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Industrialization of solar water heaters in Rwanda

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Expert
-

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Titre / *Titel*

Industrialisation de la fabrication de panneaux solaires thermiques au Rwanda

Description / Beschreibung

Suite à la demande faite par le ministère de l'éducation rwandais, le mandat sera de mettre en place une certification des panneaux solaires thermiques. Cette démarche doit permettre à l'IPRC-West de commercialiser les panneaux thermiques, y compris réservoirs d'eau chaude, fabriquées sur le site de l'école.

La fabrication de ces panneaux a débuté en 2016. Un inventaire des techniques et des méthodes de fabrication appliquées jusqu'ici devra donc être établi. Le but étant de cibler les points faibles pour apporter des améliorations du point de vue technique et méthodologique.

L'optimisation tiendra compte des points suivants :

- Analyse de la performance des panneaux
- Analyse des problématiques sanitaires
- Réalisation avec les ressources sur place
- Utilisation de matières premières locales

La rédaction d'un manuel de fabrication, sous la forme d'un mode d'emploi, est envisagée. Ces documents « méthode » devront garantir à long terme une construction uniforme des panneaux thermiques.

Parallèlement à ces travaux pratiques, il s'agit également de procéder aux démarches nécessaires afin de certifier les panneaux thermiques. Pour ce faire, l'étudiant se base sur le lien qu'entretient l'IPRC avec le ministère de l'énergie rwandais.

Concrètement cette certification implique :

- d'obtenir les exigences du dossier de certification
- de préparer les documents et dossiers nécessaires
- de déposer un dossier final (par l'IPRC)

Objectifs / Ziele

- Apporter des solutions d'optimisation pour le procédé de fabrication des panneaux solaires thermiques
- Uniformiser les installations et rédiger un guide de construction
- Effectuer les démarches administratives en vue d'une certification officielle.

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Industrialisation de la fabrication de panneaux solaires thermiques au Rwanda

Diplômant/e Matthias Kiechler

Objectif du projet

Entre 2015 et 2017, l'IPRC-Karongi a construit plusieurs systèmes de chauffe-eau solaires par thermosiphon. Le but de ce projet est d'apporter des solutions d'optimisation du procédé de fabrication et de préparer une certification officielle.

Méthodes | Expériences | Résultats

Avant d'arriver sur place, l'IPRC a dû effectuer des modifications sur le système de base pour des raisons sanitaires. Ces travaux ont provoqué des défauts majeurs qui ont rapidement été détectés lors de l'arrivée au Rwanda. De ce fait, une certification des systèmes existants n'était plus envisageable. Un nouveau prototype de collecteur fut donc développé et construit.

Deux nouveaux panneaux solaires thermiques ont été installés et testés sur le site de l'école partenaire. L'optimisation s'est faite en particulier dans le choix des matériaux, plus performants et mieux adaptés. L'eau chaude en sortie des panneaux a été mesuré à 78°C et le rendement en journée du système avec un réservoir de 300l a été mesuré à près de 60%.

Les mesures et calculs effectués ont montré que les réservoirs existants sont sujets à des grosses pertes de chaleur. Au-delà des 60°C, l'ensoleillement doit être aux maximum pour combler les pertes. C'est pourquoi la température à l'intérieur du réservoir ne dépasse guère les 55°C. La tâche principale des futurs travaux de l'IPRC devrait donc consister à l'élaboration d'un nouveau prototype.

Travail de diplôme
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Energie et techniques environnementales

Domaine d'application
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Le cuivre comme matériau principal du nouveau prototype. Bien que plus cher, le rendement est maximisé et les problématiques sanitaires sont éliminées.

Chauffe-eau solaire construit en 2017 : trois de ces systèmes sont en opération sur un hôtel. Un smart meter permet de facturer l'énergie consommée.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciation to all those people from Switzerland and Rwanda who lend me their expertise, knowledge and opinion during this work. Without you, it could not have been done.

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Last but not least, I would like to thank all those new friends I met in Rwanda. You made my stay a memorable one.

ABSTRACT

Rwanda has big opportunities in developing renewable energies in the country. This was the main reason why HES-SO concluded a partnership with IPRC-Karongi, a technical school in the western province of the country, in 2015. The research and application fields consist of hydropower, biogas and solar energy.

During the first phase of this collaboration, IPRC built different prototypes of thermosiphon solar water heaters. At the end of 2017, three systems were installed on a nearby hotel to heat water for the laundry, the kitchen and the showers. A visit of the Rwandan ministry of energy has led to the idea of certifying those systems. This is the purpose of this thesis.

Once arrived in Rwanda end of May 2018, the whole situation had changed. The systems were not in condition to be certified: the pipes had been exchanged due to rust, the insulation and sealing was poorly made and some glass covers were broken. It was therefore chosen to develop and build a new prototype to fix the various issues detected.

Before starting this new construction, a meeting with the authority in charge of certificates was carried out. The different procedures were explained and discussed. The requirements for solar water heaters are surprisingly demanding. Industrial testing and measuring facilities, which IPRC does not possess, are required.

The guidelines exposed in the Rwanda Standards served as basis for the development of the new prototype. The major optimisations were made in the choice of materials. Aluminium, copper and glass wool were used to maximise the performance and to improve the overall appearance. During this construction phase, numerous struggles were faced. Probably the biggest issue encountered was soldering the copper and absorber. Yet, for all matters, small or big, solutions were found.

Two solar collectors were build and connected with an existing tank on the school site to perform different tests. The results were optimistic: the efficiency of the whole system over a day was measured at almost 60% and the temperature of the water at the outlet of the collectors was measured at 78°C. Due to bad insulation, the water inside the tank cannot get any hotter than 55-60°C. At this point, the thermal losses overcome the solar gains. During the night, the water cools down to around 30-35°C.

The material costs for a system consisting of a tank and two solar collectors amount around 2'000$. At a first glance, this seems excessively expensive for an African product. However, these solar water heaters come with included smart meters. The income is not generated by selling the solar water heater, but by charging the actual energy consumption. This innovative billing process makes it accessible for a bigger audience. An important initial investment is eliminated.

The high electricity prices in Rwanda make these solar water heaters seriously competitive with electrical heaters. As long as the energy is charged less than the electricity, it is easy to find interested clients. Calculations show that the construction costs are paid back in about six years.

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NOMENCLATURE

α	Absorptivity	[-]
α_1	First order thermal loss coefficient	[-]
α_2	Second order thermal loss coefficient	[-]
β	Tilt	[°]
ε	Emissivity	[-]
F	Efficiency factor of solar collector	[-]
G	Solar irradiation	[kWh/m^2]
h	Heat transfer coefficient	[W/m^2K]
I	Solar irradiance	[W/m^2]
I_{sc}	Short-circuit current	[A]
K	Thermal loss coefficient of collector	[W/m^2K]
L	Length	[m]
λ	Conductivity	[W/mK]
η	Efficiency	[-]
η_0	Optical efficiency	[-]
Q	Energy	[J]
$\dot{Q}$	Thermal losses	[W]
R	Radius	[m]
τ	Transmittance	[-]
T_a	Ambient temperature	[K]
T_c	Absorber temperature	[K]
U	Global heat transfer coefficient	[W/K]
U_{oc}	Open circuit voltage	[V]

ABBREVIATIONS

EDCL	Energy development company limited
IPRC	Integrated polytechnic regional college
ISO	International organization for standardization
PROMOST	Promoting market oriented skills training and employment creation in the great lakes region
REG	Rwanda energy group
RS	Rwanda standards
RSB	Rwanda standards board
RWF	Rwandan franc
SWH	Solar water heater

1. INTRODUCTION

1.1. CONTEXT

In 2015, HES-SO Valais Wallis and IPRC-Karongi have concluded a partnership for four years. The aim of this collaboration is the development of renewable energies in Rwanda. As the HES-SO has a newly established degree in this domain, some students are able to benefit from this collaboration by doing their bachelor thesis in Rwanda. This is the case for this project, as well as others during the last three years. Other projects include the design of a micro hydro power plant and the development of biogas in the area.

The whole thesis is conducted in HES-SO's partner institution *Integrated Polytechnic Regional College Karongi* in Rwanda. Just as HES-SO, this school is present in the whole country. Counting five major locations, Karongi is the one in the western province. The school offers technical training for different levels: form secondary school up to the equivalent of a half bachelor degree in Switzerland. The departments are *Mechanical Engineering*, *Civil Engineering*, *Electrical & Electronics Engineering* and *Information & Communication Technology.*

The project is supported by Swisscontact, a precious local partner. Present all over the world, this independent foundation has an office in Kigali for the Great Lakes Region (Rwanda, Democratic Republic of Congo and Burundi). The partnership between HES-SO and IPRC-Karongi falls within the scope of the PROMST project. The primary goal is to develop the private sector by helping to improve the training systems.

As the overall collaboration between both educational institutions is all about transmitting and sharing knowledge and experience in technical domains, this project satisfies the general criteria of PROMOST. Therefore, Swisscontact bears the costs of the whole project. Without their precious financial aid and help in terms of organisation, this project could not have been conducted.

1.2. OBJECTIVES

During the first phase of the collaboration between HES-SO and IPRC-Karongi, a few solar water heaters have been built and installed on a nearby hotel. Following the request made by the Rwandan Ministry of Education, it is now question of setting up the certification process. This approach should enable IPRC-Karongi to commercialize the systems built on the school site.

The main goal is to improve the fabrication process of the solar water heaters. By doing so, the first step is to establish an inventory of the construction techniques and methods applied so far. The aim is to target weaknesses and improve them from a technical and methodological point of view.

The optimization will take into account the following points:

- Thermal performance
- Analysis of health issues
- Realization with local resources
- Use of local materials

In order to guarantee construction uniformity of future systems, a manual of instruction should be written.

The second goal is to set up the certification process. To do so, the student relies on the IPRC's link with the Rwandan Ministry of Energy.

Concretely the certification involves:

- To obtain the general requirements
- To prepare the necessary documents
- To submit a final demand (by IPRC)

1.3. APPROACH

As this project focusses on a specific product already implemented, there is an intense collaboration with IPRC-Karongi. The decisions are taken together and the work is done with the mechanical department. Figure 1 illustrates the repartition of the major responsibilities and tasks.

The main goals of the project were established in a common agreement between HES-SO and IPRC-Karongi. Ndamukunda Maurice, head of the mechanical department, acts as the IPRC counterpart of the project. Every month a work plan is established in order to accomplish the given tasks. Depending on the type, different people execute the task as shown below.

This collaboration is a major strength of the project. Even if it means also dependence from each other. Especially official requests are only to be made by IPRC representatives. One should be aware of the strong hierarchical structure in Rwanda.

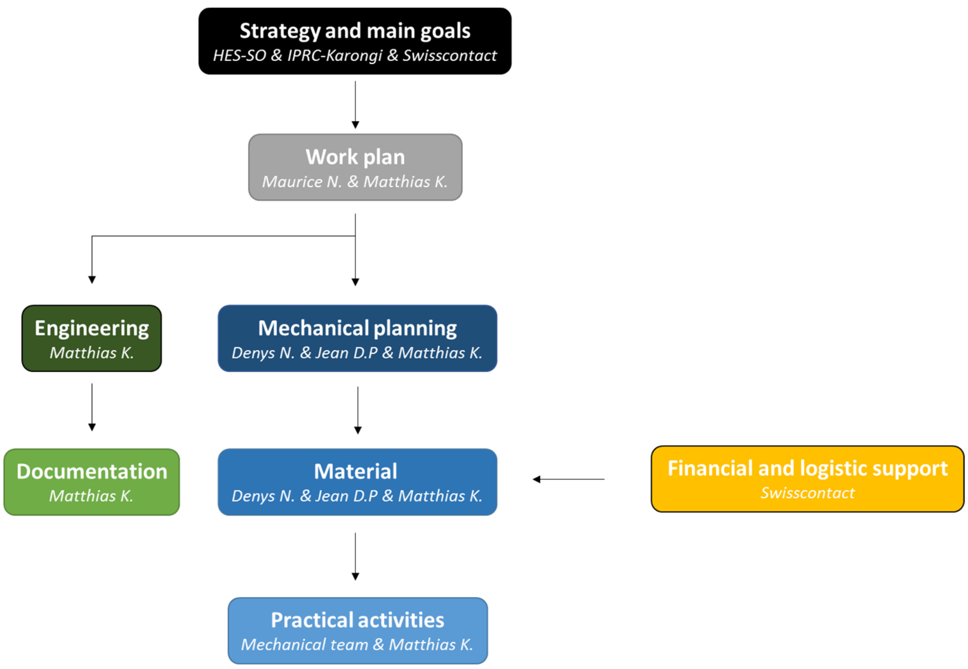


Figure 1: project responsibilities

2. IMPLEMENTED SYSTEMS BETWEEN 2015-2017

This following chapter gives an overview of the work that has been done on the solar water heaters so far. The project is running since a couple of years already but there is still no documentation about it. This part represents also the first phase of the internship in which the main goal was to establish an inventory of the built systems. This apprenticeship was necessary in order to analyse the systems in a second phase.

2.1. DESIGN

2.1.1. EVOLUTION

Since the beginning of the partnership between HES-SO and IPRC-Karongi, different types of solar water heaters were built. The first one happened to be during the first visit in 2015. Professor Stéphane Genoud gave the initial idea and supervised the building of a single prototype represented in figure 2. The construction was made with locally available materials.

Figure 2: evolution of SWH

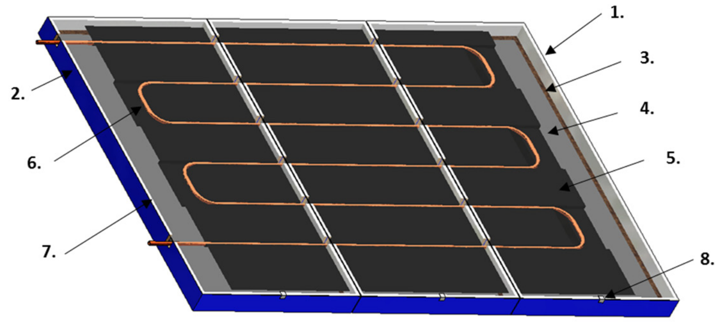
The year of 2016 marked an interruption of the project. The resources of both HES-SO and IPRC-Karongi were needed elsewhere. It was during that time that the hydro power plant project began. Eventually one year later the idea of the solar water heater came up again. IPRC built five systems based on the prototype two years before. After a few successful tests on the campus, three systems were installed on the nearby hotel "Home Saint Jean". Each system consists of three collectors and a tank and heats the water either for the laundry, the showers or the kitchen.

Shortly after installing, the water contained traces of rust due to the galvanized pipes. The reason of this issue cannot be told for sure, but beside the poor material quality, the main reason was probably the welding, which deteriorated the galvanic layer. This leaded to a direct contact between steel and water and therefore to rust. The quality of the water being a major issue, IPRC was forced to replace the pipes.

This leads to the third type of systems, the ones that are in place today. As the replacement of the galvanized pipes had to be done on site, the construction was somehow complicated. This may explain the overall uncompleted appearance. Nevertheless, those systems fulfil their primary objective of heating water.

2.1.2. SOLAR COLLECTORS AND TANK

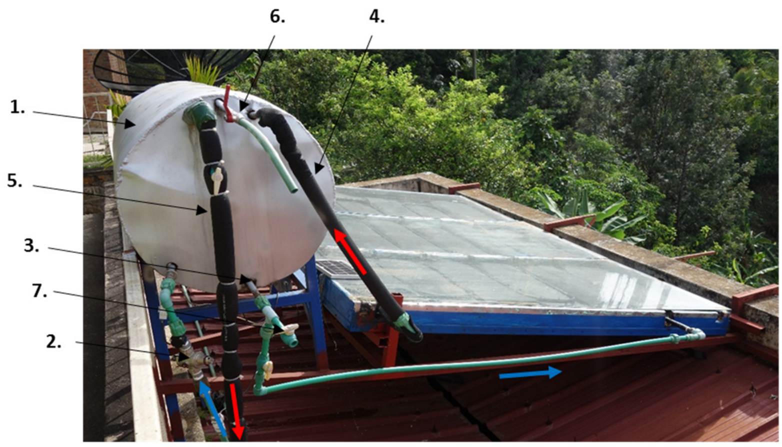
Like mentioned previously, one system consists of three collectors. However, this is not truly correct. There are three frames but only one pipe goes through them. This pipe is a single copper serpentine, which replaces the previous galvanized pipes in harp configuration. The 3D drawing and the section view hereafter show the different parts as well as the materials used.

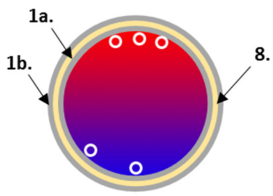


1. Frame : timber
2. Frame cover : galva steel 0.2mm, blue painted
3. Insulation : blankets
4. Mild steel sheet 1.25mm
5. Absorber : galva steel 0.2mm, black painted
6. Pipe : copper, d = ½ "
7. Glass, 4mm
8. Fixation for glass

Figure 3: 3D drawing and section view of solar collectors

The water tank is made of two cylinders put one into the other with insulation in-between both. The inner volume is approximatively 0.3 m^3 or 300 litres of water. The pipes between the collectors and the tank are made of ¾" plastic pipes with standard galvanized fittings and valves. The pipes circulating hot water are insulated with Armaflex to reduce the losses.





1. Tank
   (a) Inner : stainless steel
   (b) Outer : painted mild steel
2. Tank inlet : cold water
3. Collector inlet : cold water
4. Collector outlet : hot water
5. Tank outlet : hot water
6. Second tank outlet
7. Tank discharge unit
8. Polyurethane foam

Figure 4 : water tank and collector connection

2.1.3. SMART METERING

The SWH are equipped with smart meters that measure the hot water consumption. This highly innovative method allows billing just like electricity. It is therefore a way of selling services. The major disadvantage of solar water heaters in Africa is bypassed: the client has no expensive initial investment to do. This makes the acquisition possible for a much bigger audience.

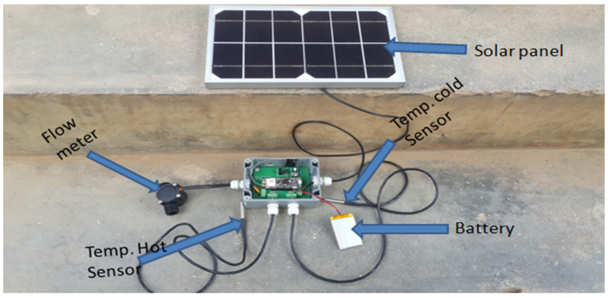


Figure 5: components and implementation of smart meters

Every system is equipped with two sensors, one measuring the hot water temperature and one the cold one. This difference of temperature is measured continuously and as soon as the third component, a flow meter, registers a use of water, the energy consumption is calculated. Each time the energy is incremented and stored in the intern memory. A GSM card sends an SMS message with the updated energy consumption twice a day to the main server at IPRC. This database is then used to do the monthly invoicing but unfortunately, this has never been made since the installation.

For unknown reasons, the main server at IPRC stopped working after a couple months and no work was done to repair it. The problem was eventually solved by exchanging the server at the beginning of June 2018. Since then, the smart metering is running properly again. The energy consumption data between December 2017 and May 2018 was never recovered.

The smart metering represents a project on its own. It is in constant development and improvement. A documentation with all the necessary explanations about the components, troubleshooting and billing is available at IPRC. Please refer to the *information and communication technology* department to obtain it.

2.2. LOCALISATION

Initially five systems were built for commercialisation. Three of them were installed on the nearby hotel Home Saint Jean and two were installed on the IPRC campus. When the sanitary issues were discovered, only the pipes of the systems on Home Saint Jean were replaced. This is why out of the five initial systems, only three of them, the ones on Home Saint Jean, are still running in May 2018. A fourth one is remaining on the campus, but without any use.

Figure 6: localisation of SWH

Kibuye is approximately 230km away from the equator. This means that the sun path is quite similar throughout the year and therefore the daytime as well. Days last around twelve hours from six in the morning to six in the evening. The sun is almost at 90° degrees during the June and December solstice. However, the path of the sun changes slightly: in June, it is turned north whereas in December it is turned south as seen in figure 7.

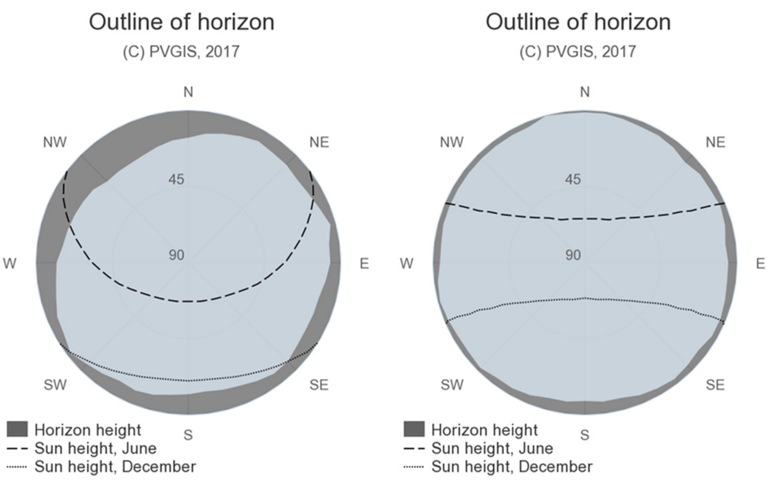
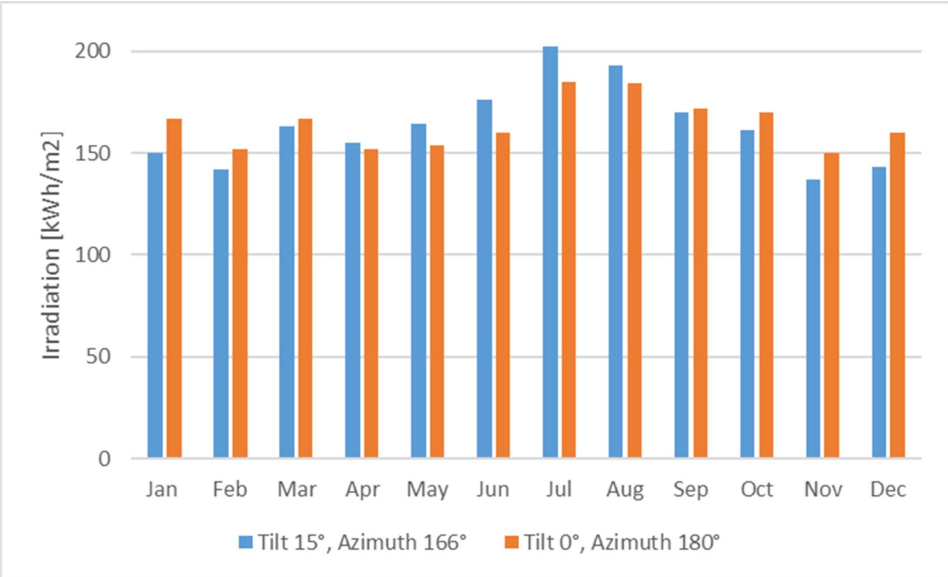


Figure 7: comparison of sun path in Sion (left) and Kibuye (right)
Source: PVGIS

Since the sun is about half the time oriented slightly south and half the time slightly north, the optimum tilt of a collector is 0°. However, if the collector is tilted either south or north the changes in irradiation are little. Only its distribution over the year will change.

All SWH installed are oriented north with a tilt around 15°. Graph 1 shows the monthly irradiation for the SWH located on Home Saint Jean laundry (in blue) and a horizontal plane. The data was generated with PVGIS [1]. The yearly irradiation is almost equal, 1956 kWh/m^2 (blue) and 1973 kWh/m^2 (red).



Graph 1: monthly irradiation on Home Saint Jean

2.3. HOT WATER PRODUCTION

The systems were said to produce water up to 80°C. The first visits of Home Saint Jean in June 2018 showed that the water is indeed hot but the output temperature is not as high as expected. By the general look of the systems, this is not too surprising actually.

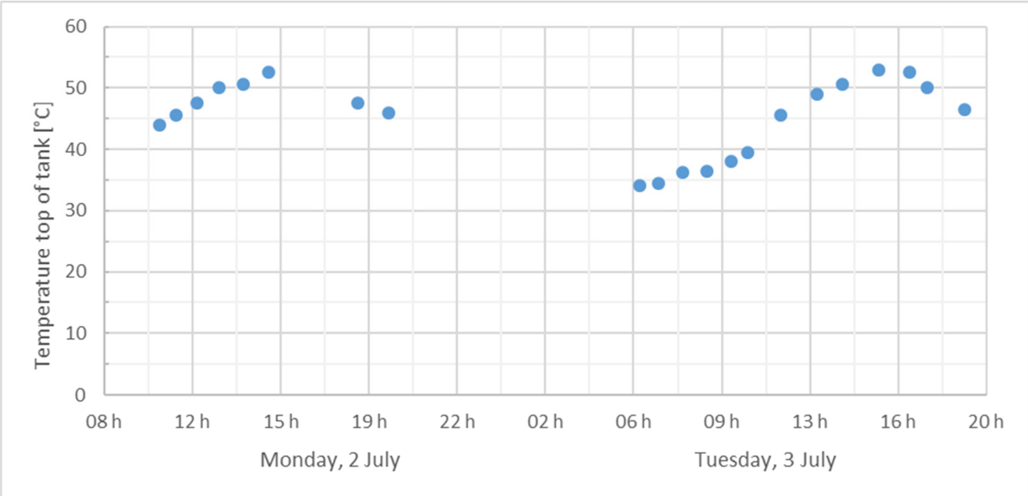
Once in possession of the accurate measuring instruments, the goal was to determine that maximum temperature. The difficulty of this undertaking however, is the fact that the systems on Home Saint Jean are in use. One never knows when and how much hot water is being taken. This induces probably misleading and incorrect statements. In order to avoid as much uncertainty as possible, the measures were taken only on the SWH intended for the laundry. This consumption is the one with the most regularity. Indeed, the water is only used in the morning during the daily laundry activities.

The test condition were as following:

- SWH tested: Home Saint Jean - laundry
- Test period: 2-3 July
- Test sample: Hot water output - top of tank valve
- Hot water consumption during test: little (estimated: less than 30 litres per day)
- Weather: Sunshine the whole day, little wind around midday
- Sunrise: 06h25 / Sunshine: approx. 18h10
- First light on collector: approx. 7h / Last light on collector: 17h40

- Air temperature: Coldest 16°C, 06h / Warmest 28°C, 15h30

The results of this test are shown in Graph 2. The maximum temperature reached was 53°C on the second day, which was a particularly sunny one throughout the whole day. There was almost no water consumption, therefore it can be concluded that the highest temperature is around that value.



Graph 2: test results of water temperature output on Laundry SWH

During this first test, the water lost almost 20 degrees Celsius from the sunshine to the sunrise. Because this drop was somehow concerning, additional tests were made. That is why over a few weeks the temperature was measured always in the evening and in the morning. Results in table 1.

Measure	***Date***	***Time***	***Temp. [°C]***	***Δ Temp. [°C]***
1	Monday, 2nd	20h00	46	12
	Tuesday, 3rd	06h15	34	
2	Monday, 9th	19h30	51	14.5
	Tuesday, 10th	07h30	36.5	
3	Tuesday, 10th	18h30	48.5	15.5
	Wednesday, 11th	08h00	33	
4	Wednesday, 11th	18h00	51	16.5
	Thursday, 12th	07h20	34.5	
5	Thursday, 12th	18h45	49	13.5
	Friday, 13th	07h40	35.5	
6	Saturday, 21th	21h30	42	7
	Sunday, 22th	07h05	35	
7	Sunday, 22th	20h35	44	7
	Monday, 23th	07h50	37	

Table 1: measured temperature losses over several nights

All the measurements concluded the same fact. The temperature loss during the night is very important. The reason must be bad insulation of the tank. This will be analysed in a following chapter.

2.4. SANITARY ISSUES

As mentioned a few times already, the systems were originally built with galvanic pipes. Figure 8 shows the remaining original one at IPRC after doing some maintenance. Before it has been out of use for a couple of months.

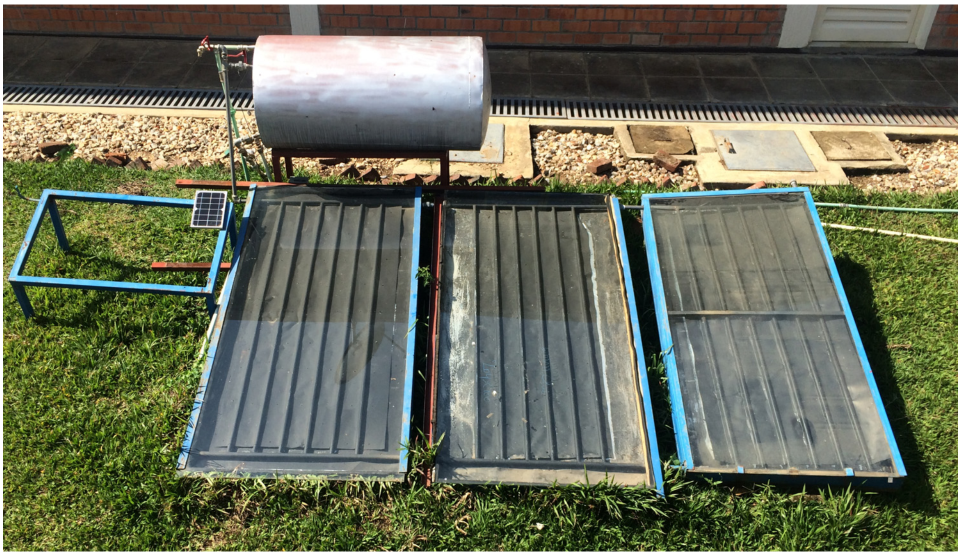


Figure 8: old SWH with galvanized pipes

A few weeks after connecting this system with the water supply again, the previously encountered issue became clearly visible. The rust inside the pipes had expanded so much that the whole water had turned into a brownish liquid. Figure 9 illustrates the seriousness of this issue.

Figure 9: rust issues detected on SWH with galvanized pipes

Fortunately, the water on Home Saint Jean never became this rusty. The problem was solved much earlier. Needless to say that this system was disconnected and disassembled. For future constructions, the galvanic pipes must be avoided by any means.

2.5. ANALYSIS

The following chapter focusses on the three remaining SWH in use. After being presented briefly in the previous chapters, they are now described and analysed more precisely.

Figure 10: SWH's on Home Saint Jean

2.5.1. REVIEW OF MAIN COMPONENTS

At a first glance, there are numerous points that one might question about those systems. Table 2 lists a few of these points. They are evaluated hereafter.

What	Observations and questionings
Glass	Diffulties to transport safely Even installed seems to break easely The fixation is a bit minimalistic
Absorber	Steel plate might not be the best material The plate doesn't fill the hole frame Is the bending technique efficient enough?
Brazing	Only ponctual weldings between pipe and absorber
Pipes	The covered area is huge compared to the little pipes in place Does a serpentine configuration perform good enough?
Insulation & sealing	Blankets seem to have lost their utility? Does the steel plate above the blankets have a function? The holes in the frames for the pipes are quite big There is no sealant between glass and frame Water can easiliy penetrate inside the frame
Tank	Seems to be leaking a bit

Table 2: questionings about implemented SWH

ABSORBER

The function of the absorber is to collect as much heat as possible and to transfer it to the water through the pipes. To complete this task the material needs a good ability to transfer heat. An absorber can be made actually in any sort of metal sheet: steel, copper, aluminium, bronze, iron etc. Obviously, some metals are better suited than others are. However, there are numerous conditions to take into consideration when choosing the appropriate material:

- Thermal conductivity
- Availability of the material
- Cost of the material
- Experiences with the material
- Resources and requirements needed in order to work with the material

Especially the affordable price and the easy access has driven IPRC to construct their first generation of absorbers with galvanized steel. In comparison with other metals, steel has a relatively low thermal conductivity as seen in table 3. Probably an upgrade to a better heat transmitter would be worth even if this involves higher costs.

In terms of thermal conductivity, of the common metals, copper is known to be the best heat conductor. That is why it is used in numerous industrial facilities involving heat exchangers. However as soon as the costs are getting as important as the efficiency, aluminium is commonly preferred to copper. It has a very good thermal conductivity and is considerably cheaper. When using aluminium, one has to consider its difficulty to join with other metals. Soldering an aluminium absorber with copper pipes for example can hardly be done without industrial processes.

Besides those two metals, the performance of others are quite ineffective. On the other side, steel is much wider used which is a considerable advantage on the Rwandan market. Table 3 is a summary of the different possibilities.

	Conductivity *[W/m*K]*	**Availability**	**Costs**	**Ressources**
Aluminum	205	-	-	--
Copper	386	--	--	-
Iron	72-80	-	+	+
Mild steel	36-54	++	++	+
Stainless Steel	16	+	-	-

Table 3: possible absorber materials
Conductivity according to Yves Jannot [2]

The collectors on Home Saint Jean have shaped metal sheet absorbers. The idea was to increase the area of contact between the absorber and the pipe without brazing.

Figure 11: absorber-bending technique on existing SWH

PIPE CONFIGURATION

There a two possible piping configurations: in serpentine or in harp. Each configuration has his advantages and disadvantages. The main reason why the piping on the implemented collectors was made in the serpentine way is its easier conception. The piping can be achieved with a single pipe that has only to be shaped in the right form and then brazed to the absorber. Whereas a harp configuration demands more resources in time and material: two different diameters for the vertical and horizontal pipes are usually used and both have to be joined. This is made either by brazing or with T fittings. Overall, this will require more time, skill and costs.

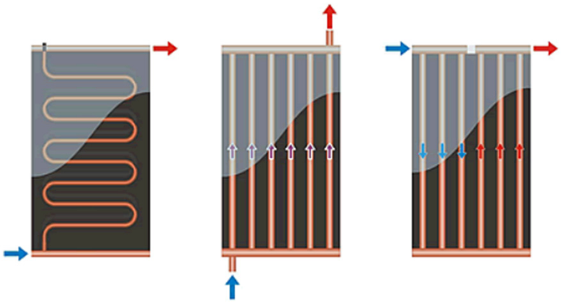


Figure 12: pipe configurations
Source: énergie+

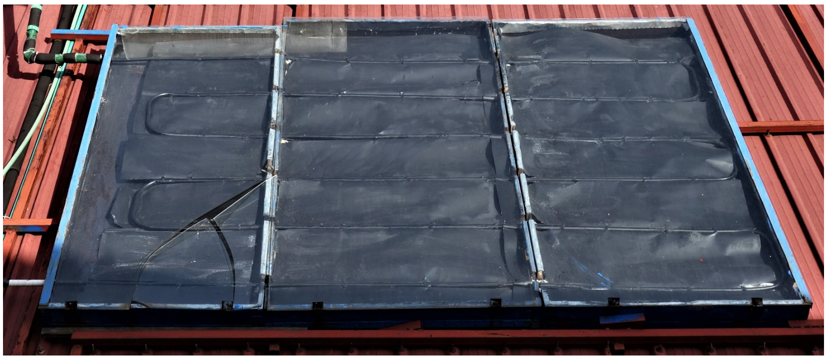


Figure 13: serpentine pipe on existent SWH

Nonetheless, in thermosiphon systems, harp configurations are widely accepted as the way to go. This is mostly because the resistivity of the pipe has to be reduced as much as possible in order to avoid compromising the natural flow of the water [3]. As the resistance increases with the length of the pipes, the shorter the way the water has to go, the better it is.

