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Final Report

SOLAMBARA

Substantiating a rational investment decision regarding the replacement of electrical water heaters by solar thermal systems on a university campus in the Usambara Mountains, Tanzania.

Solar Water Heater for pilot-testing installed at Campus B of Sebastian Kolowa Memorial University (SEKOMU). The university has totally 39 electrical water-heaters that could be replaced by solar thermal water heaters. The project SOLambara demonstrated that this investment can be economically attractive, having a payback-time well below 2 years. SEKOMU's management has evaluated the recommendations made in this report and has decid-ed to replace the electrical boilers.

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Contents

1. Summary

The Tanzanian university SEKOMU is currently paying over 43 Mio. TSH[1] (around 27'000 USD) per year for its electricity bill. Announced tariff-increases will lead next year to an annual bill of over 60 Mio. TSH (37'500 USD). The conducted measurements in combination with simulations have shown that over half of the electricity is consumed by the electrical water-heaters from the student's dorm-houses. The two installed pilot-solar thermal systems have proved to run technically without any problems, to be socially accepted by the students and to meet the warm-water-demand to a very high extend, if dimensioned correctly. The total investment needed to replace all electrical hot water heaters for the dorms is in the range of 35 Mio. TSH (22'000 USD). The annual financial savings were estimated to be 29.7 Mio. TSH (18'600 USD), which adds up to 415 Mio TSH (260'000 USD) over the lifetime of the solar thermal systems. Looking at a payback-time of only 1.2 years the investment is economically extremely attractive, especially considering the high probability of further rising energy-costs. SEKOMU's management has evaluated the recommendations made in this report and has decided to replace the electrical boilers.

In 2012 the financial officer of SEKOMU-university asked the members of the SPF-Project team - installing at the time a solar-thermal water disinfection system - if there is a way to reduce his "extremely high" electricity bill by introducing a solution based on solar-energy. He assumed that the electrical water-heaters of the student-houses on the campus were the main cause for his high bill, but he couldn't be sure because there was no data available to substantiate his assumption.

The conducted project SOLambara included reference-measurements in the student houses to track the electricity consumption of the existing water-heaters. Furthermore two first pilot-solar thermal systems were installed to make the idea of supplying the whole campus with solar-heaters more tangible. In addition to this, the project included simulations to optimize the planned installations (positioning, orientation, inclination, dimensioning etc.) and to assess the savings potential for different scenarios.

It was shown that over half of the universities electricity-demand is caused by the electrical water-heaters. The pilot-systems demonstrated that the solar thermal systems work without any technical problems and that they meet the demand of the students to a very high extent, without major loss of comfort, if they are dimensioned properly. An option to optimize the comfort-level (without additional investment costs and little remaining operation costs of only 17% compared to the current situation) could be to leave the existing electrical water-heaters in place as a back-up-solution. However, this could affect the energy savings as with solar only the students adapt their hot water consumption to the availability of solar heat.

[1] Exchange Rate (16.4.2014): 1 USD is equal to 1599 TSH.

The solar-thermal water heater (with vacuum-tubes, 200 liters-storage) has a cost of 900'000 TSH, ex works Lushoto. Since the university's staff was trained to install the system the installation costs can be neglected. Considering the money saved on the electricity bill by installing the solar thermal system, the simple payback time of the investment is only 1.2 years. In other words: already after 1.2 years the system is paid off by the money saved on electricity-bills, producing for another 14 years energy "for free".

The overall investment for the replacement of all 39 heaters corresponds to 35.1 Mio. TSH. Replacing all electrical heaters with solar thermal system will lead to annual savings of 29.7 Mio. TSH, while keeping at least the current comfort level. Over the lifetime of the solar thermal system (15 years) these savings add up to 415 Mio. TSH.

Based on the financial capacity of the university a gradual implementation can be an alternative. For example, the 39 electrical water heaters could be replaced over a time-period of 4 years, implementing every year ten solar-water-heaters at annual total costs of only 9 Million TSH. Some of the installation-companies are also willing to sell the solar thermal systems on credit. A very interesting model could be to directly to pay back the loan by the saved electricity-expenses.

Based on the results found the authors of this report and also the project partners see the investment of replacing all electrical heaters by solar heaters as very attractive, since
... there is a high savings-potential,
... the investment has a very low pay-back time and a low risk-profile, and
… there is the prospect of being less dependent on further rising energy-costs and increasing numbers of power blackouts.

2. Objectives

Based on the original project application the objectives of the project are listed as follows:

- Measure the typical energy consumption caused by the existing electrical heaters to assess the cost reduction potential when using solar thermal heaters
- Installation of two solar thermal water heaters on the dorm-houses of the campus at SEKOMU-University in Lushoto, Tanga-Region, Tanzania, together with a local technology supplier and installer (secondary objective: learn about the local practices and train the local installer and vendor with high-level expertise).
- Technical, social and economic assessment of the operation of the solar heaters in close cooperation with the involved partners (installation company, university, end-users)
- Strengthening of partnerships between SPF, SEKOMU (university), WaterKiosk Foundation and Ensol (installation company) regarding the collaboration in the field of solar energy, energy-efficiency, safe-water-supply and training
- Analysis of economic savings-potential in combination with comfort level
- <u>The overarching goal of the project is to supply the management-team of the University with the necessary information to take a rational and fact-based investment decision that leads to lower energy costs and higher planning reliability.</u>

3. Technical Solution / Applied Method

The applied methods and technical solutions to reach the objectives are described as follows (following the course of the project):

- Definition of the project-goals together with University's management
- Collection of data regarding current/past expenditures on electricity bills
- Inventory of all electrical heaters installed on the campus, including identification of their connections with the single dorms (male/female, amount of persons per dorm). In situ work, July 2013 (compare Picture 2 and Picture 3).
- Installation of 2 solar thermal water heaters as pilot-/demonstration-systems (July 2013).
    - Definition of most representative locations regarding future expansion.
    - Joint installation with ENSOL (local installation company) and SPF in order to assess the local installation practice.
    - Specification of Solar-Heater: 200 liters storage capacity and around 3.5m2 aperture surface (Chinese standard model, non-pumped, free-convection also called thermosiphon).
- Installation of measurement equipment in order to identify the current consumption of electricity for water-heating on the campus. For this purpose two representative dorms with electrical water-heaters were selected. Based on this the consumption of all existing electrical water-heaters for the campus was extrapolated
- Informal interviews about expectations of students
- Operation of solar-heaters and measurement of electricity consumption of electrical heaters.
- Continuous measurements and various site visits for technical and social feedback (October 2013, December 2013, March 2014).
- Formal interviews of various students about experience with solar-water-heating
- Evaluation of measurements and measurement-based simulations (Polysun) to assess various scenarios
- Summary of results and final information of management and local installation company
- Feedback of Management
- Dissemination of results

4. Results

Overview

In Table 1 the key-results of the project are summarized. In the sections following Table 1 it is described in detail how those numbers and findings presented have been derived.
As mentioned in the summary, the project was originated by the excessive electricity costs: SEKOMU has paid 42.5 Mio. TSH for its total electricity-consumption in 2013 (including lighting, printers etc., see also Table 5). The same consumption in 2015 will cost 64.4[2] Mio TSH p.a., because Tanesco has announced dramatic further tariff-increases. Based on measurements done within the pilot-project it was found that over half of the electricity consumption is caused by the electrical water heaters for the student's accommodation.

One solar-thermal system with 200 litres storage costs 900'000 TSH (offer Ensol from March 2014). This price is ex-works Lushoto, the installation can be done completely by the technical staff of the university because they were trained during the pilot-project[3]. Assuming that there are 40 systems to replace this leads to a total investment of around 35.1 Mio. TSH.

