Influence of the Solarus AB reflector geometry and position of receiver on the output of the concentrating photovoltaic thermal collectors

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ABSTACT

Solar energy, if harnessed efficiently can provide the world with clean and reliable power supply. Solarus AB manufactures hybrid solar PVT which provides both thermal and electrical energy using a unique design of asymmetric parabolic collector called MaReCo or Maximum Reflector Collector. The main goal of the thesis is to study, model and characterise suitable designs for a concentrating PVT collector at different locations on the globe to optimise the power at the receiver without cost penalties of the overall system. The power output on the receiver of the solar collector is analysed with respect to the time of the year, the inclination angle of the collector and also the hourly variation of the day. With standard MaReCo simulations are performed at Gävle, Lisbon and Delhi observing the change in the output as the latitude decreases gradually. It has been found that with a little orientation change in the system for lower latitude places, the performance of MaReCo improved further. A modified MaReCo model is also introduced and simulated at Lisbon and Gävle checking its feasibility and usability. Due to easier availability of solar energy and larger market potential, simulations are made at Nairobi and Lisbon and compared. Two types of symmetrical parabolic collectors are designed for such simulations. The parabolic collector with side edge receiver is found to be the best suitable collector at the equatorial region for all the season.

Keywords: MaReCo; parabolic collectors; inverted orientation;

1. Introduction

Modernisation plays a huge role in the change of behaviour of the people. The behaviour towards energy, not only in production but also in the consumption. By the end of 2016, 303 GW of PV have been installed all over the world, 16 countries installed at least 500 MW of PV, Germany ranks first in solar PV per capita with 511 watt/capita [1]. Renewable energy sources (RES) share of gross German electricity production in 2015 was 30.7% [2].

The world energy consumption at the moment is 10 terawatts (TW) per year. By the year 2050 the expected energy consumption would be 30 TW. The conclusion is an additional 20 TW of CO2 free energy source is required to balance the demand. One solution to stabilize CO2 might be to use photovoltaics (PV) and other renewables like hydro and wind for electricity (10 TW), hydrogen for the transportation (10 TW), and fossil fuels for residential and industrial heating (10 TW) [3]. Hence solar energy (photovoltaics) will play an important role in meeting the world future energy demand. The present is considered as the “tipping point” for PV [4].

Mainly flat plate solar panel and concentrated solar power systems are used today to capture the light energy from the sun. Photovoltaic thermal (PVT) hybrid system is the combination of the mentioned methods. MaReCo or Maximum Reflector Collector is an asymmetrical solar collector used in PVT hybrid systems. The main purpose of the thesis is to analyse the extent and limitations of MaReCo with respect to the location of the place on the globe and ways to improve the performance without any extra cost and major complications. Remodelling of the standard MaReCo is done and compared with the previous design. The potential of solar power lies in the equatorial region where the position of the sun rarely changes. Due to less solar position shifts, symmetrical parabolic collectors with varying receiver positions are simulated in such regions and analysed for the best situation and condition.

2. Background

2.1. The solar collector

"The sun provides more energy in four hours than the human race consumes in all forms in an entire year" [5]. To harness this solar energy, solar collectors are used. The solar collectors converts the solar energy to either electricity (Photovoltaic) or heat (Thermal) or both (PV-T). Solar collectors are mainly of two types: flat-plate collectors and concentrating collectors. Most of the simulations performed in this thesis are focused mainly on concentrated collectors.

2.1.1. Flat-plate collectors

A typical flat-plat collector is shown in Figure 1. A flat-plate collector is a metal box with a glass or plastic cover known as glazing on the top and a dark-coloured absorber plate on the bottom.

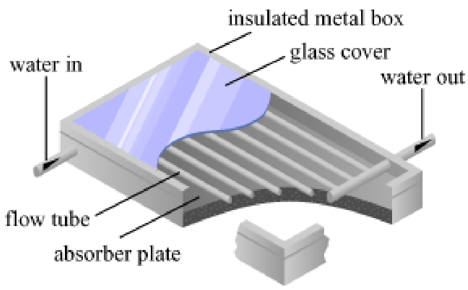


Figure 1. Flat-plate collector [7]

The sides and the bottom are normally insulated to minimize heat loss. To protect the absorber from rain and dust is another reason why the absorber is put inside a box [6]. The sunlight which passed through the glazing cover strikes and heats up the absorber plate converting the solar energy to heat energy. The heat energy is then transferred to the liquid used in the absorber pipes attached to the absorber plates.