	Serpentine	**Harp**
Conception	+	-
Ressources	+	-
Workforce	+	-
Losses	-	+
Performance	-	+

Table 4: pipe configuration comparison

BRAZING

As important as the absorber and the pipe configuration is the connection in between. The absorber collects the heat to transfer it to the water. This is achieved by areas offering a contact between the absorber and the pipe.

Usually this is made by soldering both parts. On the concerned collectors however, this is made with punctual brazing. Both techniques require a filler alloy but differ in the applied temperature. Below 450°C is considered as soldering and above is brazing [3]. The higher temperature for brazing induces more resources and that is the reason why IPRC chose that technique. It requires less gas, which eventually results in a cheaper construction.

This solution is unfortunate since the efficiency of the collector rely on a steady bond between absorber plate and pipe. This should definitely be considered in further construction. In the case of soldering, the bending of the metal sheet is not necessary anymore. The metal sheet can simply face the sun as shown in figure 14.

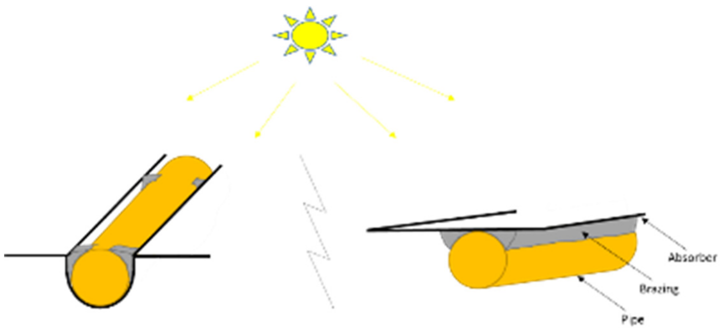


Figure 14: brazing techniques

INSULATION

A good insulation is probably one of the most important aspect in a thermal solar collector. The absorber can perform very well but if the insulation is not achieved correctly, the losses will overcome the gains. Currently the insulation layer consists of four stacked blankets. This seems to be an easy solution but is probably not the best in terms of efficiency.

Possible alternatives could be:

- Glass wool: very good insulation. Safety precautions necessary when handling it.
- Mineral wools: either rock wool or slag wool. Inflammable.
- Polystyrene: commonly used thermoplastic also called Styrofoam. Can melt above at 100°C.
- Sprayed foam: expands and hardens when it is sprayed.

Figure 15: sealing issues on current SWH

Furthermore, the general insulation is only poorly made. The collector should be as closed as possible in order to avoid thermal losses instead there are numerous spots where the heat is able to escape. For example, the holes in the frame for the pipe are excessively big and the glasses are only put on the frame without any seal or fixation.

GLASS

As experience has shown, the currently used glass is a main critical point. The transport of these components cause a lot of trouble. Numerous glasses break already during the transport from Kigali to Karongi, others break during the installation and even once installed, some still suffer of breaking.

This serious issue has to be cleared in order to reduce the overall cost and maintenance works. Following are the two possible solutions:

1. Replace the glasses with a less sensitive material. Especially tempered or toughened glass would be good option. Its strength is increased by a thermal treatment, which results in a physically and thermally stronger glass compared to normal ones. They are commonly used in applications where safety and resistance is needed: for example in vehicles, facades or showers. Being quite stronger than normal glass, tempered glass is still susceptible of damage. When it does, instead of breaking, it shatters into small pieces.

2. If no other glass can be found, the surface of the glass could be reduced by splitting it in two or more smaller glasses. This would increase the chances of transporting the glass safely and if one breaks, the losses are smaller.

TANK

In thermosiphon systems, the height between the tank and the collector is crucial. It should not be too big to avoid resistance and pressure drop but it should neither be too small, else the physical principle will hardly work. Analyses have shown that the optimum height is between 300m and 800mm [4]. The height on the systems on Home Saint Jean between around 400mm is therefore accurate.

The thermal performance of the tanks will be determined in chapter eight. The visual appearance is quite good. Besides the little rust and the warm metal surface during the day, there is nothing to mention.

2.5.2. COSTS

As there is no bill or document with the amount spend for the material to build the current systems, the price was established by making a list of every single component used during the fabrication. The price of each component is given by the current offer in Kigali. The actual cost might differ from the prices listed but for a rough approximation, this is sufficient. The listing in table 5 is made for one system consisting of three collectors, one tank, the piping and the structure to hold it.

A few main components are responsible for the majority of the costs. Especially the stainless steel sheet for the inner tank is extremely expensive. Together with the copper pipes and the gas for welding and brazing, around 50% of the costs are covered. Another costly component is the mild steel sheet of 1,25mm in each collector. This metal sheet has no particular function besides reflecting the light. According to the price, this one should be avoided in further constructions.

The overall cost is around 1’650 US Dollars for one system. Please note that the price of consumables is divided into an approximate amount. For example, the different cylinders of gas were bought to build all the systems. That is why their price is distributed to all of them.

Materials and costs SWH 2017

Collectors

	Component	Dimensions	Price RWF	Number	Total
1	Timber	1.2 x 2.4	30'000	3	90'000
2	Mild steel galva sheet, 0.2mm	1 x 0.9 m	1'900	20	38'000
3	Mild steel sheet, 1.25mm	1.2 x 2.4m	35'000	3	105'000
4	Glass	1 x 2m	26'000	3	78'000
5	Tubes, iron	0.04 x 0.04 x 6m	9'500	3	28'500
6	Copper pipe, 1/2 "	15m	140'000	1.2	168'000
7	Brazing road, copper	1 box	16'000	2	32'000
8	Flux	250g	60'000	0.2	12'000
9	Gaz for brazing	2 cylinders	95'000	0.2	19'000
10	Blankets	-	3'500	12	42'000
11	Black painting	1kg	3'000	1	3'000
12	Blue painting	1kg	3'000	1	3'000
13	Thinner	1l	7'500	5	37'500
14	Nails, screws	-	3'000	1	3'000
				Total price for collectors	*659'000 RWF*
					757 $

Tank, pipings and structure

	Component	Dimensions	Price RWF	Number	Total
1	Mild steel sheet, 1.2mm	1.2 x 2.4 m	35'000	2	70'000
2	Stainless steel sheet, 1.5mm	1.2 x 2.4 m	320'000	1	320'000
3	Stainless steel electrodes	1kg	18'000	1.5	27'000
4	Stainless steel pipes, 1/2 "	1m	5'000	4	20'000
5	Plastic pipes PPR, 1/2 "	3m	3'500	6	21'000
6	Tubes, iron	0.04 x 0.04 x 6m	9'500	6	57'000
7	ARGON gaz	1 cylinder	359'000	0.2	71'800
8	Foam	1 bottle	9'200	6	55'200
9	Armaflex	1.8m	5'000	6	30'000
10	Accessories (Fittings)	-	80'000	1	80'000
11	Spray painting	1	5'000	5	25'000
12	Redoxyde painting	1kg	3'000	1	3'000
				Total price for tank, pipings and structure	*780'000 RWF*
					897 $
				Price for whole system	***1'439'000 RWF***
					1'654 $

Table 5: construction costs existent SWH

2.5.3. OVERALL EVALUATION

Considering the numerous issues detected during this analysis, the systems are surprisingly well working. Especially the insulation and sealing is insufficient. On all three systems on Home Saint Jean, the water can easily penetrate inside the collectors. This means also that the heat is rapidly lost.

Strenghts	Weaknesses
System is working	Appearence of an old, unfinished system
Materials are affordable	No maintenance was made
Construction techniques are well known	Absorber presents only low conductivity
Pipe configuration is easily made	Insulation and sealing is not sufficient
Brazing is reduced by bending the absorber	Effective heat transfer area is small
	Glasses are very sensitive of breaking

Table 6: evaluation of existent SWH

3. CERTIFICATION

In September 2017, the Rwandan ministry of education insisted on certifying the systems on Home Saint Jean in order to build future systems. This suggestion was the driving force of the bachelor thesis.

The initial idea was to get the certification for this product to facilitate the selling and marketing. However, until the end of May 2018, the whole situation changed: the piping had to be replaced, the smart metering was defective and the overall look was deteriorating. Even if a certification of the current SWH seems hopeless, starting the whole process represents a key step. Indeed, getting in touch with the responsible authority and learn the requirements for the certification is one of the main objectives of this project.

3.1. PROCEDURE

The responsible authority for certification in Rwanda is called Rwanda Standards Board (RSB). They deliver all sort of standards for industrial and commercial purposes. The goal is guarantee the quality of a product or a service. Upon the arrival in May 2018, a meeting was scheduled in order to lay out the solar water heater project of IPRC.

This meeting eventually took place end of June and gave all the answers needed. The certification process can be divided into three parts:

1. Acquire the product standards and fulfilling the requirements
2. Having the necessary testing capacities
3. Apply form and inquiry

A certification can be obtained for any product and is based on the standard requirements. Those requirements are published in Rwanda Standards (RS), documents written by a committee of technical experts in the domain. A list of more than 1300 available RS is at disposal either, online in the standards catalogue, or directly in the RSB office in Kigali. Each RS must be purchased separately and costs 1500 RWF/page. Three major RS relate to solar water heaters: RS212, RS213 and RS214.

Once the standards are implemented in a product, the second step is to test the product based on those requirements. Some documents describe specific testing procedures that have to be deployed. Therefore, the applying company must have the necessary infrastructures and testing facilities.

Eventually, when the first two steps are fulfilled, one can officially apply for a certification. The process then takes trough different steps. A flow chart can be seen in appendix 3.

3.2. REQUIREMENTS

All the requirements of solar water heaters are published in the three following RS. These documents refer to other normative references such as other RS or ISO standards. Considering the lack of expertise in the domain of SWH fabrication in the country, those documents were mainly based on international requirements. This is probably the reason why some of the requirements tend to be over demanding or not appropriate in Rwanda.

Hereafter is a summary of each document listed in appendix 4-6:

RS 212: Domestic storage water heater - Requirements

1. Defines terms and definition and the appliance range
2. General requirements : tank, collector, piping
3. Thermal properties according to ISO 9459-2
4. Corrosion protection
5. Markings : tank (according to IEC 60335-2-21), collector and system
6. Instruction booklet : mandatory content

RS 213: Domestic storage water heater - Mechanical qualification tests

1. Stagnation : duration of 15-30 days
2. Mechanical test: fatigue, vacuum and pressure
3. Resistance to rain penetration : 12 spray nozzles at 165 l/h at a distance of 10cm from the collectors
4. Resistance of collectors hail damage : fire ice balls onto collector
5. Resistance to freezing : test room which can be controlled to any specific temperature between -20°C and 20°C
6. Resistance to dezincification (according to ISO 6509)
7. Corrosion resistance : if any corrosion is identified after the above listed tests, a salt fog test must be carried out with a test sample

RS 214: Installation, maintenance, repair and replacement of domestic solar water heating systems

1. General requirements
2. Requirements for installation of collectors, tank and piping
3. Requirements for operation, maintenance and repair

3.3. IMPLEMENTATION

Considering the highly demanding requirements, a certification of the implemented systems on Home Saint Jean is impossible. The quality of construction is simply not good enough.

As there are some inappropriate requirements, a second conversation with RSB concluded that it is possible to apply for a lightened certification. In other words, the requirements that are not fulfilled must clearly be highlighted and communicated with the clients. Furthermore, it is possible to sell SWH to private clients without certifying the systems. As soon as IPRC wants to extend his offer to governmental clients like schools, hospitals or administrative buildings, a certification will be needed.

In view of the current situation and the close future, the certification is not necessary. Yet the fabrication of new systems will take into consideration the requirements written in the RS.

4. DEVELOPMENT OF A NEW PROTOTYPE

As the analysis in chapter 2 has shown, the current solar water heaters can be much improved. In brief, there is a lack of uniformity in the fabrication process reflected in the visual appearance of the systems. A certification under such circumstances is not possible.

The biggest strength of the solar water heaters made by IPRC is their implemented smart metering. In comparison with other products in Africa, this one has not to face the primary challenge of reducing the costs. IPRC is providing the systems free of charge. The client has only to pay his hot water consumption. This difference of not having an initial investment to be made makes it possible to focus first and foremost on the performance of the solar water heater.

As a result, a new prototype will be developed. The focus will be on system performance first. The aim is to learn from the mistakes made on previous types, fix the majors issues with the current one and above all fabricate a product with a proper finishing.

4.1. MARKET SURVEY

In Rwanda, the market is reigned by imported solar systems. Those offers are mainly from European countries. Rwandan-made systems are sparse to find and none of them is certified. As a result, the systems to be bought on the market are all built after high standards.

4.1.1. TUMBA COLLEGE OF TECHNOLOGY

Part of IPRC, Tumba college of technology has also a SWH project running. Their situation is very similar. The teachers are building systems besides their main activity of teaching. The big difference is that they sell their systems. To stay competitive on the market they have to minimize the price and therefore use cheap materials. In terms of appearance, this is well succeeded. The overall look is much more professional than those build by IPRC-Karongi. On a performance point of view however, both systems are similar since these ones reach 50-60°C.

Figure 16: TCT SWH

It is interesting to see that galvanized steel is all over. It is used for the inside and outside tank, the frames of the collectors, the absorber and even the piping. Of course, this reduces considerably the costs and facilitates even the plumbing as standard fittings can be used.

Figure 17: plumbing on TCT SWH

Tumba offers two different models:

- Two collectors + tank of 200 litres for 700'000 RWF
- One collector + tank of 100 litres for 500'000 RWF

They have sold 12 systems to four different clients: a tea factory, a school in Huye, a household in Kigali and a hotel in Ruhengeri. According to them, the clients are happy with the product. There might be little issues with rust in some cases but they did not give further explanations.

4.1.2. IMPORTED SYSTEMS

There are many different offers on the market. Hereafter, one of them was chosen to compare it with the IPRC systems. The private company *Intertech*, based in Kigali, offers *Solimpeks* SWH from Turkey. This comparison makes sense since such systems are installed on a nearby hotel in Kibuye, the Bethany.

IPRC	Solimpeks
Materials	**Materials**
Absorber: Galva steel	*Absorber:* Aluminum
Tubes: Copper	*Tubes* : Copper
Glass: Glass	*Glass:* Tempered glass
Insulation: Blankets	*Insulation:* Glasswool
Caracteristics	**Caracteristics**
Number of collectors: 3	Number of collectors: 2
Surface: 6m2	Surface: 4.84m2
Collector heat carrier volume: 2.41 lt	Collector heat carrier volume: 2.54 lt
Max temp: 60°C	Max temp: 90°C
Tank volume: 300 lt	Tank volume: 300 lt
Costs	**Costs**
System: 1'500'000 RWF	System: 1'250'000 RWF

Table 7: comparison between IPRC's SWH and Solimpeks SWH
Source: Solimpeks data according to [5]

Actually, those two systems should not be compared. On the one side, there is a first prototype built by a school and on the other side, there is a worldwide sold product. A simple glance is enough to tell both systems apart.. Beside the better overall look of the industrial systems, the performance is also much better. Even if a test in same conditions cannot be conducted, the max temperature to be reached by the Solimpeks systems is 90°C. Approximately 40° C degrees more than the ones installed on Home Saint Jean.

4.1.3. MADE IN KIGALI

As mentioned before, there is a small offer of Rwandan-made systems.

SONATUBES LTD

Sonatubes is a Belgian retailer of imported materials for construction and other hardware products. Products that they do not have might very well not be available at all in Rwanda. This will be discussed in a further chapter however.

Besides their primary selling products, they offer also SWH made in their own workshops. A system consists of a single collector with a tank. The pipes as well as the absorber are made of galvanised steel. Once again, their challenge is to build a competitive system that does not cost too much.

Note that they do not face problems with rust. This is due to two facts: first, as a privileged retailer in Rwanda, they have access to the best materials and second they use an additional zinc coating to protect the steel. The product used for this is Zinga.

MANUMETAL

Manumetal was building SWH in the past but ceased their activity. There was no clear answer given why but apparently, they focussed their offers on their main activity: wood and metal furniture.

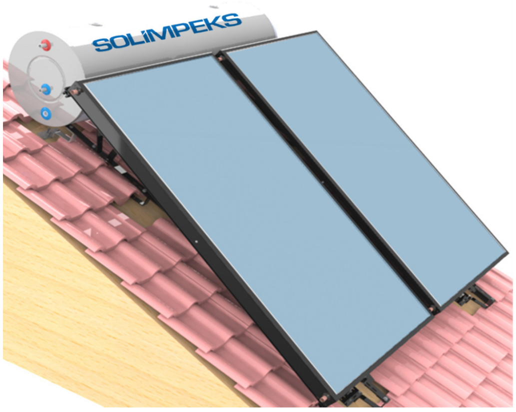


Figure 18: Solimpeks SWH
Source: Solimpeks

Figure 19: Sonatubes SWH
Source: Sonatubes

4.2. SOLARRWANDA NATIONAL PROGRAM

[6] The government of Rwanda obtained an international grant for the development of SWH in the country. Currently most water heaters are electrical and the possible annual savings by installing SWH are amounted to 23 MWh. Since the Rwanda Energy Group (REG) faces difficulties with the rising electrical demand, any savings are welcome. This is why Energy Development Corporation Limited (EDCL) created the SolarRwanda program. The aim is to promote the widespread use of SWH in the residential sector throughout the country. This is boosted by a grant/loan system where the actual price can be reduced up to 50%.

EDCL concluded a partnership with several companies offering solar systems. To make use of this offer, the system has therefore to be bought in one of those companies.

SWH CATEGORY	CAPACITY	GRANT	LOAN
1st Tier with 2 bar pressure	300L	$ 400	$ 800
	300L	$ 400	$ 800
2nd Tier with 0.6 bar pressure	300L	$300	$ 700
	200L	$ 200	$ 550
3nd Tier with Unpressurized	300-250L	$ 150	$ 500
	200-180L	$ 100	$ 400
4nd Tier with Unpressurized	Any	No grant	75% of the quotation

Table 8: subsidies for certified SWH
Source: REG

Even if IPRC does not actually sell the SWH, a partnership might still be possible. A first contact letter, refer to appendix 7, was written.

4.3. MATERIAL INVESTIGATION

Rwanda's market is geographically very limited. In fact, most materials are only available in the capital city Kigali. In Kibuye town, there are a few hardware stores. However, only the very basic stuff can be found. For example:

- Plumbing: galvanised or plastic pipes and fitting in a few standard sizes.
- Metal: little offer of steel tubes, angles and sheets
- Glass: mainly glass used for windows, dimensions are given
- Insulation: none except foam used for beds
- Wood: available from surrounding woods, strongly limited in size and variety

This limited offer forces to undertake the purchases in Kigali. Therefore, the whole process is considerably complicated because this means supplementary authorizations and procedures. Above all, this limits one's action range: in case of a missing material, a complication or a change in technique there is possibly no solution at hand.

Kigali is quite a mess if one does not know what and where to look for. It takes some time to get to know the city and its best places to buy materials. That is why, end of June, an investigation was carried out to get an overview of the available materials. In total three days were spent in Kigali to list different suppliers and their offers. Overall, the market can be divided into three parts:

- First, there are hardware shops (*quincailleries*) in every corner. Almost everything is to be found as long as you have the patience and time to go through every little shop. Several shops will have the same items but do not expect owners to have the same stocks on different days. There are a few key places in the city to know, for example Gakinjiro-Gisozi.
- Less common than the basic hardware shops are the specific ones. Usually their offer is a bit smaller but on the other hand, they have materials that are more specific to one domain. Generally, the products are more expensive. They are scattered around the city.
- Eventually, two or three stores clearly stick out of the mass. These are the places where you find imported quality products, usually ones you find nowhere else. In some cases, this will save a lot of time and trouble but be aware of the high prices.

	Number	*Quality*	*Price*	*Variety*	*Specific products*	*Examples*
Western-style shop	- -	++	+++	+	++	Fixit Chez Costa, Sonatubes
Specific shop	-	+	++	+	+	Annik, Chinese 2000, Editech
Hardware shop	++	-	+	++	-	Aound Kigali

Table 9: categorization of shops in Kigali

4.3.1. AVAILABLE MATERIALS

Hereafter is a list of the main components of a SWH and their availability in Kigali. Appendix 8 lists these different materials, their price and supplier.

INSULATION

Proper insulation is hard to find. The reason is simple: houses are not insulated so there is no real market. The rare insulating materials to be found are mainly for soundproofing; a few of those are even made of glass wool. In hardware shops however, one can bump into surprising products. For example, one roll of Isover thermal insulation was found in a small shop.

An exception to this general rule is Sonatubes who has imported rock wool in stock. This can be attributed to their own offer of solar water heaters where they use that same material. The price of this rock wool is extremely expensive.

PIPES

Galvanized pipes are found everywhere. However, copper ones are more difficult to find. Be aware that their sizing is different. Half inch of galvanized pipe is not the same diameter than half inch of copper pipe. Generally, the copper pipes are a bit thinner than the steel ones.

A few specific shops offer copper pipes, especially in downtown. The price and quality varies. One may find a few sizes in one shop and the rest in another one. The length of the pipe is everywhere the same: they are sold in rolls of 15,2m. Novitas has straight pipes of a few different sizes but they cost multiple times the amount of the same size rolled.

FITTINGS

The availability of fittings is matching the one of pipes. The basic plumbing fittings are sold at every corner. To find the more expensive fittings in copper, brass or bronze one must search longer.

GLASS

The ambition to find toughened or treated glass in Rwanda is non-existent. There is only normal glass or double layer glass, also called safe-glass. In terms of offer, Annick is the one and only retailer of glass to know in Kigali. All the other sellers of glass are buying it either from him or from his competitor next door who has the same offer but cheaper. The difference is probably due to the less good quality and service.

METAL

Metal sheets can be found in a few different places but the offer is mainly based on mild or galvanized steel. Aluminium and Inox is hard to find and copper is only available in a single place: Sonatubes.

As for angles or simple bars in steel or aluminium, they can be found in hardware stores.

4.3.2. DIFFICULTIES OF FINDING QUALITY PRODUCTS

As described previously, the market in Kigali is quite limited. Finding special items is hard if not impossible. The available materials are only the ones that are useful in the daily Rwandan life. The materials needed for a solar water heater are mainly basic construction materials that are easily found in Switzerland or Europe. In Rwanda however, most of those materials have no need. For example, the climate is too tempered to need proper insulation. As for metal, copper, aluminium, or Inox are too expensive to be widely used.

This material battle is probably the major downside of wishing to create a high-end product. Most of the materials that are needed for this project are materials that are simply not used in Rwanda. Summed up: without demand, there is no offer.

GLASS

The glass used in industrial solar collectors is treated to increase its efficiency. Efficiency in terms of a solar glass covers means that it allows the solar irradiation to enter the collector but prevents the accumulated heat to exit the collector. This is also known as greenhouse effect.

The following rule applies:

- Solar energy has a short wavelength
- Heat emitted by the absorber has a long wavelength
- The glass should therefore have a high transmittance of short wavelength and a low emissivity of long wavelength

[7] Standard window glasses as available in Rwanda have an emissivity of 0.84 in the whole wavelength spectre. Therefore, only 16% of the heat emitted by the absorber is reflected. With special coatings, for example in silver, the emissivity can be reduced to 0.04. On the other hand, conventional ways to maximise the transmittance is to decrease the amount of iron in the glass.

All those requirements can only be fulfilled with industrial facilities and is therefore not applicable in Rwanda.

A major issue in the implemented collectors was the used glass. As mentioned previously, there is no alternative to normal glass because there is no offer of treated glass on the market. Therefore, the only way to minimalize the risk of breaking the glass is to increase its thickness. There are two solutions: either simple 6mm glass or two glasses of 3mm glued together. The second one is officially sold as safe glass but the glue might compromise a part of the sunrays to reach the absorber.

In comparison with the old glass, the extra 2mm strengthen and stiffen the glass a lot. Doubling the price for a so-called safe glass seems overstated. Especially since the performance of the collector might be compromised by the thin glue layer in-between a double layer glass.

PAINT

A standard metal surface, especially if polished, has a low absorptivity of thermal energy. This is why the solar absorbers are painted in black. By doing so, the absorptivity can be increased up to 0.97. On the other hand, black paint also has high emittance, which means losses of energy. Ideally, the absorptivity is close to one whereas the emissivity is close to zero. This means that a maximum of heat is collected and a minimum is lost.

Industrial solar collector manufacturer apply special coating to optimize this process and reach values up to 0.95 for absorptivity and as low as 0.05 for emittance [8].

Special solar paints that fulfil these requirements exist. Needless to say that they are not available in Rwanda.

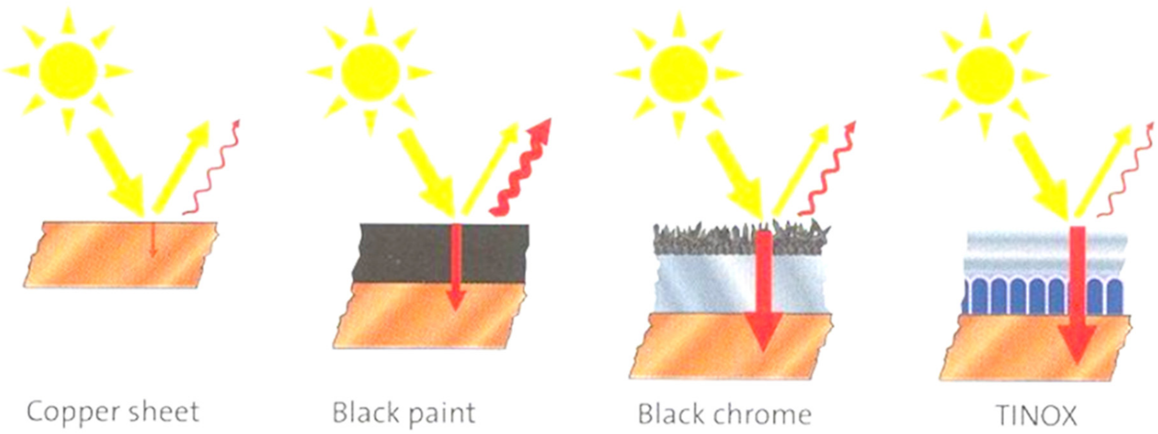


Figure 20: copper surface coating to increase absorptivity and reduce emissivity
Source: Dervey S.

FITTINGS

The fittings must fulfil following requirements:

- Suitable for joining copper pipes and plastic multilayer pipes
- Match the size of the joining pipes
- Be either in copper, brass or bronze

On the existing SWH classic plumbing material was used: galvanized fittings and plastic pipes. However, the use of galvanized components should absolutely be avoided with copper components in the same circuit. Metallic corrosion can result.

[9] Corrosion can occur by direct contact or in presence of water. The phenomenon is subject to electronegativity difference between two metals. The bigger this difference, the greater the risks of corrosion. The following statements apply:

- The component having the smaller electronegativity corrodes the one with the bigger electronegativity
- Copper has a lower electronegativity than galvanized steel
- The galvanized component will corrode

In practice, this process can take years depending on the quality of the materials. However, if the SWH are intended for commercial purposes such issues must absolutely be avoided.

For the overall construction, following things regarding corrosion have to be considered:

- Copper can be used with brass, bronze and stainless steel without corrosion issues
- Copper must be separated with aluminium otherwise corrosion occur

To find fittings that combines those three requirements is actually quite difficult. The fact the two different types of pipes must be joined, requires special compression fittings as showed in figure 21. Their availability in Kigali is limited, especially in size and material.

Figure 21: suitable brass compression fittings

SEALING

The biggest optimisation to be made on the implemented SWH is certainly in terms of insulation and sealing. Accordingly, a lot of time during the investigation was spent looking for proper sealing. The idea was to look for different types of rubber used for windows in houses or vehicles. Unfortunately, none had the exact shape and dimensions that could be used in a future construction.

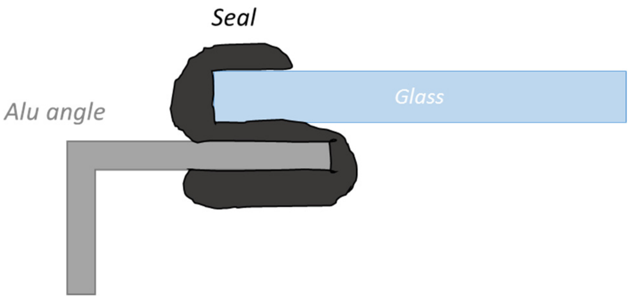


Figure 22: sealant possibility

SOLDER AND FLUX

Due to the lack of copper use in the country, there is little solder to be found for copper. The one needed contains mainly tin. Sebasol, a company in Switzerland producing their own solar collectors with copper sheets and pipes, for instance uses a 97Sn3Cu solder (the numbers representing the part percentage of the respective metal). Unfortunately, such kind of solder cannot be found in Rwanda.

Both Sonatubes and Chez Costa are supposed to have tin-solder. Sonatubes however is out of stock and Chez Costa have only one alloy: 60Sn40Pb. This alloy is one of the most common as it is used in electrical work. A spool of 250g of 1mm diameter costs 70'000 RWF.

Followings things have to be considered when using a lead-alloy for soldering:

- Lead can severely affect health
- It is prohibited in plumbing applications in many countries around the world

This is the reason why the piping must be brazed with a copper alloy. Any use of lead-solder could bring the water in contact with lead and result in health issues. Luckily, the soldering is used for joining the copper plate and pipes. There is no water contact and therefore lead-solder alloys can be used. Nevertheless, its application requires safety precautions as inhaling can also cause problems.

Flux is just as important as the solder. There are fluxes made specially for soldering copper. None of these is available in Rwanda. No liquid nor paste flux was found.

4.4. COLLECTOR DEVELOPMENT

It is henceforth possible to elaborate different solutions regarding the way of construction of the new prototype. Probably the least obvious decision to take is concerning the housing. The choice of material affects greatly the building techniques afterwards. Therefore, it is necessary to establish different solutions. The three following alternatives were made based on the material investigation.

WOOD

The first solution at hand is to build the frame in the same manner than the ones already implemented. The acquired expertise can benefit to improve the new construction since the construction challenges have already been identified. The major drawback of this solution is the fact that wood is a different raw material than the rest of the collector. This means that the collector cannot be built by the same people and additional infrastructures and machines from another domain are needed.

Wood		
	Ease of construction Insulator (therm + elec) Locally available **S**	Carpentery necessary Mounting precision Weight **W**
	O Cost of raw material Durability	**T** Work hours Finish

Table 10: wood frame SWOT

STEEL

A second option would be to use steel. Previous collectors at IPRC were built with steel doorframes. They are made of a standard profile that is bended and welded in any size. The main force of this solution is the easily available material and his price.. On the other side, steel is subject to rust and has to be treated. As seen on the existent collectors, this represents a critical point. In addition, the profile size is standardized so there is less freedom in terms of dimensions. The height is usually 150mm. The assembling and mounting of the different components seems more complicated.

Steel	S	W
	Fabrication technique Whole system in metal Mecanic resistance Costs	Thermal conductor Glass mounting Absorber inserting Rust
	O	**T**
	Weight Workforce Sealing	Limited dimensions Electric compatibility Cu/Fe

Table 11: steel frame SWOT

ALUMINIUM

The last alternative is to draw inspiration from the market. Indeed, almost all industrial collectors are made of aluminium. The general appearance is much better and there is no deterioration as time goes by. However, in terms of resources, the fabrication is much more demanding. Welding Aluminium requires skill and expensive Argon gas. That combination is the reason for the lack of expertise of IPRC in this domain.

Alu	S	W
	Visual aspect Single piece Durability	Trained workers Mounting precision Costs
	O	**T**
	Fabrication technique Weight	Argon welding Bending machine

Table 12: aluminium frame SWOT

4.4.1. FIRST ALTERNATIVE

Considering the analyses made so far, a first solution for the whole prototype was drawn:

- Absorber in copper to prevent sanitary issues
- Housing in wood, covered with a sheet of aluminium
- Glass divided into two smaller ones, to prevent glass breaking
- Combination of glass wool and polystyrene for insulation

The major force of this solution is being an extension of the collectors built so far. The main building techniques are the same, but the materials are optimised where problems were detected during the analysis. These improvements affect the price. A single collector would cost almost as much as three collectors of the existing type. However, the area might be much smaller but the effective area is not too different actually. This can be explained by the fact that there is the same pipe length in both.

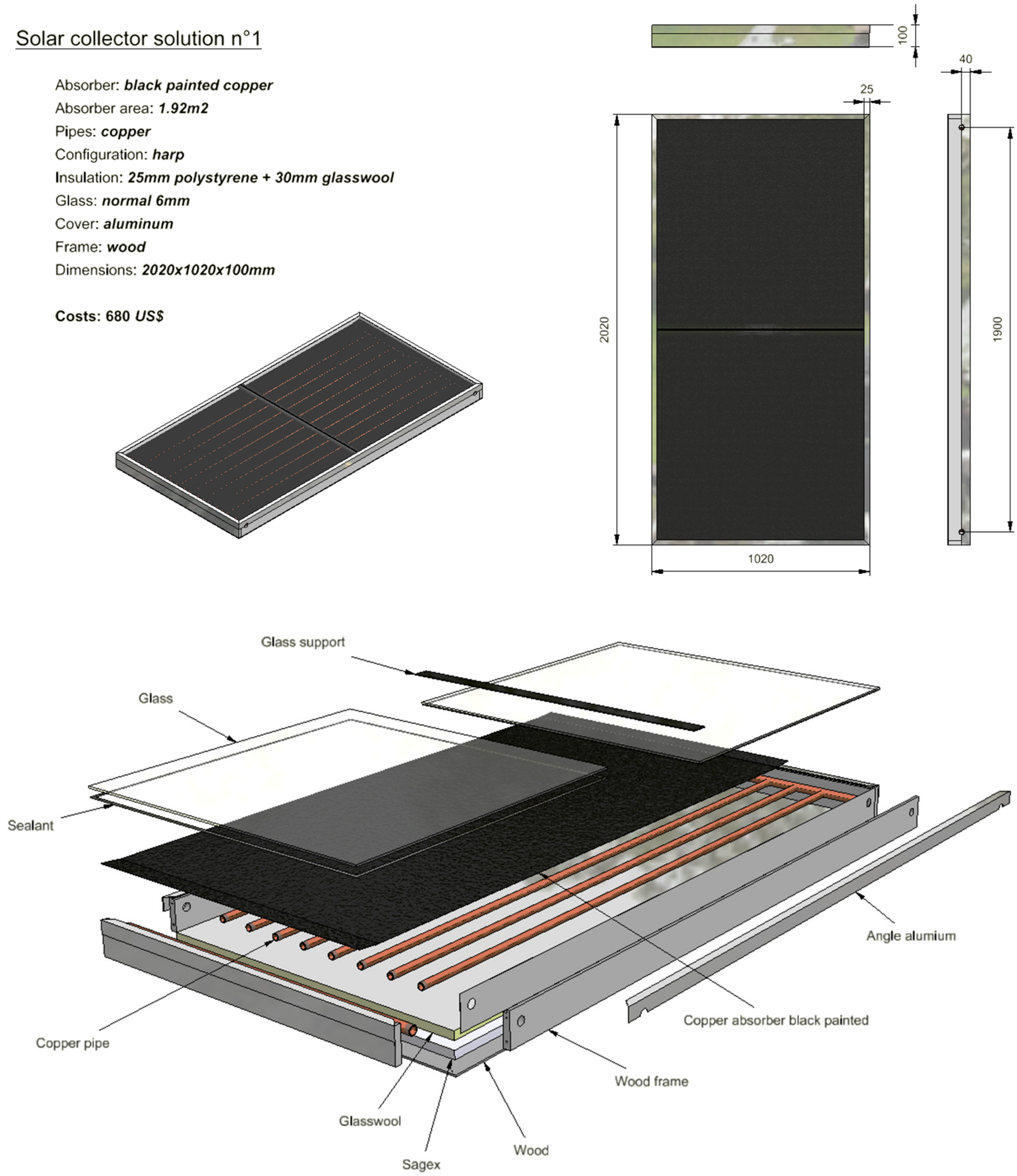


Figure 23: illustration of first collector solution

Different absorber construction techniques were compared from a financial point of view. The results are showed in appendix 9.