The energy savings by the solar thermal system depend on the consumption of hot water (total annual load and also load pattern) and, based on that, a good dimensioning and installation (orientation/tilt) of the solar thermal systems. For this, the load and load patterns have been measured. Then, annual simulations have been carried out for different scenarios. Table 1 presents results of two different scenarios on how to implement the solar thermal systems. The first one is called "comfort-standard". This scenario implies that there will be no electrical back-up solution necessary. So far the pilot-project has shown that the solar system covers the demand to a very high extent if they are dimensioned correctly (compare Chapter "Feedback from Students"). Also simulations in Polysun confirm this result (compare Figure 4 and Table 3). In this scenario all current expenses spent on electrical-water heating can be saved.

The second scenario is called "comfort-high". This scenario implies that the solar-heaters will not always meet the demand perfectly. For these occurrences the solar thermal systems has an electrical back-up solution, also called "auxiliary energy". Whenever the solar thermal systems don't deliver enough energy to cover the defined demand-curve, the electrical back-heaters will supply the energy needed. It is shown, that a correctly installed solar thermal system with an electrical back-up needs only 16.9% of the electrical energy compared to the reference system (which corresponds to the current situation of electrical water heaters, without solar). A pragmatic solution for the university could be to leave the existing electrical water-heaters in place, but operate them only for the few times a year when the solar-supply might not cover the demand.

The payback time of the investment for the solar water heaters is only 1.2 years (conservative scenario "comfort-high"). Replacing all heaters with solar systems will save over the lifetime (15 years) 415 Mio. TSH.

Considering…

- …the enormous savings-potential
- …the low pay-back time and
- …probable further increases of electricity tariffs by Tanesco

the authors of this report see the investment - replacing all electrical heaters with solar heaters - as highly attractive from an economical point of view. The project has furthermore showed that the installation and operation of the systems by the local installation company is technically convincing and that the solution is socially accepted by the students.

[2] 1 USD translates to 1599 TSH, on 15.4.2014
[3] Naturally for other institutions without trained staff additional costs for installation has to be added. Around 200'000 TSH per system are a realistic estimation.

Table 1: Key numbers regarding the investment decision

Item Description	Amount (1 USD = 1.599 TSH, 15.4.2014)	Comment
Annual energy consumption 2013	166’260 kWh p.a.	This annual electricity consumption is based on electricity bills from February 2013 until January 2014, compare also Table 5.
Electricity price 2013 Electricity price 2014 Electricity price 2015	230.2 TSH/kWh 337.8 TSH/kWh 408.7 TSH/kWh	Compare tariffs from Table 5 for 2013 and 2014. Tariff 2013/14 is a weighted average from campus A and B. A publication from Tanesco predicts electricity price for 2015, see Figure 6.
Annual Total Costs of electricity 2013	42.52 Mio. TSH p.a.	This annual costs are based on the electricity bills from Tanesco from February 2013 until January 2014, compare Table 5.
Expected annual costs of electricity for 2015	64.40 Mio. TSH p.a.	Based on the tariff in 2015 the future electricity bill will rise significantly.
Calculated electricity consumption for hot water (by existing electrical water heaters, based on measurements)	87’428 kWh p.a.	Measurement equipment was installed to track the consumption due to electrical water-heating (see table 2 for derivation).
Current (2014) annual costs for electrical water-heaters	29.52 Mio. TSH p.a.	Result is based on current tariff 2014, weighted average campus A/B.
Expected annual costs for electrical water-heaters with tariff 2015.	35.73 Mio. TSH p.a.	Measurement Equipment was installed to track the exact consumption due to electrical water-heating.
Total number of electrical water heaters	39	Every single water heater of the university was identified including allocation to student numbers male/female.
Cost for 1 Solar Water heater	0.9 Mio. TSH	This price is “ex works” Lushoto. The installation will be done by the universities technicians that were trained during the project.
Total investment cost replacing all electrical heaters	35.1 Mio. TSH	-
Savings Potential Scenario “comfort high”[4] (solar-heaters with electricity heaters as back-up)		
Payback-Time on money invested	1.2 years	-
Remaining electrical energy consumption	14‘780 kWh p.a.	-
Saved energy consumption	72‘648 kWh p.a.	-
Financial annual savings	29.69 Mio. TSH	-
Potential total Savings over investment lifetime	415.68 Mio. TSH	Lifetime of solar thermal system was assumed 15 years. (Official vendors declare 20 years).
Savings Potential Scenario “comfort standard”[5] (solar-heaters only)		
Payback-Time on money invested	1.0 years	-
Potential annual Savings	35.73 Mio. TSH p.a.	Equal to the current total costs for electrical water heating
Potential total Savings over investment lifetime	500.2 Mio. TSH	Lifetime of solar thermal system was assumed 15 years. (Official vendors name even 20 years).

[4] This scenario has a higher comfort level than there is in the existing situation / status quo. Further information can be found in the chapter “simulations”.

[5] This scenario has a different energy production curve over the year (purely based on solar-heaters) compared to the status quo (electrical heaters only). During some months of the year the production is higher than before and in some it is lower. Further information can be found in the chapter “simulations”.

Measurements and calculations of savings potential

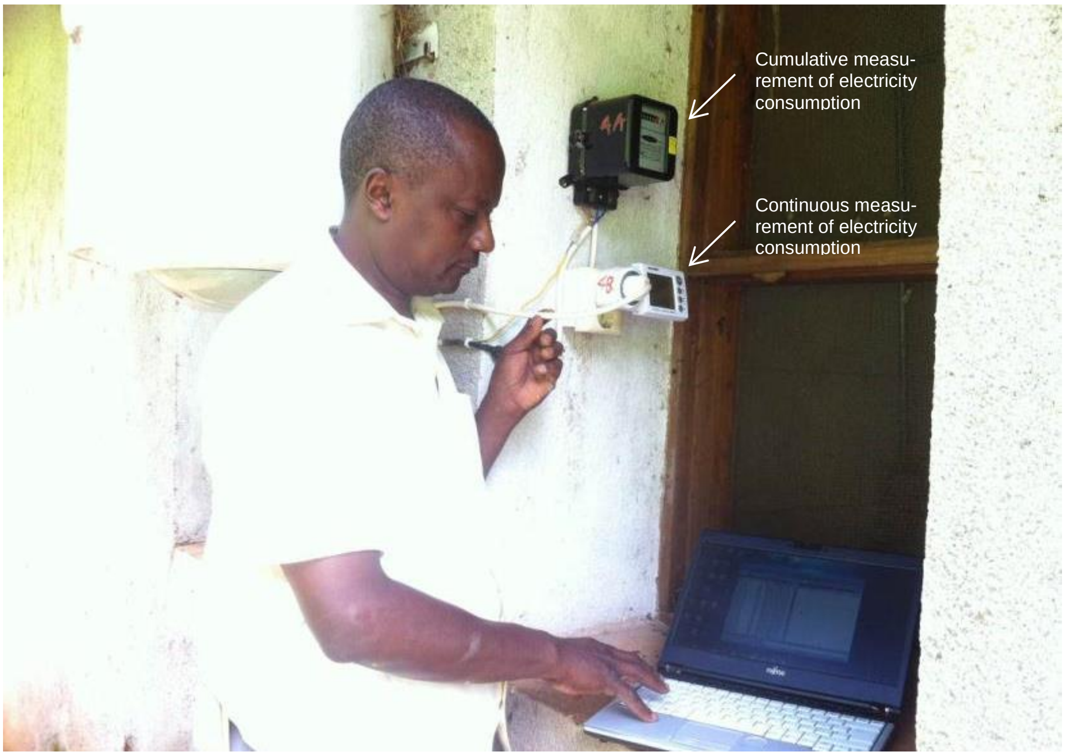
This project was originated by the question from the universities financial planner Mr. Geofrey Kingazi: *"I pay every month a huge electricity bill. I am sure that the electrical water heaters have a high consumption, but it would be good to know how their share is and what can be done about it!"*

Therefore this project included the measurement of the electrical consumption caused by the existing water heaters in order to assess the savings potential. Measurement equipment was installed at two different sites respectively two different dorms. The installed equipment consisted of a simple and robust kWh-counter (measurement of cumulated electricity-consumption) and a more sophisticated device that allowed tracking power-consumption over time in order to identify load-patterns.

