Innovative Energy & Research
ISSN: 2576-1463

Siddiqi and Watfa, Innov Ener Res 2019, 8:1
DOI: 10.4172/2576-1463.1000224

Research Article Open Access

Design and Analysis of Innovative Solar Deployment Techniques on Rotating and Non-Rotating Buildings

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Abstract

Current buildings (in Europe) constitute roughly for 40% of the energy usage out of the total energy used. This level can be dropped to 10-20% if smarter and greener buildings are incorporated around the world. Buildings can be made smart by using dynamic movement (rotation), sensors and greener by deploying solar energy to conserve power. In this research, different innovative solar tracking techniques will be deployed on different structures (non-rotating and rotating). By means of simulation (LabVIEW) and by comparing results we will be able to define the most suitable framework of solar deployment and will be able to define whether a dynamic building is more worthy than a stationary one in terms of cost and conservation of energy. The following research introduces topics like rotating buildings, different techniques of tracking the sun and rise of concern in the world about greener and smarter buildings. Through our research, we would like to initiate a movement in the direction of an innovative, greener and smarter building. As the world, doesn't realize that wasting power needlessly will come back to haunt us severely in the next few coming years. These structures and innovative deploying techniques will positively impact our eco-system, health and will help built a more sustainable future.

Keywords: Smart buildings/structures; Innovative solar energy; Solar tracking; Dynamic buildings; Simulation; LabVIEW

Introduction

In a world where people are worrying about running out of renewable resources and more importantly their aftermaths on our environment. The need for implementing renewable energy is now ever more than before. One such abundant source of energy is solar (especially in the United Arab Emirates). What's unique in this part of solar energy research is that our PV modules would not rotate themselves but will rotate the floor onto which they are located. What interests us is how this framework would be setup whether we will initiate the mechanical movement using sensors (such as intensity light sensors) or applying mathematical equations to predict the sun's orientation and making our panels always facing the sun's light (sun equation, Maximum peak-to-peak tracking (MPPT) or weather forecasting). Or even better applying latest dimensions of communications (IOT or fuzzy logic) to rotate the building structure to a minimum to achieve maximum energy management.

Literature Review

Buildings are major sources of pollution that causes urban air quality problems. In the U. S alone buildings account for 49% of Sulphur dioxide, 25% nitrous oxide and 10% particulate emissions [1]. The largest consumers of energy are the developed countries where the proportion of energy consumption by buildings is also much larger [2]. The solution to this problem is to build a green and smart building [3]. In this study a design that is inclusive of these 4 main components, was suggested as a solution:

1. Thermal power network- taking heat from different loads and preserving it by using solar thermal collectors later will be used to power thermal loads such as refrigerators in buildings.
2. DC electric power network- varying voltages from solar cells and wind power generators will be rectified to store as dc. This dc bus bar will be used to power any dc loads in the buildings and will power the electrolyzer (which will split water to produce hydrogen and oxygen).
3. AC electric power network- voltage inverters will be responsible to provide for AC loads in the building.
4. Smart energy Management Network- agent technology will be used that will properly manage the power generators and loads in the building. Dynamic allocation of energy resources with respect to smart time allocation will be the main essence of this smart energy network.

Simulation results indicated that this can lead to diminishing of existing energy problems in buildings (of high emissions of energy and waste). And contrary to old beliefs just using renewable energy to make the buildings green will not suffice. To build an effective system, renewable resources of energy need to be combined with storage devices (batteries/super capacitors and hydrogen oxygen fuel cells). However, this method is complex and complicated to implement. Maybe in the long run it may turn out to be a cost-effective solution, but such systems are having high maintenance issues.

Lighting systems are a major source of electricity consumption in the world. In Europe, the amount of electrical energy used in illuminating buildings is considerable, about 40% and leads to approximately 35% of carbon dioxide emissions [4]. Studies about sensor deployment in green buildings introduced practices' [5] that use smart LED technology in buildings, which automatically adapts itself to adjust the light intensity. Using the help of light sensors and motion sensors and wireless communication using Zigbee communication. 6 months of implementation of the system was done from winter to

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Received February 12, 2019; **Accepted** February 26, 2019; **Published** March 05, 2019

Citation: Siddiqi MR, Watfa M (2019) Design and Analysis of Innovative Solar Deployment Techniques on Rotating and Non-Rotating Buildings. Innov Ener Res 8: 224. doi: 10.4172/2576-1463.1000224

summer in a very busy office the proposed system reduced the total power consumption by 55% and by spring it raised up savings to 69%.

The major problem with sensor nodes is its deployment. Two methods have been used very commonly to deploy sensor nodes:

1) Random deployment, normally used in brutal environments such as in the battlefield.

2) Predetermined deployment. Further research into sensor nodes has now produced a third type of deployment [6] called target detection and location. The first step in this deployment is dividing the target field into grids, then after dividing model the sensor deployment and finally developing an object function. Then using an adaptive binary particle swarm optimal algorithm, the best possible optimal solution is produced. This method was compared with the standard binary particle swarm and results showed a smaller discrimination error and a better convergence rate.

The problem with people is when they hear the word "SMART" they relate it to only sensors and technology. This is not true at all. The word "SMART" is also used for defining smart rotating structures. For long architects, have thought about building bigger, wider and higher buildings. Recently though architects are thinking of building more sustainable buildings and now look forward in the fourth dimension called movement [7]. This article discusses this trend and talks about 16 amazing structures that can shift their shapes. A couple of good examples are present in his article like; the Everingham Rotating house in UK, the rotating mountain house in Helix, but what stands out is the Heliotrope house in Germany. Based on the design of Rolf Disch (aka the solar architect). This house rotates slowly enough to track the sun with a sail shaped panel on top the building. Another outstanding example, which takes rotating to another level (Suite Vollard) apartments in Brazil where each floor rotates independent of each other (rotating 360°). Rotating structures have gained a lot of fame in the restaurant and hotel industry [8]. A few early examples of rotating buildings include: In 1933, Norman Bel Geddes design of the giant rotating restaurant. With a column like structure (with elevator in it) holding an entire rotating restaurant on its top with rotation occurring every half hour. Towards the 1960's, the huge rotating tower in Stuttgart was the first debuting rotating building build post world war. In around 1961, finally the US came in to the picture by building the La Ronde in Honolulu, followed by that many other rotating structures in Seattle like the space needle. Then the trend became popular in nearby countries like Toronto (CN towers), Skylon towers in Niagara Falls, sun sphere in Knoxville and tower of the Americas in San Antonio.

Now even Dubai has welcomed dynamic structures (Buildings which will have the fourth dimension "TIME"). These buildings will not be confined to rigid shapes (you will not see the same building twice) [9]. This project initiated in 2008 is unique because it will be built upon the 6 fundamentals of architecture; economically feasible, functionality, environmentally sound, quality of engineering and finally Cost, time and construction (maintenance and design) of the project should be done in its best possible manner. This paper analyses the Dynamic architecture per 4 of the 6 principles listed before [9]:

1. **Economically Feasible:** Usage of prefabricated units (custom-made in workshops) will guarantee cost savings of 20%.