A material list and plans can be seen in appendix 10. Note that the drawings are made for a smaller edition than the solution exposed in figure 23. The reason for this change is the size of the glass. This issue will be discussed in chapter five.

Eventually this solution was abandoned due to the following reasons:

- Complex woodworking: the imagined pieces of wood require special techniques and are complicated to produce. Especially the grooves are difficult.
- Infrastructures: in addition to the obvious metal workshop, the woodworking needs additional machines and knowledge. Considering a future expansion of the business this can prove to be problematic.
- Aluminium cover: due to the medium quality of the available wood, a metal cover was imaged. However, by doing so, there is a considerable risk of humidity forming between the metal layer and the wood. This results in rotten wood.

4.4.2. RETAINED SOLUTION

In a commercial product, the visual appearance is just as important as the performance. Since the existent collectors made of steel are bad from this point of view, it was decided to create a new prototype with an aluminium housing.

The initial idea was to build the housing with a single metal sheet that is bended to a box. This turned out to be too complicated since IPRC does only own small metal brakes. Even so, in any solution considered the last side to bend caused trouble. Without special box brakes this is not possible to do.

Since already some materials had been bought, an alternative solution was found:

- Create a housing with angle aluminium bars that form the edges
- Use thicker aluminium sheets to fill in the gaps in between
- Fix the different pieces together with simple rivets

Compared to the box solution, this is an easy one. There is no need of any special machine like a box brake or expensive techniques like Argon welding. Everything can be done handmade.

The plans and drawings are exposed in chapter five.

4.5. TANK DEVELOPMENT

A few months after the SWH were installed on Home Saint Jean, one of them started to leak a little. He was replaced by one of the two tanks remaining at the IPRC campus. The one leaking was stored in the workshop but never repaired. When the development of the new prototype began, the idea of repairing this once came up.

As soon as the outer tank was cut, the real problem with the insulation was discovered. The issues were multiple:

- There was still "fresh" foam that never dried because of the lack of oxygen for the foam to expand
- The foam did not fill the whole volume
- The actual insulation only measured 2.5 cm
- The inside was wet

The last issue is probably only due to the leaking. Still the other ones are in common with all the tanks, since they applied the same technique to build them. Even if you omit the issues with the foam, the thickness is simply not big enough to ensure a proper insulation. The temperature drops during the night are enlightened.

Figure 24: insulation issues detected on existing tank

The leaking of the stainless steel tank was found to be a small hole on the back circular plate. The issue was easily fixed. The tank is therefore ready for a second life but even so, a second one will be developed. The aim is to find alternatives to the expensive stainless steel inner tank.

That is when Sonatubes solution came up again: Zinga, an anti-corrosion product made of 96% zinc. When applied, it guarantees galvanic protection. Indeed, Sonatubes is using steel pipes that are covered with a layer of Zinga.

Zinga fulfils several European sanitary standards. It can be used with potable water without any doubt, as long as the coating is applied with carefulness. One litre costs 30'000 RWF and covers approximately three to four square meters. All those points make Zinga a competitive solution for the inner tank.

The new tank will consist of following parts:

- Mild steel Zinga coated inner tank, made by standard welding techniques
- Access hatch on either side to apply Zinga on welded area
- Stainless steel pipes
- Glass wool insulation, approximately 100mm
- Internal structure to support the weight of the tank, no weight on insulation
- Mild steel Zinga coated outer tank

Applying Zinga requires an important surface preparation [10]. This preparation is made in two acts:

1. Cleaning of the surface: any dirt and mill scale must b9e removed. The ways to this are multiple; solvent or detergent cleaning (for small surfaces) or steam cleaning.
2. Creation of rough surface: either with traditional tools like a steel brush or an angle grinder; or with industrial facilities like grit or slurry blasted.

This proved to be more complicated than expected. The main reason is the bad initial surface condition of the mild steel sheet. The work was supposed to be done with an angle grinder but it worked only partially as shown on figure 25. Unfortunately, this issue was not solved until mid-September 2018. IPRC will continue this work in order to complete a new tank.

Figure 25: Zinga application on mild steel

4.6. PURCHASE OF MATERIALS

The purchase of materials in Kigali is somehow complicated. Not only prices or dimensions might be different from what was planned but also the procedures are slowing down the whole process.

In order to buy an item, one first needs a so-called Proforma, some form of quote. This document, duly signed by the supplier, lists the items and their price. Usually but depending on the price, at least two different Proforma for a same item are needed. Swisscontact then delivers cheques for Proforma above 100’000 RWF and cash for the others. After buying the items, the bills must be returned to Swisscontact.

This back and forth between suppliers and Swisscontact makes the purchase of material unnecessarily complicated.

5. FINAL DESIGN

5.1. SIZING

The size of the collectors are given by the size of the glass. There is only one standard size available in Kigali: 2440x1830mm. Even if a smaller size is needed, one must buy the whole sheet of glass. This represents a major problem. Maintaining the same dimensions of 1000x2000mm from the former collectors would mean wasting more than half of the glass. As represented below, only 2m^2 of a total of 4.46m^2 or the equivalent of 45% would be used. As a result is was chosen to divide the sheet into three equal pieces. By doing so, the waste is reduced to a small stripe of 40x1830mm.

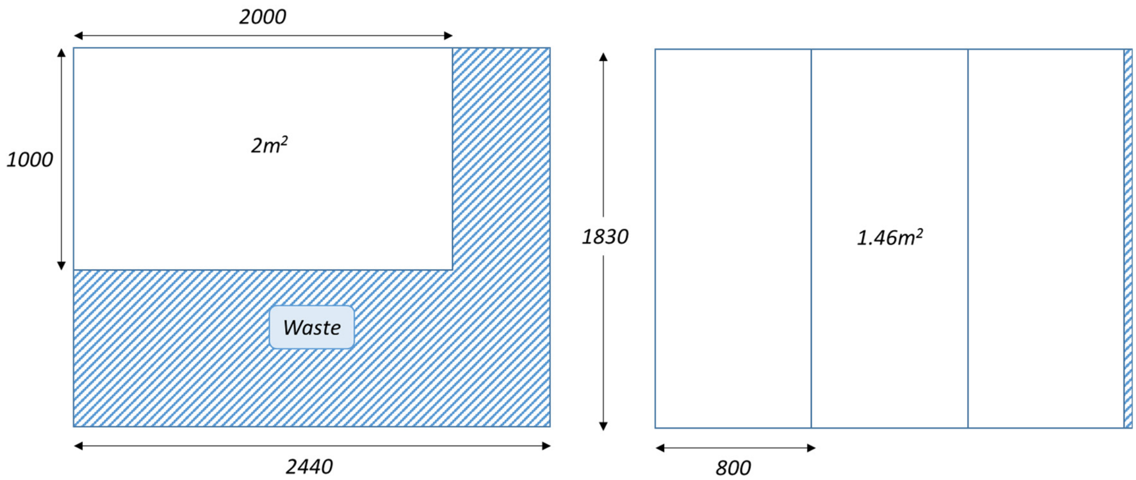


Figure 26: glass dimension issues

In comparison with the current aperture size of the collector, the surface is reduced by 27%.

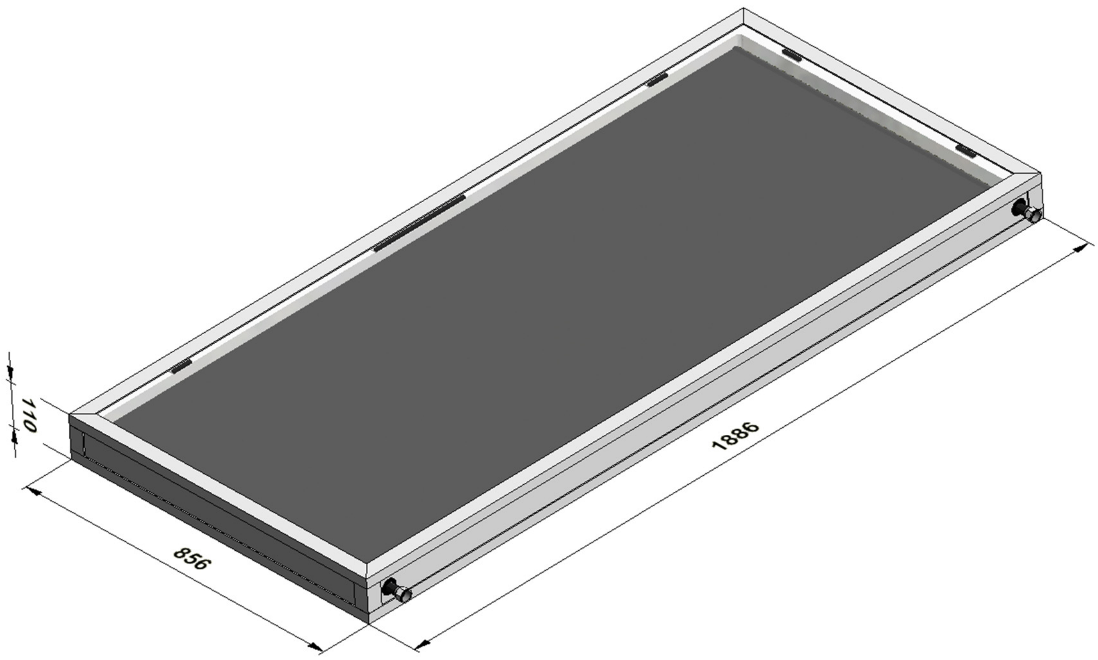


Figure 27: dimensions of collector prototype

5.2. ABSORBER

MATERIALS

To avoid sanitary issues, copper is privileged over galvanized. The market survey has shown that both pipes and plates are available in Kigali. The price might be high, but the conductivity in comparison with steel is much better.

PIPES

The pipe configuration is built in harp / parallel because it is better suited for thermosiphon systems.

- Size of the pipes: based on Sebasol's expertise, 20mm and 12mm of diameter
- Spacing of 130mm between two vertical pipes for a total of 6 pipes
- Heat carrier volume: total of 1.46 litres

	Nominal size [inch]	*Outside diameter [mm]*	*Inside diameter [mm]*	*Length [m]*	*Volume [l]*	*Number*	*Total [l]*
Horizontal	3/4"	20	18	0.91	0.232	2	0.46
Vertical	1/2"	13	11	1.74	0.166	6	1.00

Table 13: pipe characteristics

TECHNIQUES

- The pipes are brazed together
- The link between the plate and the pipes is done by soldering the whole length to guarantee the best possible heat transfer

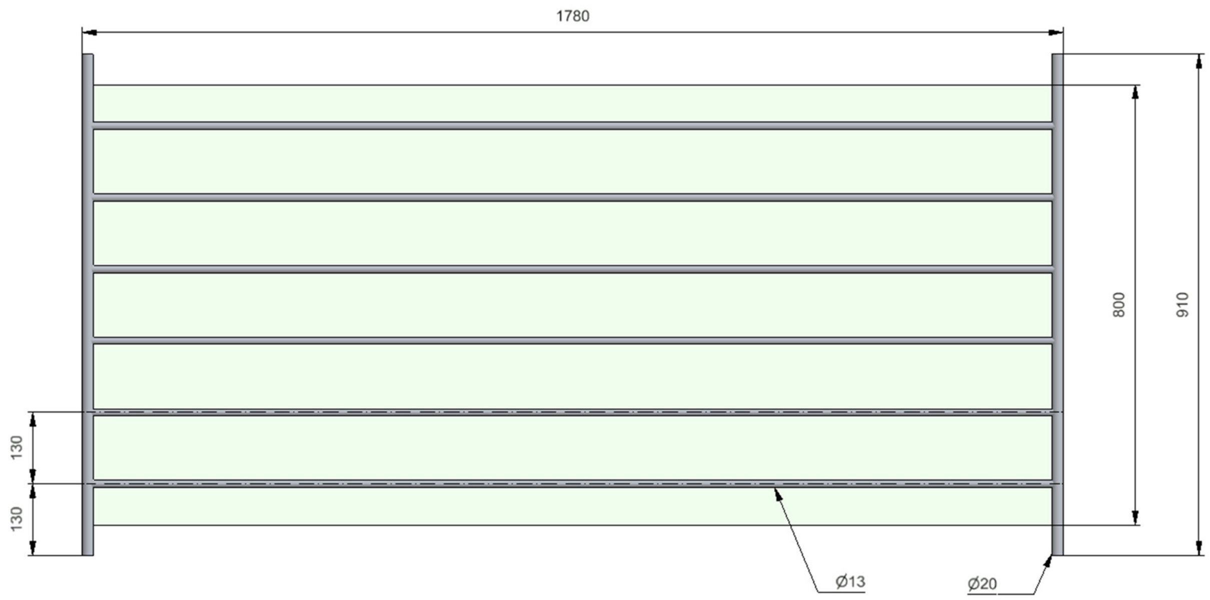


Figure 28: absorber dimensions of prototype

5.3. HOUSING

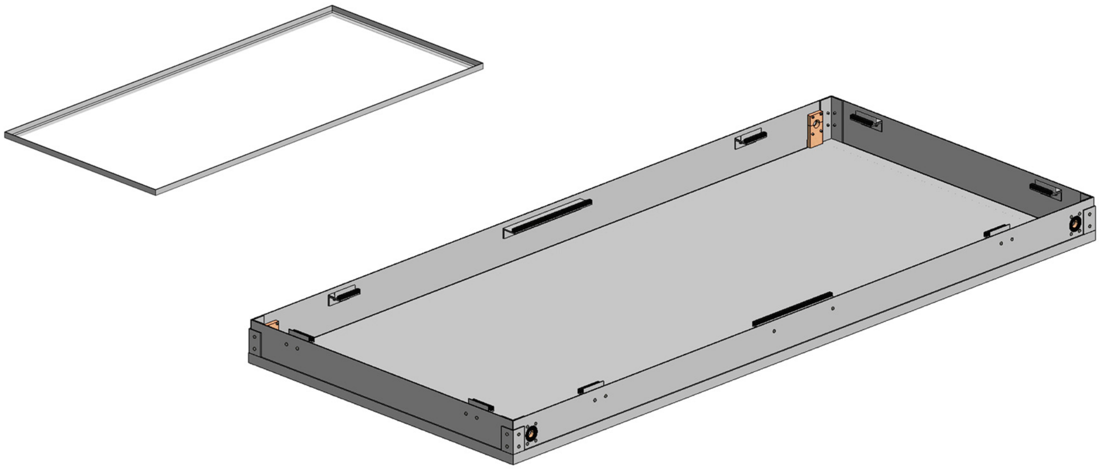


Figure 29: global 3D view of aluminium housing

5.3.1. MATERIALS

The complete housing, except some accessories, is built in aluminium:

- 0.5mm sheet for the bottom layer, dimensions: 840x1870mm
- 2mm sheet for the sides

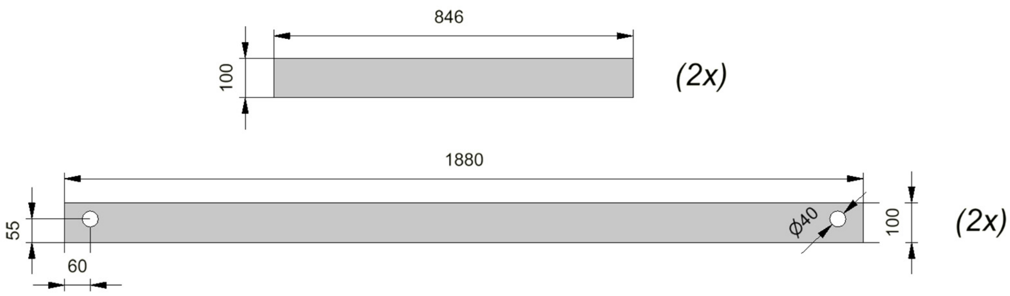


Figure 30: dimensions of aluminium side sheets

- Angle bar 25x38, 3mm thickness

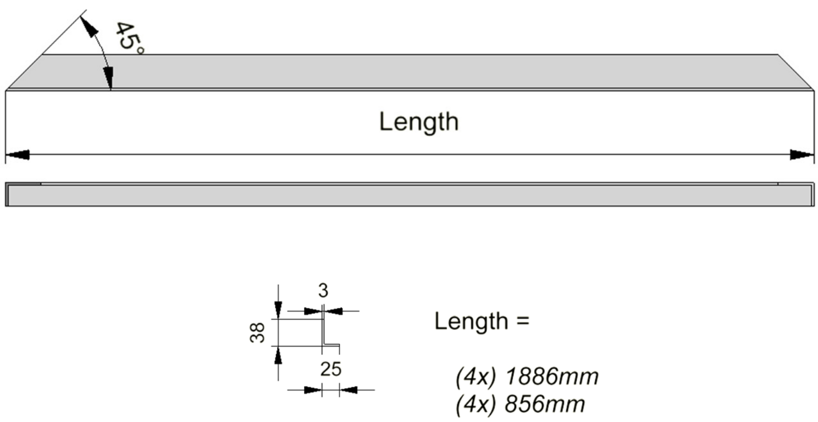


Figure 31: dimensions of aluminium profiles

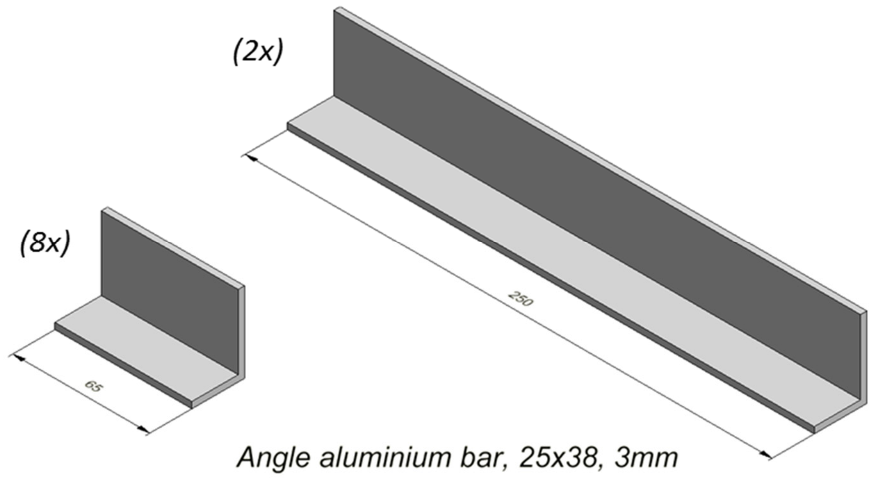


Figure 32: dimensions of aluminium profiles 2

- Angle bar 38x38, 2.6mm thickness

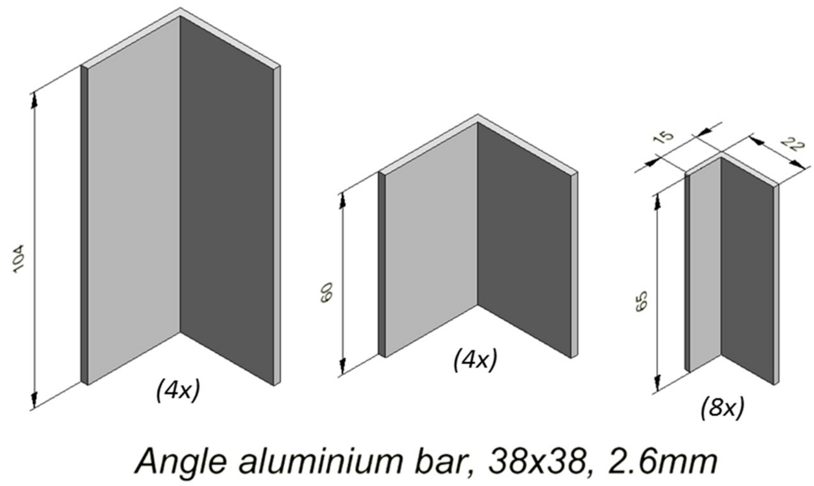


Figure 33: dimensions of aluminium profiles 3

TECHNIQUES

- The metal sheets are cut with a lever shear
- The angle bars are cut with a hacksaw

5.3.2. DETAILS

ASSEMBLING

The different pieces of aluminium are riveted together. It is an easy way to assemble without welding techniques. The diameter size of the pop-rivets is 4mm.

CORNERS

The four corners are reinforced with the thin angle bars in the inside and outside. By riveting them together, the housing gains in robustness and solidity. In this process, the two lower rivets are the most important because they link the bottom aluminium profiles and ensure solid base.

GLASS SUPPORT

The weight of the 6mm glass is supported by a series of angles covered with sealant. The angles have to be perfectly levelled among themselves. A smaller angle is riveted on the angle the other way round. The function of this piece is to center the glass correctly and avoid any gliding when inclined.

ABSORBER SUPPORT

Similar to the glass, the absorber needs a structure to support its weight. This is done with a small piece in wood in each corner. By using wood instead of metal, corrosion issues are eliminated. In addition to its first function, the wood allows to position a rubber for a proper sealing at these spots.

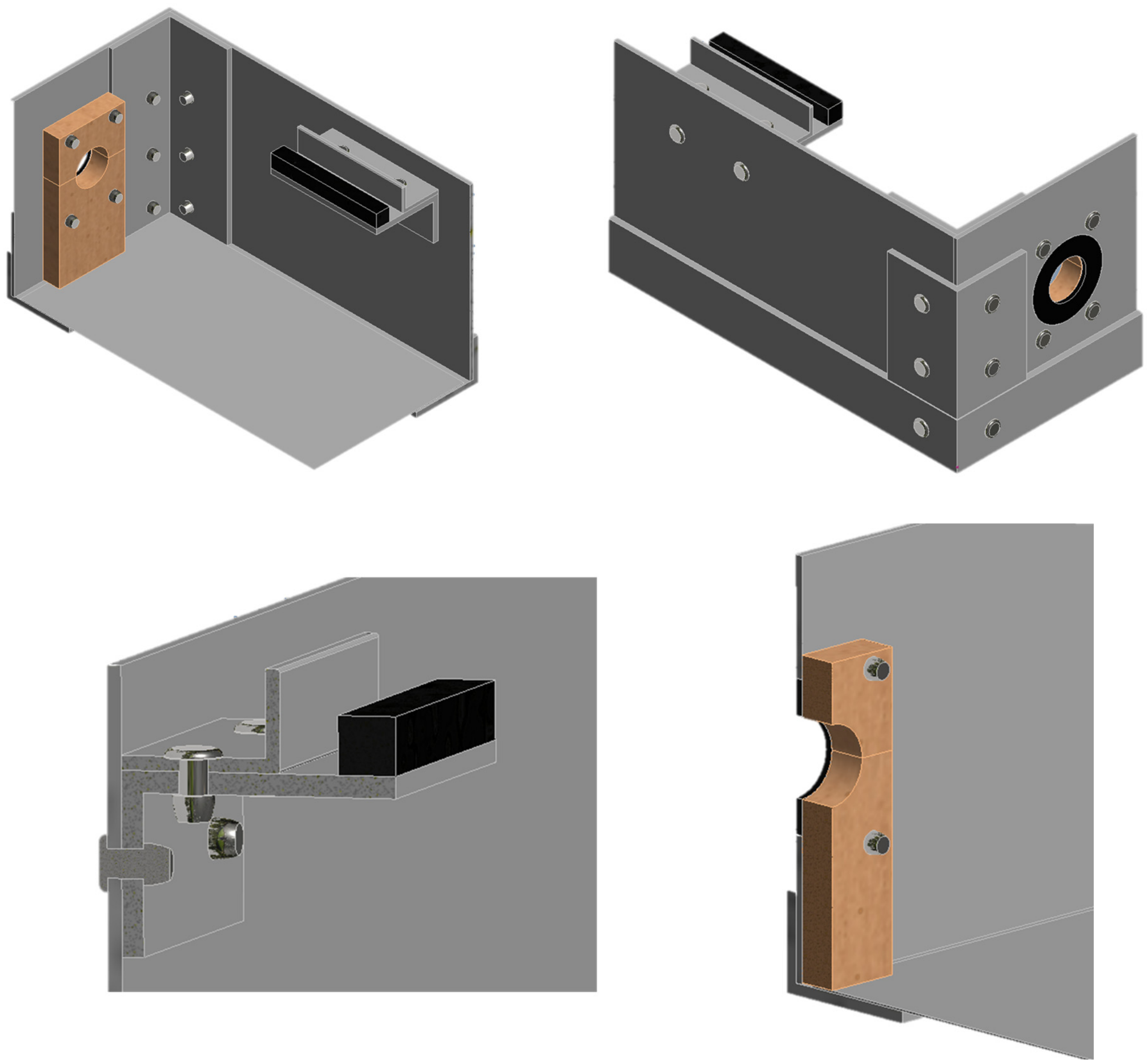


Figure 34: housing details in 3D view

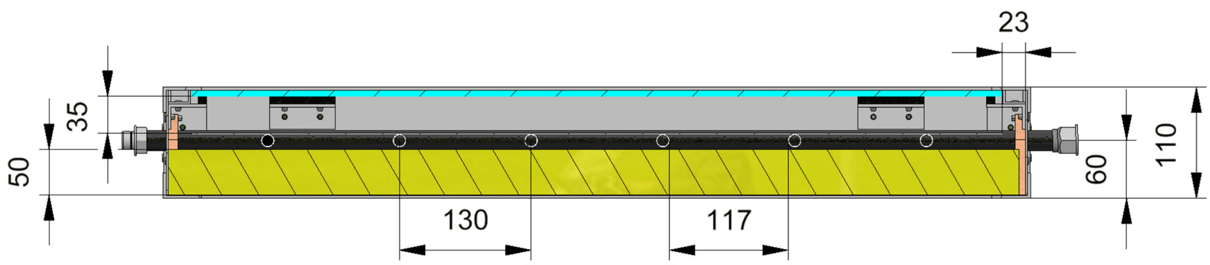


Figure 35: section view of collector

Figure 36 summarizes the main dimensions inside the collector. The overall thickness is chosen to allow:

- Insulation thickness at the back around 50mm
- Gap between absorber and glass cover around 35mm
- Easy handling and construction

The aim is reduce the thickness without compromising the thermal performance. The insulation and the gap of air have both a role as resistance to heat transfer. For example, the thermal losses through the front cover are considerably reduced with additional distance between the absorber plate and the glass cover. The gains are very high until 30mm and at around 40mm, the maximum resistance value is reached [11]. This is why a gap of 35mm is targeted.

5.4. OTHERS

INSULATION

The chosen insulation is glass wool of a thickness of 25mm. It is sold for soundproofing but since it has a low conductivity of 0.036 W/m^{2}K it can also be used for insulation matters. At the back, the layer is doubled whereas on the sides one layer is used.

SEALING

The sealing of the glass will be done with polyurethane sealant used in the car industry for front shield windows. All the remaining areas with risks of rain penetrating the inside of the collector will be covered with standard transparent silicone.

FITTINGS

The brass components presented in chapter four are chosen.

6. CONSTRUCTION

This part of the thesis focusses on the construction and on the problems encountered for that duration. This phase represents the heart of the project. The following chapters trace the chronological progress of the project with the help of numerous pictures.

Please note that the plans and 3D drawings are given in chapter five and a manual of instructions is given in appendix 11.

6.1. FIRST STEPS

The construction began with thinking about ways to make the whole process reproducible. Since the building of the absorber is quite critical from this point of view, a jig was created. This piece made of welded angle irons has slots intended for the numerous pipes and will facilitate brazing them together. It will guarantee a uniform construction on a long-term basis.

Figure 36: absorber jig built

After that, the way of brazing the pipes was tested. Not sure how well the bonds between the 20mm pipe and the 13mm pipe might hold, three different ways were explored:

i. Create a rim with a hole inside on the big pipe allowing a greater contact area with the small one
ii. Drill a hole, slightly smaller than the inside diameter of the small pipe, in the big pipe
iii. Drill a hole, the size of the small pipe, into the big one

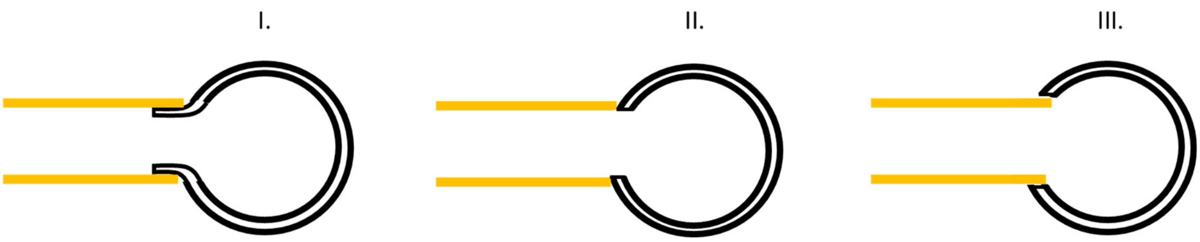


Figure 37: brazing techniques between 13 (orange) and 20mm (black) pipe

The first solution proved to be somehow complicated to implement, but all three solutions were possible. That is why the strength of the bonds were tested. Considering the different set-ups, big differences were expected but it turned out that all solutions were equally resistant. Figure 38, taken after the pipes were damaged with a Lineman's plier and a hammer, illustrates this statement. None showed any signs of cracks so solution iii. was chosen because it was the best compromise between needed skill, time and water flow resistance.

Figure 38: resistance test of brazing techniques

The last point to ensure a proper building of the absorber was to find a way to drill the holes in the 20mm pipe correctly. In other words, to guarantee that they are lined up with the jig. That is why two additional slots were drilled in front of a horizontal angle iron. This allows positioning the 20mm pipe in front of the 13mm pipe slots and marking the different centers. A special center punch was created for this purpose.

Figure 39: specific created center punch

6.2. BRAZING AND SOLDERING

First, the pipes were unrolled and cut in the right dimensions. Then they were positioned in the jig for brazing. This operation needed at least two people to braze, assist and hold in place the pipes

Figure 40: absorber brazing

This brazing should only be done by experienced people as it demands skill and training. It had to be done in two steps, as one can not heat the area from above and below at the same time. When the absorber was turned after the front side was brazed, a few weak spots were visible like the one in figure 41. Once the brazing completed, the absorber was pulled through a pressure test. The results, presented in chapter eight, were positive: there was no sign of leaking. The brazing was succesfull.

Figure 41: brazing weaknesses

Figure 42: pressure test on absorber

The next step was joining the radiator and the copper plate. To do so, the same technique used previously was applied. Soon brazing proved to be a rather bad way to do this. The required heat around 900 degrees Celsius is complicated to maintain for both pipe and copper plate without overheating the area. In addition, the copper plate tends to fold and bend with the heat, creating gaps with the pipe. This makes it even more difficult to braze.

After a few additional attempts, the undertaking had to be stopped otherwise the whole could have been seriously damaged.

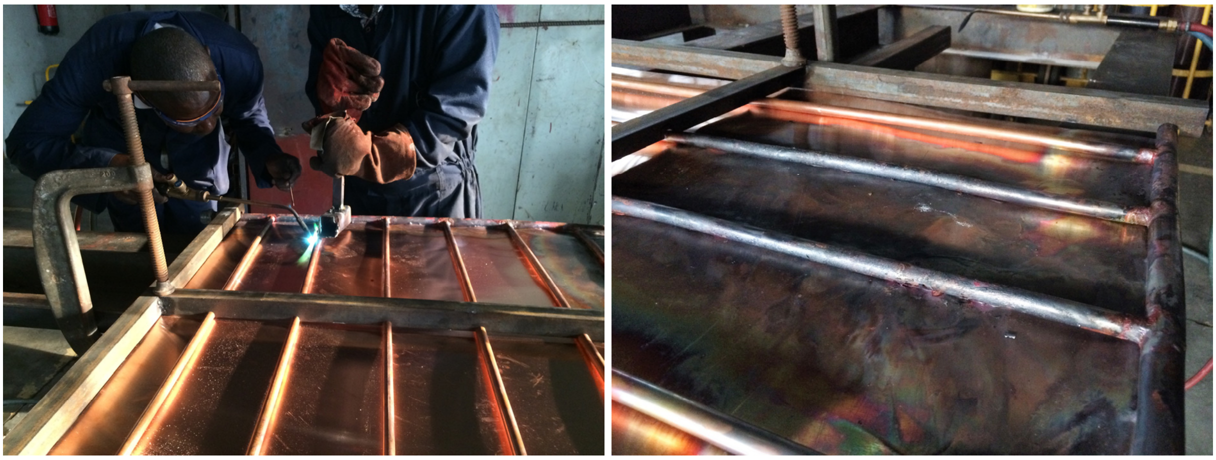


Figure 43: brazing issues with copper plate

Alternatives had to be found fast, especially since the whole construction process was relying on this absorber. Different alloys of solder were tested, all made of lead and zinc. Unfortunately, all those solutions at hand were unsuccessful.

A promising solution was found in Kigali: a car mechanic mixing his own alloy and acid for radiator purposes on vehicles. A test on site was conducted with a sample of copper pipe. Surprisingly it worked out quite well. Back at IPRC, this newfound optimism faded again. The bond was not strong enough and small cracks were visible.