It was found that the electricity in the dorms during the day was always turned off to save energy (compare Figure 1). Despite this energy-rationing the consumption of the electrical water heaters contributes to over 50% of the universities total electricity usage. Based on the measurements in two different dorms (Meter 2a on Campus B and Meter 4a on Campus A) the total annual electrical consumption by the heaters was extrapolated to 87'428 kWh. The table below shows how this result was derived from the measurements made in this project.

Table 2: In the following table it is shown how the total annual electricity consumption by the electrical water-heaters was calculated, based on the measurements that were conducted in two student houses.

Measurement of Meter-Nr. 2a Campus B (6 students, male):	1318 kWh (from 31.7.2013 until 31.3.2014)
Measurement of Meter-Nr. 4a Campus A (8 students, female):	1671 kWh (from 31.7.2013 until 31.3.2014)
Average consumption per dorm for 8 months period:	$\frac{1671\text{kWh} + 1318\text{kWh}}{2} = 1495\text{ kWh}$
Extrapolation to one year:	$1495\text{kWh} * \frac{12}{8} = 2241\text{ kWh p.a.}$
Extrapolation to total amount of 39 heaters, hence total electricity consumption by heaters.	$39 * 2241\text{kWh} = 87'428\text{ kWh}$
Ratio of energy demand from electrical heaters compared to total electricity demand	$87'428\text{ kWh}/166'260 = 53\%$



Picture 1: SPF has installed equipment in order to measure the existing electrical consumption by the water-heaters. It was found that the water-heaters at SEKOMU consume over half of the electrical energy. The costs for water-heating are estimated to 35.7 Mio. TSH per year (based on tariff 2015).

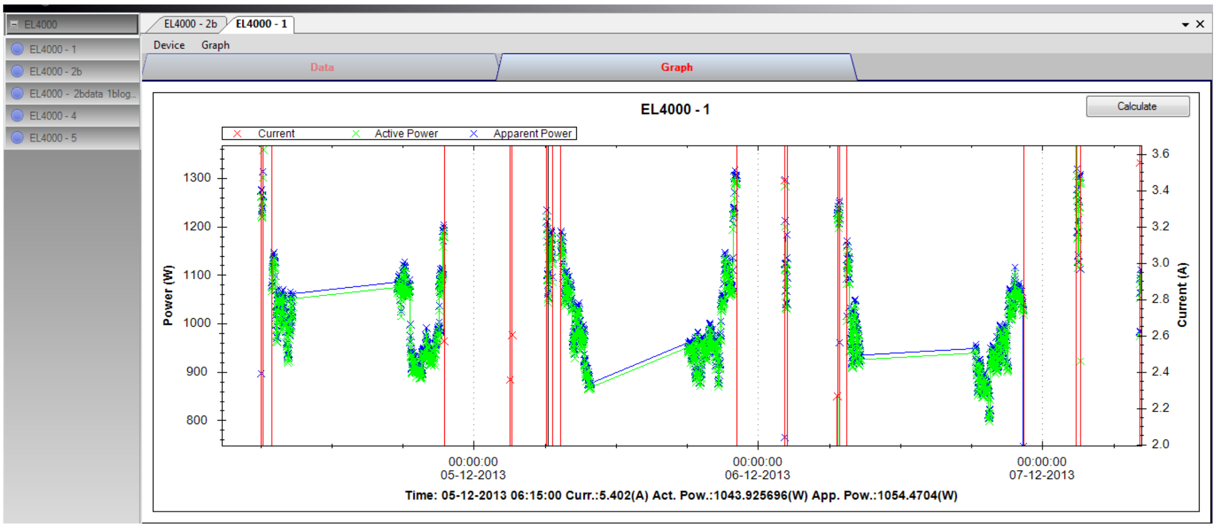


Figure 1: Extract of the continuous measurement of the electricity consumption of a single student-house. The graph shows that the electricity is only switched on for around 3.5 hours in the morning (starting between 6 and 7h a.m.) and in the evening (starting between 18.00h and 19.00h). The electricity is manually switched on/off by the university's electrician; therefore the time-patterns are not perfectly identical.

Installation and technical operation of the solar thermal systems

The installation of the two solar thermal systems (3.5 m2 collector aperture area, 200 liter storage, orientation north, tilt angle 25°) was straight-forward. The installation was done by ENSOL, a local installation company, in collaboration with one representative from SPF (Lars Konersmann), two technicians from the university and one local representative from WaterKiosk Foundation. The time to install one system took one day each. Previously the local company had visited the place to assess the situation and plan the project. The staff from Ensol was trained by SPF on how to position and install the solar-thermal system with a structured approach (see also Appendix "Installation practice of solar-thermal water-heater in Tanzania").

By now both systems are operating for almost one year without any technical problem. The technical staff from the university is now perfectly able to install the systems by itself. For the extension of the project, it is planned that the installation will be done directly by the technical university staff to reduce project costs.

Feedback from the students regarding acceptance / comfort of the solar water heaters

During the project the students were informally interviewed several times, before and after implementation of the solar water heaters. Also some videos of the interviews were taken. Before installation the students seemed to be quite skeptical towards the replacement of electrical heaters by solar thermal heaters. For most of them it was hard to believe that the solar systems can produce hot water, especially when the surrounding ambient temperature is rather low. For the Usambara-Mountains this is especially the case during May, June, July and August when temperatures are down to 10°C during night and about 14.5°Cin average during day.

After implementation of the solar-water heaters at two different student houses, the students concerned were asked about their experiences. The university is separated in two sections (campus A and campus B) that are around 500m apart from each other. One system was installed at a dorm with 8 female students (campus A). The other system (same standard size) was installed at a dorm with 6 male students (campus B). Both dorms were inhabited by first-year students. This means that they haven't experienced the existing domestic warm-water supply in the dorms of the university (electrical boilers). Both installed solar thermal systems have no electrical-back-up heating rods. It was found that the male students from Campus B were satisfied by their supply of warm water by the solar-heaters. The female students at Campus A on the other hand complained that the hot water was "sometimes not sufficient". Two reasons were identified: a) female students seem to have higher hot-water consumption per capita than males. b) The installed solar thermal system on campus A was dimensioned too small (1 system for 8 people). Regarding the extension of the project it is recommended that one solar-thermal system covers a maximum of 6 students. Looking at a current capacity of the student houses to accommodate 238 students, this leads to a total of 39 solar water-heaters. From the experiences made so far it is concluded that this dimensioning the students will be satisfied regarding the domestic hot-water supply. Compared to the previous situation they would have sometimes more and sometimes less energy for domestic hot water. Based on meteorological-data and on the student's interviews sometimes irradiation stays low for two to three consecutive days. These results in lower/insufficient production of hot water. Compared to the status quo it also has to be mentioned that the students are used to stay several days without warm-water since long-lasting power-cuts are very common all over Tanzania. The simulations in the next chapter give a more detailed insight regarding the comfort level reached by the solar-thermal-heaters without electrical backup and also the effect of including an electrical backup heating rod for maximum comfort.

Simulation of the savings potential

The previous chapter has estimated the current electricity consumption by the electrical heaters to be 87'428 kWh p.a. Furthermore the installation of the pilot solar heaters has shown that they work technically without any problems and that they meet the demand of the students to a very high extent (compare chapter "feedback from the students", and see simulation-results in Figure 4 respectively Table 3). Based on this it can be concluded that the current energy consumption of the electrical heaters is the total savings potential, when replacing them with the solar thermal systems. This assumption is called "scenario comfort standard".

As the simulations show the demand curve of a student-house (for definition of demand compare Figure 2) is met to a very high extend by the solar thermal system, but there are times over the year where demand can be higher than the solar-supply. Naturally "demand" is not a fixed entity; it is more a question on how to define the comfort-level. Management has to decide in collaboration with the students which level will still be acceptable.