2.1.2. Concentrating collectors

A very basic concentrating collector is shown in the Figure 2.below.

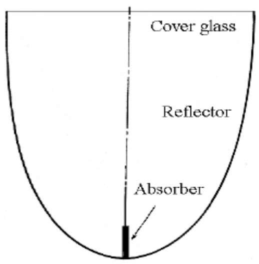


Figure 2.Concentrating Collector sketch [8]

The concentrating reflector reflects the incoming light from the sun and directs towards the absorber where it is then transferred to the heat carrying medium.

2.1.2.1. Compound Parabolic Collector (CPC)

Compound parabolic collectors belong to non-imaging concentrating collectors. These systems comprise of two parabolic reflectors with different focal points. Hence the nomenclature compound parabolic collector. Figure 3. shows the basic shape of the collector.

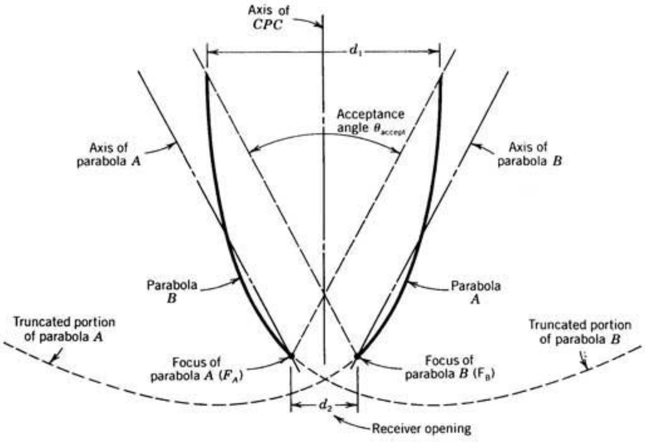


Figure 3. Compound Parabolic Collector [9]

2.1.2.2. Maximum Reflector Collector (MaReCo)

The MaReCo or Maximum Reflector Collector is an asymmetrical truncated trough-like CPC collector. It is a non-tracking collector with bi-facial absorber. The usage of bi-facial absorber helps minimize the absorber area hence reducing the cost of production. There are various prototypes of MaReCo, stand-alone MaReCo, roof-integrated MaReCo, east/west MaReCo, spring/fall MaReCo, wall MaReCo.

2.2. Solarus PowerCollector

PowerCollector compound parabolic collector developed and marketed by Solarus. The design is similar to the roof integrated MaReCo. Solarus' PowerCollector comprises of two types of collector, a hybrid concentrated photovoltaic (C-PVT) and a thermal (C-T) collector.

2.2.1. C-PVT

The hybrid concentrated photovoltaic produces both electricity and heat. Figure 4a and 4b gives an idea of the actual collector from Solarus.

Figure 4a Single PowerCollector C-PVT side view [10]

Figure 4b PowerCollector C-PVT silver [5]

PowerCollector C-PVT has two versions of products from Solarus which are C-PVT Black and C-PVT Silver. The C-PVT black is used for in roof installations. The only difference in the specifications between them is C-PVT black produces 1350 W_{th} + 270 W_{el} and C-PVT silver 1250 W_{th} + 270 W_{el}.

2.2.2. C-T

The PowerCollector C-T produces only heat either to heat up space or water. A picture of C-T is shown in Figure 5. The power specification of the PowerCollector C-T is 1500W_{th}. The collector also has an aluminium receiver but it does not come with Active Cell Cooling.

