	21,4	13,7	9,6

Figure 9: the overheating period before and after the dynamic system (source: by authors).

The quality of daylight changes continuously within a building, depending on the time of day, the weather and the season, the shading system can decease the levels of natural light in the building while rising as much as possible the need for artificial lighting. For this reason, the semi-transparent photovoltaic cells modules are used as panel's material, providing natural light quality throughout the daylight hours all year round providing ideal light quality even when the dynamic shading system is totally closed given an indoor thermal visual comfort. In order to prove the accuracy and the level of natural light and to ensure the desired illumination for office space which is considered to be 500 lux, with acceptable illumination level (300-500 lux) [27], and prevents glare in the work plan. The radiance software was used to determine the optimal visible transmittance needed, as shown in case 2 in Figure 10 with VT= 0.2, which offer a good visual comfort for the inhabitants of the office building.

Visible transmittance =0.1 for PV semi-transparent	Visible transmittance =0.2 for PV semi-transparent	Visible transmittance =0.3 for PV semi-transparent	Visible transmittance =0.4 for PV semi-transparent

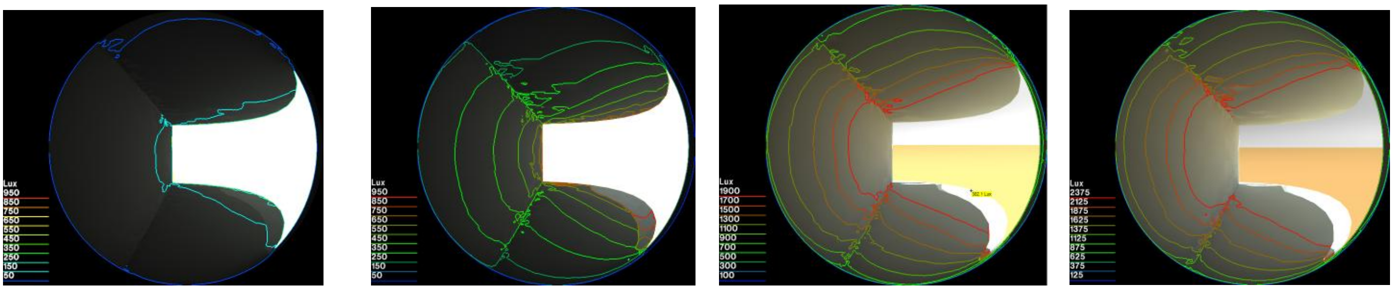

Figure 10: daylignting simulation with Radiance to choose the best case of PV semi-transparent (source: by authors)

The results obtained are very satisfactory, regarding the energy saving and on the electric generation, with an obtained values ranging from 2775.69 kW in December until the extreme values that comes up to 7680.40 kW in the month of August, with an average monthly production reached 5612.50 kW, see Figure 11.

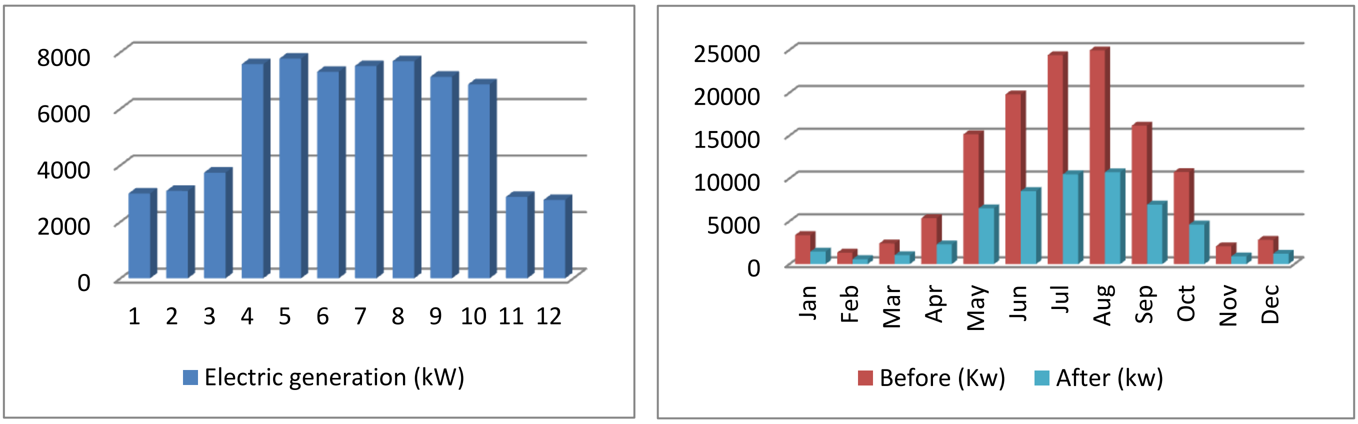

Figure 11: 1a Monthly electric generation for PV semi –transparent, 1b Comparison of kinetic systems versus reference case study for annual energy consumption (source: by authors)

The simulation demonstrated that the building before using the shading solution has subdued a huge consummation of energy due to cooling loads in summer. it was found that the maximum cooling load is marked in the warmer months, where it exceed the threshold of 24,390 kW in July and 24,952 kW in August. This dynamic shading system contribute to a significant reduction of the energy consumption reaching 43%, where we got a lower consumption up to 10,488 kW and 10,729 kW for the months of July and August respectively, and a minimum consumption of 575 kW and 895 kW for the months February and November,

7. Conclusion

This paper presents initial findings of an ongoing research about design optimization of the dynamic shading facades using parametric design. Based on the presented simulation results, it was concluded that the proposed skin delayed the periods of solar penetration and potential glare to the indoor office building space achieved acceptable thermal comfort and illumination level. Architecture must change and cannot continue to ignore climate change and the destruction of our biosphere. An effective ecological design is becoming an increasingly complex task, due to a growing demand to satisfy more ambitious environmental, societal and economic performance requirements. The building needs to be in closer relation to the climatic context, and as the building envelope is the border between the surrounding climate and the interior, the envelope design is becoming a crucial parameter in sustainable and energy efficient building design.

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