Assuming that our goal is to reach the demand curve at any time of the year to 100%, we have defined the scenario called "scenario comfort high". In this scenario the existing electrical heaters will stay in place, but will be operated only in the evenings for a few times per year when demand might not be fully met by the solar thermal system. In order to assess the electricity consumption for this scenario, simulations have been conducted. The demand level for the simulation was "calibrated" to the current annual average consumption per dorm (2241 kWh p.a.).

The simulations were conducted with the software "Polysun". Three different variants have been simulated:

- A reference variant based on electrical-heaters only (scenario respectively value "**SOLambara_Reference"**). This reference reflects the current situation at the university where water is heated purely with electrical heaters. The results from this scenario are presented directly in the section "Scenario Comfort High" to compare both scenarios with eachother.
- A second variant only using a solar thermal system to heat up the water. This system was defined in the simulation according to the installed system which was set up in a way to cover the hot water demand to a high extent (see above). This simulation variant represents the scenario **"Comfort Standard**". The saving potential is the total electricity consumption of the reference variant.
- A third variant where the solar thermal system is simulated together with a back-up electrical heating rod (SOLambara_AuxEl, this represents the scenario **"Comfort High"**). The difference in energy consumption compared to the reference variant corresponds to the savings potential per dorm/heater.

The simulations were set up in a way that the reference system has an annual electricity consumption of 2110 kWh for a typical student house (the warm-water demand is shown in Figure 2) which corresponds well to the measurements. Based on the measurements a heat demand profile for the tapping of warm water in the dorms has been defined for the simulations.

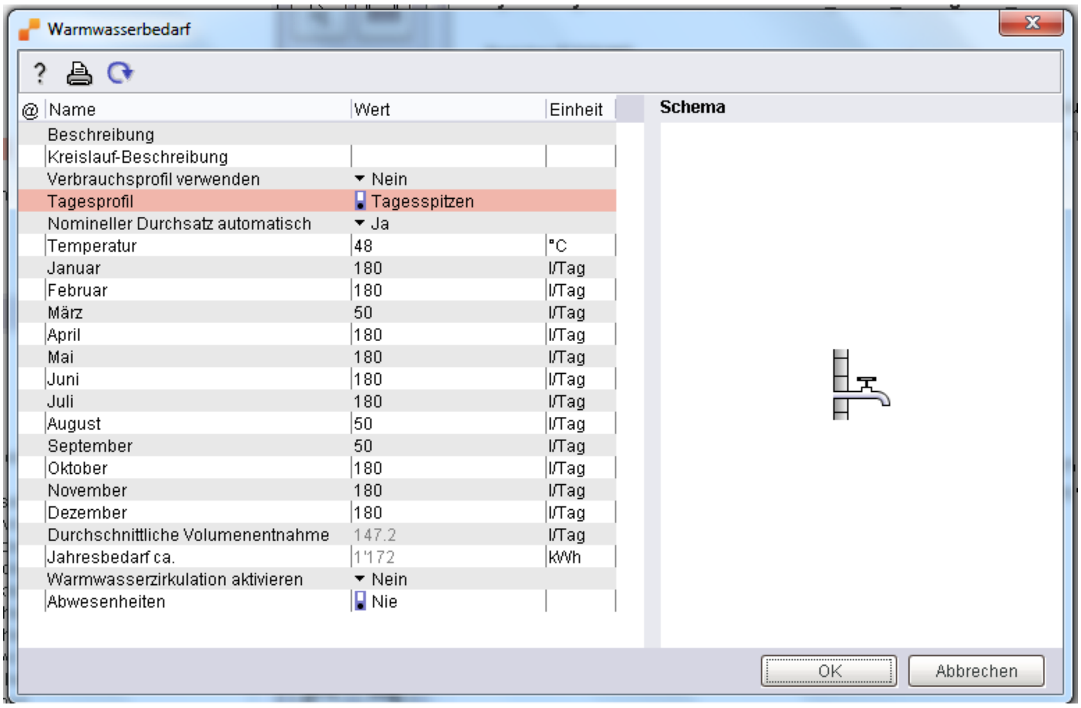


Figure 2: Warm-water demand for a student house based on the standard-user-profil in Polysun "daily-peaks") for the conducted simulations in Polysun. The daily water-usage-pattern has three peaks (morning, noon, evening).The assumed demand was "calibrated" with the real demand in the student houses. The definition of a correct comfort level does not exist, however in many places in Africa warm-water for showering is provided buckets. The assumed warm-water-consumption translates into around 2 buckets of water at 50°C.

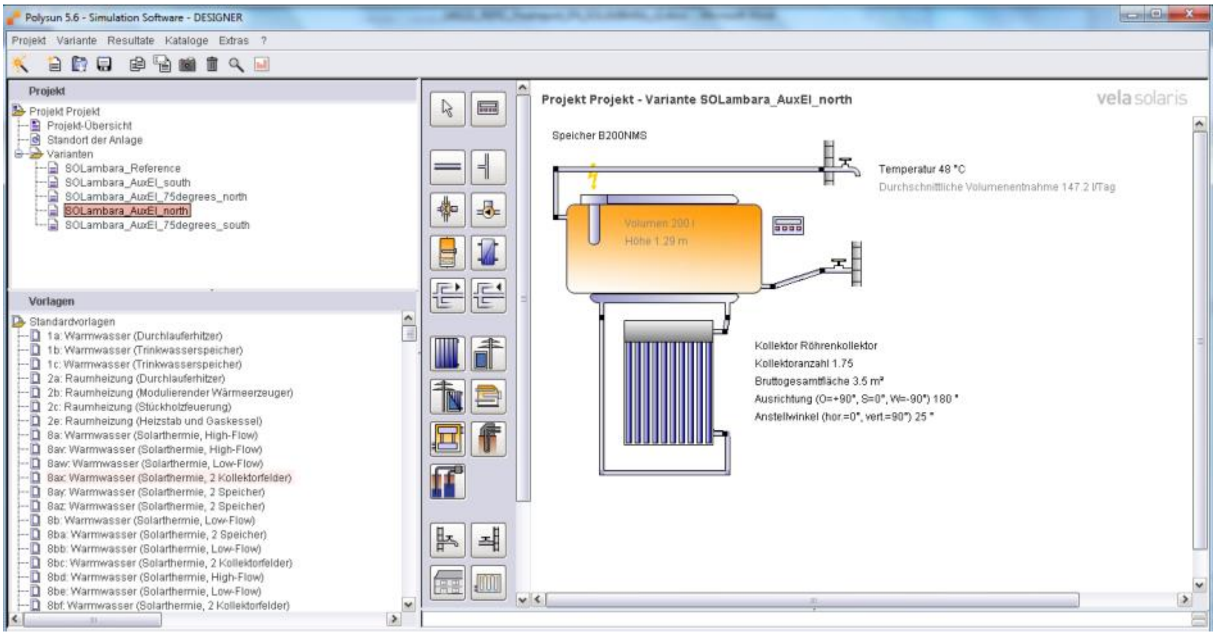


Figure 3: Screenshot from the simulation-interface in Polysun. The different variants simulated are seen on the left-hand-top area of the picture. On the right side, the variant including electrical backup heating is shown (corresponds to "scenario comfort high").

Scenario “Comfort Standard” –
Covering the demand with the solar thermal system only, no auxiliary heating

In this scenario called “Comfort Standard” it is simulated how good the solar thermal systems can meet the demand by the students, without using any auxiliary energy.

In the simulation, the heat demand based on the tapping profile (Qdem) and the actual heat that is being tapped by the students (coming from the solar thermal system via storage and piping) Quse_Solar is calculated on an hourly basis. In Figure 4 the monthly sums are presented. It can be seen that with a tight dimensioning of the solar thermal system (to keep costs low) there is a small deficit between the demand and the energy that has been used. However, a more thorough analysis has revealed that there are no times when the comfort is below a minimum: It only occurs twice in the full simulation year the temperature drops below 30 °C for more than 4 hours, and in those two situations the durations are 22 hours (from midday to midday, July 11/12) and 10 hours (from midnight to 10 am, Oct 21).
If only the deficit between supply and demand (without regarding the surplus of solar heat) is calculated on an hourly basis, it sums up to 244 kWh (which is 21% of the theoretical demand). However, the deficit reduces to 15 % if only temperatures below 40 °C are considered and 6 % if only temperatures below 35 °C are considered. As stated above, temperatures below 30 °C almost never occur (the calculated deficit is 0.6 %).