Figure 5. PowerCollector C-T [5]

3. Numerical study method:

The Solarus PowerCollectors are based on the roof integrated MaReCo. An extensive simulation is done with the roof integrated MaReCo at Lisbon which serves as the baseline for the other experimental model simulations. The power output and the number of photons collected on the receiver of the solar collector is analysed in details with respect to the time of the year, the inclination angle of the collector and also the hourly variation of the day. Firstly, to check the feasibility of the already designed and available Solarus PowerCollector in the market, simulations are performed at three different locations Lisbon, Gävle and Delhi. Changes are made with the orientation of the collector to analyse further improvement in the output of the collector. Secondly, the roof integrated MaReCo is redesigned with the receiver position shifted towards the middle section of the aperture. Comparisons are made between the collector models.

The market and solar energy potential is much higher in the equatorial regions. Parabolic collectors are designed for such regions due the symmetrical positioning of the sun. Two solar collector models - parabolic collector with receiver at side edge and parabolic collector with horizontal receiver at the focus are designed and simulated at Nairobi (1.2921° S, 36.8219° E) and at Lisbon. The results are compared afterwards with each other.

The construction of the simulation structures and all the simulations are being performed in the solar ray tracing software Tonatiuh. The output of the software is processed as binary data file. An additional software called Mathematica is used to post process the binary data file output and determine what the work requires.

4. Results and Discussions

Numerous simulations have been performed in various locations of the world, Lisbon, Gävle, Delhi and Nairobi with different solar collector models. Detailed comparative analysis of the cities with respect to each other in terms of the inclination angle of the collector, time of the year and time of the day is performed. More in-depth study about the feasibility and usability of the various collector models in different time of day at various time of the year have also been analysed. The section describes about the discussions regarding the obtained results.

4.1. Roof integrated MaReCo

4.1.1. Lisbon

4.1.1.1. Comparison of power with respect to tilt angle

Simulations are made in 21^{st} June, 21^{st} December, 20^{th} March and 22^{nd} September. The inclination angle is varied from 0^{o} to 65^{o} fixing the time of the day at 12.00. The MaReCo is facing south since the location is in the northern hemisphere. The location of the receiver is positioned in the upper part of the collector.

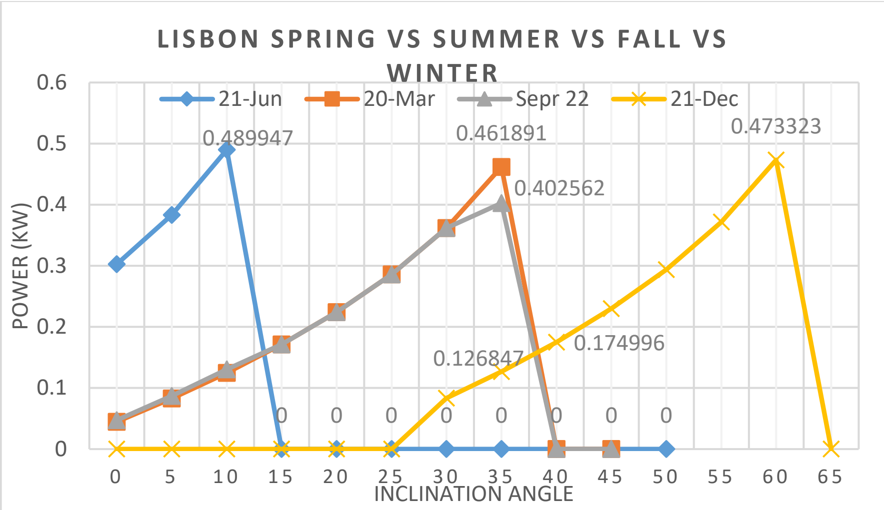


Figure 6. Comparison of the power at the receiver in Lisbon with inclination angle of the collector

The break-off point in summer, the angle after which collector stops producing power due to lack of solar radiation, is 10º. This is due to the reason that the sun is almost perpendicular to the solar collector since the elevation of the sun during summer is large. Hence, most of the solar rays from the sun are reflected back with almost no rays reaching the receiver.

4.1.1.2. Orientation change of MaReCo

However, with a little orientation change in the solar collector, the output of the collector can be tremendously improved. The MaReCo is positioned in such a manner that, although it is still facing south the receiver is located at the bottom of the collector. The change in solar collector orientation is shown properly in Figure 7a and 7b.