2. **Functionality:** The rotation of the floors is done with steel bearings and combination of air-cushion, allowing floor rotation with no vibration. 4KW of power from the motor will be required to rotate, and the motor will have placed in base of each floor so it's easy to maintain. All floors will be held together with an inner core.

3. **Environmentally:** All the previous cons of construction will be eliminated in this project, since no construction takes place at the site and only assembling. All the loading, unloading, noise, heavy vehicles and debris (waste material) will not exist. The building generates its own energy using 70 turbines and solar cell placed on the roof of each floor.

4. **Engineering:** The owners will be able to customize individual apartments per their needs. Because each room, bathroom, kitchen will be prefabricated separately. Higher quality modules will be produced as they will be prefabricated in a factory rather on the site, where quality standards can easily fall.

To construct a green building incorporation of solar energy with rotating buildings is a must. Solar energy is being used abundantly all over the world due to it being a renewable source of energy. Various solar panel systems have been designed to track the sun to achieve maximum efficiency output from the panels. Trackers using image processing and sensors like LDR's have shown to produce 30-60% more efficiency than standard fixed panels [10]. Another system of tracking the dual axis tracker using an ARM processor (BeagleBone Back-BBB) together with LDR's this system not only tracks but also allows remote monitoring of the panels from all around the world [11]. Multi-directional solar trackers [12] were tested against standard fixed panels and dual axis trackers, the proposed multi-directional tracker showed an average increase of 64% and 32% over the stationary and dual axis trackers respectively. Microcontrollers programmed with geometrical equations [13] of sun showed that a single tracker system produced 21% more power output compared to a stationary solar cell as for a dual axis solar had 42% more power generated than a stationary one. Actually using algorithms has been a very effective measure of tracking the sun, previously used algorithms such as the NREL algorithm [14,15] were very complex, but the simulation of the sun position algorithm for sun tracking [16] suggested are far more simpler and produced identical results. Other than tracking, mirror reflection has also been used very effectively to increase efficiency of solar systems. One such modification is, instead of using just standard Solar panels, cheap cost mirrors were used to reflect solar light onto the panels. In this proposed system mirrors are installed on the east and west side of the panels [17]. Results showed that during summer the power generation of the proposed system was 65% higher than the independent solar panel itself. In the winter this percentage reduced to 50% and in spring and autumn it was around 59%. Poor underdeveloped countries (for example Bangladesh) always face shortage of electricity now the government is loaning Solar Home System (SHS), these are becoming popular day-by-day. However due to its poor efficiency and high cost people oppose this evident change. However, studies in Bangladesh [18,19] to enhance the performance of SHS while reducing the cost. So, for this reason performance enhancement of solar panels by direct reflection of light was implemented. Improvements to the design show 30% more short circuit current. Due to the usage of pyranometer (in the studies) reading of irradiation remained constant during the transition period, meaning the transition of the sun's movement did not affect the irradiation on the proposed system.

However, the downfall of using reflected mirrors is that, after 25o for every increase of 1o the PV cells efficiency decreases by 0.4%-0.5% [20]. To eliminate these temperature constraints one can use an expensive cooling mechanism for the panels or better use glass dish collectors (deep paraboloid dish) [21]. Recent study shows higher efficiency in panels due to these glass dish collectors. Even though it doesn't heat the panels as much as the older reflectors but under intense sun light, temperature issues arise in panels again. All results and simulations of different trackers showed the efficiency of the panels improved as compared to fixed panels [10-13]. However, all tests were performed using light weight panels (servo motors) and so the panels are easy to rotate and setup and no maintenance issues were discussed. Adding mirrors (to the sides of the panel) to reflect light on the panels produced better results than the solar trackers alone. However, the problem arising with such reflectors over weigh its advantages. Main issues are the heating of the mirror, creation of hot spots on the panel, and mechanically this design is very fragile (strong winds can easily cause severe damage) none of these problems were addressed in any of the research.

The market for Multicrystalline silicon (mc-Si) solar cells have risen from the 1980's to 2010's. Due to two main reasons:

1) Reduction in its cost value.

2) Improved efficiency.

In the research of National Renewable energy laboratory [22] an extensive evaluation from material growth to cell processing is discussed. In the early 1980's processes like impurity gettering, hydrogen passivation, two-layer antireflective coating, plasma hydrogenation and passivated emitter solar cell with P-pretreatment sheet resistivity of around 100 Ω-150 Ω was implemented and the efficiency achieved at that time of the mc-Si solar cell was around 16%. Then around the 1990's use of laser technology with other oxide techniques started reducing the cost of fabrication of one mc-Si and their efficiency increased to around nearly 20%.

Now when approaching 2010 mc-Si was fabricated with more accurate grains and front and rear passivation was being applied which further reduced the manufacturing costs of the mc-Si and allowed the efficiency to reach a world record cell of 21%. Also, these techniques have increased the lifetime of these cells. Mc-Si material growth from several methods such as EMC (electromagnetic casting) and DSS (direct solidification system) have had promising effects on the cells by increasing their efficiency. At present mc-Si solar cells account for around 50% of the total solar cell production [23].

In general rotation in buildings has been discussed as in means to give the customer a 360° view. Only when reading about the rotating towers [9], you see the incorporation of a truly green building. Even though the whole idea of placing solar cells underneath the floors seems too farfetched and very inefficient yet because of David we are having an initiation towards the future dynamic structures.

As previously mentioned rotating structures have been discussed as a means of providing a beautiful view so far. No research incorporates any such algorithm to these rotating buildings. For example, why not rotate the floors independently based on a sun tracking algorithm by incorporating vertical panels on the windows of the building.

All results in recent studies neglect the weather conditions. For instance, considering cloud cover, gloomy/overcast conditions (that might occur during winter), which interfere heavily with the sun-light approaching the earth. With a smart reflecting mechanism of mirrors these constraints can be effectively handled and since light approaching the earth is very limited, no such temperature issues will arise.

What is left in our research is to study, design and analyze innovative solar deployment techniques (such as placing solar cells vertical, horizontally on rotating buildings and non-rotating buildings. Firstly, algorithms will be used to help rotate the independent floors of an already smart rotating building to track the sun. At the same time, I will be designing many practical frameworks of panels which will be incorporated in an existing rotating and non-rotating structure. Once these innovative solar frameworks have been implemented (important characteristics such as energy will be measured) then it will time to compare them with benchmark results to see how efficient these new deployed techniques and the question are about deploying them on rotating structures is beneficial or not (as compared to stationary buildings) will also be answered.

Methodology

Solar radiation model

The Ghouard Model was applied to calculate direct and diffuse solar radiations under namely 3 conditions:

1. Pure: This means that the solar cells are placed in an open area such as farm lands etc.
2. Normal: This means that the solar cells are placed in a residential area where the solar radiation is affected by buildings and cars hence having more diffused radiation than direct.
3. Polluted conditions: This means that the solar cells are placed in an industrial area where pollution and factories cause the direct radiation to be least and diffuse radiation is maximized.