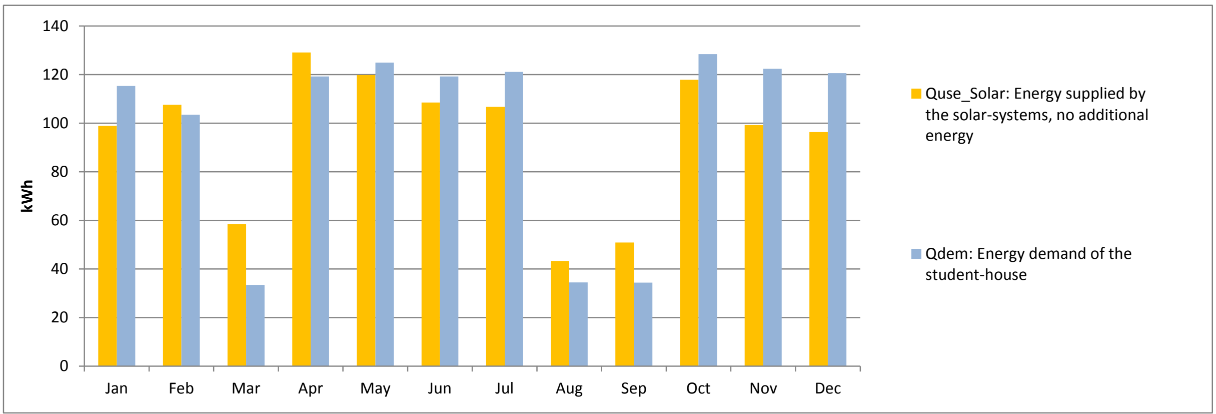


Figure 4: This graph shows to which extent the solar thermal system will meet the warm-water demand of the student house. The difference between the Quse_Solar and Qdem is equal to the deficit respectively the surplus of the solar energy production compared to the actual demand.

The **yellow bars Quse_Solar** represent the actual energy consumed by the students that was fully supplied by the solar-thermal systems. Please note that this value is much lower than the total solar thermal energy due to losses to the environment (in the storage and the pipes).

The **blue bars “Qdem”** represent the actually demanded energy by the dorm’s inhabitants, in correspondence to the defined demand curve (see also Figure 2).

The lowest consumption in March, August and September are caused by absence of most students during holidays. The solar systems is oriented north (inclined 25°, in order to cover demand especially during the colder winter month May, June, July when the sun stays north). This way the hot-water demand can be met to a high extent over the whole year.

Table 3: The results shown in this table corresponds with the graph shown above. The solar thermal systems cover the warm-water-demand of the student-house to a high extent.

	Unit	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Quse_Solar: Energy actually used by the students in the scenario comfort standard meaning that the energy is supplied by solar only.	kWh	1'136.60	98.9	107.6	58.5	129.1	119.8	108.5	106.7	43.3	50.9	117.9	99.2	96.3
Qdem: Energy demand of the student-house (equal for all scenarios/variants)	kWh	1'176.80	115.3	103.5	33.4	119.2	124.9	119.2	121.1	34.5	34.4	128.4	122.4	120.6

Scenario “Comfort High” –
Covering the demand with the solar thermal system and electrical auxiliary heating as a back-up-solution

In this scenario it was simulated how much electric auxiliary energy will be needed if the solar thermal systems are assisted with an electric heating rod to cover the small deficit that was documented in the previous section (where the solar thermal systems worked without any auxiliary energy). It was found that the electric energy consumption was reduced by 83% compared to the current reference case of purely heating with electricity. It is also shown that this way the demand is fully covered for all months of the year.

Actually the comfort will be even higher than before, since in most months with relatively high irradiation the solar thermal system will produce higher volumes of warm water than the electrical heaters did in the past (due to blocking times and lower storage capacity).

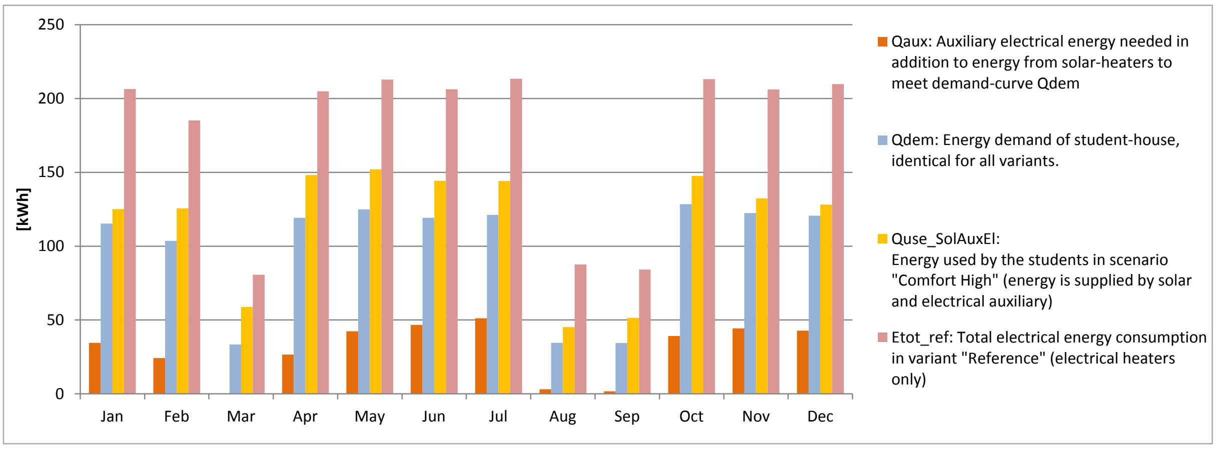


Figure 5: Results obtained from the simulations conducted in Polysun. It is shown that the auxiliary electricity consumption is far below the electricity consumption in the reference case (electrical heaters only).

The **orange bars "Qaux"** represent the auxiliary electrical energy needed to meet demand when there is a solar heater installed. The electrical consumption was reduced by the solar thermal system by over 83%, or in other words: only 17% of the electricity (from Etot_ref) will be needed in the future if the solar thermal system is installed. Please note that Qaux is not simply the difference between Qdem and Quse_Solar from the scenario "comfort standard", this is because in this scenario the electric backup always heats up to the set temperature for every hour (outside the blocking times) and hence due to the higher average temperature in the storage and the pipes the losses to environment are higher too.

The **blue bars "Qdem"** represent the actually demanded energy by the dorm's inhabitants, in correspondence to demand curve in scenario comfort-standard (previous page).

The **yellow bars "Quse_SolarAuxEl"** represent the actual energy that was used by the students of the dorm in this scenario, where energy was supplied by the solar-thermal systems and the electrical back-up heaters. It can be seen that the energy demanded (Qdem) is always met on the monthly basis, which was not the case for the scenario "comfort standard".

The **dark-red bars "Etot_ref"** correspond to the electricity used by the electrical heaters (current reference-situation without solar thermal systems). It can be seen that Etot_ref is much higher than Qdem. The reason for this is mainly that there are stand-by losses to the environment (from storage, piping). If the solar heat gain instead of the used energy Quse(provided by solar but taken out of the pipe coming from the storage) would be shown, this would look similar.

Table 4: The following table contains the results derived from the simulations conducted in Polysun (Results are graphically displayed in Figure above).