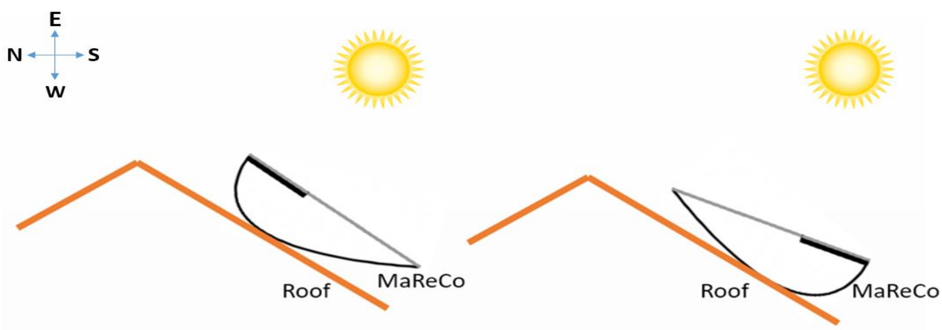


Figure 7a. Normal orientation of MaReCo Figure 7b. Inverted orientation of MaReCo

Due to this new inverted orientation, more light rays enters the collector aperture producing more output power. With the same solar collector without any extra equipment or cost, with a little adjustment in the orientation, more output power can be achieved.

4.1.1.3. Inverted orientation in summer

Fixing the time of the day and varying the inclination angle of the solar collector, simulations are performed with the inverted orientation of the collector. The maximum power output is found to be 0.53287 kW at an inclination angle of 15º with the inverted orientation. The resulting graph is shown in Figure 8.

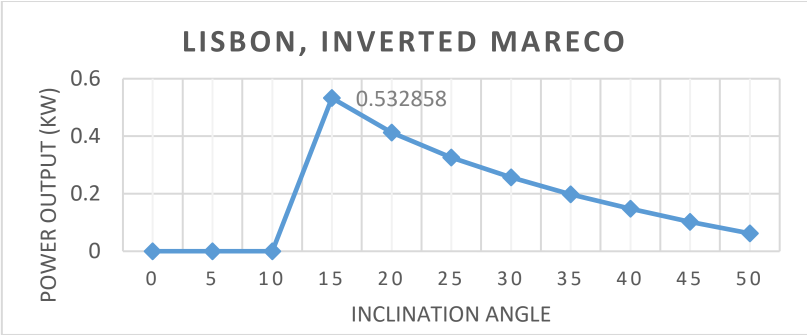


Figure 8. Power output vs inclination of the inverted MaReCo at June 21st

4.1.1.4. Inverted orientation in spring, fall and winter

To check the performance of the inverted orientation of MaReCo during spring, fall and winter, simulations are performed at 20th March, 22nd September and 21st December.

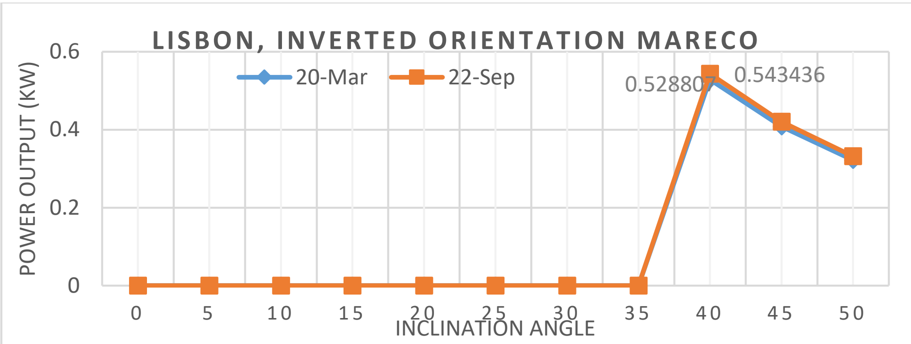


Figure 9. Power output vs inclination angle during 22nd Sept and 20th March

From the curve, it is observed that the power output starts from 40° inclination with a high value of 0.52881 kW for March 20th and 0.543436 kW for 22nd September so it is feasible after the resulted angle. The power output value is larger than the value obtained from the normal orientation. It is not feasible during winter due to no output.