The Ghouard model is governed by the following equations [24]:

Direct solar radiation=

$$(Io)*(Ct)*(A1)*(\exp -(A2/\sin(h))*(\sin(h)) \qquad (1)$$

Diffuse solar radiation=

$$(Io)*(Ct)[0.271-0.2939*A1*(\exp -(A2/\sin(h))](\sin(h)) \qquad (2)$$

Global solar Radiation=

$$(0.271Io)*(Ct)*(A1)*(\sin(h))+[0.706Io*Ct*A1*(\sin(h))(\exp -(A2/\sin(h))] \qquad (3)$$

Where; Io=solar constant, Ct= correction of the sun and earth distance, A1 and A2 are turbidity factors (explained in the table below Table 1) and h is the altitude angle of the sun.

Sun equation

To find the position of the sun always (the azimuth and the altitude angle) we applied the sun equation to our simulation [25] which were governed by the following 2 equations:

$$\text{Sun altitude}=[\![\sin\wedge(-1)\ \lfloor(\sin(\varphi)*\sin(\delta)+\cos(\varphi)*\cos(\delta)*\cos(w)\rfloor \qquad (1)$$

$$\text{Sun Azimuth}=[\![\sin\wedge(-1)\ \lfloor\cos(\delta)*((\sin(w))/(\cos(h))\rfloor \qquad (2)$$

Where; h=sun's altitude angle, w=hour angle, δ=solar declination angle and φ=latitude.

Solar panel deployment

Simulations are based on 3 categories:

1. Stationary building with a fixed panel deployment on roof top and vertically.
2. Stationary building with a rotatory panel deployment on roof top.

Climatic conditions	Sky very pure	Normal conditions	Sky very polluted
A1	0.87	0.88	0.91
A2	0.17	0.26	0.43

Table 1: Turbidity factors depending on the climate conditions.

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3. Lastly a dynamic building (discussed in detail later in the chapter).

For the first simulation, a fixed panel with a standard 5-floor building such as seen below will be deployed (Figure 1)

Building structures

This simulation will take results in all 3 different turbidity factors (pure, normal and polluted) under the 4 different types of maintenance programs. This first simulation will easily tell us which deployment is better than a fixed panel deployed on the top of the building or deployed vertically (facing south-west direction with a tilt angle of 23.5 degrees). For the 2nd simulation the same building is used but just a dual rotating solar panel is deployed on the roof top only. Just like simulation one this simulation will also go under the same 3 turbidity factors and 4 different maintenance programs. The 3rd simulation on the other hand is based on a dynamic structure. In this sort of structure, the panel does not rotate but in fact the floors of the building will rotate. Such a dynamic structure does not exist but with some help from our mechanical engineers (Muhammad Faiq Ali Siddiqi) and a little inspiration from the first ever spinning structure in the world, Suite Vollard in Brazil [26] we have been able to realize some architectural designs for our dynamic structure.

As seen in the fig 4 that the building is circular in shape to allow smooth rotation. On top of that each floor of the building is around 3.5 meters in height with the roof being approximately around 2.5 meters in height (and open to air). The building is having a diameter of around 22 m and a circumference of 140 meters. In our 3rd simulation category we have designed the building of different size (varying the number of floors of the building). For category 3 we have 5 different sizes of buildings they are:

1. 3 floors (ground+1 floor+rooftop)
2. 4 floors (ground+2 floors+rooftop)
3. 5 floors (ground+3 floors+rooftop)
4. 6 floors (ground+4 floors+rooftop)
5. 7 floors (ground+5 floors+rooftop)

All floors of the building rotate and will be deployed with a fixed panel except for the ground floor only, it does not rotate and won't be deployed with a panel. As seen on figures, each floor will have at least 4 apartments. The idea of rotation is very simple a static core (which holds the elevator of the building) will remain static. As for the floors, will rotate around this static core. Or if possible, only the window frames installed with panels will slide around the circumference of the building. For the piping and electricity lines we will be using the owl connection [26] which basically means using rubber connections to allow fixed but flexible connections to be used. Due to simplicity, only a single panel has been deployed on each floor (except for ground floor, it has no panels installed). All these plans are still in their primary stage, but just for us to set up our simulator (to present accurate results) we must present some-sort of vision for our dynamic building and hence these drawings enabled us to setup simulators for category 3 structures (Figures 2-4).

Financial Analysis

For setting up a fixed or a rotatory solar panel you need the following equipment this equipment used will produce fixed costs, all of which has been shown below:

1. Solar panel (size 20 m × 20 m), cost around 6,500 AED (varies with size).
2. Charge controller, cost around 200 AED (life span of 10 years)
3. Battery, 200 AED. (varies with size) (life span of 5 year)
4. And an inverter, 100 AED (Life span of 10 years)
5. Installation cost for stationary panel 2,000 AED and cost for installing rotatory panel 2,500 AED.

Figure 1: Stationary building with a fixed solar panel deployed on the rooftop (left), stationary building with a fixed solar panel deployed horizontally on the building (right).

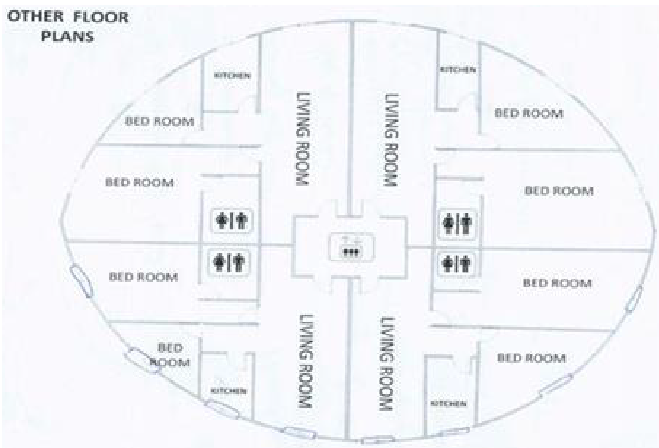

Figure 2: The architectural design for the other floors.

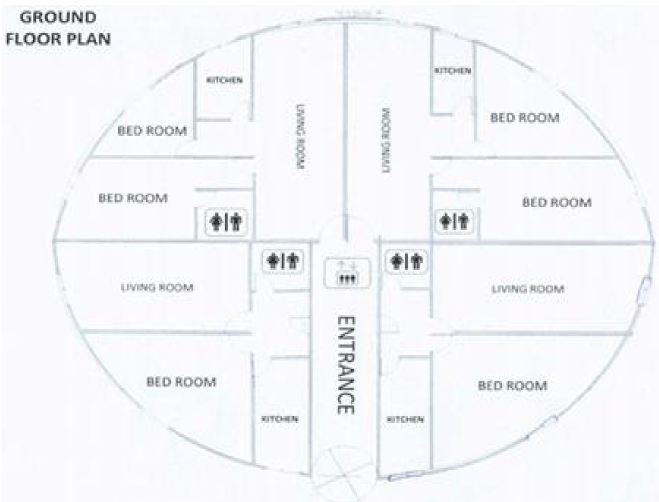

Figure 3: The architectural design for the ground floor plan.