	Unit	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Qaux: Auxiliary electrical energy needed in addition to energy from solar-heaters to meet demand-curve Qdem	kWh	356.7	34.6	24.2	0	26.6	42.4	46.7	51.2	3.1	1.7	39.2	44.3	42.8
Qdem: Energy demand of student-house (identical for all variants)	kWh	1'176.80	115.3	103.5	33.4	119.2	124.9	119.2	121.1	34.5	34.4	128.4	122.4	120.6
Quse_SolAuxEl: Energy used by the students in scenario "Comfort High" (energy is supplied by solar and electrical auxiliary)	kWh	1'402.90	125.1	125.7	58.9	148.1	152.1	144.2	144.1	45.2	51.4	147.5	132.3	128.1
Etot_ref: Total electrical energy consumption in variant "Reference" (electrical heaters only)	kWh	2'110	206.4	185.2	80.6	204.8	212.8	206.2	213.3	87.6	84.2	213.1	206.1	209.7

5. Outcomes

As follows the outcomes of the project are listed:

- Providing necessary information for management of SEKOMU-university to take a fact-based investment decision
- Demonstration of potential savings of at least 29.7 Mio. TSH p.a. respectively 415.7 Mio. TSH over lifetime (conservative scenario comfort high)
- Demonstration of operation of simple solar thermal systems without any technical problems
- Demonstration of how to assess (and partly solve) energy-related economical threads
- Training of collaborating installation-company (and technical staff of university) on how to correctly install solar-thermal water-heaters. The collaborating installation company Ensol is one of the top three solar-installation companies in Tanzania.
- Students and staff of the university are informed and sensitized about the advantages of solar-water-heating. Several smaller events have been conducted for this purpose. The students come from all over the country and will spread their know-how far beyond the boundaries of the Tanga-region.
- The project has a strong light-house-effect and can be scaled to other institutions (private households, dispensaries/hospitals, religious institutions, etc.) Most of the results documented in this report hold true for different kind of settings. For most of Tanzania's other geographical regions solar-irradiation is higher, hence the payback-time will be even lower.
- The local staff from WaterKiosk Foundation was trained to install the solar thermal water heaters. WaterKiosk Foundation is working mainly in schools and hospitals. For this year it is planned to install another 50 water-purification systems in around 30-40 schools. Many of these institutions have already asked for an affordable warm-water-supply and have expressed their willingness/ability to pay. To name a few: St. Gogarty High School in Usa-River near Arusha, Huruma Vocational Center, near Rombo, Sister-house of Kilimanjaro in Moshi, and many more. One of WaterKiosks staff-members is now committed to start a side-business by installing the solar thermal water heaters for the institutions in need.
- A further result was the integration of the topic solar thermal water heating into the education-plan of the SEKOMU-university within the faculty of "nature and conservation". The head of the department was trained to teach the students the topic "solar thermal energy".

6. Impacts and Future Prospects

As follows the main future prospects of the project are listed:

- The most important and next step is that the SEKOMU's management will evaluate the recommendations made in this report. As a matter of fact, the management has already decided to replace all water-heaters. Now it only has to be decided on how the implementation will be done. Basically there are three options: a) install all 39 systems at once b) install the systems over a time of e.g. 4 years with 10 systems per year to reduce the weight of the financial investment c) purchase the systems with a "credit"-model, ideally where the University pays the same amount to the solar-company as they pay now to the electricity provider, only the payments ends after a short time (e.g. 2 years). The involved solar-company Ensol has confirmed that they are able and willing to give a credit for the systems with a duration of at least 6 months.
- Communication of the results to the members of the Tanzanian Renewable Energy Association for further dissemination.
- The project has a strong light-house effect, since the university is well visible and is visited often by important government officials. Furthermore the students come from all over the country and will spread their know-how. It is therefore expected that the project will stimulate new investments related to solar-water-heating.
- As the company ENSOL has been involved, a direct multiplication will be possible with comparably high quality of planning, dimensioning, installation and calculation of economics for similar locations/applications in Tanzania.

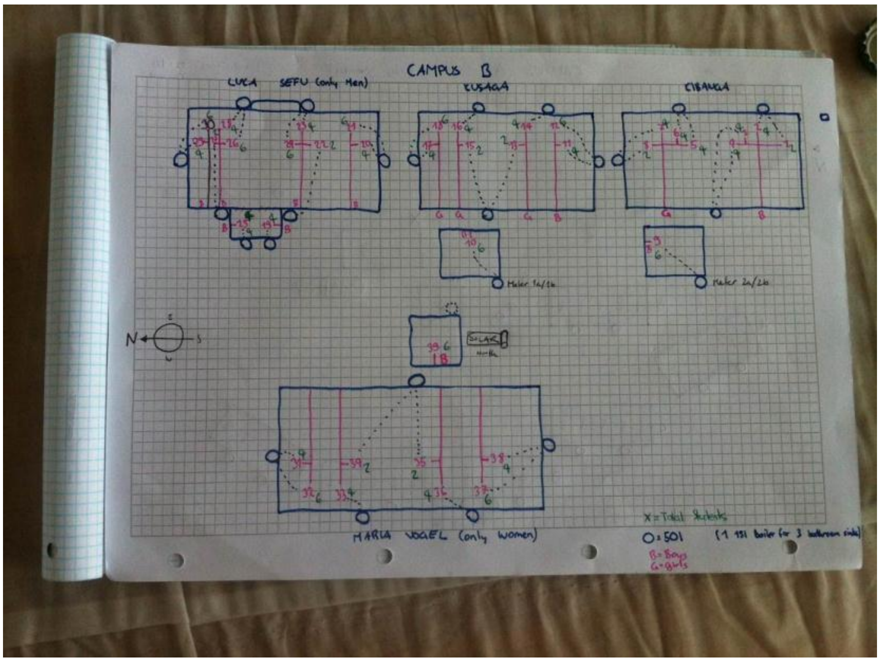
7. Conclusions

The project has started with a complaint from the universities financial planner about his high electricity bills. At the beginning of the project there were some major question marks about the economical attractiveness, the social acceptance and the technical functionality of solar thermal heaters in the applied setting of rural Africa. Based on the installation of two demonstration-systems it was shown that this systems work technically well. The measurement of the energy consumption by the electrical water heaters in two student houses showed that the financial planner was right: the heaters accounted for over half of the universities electricity consumption. The demonstration systems in combination with energy-simulations showed that over 80% of the energy can be saved by installing a simple solar-water-heater system with 200 liters capacity on each dorm, keeping at least the same comfort level as before. It was also shown that the correct positioning, orientation and inclination of the system has a strong impact on the electricity savings. The most significant change from when the proposal for this project was written is the dramatic increase of electricity tariffs. This tariff-increase in combination with lower prices for the solar thermal systems helped to reduce the pay-back time of the investment well below two years. Originally the authors assumed payback-times of 4-6 years. Based on these positive results the findings of the project can be reduced to the following statement:

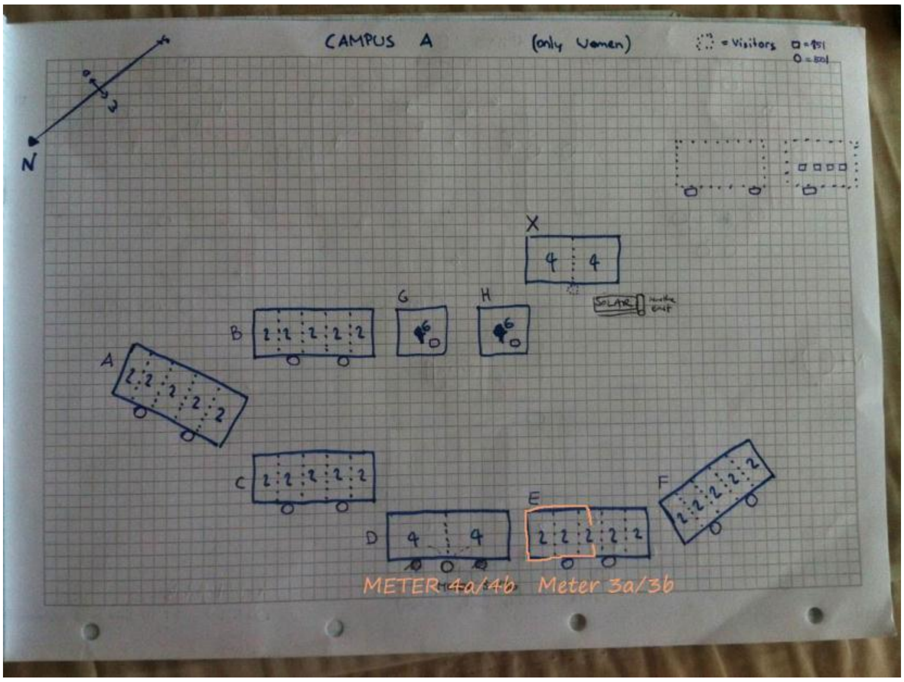
"*Everybody regularly heating water with an electric boiler in Tanzania can and will save a lot of money by appropriately installing a solar-thermal water-heating-system."*

Appendix 1

Project-Documentation with pictures



Picture 2: Every single electrical boiler has been identified on Campus B including allocation to number and gender of students (160 students and 25 electrical heaters).). GPS-coordinates: 4°44'59.9"S 38°17'50.4"E.