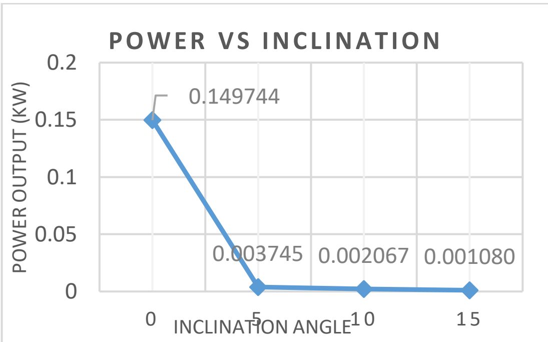
4.2. Parabolic Collector with side edge receiver

Keeping the area of the aperture of the collector the same, symmetrical parabolic collectors are designed for equatorial regions. Here the receiver is located at the side edge of the collector. The feasibility of the parabolic collector with the side edge receiver is checked in Lisbon and Nairobi a city close to the equator.

4.2.1. Lisbon

4.2.1.1. Simulations with normal and inverted orientation in summer

Two sets of simulations are performed during the summer in 21st June with the two orientations, normal and inverted, of the collector.



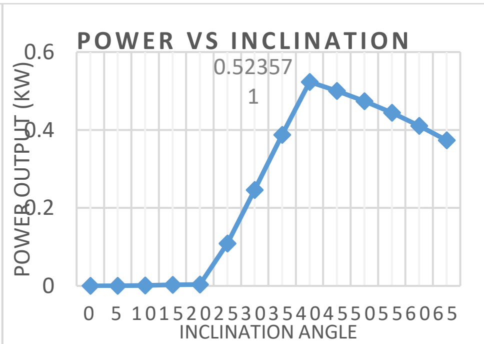


Figure 10a. Lisbon, normal orientation Figure 10b. Lisbon, inverted orientation

An efficient and useful power output can be obtained when the parabolic solar collector with receiver at the side edge is oriented inverted from the normal way. The maximum power output, 0.52357 kW, is obtained at 40° during summer in Lisbon. Comparing with the standard MaReCo, the maximum power output with a value of 0.53286 kW is received at a tilt angle of 15° with the inverted orientation. The feasibility of the two designs is only feasible after a collector tilt angle of 40° from the horizon.

4.2.1.2. Comparison of power with respect to inclination angle

The Figure 11. shows the power curve with respect to the inclination angle during spring, fall and winter during normal orientation.

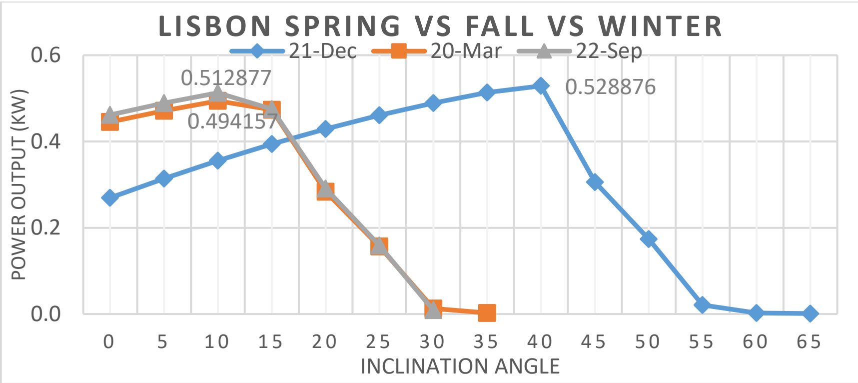


Figure 11. Comparison of the power at the receiver in Lisbon with inclination angle

The power output starts at a lower tilt angle of the receiver for all the curves reaching maximum output at 10° for spring and fall and 40° for winter. The curve depicting spring and fall are almost identical as usual. The design is very well suited for spring and fall. However, for summer and winter unless the house roof angle is less than 40°, the parabolic collector with side edge receiver is well suitable.

4.2.2. Nairobi

Nairobi, the capital city of Kenya in Africa lies very close to the equator with latitude and longitude 1.2921° S and 36.8219° E respectively.