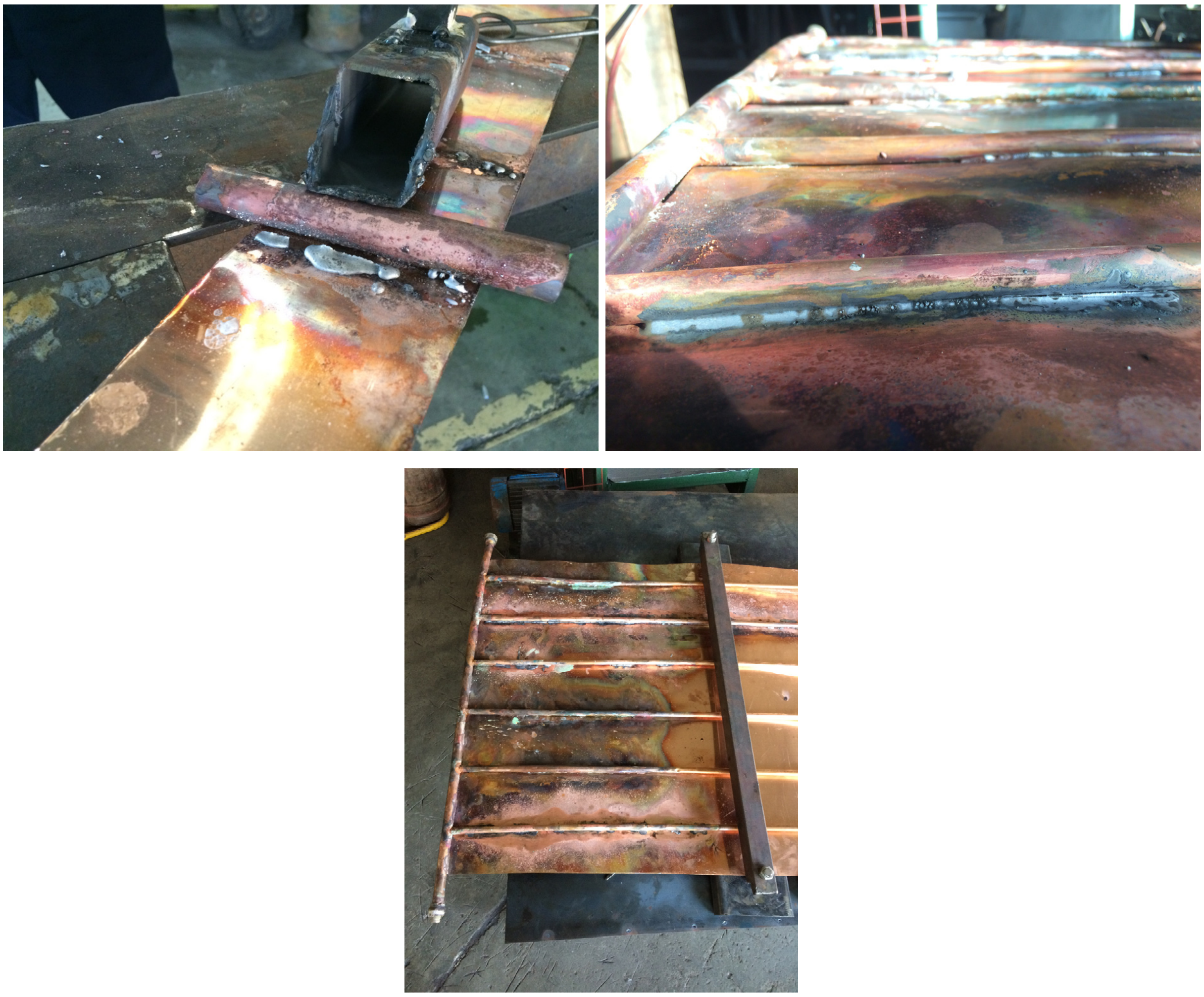


Figure 44: brazing marks and problems

As described in the previous chapter, copper is usually soldered with tin. Because tin cannot be found in Rwanda, the only alternative was to fly in some solder and flux from Switzerland. This took some time, so the construction of the absorber was temporarily interrupted. During this time, the housing of the solar collectors started.

Figure 45: flux and tin-solder from Switzerland

Once in possession of the correct material, the soldering was easy work. Within a day, the soldering of both absorbers could be completed. Nevertheless, the soldering demands careful work. Refer to appendix 11 for a complete step-by-step manual.

Figure 46: comparison between brazing and soldering techniques

6.3. HOUSING

Appendix 11 describes the building precisely. Hereafter are only some photographs to illustrate the main steps.

At a first glance, one might think that the housing is easily made. But in truth it is hard, precision work. Even if the construction needs little materials, the time to create these countless parts is quite important.

The whole housing is basically made of two different sheets of aluminium, two different sizes of anlge aluminium and plenty of rivets to hold them together. The metal sheets were cut either with a lever shear or with metal cutting scissors whereas the angles were cut with a hacksaw.

Figure 47: first steps of housing construction

The bottom is made of four angles hold together by a thin aluminium sheet. To strengthen and stiffen the whole, angles are fixed inside the four corners. Later, a second layer of angles is fixed on the outer side.

To support the weight of the glass, a series of angles were fixed inside the box. For this purpose, a small wood jig was created to guarantee the same height of fixing. The glass has to be perfectly levelled therefore this step must carefully be done.

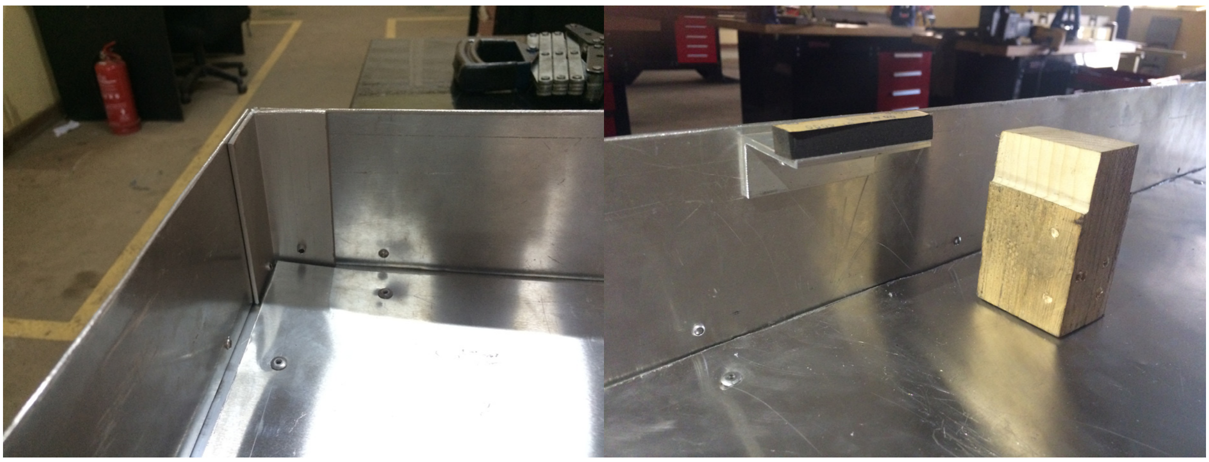


Figure 48: edge reinforcement, glass support and wood jig

Because the fittings had to be brazed onto the absorber for pressure tests previously, the housing was considerably complicated. Big holes had to be drilled on the sides to insert the absorber. As figure 49 shows, this makes it more difficult to seal and center it properly. A few different solutions were tested.

Figure 49: sealing of housing side holes

The last step to complete the housing, is to pre fix the front angles. Indeed, drilling the holes for the rivets causes a lot of burr and dust falling inside. In addition, by doing so, it allows to do last adjustments especially to match the 45° angles in the corners.

Figure 50: preparation of rivet holes for top

When the housing is completed, the top is dismounted again. In addition, one of the two longer sides of the collector is dismounted as well. Previously, only a few pop-rivets were fixed on that particular side to hold the structure and adjust the angle bars.

By removing this one side, the absorber can easily be inserted in the housing during the assembling. Figure 51 shows the box ready for assembling, with only three sides fix and one side detachable. Once the insulation and the absorber inside the housing, the detachable component can be glided back again between the two respective angle bars reinforcing the corners and be fixed with rivets.

6.4. ASSEMBLING

Once all the different parts are ready, the assembling can start. The insulation is positioned inside the housing. Note that one side is left open to insert the absorber.

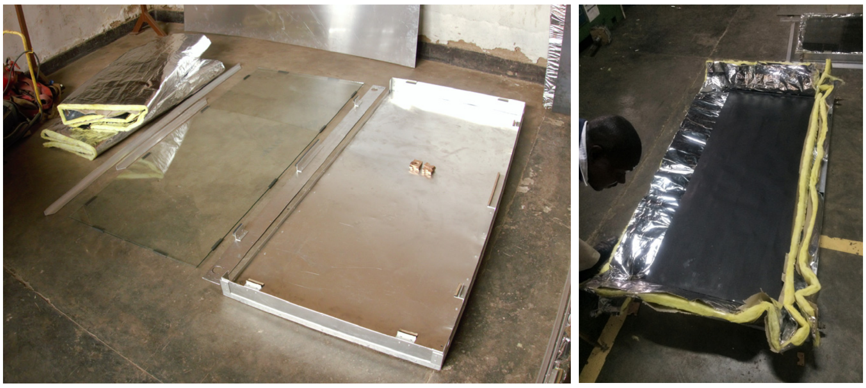


Figure 51: preparation and first steps of assembling

When this one is fixed again, the wood pieces are inserted to ensure a proper placement of the absorber. Eventually the insulation is carefully folded inside the housing and the glass can be positioned.

Figure 52: sealing and glass mounting

The next step consist of applying the silicone on the glass, placing the angles and fixing the rivets. All this has to be done quickly to guarantee a proper sealing. Eventually the rubbers are fixed with adhesive polyurethane and a last layer of transparent silicone is applied on all edges of the aluminium profiles. This is necessary to avoid rain penetration between the angle and the aluminium sheet.

Figure 53: silicone applying

6.5. EQUIPMENT

Hereafter is a complete list of the tools, equipment and machines used during the construction and installation.

Figure 54: list of necessary tools

1. Gloves
2. Drill with 4mm drill bit & 40mm hole saw
3. Metal hacksaw
4. Files (round, half-round & flat)
5. Level
6. Lead-Zinc solder sticks
7. Lead-Zinc solder spool
8. Flux (paste & powder)
9. Tin-Lead solder
10. Glasses
11. Soft jaws
12. Infrared thermometer
13. Hollow punch set
14. Calliper (classic & digital)
15. Tape measure
16. Bevel protractor
17. Combination wrench
18. Needle files
19. Drills (20mm, 13mm)
20. Carving tool
21. Wire brush
22. Lazy tong riveter
23. Cutter
25. Sandpaper
26. Tape
27. Clamps
28. Rivets (4mm, length 9mm & 15mm)
29. Hammer
30. Center punch/scriber
31. Acid
32. Liquid flux
33. Zinga
34. Water
35. Thinner
36. Black paint
37. Silicone (black & transparent)

Not on picture

38. Try square
39. Pipe cutter
40. Metal cutting scissors
41. Homemade center punch
42. Wrench (adjustable & pipe)
43. Teflon
44. Polyurethane adhesive
45. Caulking gun
46. Copper brazing rods
47. Angle-grinder
48. Oxy-Acetylene torch
49. Pressure test pump
50. Lever shear
51. Workbench with vice
52. Geared head drill press

7. INSTALLATION

The idea was to install the prototype on Home Saint Jean. Since the tank was not finished however, the solar collectors were connected to the remaining tank on the IPRC campus. Situated behind the Hospitality center, it remained unused since the galvanized collectors were disconnected. Therefore, it could be used for testing purposes of the new prototype.

7.1. GLASS ISSUES

Even before installing, the unthinkable happened. One of the glass broke after being exposed to the sun for less than 30 minutes. Luckily, a third glass had been bought. The replacement was done within a day.

Figure 55: glass breakage detection during installation

The glass broke without any external cause and this was not the first time IPRC faced this issue. Clearly, it had to be related to the heat. This incident happened around 11h, when the solar irradiance is very high. In around 20 to 30 minutes perfectly exposed to the sun, the absorber heated so much that even the housing became hot. If someone laid the palm of his hand on the glass, he took high risks of being burned.

Researches showed that the reason was indeed the temperature. It is known as thermal breakage and explained by the fact that the same glass is at different temperatures [8]:

- Glass is subject to thermal expansion just like every other material
- Different temperatures induce different coefficients of thermal expansion
- If the temperature difference is bigger than 30°C it can lead to breakage

The temperature differences can be very local and this was exactly the case of this issue here. The thin part, about one centimetre, of the glass being under the aluminium angle heated much less than the rest being directly exposed to the sun. The temperatures might have been around 30-40°C and 60-70°C to fulfil the requirements.

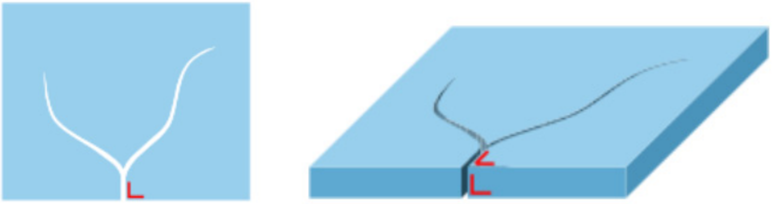


Figure 56: thermal breakage illustration
Source: energieplus-lesite

Thermal breakage is recognised by the way the glass actually breaks. It always starts from an edge and most of the time the crack is perpendicular to the edges. This is exactly what can be observed in figure 55.

During the construction phase, little issues were faced when riveting the angle aluminium. Some rivets had to be forced to enter the pre-drilled holes. Probably this boosted the breakage. It could also explain why only one of the two collectors broke.

The new glass was fixed carefully. The holes were slightly increased to avoid any additional risks. During the second installation, all the safety precautions were taken. The collectors were installed early morning and they were covered during the whole time with some blankets to avoid overheating.

Figure 57: finished system

Once operating, the risks is reduced by the water inside the pipes. The water acts as a cooler and avoids letting the absorber plate rise too much in temperature. The glass gets warm as well but it can be touched without risks of being burned. No further breakage can be expected therefore.

However, this issue must be considered for further constructions. The only way to avoid this problem is to use toughened glass that can withstand five times higher thermal shocks. Because such glass is not available in Rwanda, particular caution has to be exercised during the installation.

7.2. PLUMBING

Once the glass issues fixed, the rest was rapidly done. The multilayer pipes ease a convenient connecting process. Figure 58 illustrates which kind of fittings were used where. To guarantee a proper sealing of the female adapters, they were strengthened with polyurethane sealant.

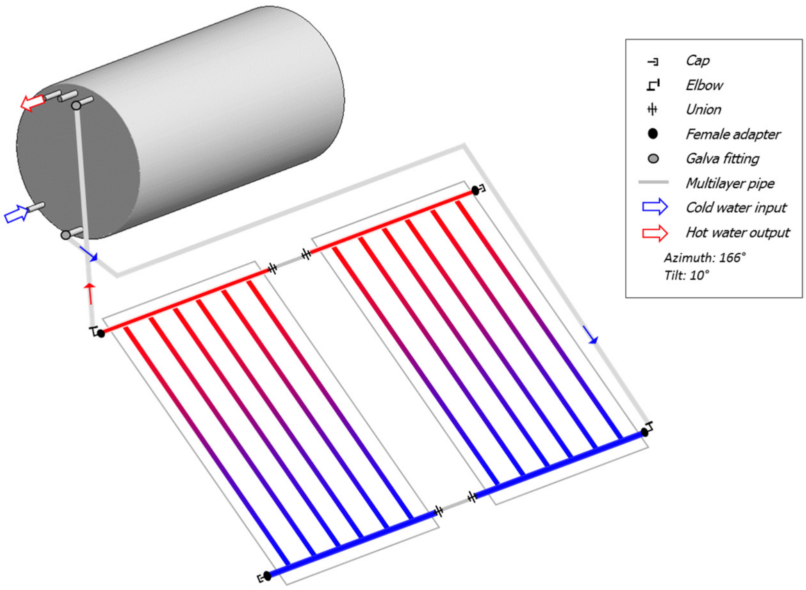


Figure 58: installation schematic

It is important to note that there are a few galvanized fittings used to connect the multilayer pipes with the tank. Chapter four showed that this can lead to corrosion. However, this installation is only provisory and the solar collectors are meant to be installed on Home Saint Jean as well. This implementation is only done for testing purposes. No serious issue will occur during this limited time.

7.3. ILLUSTRATIONS

Figure 59 illustrates the different fittings used.

Figure 59: view of fittings and piping

Figure 60 illustrates some details and finishing work.

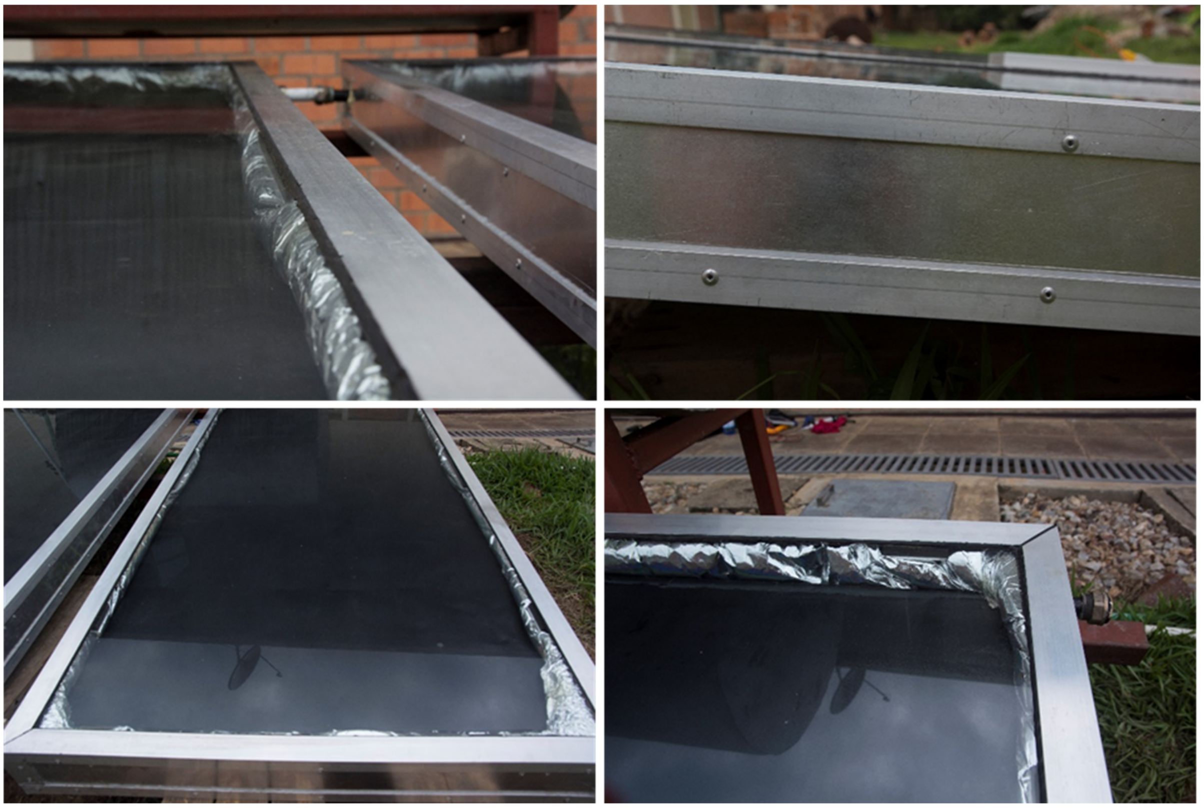


Figure 60: detail view of finishing

7.4. HUMIDITY AND DUST

During the night, dew occurs on the glass of the solar collectors. This phenomenon itself is not particularly problematic since the condensed water dries quickly in the morning. The actual problem is the dust that is deposited on the glass when the water dries. This layer of dust compromises the solar irradiance to actually hit the absorber and therefore weaken the performance of the system. The difference between a dirty and a clean glass cover, as represented in figure 61, is quiet big.

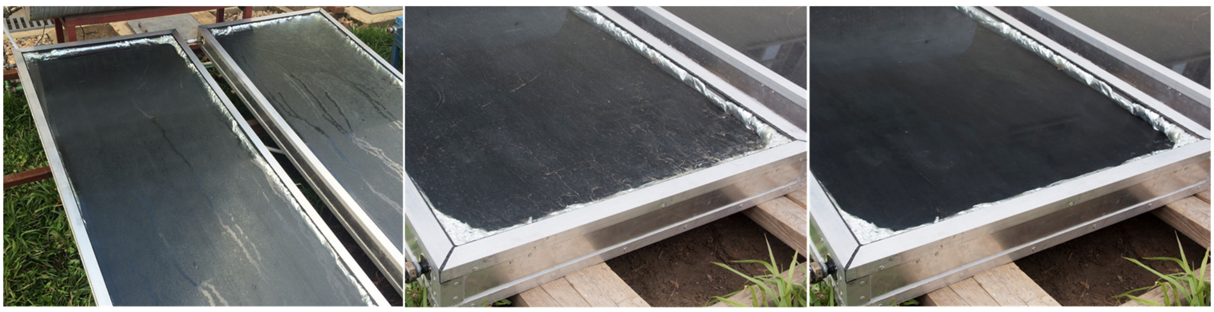


Figure 61: surface conditions on glass cover

This same issue, even if less severe, was observed on Home Saint Jean as well. Most likely, the dirt road next to the IPRC campus is the responsible for this situation. A permanent installation of a SWH at such spot has absolutely to be avoided.

8. CHARACTERIZATION

8.1. STANDARDIZED EFFICIENCY OF SOLAR COLLECTORS

The European reference norm EN 12975 defines the efficiency of a solar collector as following [9]:

$$\boldsymbol{\eta = \eta_0 - (a_1 * x) - (a_2 * G * x^2)} \quad (1)$$

With: $x = \frac{T_c - T_a}{I}$ and I = Solar radiation [W/m²]

T_a = Ambient temperature [°C]

T_c = Collector temperature [°C]

Obviously, the efficiency depends on three characteristics:

OPTICAL EFFICIENCY : η_0

Representing the actual energy absorbed by the absorber. It is calculated as following:

$$\boldsymbol{\eta_0} = \tau\boldsymbol{\alpha}\mathrm{F} \quad (2)$$

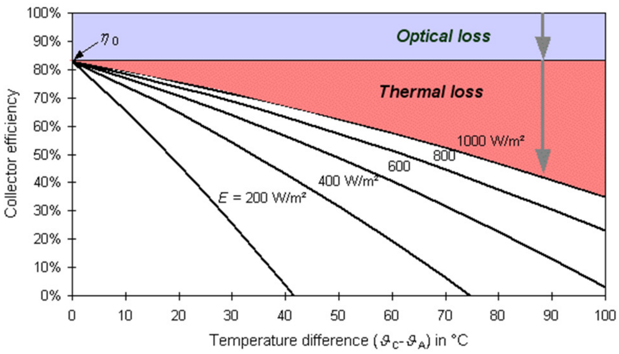
- τ [-] : transmittance of the glass cover
- α [-] : absorbance of the absorber
- F [-] : collector efficiency factor

THERMAL EFFICIENCY : A_1 AND A_2

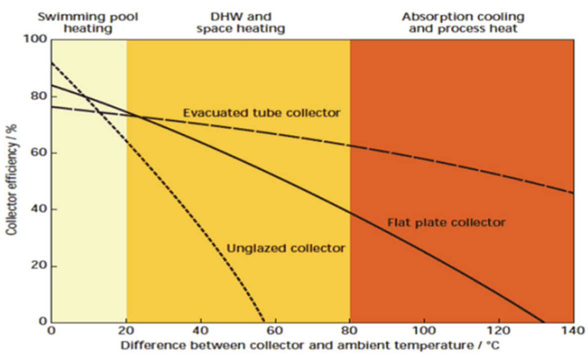
Representing the energy losses of the collector, those coefficients are given by the manufacturer. They are carefully measured in laboratories.

- a_1 [W/m²K] : first order loss coefficient
- a_2 [W/m²K²] : second order loss coefficient

The efficiency varies at different weather conditions. Therefore, the efficiency is usually represented as function of the difference of temperature between the collector and the ambient air. This allows simple performance comparing between different collectors. Each collector type has its own distinctive efficiency curve as shown in Graph 4.



Graph 3: how losses affect efficiency curve
Source: energieplus-lesite



Graph 4: efficiency curves for different collector types
Source: consulente-energia

8.2. COLLECTOR EFFICIENCY

The role of a solar collector is to convert the incoming solar irradiation into thermal energy stored in water. This energy flow is represented in figure 62.

The ratio between the output and input energy gives the efficiency of the collector:

$$\eta_{global} = \frac{Ouput\ energy}{Input\ energy} = \frac{Qeff}{\int_0^t G * S\ dt} \tag{3}$$

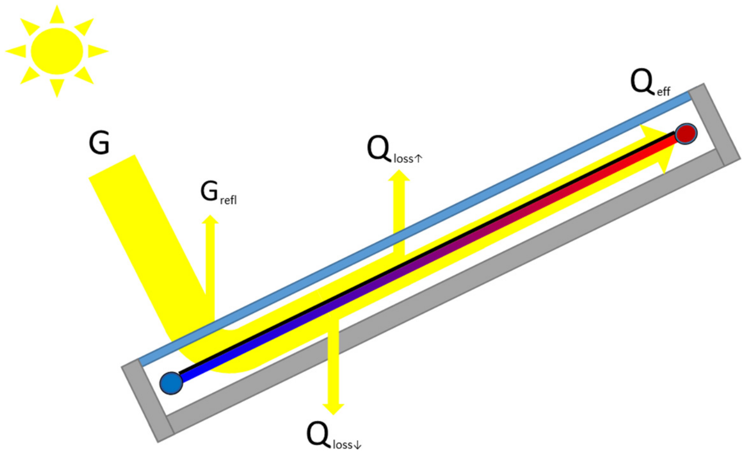


Figure 62: energy flow in solar collector
Adapted from: energieplus-lesite

with G = solar irradiation [kWh/m²]

G_{refl} = solar irradiation reflected by glass cover [kWh/m²]

$Q_{loss\downarrow}$= thermal losses through the back and the sides by conduction [kWh]

$Q_{loss\uparrow}$= thermal losses through the front by radiation and convection [kWh]

Q_{eff} = effective heat [kWh]

Similar to the standardized efficiency determination, the losses are either optical or thermal.

8.2.1. OPTICAL LOSSES

TRANSMISSION OF GLASS COVER

The transmission of the glass cover used is not known exactly. However, as it is a standard window glass it can be estimated. The commonly agreed transmission coefficient range from around 0.84-0.87 for standard glass [13]. Since the available materials in Rwanda are generally of a lower quality, a transmission of 0.84 is considered.

ABSORPTIVITY OF BLACK COPPER SHEET

The copper sheet itself has an absorptivity of 0.3. Thanks to the black painted surface, this coefficient is increased up to 0.94 [3]. The third factor of equation 2 is omitted, which gives an optical efficiency of:

$$\eta_0 = \tau\alpha = 0.84 * 0.94 = 0.79$$

8.2.2. THERMAL LOSSES

The thermal losses can be defined as following [14]:

$$\dot{Q}_{loss} = K * A * \Delta T \tag{4}$$

with $\dot{Q}_{loss}$ = thermal losses [W]

K = thermal loss coefficient [W/m²K]

A = area of collector [m²]

ΔT = temperature difference between absorber and ambient air [K]

Obviously to determine the losses, one first has to know the global loss coefficient.

METHOD ONE [15]

Yves Jannot expressing the thermal loss coefficient as:

$$K = \overbrace{\frac{1}{\underbrace{\frac{1}{h_{cc,p-c} + h_{r,p-c}}}_{\substack{\text{Heat transfer} \\ \text{absorber - glass cover}}} + \underbrace{\frac{1}{h_{c,c-a} + h_{r,c-a}}}_{\substack{\text{Heat transfer} \\ \text{glass cover - ambient air}}}}}^{\text{Losses through the front}} + \overbrace{\frac{1}{\underbrace{\frac{e_i}{\lambda_i * A} + \frac{1}{h_{c,c-a}}}_{\substack{\text{Heat transfer} \\ \text{insulation - ambient air}}}}}^{\text{Losses through the back}} \tag{5}$$

with $h_{cc,p-c}$ = heat transfer coefficient by conduction and convection from absorber to glass cover [W/m²K]

$h_{r,p-c}$ = heat transfer coefficient by radiation from absorber to glass cover [W/m²K]

$h_{c,c-a}$ = heat transfer coefficient by convection from collector to ambient air [W/m²K]

$h_{r,c-a}$ = heat transfer coefficient by radiation from glass cover to ambient air [W/m²K]

e_i = thickness of insulation [m]

λ_i= conductivity of insulation [W/mK]

A = area of collector [m²]

The mentioned reference explains the different steps to determine the thermal loss coefficient by knowing the dimensions and the thermal characteristics of the materials used. Since some parts are quite complicated, they were calculated with MatLab. Overall, many estimations and assumptions had to be made. The major parameters are listed hereafter. The ones with a star are calculated with other equations given.

- Temperature: Ambient, 273K / Absorber, 353K / Glass cover*, 313K
- Emissivity of sky*: 0.839
- Absorptivity: absorber, 0.94 / glass cover, 0.08
- Outside heat transfer coefficient by convection: 15 W/m²K
- Heat transfer coefficient by conduction/convection between two surfaces*: 5.2 W/m²K

The global thermal loss coefficient obtained with equation 5 is 4.88 W/m²K. This result seems conceivable; however, the steps taken allow many inaccuracies so that the final value might differ considerably.

METHOD TWO [16]

This second method expresses the global thermal loss coefficient as an addition of the superior, inferior and lateral thermal loss coefficient:

$$K = K_{front} + K_{back} + K_{sides} \tag{6}$$

- Losses through the front

The front losses through the glass cover are characterized by convection and radiation heat transfer. An empirical equation defines them as following:

$$K_{front} = \left(\frac{N}{\frac{C}{T_{pm}} * \left[\frac{T_{pm} - T_a}{N + f}\right]^e} + \frac{1}{h_c} \right)^{-1} + \frac{\sigma(T_{pm} + T_a)(T_{pm}{}^2 + T_a{}^2)}{\frac{1}{\varepsilon_p + 0.00591 * N * h_c} + \frac{2N + f - 0.133 * \varepsilon_p}{\varepsilon_g} -} \tag{7}$$

with N = Number of glasses

T_{pm} = mean temperature of absorber [K]

T_a = ambient temperature [K]

ε_p = emissivity of absorber [-]

ε_g = emissivity of glass cover [-]

β = tilt of collector [°]

h_c = heat transfer coefficient by convection between glass cover and ambient air [W/m²K]

e = 0.43(1-100/T_{pm})

f = (1+0.089h_c-0.1166h_c*ε_p)(1+0.07866N)

c = 520(1-0.000051 β^2)

The parameters T_{pm} =353K, T_a=273K, ε_p=0.94, ε_g=0.08, β=15° and h_c=15W/m²K coefficient of 3.51 W/m²K.

- Losses through the back

The back losses can be reduced to the actual heat transfer by conduction through the insulation. The back thermal loss coefficient becomes:

$$K_{back} = \frac{\lambda_{insu}}{e_{insu}} = 0.72 \text{ W}/m^2\text{K} \tag{8}$$

with λ_{insu} = thermal conductivity of insulation [W/mK]

e_{insu} = thickness of insulation [m]

- Losses through the sides

The side losses are the same as the ones through the back, except that the thickness of the insulation differs. Since the area is not the same than for the two other categories of losses, a factor is added.

$$K_{sides} = \frac{\lambda_{insu}}{e_{insi}} * \frac{A_{sides}}{A} = 0.54 \text{ W}/m^2\text{K} \tag{9}$$

with A_{sides} = side areas [W/mK]

Summed up, the global thermal loss coefficient is 4.77 W/m²K. Both methods show similar results even though the methods have major differences. This second method is slightly more conceivable and the steps taken are easier to understand. This is why this result is retained.

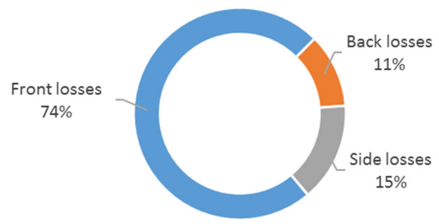


Figure 63: distribution of thermal losses

8.2.3. EFFICIENCY

The determined loss coefficient make it possible to calculate the efficiency as following [8]:

$$\eta = \eta_0 - \frac{K * (T_c - T_a)}{I} \tag{10}$$

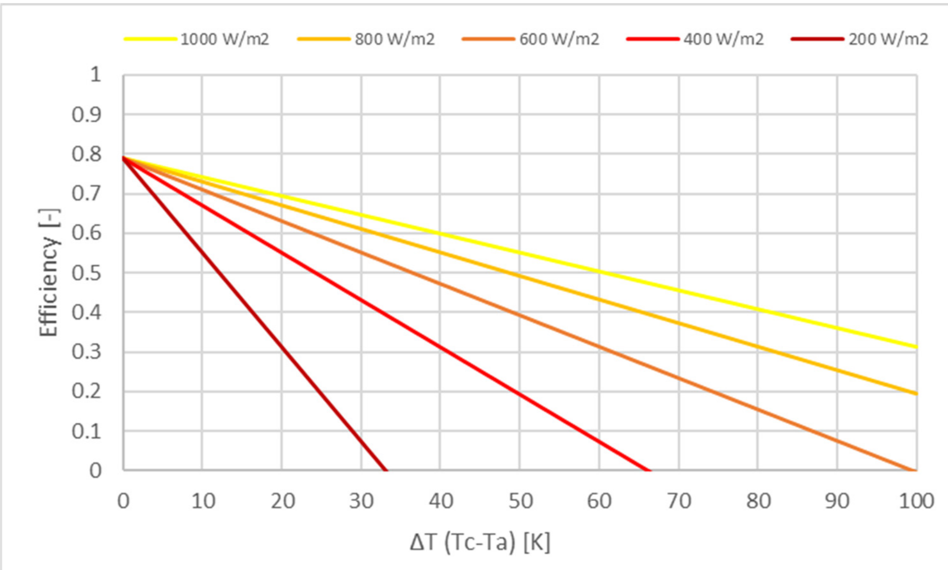
with η = efficiency [-]

η_0 = optical efficiency [-]

K = thermal loss coefficient [W/m²K]

I = Solar irradiance [W/m²]

$(T_c - T_a)$ = temperature difference between absorber (T_c) and ambient air (T_a) [K]



Graph 5: calculated efficiency curve of solar collector prototype

The results obtained seem accurate. Nevertheless, they are only theoretical and rely mainly on the assumptions made during the determination of the thermal loss coefficient. Small changes might induce considerable variations. Still it is an interesting comparison tool with the practical efficiency determination.

8.3. TANK EFFICIENCY

8.3.1. DETERMINATION OF THERMAL TRANSMITTANCE, U-VALUE

METHOD BASED ON MEASURES

During the temperature measurements of the SWH on Home Saint Jean, important losses were recorded. The maximum temperature drop of 19.5°C was measured during the night of 2nd-3rd July. As later investigations on the tank have shown, the insulation is not properly made. Theoretically, the polyurethane foam used for this purpose has a thermal conductivity of 0.036 W/mK. Practically this value cannot be reached.

The loss of energy during this night is calculated with the following equation:

$$Q = mc\Delta T \tag{11}$$

with m = mass [kg]

c = specific heat capacity [J/kg*K]

ΔT = temperature difference between initial and final state [K]

By using m=300kg, c=4180J/kg*K and ΔT = 19.5K the total energy loss in those 13 hours is 24'453'000 J, or 6.79 kWh. The average loss $\dot{Q}_{mes}$ is therefore 523W.

The heat transfer of the tank can be approximated with equation 12 [14]. Only the exchange by conduction is taken into account. Convection and radiation are omitted.

$$\dot{Q_{mes}} = h_{cond} * A * \Delta T = {}^{\lambda_{insu}}/_{e_{insu}} * A * \ \Delta T \tag{12}$$

with $\dot{Q_{mes}}$ = thermal losses [W]

h_{cond} = heat transfer coefficient by conduction [W/m²K]

λ_{insu} = thermal conductivity [W/m*K]

e_{insu} = insulation thickness [m]

A = area [m²]

ΔT = temperature difference between inside and outside [K]

With $\dot{Q}_{mes}$ = 523W, S=2.73m² and ΔT=25K the heat transfer coefficient becomes:

$$h_{cond} = \frac{\dot{Q}_{mes}}{A \ * \Delta T} \ = \ 7.66 \ {}^{W}/_{m^2 K} \tag{13}$$

The total thermal transmittance is:

$$U_{mes} = h_{cond} * A = 20.92 \, {}^{W}/_{K} \tag{14}$$

METHOD: BASED ON CALCULATIONS

A study conducted with the support of the Swiss Federal Office of Energy specifies the way to determine the total U-value in W/K of a thermal solar tank as following [17]:

$$U_{cal} = U_{main} + 2U_{top/bottom} + U_{fittings} \tag{15}$$

$$U_{main} = 2 * \pi * L * \left(\frac{\ln(\frac{R + e_{insu}}{R})}{\lambda_{insu}} + \frac{1}{h * (R + e_{insu})} \right)^{-1} \tag{16}$$

$$U_{top/bottom} = \pi * R^2 * \left(\frac{R_t}{\lambda_{insu}} + \frac{1}{h} \right)^{-1} \tag{17}$$

with U = total thermal transmittance [W/K]

L = length of inner tank [m]

R = radius of inner tank [m]

h = exterior heat transfer coefficient [W/m²K]

For application reasons, the losses through the fittings are omitted. With L = 1.1m, R=0.3m, d=0.025m, h=20W/m2K and λ=0.036W/m*K the thermal transmittance becomes:

$$U_{cal} = 2.83 \, {}^{W}\!/_{K} + 2 * 0.19 \, {}^{W}\!/_{K} = 3.21 \, \frac{W}{K}$$

For comparison, the total thermal transmittance for a 300l tank allowed in Switzerland is 2.22W/K [17]. This means an excess of 45% without considering the losses through the fittings that might be just as important.