Picture 3: Every single electrical boiler has been identified on Campus A including allocation to number and gender of students (78 students, all female and 14 electrical heaters)). GPS-coordinates: 4°45'27.7"S 38°17'45.2"E.

Picture 4: The two solar water-heaters for the pilot-project were delivered in July 2013, by the local company Ensol having a branch office in Lushoto. The works of installation were accompanied by the Swiss project partner SPF.

Picture 5: Installation of solar thermal system on Campus A of the SEKOMU-university.

Picture 6: Installation of solar thermal system on Campus B of the university.

Picture 7: The installation of the system at Campus A.

Picture 8: The installation of the system at Campus A on July 17th 2013, delivering hot –water for one student-house accommodating 8 students from July 18th.

Picture 9: The installation team of the system at Campus B with an Ensol representative, SPF (Lars Konersmann) and SEKOMU (Hamis, Sadiki) and WaterKiosk Foundation (Peter Ndumwa).


TANZANIA ELECTRIC SUPPLY COMPANY LIMITED
Date of Invoice 28/02/2014
TAX INVOICE
HEAD OFFICE
P.O Box 9024
Telephone: 111041/8
Telegrams: "Tanesco"
DAR ES SALAAM
TANZANIA
TANESCO
THE MAGAMBA SECONDARY SCH.
P.O. BOX 99
LUSHOTO
Code: 00
Tarehe iliyosomwa mita
Meter Reading Date
29/01/2014
SECONDARY SCHOOL AT MAGAMB
Prop Ref: H09.97.00710
Cust Ref: 53029217
Tariff 1
METER NUMBER KWH
WA SASA / PRESENT 8644558
ULIOPITA PREVIOUS 701634
MATUMIZI / UNITS CONS 690721
10.913
GHARAMA YA KWH
KWH CHARGE 3,339,378.00
0.00
THIS INVOICE SHOULD BE SETTLED WITHIN SEVEN DAYS FROM THE DATE
RECEIVED 10/02/2014
Meter Number KVA
Usomanji wa KVA READING 0.00
Recpts:
Adj: 0.00
VRN 10-005396-Z
Serv. Charge: 5,520.00
133,575.12
Idadi iliyobaki / Balance B/FWD 0.02
Total Charge This Month 3,478,473.12
Jumla ya Fedha / Total Amount Due 3,478,473.10
SEE OVERLEAF FOR NOTES
Interest(VAT Incl): 0.00

Picture 10: The Tanesco Bill for February 2014 only for Campus B (3.478 Mio. TSH per month for 10913kWh). The cost for electricity in Tanzania is around the same as it is in Europe. From next year it will be even much higher. This makes solar-energy an excellent alternative for a solar-blessed country like Tanzania.

Figure 6: The Tanzanian electricity provider has dramatically raised tariffs lately. See also tariffs in Table 5. Further tariff-massive increases are planned for 2015. See the following extract from the Tansesco-report that can be found on: http://www.ewura.go.tz/newsite/attachments/article/119/TANESCO%20Tariff%20Application%202013.pdf

AVERAGE TARIFF YIELD, MULTI-YEAR TARIFFS

Year	Current Tariff Yield TShs/kWh	Revenue Required TShs/kWh	Annual Increase Required
2012	197.81		
2013		332.06	67.87%
2014		374.38	12.74%
2015		408.71	9.17%

Picture 11: The installed solar water heater system at Campus B.

Picture 12: The students living in the dorms on campus A and B, where the solar thermal system has been installed, were interviewed several times regarding the comfort on hot water. It was found that the boys at Campus B had no complaints (a dorm with 6 boys for 1 system). The system at Campus A delivered hot water for a dorm with 8 girls. It was found that it would be better to have two systems for 8 girls to cover their warm-water-demand.

Picture 13: At various projects stages smaller info-events and workshops have been conducted with the stake-holders, such as management and university staff and students.

Picture 14: At various projects stages smaller info-events and workshops have been conducted with the stake-holders, such as management and university staff and students.

Picture 15: Mr. Hamis from SEKOMU is installing the meters to track the consumption by the water heaters. The technical staff of the university was also trained to install the solar-heaters independently.

Picture 16: “Quality control “at one of the solar-showers: Yes, the water is hot!

Table 5: Electricity consumption, total charge and tariffs paid from February 2013 until January 2014, split into the three separately metered areas of the university, namely Campus A, Campus B and Lecture-Hall.

Campus A			
Month	**Units consumed (KWh)**	**Total Charge (TZ Shilling)**	**kWh-Tariff (TZ/KWh)**
February 2013	6'603	1'784'987	270.3
March 2013	1'055	289'135	274.1
April	4'121	1'115'790	270.8
May 2013	5'657	1'529'926	270.4
June 2013	7'156	1'934'087	270.3
July 2013	6'188	1'673'095	270.4
August 2013	6'024	1'628'877	270.4
September 2013	3'129	848'327	271.1
October 2013	2'696	731'582	271.4
November 2013	4'710	1'214'597	257.9
December 2013	5'544	1'499'459	270.5
January 2014	5'946	2'226'495	**374.5**
Total	**58'829**	**16'476'356**	280.1

Campus B			
Month	**Units consumed (KWh)**	**Total Charge (TZ Shilling)**	**kWh-Tariff (TZ/KWh)**
February 2013	11'529	2'653'666	230.2
March 2013	1'814	420'771	232.0
April	7'505	1'728'790	230.4
May 2013	11'317	2'604'940	230.2
June 2013	12'430	2'860'752	230.1
July 2013	11'601	2'670'215	230.2
August 2013	10'775	2'480'367	230.2
September 2013	4'298	991'693	230.7
October 2013	1'865	432'493	231.9
November 2013	8'170	1'881'634	230.3
December 2013	9'830	2'263'168	230.2
January 2014	10'913	3'478'473	**318.7**
Total	**102'047**	**24'466'963**	239.8

Lecture Hall			
Month	**Units consumed (KWh)**	**Total Charge (TZ Shilling)**	**kWh-Tariff (TZ/KWh)**
February 2013	915	251'388	274.7
March 2013	256	73'709	287.9
April	75	24'908	332.1
May 2013	267	76'675	287.2
June 2013	500	139'496	279.0
July 2013	232	67'238	289.8
August 2013	461	128'981	279.8
September 2013	200	58'610	293.1
October 2013	395	111'186	281.5
November 2013	617	169'693	275.0
December 2013	722	199'352	276.1
January 2014	744	284'484	**382.4**
Total	**5'384**	**1'585'719**	294.5

Total all areas	166'260	42'529'038	

Appendix 2 -

Installation practice of solar-thermal water-heaters in Tanzania

The project was conducted in collaboration with WaterKiosk Foundation as implementing partner. WaterKiosk Foundation is working for several years in Tanzania and has realized over 50 projects in the country, most of them in the field of solar thermal water disinfection. Lars Konersmann, working at SPF, was mandated as general manager for the Foundation and has made over 12 fieldtrips over the last 3 years to Tanzania. During these visits he had the chance to assess many installations of solar-thermal water-heaters.