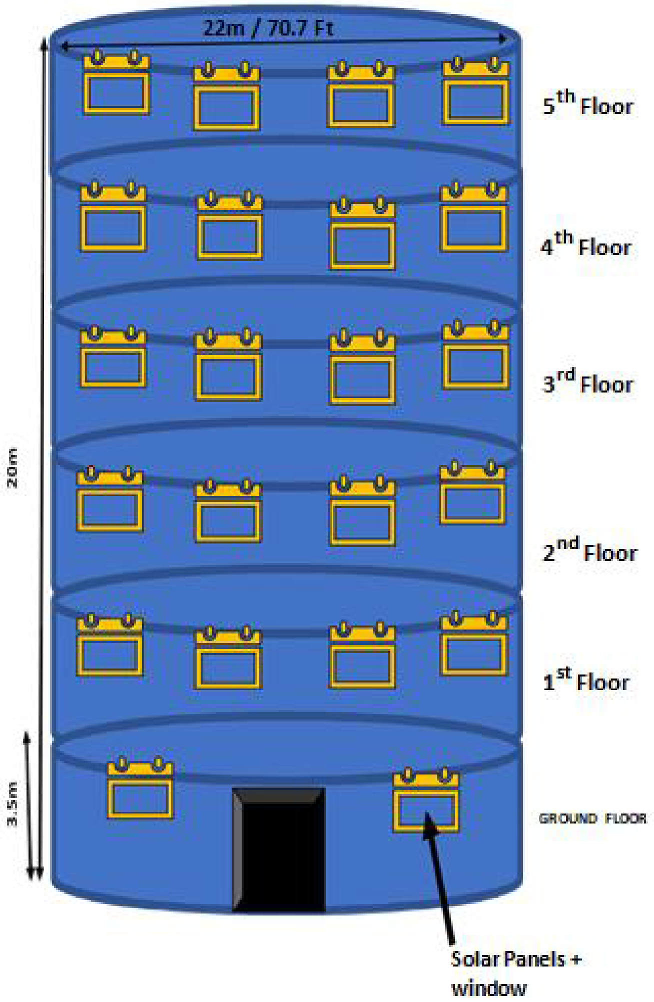

Figure 4: An artistic impression of the dynamic structure used for simulation purposes.

The price for building a stationary building has been excluded because an already existing standard 5 floor stationary building has been implemented with a solar panel. One of the most important current costs that will keep varying are the maintenance costs, the cost of maintenance is the following (renewableeconomy.com):

1. Fortnight (75 AED a total of 1800 AED annually).
2. Monthly (50 AED a total of 600 AED annually).
3. Every 2 months (50 AED a total of 300 AED annually).
4. Every 6 months (100 AED a total of 200 AED annually).

These costs are based on per panel basis. Since our simulation for dynamic structure varies with different sizes of floors the cost of the buildings varies, the cost of each different structure can be seen below in the Table 2.

The costing for the dynamic building is very similar to a stationary building. Simply each floor almost cost around a million dirhams, the roof costs almost half a million and the foundation works costs around another half a million. A very important fact to be remembered is that since dynamic buildings rotate it is important to consider the amount of energy required to rotate lost to the motor is around 370 watts for a rotation of 360 degrees in an hour. Based on our results the maximum our floors need to rotate is around 210 degrees and all the way back in exactly 24 hours that is around 420 degrees in 24 hours (meaning almost 18 watts per hour or almost 160 kW per annum). Although we have taken mechanical losses to be approximately 5% in our category 3 simulation based on our calculations the mechanical losses are very small and can be easily further reduced by improving the pivot in the structure.

Revenue for each building will be generated based on the amount of energy that will be produced by the solar panel in KWh, this energy than will be multiplied into the unit rate of the electricity bill in the UAE (38 fils/KWh). By using such standards, we will be able to analyze each and every simulation result we produced. So, in the next segment of this chapter we are going to analyze each simulation based on two factors they are:

- Energy production (how much energy was produced by the solar panel under certain conditions and factors kept in mind). The bigger the amount of energy production from the panel the better it is.

Results and Analysis

Results of simulation 1

The results of the total energy produced by the panel for category 1 can be seen below Table 3. In general, for all the structures in category 1 the following points can be concluded:

1. Fortnight maintenance is not recommended as it does not produce sufficient revenue to generate a payback.
2. The three highest revenues were generated respectively by simulation 1.5 (under monthly and 6 months' maintenance) and simulation 1.2 (under monthly and 2 months' maintenance).
3. The top three paybacks were calculated to be from simulation 1.5 and 1.2 both under 6 months' maintenance contracts as they have the lowest running costs.
4. Pure conditions generate the highest solar energy and the highest revenues.
5. Placing the solar panel either on top of the roof or vertically on the building does not make a big difference (if the solar cell placed vertically or the rooftop is oriented to the south-west direction at 23.5 degrees' tilt angle, this only true for U.A.E location). Although the rooftop panels do seem to perform slightly better than its vertical counterpart (the difference however is too small and so negligible).

So, in short to summarize category 1 the best suited deployment of solar cells would be in pure conditions either rooftop/vertically placed, under monthly/2 months maintenance contract, which is also evident from the graph (simulations 1.2 and 1.5) (Figure 5).

Results of simulation 2

The results of the total energy produced by the panel for category 2 can be seen below Table 4. In general, for all the structures in category 2 the following points can be concluded:

Dynamic building structure	Cost in AED
G+1+R	3 million
G+2+R	4 million
G+3+R	5 million

Table 2: Cost in AED for each different dynamic structure.

Simulation number	Total annual energy produced (KWh)	Total annual Revenue (AED)	Initial cost of the panel (AED)	Total annual running cost of the panel (AED)	Payback Period (years)
1.1 (Fortnight)	2163.797095	822/-	9,000/-	1800/-	Not possible
1.1 (Monthly)	2128.25226	809/-	9,000/-	600/-	43.1
1.1 (2 Months)	2164.336255	822.5/-	9,000/-	300/-	17.2
1.1 (6 Months)	2174.110188	826.2/-	9,000/-	200/-	14.4
1.2 (Fortnight)	2360.899	897/-	9,000/-	1800/-	Not possible
1.2 (Monthly)	2375.01	902/-	9,000/-	600/-	29.8
1.2 (2 Months)	2374.293	902/-	9,000/-	300/-	14.95
1.2 (6 Months)	2343.886	891/-	9,000/-	200/-	13.02
1.3 (Fortnight)	1896.862909	720.8/-	9,000/-	1800/-	Not possible
1.3 (Monthly)	1896.734109	720.75/-	9,000/-	600/-	74.5
1.3 (2 Months)	1896.338719	720.61/-	9,000/-	300/-	21.4
1.3 (6 Months)	1896.91695	720.83/-	9,000/-	200/-	17.3
1.4 (Fortnight)	2178.978598	828/-	9,000/-	1800/-	Not possible
1.4 (Monthly)	2178.580549	827.9/-	9,000/-	600/-	39.49
1.4 (2 Months)	2178.126406	827.7/-	9,000/-	300/-	17.06
1.4 (6 Months)	2177.874104	827.6/-	9,000/-	200/-	14.34
1.5 (Fortnight)	2285.036	868.3/-	9,000/-	1800/-	Not possible
1.5 (Monthly)	2375.01	902.5/-	9,000/-	600/-	29.75
1.5 (2 Months)	2366.318	899.2/-	9,000/-	300/-	15.02
1.5 (6 Months)	2373.437	902/-	9,000/-	200/-	12.82
1.6 (Fortnight)	1897.261	721/-	9,000/-	1800/-	not possible
1.6 (Monthly)	1896.734	720.75/-	9,000/-	600/-	74.5
1.6 (2 Months)	1896.339	720.6/-	9,000/-	300/-	21.4
1.6 (6 Months)	1896.119	720.5/-	9,000/-	200/-	17.3

Table 3: Analysis of results for category 1 simulation.