In this case, the heat transfer becomes:

$$\dot{Q}_{cal} = U_{cal} * \Delta T = 3.21 * 25 = 80.3 \, W \tag{18}$$

Which equals to a total energy loss of 1.043 kWh for the measured night.

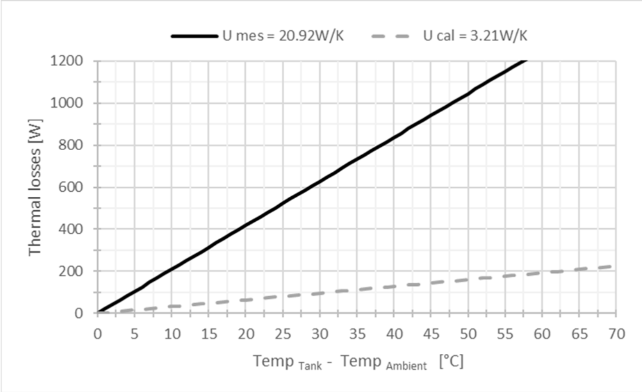
COMPARISON OF RESULTS

There is a factor 6.5 between the theory and the practice. In other words, the insulation is roughly seven times less effective than it should be. The issues detected during the dismantling of the tank are confirmed.

8.3.2. DETERMINATION OF HEAT TRANSFER

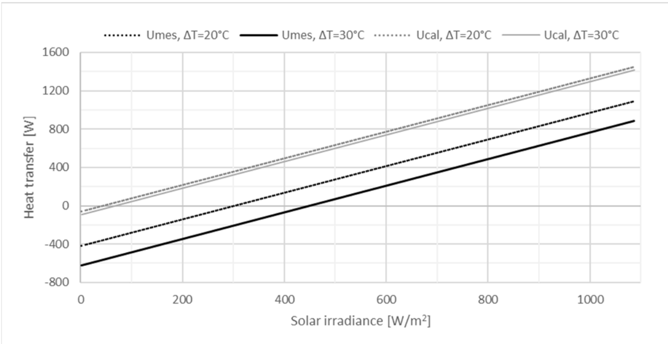
The water inside the tank gets only around 55°C even if the water coming from the collectors can get 20°C hotter. The U-value has shown that the insulation is very poor. Probably the temperature inside the tank cannot get any hotter than this because the losses overcome the gains.

For both cases, the measured U-value and the calculated U-value, the losses as function of the temperature difference are represented in graph 6. It is interesting to notice the evolution of the losses for the measured U-value: they increase very fast. At 20-30 degrees difference between the ambient temperature and the water inside the tank, they become as big as 400- 600W. This difference is typically reached for the critical range of 50-55°C.



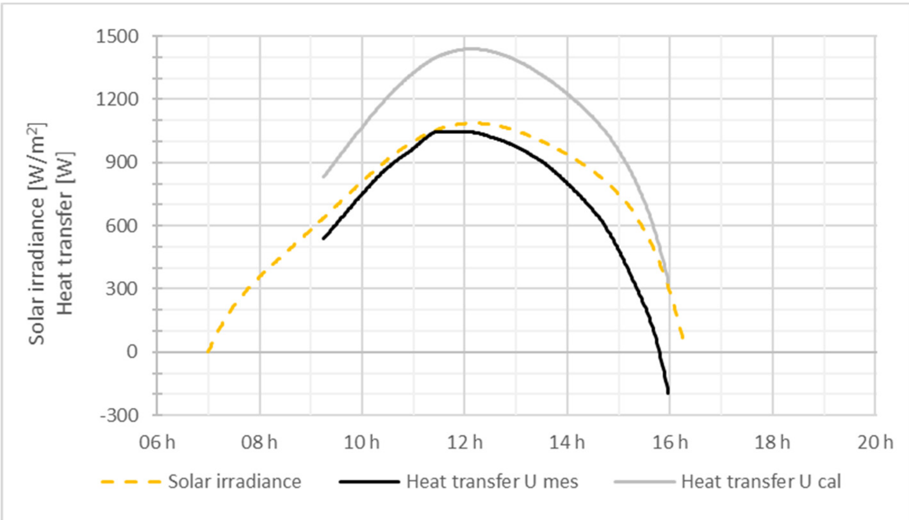
Graph 6: comparison of thermal losses between measured and calculated U-value

The actual heat transfer at different solar irradiances is shown in graph 7. For this same temperature range, a solar irradiance of minimum 300W/m^2 is necessary to overcome the losses.



Graph 7: balance of thermal losses and solar gains at different irradiances

Graph 8 shows approximately the heat transfer for the measured day. It is clearly visible that the system lost heat after 15h30. At that time, with the better U-value, the solar gains would still have overcome the losses.



Graph 8: calculated evolution of heat transfer during test day

In conclusion, it can be said that the combination of a bigger temperature difference along the day and the decrease of solar irradiance from the middle of afternoon make it impossible for the water inside the tank to raise its temperature above 60°C. The losses become simply too big for the solar irradiation available at the time the water becomes as hot.

8.4. MEASURES AND TESTS

8.4.1. PRESSURE RESISTANCE

During the fabrication, the absorber was tested to its pressure resistance. To do so a manual pressure pump was used to increase the pressure. The fittings presented some difficulties. The valve to connect the pump was slightly oversized. Small leaking induced pressure drop over time. The higher the pressure the more this caused problems.

Following tests were conducted:

- Instant pressure drops: 25 bar for 1-2 seconds
- High pressure for short time : 15 bar for 15-30 seconds
- Duration test: 5-10 bars for 15min

None of the tests showed any sign of leakage in the pipes. The absorber will withstand easily the pressure variation in the water network. In Kibuye, the pressure can instantly increase to five or six bars.

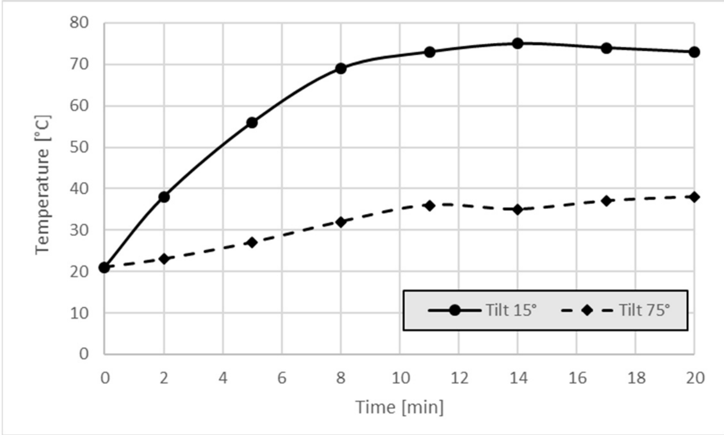
Figure 64: manual pressure pump test

8.4.2. ABSORBER HEATING

Before inserting the absorber into the housing, his rise of temperature in the sun was tested. The aim was to evaluate the maximum temperature to be reached as well as the time necessary. The test was conducted during end of august during a sunny day at 11h30. The solar irradiance could not be measured at that time. Considering an orientation of 15 degrees north and a tilt of 15 degrees, the sunrays hit the absorber almost vertically. Therefore, the power delivered by the sun is estimated to be around 1000 W/m^2.

The results in graph 9 show that the absorber reacts very fast to incoming sunlight. As soon as the absorber was moved from a shady area to the test spot, the temperature increased immediately. During this heating process, the temperature rises at around 6°C per minute. It took around 10min to reach the maximum temperature range between 70 and 75 degrees Celsius. The second absorber, who was laid against a wall at the same spot, saw much less temperature difference. This illustrates the importance of correct orientation.

Figure 65: absorber during test



Graph 9: temperature rise of absorber test

This first test shows the benefits of a copper absorber. Considering a proper housing and insulation, the temperature might rise around 80 to 90 degrees Celsius. With water inside the pipes, the absorber sheet will be cooled down but the water might still reach close temperatures to the ones measured.

8.4.3. RAIN AND HAIL PROTECTION

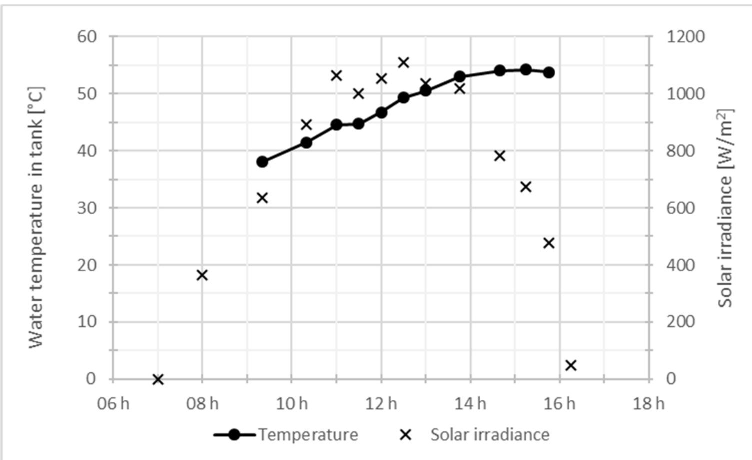
The day of installation, a heavy thunderstorm struck Kibuye. Heavy rainfall was followed by a short period of hail, approximately 15 seconds. No visible damage was detected afterwards. Neither on the outside, on the glass due to the impact, nor in the inside, due to water penetration. The following day's heavy rainfall persisted. The collector showed no sign of leaking.

8.4.4. WATER TEMPERATURE AND FLOW

TEMPERATURE

The output temperature was measured in two ways: by opening the outlet valve at the top of the tank and by disconnecting the collectors from to tank to get the actual water temperature coming from the collectors.

The water inside the tank was measured over a day in September. The aim was to detect the maximum temperature and to see the evolution over a day. The results are shown in graph 10. To understand how the solar irradiance was measured, refer to chapter 8.4.6.



Graph 10: temperature evolution in tank during test day

$$Tmax_{mes} = 56°C \qquad \Delta T_{mes} = 31°C$$

The measures were taken the first day of installation. That is the reason why some data is missing. The initial temperature at the top of the tank was around 30 degrees Celsius. The weather deteriorated badly from 15h30 and start from 16h, the sky was completely dark. Unfortunately, no other measures could be taken due to the bad weather in the remaining time in Rwanda.

The water output from the collectors was measured only once as well. This test however confirmed the expectations. The conditions and results were the following:

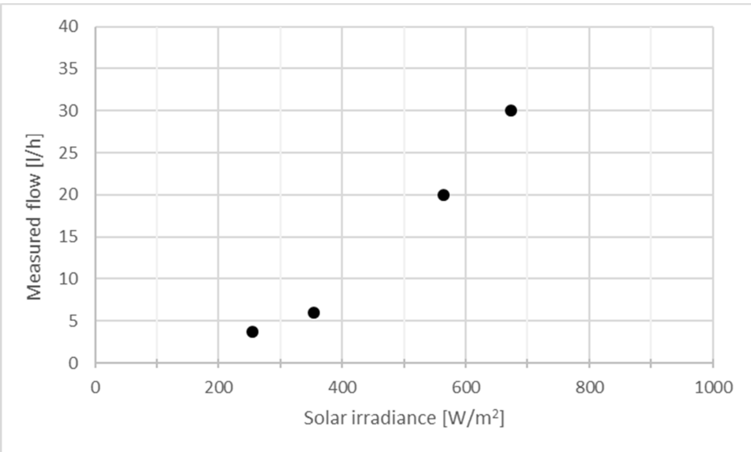
- Test sample: water output from collectors
- Day: 14. September 2018, Time: 10h
- Weather conditions: Sunny, Solar irradiance around 700-800 W/m^2
- Temperature measured: **78.6°C**

This temperature proves that the water gets indeed hot. It is probably not even the maximum since the solar irradiance can still increase a decent amount. At such conditions, the copper pipe cannot even be touched without being burned.

FLOW

The flow was measured the same way than the water output from the collectors. The system was disconnected between the collectors and the tank. By natural convection, the flow continued to run.

The water was recuperated in a 5dl bottle. The time to fill the bottle was taken for different weather conditions. This is related to different solar irradiances. See graph 11.



Graph 11: flow measures

These results have to be analysed with carefulness. The act of taking these measures goes with many inaccuracies. These values give an approximation of what the flow might be but they should not be used for extrapolation. They have first to be reproduced and confirmed.

8.4.6. EFFICIENCY

The efficiency of the system was measured based on equation 3. The input being the solar energy received on the collector's surfaces and the output being the hot water stored in the tank. Note that this efficiency takes into account the whole system and not just the solar collectors.

INPUT

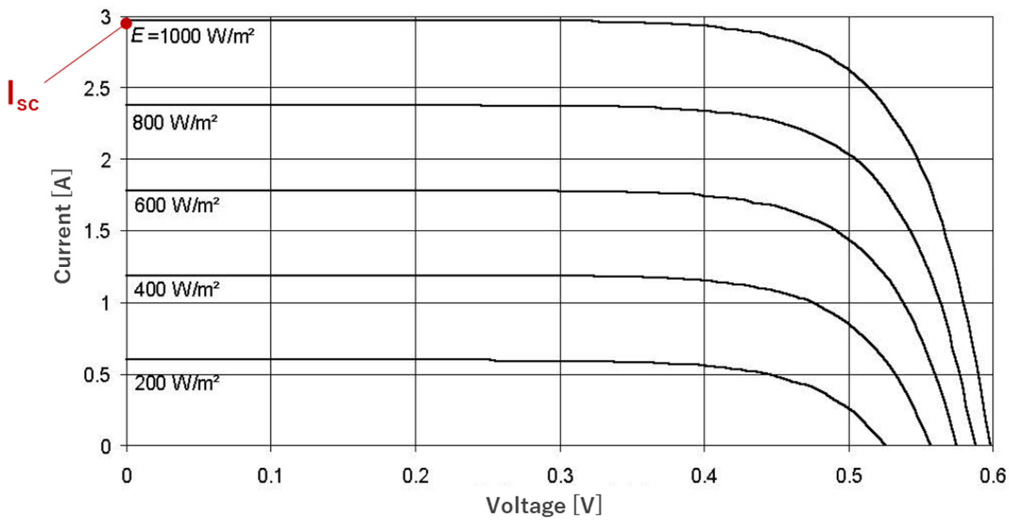
The instrument usually used to measure the solar irradiance is a pyranometer. Too expensive, such tools are not available in Rwanda. Another solution was found by using a solar panel from the smart metering. The actual solar irradiance can be calculated with its following characteristics:

Monocrystalline solar panel, 6W
Test conditions AM1.5, 25°C, 1000W
Voc = 7.5V / Isc = 1.1A

The photoelectric current of any PV module reacts almost linear to incoming light [18]. An example is represented in graph 12. Therefore, knowing the short circuit current for 1000W, the solar irradiance can be calculated as:

$$I_{mes} = \frac{1000W}{1.1A} * Isc_{\ mes} \qquad (19)$$

Note that this equation assumes that the testing conditions are still true. This is not exactly the case since the atmosphere thickness in Rwanda is smaller than the reference value of AM1.5 and the temperature is not steady at 25°C. These inaccuracies however are very small to other assumptions made later. This is why they are omitted.



Graph 12: behaviour of short-circuit current in a solar module depending on solar irradiance
Source: énergie solaire photovoltaïque - Christoph Ellert

To measure, simply connect a multimeter to the PV module laid on the same plane than the solar collectors. By taking measurements over a period of time, for instance a day, the daily solar irradiance curve can be plotted.

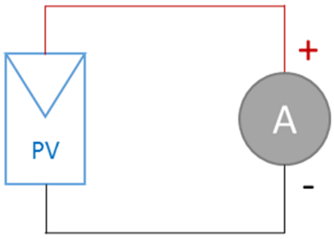


Figure 66: short-circuit measures with a multimeter

OUTPUT

To measure the energy stored in the tank, the solution retained is to empty the whole water by measuring the water temperature every few litres. By knowing the initial water temperature, the energy can be easily calculated with equation 11:

$$Q = mc\Delta T$$

with m = mass [kg]

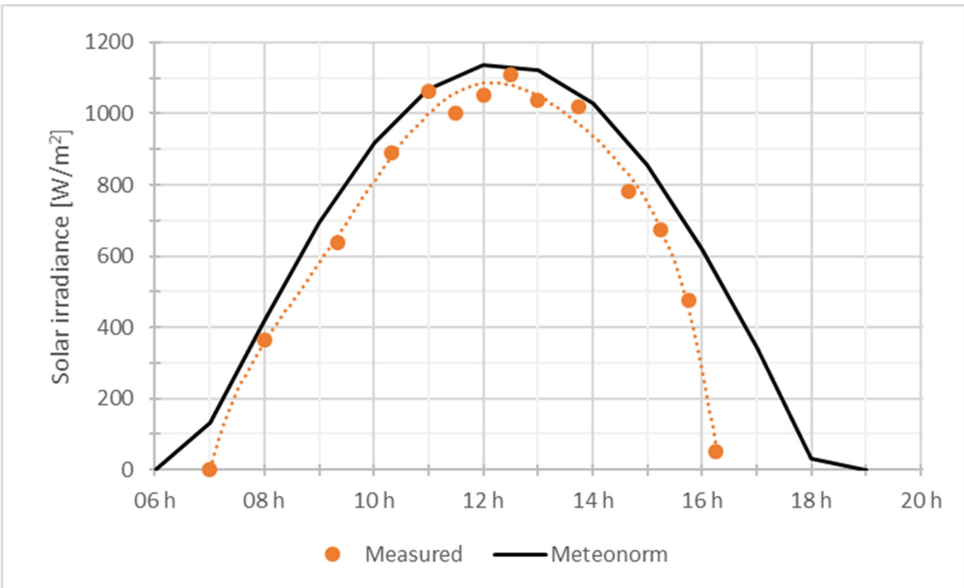
c = specific heat capacity [J/kg*K]

ΔT = difference of temperature between initial and final state [K]

The tank was emptied into two containers of ten litres each. While one was filled, the water in the other one was first measured and then emptied to invert the roles. This way the test could be conducted rapidly without losing too much temperature.

RESULTS

The measured solar irradiance is displayed on graph 13. A set from *Meteonorm* [19] is added in the same plot to compare the measurements with actual data. This data, an average between 1995 and 2015, represents the maximum daily values for sunny days in September.



Graph 13: comparison of solar irradiance measures and Meteonorm data

To calculate the total energy the following assumptions are made:

- The test day was very cloudy but the irradiance measures were only taken when the view was not obstructed by clouds. Little clouds can instantly drop the irradiance from 1000W down to 200W. That is why the irradiance is divided by two to take into account an average of 50% clear sunny view.
- The total collector surface is 2.78m^2.
- 1 kWh equals 3.6 million joules.
- The energy is calculated with:

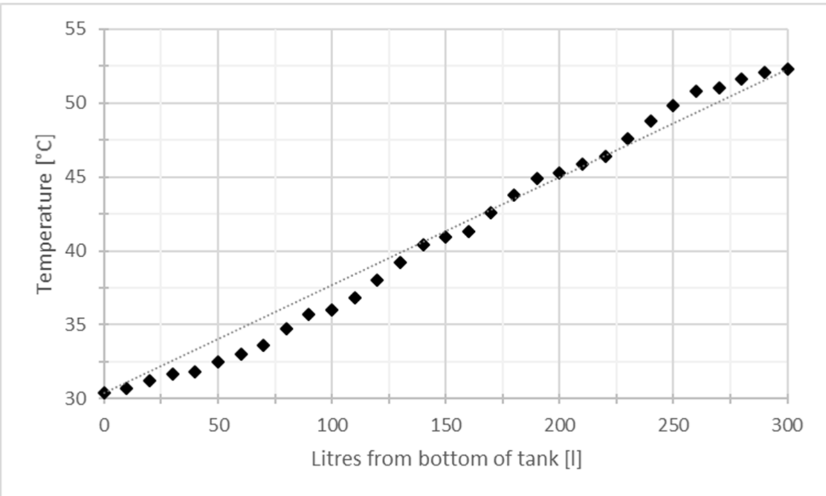
$$Q_{eff} = \int_0^t \frac{I_{mes}}{2} * S\, dt \tag{20}$$

The total input energy calculated is 9.69 kWh.

To calculate the total energy stored in the tank the following assumptions are made:

- Every ten litres a measure is taken. The mass equals to 10kg.
- The specific heat capacity of water equals 4'180 J/kg*K.
- The initial temperature is 25° Celsius.

The temperature profile of the water tank, based on the water measurements, is illustrated in graph 14. It shows that the stratification is almost linear. By summing the energy calculated with equation 11 for each value, the total energy output is 5.76 kWh.



Graph 14: temperature evolution and stratification inside the tank

According to equation 3, the total efficiency of the system becomes:

$$\eta_{mes} = \frac{Output\ energy}{Input\ energy} = \frac{5.76\ kWh}{9.69\ kWh} = 59\%$$

This calculated efficiency does only take into account the sunny part of the day. The evening and night losses are not included and therefore the result is in line with studies showing an efficiency between 0.4 and 0.6 of flat plate solar collectors [20]. Comparing with the previously made efficiency curve, this value seems slightly overrated.

9. FINANCING

9.1. TOTAL COSTS

The costs of a SWH can be divided into three categories: construction, smart metering and installation.

CONSTRUCTION

All materials used during this project were bought in Kigali. Compared to the global market offer, most of these materials are situated in the far end of the price range. This is due to two facts: the raw materials are more expensive and the offer is smaller.

Materials and costs prototype 2018

One collector

	Component	*Dimensions*	*Price RWF*	*Number*	*Total*	*in $*
1	Copper sheet, 0.8mm	1 x 2m	176'100	1	176'100	202
2	Alumium sheet, 0.5mm	1 x 2m	25'300	1	25'300	29
3	Alumium sheet, 2mm	1.2 x 2.4m	128'800	0.25	32'200	37
4	Glass, 6mm	2.44 x 1.83m	60'750	0.33	20'230	23
5	Copper pipe, 3/4"	15.2m	118'000	0.12	14'160	16
6	Copper pipe, 1/2"	15.2m	70'000	0.66	46'200	53
7	Brass socket/elbow	1 piece	4'800	3	14'400	17
8	Brass female adapter	1 piece	5'200	2	10'400	12
9	Brass plug	1 piece	4'000	1	4'000	5
10	Glasswool, 25mm	1.2 x 1m	6'000	4	24'000	28
11	Angle alumium, 25x38mm	1m	5'000	12	60'000	69
12	Angle alumium, 38x38mm	1m	5'000	2	10'000	11
13	Copper brazing rod	1 piece	1'000	5	5'000	6
14	Tin-lead solder, Swiss	0.5kg	39'150	0.5	19'575	23
15	Flux, Swiss	0.5kg	48'700	0.125	6'088	7
16	Polyurethane sealant	0.3kg	6'000	1	6'000	7
17	Silicone	0.3kg	6'000	1	6'000	7
18	Black painting	1kg	3'000	1	3'000	3
19	Rivets	1 pack	6'000	0.5	3'000	3
				Price for one collector	*485'652 RWF*	*558 $*

Tank and piping

	Component	*Dimensions*	*Price RWF*	*Number*	*Total*	*in $*
1	Mild steel sheet, 2mm	1.2 x 2.4m	66'000	1	66'000	76
2	Mild steel sheet, 1mm	1.2 x 2.4m	32'000	1	32'000	37
3	Welding rod	1 piece	10'000	1	10'000	11
4	Stainless steel pipes, 1/2 "	1m	5'000	1	5'000	6
5	Multilayer pipes, 3/4 "	1m	2'000	4	8'000	9
6	Brass elbow	1 piece	4'800	4	19'200	22
7	Brass female adatper	1 piece	5'200	4	20'800	24
8	Brass reduction male/female	1 piece	4'500	4	18'000	21
9	Valve	1 piece	11'000	1	11'000	13
10	Armaflex, 3/4"	1.8	4'500	1	4'500	5
11	Glasswool	1.2 x 1m	6'000	10	60'000	69
12	Zinga	1kg	30'000	2	60'000	69
13	Thinner	1l	7'500	2	15'000	17
				Price for tank and piping	*329'500 RWF*	*379 $*
				Price for a whole system	**1'300'805 RWF**	**1 495 $**

Table 14: construction costs of prototype

Some materials had to be bought in bigger quantities than needed. This is valid for all those items that cannot be bought in single units like copper pipes, flux or aluminium sheets. However, these costs are not included in the following price list. Only the effective costs are considered. This explains the quantities below one in column *Number.* For example, the 0.25 for the Aluminium sheet 2mm means that it is big enough to build four collectors.

The total price for the construction of the prototype is 1’495$. This includes two solar collectors and a tank. The costs can be attributed to the different components as showed in figure 67.

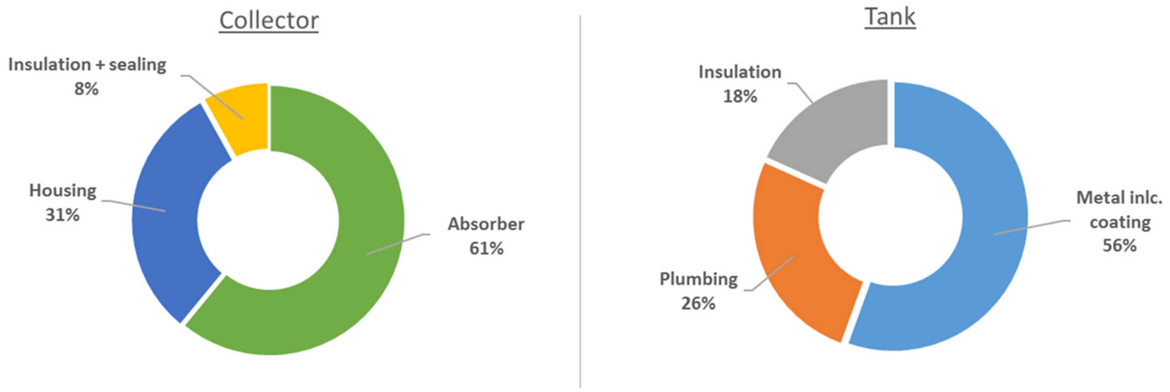


Figure 67: costs composition of collector and tank

SMART METERING

For all smart metering matters, IPRC relies completely on the knowledge of HES. The smart meters are produced in Switzerland. The costs are estimated to 300$ for a system. This includes the construction of the PCB, electronic components, temperature sensors, a flow meter and PV module.

INSTALLATION

The actual installation costs vary on each site. The structure to support the SWH, the length of the pipes and other plumbing matters might differ a lot. The following costs were listed for the installation on Home Saint Jean:

- Tubes, for the structure: 57’000 RWF
- Plastic pipes: 21’000 RWF
- Pipe insulation: 30’000 RWF
- Additional plumbing fittings: 25’000 RWF

The total equivalent in dollars is about 115$.

TOTAL

The total costs as listed previously amount to 1’913$. Considering the various possible inaccuracies, the total is rounded to 2’000$.

9.2. PAYBACK MODEL

Since the service and not the product is sold, the payback stretches out over a certain period. It is interesting to know how much time this takes.

To establish an approximation, the yearly income has to be determined depending on:

- Solar irradiation
- Overall efficiency of SWH
- Energy price

SOLAR IRRADIATION

Obviously, the solar irradiation is the most important factor. Since there is no weather station around Kibuye, there is no actual historical data. However, different tools of solar data exists. Two of them are:

- **PVGIS**: primary used for PV applications, this access free tool provides different solar data calculated from satellites data. [1]
- **Meteonorm**: database calculated from models based on weather stations and satellites. A license is required. [19]

Different data sets were generated with these tools. The database from PVGIS is slightly overrated compared to the one from Meteonorm. Both are in accordance with the solar map in figure 68.

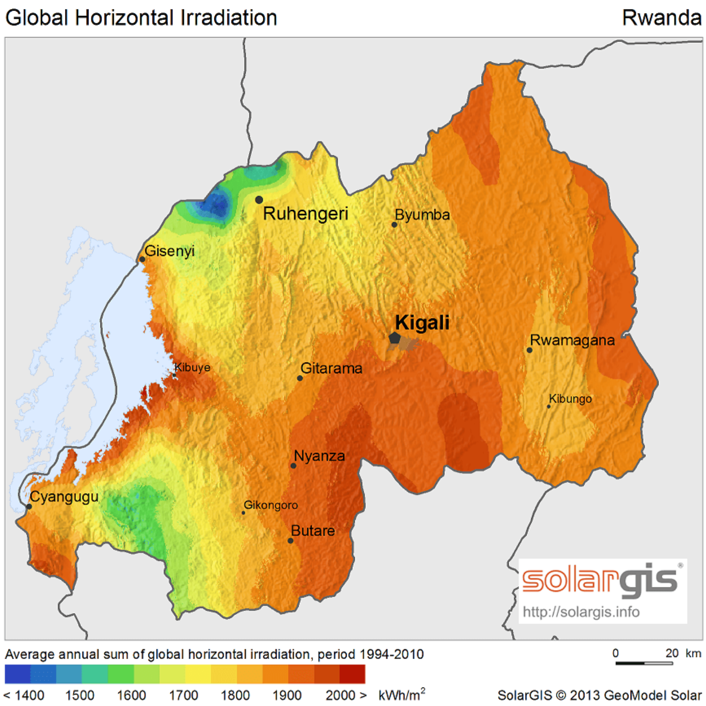


Figure 68: solar irradiance in Rwanda
Source: Africa-EU RECP

EFFICIENCY OF SWH

Not the complete solar irradiation is converted into effective useful energy. An important part is lost in between. The measured efficiency of the prototype is about 60%. This efficiency is considered in the calculations.

ENERGY PRICE

The business model of these SWH is to offer hot water for a cheaper price than it would cost with a standard electric heater. Therefore, the price for a produced kWh must be smaller than the electricity price for a kWh. Note that the following assumption is made: the efficiency of the electrical heater is 100%. All the electrical energy is converted into heat.

CATEGORY	CONSUMPTION (KWH) BLOCK/MONTH	FRW/KWH (VAT EXCLUSIVE)
Residential	[0-15]	89
	[>15 – 50]	182
	>50	210
Non Residential	[0-100]	204
	>100	222
Hotels	All	126
Health Facilities	All	192

Table 15: electricity tariffs for non-industrial customers categories
Source: REG

The electricity prices are set for different categories [7]. The main targeted audience for the SWH so far are hotels. Compared to other categories, they pay much less for electricity. Yet, the price of 126 RWF equals to 0.145 $ which is still a big amount of money. Pricing the energy consumption at 100 RWF/kWh seems very reasonable. This represents a reduction of more than 20% for hotels.

RESULTS

Those simple calculations show that the business with SWH is indeed cost-effective. After about six years, the investments are paid back and the rest of the SWH lifetime is operated with profits.

	Metenorm	PVGIS	PVGIS Tilt = 15°, Azimuth = -15°	Kigali	
*Annual irradiation on horizontal plane**	1861	1962	1943	1870	kWh/m^2
Average monthly irradiation	155	164	162	156	kWh/m^2
Average daily irradiation	5.10	5.38	5.32	5.12	kWh/m^2
Average hourly irradiance	212	224	222	213	W/m^2
Monthly irradiation on collectors	431	455	450	433	kWh
Monthly converted energy	259	273	270	260	kWh
Monthly income	30	31	31	30	$
Annual income	357	376	373	359	$
Total costs	2000	2000	2000	2000	$
ROI	5.6	5.3	5.4	5.6	Years

**Except PVGIS, Tilt=15°*

Table 16: payback calculations of a SWH prototype

Note that these calculations are based the following assumption: the entire heat in the tank is consumed. In reality, this is impossible. Nevertheless, it shows the importance of sizing correctly the system.

10. OUTLOOK

10.1. ACHIEVEMENTS

The construction of the new solar collector was successful. The measures proved a considerable performance improvement compared to the old ones. Hereafter is summary of the main characteristics of the new prototype.

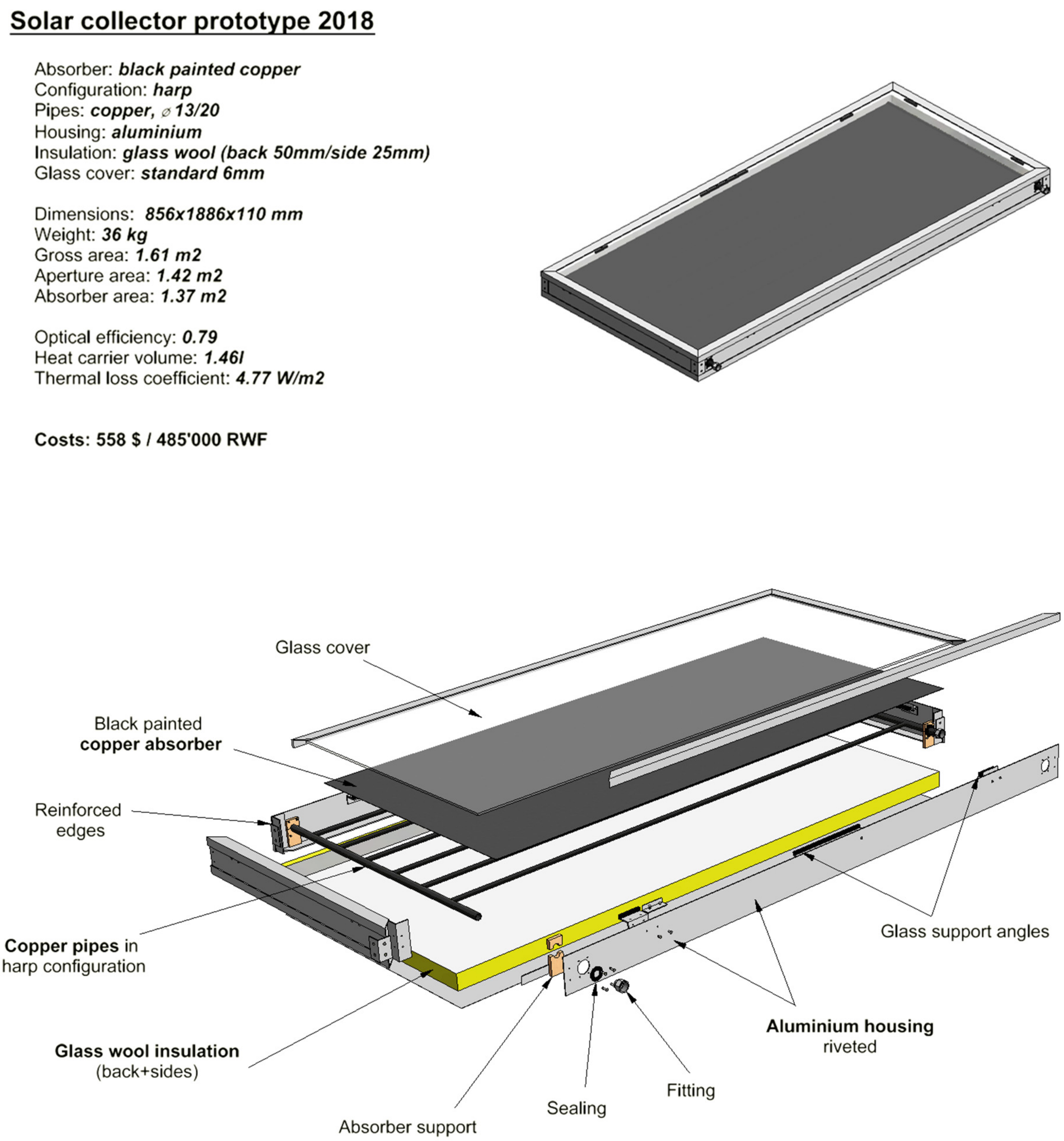


Figure 69: key information and exploded view drawing of collector prototype

10.2. THOUGHTS AND FEEDBACK

The whole process; from market survey, over material purchases to construction and installation, gave a precise insight of the possibilities and a significant expertise in the domain. Hereafter is a summary of the essential points.