His main findings are summarized as follows. It is planned to send the results also to the members of the Tanzanian Renewable Energy Association (Tarea, http://www.tarea-tz.org/)

Selection of the site & positioning of the collector:

- The location of the solar system has to be selected carefully. When selecting the site for the solar thermal system all these social and technical aspects have to be taken in consideration. It is always necessary to speak with the client/beneficiary and ask him many critical questions about the potentially best suited site for the planned installation. In many locations systems with broken tubes or flat-plat-collectors with broken glass-covers were encountered. One of our systems was e.g. installed close to a mango tree. Children threw stones to harvest the mangos. A stone landed on the collector and a vacuum-tube was broken after only 2 weeks of operation time. Often the best location (from an energetic point of view) turned out to be less suited for other reasons. In many institutions where WaterKiosk Foundation has installed a solar-thermal system the users/owners of the systems have come up with creative ways of protecting the system (Picture 18, Picture 19).
- The selection of the site seems often to be carried out “randomly”, without any clear idea on what influences system performance. Many systems have been sighted where shadow-problems (trees, buildings, horizon etc.) could have easily been avoided. Installer should be able to anticipate the suns path over the year and conclude from that which location and orientation is best.

Orientation & inclination

- The orientation and inclination of a solar-thermal system near the equator respectively in the tropics is not always intuitive. The question arises if the aim is to optimize the total yield over the year (this could mean that the yield is high in the summer-time and low the winter, where the solar thermal energy is less needed) or if the aim is to cover the demand curve of warm water as good as possible, hence to substitute as much electricity used for the electrical heaters. For our case it is clear that the second goal is the preferred one. The first aim (optimization of total yield) would be e.g. interesting for the case of a solar-power-plant that feeds into the grid with a fixed feed-in tariff. **Simulations in Polysun have shown, that the solar thermal systems should be directed towards north and be inclined between 20 and 25°. This rule-of-thumb can be applied for solar thermal systems in the whole area of Tanzania.**
- The proposed angle of inclination is not an energetic optimum (it would be lower 20°), but it is necessary for the good functioning of the thermosiphon-system that work with convection (instead of active pumping). Furthermore auto-cleaning of the tubes or collectors work better if not mounted flat.
- Very often solar-thermal-system where seen with steep inclination angles of around 75°. This is probably due to the pre-fabricated mounting structures of many models (often Chinese brands). The mounting structure has a steep fixed angle that is not suitable for sun’s path in Tanzania). Sometimes these systems are installed on roofs that have an inclination angle themselves. Adding up the solar systems result to be almost vertically mounted. Simulations in Polysun have shown that a system that is installed with an inclination angle of 75° (facing north) is performing much worse than a system is inclined only 25° (see simulation-results in Table 6 and in Figure 7. These results are in line with the situation presented in the chapter “simulations”.) For the defined demand curve of a typical student dorm an electrical water heater would consume 2110 kWh p.a. A correctly installed solar-thermal heater would only use 357 kWh, whereas a solar-heater with an inclination of 75° will use three times more auxiliary energy, namely 1024 kWh.

Correct dimensioning of the solar-thermal system

- Solar thermal systems in Tanzania seem usually to be dimensioned with the „rule-of-thumb-“ or “experience-approach”. Naturally ease-to-use energy-simulation-programs could help a lot to optimize the dimensioning of the systems.
- Often it is also not quite clear how much warm-water per person will be needed. In many cases the status quo means a bucket of hot water that was heated in the kitchen with wood. Depending on the type of institution or household, warm-water is often still a luxury-good in Tanzania. How to define the comfort-level is therefore not an simple task. It was witnessed in many institutions that the people use as much as they can, as long as it is for free.

Operation and maintenance of the systems:

- Often solar-thermal systems were witnessed that have broken down and were out of service. A classic syndrome of donor-based projects. Often these types of systems are part of a donation project, where the solar thermal systems were specifically imported for the project. No replacement parts are locally available and no local expert can repair the system in case of problems. In our project we have collaborated with a strong local partner that has a branch office near the institution. In case of problems the experts will be on site within 30 minutes including the necessary replacement-parts.

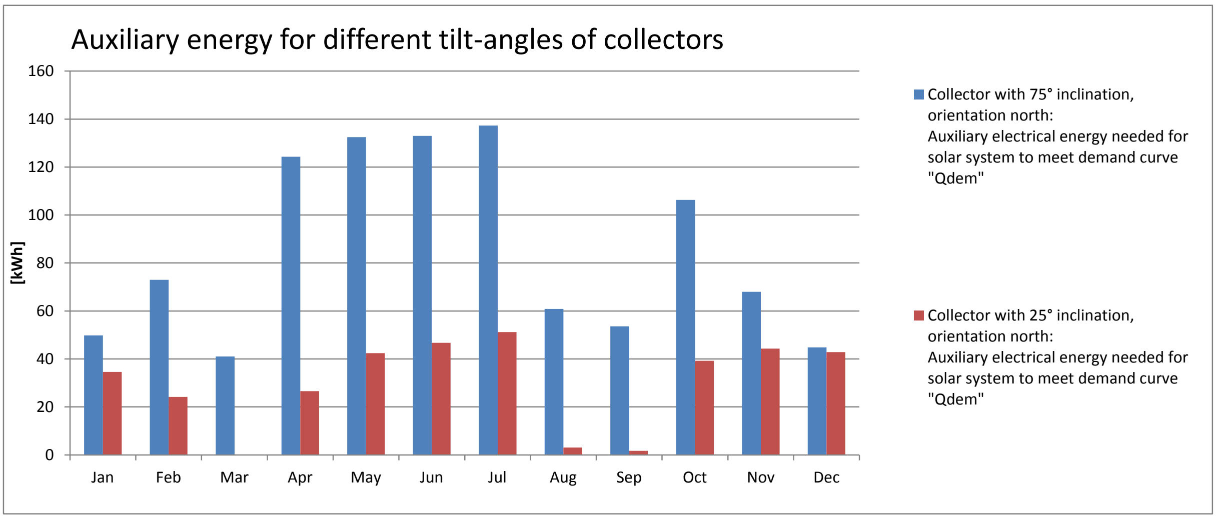


Figure 7: The graph depending on the inclination angle of the solar systems, different auxiliary energy is needed to cover the same demand curve according to the simulations from the simulations chapter (Figure 5 and Table 4).

Table 6: In correspondence with Figure 7 in the following table it is shown that the inclination angle of a solar-thermal system has a strong influence on the systems performance.

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Collector with 75° inclination, orientation north: Auxiliary electrical energy needed for solar system to meet demand curve "Qdem"	kWh	1'024.40	49.8	73	41	124.3	132.5	133	137.3	60.8	53.6	106.3	68	44.8
Collector with 25° inclination, orientation north: Auxiliary electrical energy needed for solar system to meet demand curve "Qdem"	kWh	356.7	34.6	24.2	0	26.6	42.4	46.7	51.2	3.1	1.7	39.2	44.3	42.8

Picture 17: Better than nothing, but actually not much better than nothing. Many systems are delivered with a standard frame designed for typical Chinese tilt angles. This leads to a very poor performance. Simulations show that the system must not be installed with a high tilt angle as seen in the picture in countries like Tanzania in the tropics, (here -4°45'27.7"S southern geographical latitude). It is recommended to install the systems with an inclination angle of 20-25° versus north to substitute as much auxiliary energy as possible (compare Figure 7).

Picture 18: The picture shows a solar thermal installation at a secondary school. The protection fence was installed after the glass cover of one of the collectors was broken.

Picture 19: The glass parts of solar collectors (vacuum tubes as well as flat-plate) can break when things fall on them. The right positioning of the system is important (e.g. not close to a mango-tree or next to the soccer-playground). Local institutions are often creative to protect their solar systems as seen above with “chicken-fence-wood”-construction.