4.2.2.1. Comparison of power with respect to inclination angle

The Figure 12. shows the comparison of the four seasons in Nairobi at 12.00 with varying angle of inclination of the collectors. Regarding Nairobi, since it is located at the equatorial region the orientation of the collector is of less factor to consider. Hence, the solar collector is oriented in the best output condition.

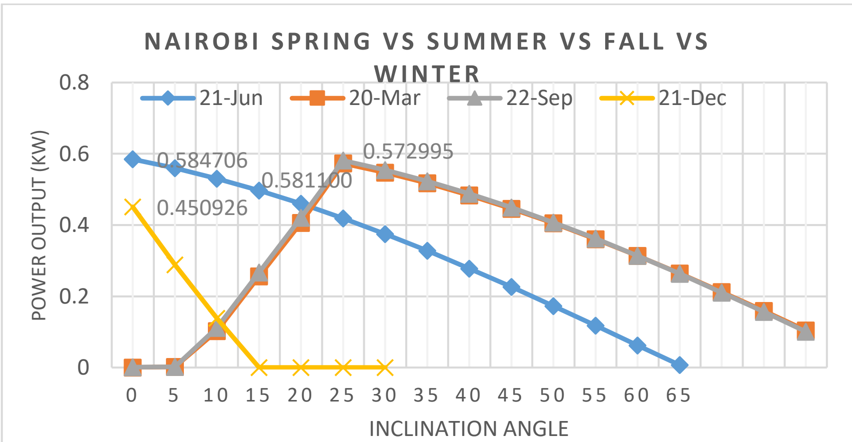


Figure 12. Comparison of the power during 21st June, 20th March, 22nd Sept and 21st Dec at the receiver in Nairobi at 12.00 with inclination angle of the collector ranging from 0° to 65°

The power outputs starts very early for all the four seasons in Nairobi. This is because of the high elevation position of the sun near the equator. The maximum output at summer is obtained at 0° inclination with a value of 0.584706 kW. The curve trend of spring and fall shows identical behaviour with maximum power output angle at 25°. Moreover, the angle of inclination for maximum power output for December is 0°. Hence, the parabolic collector with side edge receiver is very feasible for locations near the lower latitude for all the seasons.

4.3. Comparison

Table 1. Comparison between the designs

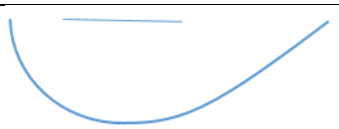
<table>
<tr><th colspan="2">Simulation structure</th><th colspan="3">Max. power output inclination angle</th><th>Feasibility and suitability</th></tr>
<tr><td rowspan="5">
Roof Integrated MaReCo</td><td>Month</td><td>Lisbon</td><td>Delhi</td><td>Gävle</td><td rowspan="5">Lisbon: Better results in spring, fall and summer with inverted orientation
Gävle: Better results in summer with inverted orientation, not suitable for winter
Delhi: Perfect for all seasons, better with inverted orientation during summer, spring and fall</td></tr>
<tr><td>Mar 20</td><td>35</td><td>25</td><td>60</td></tr>
<tr><td>June 21</td><td>15</td><td>10</td><td>30</td></tr>
<tr><td>Sept 22</td><td>35</td><td>25</td><td>60</td></tr>
<tr><td>Dec 21</td><td>60</td><td>50</td><td>n/a</td></tr>
<tr><td rowspan="5">
Redesigned MaReCo</td><td>Month</td><td>Lisbon</td><td colspan="2">Nairobi</td><td rowspan="5">Lisbon: Suitable for spring, summer and fall but lesser output than actual roof integrated MaReCo, not suitable for winter
Nairobi: Suitable for all the seasons</td></tr>
<tr><td>Mar 20</td><td>40</td><td colspan="2">0</td></tr>
<tr><td>June 21</td><td>15</td><td colspan="2">25</td></tr>
<tr><td>Sept 22</td><td>40</td><td colspan="2">0</td></tr>
<tr><td>Dec 21</td><td>65</td><td colspan="2">25</td></tr>
<tr><td rowspan="5">
Parabolic Collector with side edge receiver</td><td>Month</td><td>Lisbon</td><td colspan="2">Nairobi</td><td rowspan="5">Lisbon: Suitable for all the seasons, better output than standard MaReCo, works best for winter
Nairobi: Perfect for all the seasons</td></tr>
<tr><td>Mar 20</td><td>10</td><td colspan="2">25</td></tr>
<tr><td>June 21</td><td>40</td><td colspan="2">0</td></tr>
<tr><td>Sept 22</td><td>10</td><td colspan="2">25</td></tr>
<tr><td>Dec 21</td><td>40</td><td colspan="2">0</td></tr>
<tr><td rowspan="5">
Parabolic Collector with horizontal receiver</td><td>Month</td><td>Lisbon</td><td colspan="2">Nairobi</td><td rowspan="5">Lisbon: Lesser output compared to other models, in winter it acts like a wall MaReCo
Nairobi: Lesser output compared to other models, Modified MaReCo in Nairobi gives better output</td></tr>
<tr><td>Mar 20</td><td>30, 50</td><td colspan="2">10</td></tr>
<tr><td>June 21</td><td>25</td><td colspan="2">10,30</td></tr>
<tr><td>Sept 22</td><td>30, 50</td><td colspan="2">10</td></tr>
<tr><td>Dec 21</td><td>55, 75</td><td colspan="2">10,30</td></tr>
</table>