KEY STRENGTHS

- Performance prove

Probably the most important point is the proper functioning of the new prototype. Its thermal performance has proved to be much better than the previous ones even if the surface area is much smaller.

- Public interest

The fact that there is a real interest in this project should encourage further constructions. Clients seem to be greatly interested in the new billing system. This also applies to public entities like RSB who encourage Rwandan made solar water heaters.

- Construction expertise

Apart from the tank, the whole construction process has been done more than once. All the difficulties have been identified. A future construction can be much optimized, in time and quality. The approach is completely different if one knows the tasks awaiting.

- Absorber

The construction of the radiator can be seen as a great success. Especially since the solder-issues were solved. The techniques are simple to reproduce and a satisfying result is guaranteed.

- Housing needs

The whole housing is handmade with only two different materials: aluminium sheets and angle bars. There is no need of special infrastructures or machines.

- Suppliers

Having gone through Kigali numerous times, the right suppliers for each kind of material are well known.

- Costs

The material costs for the new prototype are similar to the costs of the systems on Home Saint Jean. Thanks to a better performance, the area and therefore the materials are reduced.

CRITICAL POINTS

- Precision handwork

The whole construction process of the housing requires careful and precise work. The dimensions and angles have to be respected rigorously otherwise problems will occur eventually. The most crucial point is fixing the angles to support the glass cover. They must be levelled to guarantee a best possible fixation of the glass.

- Sealing

A major downturn of the housing construction is the sealing. Indeed, water can infiltrate between the angle bars and the metal sheet. This forces to apply sealant on the concerned area. The overall appearance is clearly deteriorated with this process.

- Glass breakage

This issue is once again up to date. However, the reason has been detected so all efforts can be put into avoiding this problem.

- Solder

A correct copper solder is essential for a successful absorber construction. However, no supplier of tin-solder has been found in Rwanda. The one used during the construction was from Switzerland. A local supplier must be found.

- Fittings

The fittings are slightly oversized to ensure a proper sealing. Therefore, they must be brazed to the absorber. This represents additional difficulties for the housing because the holes, to insert the absorber, must be enlarged. Probably another supplier can be found in Kigali.

10.3. FUTURE CONSTRUCTIONS

10.3.1. BASED ON PROTOTYPE

The new way of construction requires some time, especially the housing is very demanding. However, new collectors should take much less time than the prototype did since all the difficulties have been solved. Most tasks need two people but the different pieces can be prepared alone.

Some recommendations:

- The absorber should imperatively be built in copper. Using steel is too much of a compromise in terms of performance. The heat transfer is about ten times lower. On demand, Sonatubes Ltd. can offer sheets with 0.3mm thickness. Compared to the copper plates bought for this project, the price will decrease as well. This seems to be the way to go.
- If the collector size is maintained, the width of the absorber plate should be reduced between 10 and 20mm on each side. This will facilitate the placement of the insulation.
- Look for better-suited fittings. Probably other sizes exist in in brass or copper.
- The initial size of the pipes was chosen because of the fittings. Since they had to be brazed eventually, another solution might be better. If other fittings are found, the size of the pipes can be slightly increased. Ideally, replace the following pipes:
  - 1/2” by 5/8” and
  - 3/4” by 7/8”
- Since the glass issue is not solved with thicker glass, 4mm might serve just as well.

- The insulation should be reduced in the corners, either by cutting the insulation smaller or simply by removing some of the yellowish texture once assembling.
- Follow closely the instructions given in the manual.

In addition, IPRC-Karongi should seriously consider introducing the construction of the SWH in some student projects. Obviously, the process would need close supervision and follow-up. On the other side, the mechanical courses could be enlarged and the students would benefit.

10.3.2. DIFFERENT HOUSING

WOOD

Probably the best alternative to the current prototype construction is building the frame in wood. Just like the old ones, but in good quality wood instead of timber. The construction could base on the solution that has been developed previously in this project with one major change: no metal cover and angle bars. A simple treatment on the surface of the wood should ensure a life span just as long as other materials. The sealing between glass cover and the frame can be done with the sealant used in the car industry. The machines in IPRC's carpentry are recent and in good condition so that the cutting of the different pieces should be possible.

ALUMINIUM BOX

Another solution is either to buy or to create a bending brake. The principle is the same than a standard sheet metal brake with one extra feature: the piece of metal that bends the sheets is actually not a single piece but consists of numerous smaller ones. If they are detachable, they can be arranged in any position. This would make it possible to bend the four sides.

Buying such a machine seems hopeless for IRPC and building one is obviously not an easy task. However, there are countless explanations and examples to be found on internet on how to create a standard bending brake. With some imagination and skill, which can doubtlessly be found in IPRC's mechanical team, they can surely be expanded to a box bending brake.

10.4. CERTIFICATION

The commercial use of SWH with private clients such as hotels does not need any certification. IPRC can therefore develop their concept. If the certification comes up again in the future, the following steps must be considered:

- Requirements of both tank and solar collector must be fulfilled. Standing losses should not excess 20%. With the current insulation issues of the tank, this cannot be achieved.
- Sanitary issues represent a no-go for the certification. The whole system should be equipped with non-corrosive materials, ideally only in copper. The current galvanized fittings on the tank should be avoided.
- Acquire the necessary testing facilities to test mechanical strength, rain penetration, hail damage and corrosion resistance is necessary. Probably the government can provide some support in this complicated task.

11. CONCLUSION

The primary goal of this project was to optimise existing thermosiphon solar water heaters built by IPRC-Karongi, a technical school in western Rwanda. Those optimisations should have led to a certification of the implemented systems. In the end however, the project took a different turn. None of the systems was certified but new solar collectors have been built.

The reason for this change in events was the poor quality of the implemented systems. The solar collectors had gone through different replacements and repairs. All of them affecting the overall look and performance. Bad insulation, close to none sealing, no uniformity in size are just a few of the detected issues.

A new design was developed and elaborated, with performance improvement as the main challenge and focus. This was achieved with better materials than the previous ones. Better in terms of thermal performance, with copper as absorber and glass wool as insulation, but also in terms of visual appearance, with an aluminium-only made housing.

New materials means new constructions techniques. Indeed, the project has shown that the use of expensive materials has also some drawbacks. The offer is much smaller and alternatives are harder to find. This represented a serious issue with the soldering of copper. No suitable combination of flux and solder could be found in Rwanda and was therefore imported from Switzerland.

Eventually two solar collectors have been built, installed and tested. The third component, a tank could not be completed due to different issues and missing materials. This is quite unfortunate since the insulation of the existing tanks proved to be out of poor quality. Calculations have shown that the losses are around five to ten times bigger than they should be. These losses induce a significant temperature drop during the night and even compromise the rise of temperature during the day above 55-60°. At that point, the solar irradiance has to be at its strongest to overcome the losses.

The new collectors were tested on an existing tank with successful results: the water was measured up to 78°C at the collectors' outlet. The efficiency of the whole system over a day was measured at around 60%. Further measurements should be done to confirm those values. However, compared to the old systems the improvement is obvious.

There are still optimizations to be done. All of those can easily be corrected with the experience gained during this project. As for the certification, this is no longer relevant. The requirements are based on European standards hardly applicable in Rwanda. Industrial testing and measuring facilities are required. In addition, the initial thought of needing a certification for commercialization is not valid unless the product is meant for governmental institutions.

Over the past four years, the construction of solar water heaters at IPRC was gradually taken to another level. At present they have the required expertise to do the things right. If they are able to take advantage of this, they will easily become competitive on the market. Especially since the included smart-meters give them an advantage over any contender.

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APPENDICES

APPENDIX 1: PROJECT PLANNING

Work plan - June 2018

Work group

- Project leader : Ndamukunda Maurice
- Junior Expert : Kiechler Matthias
- Instructors : Damascene, Denys, Jean De la Paix, Thomas

Objectives

A. Manual of instruction
   Goal: Write down techniques used for the fabrication in 2017.
   a. **Working principle**
      Explain the major functionalities
   b. **Design and construction**
      Describe the different steps one by one to build a system based on those implemented on the hotel "Home Saint Jean".
      i. Collectors
      ii. Tank
   c. **Installation**
      Key points to take into consideration when installing.

B. Analysis of the existent systems
   Goal: Evaluate and compare the global performance of the system
   a. **Strengths and Weaknesses**
      Point out the main facts based on different parameters
      i. Design
      ii. Efficiency
      iii. Costs
   b. **Comparison with other systems**
      Compare it to the systems offered by Wasac or other companies

C. Recommendations
   Goal: Suggest further improvements based on analyses made. These points could be implemented during the second part of the project, which consists in developing new collectors.

IPRC-Karongi, 29.05.2018

Work plan - July 2018

Work group

- Project leader : Ndamukunda Maurice
- Junior Expert : Kiechler Matthias
- Instructors : Damascene, Denys, Jean De la Paix, Thomas

Objectives

A. Performance of the implemented systems
   Goal: Evaluate the performance of the systems installed on Home Saint Jean
   a. **Measures**
      Take measurements on site, find out the temperature range of the systems, and compare it to the data obtained by the smart meters.
   b. **Analysis**
      Evaluate the performance considering the losses during day and night

B. Certification
   Goal: Define if it is possible to certify new systems
   a. **RS212/213/214**
      Study the documents and:
      i. Emphasis the requirements and list other standards that have to be bought
      ii. Arrange, if needed, an appointment with RSB to clarify possible questionings
   b. **Standards**
      Make a list of the standard requirements that:
      i. are already fulfilled
      ii. have to be fulfilled
   c. **Decision**
      Determine the possibility of certifying a new prototype, based on the standards given and the analysis made. Then:
      i. Determine the next steps for the certification process
      ii. Determine the requirements to be considered during the fabrication

C. Building a prototype
   Goal: Build a new solar water heater system
   a. **Recommendation June**
      Finish the analysis of June by working out different solutions. Choose the best one according to the calculations made and the price/performance ratio
   b. **Establish the plans**
      Draw 3D plans of the retained solution and establish a list of materials and costs
   c. **Buying materials**
      Plan a trip to Kigali in order to buy the materials listed previously
   d. **Building**
      Fabricate the prototype

IPRC-Karongi, 30.06.2018

Work plan - August 2018

Work group

- Project leader : Ndamukunda Maurice
- Junior Expert : Kiechler Matthias
- Instructors : Damascene, Denys, Jean De la Paix, Thomas

Objectives

A. Planning
   Goal: Take advantage of senior experts and take decisions of last uncertainties
   a. **Fabrication techniques**
      Discuss about the fabrication idea and determine last uncertain points
   b. **Establish the plans**
      Draw 3D plans of the retained solution and establish a list of materials and costs
   c. **Buying materials**
      Plan a trip to Kigali in order to buy the last materials needed

B. Building the prototype
   Goal: Build the new solar water heater system.
   a. **Create jigs**
      Build first jigs where possible and needed
   b. **Absorber**
   c. **Frame**
   d. **Tank**

C. Assembling and installation
   Goal: Prepare for performance tests
   a. **Assembling**
      Assemble the different parts of the system
   b. **Installation**
      Find an accurate place to install the system, either on IPRC campus or on Home Saint Jean

IPRC-Karongi, 30.07.2018

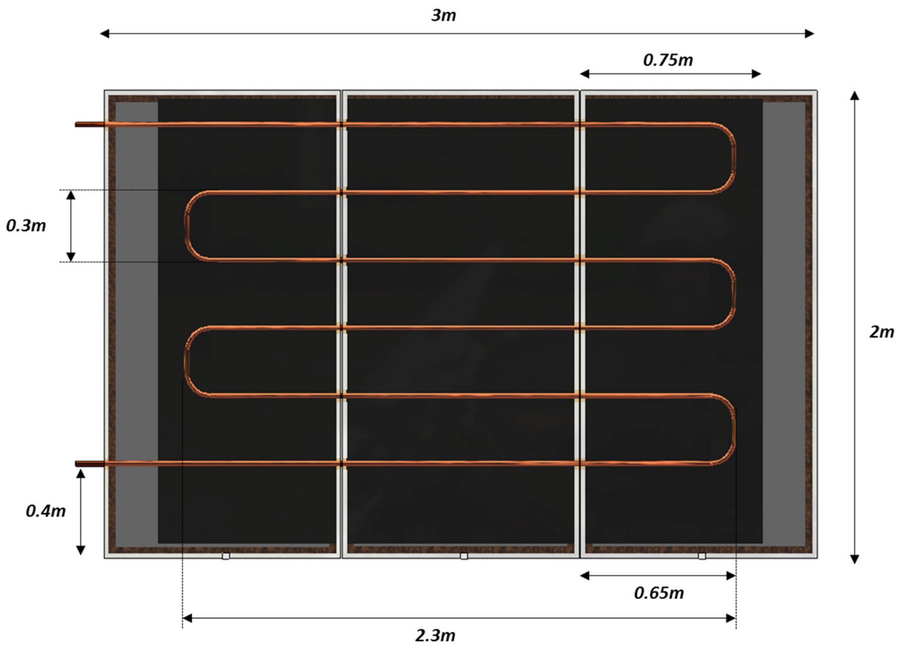
Working progress

Solar water heater project — Version of : **15.09.2018** — Project leader : NDAMUKUNDA Maurice
IPRC-Karongi — Junior expert : KIECHLER Matthias

Month	*Objectives and tasks*		*Deliverable*	*Main results and comments*
June	☑ A. Manual of instruction a) Working principle b) Design and construction c) Installation	 ✓ ✓ ✓	**SWH_2017.doc**	Document explains how the systems on Home Saint Jean were implemented Content: Evolution of design; List of materials; Schematics and plans; Building procedures of tank and collector; Installation
	☑ B. Analysis of the existent systems a) Strenghts and weaknesses b) Comparison with other systems	 ✓ ✓	**AnalysisSWH_2017.doc**	In-depth review of each component of the system: things to optimize Comparison with Solimpeks systems and complete material list with costs Overall strengh and weaknesses of the system
	☒ C. Recommendations a) Material investigation	 ✓	**MaterialCosts.xlsx**	Based on analysis of the implemented systems and on the investigations made Material investigation has been conducted in order to get an overview of the available materials
July	☑ A. Performance of the implemented systems a) Measures b) Analysis	 ✓ ✓		Temperature measures were taken on Home Saint Jean Hot water output is between 30°C and 55°C with major losses during the night
	☑ B. Certification a) RS212/213/214 b) Standards c) Decision	 ✓ ✓ ✓	**SummaryRS.doc**	RS212-214 have been studied and summed up in document First questionings have been answered by RSB: testing facilities; necessity of certification; discount on supplementary RS
	☒ C. Building a prototype a) Recommendation June b) Establish plan c) Buying materials d) Building	 ✓ ✓ ≈ ☒		Different solutions of a new prototype were made, based on material investigation and analysis of implemented systems Choosen solution: wood frame, glass inside with angle aluminium protection 3D plans and fabrication procedure were made Materials buying in Kigali was complicated. Four days instead of 2. Issues with suppliers Plans had to be adapted in order to match with availabilities on market.
August	☑ A. Planning a) Fabrication techniques b) Plans c) Buying materials	 ✓ ≈ ✓		During the visit of the senior expert, the whole construction of the frame was changed -> metal instead of wood Metal will be aluminium with angles. Techinque : pop-rivet The missing materials were bought in Kigali.
	☒ B. Building the prototype a) Jigs b) Housing c) Absorber c) Tank	 ✓ ≈ ≈ ≈	**Jigs**	Jigs were constructed to facilitate the building of absorber and brazing of plate-pipe 2 absorber were started. The pipes were brazed. Problem: brazing of copper plate to copper pipes Old defective tank was dismounted: insulation problems detected New tank with Zinga coating is prepared Beginning of aluminium housing construction
	☒ C. Assembling and Installation			The building could not be completed therefore no assembling and instalation
September	***No workplan established : main tasks as following*** ☑ A. Finishing the prototype a) Absorber b) Housing c) Tank	 ✓ ✓ ☒	**2 finished collectors**	New flux and solder form Switzerland solved the absorber brazing problems. Eventually soldering completed easily Housing was finished, took more time than expected, precise handworking New tank could not been finished: surface preparation of Zinga coating is complicated
	☑ B. Assembling and Installation			Assembling was rapidly done, too much insulation applied in the corners - visual appearance deteriorated Glass breakage during installation, forced to replace the glass, second installation ok
	☑ C. Tests and measures			Several tests and measures have been conducted: water temperature in tank & in collector outlet, flow rate, efficiency of system

APPENDIX 2: IMPLEMENTED SYSTEMS

I. Collectors



MATERIAL LIST

- *(3x)* Timber plate, length 1m, height 2m, thickness 3cm
- *(6x)* Timber plate, length 9cm, height 2m, thickness 3cm
- *(6x)* Timber plate, length 9cm, height 1m, thickness 3cm
- *(12x)* Blankets
- *(3x)* Mild steel sheet, length 0.9m, height 2m, thickness 1.25mm
- *(2x)* Mild steel sheet, length 0.65m, height 2m, thickness 0.2mm
- *(1x)* Mild steel sheet, length 0.9m, height 2m, thickness 0.2mm
- *(1x)* Circular copper pipe, length 15m, diameter ½ inch
- *(3x)* Glass, length 1m , height 2m, thickness 4mm
- *(3x)* Angle iron
- *(12x)* Angle bar
- *(-)* Nails, screws
- *(-)* Black colour

BUILDING PROCEDURE

1. Building the frame
   a. Cut three timber in the standard dimensions of the panels
   b. Cut the four sides of each panel and fix them to the bottom timber with nails
   c. Cover the frame with steel sheets and fix them with screws
   d. Reinforce the corners with angle bars
2. Building the absorber
   a. Bend the shape of the tubes in the three steel sheets
   b. Incurve the copper tube

c. Braze the pipes on the steel sheets

d. Colour the sheets and the pipe in black

3. Assembling

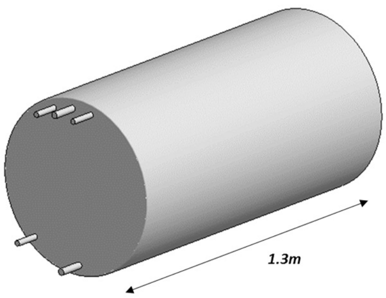
   a. Insert four blankets in each panel

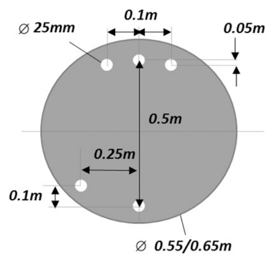
   b. Cover the blankets with a single galvanized steel plate

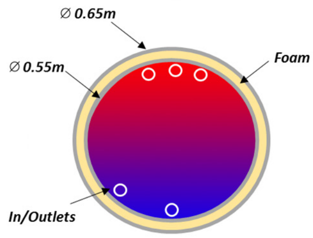
   c. Insert the absorbers in the frames

   d. Place the glasses on top of the frames and fix them with an angle iron

II. Tank and piping







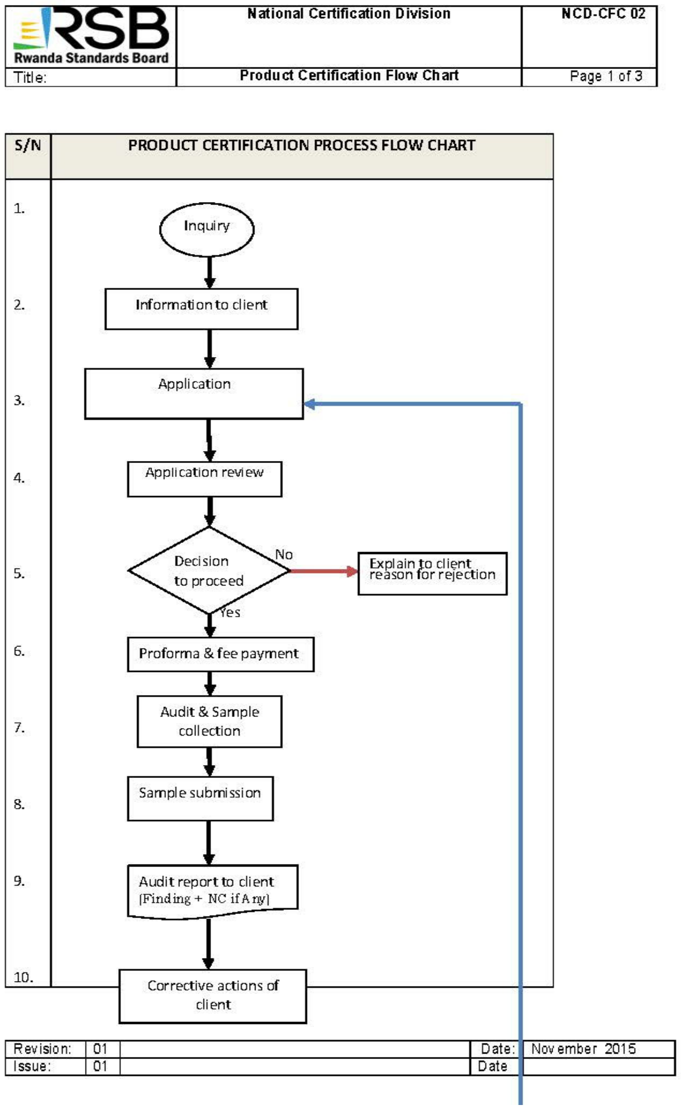
MATERIAL LIST

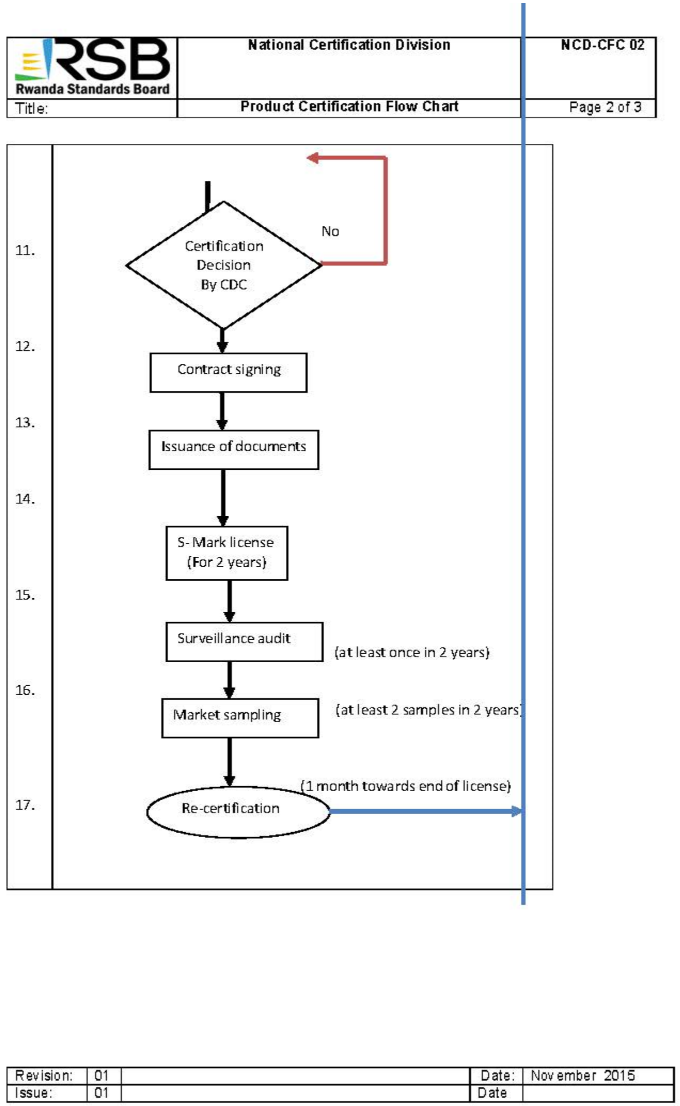
- *(1x)* Mild steel sheet, length 2.4m, height 1.2m, thickness 1.2mm
- *(1x)* Stainless steel sheet, length 2.4m, height 1.2m, thickness 1.5mm
- *(-)* Plastic pipes PPR, fittings, elbows etc.
- *(-)* Foam and pipe insulation

BUILDING PROCEDURE

1. Cut the inner and outer steel plates : dimensions as shown in the plans
2. Cut the top and bottom circular plates : dimensions as shown in the plans
3. Drill holes in the circular plates : dimensions as shown in the plans
4. Inner tank
   a. Bend the stainless steel plate and weld it
   b. Add the bottom and top stainless steel plates and weld them
   c. Place the stainless steel pipes in the holes and weld them
5. Outer tank
   a. Bend the mild steel plate and weld it
   b. Add the bottom mild steel plate and weld it
   c. Place some wood sticks inside on the bottom of the tank to create a space for isolation
   d. Drill some access holes for the insulation in the main plate and in the top plate
6. Put the inner tank in the outer tank by taking care of having an equally arranged space in between them
7. Introduce the isolation foam through the different access holes in the main plate
8. Add the top plate of the outer tank and weld it
9. Introduce more foam through the top plate
10. Cover the access holes

APPENDIX 3: CERTIFICATION PROCESS





APPENDIX 4: RS212

Domestic storage solar water heating systems — Requirements

1 Scope

This standard specifies the requirements for integral, close-coupled and split domestic storage solar water heating systems and includes specific requirements for solar collectors for solar water heating systems.

It is not applicable to solar water heating systems for swimming pools or to industrial and commercial solar water heating systems, or instantaneous type domestic solar water heating systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

RS 116-1, *Electrical wiring of premises – Part 1: Low-voltage installations.*

RS 2, *Potable Water - Specification*

RS 213, *Domestic solar water heaters – Mechanical qualification tests.*

RS 214, *The installation, maintenance, repair and replacement of domestic solar water heating systems.*

RS IEC 60335-2-21, *Household and similar electrical appliances– Safety – Part 2-21: Particular requirements for storage water heaters.*

RS ISO 9459-2, *Solar heating - Domestic water heating systems -- Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems*

RS ISO 9806, *Solar energy -- Solar thermal collectors -- Test methods.*

3 Terms and definitions

For the purposes of this standard, the following terms and definitions apply.

3.1
absorber
part of a solar heating collector that receives radiant energy and transforms it into thermal energy, which is used to heat the heat-transfer fluid passing through the collector or to heat the water directly

3.2
acceptable
acceptable to the authority administering this standard, or to the parties concluding the purchase contract, as relevant

3.3
aperture
area in a collector cover through which unconcentrated solar radiant energy is admitted to the absorber

3.4
close-coupled system
system, in which hot water is stored in a separate but close-coupled water storage tank, where the mechanical coupling between the collector and the tank are pre-manufactured and controls the position of the collector in relation to the tank

3.5
collector
device that contains or incorporates an absorber and a means for transferring thermal energy from the absorber to a fluid passing through the device

3.6
collector cover
transparent or translucent material that covers the aperture and provides thermal retention and environmental protection of the unit

3.7
daily heat output
energy output above mean inlet temperature of a collector ($Ta - Tc$ = 10 °C) as determined by the thermal performance test, and normalized to a base of 20 MJ/ m^2/d of solar energy input

3.8
direct heating system
heating system in which the potable water to be heated is circulated through the absorber, and the solar heat gathered by the collector is transferred directly to the potable water itself

3.9
hail cover
cover for collector other than glazing that shall prevent hail impact damage

3.10
heat exchanger
device specifically designed to transfer heat between two physically separated fluids

3.11
heat transfer fluid
medium, such as air, water or other fluid, that passes through a collector and carries absorbed thermal energy from the collector to the potable water to be heated

3.12
indirect heating system
system in which an absorber transfers heat via a heat exchanger to the potable water to be heated

3.13
integral system
system in which the hot water storage tank is incorporated integrally with the collector and water is stored in the body of the collector-storage tank unit

3.14
pumped circulation
system in which water is circulated between the collector and storage tank by means of a mechanical circulation device

3.15
separate storage system
split system in which the hot water storage container is remote from the collector(s)

3.16
solar water heating system
complete operating system that uses radiant energy from the sun to produce hot water and comprises one or more collectors, one or more hot water storage tanks whether supported by supplementary energy sources or not, and all necessary interconnecting pipes and functional components

3.17
supplementary energy sources
auxiliary heating source independent of solar thermal radiation

3. 18
thermosiphon circulation
system in which water is circulated between the collector and storage tank by means of density changes of the heat transfer fluid

4 Requirements

4.1 Types

A solar water heating system shall be one of the types given in table 1:

Table 1 — Solar water heating systems

1	2	3	4	5	6	7	8	9
Collector/Storage combinations								
integral	close-coupled				split			
Heat transfer method								
direct	direct		indirect		direct		indirect	
Circulation method								
thermo-siphon	thermo -siphon	pumped	thermo-siphon	pumped	thermo-siphon	pumped	thermo-siphon	pumped
NOTE Pumped (forced) circulation can be achieved with electrical mains or photovoltaic powered pumps								

4.2 Hot water storage tank

4.2.1 A hot water storage tank, with supplementary heating or with provision for supplementary heating (or with an integral heat pump) shall comply with RS IEC 60335-2-21.

4.2.3 Electrical components of a hot water storage tank that is intended to be installed on the outside of a building shall be at least IPX4, and effectively protected, by means of a corrosion resistant outer casing, against the effects of rain, wind and other elements. Other water heaters shall be at least IPX1.

4.2.4 Seams on the outer casing and the entry holes for pipe connections shall be effectively sealed to make a permanent watertight closure. All exposed piping or fittings (or both) which form part of the storage tank, shall be of a non-corrosive material or protected against corrosion.

4.3 Collector

4.3.1 Collector cover

4.3.1.1 If constructed in solid sheet form, the collector cover shall be secured so as to resist an upward and downward force of 200 N/m^2.

4.3.1.2 The collector cover of a solar water heating system shall be of such quality and strength that, when it is tested in accordance with RS 213 and/or RS ISO 9806, it does not suffer any damage that could impair its normal operation unless fitted with a hail cover.

4.3.1.3 The collector cover shall have a high transmission of visible and near infra-red radiation of wavelength up to 2.4 µm in order to maximize the input of solar radiation.

4.3.1.4 The collector cover shall have a low transmission of infra-red radiation of wavelength exceeding 3 µm in order to minimize heat losses.

4.3.2 Hail cover

The hail cover of a solar water heater shall be of such quality and strength that, when it is tested in accordance with RS 213, the collector and hail cover does not suffer any damage that could impair its normal operation. A hail cover shall be corrosion resistant and easily removable for cleaning.

4.3.3 Thermal insulation

4.3.3.1 Thermal insulating material used in the construction of the collector shall be of such quality and composition and so applied that after stagnation testing in accordance

a) when in contact with a metal, it does not cause corrosion of the metal, with RS 213;

b) it does not react in the presence of heat in a manner that shall produce corrosive salts or vapours; and

c) it is dimensionally stable under dry conditions at the maximum expected temperatures likely to be reached in the collector.

4.3.3.2 Compliance may be confirmed by inspection.

4.3.4 Stagnation requirements

The construction of a collector and the quality of the different materials used shall be such that, when the collector is tested in accordance with RS 213 or RS ISO 9806, any:

a) deformation of any part of the collector,

b) vapour deposition on the underside of the collector cover,

c) degrading of paint, sealants, seals or insulation, and

d) cracking, flaking, blistering or loss of cohesion of the absorber paint film, shall not be of such magnitude as to impair the operation of the collector. This visual evaluation shall be repeated during and at the end of thermal properties test in accordance with RS ISO 9459-2.

4.3.5 Resistance to freezing

4.3.5.1 A solar water heating collector that is marked as resistant to freezing shall, when tested in accordance with RS 213 or RS ISO 9806, show no sign of any damage that could impair its normal operation.

4.3.5.2 Collectors that include a drain down valve or dumping valve or anti-freeze valve are not acceptable methods for freeze protection.

4.3.6 Resistance to rain penetration

When the collector of a solar heater is tested in accordance with RS 213 and/or RS ISO 9806, the interior of the collector shall remain free from any water penetration and condensation shall disappear within 4 h in dry conditions.

4.3.7 Resistance to fatigue and hydrostatic pressure

When a collector is tested in accordance with RS 213 and/or RS ISO 9806, there shall be no leakage or any sign of damage or deformation that could impair the normal operation of any of its components.

4.3.8 Pipe connectors

Joints between components shall be of acceptable design and quality and shall not leak and shall comply with relevant product standards.

4.3.9 Polymeric materials

4.3.9.1 Components in contact with hot potable water

These components shall comply with the relevant material standard requirements and shall be of food grade.

4.3.9.2 Components not in contact with hot potable water

Polymeric material shall have been acceptably heat-stabilized and protected from the effects of ultraviolet light by incorporation of acceptable ultraviolet (UV) stabilizer in appropriate quantities.

This shall be verified by means of a declaration by the manufacturer with supporting technical evidence.

4.3.10 Sealants

Sealant material shall be suitable for its intended purpose. This shall be verified by means of a declaration by the manufacturer with supporting technical evidence. When tested in accordance with RS 213, the interior of the collector shall remain free from any water.

4.4 Connecting pipe work within the system

4.4.1 The connecting pipes in the primary circulation loop between the collectors and the storage tank shall comply with the relevant approved product standards on plain-ended solid drawn copper tubes for portable water.

4.4.2 Piping from the tank to the collectors should be as short as possible and insulated to reduce heat loss. Increase the pipe insulation if the collectors are a long distance from the storage tank.

4.5 System construction

4.5.1 General

All components of a solar water heating system including temperature and pressure control equipment shall comply with the relevant approved product standards. Installation of a solar water heating system shall be in accordance with annex A.

4.5.2 Circulation pump

Circulation pumps in primary loop shall be suitable for operation with water temperatures of at least 95 °C. This shall be verified by means of a declaration by the manufacturer.

4.5.3 Galvanic action

Where different materials are joined together or coupled in the same system, acceptable precautions shall be taken in respect of the choice of materials, the method of jointing and the use of inhibitors, in order to reduce the possibility of galvanic action under wet and dry conditions in accordance with relevant standards for water supply installations for buildings.

