THE RAPID PLANNING ENTRY PROJECT IN KIGALI/ RWANDA: SOLAR ROOFTOP PV FOR THE POWER SUPPLY OF BIRYOGO PRIMARY SCHOOL

Background

According to the management of Biryogo Primary School, the monthly electricity bill was between 40,000 and 50,000 RWF in 2015. With residential customers (also schools of this size) paying 134 RWF/kWh (VAT exclusive, 18% VAT) within the first half of 2015, the power consumption was between 250 to 316 kWh per month. However, 16 out of 28 classrooms had no lighting and there were only 600 simple low budget laptops for 1,843 pupils. Both, lighting and use of electronic devices may increase as several examples showed in the past. Furthermore, electricity prices increased to 189 RWF/kWh (VAT exclusive) in 2017 pursuant to No05/BD/ERLER/RURA/2016. Although, electricity demand and electricity bill didn't change significantly within the last two years, a long-term growth should be taken into account.

Due to the connection to the national power grid, there are several power blackouts in addition to high electricity prices. A solar photovoltaic (PV) system with self-consumption could be used to circumvent these problems. Thus, appropriate sites for PV and the climatic conditions have to be analyzed in detail. Solar rooftop PV seems to be a promising approach by looking at the premises of the school in figure 1.

Figure 1: Area of Biryogo Primary School

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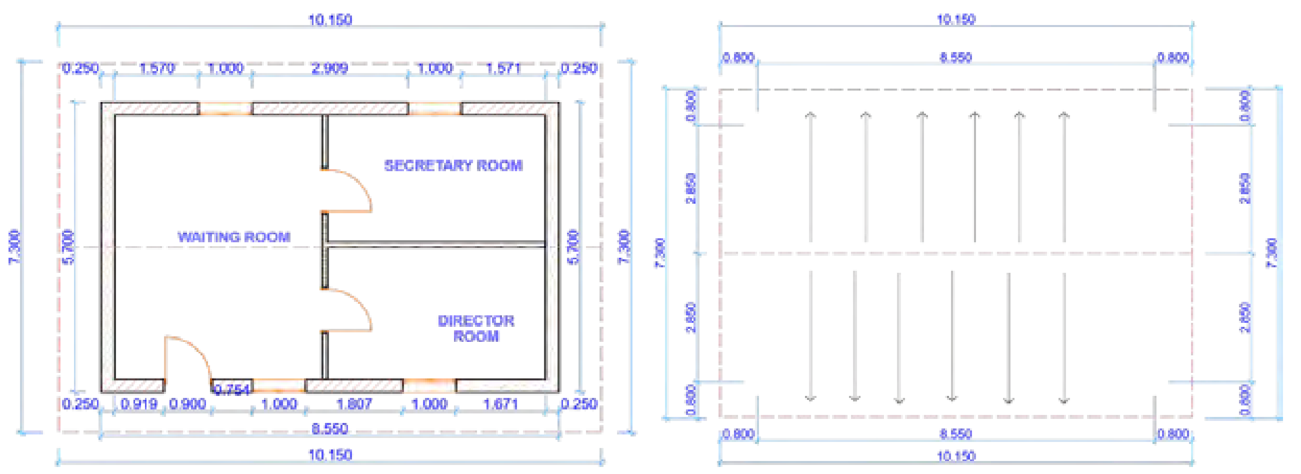
Analysis of the statics and the substance of the office building and its roof

Keeping all this in mind, the office building (see red circle in figure 1) had been analyzed in more detail. It was built in 1982 and characterized by one entry and three rooms (waiting, secretary and directors room). The total floor space is 48.735 m² and the flat roof space 74.095 m². These are the exact numerical values, while 76 m² flat roof space of the building in figure 1 was a first approximation by University of Tübingen with remote sensing (GIS analysis).

The external walls are made of rubble stone and are 3 meters high. The internal walls are made of plywood, the ground floor of concrete, windows and door of metal. The room has no ceiling, the roof truss is made of eucalyptus wood covered by iron sheets called TORIRWA. Figure 2 shows the building and especially the roof from outside and inside. Figure 3 illustrates measurements of the building (left) and of the roof (right), the dashed line shows the outline of the roof.