- Just again as structures of category 1 Fortnight maintenance is not recommended as it does not produce sufficient revenue to generate a payback. Although all simulations of category 2 produced the highest revenue for fortnight maintenance but the difference in between these maintenance revenues is a dirham, then why does the fortnight maintenance still not produce a payback is because of the running cost. The running cost of the fortnight maintenance is more than 50% of other maintenance contracts.
- The two highest revenues were generated respectively by simulation 2.3 and 2.4 again this was produced under pure conditions with maximum revenue of 1582 and a minimum of 1551 dirhams.
- The top two paybacks were calculated to be from simulation 2.3 and 2.4 both under 6 months' maintenance contracts as they have the lowest running costs.
- pure conditions generate the highest solar energy and the highest revenues.

So, in short to summarize category 2 the best suited deployment of solar cells would be in pure conditions (simulation 2.3), under 6 months' maintenance contract as evident from the graph (Figure 6).

Results of simulation 3

The results of the total energy produced by the dynamic buildings can be seen below Table 5. Some important facts that can be concluded from the tables above are (simulations 3.1, 3.2 and 3.3):

Total (G+1+R): The energy produced by the cells keeps on reducing as the maintenance period lengthens, but by a very small amount (almost negligible).

- The payback period also keeps on reducing since the cost of maintenance reduces considerably as compared to energy produced.
- Pure conditions produce the highest revenues and the smallest paybacks and polluted conditions the lowest revenues with highest paybacks.
- In all cases "fortnight" maintenance does not produce enough revenue to generate a possible payback period. Hence maintenance under fortnight is not recommended at all.
- In terms of revenue and payback best simulation is 3.2.
- When analysing the payback with cost of building the best result is produced by simulation 3.2 under 6 months' maintenance (1302 years). The payback is in thousands of years, but this is our worst-case scenario (when we are not even able to sell one apartment of the building), but under the best scenario meaning if we are able to sell all our apartments (in total 8 apartment) at a cost of 500 K dirhams then the profit per annum is (8*500 K) is 4 million dirhams. Meaning you will have a payback within the first year of the building. And to generate break even in the first year you require to sell at least 6 apartments at the price of 500 K.

Some important facts that can be concluded from the tables above are (simulations 3.4, 3.5 and 3.6).

Total (G+2+R):

- The energy produced by the cells keeps on reducing as the maintenance period lengthens, but by a very small amount (almost negligible).

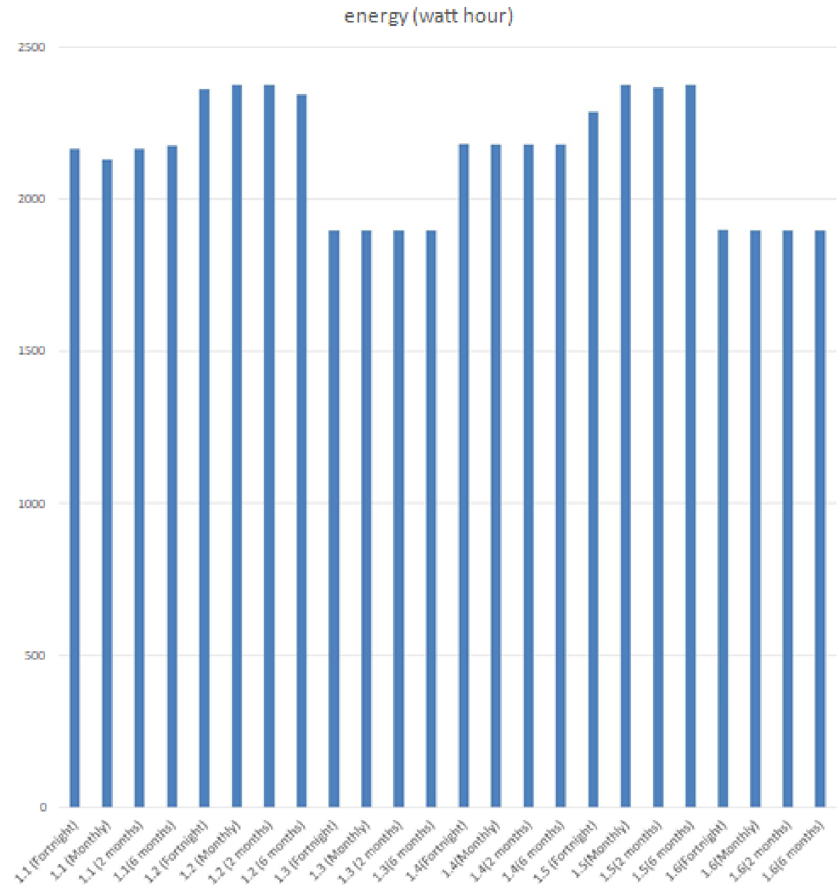

Figure 5: The category simulation 1 energy produced.

Simulation number	Total annual energy produced (KWh)	Total annual Revenue (AED)	Initial cost of the panel (AED)	Total annual running cost of the panel (AED)	Payback Period (years)
2.1 (Fortnight)	3782	1437.2/-	9,500/-	1,800/-	Not possible
2.1 (Monthly)	3780.918	1436.74/-	9,500/-	600/-	11.35
2.1 (2 months)	3780.13	1436.4/-	9,500/-	300/-	8.36
2.1 (6 Months)	3779.692	1436.3/-	9,500/-	200/-	7.68
2.2 (Fortnight)	3705.565	1408/-	9,500/-	1,800/-	Not possible
2.2 (Monthly)	3704.536	1407.7/-	9,500/-	600/-	11.76
2.2 (2months)	3703.763	1407.4/-	9,500/-	300/-	8.58
2.2 (6 Months)	3703.334	1407.3/-	9,500/-	200/-	7.87
2.3 (Fortnight)	4165.032	1582.7/-	9,500/-	1,800/-	Not possible
2.3 (Monthly)	4163.875	1582.3/-	9,500/-	600/-	9.67
2.3 (2 Months)	4163.007	1581.9/-	9,500/-	300/-	7.41
2.3 (6 Months)	4162.524	1581.8/-	9,500/-	200/-	6.88
2.4 (Fortnight)	4080.89	1551/-	9,500/-	1,800/-	Not possible
2.4 (Monthly)	4079.756	1550.3/-	9,500/-	600/-	9.997
2.4 (2 Months)	4078.906	1549.98/-	9,500/-	300/-	7.6
2.4 (6 Months)	4078.433	1549.8/-	9,500/-	200/-	7.04
2.5 (Fortnight)	3254.426	1236.7/-	9,500/-	1,800/-	Not possible
2.5 (Monthly)	3253.521	1236.3/-	9,500/-	600/-	14.9
2.5 (2 Months)	3252.843	1236.1/-	9,500/-	300/-	10.15
2.5 (6 Months)	3252.466	1235.9/-	9,500/-	200/-	9.17
2.6 (Fortnight)	3188.68	1211.7/-	9,500/-	1,800/-	Not possible
2.6 (Monthly)	3187.794	1211.36/-	9,500/-	600/-	15.54
2.6 (2 Months)	3187.129	1211.1/-	9,500/-	300/-	10.43
2.6 (6 Months)	3186.76	1210.9/-	9,500/-	200/-	9.4

Table 4: Simulation category 2 results and analysis of energy and payback periods.