4.5.4 Rated working pressure

A solar water heating system shall be designed for a rated working pressure of atmospheric pressure, 100 kPa, 200 kPa, 300 kPa, 400 kPa or 600 kPa, as required. The design and construction of any component or system shall be such that, when the component or system is tested in accordance with RS 213, there is no failure that could affect the acceptable operation of the component or system.

4.5.5 Frame and stand

4.5.5.1 Any stand or frame that carries a storage tank on top of a roof shall comply with the following:

a) the stand shall include a structurally sound load spreading support that evenly distributes the loads, on the rear legs and that protrudes at least 300 mm past each leg; and

b) the stand shall include cross braces that stabilize the frame.

4.5.5.2 Any stand or frame that shall determine the angle of the collectors or the storage tank (or both) shall comply with the following:

a) the stand or frame shall allow for the system to be installed at the inclination specified by the manufacturer, on any roof pitch as nominated by the manufacturer;

b) the manufacturer shall provide clear instructions on how to adjust the inclination of the frame. This shall be verified by following the instructions provided by the manufacturer; and

c) after adjustment the frame shall still comply with all material, corrosion and structural requirements stated in this standard.

4.5.6 Heat transfer fluid

4.5.6.1 The heat transfer fluid used in an indirect heating system shall be non-toxic and non-corrosive.

4.5.6.2 Heat transfer fluids should also have a colour added in order to detect a rupture between close and open circuits if it happens.

4.5.7 Electrical components

Electrical components that are intended to be installed on the outside of a building shall be IP32, and effectively protected, by means of a corrosion resistant outer casing, against the effects of rain, wind and other elements

4.6 Thermal properties

4.6.1 For thermosiphon split systems, the bottom of the storage tank shall be no more than 350 mm above the top of the collector.

4.6.2 For pumped split systems, the connecting pipes between the collector and the storage tank shall be at least 3 m on the inlet as well as on the outlet sides.

4.6.1 Thermal performance

When the thermal performance of a solar water heating system is evaluated in accordance with RS ISO 9459-2, the daily heat output shall not be less than 5 MJ and not more than 10 MJ per day per 50 l of stored capacity at a 20 MJ /m²/ d.

4.6.2 Standing loss

When the standing loss of a solar water heating system is determined in accordance with RS ISO 9459-2, the heat loss shall be not more than 20 % of the initial energy. The system shall retain at least 80 % of the energy.

4.6.3 Mixing factor

When the mixing factor of a solar water heating system is evaluated in accordance with RS ISO 9459-2, the temperature for the hot water output measured in accordance with 4.6.4, the mean water temperature *T*p shall be at least 50 °C.

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4.6.4 Hot water output test

4.6.4.1 Immediately after the standing loss test, switch off the electrical supply. By letting in coldwater, withdraw a quantity of water equal to the rated capacity of the water heater at a constant rate of flow.

4.6.4.2 In the case of open outlet type water heaters, control the flow using the inlet valve.

4.6.4.3 In the case of the other types of water heaters, control the flow using a valve fitted in the outlet.

4.6.4.4 Adjust the rate of flow to:

a) 4 L/min for water heaters that have a rated capacity of less than 10 l

b) 10 L/min for water heaters that have a rated capacity of 10 l up to and including 100 l;

c) 20 L/min for water heaters that have a rated capacity of more than 100 l - 200 l; and

d) 10 % of the capacity per minute for water heaters that have a rated capacity exceeding 200 l.

4.6.4.5 Take continuous temperature readings of the water using a thermocouple placed through and as near as practicable to the outlet into the upper half of the water in the container.

4.6.4.6 Measure the temperature of the withdrawn water and determine its average temperature *T'*p in degrees Celsius.

4.6.4.7 Measure the temperature of the cold inlet water *T*c in degrees Celsius. Take the controlled water temperature to be 65.0 °C.

4.6.4.8 Calculate the mean water temperature *T*p in degrees Celsius, using:

$$T = 45\frac{T_p' - T_c}{65 - T_c} + 20$$

Where,

T_c temperature of the cold inlet water

T'_p average temperature.

4.7 Corrosion protection

NOTE See annex B for information on factors governing corrosion and internal scaling of solar water heating systems.

4.7.1 Materials in contact with potable water

4.7.1.1 All materials, including surface protection materials, that are intended to be in contact with potable water, shall be non-toxic, shall not cause the water to become toxic, and shall not impart any colour or objectionable odour to the water if tested in accordance with of RS 2.

4.7.1.2 All copper alloy components in direct contact with water shall when a specimen is tested for dezincification in accordance with RS 213, show a depth of penetration not exceeding 250 µm.

4.7.2 Corrosion resistance of components

The material of the component or quality and method of application of surface protection coatings (including surface coatings of absorber surfaces), as relevant, shall be such that, when any metallic component of a solar water heating system is tested in accordance with RS 213, there is no visible sign of corrosion of the basic material or penetration of the surface coating.

NOTE The test are done in the following sequence, one immediately after the other: Stagnation test for collector, Mechanical strength, Resistance to rain penetration, Resistance to hail, Resistance to hail, Dezincification resistance, Corrosion resistance, Thermal properties.

5 Marking

5.1 Tank markings

Each hot water storage tank shall be marked according to RS IEC 60335-2-21.

5.2 Collector markings

All collectors shall be legibly and indelibly marked with the following information:

a) the manufacturer's name or trade name or trademark;

b) date of manufacture or batch traceability number;

c) the rated working pressure;

d) collector model;

e) the aperture area; and

f) whether a hail cover is required.

5.3 Evacuated tube markings

All tubes shall be legibly and indelibly marked with the following information:

a) manufacturer's name or trade name or trademark; and

b) tube model identification

5.4 System markings

The system marking shall be attached to a major component of the system and shall include the following:

a) manufacturer's name or trade name;

b) system model;

c) tank name and model;

d) collector name and model;

e) freeze resistant status;

f) specification of transfer fluid and mixing ratio (for indirect systems);

g) energy rating for standard day (MJ/day);

h) overnight energy losses (%); and

i) system type as per 4.1.

6 Instruction booklet

A booklet or leaflet in one of official languages used in Rwanda shall be attached to each solar water heating system and shall set out the following:

a) instructions for the safe and correct installation of the complete solar water heating system, with a description of all operating components e.g. collector installations, orientation, piping, electrical connections, wiring diagrams, temperature sensors, freeze and hail protection etc;

b) instructions for the safe and correct operation of the complete solar water heating system;

c) instructions for regular maintenance e.g. battery, transfer fluid, sacrificial anode, replacement intervals, corrosion prevention and warning details etc;

d) safety precautions;

e) relevant technical details of all major components e.g. collector, tank, electrical components, battery, pump etc; and

f) inclination angle (or range of angles) at which the system shall be installed, and the method of adjusting the frame accordingly.

Annex A
(normative)

Installation, replacement and retrofit

A.1 Hot water systems in buildings are regulated by means of the relevant national legislation and local water services bylaws.

A.2 In terms of the relevant national legislation, solar water heating installations are required to comply with the following regulations and standards as applicable: Rwanda building control regulations, Regulation on Electrical installations in Rwanda, Solar water heating regulations, relevant part of RS IEC 60364 and RS 116-1.

A.3 New installations (where there is no pre-existing hot water installation), and installations in which the existing hot water installation is removed and replaced with a solar water heating system should comply with one of the options given in table 1.

A.4 Where solar water heating installations are retrofitted to existing electrical hot water installations, either a solar pre-heater retrofit option (a) or a solar circulating retrofit option (b) given below are suitable.

A.4.1 **Option a) - solar pre-heater retrofit;** there shall be no continual circulation of heated potable water between the solar water heating system storage tank and pre-existing electrical storage water heater. The cold inlet to the solar pre-heater is connected downstream of the existing pressure control valve, and the hot outlet of the solar pre-heater is connected to the inlet connection of the existing electrical storage water heater, not into its hot outlet pipe. Flow of solar heated water to the pre-existing electrical water heater only occurs when hot water is drawn off at terminal fittings. This option may negatively affect flow pressure performance at terminal fittings due to the additional in-line friction pressure losses.

A.4.2 **Option b) - solar circulating retrofit;** any appropriate system in table 1 may be used. The circulating potable water between the solar water heating system and the existing storage water heater shall be connected so that the heated water is circulated between the retrofitted solar water heating system and the existing electrical storage water heater.

A.5 In both options (a) and (b) the hot water supply or circulating pipes from the solar water heating system may not be connected to the hot outlet pipe of the existing electrical storage water heater. The pressure rating of the solar water heating system shall be matched to that of the existing electrical storage water heater.

Annex B
(normative)

Factor governing corrosion and internal scaling of solar water heating systems

B.1 The tendency for metal corrosion or scaling to occur in a solar water heating system shall depend on the characteristics of the water in the system. The evaluation given in B.2 - B.4 may be included to aid in developing an acceptable corrosion prevention procedure.

B.2 A full water analysis should be carried out and the Langelier Saturation Index and the Ryznar Stability Index calculated to give a guide as to the expected scaling/corrosion tendency of the water.

B.3 The known performance of metals in a particular water should be ascertained from local user and supplier experience and checked against the likely performance as predicted from chemical analysis of the water. It should always be remembered, however, that design factors (open circuit, closed circuit, material choice, crevices, etc.) may override factors predicted from water chemistry or from the corrosion history.

B.4 In water with a high chloride or high sulphate content, predictions calculated from a chemical analysis of the water should be treated with caution. It is difficult to define what high chloride content is since this could vary from water to water and from metal to metal. The hardness of the water could be an important factor in terms of the chloride tolerance of a metal.

APPENDIX 5: RS213

Domestic solar water heaters — Mechanical qualification tests

1 Scope

This standard specifies test methods for the mechanical qualification of domestic solar water heaters.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

RS ISO 6509, *Corrosion of metals and alloys – Determination of dezincification resistance of brass.*

RS 212, *Domestic solar water heaters-Requirements.*

RS ISO 9459-2, *Solar heating - Domestic water heating systems - Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems*

RS ISO 9227, *Corrosion tests in artificial atmosphere salt spray test.*

3 Terms and definitions

For the purposes of this standard, the terms and definitions given in RS 212 apply.

4 Mechanical qualification tests for collectors

4.1 Sequence of tests

Carry out the tests given in 4.2 - 4.6 on the same water heater and in the sequence given.

4.2 Stagnation test for collectors

4.2.1 Preparation

Mount the collector of the water heater as in practice, with the inlets closed and the outlets open, and in a run-dry condition, with no transfer fluid anywhere in the collector.

4.2.2 Procedure

Expose the collector to insulation over a period of 15 - 30 consecutive days, keeping a record of the daily insulation and the weather, until at least 315 MJm^2 cumulative insulation or 30 days is reached.

4.2.3 Evaluation

Inspect the test installation regularly during this test, and each time record the date, the time of day, and any occurrence of changes that might impair the continued operation of the water heater, such as:

a) deformation of any part of the collector;

b) vapour deposition on the underside of the collector cover;

c) degradation of paint, sealants or insulation; or

d) degradation of the absorber paint film.

4.3 Test for mechanical strength

4.3.1 Test sample

The solar water heater presented for testing shall be a complete operating unit of one of the following types:

a) close-coupled water heater;

b) integral water heater;

c) separate storage tank, collector and interconnecting pipe work coupled together in an acceptable manner; or

d) any other water heater erected and coupled in an acceptable manner.

4.3.2 Resistance to vacuum (closed type and open outlet type water heaters)

The water container shall be so designed and constructed that, when subjected to the vacuum test, it does not collapse or implode.

4.3.3 Test for resistance to vacuum

Fill the container with water, close the outlet pipe (with a plug if necessary), and subject the container to a vacuum of 15 kPa maintained for 30 min. After 30 min relieve the vacuum and check for compliance with the requirements of 4.3.2.

4.3.4 Fatigue and hydrostatic pressure test

Use the test method given in 4.3.5 and 4.3.6 and test the water heater at a pressure equal to the marked working pressure. In the case of open (non-pressure) type water heaters, use a pressure of 50 kPa.

4.3.4.1 Resistance to fatigue (all closed type water heaters)

The container of a closed type water heater shall be so designed and constructed that, when subjected to the fatigue test given in 4.3.5.

a) the container shall, during the test, show no sign of leakage or any deformation that may impair its performance; and

b) when relevant, the lining shall, at the conclusion of the test, still remain intact.

4.3.4.2 Resistance to hydrostatic pressure (closed, open outlet and cistern type water heaters)

4.3.4.2.1 Closed type water heaters

When tested in accordance with 4.3.6.1, a closed type water heater shall withstand the hydrostatic test pressure without leakage, collapse or any deformation that may impair its operation.

4.3.4.2.2 Open outlet and cistern type water heaters

When tested in accordance with 4.3.6.2, an open outlet type and a cistern type water heater shall withstand the hydrostatic test pressure without leakage, collapse or any deformation that may impair its performance.

4.3.5 Test for resistance to fatigue (closed type water heaters)

4.3.5.1 Connect the cycling timer to the water heater, one valve fitted close to the water heater inlet and the other valve close to the water heater outlet. Connect the inlet valve to a water supply (ambient temperature) at a pressure equal to the rated pressure of the water heater under test subject to a tolerance of $^{0}_{-10}$ %. In the case of appliances that incorporate heat exchangers, pressurize the heat exchanger to its marked (rated) working pressure before and during the fatigue test and the hydrostatic pressure test.

4.3.5.2 Fill the water heater with water, ensuring that no air is entrapped, and set the cycling timer in action.

4.3.5.3 Adjust the setting of the valves to ensure that, during each cycle the water pressure in the water heater rises to the rated pressure of the water heater $^{0}_{-10}$ % and reduces to a value of between 5 % and 10 % of the rated working pressure.

4.3.5.4 Subject the water heater to 250 000 cycles under these conditions.

4.3.5.5 During the test, inspect the container for any deformation or leakage and verify for compliance with the requirements of 4.3.4.1a). At the conclusion of the test visually examine any lining, when relevant, for compliance with the requirements of 4.3.4.1b).

4.3.6 Test for resistance to hydrostatic pressure (closed, open and cistern type water heaters)

4.3.6.1 Closed water heaters

At the conclusion of the fatigue test, close the outlet pipe of the water heater, subject the water container for 15 min to the appropriate hydrostatic test pressure given in column 2 of table 1 and then examine the water container for compliance with the requirements of 4.3.4.2.1.

Table 1 — Test pressure

1	2
Type of water heater	Hydrostatic test pressure
Rated at ≤ 50 kPa	50 kPa
Rated at > 50 kPa	2 × working pressure

4.3.6.2 Open outlet and cistern type water heaters

Subject cistern type water heaters and open outlet type water heaters (after the vacuum test) for 15 min to the appropriate hydrostatic test pressure given in column 2 of table 1 and examine the water container for compliance with the requirements of 4.3.4.2.2.

4.4 Test for resistance to rain penetration of collectors

4.4.1 Apparatus

4.4.1.1 Apparatus fitted with 12 spray nozzles of which the mounting positions can be so adjusted that the water sprays are directed onto the joints along the top and sides of the collector cover. The capacity of the nozzles is such that they deliver 165 L of water per hour.

4.4.1.2 Test nozzles shall not be closer than 10 cm from the collectors.

4.4.2 Preparation of test collector

4.4.2.1 Test shall be performed on a fully assembled system.

4.4.2.2 Electrical components intended for indoor installation shall be protected against contact with water.

4.4.3 Procedure

Spray the collector for 5 min every 30 min for a period of 3 h, allowing the run-off water to drain away through the drain connection.

4.4.4 Evaluation

Observe whether the interior of the collector remains free from accumulated water, and evaluate in accordance with 4.2.3.

4.5 Test for resistance of collectors to hail damage

4.5.1 Procedure

4.5.1.1 Use a suitable apparatus that can fire an ice ball onto the test sample. Ensure that the ice ball is fired at the appropriate aperture area of the collector which is either:

a) the collector cover or, when it forms a permanent part of the collector, the hail screen of a covered collector;

b) the open absorber surface of unglazed or unprotected flat plate collectors; or

c) the evacuated tubes (as fitted on the system), to 12 perpendicular impacts (for flat plate collectors), each with an impact energy of 11 J ± 1 J, and delivered to various points on the tested surface. Ensure that eight of these points are between 30 mm and 50 mm from the inner edge of the collector.

4.5.1.2 In the case of evacuated tubes, only apply one impact to each tube at different positions.

Ensure that at least one tube is impacted not less than 100 mm from the exposed bottom end, and at least one tube is impacted not less than 100 mm from the exposed top end.

V

4.5.2 Evaluation

Observe whether the collector or evacuated tubes suffers any damage that could impair its normal operation, and evaluate in accordance with RS 212.

4.6 Test for resistance to freezing

4.6.1 General

The transfer fluid used for this test shall be the same type and concentration as for all other tests on this system, specifically in accordance with the thermal performance test given RS ISO 6459-2.

4.6.2 Test room

A cold room in which the temperature can be controlled to any specific temperature of between −20 °C and + 20 °C.

4.6.3 Procedure

4.6.3.1 Install the system in the cold room. Ensure that:

a) it is filled to its normal capacity with the intended circulating fluid;

b) it is at its marked design pressure;

c) all operating components are be fitted in an acceptable manner and positioned as specified by the manufacturer;

d) the water temperature is between 30 °C and 37 °C;

e) electrical heating elements are disconnected;

f) any backup batteries shall be fully charged for the start of the test, and these batteries shall not be charged for the duration of all the test cycles; and

g) batteries and control panels are allowed to be outside of the test room.

4.6.3.2 Switch off the electrical supply, including PV cells, to the system, and connect any backup batteries.

4.6.3.3 Reduce the test room temperature to 5 °C ± 3 °C. Maintain this temperature for 180 min.

4.6.3.4 Reduce the test room temperature to −20 °C ± 3 °C in no longer than 60 min. Maintain this temperature for 120 min.

4.6.3.5 Increase the test room temperature to 20 °C ± 5 °C.

4.6.3.6 Disconnect any backup battery.

4.6.3.7 Maintain the test room temperature to 20 °C ± 5 °C for a minimum of 360 min.

4.6.3.8 Inspect the system for any failures.

4.6.3.9 Repeat the procedure described in 4.6.3.1 to 4.6.3.5 a further three times. Ensure that a total of four test cycles are completed. These steps can be repeated immediately, or with a time delay.

NOTE This procedure does not allow for testing of systems that include drain down valves, dumping valves, anti-freeze valves for freeze protection.

4.6.4 Evaluation

Inspect all the components installed in test room, and perform a pressure test (see 4.3.4). If necessary, identify any physical damage that could impair normal operation.

4.7 Test for resistance to dezincification

Use the method given in RS ISO 6509 to test all brass components in direct contact with potable water.

4.8 Test for water absorption of composite and plastics components (excluding pipes)

4.8.1 Preparation

Cut a test specimen of the composite or plastics, of size approximately 50 mm × 50 mm from each sample. Seal composite specimens round the cut edges with a water-resistant sealing material to an acceptable thickness.

4.8.2 Procedure

Weigh the specimen to an accuracy of 0.05 %. Place it in a beaker of distilled water at room temperature for 28 days. Remove the specimen from the water, wipe off all surface moisture, and weigh the specimen again.

4.8.3 Calculation

Calculate the water absorption, expressed as a percentage by mass, using the following equation:

$$\text{Water absorption} = \frac{B-A}{A} \times 100$$

Where,

B is the mass of the specimen after immersion, expressed in grams (g); and

A is the mass of the specimen before immersion, expressed in grams (g).

4.9 Test for corrosion resistance (excluding pipes)

4.9.1 Procedure

4.9.1.1 Visually inspect all exposed surfaces for any signs of corrosion that formed during the test process.

4.9.1.2 If any corrosion is identified, perform a 1 000 h salt fog test on acceptably sized and prepared samples of the metallic materials (except intrinsically corrosion-resistant materials) of those system components that are exposed to the environment, in accordance with RS ISO 9227.

4.9.1.3 Seal the cut surfaces carefully with a compatible and corrosion-resistant coating before the salt fog test is started.

NOTE In the case of large components, acceptably sized test specimens may have to be cut out.

4.9.2 Evaluation

Immediately after completing the salt fog test, inspect the samples first for penetration of the coating and then for any corrosion of the basic material under the coating. Compare the results with the requirements of the relevant specification.

APPENDIX 6: RS214

Installation, maintenance, repair and replacement of domestic solar water heating systems — Requirements

1 Scope

This standard specifies the requirements for maintenance, repair of the water heating systems and the safe installation of new and replacement domestic solar water heaters complete with all the relevant and applicable control units.

It does not cover the installation of water heaters for swimming pools and commercial buildings

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

RS 212, *Domestic solar water heaters — Requirements.*

3 Terms and definitions

For the purposes of this standard, the terms and definitions given in RS 212 and the following apply.

3.1
acceptable
acceptable to the local authority in whose area of jurisdiction the system is installed, or to the body administering this standard, as relevant

3.2
approved
approved by the local authority in whose area of jurisdiction the system is installed, or by the authority administering this standard, as relevant

3.3
competent person
person who is able, by virtue of possessing a relevant professional qualification or applicable knowledge, training and experience, to solve or resolve problems that relate to the subject matter.

4 Requirements

4.1 General

4.1.1 The symbolic signs given in figure 1 are used to identify the type; nature and combination of the varieties of valves recommended for particular systems (see figures 2 - 7, inclusive)

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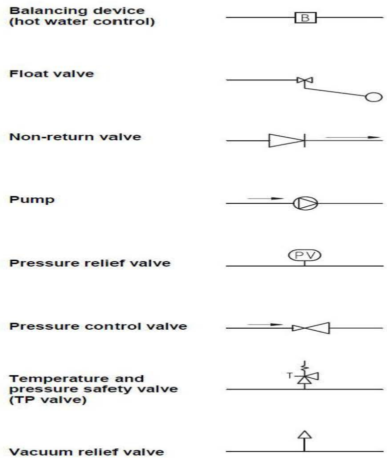

Figure 1 — Symbolic signs

NOTE The figures are for information only and do not represent all the systems in the market place.

4.1.2 Solar water heaters consist basically of an absorber unit that collects the incident solar radiation during the day, and a storage tank to contain the heated water. These two main components are separate in most conventional systems, as shown in figures 2, 3, 4 and 5, but can also be combined to form a single absorber and storage unit

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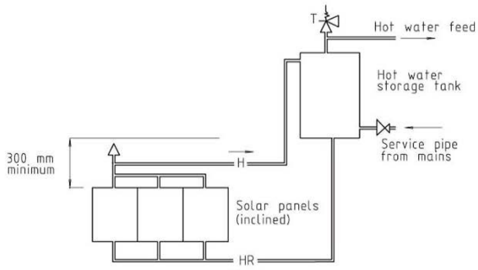

NOTE H is the hot water pipe and HR is the hot water reserve pipe

Figure 2 — Thermosiphonic hot water system

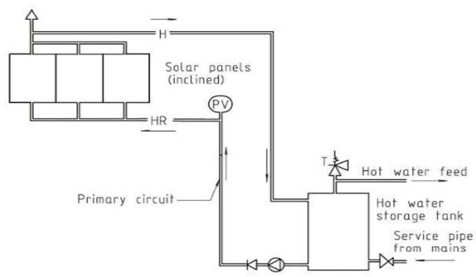

Figure 3 — Pumped direct solar hot water system

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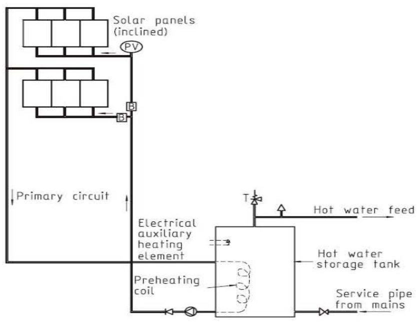


Figure 4 — Pumped indirect solar water system

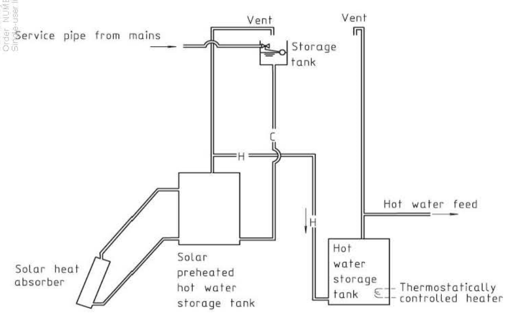


Figure 5 — Solar water heater used for preheating in a hot water system

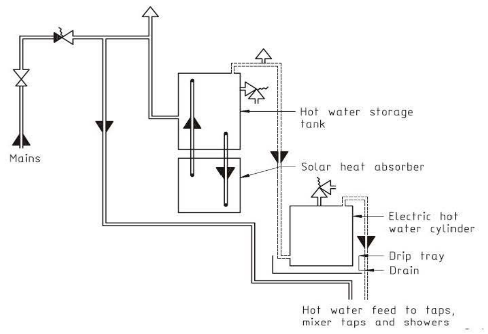


Figure 6 – Solar water heater used as pre-heater in a hot water system

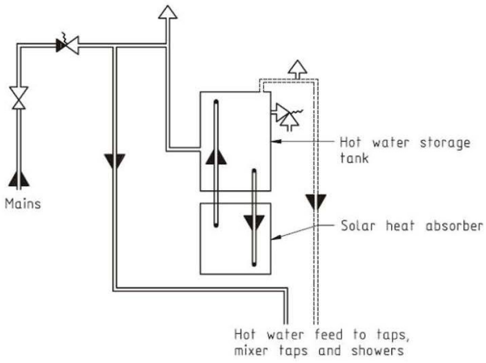


Figure 7 — Thermoscopic hot water system with no supplemental heat source

4.1.3 The type of system to be used should be determined from the average efficiencies of different types of solar absorbers as given by the manufacturer.

4.2 Assembly

4.2.1 All components used in an assembly shall be of an approved type.

4.2.2 The system assembly shall comprise:

a) fittings and components, of which the type and quality shall comply with appropriate acceptable standards;

b) solar water heater that complies with RS 212;

c) solar collectors; and

d) for systems with a storage tank installed under the roof, a drip tray.

NOTE Additional power supply and valves are required to control the circulation of the heated fluid. To achieve independency from the mains supply, a solar photovoltaic panel is used to power the circulation pump.

4.2.3 In systems where the storage tank is below the absorber unit, a non-return valve shall be installed in the primary return pipe.

4.2.4 The system shall be fitted with a drain pipe and a circulation pump with intelligent controls (pump, valves and temperature sensors) if the bottom of the storage tank is less than 300 mm above the top of the panels.

4.3 Operation of the system

All the components of the system shall be installed in accordance with the manufacturer's instructions and in such a manner and position as to ensure:

a) the safe and effective operation of the system and of each individual component part;

b) that shut-off valves are installed to enable the easy, effective and correct removal and replacement of component parts or spare parts during maintenance, replacement or repair; and

c) the effective discharge and drainage of water from the system.

5 Installation

5.1 Freeze protection

Domestic solar water heaters installed in areas where freezing is known to occur, shall be protected against freezing.

5.1.1 Antifreeze chemicals

Freeze protection may be accomplished through the use of chemicals either as or in the heat transfer fluid.

5.1.2 Automatic draining

Freeze protection may be accomplished through the use of system controls which automatically allow heat transfer fluids to drain from parts of the system exposed to freezing temperatures, as in the drain down or drain back systems. Electrically operated valves shall drain the system when there is a power outage (that is, fail safe).

5.1.3 Automatic recirculation

Freeze protection may be accomplished through the use of system controls which automatically circulates heat transfer fluids through the system when outdoor temperatures reach predetermined levels. This freeze protection does not operate during periods of power outage unless an auxiliary source of power is provided. This freeze protection system is not recommended for use in areas with frequent or severe freeze conditions, and may increase the heat loss of the system during off periods.

5.1.4 Manual draining

Freeze protection may be accomplished through the use of system controls which allow an operator to manually drain the system of heat transfer fluids. Caution should be exercised when depending on this method of freeze protection since it requires human attention for proper operation. Failure to operate the system properly may result inconsiderable damage.

5.1.5 Low wattage electric resistance heating

Freeze protection for tank absorber systems may be accomplished through the use of low wattage (less than 300 W) electrical resistance heaters and system controls that supply heat to the tank and adjacent piping/fittings only when temperatures inside the system reach 35 °F + 2 °F (2 + 1 °C). This freeze protection system does not operate during periods of power outage unless an auxiliary source power is provided.

5.1.6 Freeze tolerant materials

Freeze protection maybe accomplished through the use of materials which are not damaged by repeated cycles of freezing and thawing while filled with potable water, provided evidence that the material can withstand such cycling is supplied.

5.2 Solar collectors

5.2.1 Solar collectors shall be installed in accordance with the manufacturer's instructions.

5.2.2 Before installation, an assessment of the roof structure that will support the solar collector and its related (i.e. wind and rain) and anticipated loads shall be carried out by a competent person, in accordance with the requirements of Rwanda building Control regulations, relative standards and Solar water heating regulations

5.2.3 Structural supports shall be constructed to support the collector under anticipated extremes of environmental conditions and to withstand local conditions and anticipated loads, such as wind, seismic, rain, snow, and ice so that the solar system does not impair the resistance to damage of the building. Neither wind loading nor the additional mass of filled collectors shall exceed the live and dead load ratings of the building, roof, foundation, or soil.

5.2.4 The solar collectors shall be provided with supports to maintain collector tilt and orientation within the design conditions.

5.2.5 The orientation of the solar collectors and the tilt angle shall be determined by a competent person.

NOTE See annex A for design considerations and positioning of solar collectors.

5.2.6 The collectors shall be installed in a manner that will ensure that they do not contribute to the acceleration of roofing material deterioration.

5.2.7 Access to components that require maintenance and repair shall be provided without disturbing roof, collector supports, or collector panels..

5.2.8 Collectors and supports shall be installed in such a manner that water flowing off the surface of the collector does not cause water collection on certain parts of the roof.

5.2.9 The solar collectors shall not be positioned (located) where they are likely to be shaded between the hours of 09:00 and 15:00.

NOTE The shadows of tall objects nearby can severely limit the satisfactory operation of a solar system.

5.2.10 Solar collectors to be installed on thatched roofs shall be approved by a competent person.

5.2.11 Structural supports shall be selected and installed in such a manner that thermal expansion of the collector subsystem will not cause damage to the collector, structural frame, or building.

5.2.12 Collectors and supports shall not create a hazard by blocking any means of egress.

5.2.13 Protection of collectors and components shall be provided during handling and installation to prevent damage.

5.2.14 Frames, braces, and fasteners used in collector installation shall be made of materials suitable for exterior location.

5.2.15 Collectors shall not reduce the fire rating of the roof as prescribed in applicable building codes.

5.2.16 Roof penetrations necessitated by a collector array should be kept to a minimum.

5.2.17 The collector array should not move with frost heave unless adequate provisions for flexing have been provided.

5.2.18 In thermosiphon systems, the bottom of the storage tank should be above the top of the collector.

5.3 Solar storage tank

5.3.1 The minimum storage capacity of a container in any solar hot water system shall, unless otherwise required, be as follows:

a) if no supplementary energy source is provided, a storage capacity of 20 % in excess of the daily hot water demand under winter conditions; and

b) if a supplementary energy source is provided,

1) for an integral solar heater system, a storage capacity of at least 100 % of the daily hot water demand under summer conditions; and

2) for an integral solar heater and supplementary storage container system, a storage capacity of:

i) in the case of the solar container, at least 25 % of the daily hot water demand under summer conditions; and

ii) in the case of the supplementary container, at least 75 % of the daily hot water demand under summer conditions.

5.3.2 Where heat losses might occur, the storage tanks shall be thermally insulated in an acceptable manner to prevent heat loss.

5.3.3 When the storage tank (complete with its ancillary components) is installed in a manner and position where any leakage from the storage tank and its ancillary components can cause any damage to property, it shall be furnished with a drip tray, and:

a) such a drip tray shall be fitted with a discharge pipe connected to the discharge connection of the drip tray and be led through an external wall in a visible position in order to discharge on the outside of the building; and

b) the joint between the discharge pipe and discharge connection of the tray shall be made leaktight.

D

5.3.4 Where the storage tank is fitted with an overflow valve, the outlet thereof shall be directed to where it shall not cause damage to the building.

5.4 Safety devices and controls

5.4.1 Control systems components shall comply with the relevant national, regional or international standards.

5.4.2 Pressure relief and temperature relief valves shall be installed in those parts of the system which can be isolated and contain a heat source.

5.4.3 The system shall incorporate a means of alerting the user of the malfunctioning of the system.

5.4.4 Systems that rely on air to facilitate drainage shall be fitted with vacuum breakers that comply with the requirements of relevant approved standards for functional-control valves and safety valves for domestic hot and cold water supply systems.

5.4.5 Where the temperature of the stored water is not set to 60 °C, the system shall be fitted with a mixing valve.

5.4.6 If necessary, pressure either to the working pressure of the system incorporated in the installation or to the maximum permissible pressure allowed in the installation. The pressure control valve shall be situated at a convenient position in the incoming cold water supply pipeline.

5.5 Pipe work

5.5.1 Pipe work shall be designed to withstand the expected working pressures and temperatures.

5.5.2 The pipe network layout for both hot and cold water systems shall be such that length and directional changes are minimized.

5.5.3 Where heat loss might occur, the piping shall be acceptably insulated.

5.5.4 Copper pipes shall comply with the requirements of relevant approved standard for copper tubes for potable water.

5.5.5 Unless galvanic action is unlikely to occur, or unless effective measures are taken to prevent such deterioration, metal pipes of different materials shall, as far as possible, not be connected to one another.

NOTE 1 Galvanic action will be reduced when the sequence of metals, in relation to the normal direction of flow, is galvanized steel (zinc) to uncoated iron to copper.

NOTE 2 A copper supply pipe connected to a galvanized steel storage tank or coated steel storage water heater will result in galvanic action occurring in the tank or heater.

5.5.6 Piping shall be done in accordance with the instructions of the manufacturer (of the system).

5.5.7 Pipes, fittings and components shall, when necessary, be protected against freezing. The insulation provided shall be appropriate to the minimum temperatures to be expected in that geographical area.

5.6 Pumps

5.6.1 Pumps shall be installed in accordance with the manufacturer's instructions, and shall be installed in such a way that there is access for maintenance and repair.

5.6.2 Pumps shall not be audible above the background noise.

5.6.3 The inlet and outlet connections to pumps shall be fitted with full way valves.

6 Operation and maintenance

6.1 On completion of the installation, the installer shall furnish the owner with an operation manual that contains:

a) proper operating and safety procedures; and

b) emergency shutdown procedures.

6.2 The owner shall also be provided with written and schematic instructions for routine maintenance.

6.3 The maintenance of the system shall include:

a) cleaning of the solar collector glazing,

b) cleaning of components, and

c) recommended maintenance intervals.

7 Repair

7.1 Repair of solar water heating systems shall be carried out by a competent person, or under his personal supervision.

7.2 Repair of a solar water heating system shall ensure that the system is restored to full and effective operational readiness and that it complies with the requirements of the original manufacturer.

Annex A
(informative)

Design considerations and positioning of solar collectors

A.1 Solar heaters effectively absorb heat from the sun from about 10:00 until about 16:00. Solar irradiance is at its peak between about 12:00 and 14:00. However, sufficient quantities of hot water have to be stored for use after 16:00.