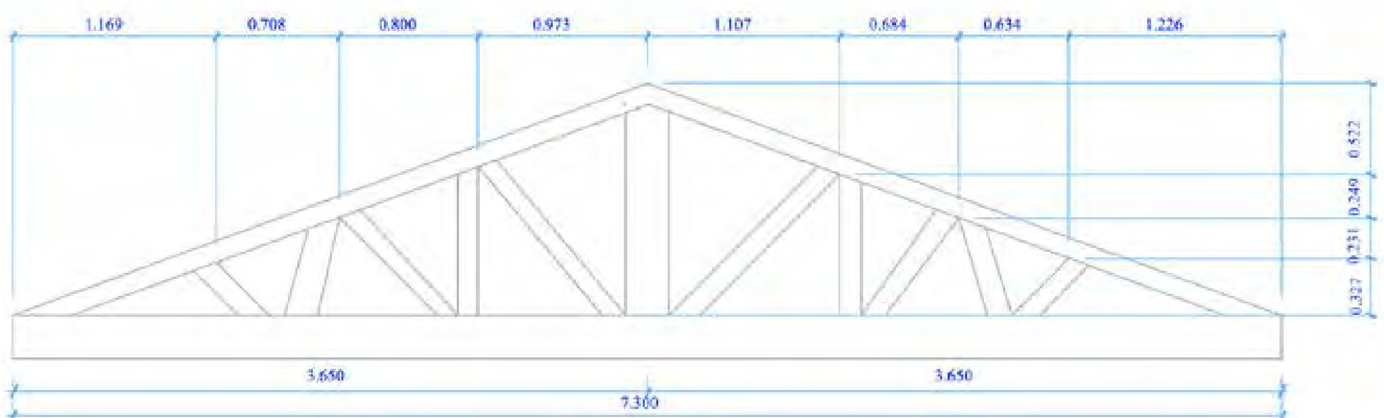
Figure 2: Office building of Biryogo Primary School from outside (left) and inside (right)

Figure 3: Office building of Biryogo Primary School – ground floor plan (left) and roof plan (right) with measurements (in meters)



For roof-mounted PV systems, several parameters are needed to ensure an expedient and safe operation. An essential factor is the load bearing capacity of the roof and the whole building. This is defined by the ability to support loads without any collapse or any failure. Figure 4 shows a vertical cut of the roof, which is called gable roof, due to the two pitched sides, each with a slope angle of 20°.

Figure 4: Vertical cut of the office roof with measurements (in meters)



The roof area with slope is 74.095 m² / cos 20° = 78.850 m². According to the coefficients of BS 6399 (British standards – loading for buildings) and the calculations of Remy Ruberambuga, an engineer and a local partner of the Rapid-Planning-Team from Kigali, the roof can carry between 3 and 5 kN/m², 300 to 500 kg/m² respectively. Dead, live and design load of the walls and roofing materials were taken into account. Thus, permanent and temporary loads were calculated, while the snow load could be neglected due to climate conditions in Kigali. Polycrystalline PV modules have a weight of up to 12 kg/m² and are therefore heavier than monocrystalline or thin film solar modules. Nevertheless, the roof should be strong enough for solar rooftop PV, even with mounting. Not just the static calculations, but also climatic calculations are needed for detailed engineering.

Analysis of the climatic conditions

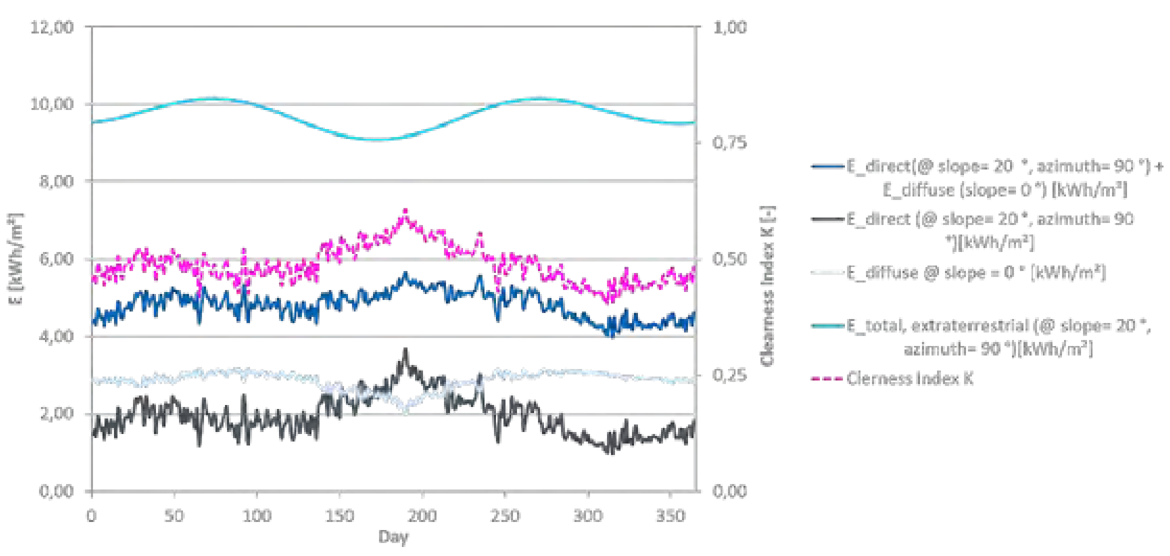
Biryogo Primary School has a total flat roof area of over 2,300 m². However, only a small portion of the roof is needed for PV to cover the energy demand of the school, as the optimum site data of Kigali according to [1] shows in the following:

- Global horizontal irradiation (GHI) ~ 1,900 kWh/m² per annum (p.a.)
- Direct normal irradiation (DNI) ~ 1,300 kWh/m² p.a.
- Diffuse horizontal irradiation (DIF) ~ 900 kWh/m² p.a.
- Global tilted irradiation (GTI) ~ 1,900 kWh/m² p.a.

Polycrystalline modules have an area efficiency of up to 170 Wp/m². In consideration of the site data above, the yearly PV power output is 1,426 kWh/kWp respectively 257 kWh/m². Thus, 12 to 15 m² would generate the needed 3,000 to 3,800 kWh. However, energy storage is crucial to match supply and demand. Due to the fact, that the energy demand of a school is mainly during daytime (at Biryogo Primary School two shifts: 7:20 – 11:50 am and 12:40 – 5:00 pm) PV seems to be expedient and the energy storage system could be kept to a minimum.

Notwithstanding the optimum, inclination and azimuth decrease the value of the previously mentioned factors. According to figure 1, the orientation of the roof is nearly east-west. Thus, the modules facing 90°, are tilted at 20° and therefore have a long-term yearly average energy output of 1,380 kWh/kWp with a global tilted irradiation of 1,860 kWh/m² [1]. Considering the daily averages, PV electricity generation is 3.8 kWh/kWp and global tilted irradiation is 5.1 kWh/m² [1]. These values have been validated by the author with a tool of IER, Uni Stuttgart [2]. The detailed results are represented in figure 5.

Figure 5: Daily specific solar energy levels over a year and clearness index K in Kigali by facing 90° and tilted 20°



Results

With a yearly energy demand of 3,000 to 3,800 kWh before 2016, preliminary long-term calculation are based on 5,000 kWh. To cover the 5,000 kWh p.a., about 3.6 kWp installed capacity respectively 21.4 m² of polycrystalline modules are needed. A turnkey plant of this size should not exceed 5,400 € [3]. However, there is an imbalance between supply and demand. Thus, battery energy systems would be beneficial.

Outlook

With capacity prices of about 1,200 €/kWh [4] for lithium iron phosphate systems, they are crucial for the economic efficiency of the energy supply. The cumulated daily demand of the school is about 14 kWh. Thus, the question about the degree of self-sufficiency arises, with and without energy storage. For a detailed configuration of the solar PV system and the storage system, smart meters will be installed to get a daily load curve and the exact energy demand with a resolution of 30 minutes. For this, a market analysis is in progress and cooperation with local partners have been initiated. Single phase GPRS smart meters seem to be expedient. They come with an active network roaming SIM card for multi-network resiliency. This makes them an ideal solution for remote monitoring of energy consumption and later on also for energy generation on solar PV systems. The meter readings will be automatically updated daily on the Openmetrics web portal. Thus, any stakeholder could use the data for research or planning.

Sources:

[1] World Bank Group (2017): Global Solar Atlas; http://globalsolaratlas.info/?c=-1.945579,30.156784,11&s=-1.97097,30.147171
[2] Dimitrij Chudinzow (2016): RP Solar Calculator; IER, Uni Stuttgart
[3] own calculation based on ENF Ltd. (2017): https://de.enfsolar.com/pv/panel?page=1
[4] own calculation based on C.A.R.M.E.N. (2016): https://www.carmen-ev.de/files/Sonne_Wind_und_Co/Speicher/Markt%C3%BCbersicht-Batteriespeicher_2016.pdf

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