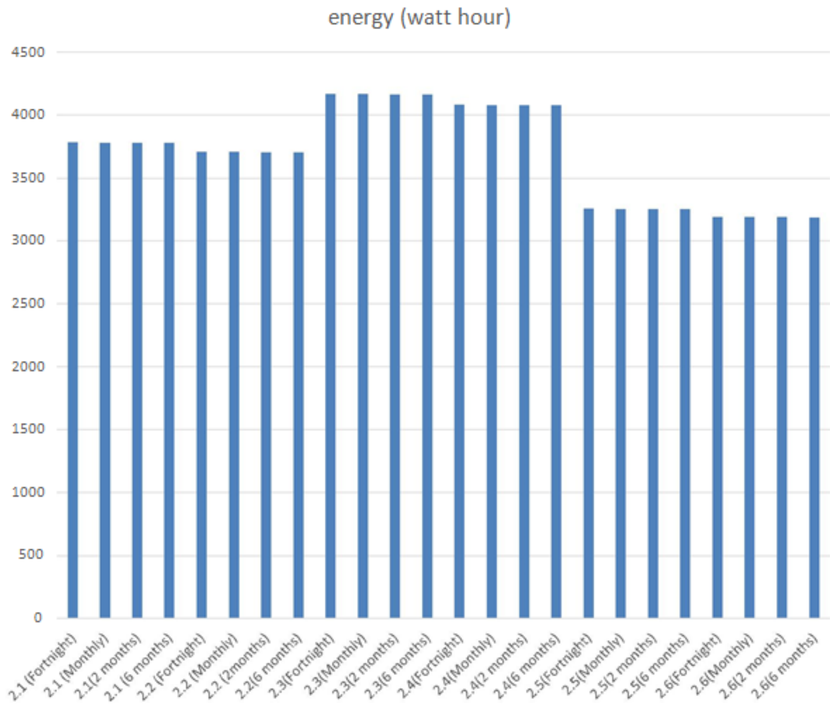

Figure 6: Total energy produced by each simulation of category 2.

Simulation number	Total annual energy produced (KWh)	Total annual Revenue (AED)	Initial cost of the panel (AED)	Total annual running cost of the panel (AED)	Payback Period (years)	Payback Period w/o building cost (years)
3.1 (Fortnight)	6496.894	2468.82/-	(18000)+(3M)	3200/-	Not possible	Not possible
3.1 (Monthly)	6495.089	2468.13/-	(18000)+(3M)	1200/-	2379.9	14.2
3.1 (2 Months)	6493.735	2467.62/-	(18000)+(3M)	600/-	1616	9.64
3.1 (6 Months)	6492.982	2467.33/-	(18000)+(3M)	400/-	1459.9	8.7
3.2 (Fortnight)	7156.822	2719.59/-	(18000)+(3M)	3200/-	Not possible	Not possible
3.2 (Monthly)	7154.833	2718.84/-	(18000)+(3M)	1200/-	1987	11.9
3.2 (2 Months)	7153.342	2718.3/-	(18000)+(3M)	600/-	1424.7	8.5
3.2 (6 Months)	7152.513	2717.95/-	(18000)+(3M)	400/-	1302	7.77
3.3 (Fortnight)	5588.77	2123.73/-	(18000)+(3M)	3200/-	Not possible	Not possible
3.3 (Monthly)	5587.217	2123.14/-	(18000)+(3M)	1200/-	3269.3	19.5
3.3 (2 Months)	5586.052	2122.7/-	(18000)+(3M)	600/-	1982	11.8
3.3 (6 Months)	5585.405	2122.45/-	(18000)+(3M)	400/-	1752.1	10.5
3.4 (Fortnight)	9852.432	3743.92/-	(27000)+(4M)	5400/-	Not possible	Not possible
3.4 (Monthly)	9849.695	3742.89/-	(27000)+(4M)	1800/-	2072.7	13.9
3.4 (2 Months)	9847.642	3742.1/-	(27000)+(4M)	900/-	1416.9	9.5
3.4 (6 Months)	9846.501	3741.67/-	(27000)+(4M)	600/-	1281.8	8.6
3.5 (Fortnight)	10853.2	4124.216/-	(27000)+(4M)	5400/-	Not possible	Not possible
3.5 (Monthly)	10850.19	4123/-	(27000)+(4M)	1800/-	1733.5	11.6
3.5 (2 Months)	10847.92	4122.2/-	(27000)+(4M)	900/-	1249.8	8.4
3.5 (6 Months)	10846.67	4121.73/-	(27000)+(4M)	600/-	1143.5	7.7
3.6 (Fortnight)	8475.278	3220.6/-	(27000)+(4M)	5400/-	Not possible	Not possible
3.6 (Monthly)	8472.923	3219.7/-	(27000)+(4M)	1800/-	2836.5	19
3.6 (2 Months)	8471.156	3219/-	(27000)+(4M)	900/-	1736.5	11.6
3.6 (6 Months)	8470.175	3218.7/-	(27000)+(4M)	600/-	1537	10.3
3.7 (Fortnight)	13279.37	5046.1606/-	(36000)+(5M)	7200/-	Not possible	Not possible
3.7 (Monthly)	13275.68	5044.7584/-	(36000)+(5M)	2400/-	1904	13.6
3.7 (2 Months)	13272.91	5043.7058/-	(36000)+(5M)	1200/-	1310.2	9.37
3.7 (6 Months)	13271.37	5043.1206/-	(36000)+(5M)	800/-	1186.9	8.48
3.8 (Fortnight)	14628.23	5558.727	(36000)+(5M)	7200/-	Not possible	Not possible

3.8 (Monthly)	14624.16	5557.183	(36000)+(5M)	2400/-	1595	11.4
3.8 (2 Months)	14621.12	5556.024	(36000)+(5M)	1200/-	1156	8.26
3.8 (6 Months)	14619.42	5555.381	(36000)+(5M)	800/-	1059	7.57
3.9 (Fortnight)	11423.2	4340.816	(36000)+(5M)	7200/-	Not possible	Not possible
3.9 (Monthly)	11420.03	4339.61	(36000)+(5M)	2400/-	2596	18.6
3.9 (2 Months)	11417.65	4338.705	(36000)+(5M)	1200/-	1604.5	11.5
3.9 (6 Months)	11416.32	4338.203	(36000)+(5M)	800/-	1423.3	10.2

Table 5: Energy and the payback periods of simulation under category.