A.2 A critical factor in the installation of solar heating systems is the position of the collector relative to the movement of the sun. In the southern hemisphere, collectors should be pointed true north and tilted at an angle above the horizontal equal to the latitude of the site plus 10°. This angle is chosen mainly to favour the collection of solar heat during winter when the sun is fairly low in the sky, to obtain year round efficiency. A deviation of up to 45° east or west of north may, however, be acceptable in many cases.

A.3 The design of the absorber unit can vary from a simple flat plate to an evacuated tube reflector type absorber. Ideally, the exposed surface of the collector should absorb the maximum amount of incident solar radiation with a minimum of heat loss.

A.4 The transparent cover over the collector prevents ingress of rain, reduces the cooling effect of outside air movement over the collector and restricts re-radiation losses, the latter probably being the most important. This means that the incident solar radiation has to be transmitted through the transparent cover with a minimum loss of heat energy due to absorption.

A.5 Thermosiphonic circulation can be created by placing the absorber at the lowest point of the system. The resulting circulation pressure is fairly small and any obstruction or an accumulation of air bubbles in the system can impede the natural flow of the water. The absorber and all pipes are therefore sloped in such a way that air can escape to the tank to be vented off.

A.6 While the thermosiphonic system, as shown in figure 2, is the most popular one for domestic applications, pumped systems permit greater freedom in the placement of the absorber(s), which can then be situated either above or below the storage tank. A typical pumped system is shown in figure 3. Pumped systems can be direct (where the potable water itself circulates through the solar collector) or indirect as shown in figure 4, where the potable water is heated via a heat exchanger.

A.7 In an indirect system, additives can be added to the solar panel water (or primary circulating water) to control corrosion. Figure 5 shows a more complex arrangement in which a solar installation is used to preheat the feed tester for the main hot water storage tank.

A.8 Indirect systems are less efficient than direct systems, owing to losses from the heat exchanger. Indirect systems do, however, have the following advantages over both thermosiphonic and pumped direct systems:

a) frost damage can be prevented by the use of a suitable heat transfer fluid, usually water with an antifreeze additive;

b) damage due to boiling can be prevented if a suitable heat transfer fluid with a high boiling

c) temperature is selected;

d) corrosion within the primary system can be minimized by the use of a corrosion-inhibited heat

e) transfer fluid; and

f) scale formation within the primary system can be more effectively controlled.

APPENDIX 7: MATERIAL INVESTIGATION

Material investigation: availability and costs

Metal sheets

	Component	Dimensions	Price RWF	Supplier
1	Copper, 0.8mm	1 x 2m	176'000	Sonatubes
2	Aluminum, 2mm	1.25 x 2.5m	128'800	Sonatubes
3	Aluminum, 0.5mm	1.25 x 2.5m	42'600	Sonatubes
4	Aluminum, 0.5mm	1 x 2m	25'300	Sonatubes
5	Stainless steel 304, 1.5mm	1.25 x 2.5m	260'000	Mateco
6	Galvanized, 0.6mm	1.25 x 2.5m	31'500	Sonatubes
7	Mild Steel, 2mm	1.25 x 2.5m	66'000	Mateco
8	Mild Steel, 1.2mm	1.25 x 2.5m	57'300	Sonatubes
9	Mild Steel, 1.2mm	1.25 x 2.5m	35'000	Mateco
10	Mild Steel, 1mm	1.25 x 2.5m	37'500	Sonatubes
11	Mild Steel, 1mm	1.25 x 2.5m	30'000	Gisozi

Pipes

	Component	Dimensions	Price RWF	Supplier
1	Copper, 1"	1.8m	30'000	Super Engineering Suppliers LTD.
2	Copper, 1"	1m	15'000	Editech
3	Copper, 7/8"	15.2m	250'000	Super Engineering Suppliers LTD.
4	Copper Mueler, 7/8"	15.2m	142'000	Editech
5	Copper, 3/4"	15.2m	150'000	Super Engineering Suppliers LTD.
6	Copper Mueler/Maksal, 3/4"	15.2m	118 / 142'000	Editech
7	Copper, 5/8"	15.2m	100'000	Super Engineering Suppliers LTD.
8	Copper Mueler/Maksal, 5/8"	15.2m	89 / 112'000	Editech
9	Copper, 1/2"	15.2m	70'000	Novitas
10	Copper, 1/2"	15.2m	80'000	Super Engineering Suppliers LTD.
11	Copper Mueler/Maksal, 1/2"	15.2m	83 / 106'000	Editech
12	Copper, 3/8"	15.2m	50'000	Super Engineering Suppliers LTD.
13	Copper Mueler/Maksal, 3/8"	15.2m	53 / 59'000	Editech
14	Copper, 1/4"	15.2m	25'000	Super Engineering Suppliers LTD.
15	Copper Mueler/Maksal, 1/4"	15.2m	15 / 17'000	Editech
16	Galvanized, 1"	5.8m	33'125	Sonatubes
17	Galvanized, 1/2"	5.8m	19'800	Sonatubes
18	Multilayer, 1/2"	1m	1'200	Acqualion
19	Multilayer, 3/4"	1m	2'000	Moonlight Hardware

Insulation

	Component	Dimensions	Price RWF	Supplier
1	Rockwool	1 x 8m	300'000	Sonatubes
2	Isover glasswool	1.2 x 12m	80'000	Chantal, Gisozi
3	Isover glasswool	1.2 x 20m	260'000	Novitas
4	Glasswool	1.2 x 20m	120'000	Joseph Habyarima, Gisozi
5	Air insulation, d = 1m	1.2m	8'000	Silas, Gisozi
6	Styrofoam, 50mm	1 x 2m	80'000	Joseph Habyarima, Gisozi
7	Styrofoam, 25mm	1 x 2m	25'000	Joseph Habyarima, Gisozi
8	Styrofoam, 25mm	1.2 x 2.4m	40'000	Chantal, Gisozi
9	Polyethurane Foam Smartfix	845g	8'200	I-Powerindustry
10	Cystosepiment, 30mm	0.6 x 1.8m	8'000	T2000
11	Armaflex, 1/4"	1.8m	3'500	Editech
12	Armaflex, 3/8 - 1/2"	1.8m	4'200	Editech
13	Armaflex, 3/5 - 5/8"	1.8m	4'500	Editech
14	Armaflex, 7/8"	1.8m	4'800	Editech
15	Armaflex, 3/4"	1.8m	6'000	Super Engineering Suppliers LTD.

Fittings

	Component	Dimensions	Price RWF	Supplier
1	T's and elbows Copper, 3/4 - 7/8"	1 piece	10'000	Super Engineering Suppliers LTD.
2	T's and elbows Copper, 3/4 - 7/8"	1 piece	5'000	Editech
3	T's and elbows Copper, 1/2 - 5/8"	1 piece	8'000	Super Engineering Suppliers LTD.
4	T's and elbows Copper, 1/2"	1 piece	4'500	Editech
5	T's and elbows Copper, 5/8"	1 piece	4'000	Editech
6	T's and elbows Copper, 1/4 - 3/8"	1 piece	5'000	Super Engineering Suppliers LTD.
7	T's and elbows Copper, 5/16 - 3/8"	1 piece	3'000	Editech
8	T's and elbows Copper, 1/4"	1 piece	2'400	Editech
9	Copper, 1/2"	1 piece	3'500	Acqualion
10	Brass socket and elbows, 20mm	1 piece	4'800	Moonlight Hardware
11	Brass female adapter, 20mm	1 piece	5'200	Moonlight Hardware
12	Brass plug, 20mm	1 piece	4'000	Moonlight Hardware

Glass

	Component	Dimensions	Price RWF	Supplier
1	Simple, 4mm	1m2	9'000	Anick
2	Simple, 6mm	1m2	16'000	Anick
3	Simple, 8mm	1m2	25'000	Anick
4	Double + sec. layer, 6mm	1m2	30'000	Anick
5	Double + sec. layer, 8mm	1m2	35'000	Anick
6	Double + sec. layer, 10mm	1m2	38'000	Anick
7	Simple 6mm	1.83 x 2.44	71'500	Anick
8	Simple 6mm	1.83 x 2.45	63'000	Next to Anick
9	Double + sec. layer, 6mm	1.6 x 2.1m	110'000	T2000
10	Plastic, 3mm	1.2 x 2.4m	70'000	T2000
11	Plastic, 4mm	1.2 x 1.8m	60'000	T2000

Others

	Component	Dimensions	Price RWF	Supplier
1	Pladeck, 18mm	0.6 x 2.5m	45'000	A&KN TEK Solutions
2	Tube Aluminum, 20 x 20mm	3m	38'000	Sonatubes
3	Angle Aluminum, 30 x 30mm	3m	14'000	Sonatubes
4	Angle Aluminum, 25 x 40mm	1m	5'000	Silas, Gisozi
5	Angle Aluminum, 25 x 50mm	6m	35'000	A&KN TEK Solutions
6	Angle Aluminum, 25 x 25mm	6m	15'000	A&KN TEK Solutions
7	Angle steel, 100 x 100mm	6m	110'000	Mateco
8	Brazing rod, Copper flat	460g	25'000	Super Engineering Suppliers LTD.
9	Brazing rod, Copper flat	1 piece	'590	Editech
10	Brazing rod, Copper square/round	1 piece	1'180	Editech
11	Brazing rod, Copper square/round	1 piece	1'000	Novitas
12	Argon	1 cylinder	360'000	Stephen Kayizzi, Nyurugenge
13	Acetylene	1 cylinder	75'000	Stephen Kayizzi, Nyurugenge
14	Oxygene	1 cylinder	18'000	Stephen Kayizzi, Nyurugenge
15	Flux	250g	60'000	Super Engineering Suppliers LTD.
16	Rubber	1m	'700	Silas, Gisozi
17	Polyurethane Silicone	1m	6'000	Cruiser auto glass
18	Standard silicone	1m	3'000	Gisozi
19	Wood board	1 x1.92m	29'000	T2000
20	Zinga	1l	30'000	Imexco

APPENDIX 8: SOLARWANDA PROGRAM

IPRC-Karongi
Kibuye, Gisovu Road
P.O. Box 85 - Kibuye

EDCL - Energy Development Corporation Limited
KN 2 ST, Nyarugenge District
P.O. Box 3855 - Kigali

Karongi, 12th July 2018

Request for partnership between SolaRwanda and IPRC-Karongi

Dear Sir or Madam,

IPRC-Karongi is currently working on a solar water heater project in collaboration with the HES-SO Valais/Wallis Switzerland. In 2017, three systems have been built and installed on a hotel in Karongi and new installations are planned for 2018.

With the arrival of a Junior Expert from HES-SO, the systems are now analyzed in order to improve their performance and their building techniques. As IPRC-Karongi expects an increase of demand in new systems, we want to certify the collectors and the tanks to guarantee the quality assurance of our products.

As we are facing competition with imported systems from all over the world, our selling method is slightly different from what is to be found on the market: we offer the systems for free but charge the hot water consumption. The metering is made with included smart-meters. We think that this method of selling services presents big advantages considering the high investment costs otherwise.

In order to push the renewable energies in Rwanda and reducing the electricity consumption we think we could combine our strengths. We refer especially to your SolaRwanda program which promotes the use of solar water heaters. The grant system that you offer for imported domestic solar water heaters cannot be applied in our case, because of the lack of initial investment. However other ways of subsidies are imaginable. For example paying a percentage of the monthly consumption or financial support for the development and fabrication processes.

We hope that you can provide us some help in our development of solar water heaters. Let's take the SolaRwanda program a step forward by promoting Rwanda-made systems!

We look forward hearing from you.

Yours sincerely,

NDAMUKUNDA Maurice
Head of Mechanical Department IPRC

Eng. GATABAZI Pascal
Principal of IPRC-Karongi

APPENDIX 9: CONSTRUCTION ALTERNATIVES

Model +

Pipe configuration	**Harp**
Connection	**Brazing**
Absorber	**Copper**
Insulation	**Glasswool**

Materials and costs

List for 1 collector

	Component	*Dimensions*	*Price RWF*	*Number*	*Total*
1	Wood	1.2 x 2.4	30'000	1	30'000
2	Copper sheet, 0.8mm	1 x 2 m	176'000	1	176'000
3	Alumium sheet, 0.5mm	1.2 x 2.4m	42'600	1	42'600
4	Glass, 6mm	1 x 1m	16'000	2	32'000
5	Copper pipe, 1"	1m	30'000	2	60'000
6	Copper pipe, 3/4"	15m	142'000	1	142'000
7	Copper fittings	-	5'000	4	20'000
8	Glasswool, 30mm	1.2 x 2m	12'000	1	12'000
9	Polystyrène, 25mm	1 x 2m	25'000	1	25'000
10	Angle alumium, 20x40mm	3m	14'000	2	28'000
11	Seal	1m	1'000	10	10'000
12	Silicon	-	2'500	2	5'000
13	Copper brazing sticks	-	25'000	2	50'000
14	Flux	80g	13'000	1	13'000
15	Oxygène	150bar	20'000	0.2	4'000
16	Acetylène	15bar	70'000	0.2	14'000
17	Black painting	1kg	3'000	1	3'000
18	Thinner	1l	7'500	1	7'500
19	Nails, screws	-	3'000	1	3'000

Total price for a single collector **677'100 RWF**
$ 778

Tank, pipings and structure

	Component	*Dimensions*	*Price RWF*	*Number*	*Total*
1	Mild steel sheet, 1.2mm	1.2 x 2.4m	35'000	2	70'000
2	Stainless steel sheet, 1.5mm	1.2 x 2.4m	260'000	1	260'000
3	Steel electrodes	1kg	18'000	1.5	27'000
4	Stainless steel pipes, 1/2 "	1m	5'000	4	20'000
5	Multilayer pipes, 3/4 "	1m	1'200	20	24'000
6	Tubes, acier	0.04 x 0.04 x 6m	9'500	6	57'000
7	ARGON gaz	150bar, 1 cylinder	359'000	0.2	71'800
8	Glasswool	1.2 x 2m	12'000	3	36'000
9	Armaflex, 3/4"	1.8m	5'000	6	30'000
10	Accessories (Fittings)	-	80'000	1	80'000
11	Spray painting	1	5'000	5	25'000
12	Redoxyde painting	1kg	3'000	1	3'000

Total price for tank, pipings and structure **703'800 RWF**
$ 809

Price for whole system **1'380'900 RWF**
1'587 $

Base model

Pipe configuration	**Harp**
Connection	**Bending**
Absorber	**Alumium**
Insulation	**Glasswool**

Materials and costs

List for 1 collector

	Component	*Dimensions*	*Price RWF*	*Number*	*Total*
1	Timber	1.2 x 2.4	30'000	1	30'000
2	Alumium sheet, 0.5mm	1.25 x 2.5m	42'600	2	85'200
3	Double layer glass, 6.38mm	1 x 1m	30'000	2	60'000
4	Copper pipe, 1"	1m	30'000	2	60'000
5	Copper pipe, 1/2"	15m	112'000	1	112'000
6	Glasswool	1.2 x 2m	12'000	2	24'000
7	Angle alumium, 30x30mm	3m	14'000	2	28'000
8	Seal	1m	1'000	10	10'000
9	Copper brazing sticks	-	25'000	1	25'000
10	Flux	80g	13'000	1	13'000
11	Gaz for brazing	-	50'000	1	50'000
12	Black painting	1kg	3'000	1	3'000
13	Blue painting	1kg	3'000	1	3'000
14	Thinner	1l	7'500	5	37'500
15	Nails, screws	-	3'000	1	3'000

Total price for a single collector **543'700 RWF**
$ 625

Economic model

Pipe configuration	**Harp**
Connection	**Brazing**
Absorber	**Mild steel**
Insulation	**Glasswool**

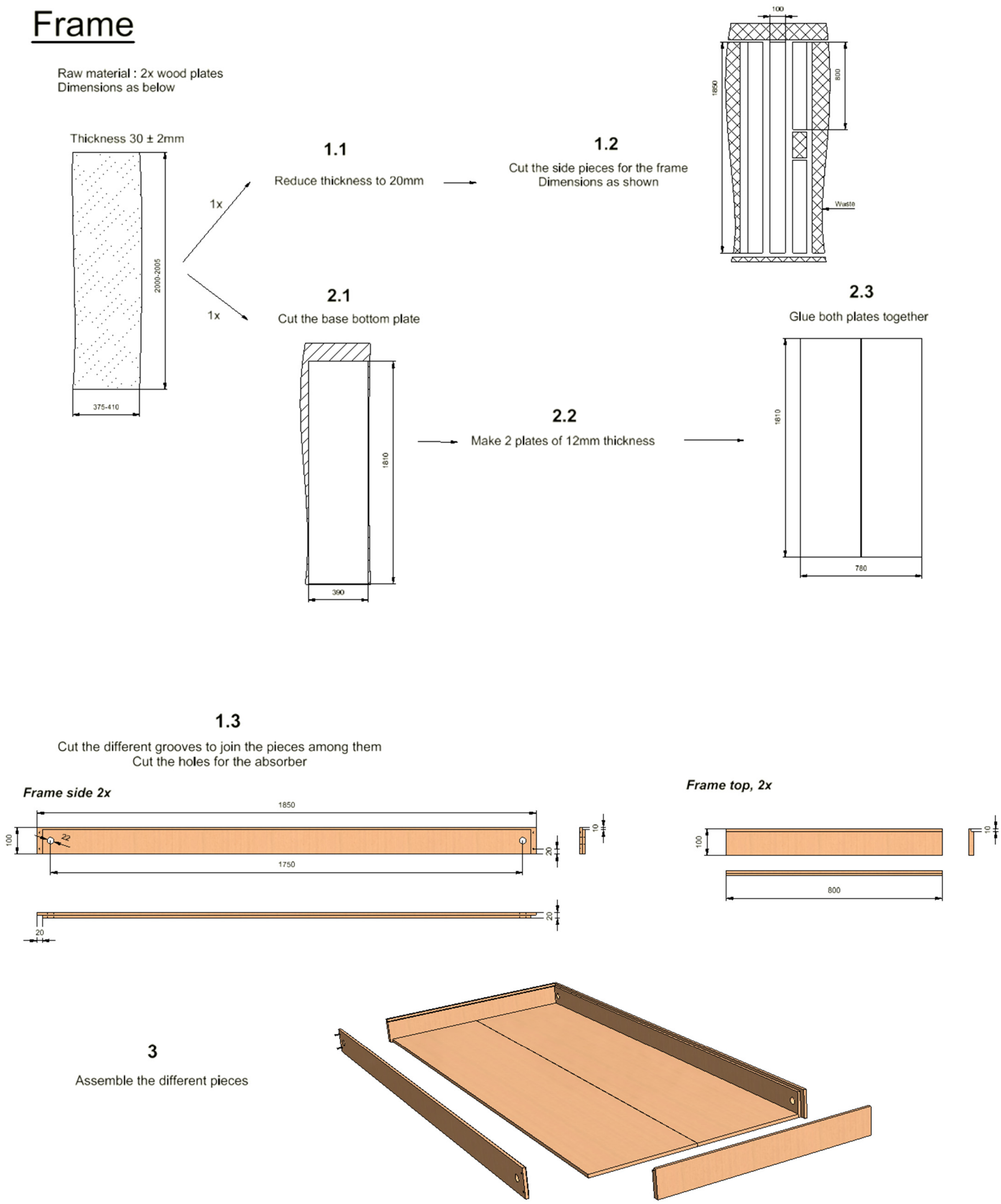
Materials and costs

List for 1 collector

	Component	*Dimensions*	*Price RWF*	*Number*	*Total*
1	Timber	1.2 x 2.4	30'000	1	30'000
2	Mild Steel sheet, 0.2mm	0.9 x 1m	1'900	12	22'800
3	Zinga	1l	30'000	1	30'000
4	Glass, 6mm	1 x 1m	16'000	2	32'000
5	Galvanized pipe, 1"	1m	5'000	2	10'000
6	Galvanized pipe, 1/2"	15m	30'000	1	30'000
7	Glasswool	1.2 x 2m	12'000	2	24'000
8	Angle alumium, 30x30mm	3m	14'000	2	28'000
9	Seal	1m	1'000	10	10'000
10	Brazing sticks	-	25'000	1	25'000
11	Flux	80g	13'000	1	13'000
12	Gaz for brazing	-	50'000	1	50'000
13	Black painting	1kg	3'000	1	3'000
14	Blue painting	1kg	3'000	1	3'000
15	Thinner	1l	7'500	5	37'500
16	Nails, screws	-	3'000	1	3'000

Total price for a single collector **351'300 RWF**
$ 404

APPENDIX 10: PLANS OF FIRST SOLUTION

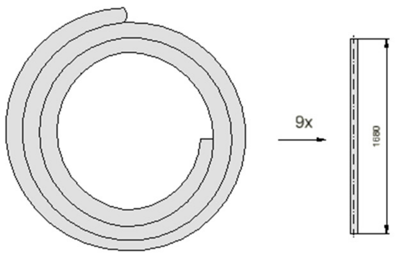


Pipes

Material :

- *Copper pipe 1/2", 15.2m*

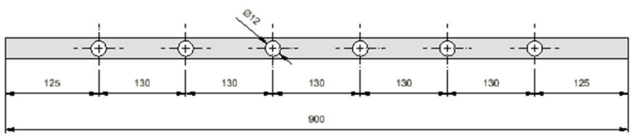
1. Cut into 9 equal pieces of a length of 1.68m
Proceed by bending the roll
Bend the pipes straight



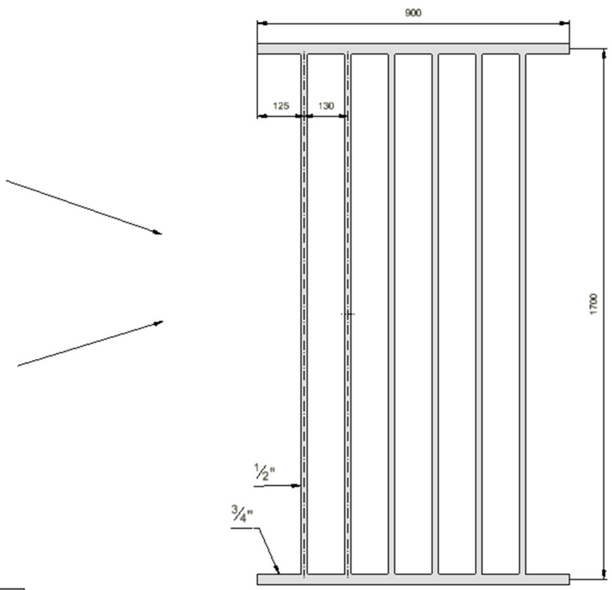
- *Copper pipe 3/4", 1.8m*

2.1 Cut into two pieces of 0.9m

2.2 Drill holes for the placement of the vertical pipes



3. Weld the vertical pipes to the horizontales pipes



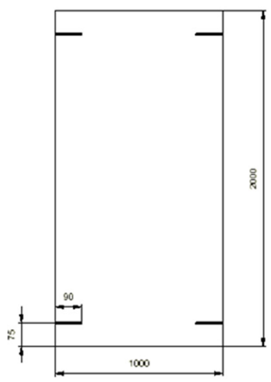
Aluminum cover

Material :

- *Aluminum plate 0.5 mm, 1x*

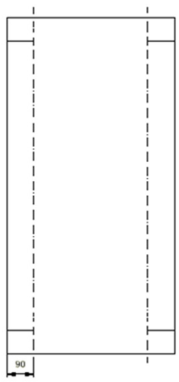
1.

Cut 4 lines into the plate



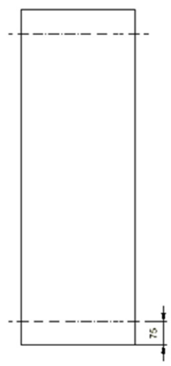
2.

Bend the plate lengthwise



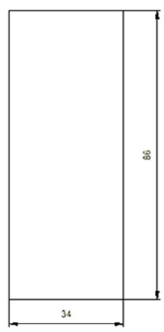
3.

Bend the plate widthwise

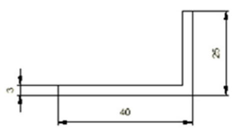


4.

Final dimensions



- *Aluminum angle 3m, 2x*



1. Cut each angle bar into two pieces: one of 1856mm and one of 826mm length

2. Cut the endings in 45°

Materials and costs

One collector

	Component	*Dimensions*	*Price RWF*	*Number*	*Total*
1	Wood	1.2 x 2.4	30'000	1	30'000
2	Copper sheet, 0.8mm	1 x 2 m	176'000	1	176'000
3	Alumium sheet, 0.5mm	1.2 x 2.4m	42'600	1	42'600
4	Glass, 6mm	1 x 1m	16'000	2	32'000
5	Copper pipe, 1"	1.8m	30'000	1	30'000
6	Copper pipe, 3/4"	15m	142'000	1	142'000
7	Copper fittings	1 piece	5'000	4	20'000
8	Glasswool, 30mm	1.2 x 2m	12'000	1	12'000
9	Polystyrène, 25mm	1 x 2m	25'000	1	25'000
10	Angle alumium, 20x40mm	3m	14'000	2	28'000
11	Alumium bar, 50mm	1m	5'000	1	5'000
11	Seal	1m	1'000	10	10'000
12	Silicon	300ml	3'000	2	6'000
13	Copper brazing sticks	1 piece	1'000	10	10'000
14	Black Chrome painting	1kg	5'000	1	5'000
15	Thinner	1l	7'500	2	15'000
16	Nails, screws	-	3'000	1	3'000
			Price for one collector		591'600 RWF
					$ 680

APPENDIX 11: CONSTRUCTION MANUAL

1. Absorber

A) Radiator

a. Cutting the pipes

1. Take a coil of 20mm copper pipe and cut two pieces of 0.91m length.
2. Straighten the single pipes by slapping them slightly on a flat surface.
3. Deburr the endings properly.
4. Repeat this process with a coil of 13mm copper pipe and cut six pieces of 1.74m.

b. Drilling the holes

1. Position a 20mm pipe in the spot of the jig intended for scribing purposes.
2. Fix the pipe with a clamp by measuring the same distance on both side of the endings.
3. Mark the center of each hole with the provided center punch.
4. Use a 12mm drill and a head drill press for the holes.
5. Repeat these steps with the second pipe.

c. Preparing the brazing

1. Arrange the pipes in the jig and make sure the holes are lined up.
2. Note that the length of the vertical pipes is on purpose slightly too long.
3. Shorten the endings with a round file in order to match both shapes.
4. Clean the areas to be brazed with sandpaper.

d. Brazing

Note: Hold one end of the pipe in place while working on the other for the following steps. Be sure to use gloves.

1. Heat the area uniformly with an oxy-acetylene torch. Do not overheat!
2. Dip the copper brazing rod in the flux powder and touch the area to be filled.

   Caution: Keep the flame away from the brazing rod. The filler is melted by contact with the pipes.
3. Let the joint cool and clean off the area.
4. Proceed to the other end of the pipe and repeat the brazing.
5. Do these steps for all six vertical pipes.

e. Adding the fittings

1. Place two brass socket fittings on one vertical side and two brass female adapters on the other.
2. Repeat the brazing steps for each fitting. Ensure the fittings are lined up properly with the axis of the pipes.

f. Pressure test

Note: Seal the fittings if necessary with small amounts of Teflon.

1. Connect the pressure test pump to a female adapter. Use a tap if necessary.
2. Close the second female adapter with a plug and both socket fittings with a cap.
3. Fill the container of the pressure test pump with water and start to pump water inside the radiator.
4. Pump until reaching 15 bars. Leave the installation like this for one hour.
5. Check if there is any leaking. If so, repeat the brazing on that spot. Proceed to this test again.

B) Copper sheet

a. Cutting the metal sheet

1. Measure and draw a rectangle of 0.8x1.74m on the copper sheet.
2. Cut the rectangle with either an angle grinder or a lever shear.
3. Smoothen the edges of the copper sheet with a flat file.

b. Preparing the soldering

1. Position the radiator on the metal sheet by ensuring it is well centered.
2. Mark the pipe passages on the copper sheet and clean these areas with sandpaper.
3. Clean all the pipes on their lower side as well.

   Caution: Do not forget the horizontal areas on the top and bottom of the metal sheet. Ensure to clean the entire areas to be joined properly. The upper coating of the copper must be removed and a whitish surface must be visible. Do not forget to remove all the dust created by this cleaning.

c. Soldering

1. Fix a tube, with a clamp on each side, above the pipe to be soldered. Do not tighten it for now.
2. Apply a thin layer of tin-lead flux paste between the pipe and the metal sheet and then tighten the clamps.
3. Check if there is any space left between the pipe and the metal sheet. If so, this has to be rectified.

   Caution: Small gaps can be eliminated by inserting a piece of metal from below between the workbench and the copper sheet. Once the solder has cooled on the area, the piece of metal can be removed and inserted elsewhere.
4. Heat the pipe and metal sheet from one side and apply the solder on the other.

   Caution: Do not get too close with the flame in order to avoid overheating, as it might weaken and warp the pipe. The needed temperature is reached as soon as the flux turns colour. The solder melts by itself when in contact with the metal and spreads over automatically to fill the joint.
5. Solder the whole length of the pipe as well as the top and bottom areas.
6. Let the solder cool down, remove the clamps and clean the remaining flux off. Use some water.
7. Repeat these steps for remaining pipes.

C) Painting

1. Dilute black colour with thinner. Add approximately 1/10 to 1/5 of thinner. Mix it properly.
2. Use a paintbrush to apply uniformly the black colour. Do it on a flat workplace.
3. Let the paint dry for a whole day and apply a second layer.

   Caution: The thinner helps to ensure a strong bond between the paint and the metal surface. However, do not scrape the painted surface. Exposed in the sun the paint might soften because of the heat. The paint can then be removed easily with bare hands, so be careful when handling the absorber after painting.

2. Housing

A) Preparation

a. Metal sheets

1. Measure and draw a rectangle of 0.835x1.865m on the 0.5mm aluminium sheet.
2. Cut the rectangle with metal cutting scissors and smoothen the edges with a flat file.
3. Measure and draw a rectangle of 0.1x1.88m on the 2mm aluminium sheet.
4. Cut the rectangle with a lever shear and remove the burr created with a flat file.
   Caution: Ensure a properly done deburring. Every edge must be smoothed. This applies to all materials being cut with a lever shear or a hacksaw. Use flat files for rough deburring and needle files for the finishing.
5. Repeat steps 3-4 for a second rectangle of the same size.
6. Repeat steps 3-4 for two rectangles of 0.1x0.846m.
7. For both sheets of step 5, mark the center of the passing holes. The distance between both must be 1760mm.
8. Take a hole saw, cute the four holes of 40mm each and deburr them.

b. Angle aluminium, 25x38mm

1. Take an angle aluminium of 25x38mm, 3mm thickness and 3m length.
2. Measure a piece of 1.886m from one side, mark it with a scriber and cut it with a metal hacksaw.
3. Measure a piece of 0.856m from the other side and do the same again.
4. Take the two cut pieces, face the larger 38mm side and draw a 45° angle on each end.
   Caution: Use either a bevel protractor or a try square with integrated 45° angle.
5. Cut the drawn angles with a hacksaw and deburr all the cut edges.
6. Take the remaining piece of the initial angle aluminium, cut four pieces of 65mm and deburr the edges.
7. Repeat steps 2-5 for three additional angle aluminium of 3m each.
8. Repeat step 6 for one piece and leave the two remaining pieces like this. Deburr the edges.
9. Take the two finished pieces of step 5 and mark five respectively three holes on each.
10. Make sure the marks are on the 25mm side on the low-end side 5mm from the edge.
11. Drill the holes and deburr them.

c. Angle aluminium, 38x38mm

1. Measure a piece of 100mm, mark it with a scriber, cut it with a hacksaw and deburr it. Do four pieces in total.
2. Repeat step 1 for a length of 60mm.
3. Repeat step 1 for a length of 65mm but do eight pieces in total.
4. Reduce the dimensions of the eight pieces in step 3 into 25x15mm. Use a hacksaw and deburr the edges.
5. Drill two holes in each of the angle of step 4 with a distance of 30mm in between. Deburr.

C) Assembling

a. Base

1. Place top of four adjusted 25x38 angles carefully on the thin metal sheet.
2. Make sure the corners are right-angled and fix them with adhesive tape.
3. Drill 4mm holes equally spaced on each side and rivet the metal sheet with the angles.
4. Place the structure in an upright position on a workbench to fix the side metal sheets.
5. Tighten the whole with clamps
6. Drill again 4mm holes equally spaced than the ones made previously and deburr them
7. Rivet the side metal sheet and repeat the steps 4-7 for each side metal sheet.
8. Place a 38x38x100mm angle on the inside and a 38x38x65mm angle on the outside of a corner.
9. Fix both angles with 4mm Rivets of a length of 12mm.
10. Fix the inside angle with two additional rivets to the angle bars forming the base.
11. Repeat steps 8-10 for every corner.

b. Glass support angles

1. Mark the side metal sheet for the placement of a 25x38x65mm angle. The 25mm side against the side.
2. Mark also two holes for each angle.
3. Hold one angle in place with a specially created jig. Use the wood jig if possible.
4. Make sure the top of the angle is at 92mm from the bottom angle bar
5. Fix the angle to avoid movement and drill the 2 holes
6. Deburr and rivet the angle.
7. Place a 25x38x65mm angle on top of the fixed angle and mark the center of the holes through this one
8. Remove the small angle and drill the holes. Deburr it and fix it with rivets.
9. Cut a piece of sealant and stick it on the big angle as a support of the glass.
10. Repeat step 1-6 for each of the ten angles.
11. For each additional angle, make sure the angles are levelled among them. Use a level.

c. Top

1. Lay the glass on the supports.
2. Place the four remaining angles on top and check their compatibility. Use a file if needed.
3. Fix the angles with some adhesive tape.
4. Mark the side metal sheets through the holes of the angles of step 2.
5. Drill the holes and deburr them.
6. Remove the angles and the glass.

3. Assembling

a. Preparation

1. Choose one of the longer side and remove the base rivets by drilling, do the same for both angles.
2. Detach the side metal sheet of step 1.
3. Cut a wood piece in 90x50mm and mark a line at 54mm.
4. Mark the center of the line and drill a 20mm hole.
5. Take a hacksaw and cut the piece in two at the line.
6. Repeat steps 3-5 four times in total.
7. Unroll the glass wool and cut two pieces of 2.2m

   Caution: the glass wool irritates the skin. Wear gloves and protection jackets.
8. Take a tire of 2mm and a hole saw and cut four pieces of 40mm.

b. First steps

1. Insert both layer of insulation into the housing. Make sure it is well centered.
2. Take a sharp concrete iron and pierce both insulation layers in every corner.
3. Insert one side of the absorber into the insulation and housing.
4. Take the removable remaining metal sheet and insert it first in the absorber, then into the housing.
5. Place the wood pieces in each corner and fix them with rivets.
6. Shape the insulation from the absorber to the metal sheet.
7. If needed fix it with transparent adhesive tape.
8. Remove all the dust created and place the glass cover.

c. Sealing

1. Apply a thin layer of polyurethane sealant on the edge of one side of the glass.
2. Take the corresponding angle aluminium and place it on top.

   Caution: Make sure to be quick for steps 1-2 in order to avoid drying.
3. Fix the angle with rivets.
4. Repeat step 1-3 for each side.
5. Apply enough sealant in the edges.
6. Apply some polyurethane foam on the outside of a wood piece.
7. Take a rubber and fix it on the respective wood piece.
8. Apply transparent silicone on every outside edge of the housing.
9. Let the sealing dry.
10. Cut the remaining sealant in order to get a proper and clean finish.
11. The collector is ready for installation.