Table 2. Comparison between normal and inverted orientation of roof integrated MaReCo

	Gävle	**Tilt angle**		**Power (kW)**
 **Roof Integrated MaReCo**	Normal orientation	Mar 20th	60	0.59844
		June 21st	30	0.44454
		Sept 22nd	60	0.61715
		Dec 21st	n/a	n/a
	Inverted orientation	Mar 20th	n/a	n/a
		June 21st	40	0.52733
		Sept 22nd	n/a	n/a
		Dec 21st	n/a	n/a
	Lisbon	**Tilt angle**		**Power (kW)**
	Normal orientation	Mar 20th	35	0.46189
		June 21st	10	0.48995
		Sept 22nd	35	0.40256
		Dec 21st	60	0.47332
	Inverted orientation	Mar 20th	40	0.52881
		June 21st	15	0.53286
		Sept 22nd	40	0.54344
		Dec 21st	n/a	n/a

5. Conclusion

The thesis work is mostly simulation based done with unique solar collector models. The next step to simulations is experimental proof to compare the real time values with the simulated results. However the importance of simulation lies much deeper than perceived. It is a very powerful tool to expose the design model to divergent conditions with no caution of accidents to consider whatsoever ensuring a very safe conditions at almost free of cost. Simulation can be perceived as an investment which will be fruitful in the future and save the user from various problems and difficulties.

The PowerCollector MaReCo from Solarus is a roof integrated model. The actual real time result from the company regarding Gävle goes very well with the simulation results. In case of Lisbon and Delhi where the elevation of the sun is higher than Gävle, the thesis work includes result where a little shift in orientation of the solar collector can result huge improvement with no extra cost. The solar MaReCo still faces south but in the inverted position as described in section 4.1.1.2. A higher output is obtained with the same solar collector. Keeping the area of aperture of the collector in check, symmetrical parabolic collectors are designed for equatorial regions. The cost of production is proposed to be approximately similar since additional materials are not used. Simulations are performed at Nairobi, the capital of Kenya which is located at the equatorial region. The parabolic collector with receiver at the side edge is the best suitable solar collector not only for equatorial region but also for places with lower latitude. The roof integrated MaReCo has difficulties producing effective results during winter. However, the parabolic collector with side edge receiver is feasible with better output than MaReCo during winter. Although there exist a lot of rooms to improve and many factors to be considered more like the thermal aspects, the non-uniform arrangement of the cell along the receiver, unpredictable weather conditions, the simulation results obtained in the thesis work can serve as an important proposition for the following step to be taken. It can be used as a guide post for the next set of simulations and future works proposed which would take part in shaping the future energy demand leading towards a reliable and carbon free environment.

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