- The payback period also keeps on reducing since the cost of maintenance reduces considerably as compared to energy produced.
- Pure conditions produce the highest revenues and the smallest paybacks and polluted conditions the lowest revenues with highest paybacks.
- In all cases "fortnight" maintenance does not produce enough revenue to generate a possible payback period. Hence maintenance under fortnight is not recommended at all.
- In terms of revenue and payback best simulation is 3.5.
- When analysing the payback with cost of building the best result is produced by simulation 3.5 under 6 months' maintenance (1143.5 years). The payback is in thousands of years, but this is our worst-case scenario (when we are not even able to sell one apartment of the building), but under the best scenario meaning if we are able to sell all our apartments (in total 12 apartment) at a cost of 500 K dirhams then the profit per annum is (12*500 K) is 6 million dirhams. Meaning you will have a payback within the first 6 months of the building. And to generate break even in the first year you require to sell at least 8 apartments at the price of 500 K. Some important facts that can be concluded from the tables above are (simulations 3.7, 3.8 and 3.9).

Total (G+3+R):

- The energy produced by the cells keeps on reducing as the maintenance period lengthens, but by a very small amount (almost negligible).
- The payback period also keeps on reducing since the cost of maintenance reduces considerably as compared to energy produced.
- Pure conditions produce the highest revenues and the smallest paybacks and polluted conditions the lowest revenues with highest paybacks.
- In all cases "fortnight" maintenance does not produce enough revenue to generate a possible payback period. Hence maintenance under fortnight is not recommended at all.
- In terms of revenue and payback best simulation is 3.8.
- When analysing the payback with cost of building the best result is produced by simulation 3.8 under 6 months' maintenance (1059 years). The payback is in thousands of years, but this is our worst-case scenario (when we are not even able to sell one apartment of the building), but under the best scenario meaning if we are able to sell all our apartments (in total 12 apartment) at a cost of 500 K dirhams then the profit per annum is (16*500 K) is 8 million dirhams. Meaning you will have a payback within the first 3 months of the building. And to generate break even in the first year you require to sell at least 10 apartments at the price of 500 K.

In general, for all the structures in category 3 the following points can be concluded:

- Just again as structures of category 1 and 2. Fortnight maintenance is not recommended as it does not produce sufficient revenue to generate a payback. Although all simulations of category 3 produced the highest revenue for fortnight maintenance but the difference in between these maintenance revenues is a dirham or two, then why does the fortnight maintenance still not produce a payback is because of the running cost. The running cost of the fortnight maintenance is more than 50% of other maintenance contracts.
- In all cases of structures in category 3 always the pure condition produced the highest revenues and the lowest paybacks.
- When comparing the sizes of the building it can be analysed that, as the size of the building increases so does the panels deployed in the building increase (every floor adds another a solar panel) and hence the energy produced by the panels in totality increases and the payback decreases. Which basically means that the profit produced by the panels is greater than there cost as the building size increases. As evident from the graph below (Figure 7).
- This is all good and true when the panels are analysed only without the cost of the building. Upon adding the cost of the building. It was found that the lowest payback was by 3.8 under 6 months' maintenance. Meaning under worst case scenario (1059 years) it seems a taller building in size (more number of floors) will benefit more and will help in reducing the payback even more in the worst-case scenario.

Since all results now have been analysed it is now time to compare these structures against each other. In the following chapter (conclusion and recommendations) we will compare all the three different simulations and answer a key question, based on revenue, energy and payback which of the structures is the best, or is it even feasible to build a dynamic structure or we can just rely on fixed structures with rotating or even better stationary panels. All the comparisons between each simulation will be made and then the best structure will be recommended. Plus, did the simulation fulfil the objective of this research or not, if it did/did not what more can be added to improve the existing simulation.

Discussion

Data initially was collected, simulations were developed using LabVIEW. Results were collected and analysed. Now comes the point to make the conclusion and light the future of solar panels and smart dynamic buildings. This chapter will answer all questions but most importantly will answer these two vital questions:

Citation: Siddiqi MR, Watfa M (2019) Design and Analysis of Innovative Solar Deployment Techniques on Rotating and Non-Rotating Buildings. Innov Ener Res 8: 224. doi: 10.4172/2576-1463.1000224

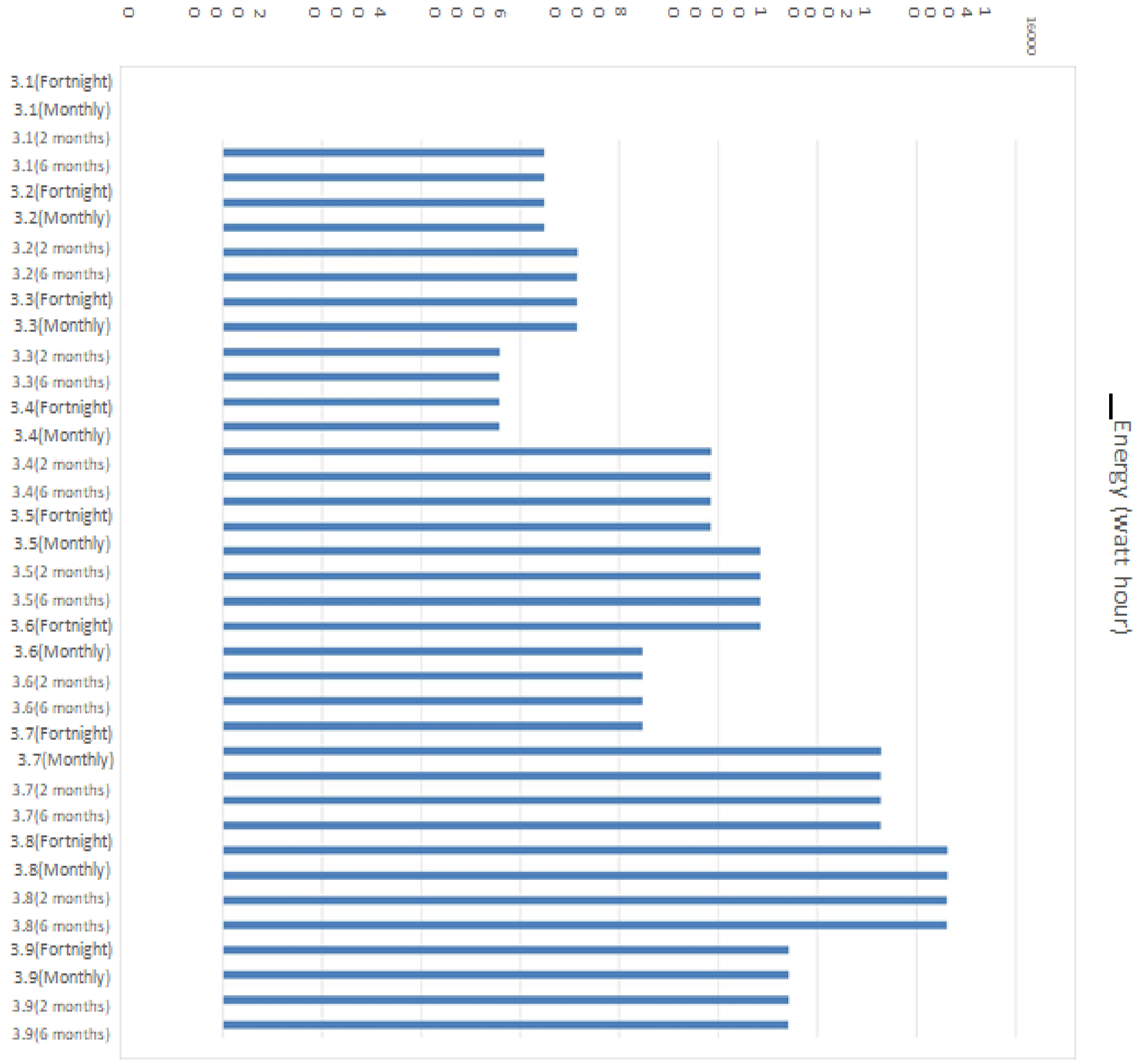

Figure 7: Energy produced by each dynamic structure under category 3 simulation.

1) Firstly a comparison between stationary and rotating panels on already existing stationary buildings and

2) Secondly and the most important the comparison of stationary and dynamic structures deployed with solar panels on them.

With the aid of this conclusion we will be able to present recommendations on how to deploy solar panels effectively on buildings and whether this building should be dynamic in nature or not. Hopefully after this conclusion our simulation would be a bench mark to many researchers who are looking for answers in this area of research.

How accurate are the results of the simulator?

The accuracy of our simulation depends upon the generation of the sun's azimuth and altitude angles. The results of these two angles for the location Fujairah, U.A.E. where compared with the solar calculator available online (websites like (1) www.pveducation.org and (2) suncalc.org). At all times of comparison, the simulations produced and calculate the correct position of the sun.

Which is a better panel (fixed) deployed on rooftop/vertically?

Based on results presented in chapter 9 the two panels' best performance needs to be compared, as shown in Table 6. It is very important to note that both panels produce the same revenue and the vertically deployed panel produces a payback slightly earlier than the rooftop one but almost they are the same. The difference between each of them is very small. Hence it is safe to say that whether the panel is deployed on the roof or vertically on the wall it will produce or generate the same revenue. But both panels have been oriented to its optimum position based on the location UAE (orientation south-west with tilt angle of 23.5 degrees).

Which is better rotating panels or fixed panels?

Based on results presented in chapter 9 the two panels' best performance needs to be compared, as shown Table 7. Despite the rotating panels are facing mechanical losses, still they perform at least 50% better than the fixed panels. Even the worse revenue generator for the rotating panel produces higher revenue and lower payback then the fixed panels.

Panel deployment	Highest revenue	Earliest payback	Structure number
Rooftop	902/-	13.02	1.2 under pure conditions
Vertically	902/-	12.82	1.5 under pure conditions

Table 6: Comparison between panels placed on the rooftop or vertically.

Panel deployment	Highest revenue	Earliest payback	Structure number
Rotating (Rooftop)	1582.3/-	6.88	2.3 under pure conditions
Fixed (Vertically)	902/-	12.82	1.5 under pure conditions

Table 7: Comparison between rotating and non-rotating panels.

Structure number	Highest revenue	Earliest payback
2.3 under pure conditions	1582.3/-	6.88
1.5 under pure conditions	902/-	12.82
3.8 (rooftop panel) under pure conditions	1433.65/-	7.3

Table 8: Comparing three best structures from the 3 different categories.

Structure number	Total highest revenue	Initial cost of the panel +building (AED)	Total annual running cost of the panel (AED)	Payback Period (years)	Payback Period w/o building cost (years)	Ratio of profit over cost
Stationary building (G+3+R)	4288.3/-	(36500)+(4.5M)	800/-	1300.5	10.5	0.000769
3.8 (G+3+R)	5557.183/-	(36000)+(5M)	800/-	1058.6	7.57	0.000945

Table 9: Comparison showing a stationary building compared to a dynamic building.

Reason for this being that the panel when continuously rotating always fixes its angle towards the sun and hence always makes the panel face the sun. Hence it is recommended to use rotating panels for stationary structures.

Do we really need to build dynamic structures? are they worth it?

In the beginning it was clearly mentioned that stationary buildings 40% of the energy usage [27]. Hence one should regardless of the cost should implement a green architecture initiative. But our simulation results further prove this. Based on results presented in chapter 9 the three structures best performance needs to be compared, as shown below Table 8.

When seen individually the rotating panel (on rooftop of a stationary building) produces the highest revenue and the lowest payback. But as proved earlier that as the size of the dynamic building increases the revenue generated by the rooftop panel increases as the shading losses reduce. So most probably if the dynamic structure is also (G+5+R) it will produce similar results to its counterpart 2.3 structure panel. However, comparison over here is debatable hence comparison as a structure is very important. The two worst-case scenarios of both the structures are shown in Table 9.

From our mechanical team (Muhammad Faiq Ali siddiqi) it was suggested that the building cost of a stationary building will be half a million cheaper, hence the cost of building is taken as 4.5 million dirhams. And since the building is stationary we can only deploy a rotating panel on the rooftop and elsewhere on the floors we have to place fixed panels hence the total revenue calculated is 4288.3/- AED (1582.3/-+902/-*3). Based on a structural basis for comparison the dynamic building produces higher total revenue and lower payback periods (for with and without building cost). So, in this comparison one of our major questions of this research gets answered, which is that dynamic structures can produce greater revenue, lower payback periods as compared to a stationary building of the same size.

So, do we need to start venturing in the dynamic structure business? Is the difference so big? To answer look at the last column of the previous table (the profit/cost ratio) the bigger the number the better it is, and again the ratio for the dynamic building is bigger than the stationary building. Which answers our question to start venturing in dynamic structures is a, yes. In this modern age with technology increasing day by day the cost of making dynamic buildings (as we improve our understanding about dynamic structures) will eventual keep going down (and the profit to cost ratio will keep getting bigger). Using smart dynamic structures with solar panels seems to be future of smart buildings and should be pursued. In conclusion (based on my results and analysis) dynamic structures to be deployed with solar energy are more feasible financially and in terms of energy production than stationary structures deployed with solar energy.

As a part of continuing research in this direction a few recommendations are necessary:

- Due to time constraints only the Ghouard model was applied, since it was the most accurate and precise model [24]. However, other models are also available such as Perrin Brimchambaut model, Capderou model, and many more such models. By applying different models, we can see which of these models most closely resembles the global radiation pattern of U.A.E.
- To make the simulation more realistic it is recommended to add variation of the solar panels with changes in the temperature. Because some panels show an increase in efficiency when the temperatures increase [28-43] so using them in places like U.A.E is ideal.

Conclusion

Just to summaries my conclusion the findings o f t his r esearch direct towards using rotating panels over fixed panels on stationary buildings. However, the results give a clear indication that a dynamic structure is more energy productive and financially feasible than using stationary structures and that architects around the world need to innovate the building architecture around us. Lastly a very strong and reliable simulation has been made using LabVIEW to present real-life situations with the need of any sort of hardware (free of cost).

Acknowledgment

First and foremost, my greatest thanks goes to Allah for he is the reason behind all. Secondly, I would like to extend my warmest of thanks to my dissertation advisor Dr Mohammad Watfa, because of him we were introduced to the topic of my research and more importantly his kind advice lead to the result of what I have managed to do in this proposal so far. Also, we would like to pass my thanks to my family and friends who helped me proof read my work and most importantly understood the long weekend hours I spent in front of my computer just ignoring them all and completing my research.

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